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QUADCOPTER MODEL BRUSHLESS MOTOR, PROPELLER, ESC AND LI-PO BATTERY SELECTION PROCEDURES WITH NUMERICAL, EMPIRICAL AND SOFTWARE ANALYSIS

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ABSTRACT

A Quadcopter frame size has been estimated during the initial phase of the project. The customer requirement leads to initial concept development along with the estimated weight of the Quadcopter. The frame size should assure that the propellers will not overlap with central frame and the estimated frame dimension will be in more safe ranges after the selection of actual propeller. Initially we estimated the thrust-to-weight ratio after the initial Quadcopter requirement with a maximum allowable weight of the Quadcopter as 2Kg. The Quadcopter will carry a load of 1.5 Kg to be lifted by each propeller which is a basic input for motor selection. The availability of components in the market, price and budget are main factors for the procured components. Motor-Propeller-ESC-Battery selections require analysis in reverse Engineering. The recommended procedures followed in the selection procedures are clearly defines and analyzed in the manuscript. The main selection factors in our project are cost, reliability, functionality and availability. All the components selected are finally listed with their basic specification after some mathematical, numerical and logical analyses.

Keywords: Quadcopter, Brushless motor, Propeller, ESC, Li-Po battery, Design process

I. INTRODUCTION

One special kind of UAV that can do Vertical Take Off and Landing (VTOL) is the Quadcopter. The inherent dynamic nature of the Quadcopter gives it an advantage in maneuverability. A Quadcopter's simpler mechanical construction gives it an advantage over a traditional helicopter. In addition, Quad copter uses separate propeller manipulation to shift direction [1].

Two of the Quadcopter's' four blades rotate in one direction, while the other two spin in the opposite direction. Although each of the four blades will produce lift, they will also exert torque on one another. To ensure that the machine rises straight and keeps its orientation, all of the blades eventually cancel out the torque. BLDC-Motors, Propellers, ESC (Electronic Speed Controllers), Frame, Flight Controller, Receiver, Power Distribution Board (PDB), Telemetry, Li-PI Battery, and Payload are among the several parts that typically make up a Quadcopter.

Brushless DC (BLDC) motors are frequently utilized in Quadcopter. The KV rating indicates the motor's vital rating. KV (rpm/V) stands for revolutions per minute for the motor's voltage. Two clockwise and two counter clockwise propellers are used by Quadcopter. The length and pitch of the propellers are defined [2] [3].

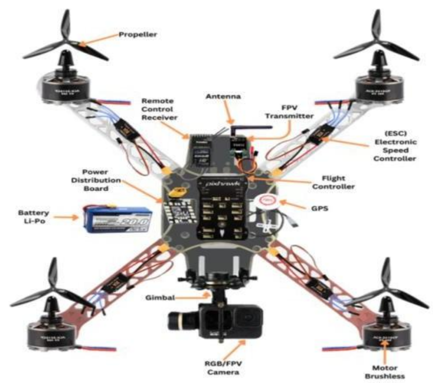

Figure: 1 Quadcopter Parts

II. QUADCOPTER LITERATURE REVIEW

2.1 Quadcopter Structure

Selecting a frame configuration is the first stage in manufacturing a Quadcopter drone. All the remaining parts of the drone are held together by the frame, which serves as its backbone. Selecting a Quadcopter frame that is appropriate for our application is crucial because they come in a variety of sizes and designs. As its name suggests, the Quadcopter's frame, which has four arms, is its essential component. To accommodate a LIPO battery, which is kept in the middle to modify the mass

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distribution, the flight controller board, and the payload, the frame needs to be both lightweight and stiff. When designing, the torque and forces of four propellers and four brushless DC motors (BLDC) should be taken into account. The motors are positioned on opposite sides, equally spaced from the center. A crude calculation and adjustment are made to the distance between motors to prevent any aerodynamic interaction between propeller blades [4].
Design selection processes and the benefits of carbon fiber, aluminium, and plastic for a particular model are used to choose the frame materials. Analyzing the fundamental weight parameter entered at the beginning of the project is greatly aided by the weight estimation of materials based on their characteristic density. Each component is designed with basic dimensions and material selection during the detail design stage [5]. Carbon fiber is intended to be used in the construction of our Quadcopter model. At the beginning, the Quadcopter model is chosen by contrasting and comparing several design configurations. Figure 2 illustrates the various varieties or combinations of Quadcopter designs. Our weighted decision analysis led us to choose the Quadcopter "X" configuration for our design.

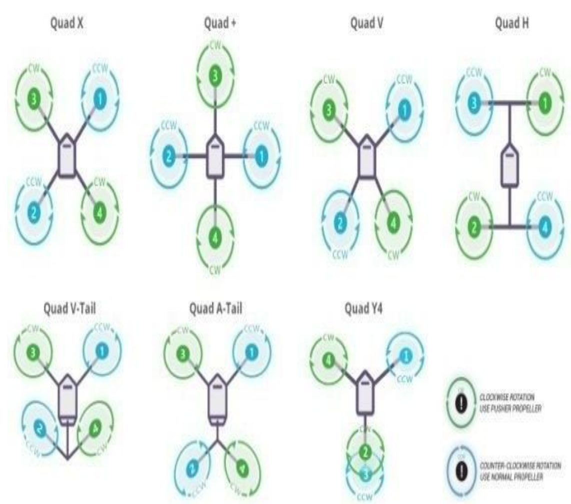

Figure 2: Main Types of Quadcopter Configurations

2.2 Quadcopter Electronic Components

The Electronic Speed Controller, or ESC, is a circuit that uses a PWM signal from the Flight Controller to provide BLDC motors with a changeable voltage. The primary function of an electric circuit known as an electronic speed controller (ESC) is to track and adjust the drone's speed while it is in flight. ESCs need a Power Distribution Board (PDB) to connect to Li-Po batteries. At the very least, a flight controller is made up of two components.

Figure 3: 30A ESC

An accelerometer and a processor. The small, dark blue board on the right is the accelerometer. In order to power the brushless motors, the ESC is also in charge of converting DC battery power into AC power [6]. First, a radio transmitter sends a signal to a radio receiver attached to the UAV. The pilot then sends the signal to the flight controller board, which creates the proper signal and sends it to the BEC/ESC, which, based on the signal's strength, accelerates the motor as shown in Figure 4 [7].

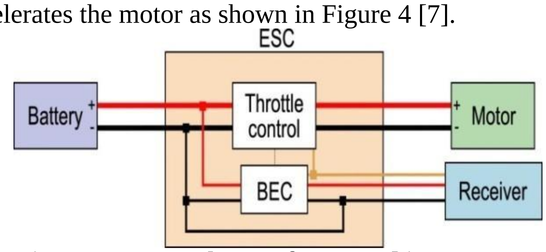

Figure 4: Internal part of ESC and its I/O ports

The cables that connect the two parts of the CW motors are simple to understand: left to left, center to middle, and right to right. However, you have to be careful to switch things up a bit while attaching the CCW motor as shown in Figure 5 below [8].

Figure 5: ESC CW and CCW motor connection

Brushless DC (BLDC) motors communicate without the usage of brushes. Better speed vs. torque characteristics, great efficiency, noiseless operation, and a very large speed range with longer life are the key benefits of these electronically commutated motors. To control the motor, we require an electronic speed controller. The BLDC motor has a substantially longer lifespan because there are no brushes to wear out [9].

Figure 6: BLDC Motor construction [10]

KVs are typically used to refer to BLDC motors. A BLDC motor's KV rating is equivalent to its RPM per VOLT applied. Therefore, when 1 volt is delivered, a BLDC motor with a 1000 KV rating will spin at 1000 RPM. A propeller is installed on each brushless motor. In actuality, two propellers are identical to produce the same torque while the other have two are opposite to counter the torque. Compared to other lithium batteries, Li-Po batteries offer a higher specific energy in the majority of Quadcopter. The flying time is determined by battery power; hence battery selection is crucial [11]. There are some parameters labeled on specific Li-Po battery; they are Battery Capacity, Battery Voltage, Cell Configuration and Discharge Rate.

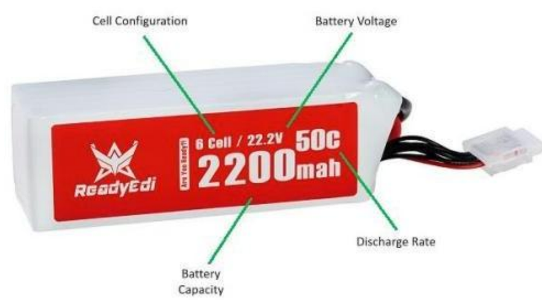

Figure 7: Basic Li-Po battery parameters

The nominal voltage of a cell, which is essentially inside a battery, is 3.7V. The voltage can rise to 22.2V for a six-cell battery, 14.8V for a four-cell battery, and so forth by connecting additional of them in series. The capacity can be raised by attaching additional batteries in parallel [12]. The voltages in 3S and 4S battery packs can be calculated;

Li-Po cell nominal voltage is 3.7V,

Li-Po cell is equal to 1 cell = 1S = 3.7V,

In a 4S, there are four cells in series,

Therefore, a three-cell (3S) battery pack is (3x3.7=11.1V

and

A four-cell (4S) battery pack is (4x3.7=14.8V).

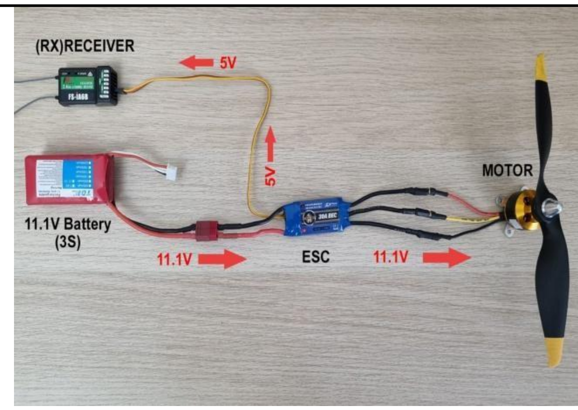

Figure 8: Voltage distribution from battery

The choice of flight controller is crucial when designing a Quadcopter since it will serve as the "brains" of the device. In essence, the flight controller is the tiny computer that steers the aircraft and decodes the data sent by the transceiver to direct the Quadcopter. The flying controller keeps the Quadcopter stable during this whole loop. Using the sticks, we provide inputs. This is a lot of data, and your flight controller's gyroscope and accelerometer are continuously sending data that they get from these disruptions, which causes the Quadcopter's location to shift [13].

Numerous sensors, including gyroscopes, barometric pressure sensors, airspeed sensors, and GPS, are part of the flight control system. The most significant inputs to flight computations are still the gyros and accelerometers. Acceleration is measured by accelerometers. It features Inertial Measurement Units (IMUs), which are the silent conductors of motion tracking. They capture the dynamic path of objects across space by seamlessly combining gyroscopes and accelerometers [14].

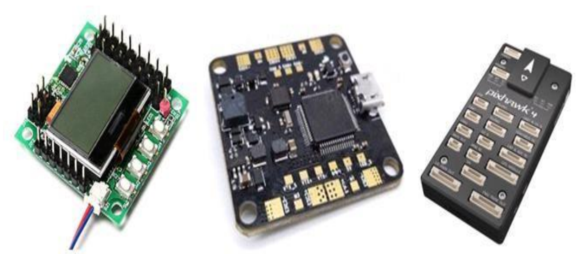

Figure 9: Flight Controller (KK2, F4S and PX4) (From Left to Right)[15] [16] [17]

Each Quadcopter component has a unique connectivity process based on its function and purpose. Figure 10 displays the standard Quadcopter circuit diagram [18].

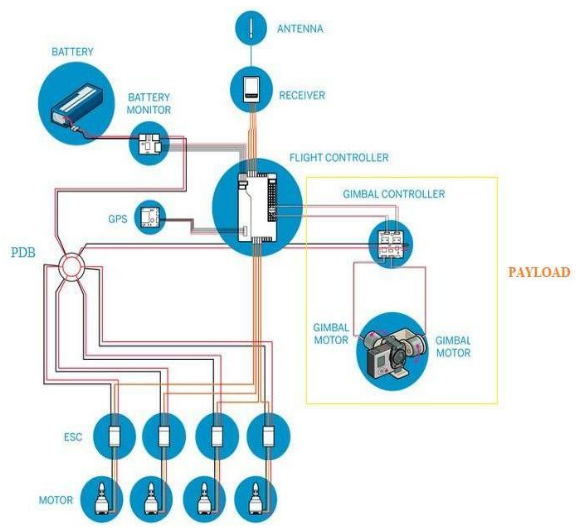

Figure 10: Quadcopter detail wiring diagram

2.3 Basic Quadcopter Formula

1. **Quadcopter flight times**

The Quadcopter flight time is calculated by;

$$Quadcopter\ Flight\ Time = \left(\frac{Battery\ Capacity \times Battery\ Discharge}{Average\ Amper\ Drawn}\right) \times 60$$

2. **Flight duration**

Expected duration (in Hours) of Quadcopter flight is given as;

$$Duaration = \frac{Capacity\ of\ Battery\ in\ Ah}{Max. Current\ drawn\ by\ Motor}$$

The above equation gives us information about pair of DC motors with speed and load carrying capacity of Quadcopter model [19].

3. **Advance Ratio**

There are some general terms which are used in drone technology mathematical terms;

Propeller efficiency can be measured against advance ratio (J), the ratio of forward to rotational speed of the propeller

$$J = \frac{V}{nD}$$

Where V is forward speed of aircraft, n is the propeller rotation speed in revs/sec and D is the diameter of the propeller

4. **Motor Power**

Voltage has an impact on motor and its speed. The higher voltage is, the higher power of the motor which is calculated by the formula;

$$P = U \times I$$

Where P is power, U is voltage and I is current.

5. **Battery Capacity and Discharge Rating**

Battery capacity is a measure of how much power a battery can hold and its unit of capacity is milliamp hours (mAh). Li-Po battery capacity is calculated by multiplying the nominal voltage by the rated capacity. For example, if we have a 4S (Four-cell) Li-Po battery with a rated capacity of 5000mAh has a capacity of 14.8 volts x 5000mAh = 74 Wh. However, the capacity of a Li-Po battery can decrease over time due to a number of factors throughout its service time.

6. **Propeller efficiency**

The propeller efficiency is defined as the fraction of engine power that is converted into propulsive power;

$$Propeller\ Efficiency = \eta_p = \frac{T \times u}{p_{shaft}}$$

Where: η_p = propeller efficiency, T = thrust, u = aircraft speed Shaft and p_{shaft} = Shaft power

7. **Thrust-to- weight ratio**

A Quadcopter's thrust-to-weight ratio (TWR) is a factor used to ensure stable flight and enough lifting capacity. There are different TWR recommendations for different designs.

$$TWR = \frac{Total\ Thrust\ of\ all\ Motors}{Total\ Weight\ of\ a\ Model}$$

8. **Payload Capacity**

$$Payload_{capacity} = (Motor_{thrust} \times N_{motors} \times Hover\ Throttle\ in\ \%) - Weight_{model}$$

Where N_{motors}=Number of motors

9. **Power consumption**

The basic formula for calculating a Quadcopter motor's power consumption is;

Power (W) = Voltage (V) x Current (A),

This requires figuring out the voltage that the motor receives and the current that it draws while operating. This can be further broken down by taking into account variables like propeller efficiency, drone weight, and flight conditions [20].

10. **KV Rating**

By measuring the electromechanical relationship, the torque constant K_t can be determined from that Kv rating. Kv rating is the selection criteria for motors. K_v rating is calculated by [21];

$$K_v = \frac{0.01794}{K_t}$$

The torque can be calculated as;

$$T = I \times K_t$$

K_v is calculated by using RPM or speed formula as;

$$RPM = K_v \times Voltage\ Input$$

11. ESC current rating

Every ESC has a current rating, which indicated the maximum current provide to motor without overheating. The ESC rating is higher than motor Amp, so [22];

$$ESC\ rating = (1.2\ to\ 1.5) \times I_{max}$$

$$Where\ I_{max}\ MaxAmpere\ Rating\ of\ Motor$$

12. Max Current withdrawn by motors

The cells are usually connected in series, making the voltage higher but giving the same amount of Amp in hours. The ESC rating is higher than motor Amp, so maximum current withdrawn by motor is given as [23];

$$Max\ Current\ Withdrawn\ by\ Motors = Number\ of\ Motors \times I_{max}$$

Where I_{max} is the Max Current withdrawn by a single motors

13. Thrust and Weight (Mass) Analysis

The thrust (in Newton) can be given as [24];

$$Thrust = \frac{\pi \times D^4 \times \rho \times v \times \Delta v}{4}$$

Where ρ = Density of air (kg/m3)
v =Velocity of air (m/s)
Δv=Velocity of the air accelerated by propeller

The total mass lifted by a Quadcopter (M) will be;

$$M = \frac{Thrust}{g}$$

The relationship governing the lift capabilities of flight system is;

$$Lift\ (Kg) = \frac{W \times D^2 \times N^2 \times [\frac{\rho \times 24}{C_f \times 29.9}]}{2.2}$$

Where C_f = Lift coefficient

14. Weight to Rpm Ratios

Generally we follow the design to be of reduced weight by increasing the lifting force of the flight system. Unknown weight of Quadcopter is given by [2];

$$W = \frac{Required\ rpm}{Reference\ rpm} \times reference\ weight$$

Where W= Unknown weight of Quadcopter (N);

15. Propeller Length to Weight Ratios

For the design, the Unknown propeller length is given by [2];

$$Y = \frac{Required\ Weight}{Reference\ Weight} \times Reference\ Propeller\ Length$$

Where, Y = Unknown propeller length (cm);

16. Total Time of Flying

Total time of flying [25];

$$t = \frac{2x \times n_c}{\frac{1}{\sqrt{\rho A}} \left(\frac{g}{\eta_p}\right)^{1.5}} \times \frac{m_b}{(m_f + m_b)^{1.5}}$$

Substituting to the equation;

$$\Lambda = \frac{2x \times n_c}{\frac{1}{\sqrt{\rho A}} \left(\frac{g}{\eta_p}\right)^{1.5}}$$

Total time of flying;

$$t = \Lambda \times \frac{m_b}{(m_f + m_b)^{1.5}}$$

III. MATERIAL AND METHODS

3.1. Estimating the Basic Model Quadcopter Initial Parameters

The Quadcopter basic parameters are estimated initially for reference but they may vary during the design processes. Buying a pre-made drone can be expensive. Instead, why not build our own even if making our own drone is a great way to learn about electronics and engineering. In this document we follow the following steps in building our own model Quadcopter.

Table 1: Initial Estimated Parameters

S/N	PARAMETERS	VALUE	REMARK
1	Range	1.5Km	*Estimated within our visual of site*
2	Endurance	10 mn to 15mn	*estimated*
3	Service ceiling height	<50 meter	*Common for visual control*
4	Payload	0 Kg	
5	Speed	40mph	*Recommended for camera UAVs*
6	Weight	2Kg max	*estimated*
7	Mission	Controlled by *QGroundControl* open source software	

3.2 Calculation of Some Estimated Parameters

1. Initial estimation of weight ratio

The basic calculation to estimate the model Quadcopter weight is done assuming the Quadcopter is at hover with just half throttle.

$$Weight\ ratio = \frac{Battery\ Weight}{Frame\ Weight}$$

The frame weight is equal to weight of Quadcopter without battery. The given data from the Quadcopter model assumed parameters. The range or distance travelled by the Quadcopter is calculated by;

$$R = E \times \eta_{total} \times \frac{1}{g}\frac{L}{D}\frac{m_{battery}}{m_{total}}$$

Where m_{total} is total frame weight

η_{total} is the total efficiency typically 0.7 to 0.8 for batteries

$\frac{L}{D}$ Is lift over drag, it is constant number

Therefore by rearranging the formula we can get [26];

$$\frac{m_{battery}}{m_{total}} = \frac{R\frac{D}{L}g}{E\eta_{total}}$$

By calculating the above values, the weight ratio will be;

$$\frac{m_{battery}}{m_{total}} = 0.29 \approx 0.3$$

Weight ratio 0.3 shows that the design is in optimal range (see the graph). The estimated maximum weight of the model is 2Kg. Therefore the estimated weight of battery will be;

$$Estimated\ Weight_{battery=}\ 0.3 \times 2Kg = 0.6Kg$$

Theoretically at weight ratio=2 maximum flight time can be attained which is impossible at current technologies.
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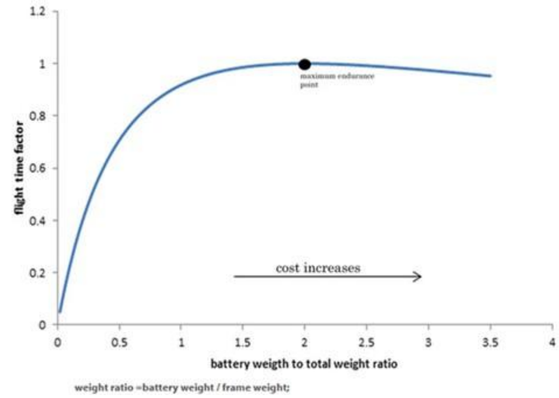


Figure11: Flight time and battery weight relationships

3.3. Estimated Model Quadcopter Design Weight for TTW Calculation

Prior to figuring out the drone motor's ideal thrust, we must choose one more crucial factor: the thrust to weight ratio. Drone motor manufacturers measure thrust in grams or ounces. To enable the drone to hover at half throttle, we should generally select the optimal ratio for our design. TWR for smooth flight is 2:1, for FPV videos or races 4:1 or 5:1 and aerobatic flying could require a ratio as high as 7:1. The TWR relationships show that if TWR > 1, the drone can lift off. If TWR = 1, the drone is just hovering but at TWR < 1, the drone will not be able to lift off or hover [27]. To calculate the estimated thrust supported by each propeller, we have to calculate the estimated Quadcopter weight;

Table 2: Initial Estimated Component Weight

Description	Weight	
Airframe weight	900 gm	
Batter weight	1000 gm	
Equipment weight		
PX4 flight controller weight	200 gm	300 gm
GPS weight	32 gm	
Telemeter weight	15 gm	
Receiver weight	15 gm	
Others (ESC, PDB, wirings)	38 gm	
Total	**2200 gm (2.2 Kg)**	

This drone motor calculation helps to determine the thrust required for drone motor to get a drone up in the air. This is the best tool for a new Quadcopter model designed.

W= 2.2 Kg estimated design weight
Thrust/Weigh=2 (for gentle flying)
Total Thrust =2Weight = 2(2.2Kg) = 4.4Kg
Thrust supported by each propeller will be;
Thrust $_{Propeller}$ = 4.4Kg/4 = 1.1Kg **=1100gm**

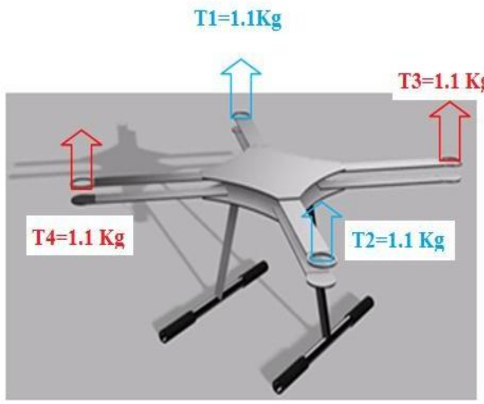


Figure 12: Quadcopter model thrust distribution

IV. RESULTS AND DISCUSSIONS

4.1 Component selection methodology Depending on Availability, Operation and Cost)

1. Motor Selection Procedures

The next step is to select the motors and propeller from the estimated maximum design payload. These components are responsible for lifting the drone off the ground and keeping it in the air. You'll need four motors and propellers, one for each corner of the frame. The size of the motors and propellers will depend on the weight of our drone suitable for the frame we have chosen. Selection of motor and propeller requires a lot of steps, calculations and charts. In our case we chose the following motors and propellers.

a. Selecting Motor from Different Brand Types

Table 3: Motors Brand Types for selection

Brand	Availability	Remark
T-Motor ***	Easily available at local market	Cheapest
Dji motors	Available but not like T-motors	Relatively cheapest
Tarot	High efficiency motors	Relatively expensive
EMAX	Not available easily	Preferred for racing
Ethix	Not available easily	Preferred for racing
Flight	Not available easily	Expensive
Nvision	Not available easily	Expensive
RMRC	Not available easily	Expensive
STRIX	Not available easily	Expensive
SunnySky	Not available easily	Expensive
Team Black Sheep	Not available easily	Expensive

b. Selecting Motor from T-Motor Brand Types

Table 4: T-Motor series types for selection

Type	Designation	Remark
U Series Expensive	U3/U5/U7	Heavy weight and strong driving motor for heavier weights
P Series Expensive	P80	Constantly used for agricultural drones that provides 17kg+ thrust
Navigator Series *** Cheap (Available)	MN605-S/ MN2212/ MN4014/ MN2212/MN3510 MN4014	More suitable series for our project found here
Antigravity Series Expensive	Antigravity MN5008/ Antigravity MN4004/ Antigravity MN4006	Ultra light, high efficiency, Devote to long flight, Quadcopter of 4.5kg, 60mins flight time,
QAD Expensive	Q1418/ Q2434/ Q1824	Quick mounting

The cheap and easily available motors that fit our Quadcopter weight from the navigation series selected is MN 3510/360KV motor.

MN 3510/360KV motor

Figure 13: Selected T-motor Type

c. MN 3510/360KV Motor Manufacturer Data Sheet

Selecting the suitable T-motor supplementary components and parameters from the navigator Series and motor data table of the manufacturer can be processed in to the following procedures.

Item No.	Volts (V)	Prop	Throttle	Amps (A)	Watts (W)	Thrust (G)	RPM	Efficiency (G/W)	Operating temperature(℃)
MN3510 KV360	14.8	T-MOTOR 14*4.8CF	50%	1.2	17.76	280	2600	15.77	40
			65%	2.5	37.00	500	3400	13.51	
			75%	3.5	51.80	620	3800	11.97	
			85%	4.9	72.52	760	4300	10.48	
			100%	5.7	84.36	870	4600	10.31	
		T-MOTOR 15*5CF	50%	1.5	22.20	340	2600	15.32	42
			65%	3	44.40	580	3300	13.06	
			75%	4.5	66.60	760	3800	11.41	
			85%	5.8	85.84	900	4100	10.48	
			100%	6.8	100.64	1000	4400	9.94	
		T-MOTOR 16*5.4CF	50%	1.73	25.60	380	2450	14.84	40
			65%	3.6	53.28	630	3200	11.82	
			75%	5.3	78.44	800	3700	10.20	
			85%	6.9	102.12	1000	4000	9.79	
			100%	8.1	119.88	1100	4300	9.18	
	22.2	T-MOTOR 12*4CF	50%	1.6	35.52	350	4300	9.85	43
			65%	2.7	59.94	560	5300	9.34	
			75%	4	88.80	760	6000	8.56	
			85%	5.5	122.10	930	6600	7.62	
			100%	6.4	142.08	1060	7000	7.46	
		T-MOTOR 13*4.4CF	50%	1.8	39.96	460	4200	11.51	43
			65%	3.4	75.48	730	5300	9.67	
			75%	4.8	106.56	900	5900	8.45	
			85%	6.2	137.64	1100	6500	7.99	
			100%	7.5	166.50	1300	6900	7.81	
		T-MOTOR 14*4.8CF	50%	2.5	55.50	660	4000	11.89	50
			65%	4.7	104.34	1000	4900	9.58	
			75%	6.8	150.96	1280	5500	8.48	
			85%	8.8	195.36	1500	6000	7.68	
			100%	10.6	235.32	1700	6500	7.22	
		T-MOTOR 15*5CF	50%	3	66.60	780	3800	11.71	60
			65%	5.6	124.32	1180	4500	9.49	
			75%	7.7	170.94	1460	5300	8.54	
			85%	10.6	235.32	1700	5720	7.22	
			100%	12.5	277.50	1900	6040	6.85	

Notes:The test condition of temperature is motor surface temperature in 100% throttle while the motor run 10 min.

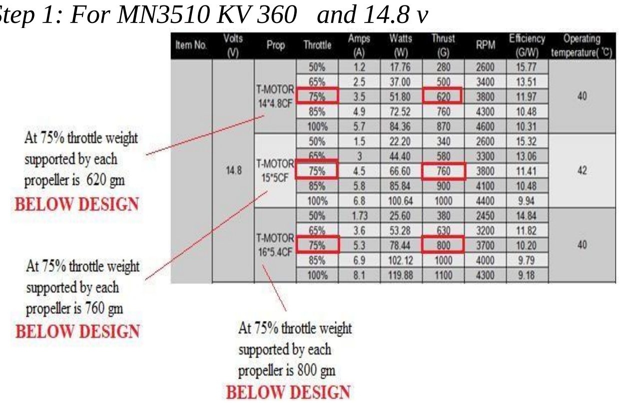
Figure 14: MN 3510/360KV motor manufacturer's data table [28]

2. **Propeller and Li-Po battery Selection procedures**

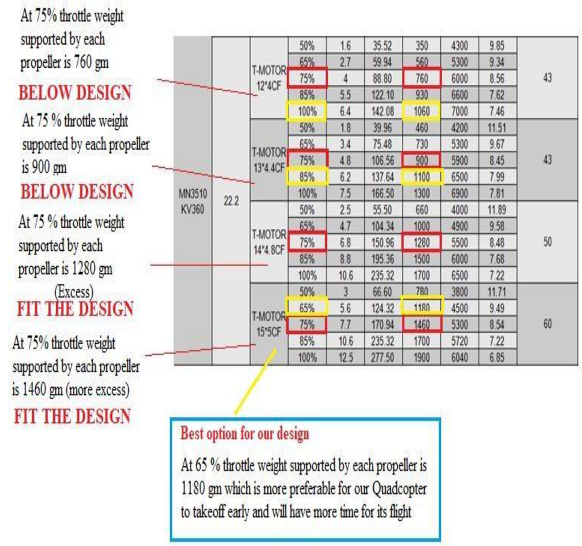
   a. **Selection Process Using Table with Thrust-to-Weight Ratio**

Selecting the suitable T-motor from the navigator Series and motor data table.

Step 1: For MN3510 KV 360 and 14.8 v



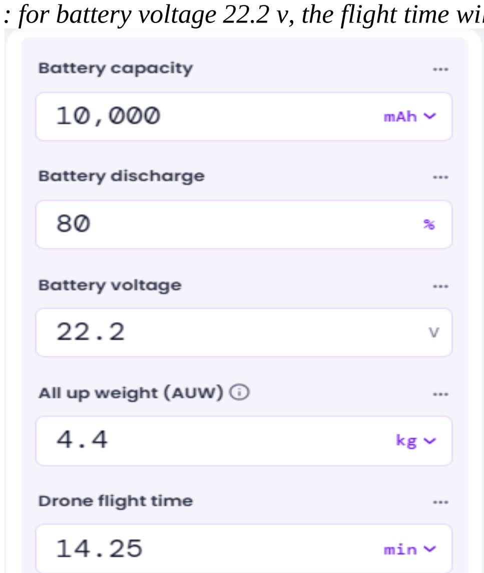
Step 2: For MN3510 KV 360 and 22.2 v



According to the thrust-to-weight ratio calculated from the above steps and from selection design methodologies of MN3510 parameter chart, three propeller types can fit our design. Depending on the takeoff weight 22.2 V (6S) Li-Po battery and 15'5 CF propellers are found suitable for our model. The reason is that the Quadcopter can take off early at 65 % of throttle for the specified weight which is more preferred assumption.

b. **Selection Process Using Software for Flight Time (Omni Calculator)**

Step 1: for battery voltage 22.2 v, the flight time will be;



From the above parameters, for more flight time 15 inch propeller with 22.2v (6s) Li-Po battery fits the design for takeoff weight and flight motion.

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15 inch propeller with 22.2v (6s)

c. Voltage and current values at PDB board

The actual voltage output from the Li-Po battery i.e 22.2 voltage is dissipated and distributed to every components of the Quadcopter. PDB distribute the power to Quadcopter, and connects a battery to all of the ESC's. It has positive and negative terminals. Integrated PDB boards are incorporated in fiberglass plates, as carbon fiber conducts electricity. All carbon fiber Quadcopters have a separate power distribution board which can be mounted on multirotor frame [29].

A voltage regulator, sometimes referred to as a BEC, is another component found on some PDB boards. A simple circuit known as a voltage regulator controls the voltage to a predetermined level, usually 5V or 12V. The battery's maximum discharge rate, represented in multiples of its capacity, is known as the C-rating. Because they run the danger of overheating or damaging, lower C-rated batteries might not be appropriate for high-drain applications. Incorrect use of C-rating can result in decreased performance and possible risks, according a study published in the International Journal of Electronics [30].

Table 5: Li-Po battery data

Li-Po Battery Capacity	10000 mAh
Battery discharge rate	25C
Flight time	14.25 mn

Maximum total current at PDB = 4 x (Current rating of ESC) = 4 x I_{ESC}

From the above statement since the power module draws maximum current of 3A from the Li-Po battery, the remained current to the PDB will be, 59.38A-3A = 56.38A. According to F450 Quadcopter frame kit, the PDB connects the ESC in parallel meaning voltage is constant but the current is the summation of all ESC components. Dividing the input current to PDB by 4, we get 14.09A for each ESC as shown in Figure 15.

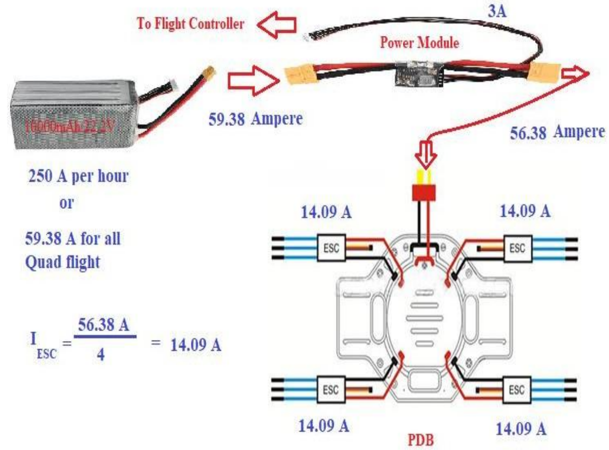

Figure 15: F450 PDB current distribution

Since the current flowing to each ESC is 14.09A, a 20A ESC or greater values can with stand the working current.

$$I_{ESC\ selected} > I_{actual}$$

In the new Quadcopter model, an integrated F450 PCB board is used as shown in the figure below. The F450 board can accommodate current up to 30A. Above this value the PCB board.

Recommended current from F450 PCB Board, I_{in}=14.09A

F450 PCB Board Recommended Current of ESC can be I_{value}>14.09A (20A, 30A, 40A…)

d. Final Selection of Electron Speed Controller (ESC)

In cases of compatibility issue for the selected T-motor, it is recommended to select the same brand. There are different series of ESC of the T-motor as shown in the table below;

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Table 6: ESC series selected from T-Motor Series

ESC Series	Designation
ALPHA Series (FOC)	
THUNDER Series	
FLAME Series	
Air Series ***	

The decision analysis for selecting the ESC series shows that T-Motor air series is more preferred product. Air series 20A ESC selected for our design.

Air series 20A ESC

4.2 Basic motor design specifications for actual Quadcopter airframe model design.

The main objective of the above preliminary selection procedures is to find basic data for our design phase. The motor size is the basic input for our airframe design to be worked out using SOLIDWORK. The customer need, requirement analysis and product specification development are initially identified. Concept generation with decision analysis is performed to select our Quadcopter conceptual design. The conceptual design is supposed to make the frame with two carbon fiber sheet connected with overhead studs.

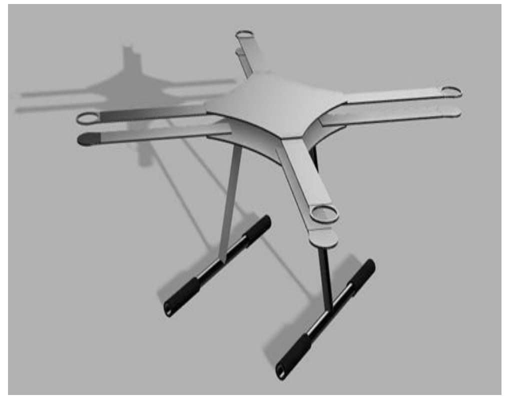

Figure 16: Initial Concept of our Model Design

Therefore for the next phase of the project the following T-Motor MN3510 drawings are used as input for our model. It determines the gap between the plates, the holes for motor fixtures and the gap of propeller and upper plate.

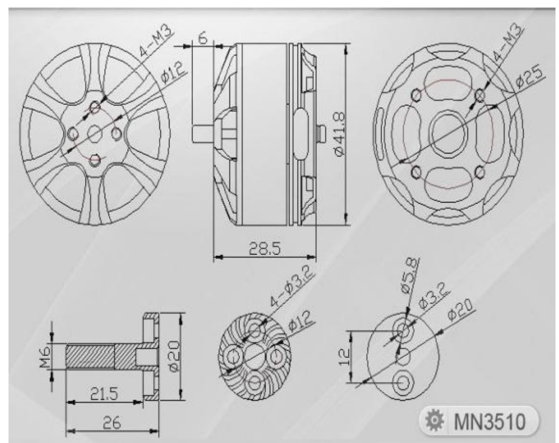

Figure 17:MN3510 motor dimensions

Figure 18: Motor Mounting flange for holes

V. CONCLUSIONS

The Quadcopter model brushless motor, propeller, ESC and LI-PO battery selection procedures show a various technical and parametric steps. The main step begins with thrust-to-weight ratio value. Comparing and contrasting different motor brands. T-Motor type MN3510 is selected and acquired the manufacturer's data sheet to analyze the thrust-to-weight ratio in order to select the types of Li-Po battery and propeller design. According to the analysis three propeller types fits our design. A 22.2 V (6S) Li-Po battery and 15'5 CF propellers are selected component specifications for our model at throttle value of 65 %. A Li-Po battery of 10000mAh is selected to get a better flight time of 14.25 mn. The battery capacity of 10Ah can discharge a current of 250A in one hour from the selected specification. The Quadcopter flight time of 14.25 mn duration discharges 59.38A from the battery. Each ESC can draw a current of 14.09A from PDB. Since the current flowing to each ESC is 14.09A, a 20A ESC or greater values can with stand the working current. Therefore Air Series 20A ESC is selected component for our design. Finally from manufacturer's datasheet, T-Motor MN3510 drawings are used as an input for our detail design, analysis, simulation and manufacturing of the Quadcopter model.

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