Design and configuration of a drive system for a human multi-rotor propulsion aircraft

Capstone Project-II Report

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It is certifiedthat this project report **“Design and configuration of a drive system for a human multi-rotor propulsion aircraft”** is the bonafide work of **“Shreyansh Pandey (1714105011)** and **Ashutosh Chaudhary (1714105004)”** who carried out the project work under my supervision.

Signature of the Supervisor

DECLARATION

We, here by, declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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APPROVEL SHEET

Design and configuration of a drive system for a human multi-rotor propulsion aircraft is approved for the degree of Bachelor of Technology in Mechanical Engineering.

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(Shreyansh Pandey)

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ABSTRACT

Road traffic and congestion control have always been an issue on Indian roads. Besides this, the burning of fossil fuels, environmental harm, and related problems are always there. To avoid this, aerial vehicles (drones) are among the best options to adopt and reduce road traffic. This paper aims to study and review the technologies for an aerial vehicle that can lift a human, i.e., a human-driven drone. Countries like the USA and China are already using big and small drones for delivery, surveillance, medical support, etc. This paper will try to upgrade the Unmanned Aerial Vehicle (UAV) system to a Manned Aerial Vehicle (MAV). The results reveal that ten 150kV out runners BLDC motor propulsion systems (decacopter) with 12s Li-Po batteries with a 15C continuous discharge rate, 275A ESCs, and 32 x11.5inches, carbon fiber propeller blades can lift the aircraft aloft with a human weighing up to 90kg

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List of abbreviations

1.	UAV	Unmanned Aerial Vehicle.
2.	MAV	Manned Aerial Vehicle.
3.	BLDC	Brush Less Direct Current.
4.	ORBLDC	Out Runner Brush Less Direct Current.
5.	IRBLDC	In Runner Brush Less Direct Current.
6.	GTOW	Gross Takeoff Weight.
7.	ESC	Electronic Speed Controller.
8.	RPM	Round per Minute.
9.	CF	Carbon Fiber.
10.	FET	Field Effect Transistor.
11.	BEC	Battery Elimination Circuit
12.	PDB	Power Distribution Board
13.	UART	Universal Asynchronous Receiver/Transmitter
14.	GPS	Global Positioning System
15.	RC	Radio Control
16.	SBEC	Switching Battery Elimination Circuit
17.	UBEC	Universal Battery Elimination Circuit

Chapter 1

Introduction

1.1 Project background

1.1.1 Existing propulsion systems

There are many categories and sub categories under unconventional drones, in which the main categories are UAVs and MAVs. Manned aerial vehicles are generally seen in military whether unmanned aerial vehicles can be seen in military use, commercial use as well as personal use. There are many companies which provides small drones for personal use, in which DJI is the biggest name among all. If we talk about manned aerial vehicles then the most common are helicopter, aero planes and jets. Most of the UAVs runs on battery power and most of the MAVs runs on natural fuels.

1.1.2 Fuel based propulsion system

The required fuel fraction method or RF method is used in large-sized aircraft that use jet fuel or gas motors [1]. This method limits the size of the machine and components like transmission, rotor blades, drive shafts, thus reducing the GTOW (Gross Take-off Weight) with appropriate weight after calculation. This method is proposed only for the motor-based propulsion system, and no such process is proposed for electric propulsion systems though people are working on it. Ampatis worked on an approach that optimizes the data from the battery, ESCs, and motors to balance the payload and design of the system [2]. He defines the vehicle dimensions, motor dimensions, and battery weight. The authors also consider the effects of varying the number of motors on the design. Also presented are thoughts on the modelling of electrical propulsion systems.

1.1.3 Electric propulsion system

For heavy payloads with electric drive system, there are some drones like DJI Phantom series which are being used for product delivery up to 2.5 kg which makes no sense when it comes to lifting human. If we want to lift heavy weight then we have to increase the thrust and to increase the thrust there are to options, first is to increase the length of the propeller and second is to increase the number of motors. With this we have the solution but still don't have the correct configuration of the drive system to get that much of thrust. This thesis is all about that configuration that can generate enough thrust to lift up an adult human along with aircraft weight and all gears. There are some noncommercial aircraft like VoloDrone, Griff Aviation's, Omni hover board and Versadrone that are capable to lift such load but nothing is revealed by anyone of them about the drive system. Most of them are using 8 or more than 8 motors to perform the task.

1.2 Research purpose and meaning

With the increasing demand of fossil fuel we must think if some alternatives. As we all know at some point there will no natural fuel on which we can rely and electric and hydrogen fuel is the future. That is why this thesis report propose an alternative that people can use as their daily commuter as well as for commercial use. Today's market have number of UAVs available, which is commonly known as drones. From small size fun drones to large size military, many options are there. Most of these drones uses battery power to function, which restrict them to lift heavy weight. But if, this constrain can be rectify them UAVs can be turned into MAVs. The purpose of this thesis report is to configure a drive system and to optimize the design of a drone that can lift a weight of a human. This will have many advantages. If there is personal commuter that can make human fly then things like rescue operation, daily commuting, environmental protection, police surveillance and many more. Along with these applications it will also help in controlling the pollution and provide a fast mode of transportation.

Along with all these productive applications and advantages there is one more reason to build these kind of aircraft and that is human desire to fly. Man has reached to every possible inventions in mobility sector and it becomes a desire to fly in air and experience a whole new way of commuting. This thesis report contributes in such desirable development of an aircraft.

1.3 Objective of study

While building a heavy weight lifting drone, the development process is broken into several sections. These sections can be as follows:

Construction of the drive system

It is the most important and the most complex part of the development process. While calibrating a drive system of such aircraft the main point of concern is to churn out the maximum thrust that a system can produce. In this process the parameters of motors, propeller blades, ESCs and the batteries should be considered. The main challenge that occurs in this is the overheated and burning of the components of the drive system. Because it a bit difficult task to get that much amount of thrust, so the system should run in the most optimized manner without overheating the components.

Selection of proper electrical boards

To get the required thrust, the batteries has to deliver very high voltage current to the drive system. And at the same time there are many other components on board which required small voltage of current, for that BEC is used. This cut of a small amount of voltage (5 volts) to operate the other components. Along with this there is a PDB, that distributes the battery current to different ESCs, motors, sensors, receiver etc.

Selection of proper electronics and flight controller

After getting the proper drive system now the biggest challenge is to stabilize the aircraft as there are many forces acting on the aircraft at the time of flight. To counter this a proper flight controller should be selected along with different sensors to balance the aircraft and to increase the safety. Sensors like accelerometer, gyroscope, magnetometer, barometer and GPS should be used.

Design optimization

There are many design parameters that affects the efficiency of the aircraft like, arrangement of the motors, balancing the center of gravity, ducting of propeller blades and many more. All these designing parameters are optimized in this thesis report.

Chapter 2

Literature review

2.1 Introduction

There are many drones of different sizes and can counter various payloads dependent on their framework [3]. In huge air creates that are intended to lift an enormous measure of burden, the RF technique is utilized to get the appropriate lift [1]. The utilization of electric drive framework over fuel-based motors is clear as far as adjustment and introductory force age as electric engine gives better productivity [4]. The size of the airplane or the size of the propeller is the primary thought while fostering a weighty lift multi rotor framework as greater propellers produce more push [5]. To get the ideal pushed, the quantity of engines ought to likewise increment on the grounds that a solitary electric engine can deal with a specific measure of burden. To fabricate a hefty lift multi rotor drive framework, the plan ought to contain in excess of 6 engines alongside huge size propellers [2]. The determination of the segments for a dependable drive framework ought to be made such that none of the segments will get any sort of harm and forestall the overheating of the circuit loads up and ESCs during the flight activity [6]. Brushless DC engines are more proficient as they have less contact focuses and can run at high rpm. The best reasonable engine to drive enormous propeller edges is out runner brushless DC (ORBLDC) as out runner gives more force than the in runner BLDC engines [7]. The mass of the engine ought to be kept as low as conceivable to diminish the absolute load of the airplane [1]. Masses of other drive segments are likewise a basic boundary to get the legitimate lift, masses of parts ought to be kept to their base without trading off the work effectiveness [8]. The plan of the propeller ought to be such that it ought to make a base air vortex at the edges as it diminishes the propeller productivity [9]. In the wake of getting the ideal alignment, it is essential to get precise programming and appropriate taking care of the module [10].

2.2 Review

There are many parameters and point of considerations that one will have to keep in mind. While building a drone or an aircraft that is capable to carry load of an adult human body, on one field of engineering is not enough. So, it becomes necessary to read and to reviews the work of others in the same field.

Many of the researchers and students have contributed in this field as it is shown in above introduction. Some of them shared some knowledge about the conventional mode of aerial vehicle and told us about the history propulsion system. While most of them have thrown some light on the new era electric propulsion system. These well performed and studied works gives us knowledge from different type of motors and how they function to different type of frames that one can use.

Some of them teaches us the functioning of the motors, type of the motors, which motor has more efficiency and many more things. While some of them shows us the about the different electronics and electrical boards. People have also worked on the alignment and the way how should a motor be fixed on the frame along with the propeller to get the best efficiency. With all these reviews, it is clear that student or a person with only mechanical or electrical knowledge cannot fabricate a drone with this much capabilities as it needs not only mechanical but also electrical and electronic as well as computer coding knowledge.

By reviewing all these work this thesis report is capable to deliver sound knowledge and development process of human carrying drone. They provide us knowledge about motors, ESCs, batteries, different electrical boards, design and how to stabilize the aircraft.

Chapter 3

Problem description

3.1 Problem description

This thesis report proposes a concept of a heavy lift multi-rotor propulsion system. The current investigation plans to make a hover board sort of casing plan for drone. It is troublesome however conceivable to make a robot that can lift a human. In this way, a BLDC engine with legitimate kv and fitting ESC and battery can get the right rpm, and with propellers of successful pitch and length, can get the ideal pushed power. Critical aftereffects of various exploration in this field have likewise mulled over to get the most ideal items, and it is unimaginable to expect to get the necessary pushed with only four to six engines, as the propeller length can't be surpassed past a particular worth, thus then the engines won't convey sufficient force to turn the propeller.

3.2 Construction of the drive system

The drive system of a multi rotor drone is simply consist of motors, propeller, speed controllers and batteries. So, in this section, a broad description about the components of the drive system is provided.

3.2.1 Motors

There are many different type of motors present today, which are specially designed and build for some special purpose. There is mainly to types of motors that are used on a wide scale and that is Asynchronous and synchronous.

Asynchronous motors

An asynchronous motors is an AC electric engine where the electric flow in the rotor expected to deliver force is acquired by electromagnetic acceptance from the attractive field of the stator winding. An acceptance engine can thusly be made without electrical associations with the rotor.

Synchronous motors

The engine which runs at coordinated speed is known as the simultaneous engine. The coordinated speed is the steady speed at which the engine creates the electromotive power. The coordinated engine is utilized for changing over the electrical energy into mechanical energy.

They can be broad categorization of motors as shown in below figure 3.1

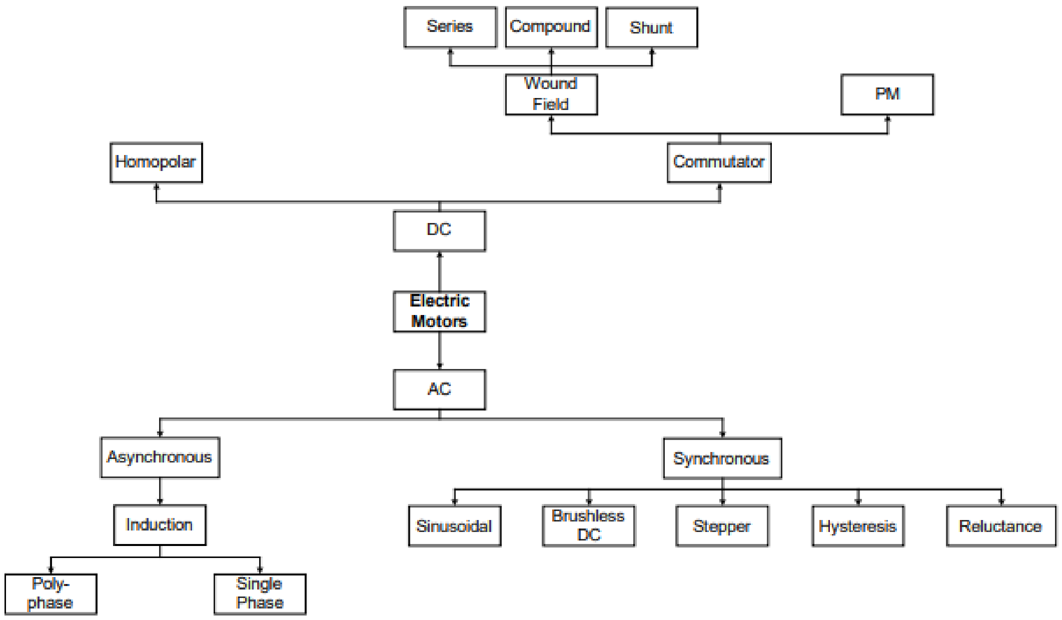

Figure 3.1 Categorization of electric motors [11]

Brushless DC motor

While developing this multi rotor heavy lift drone, the main focus will be on synchronous BLDC motors because of their higher efficiency. Brushless DC (BLDC) engines are utilized for pretty much the entirety of the vehicles portrayed by this paper. These are by and large liked over more established, brushed plans for their more noteworthy effectiveness in changing over electrical to mechanical energy. BLDC engine plans have two designs, out runner (OR) and in runner (IR), which characterize the part of the engine that turns and is appended to the yield or incitation pivot. IR engines turn a pivot with magnets within exhibit of windings masterminded circularly around it.

BLDC engines reverse the IR plan and fold a ringer of magnets over the winding cluster. Despite the fact that IR engines take into account some more tight establishments because of the body of the engine being static, the OR design permits those engines to produce more force than their IR partners. This settles on IR BLDC engines a typical decision for some little (< 100 g) multi rotor fabricates, and additionally a decent decision for anything bigger. It is feasible to utilize equipping (Parrot AR drone is a mainstream configuration) also however because of the natural intricacy, numerous plans utilize direct drive BLDC OR engines. In an immediate drive plan, the propeller is straightforwardly joined to the engine hub. One advantage anyway of an outfitted plan is the possibility to conceal an engine's hub for the most part inside the engine body, making it more solid in case of an accident. Obviously, the outfitting is currently tolerating the brunt of the accident energy, yet this might be simpler to supplant than an engine hub. Seemingly the main boundary of engine choice is the speed steady, or kv, estimated in RPM/V. It is the producer’s sign of generally how quick the engine will turn when dumped per applied volt across its wires. This worth should be appropriately coordinated to the choice of the propeller and battery, just as picked for coming about productivity and lift capacity. For the previous, the engine ought to have the option to deal with the mechanical and force electrical force loads applied by turning the propeller. Excessively high of a kv or voltage, and the engine might be not able to deal with the heaps at high choke, or may turn in a lower effectiveness. Here is a section view of an IRBLDC motor that shows different parts of it.

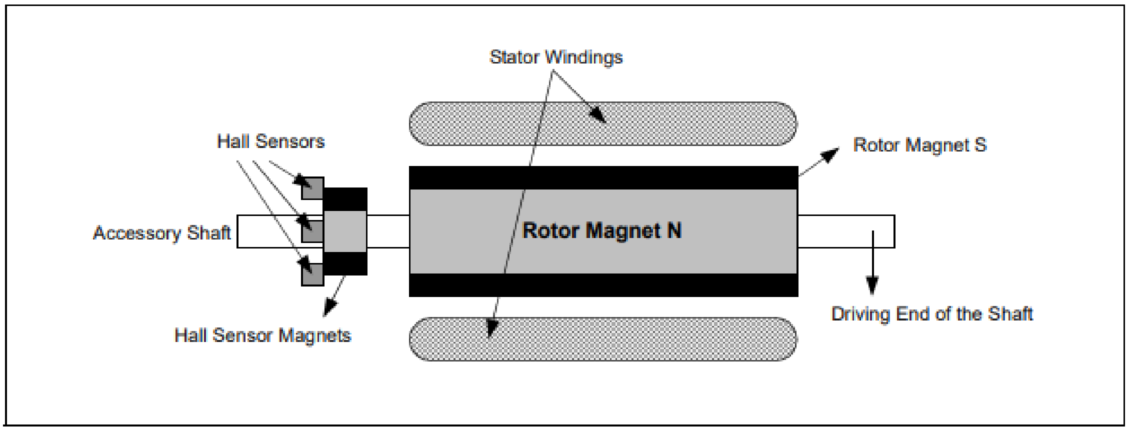

Figure 3.2 Section view of BLDC motor. [12]

Brushless DC engines are considered over conventional brushed DC engines for better effectiveness and long lifetime. BLDC engine accompanies two arrangements: out runner (OR) and in runner (IR), characterize the situation of stator and rotor. In IR engines, the armature runs on its pivot and magnets (either perpetual or electromagnet) and is situated on the horizontal side of the armature, thought about stator. While in the OR BLDC engine, the turning part doesn't turn on the pivot; all things being equal, the entire external magnets and the engine body pivot over the stator. Both OR and IR BLDC engines have comparable effectiveness with a slight contrast contingent on the different conditions. The principle distinction among IR and additionally BLDC engine is the force age. Or then again BLDC engines have more noteworthy force yield than IR BLDC engines [2]. This powers clients to pick between the IR BLDC engine for unobtrusive forms (under 100g) and the OR BLDC engine for hefty use. That is the reason it uses OR BLDC in our task. There are two drive frameworks one is immediate drive, and the other is gear drive. Stuff drives are for the most part fitted inside the engine body, hence giving additional room to ingest crash energies. Then again, an immediate drive framework is utilized when it needs moment force and saves battery energy.

3.2.2 Propeller

There are m any types of propeller in the present time, but in order to get high amount of thrust, big propellers should be taken into consideration as big propellers cuts large slices of air thus producing more thrust and uplift force. There are mainly two types of build characteristics in propeller that is fix blade propellers and foldable propellers. The main designing challenge in propeller design is the reduction of air vortex formation at the edges of the propellers. Propeller with less air vortex formation would be the best in terms of good efficiency rate. Below figures shows the two types of propellers.

Figure 3.3 Foldable propellers [13]

Figure 3.4 Fixed propellers [14]

It is clear that to get an adequate pushed, and the propeller length ought to be huge. What's more, the pitch of the propeller ought to be enough planned with the goal that it can uproot the most extreme air and gain the best effectiveness. At the point when the length of the propeller is expanded, the edges become delicate and adaptable (in plastic and nylon) consequently making an air vortex and influence the effectiveness. Adaptable in nature will change the approach at the external finish of the sharp edge, hence influencing the unique presentation of the propeller. Thus, the synthesis material ought to be firm enough for the enormous propellers to experience diversion toward the end. This impact is depicted completely by Harrington in his work [15]. In the event that the pitch and number of cutting edges are expanded in a propeller, it will uproot more air, in this way giving more push. Be that as it may, whenever continued speeding up, it will likewise build the framework's weight, and proficiency will diminish. The most ideal approach to build the push without expanding the number is to build the sharp edge span to the degree that the engines and other gadgets can deal with it.

Propeller piece, span, pitch, and number of cutting edges should likewise be picked to work appropriately with the picked engine. The material from which the propeller is made may influence the productivity of the propeller at various RPMs. This may happen for gentler propellers because of flexure of the sharp edges changing compelling point of assault at spiral areas from planned points. This impact is depicted by Harrington.3 Expanding the propeller pitch and number of edges by and large produces more push, yet at an expense of effectiveness and expanded electrical and mechanical force prerequisites on the engine. Expanding the propeller's sweep is by and large more proficient, accepting the remainder of the drive framework is fit for dealing with the heap. This is on the grounds that the bigger propeller, with all else being equivalent, may turn more slow to create a similar lift. This permits the actuated speed to drop, along these lines expanding propulsive productivity.

3.2.3 Battery

This investigation thinks about normal, current, diversion grade batteries. Fresher diversion grade battery lithium polymer (Li-Po) creations are fit for explicit energy of up to around 250 Wh/kg, 15 about a significant degree lower than explosive, and two significant degrees lower than kerosene. Numerous COTS batteries are effectively equipped for releasing at flows more prominent than 100 A, some for expanded timeframes. These batteries have everything except supplanted the past Ni-Cd and NiMH batteries which were utilized for interest grade vehicles in the past. Another structure known as lithium particle (Li-ion), generally utilized in purchaser gadgets such as PCs, has a particular energy half better than Li-Po organizations, albeit greatest release rates are lower, which settles on them better decisions for more effective vehicles

Different syntheses incorporate lithium iron phosphate (Li-Fe or LFP), which are have a particular energy of around 100 Wh/kg. While they are heavier than other lithium structures, they are viewed as additional stable under release and when exposed to harm. In contrast to Li-Po batteries, they won't detonate when penetrated and their cells presented to the air. These batteries are additionally answered to have the option to withstand a more prominent number of releases than different kinds referenced previously. Beside substance arrangement, other primary boundaries should be viewed as while choosing a battery or on the other hand batteries for the vehicle, despite the fact that they are not really free. The battery's cell arrangement also, limit should be thought of. The battery should be picked with the end goal that adequate however not inordinate voltage exists to control the drive framework and flying. Li-Fe cells have a most extreme charged voltage of around 3.65 V/cell, though Li-Po and Li-ion cells are charged to 4.2 V/cell. Batteries are worked by stacking cells in arrangement (S) and equal (P) to accomplish perseverance and release rate objectives. Stacking cells in arrangement increments the pack's voltage, while adding more cells in equal expands its ability. For instance, a 4S1P Li-Po battery has four cells in arrangement and one in equal, giving a completely energized voltage of 16.8 V, while the equivalent setup Li-Fe battery will be completely energized at 14.6 V. This worth should relate with the determination of engine kv and propeller to accomplish appropriate RPM and push esteems to lift the vehicle, alongside any controllers that force other locally available electrical frameworks. The limit, typically estimated in mAh, decides the energy stockpiling of the battery. A 1500 mAh battery can give 1.5 Amp of current to 1 hour whenever released to 100%. Batteries which are released to around 80% of their ability per use likewise keep an eye on last more than those which are released to a more prominent degree. The release rate, identified with the purported "C-rating" of a battery, is a maker's sign of the release capacity of the battery. A 40 C 1500 mAh battery in an operational condition is skilled of supporting 60 A release for some measure of time. The force prerequisites of the drive framework should be considered while choosing the battery.

There are primarily two kinds of batteries that has being utilized to fabricate substantial robots and they are Li-ion battery and Li-Po battery.

Basis	**Li-ion**	**Li-Po**
Aging	Charging capacity degrades with time	Retain charging power better than Li-ion
Energy density	High energy density	Low as compared to Li-ion
Conversion rate	85-95%	75-85%
Safety	Volatile	Safe
Cost	Cheaper	Expensive by 30%
Weight	Heavy	Light weight
Charging time	Longer than Li-Po	Comparatively shorter

Table 1: Shows how Li-Po batteries are more appropriate in building a robot

The above table 1 shows how Li-Po batteries are more appropriate in building a robot whether it is a little one or enormous one.

3.2.4 Electronic Speed Controller

At an undeniable level, the electronic speed regulator (ESC) takes a PWM control signal, by and large 1 ms (off) to 2 ms (full), and converts it to AC current. The recurrence of the exchanging, done by locally available FETs, turns the rotor on the BLDC. The primary boundary while choosing ESCs to consider is the most extreme appraised amperage. This should be adequately higher than the necessary drive current per engine with the end goal that the FETs do not overheat and fall flat. An optional choice is whether to utilize ESCs with a battery eliminator circuit (BEC) locally available. These direct primary battery voltage down to normally 5 V to control other aeronautics. On the off chance that this isn't required, it is at times better to utilize optically disengaged (OPTO) ESCs to save energy and warmth, as the BECs will in general be wasteful and may cause pointless warming and energy misfortune.

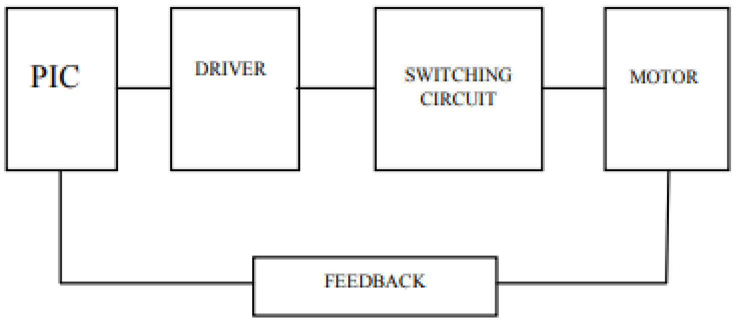

Figure 3.5 Block diagram of ESC working [16]

By and large BLDC engine comes in three stage design as they are more proficient. What's more, to run these engines we need an electronic gadget that can switch the current stream at an incredible recurrence to run the engine at high rpm. ESC is put between the battery and the engine, takes the force from battery and conveys it to the engine such that engine requires it. ESC works with PWM (Pulse Width Modulation) control signals. Installed FETs (Field impact Transistor) are utilized for exchanging circuits. Numerous ESC gives the opportunity to reinvent the Switching recurrence in a scope of 8 to 16 kHz to expand the rpm however at the expense of overheating of FETs. There are other aeronautics that requirements less ability to work, for that BEC proficiency. OPTO disconnects a low voltage power from the principle power supply to ensure the other hardware like beneficiary and other control sheets. OPTO inbuilt unit ESC and kill the utilization of BEC.

3.3 Parameterization of components of the drive system

3.3.1 Motors

The most significant and questionable boundary of engine determination is the kv of engine or speed steady. One kv is one unrest each moment on applying 1 volt to a dumped engine. kv is with respect to Volt, 2 volts will turn twice worth of kv. It is a rating that shows how quick a dumped engine will run when a specific measure of potential distinction is made across it, it is estimated in RPM/V (Round Per Minute/Volt). To get the best yield and most productive outcome, kv of the engine alongside propeller, battery and ESC (Electronic Speed Controller) ought to be chosen cautiously. Too high kv engine or too high voltage can harm the engine when the framework is open to max speed hence affecting the RPM and proficiency of the engine. For the most part, for a rock solid form, a lower kv engine at high voltage is utilized in design with low pitch enormous propeller sharp edges to get the adequate lift. Also, assuming we select a little high pitch propeller with high kv engines, it will be appropriate for fast gymnastic robots.

The information appeared here think about both IR and additionally engines, the last being a more famous decision for some multi rotor setups for their by and large higher force (per mass) and simplicity of establishment. Figure 3.6 shows the pattern of high kv engines having low mass and the other way around, additionally concentrated by Gur [8], in spite of the fact that with less engines, and with a more extensive spotlight on engine types, including hard core/high voltage engines. Both IR or potentially engines are plotted in the figure.

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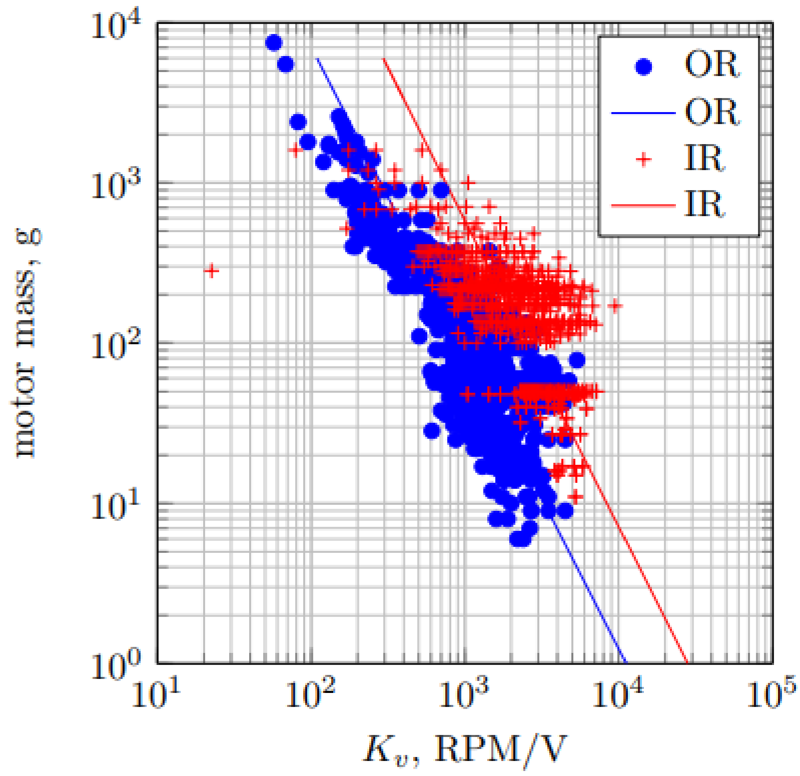

Figure 3.6 Relationship between mass and kv [9]

Assuming it is planned a substantial multi rotor framework, we should choose a low kv rating engine as low kv engine produce enormous force that is expected to turn the huge propellers. Yet, there is a connection among kv and mass of the engine.

3.3.2 Propellers

Mass of the propeller ought to be painstakingly thought of while building an airborne worker and ought to limit the load to the best without bargaining the proficiency and unwavering quality. Dmitry has shown a connection between the majority and the breadth of various arrangements on propeller sharp edges [9].

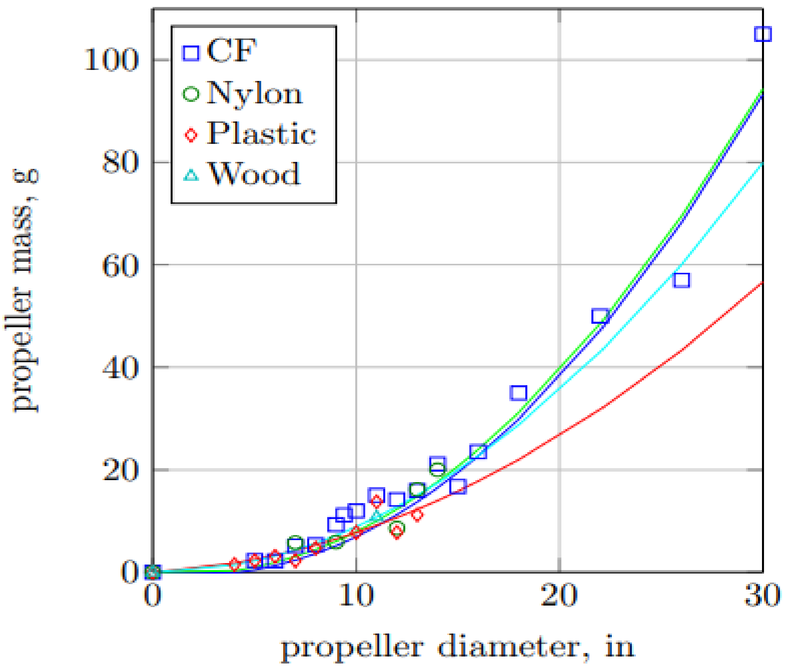

Figure 3.7 Relationship between mass and diameter of propeller [9]

As here can be found in Fig. 3.7, that carbon fiber (CF) is the lone material that can be utilized for enormous propellers. Carbon fiber is multiple times more grounded than steel that implies it is sufficiently solid to offset the air vortex age at the edges. There are numerous producers of propellers, yet Eolo€ gives best motoring plans with various test boundaries. When driven at a most extreme rpm of 4450, the propeller with 32 inches width and 11 inches pitch can create push up to 23 kg.

So, with the above data it is clear to use carbon fiber propellers. The by choosing carbon fiber propellers the strength and rigidness of the propellers will increase but still have a threshold value for the operation at maximum rpm and consideration of other factors. Below a graph is provided with some factory tested data which is using 32X11.5 inches propeller blades, and the amount of thrust it is producing at different RPMs. The maximum rotational speed at which this specific propeller can work is 4450 round per minute. If the speed is extend by this value then the efficiency will decrease as deflection can be seen on propeller blades or it can totally destroy the blades.

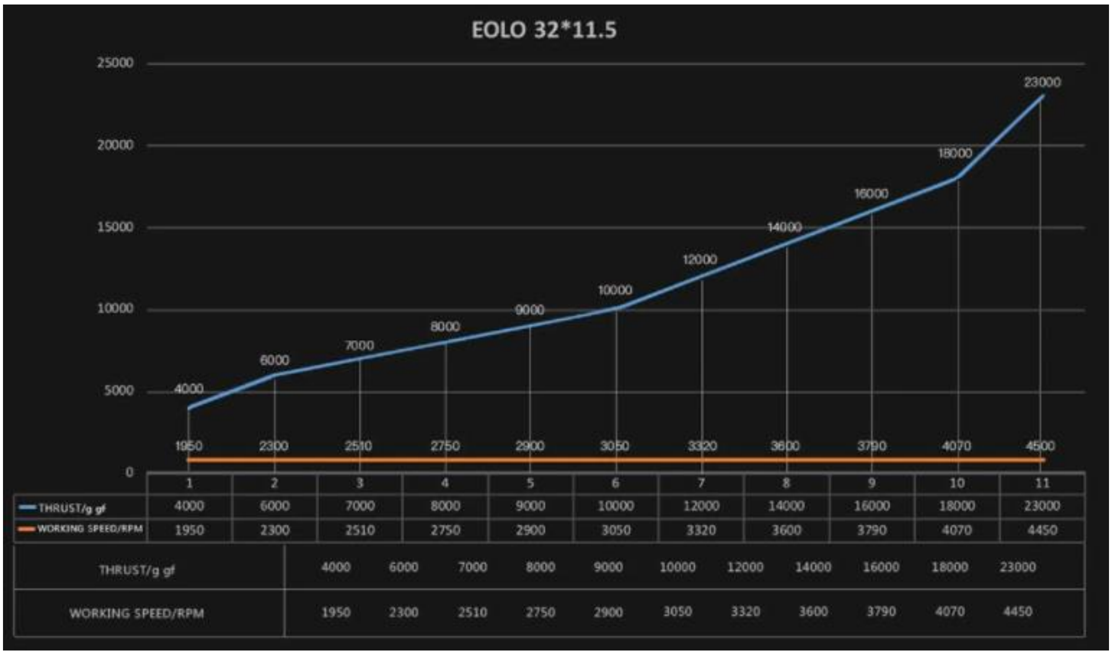

Figure 3.8 relationship between thrust generation and motor RPM [13]

We cannot exceed the max running velocity of propeller which means we cannot perform the gadget at complete throttle in any other case it'll harm the blades in addition to can harm the ESC.

3.3.3 Electronic Speed Controller

Those fundamental parameter is the ampere of the ESC. Motor, battery Also ESC meets expectations together something like that it relies upon what battery we need aid utilizing Furthermore what will be those release rate of that battery. Makers gatherings give those greatest ampere worth that ESC could handle. To example, on we make a battery for 5200 mAh with release rate from claiming 40C that point (5. 2 X 40 = 208A) 208A will make the current yield. So, those ESC must have the ability should handle the current up to and Past 208A Overall the FETs will get in warmed or could short also.

3.3.4 Battery

a) Battery capacity

Battery ability may be the measure from claiming vitality that An battery camwood hold. It is characterized Similarly as the result from claiming present drawn from those battery until the voltage may be dropped will An specific purpose to each Mobile. It will be measured for amp hour (Ah) and milliampere hour (mAh) for high capacity batteries. Assume you require 500 milliamps from claiming present for 2 hour after that it ought to be from claiming limit indicated underneath.

500 (milliampere) X 2 (hour) = 1000 mAh.

Be that as battery ability majorly relies upon the release rate of the battery.

b) Discharge rate

Discharge rate (or C-rate) will be those rate from claiming present release starting with those battery. It may be the constant release rate that battery camwood handle. For instance assuming that we bring a 5200mAh battery for nonstop release rate 40C afterward those withdrawal current will be.

5. 2(Ah) X 40 = 208A.

A portion batteries have constant What's more greatest release rate (like 40C/80C) that is the most extreme present that could a chance to be withdrawal.

e) Configuration

A battery is aggravated dependent upon from claiming a few little cells, for the most part each cell may be from claiming 3.3 with 3.7 volt. These phones need aid orchestrated in arrangement on expand those voltage. This setup is indicated toward letter “S”. Similar to battery about 6 cells, it if make composed as 6S1P. The place 6S means 6 cells. What's more 1P means that they would associated in arrangement.

d) Mass of the battery

Mass of the battery continues expanding likewise we expand those amount of cells. It could make caught on by the chart spoke to beneath in figure 3.9.

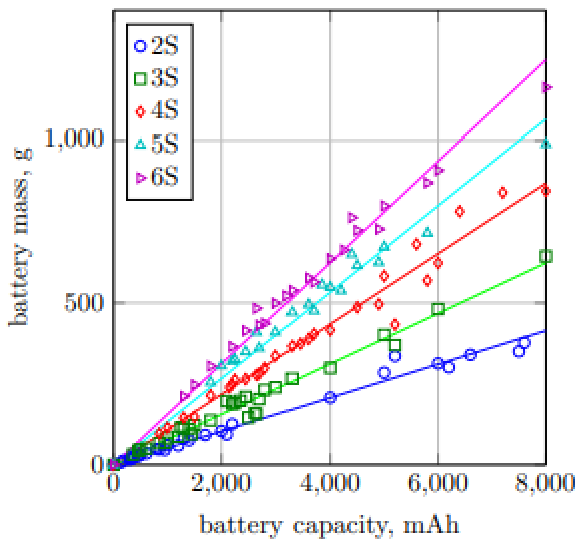

Figure 3.9 Relationship between mass and capacity of the battery [9]

Previously, figure 3. every last bit batteries recognized are for 1P setup and demonstrates that 6S setup is those heaviest and diminishing Similarly as we move towards 2S. This outcome may be demonstrated Eventually Tom's perusing acknowledging 30 basic Li-Po batteries. In we detract batteries for same chemistry, them those mass may be straight for those number of cells it will be holding.

3.4 Selection of proper electrical boards and electronics

Picking the best robot board that suits every one of your requirements is a difficult undertaking. There is a heap of robot regulator sheets out there, and each has its fortifications and shortcomings. With innovative progressions, drone sheets have developed a great deal in the previous decade. Producers are utilizing secure and viable miniature regulators to make solid and incredible robots.

Innovation has made some extraordinary achievements since the time of the KK2 loads up. The first KK2 sheets and their replacements were more huge than their advanced partners, little in size with super preparing limit. While there are a few elements to weigh when purchasing a robot regulator board, this thesis report will walk us through how to pick the best board regulator that meets your requirements.

3.4.1 Circuit board used in drones

A robot board has a few sensors for seeing the movement of the gadget and the overseer orders. With this data, it can manage the speed of the motors and make the robot move properly. These are the fundamental highlights of a robot board.

a) Power Distribution Board (PDB)

A Power Distribution Board is otherwise called PDB, is a neglected segment basically on the grounds that it is obsolete. Electronic parts have made some amazing progress in the previous decade. Once upon a time, PDB's were a fundamental part in the structure of a robot.

PDB's basically circulate the force from the battery to the robot esc. In any case, the innovation has improved such a huge amount as of late that PDB's likewise appropriate capacity to some different peripherals like Transmitters, and the Quad copter Flight Controller itself. Some advanced flight regulators have coordinated PDB's, are restricted by space and can unfortunately oblige a limited amount of much that they don't do a generally excellent occupation at sifting the voltage spikes from the crazy current draws from our quads.

Having said that, Power Distribution Board are as yet liked, as they decrease the weight on the Flight Controllers and normally are better separated from electrical clamor.

b) Processor or Flight controller

The Drone board processor is otherwise called a microcontroller unit (MCU). It will help on the off chance that you have it to keep your firmware codes and tackle confounded estimations. There are five essential kinds of robot board processors dependent on the preparing force and memory size, F1, F3, F4, F7, and H7.

For drones which have heavy lift capabilities and uses more numbers of motors the best flight controller that one can use and which is also referred in this thesis report is **Pixhawk 2.1 or cube.**

Key Features of pixhawk 2.1 flight controller

- 32bit STM32F427 Cortex-M4F center with FPU
- 168 MHz/252 MIPS
- 256 KB RAM
- MB Flash (completely available)
- 32 bit STM32F103 safeguard co-processor
- 14 PWM/Servo yields (8 with safeguard and manual abrogate, 6 assistant, high-power viable)
- Bountiful availability alternatives for extra peripherals (UART, I2C, CAN)
- Coordinated reinforcement framework for in-flight recuperation and manual abrogate with committed processor and independent force supply (fixed-wing use)
- Reinforcement framework coordinates blending, giving steady autopilot and manual abrogate blending modes (fixed wing use)
- Repetitive force supply sources of info and programmed failover
- Outer security switch
- Multicolor LED principle visual marker
- High-power, multi-tone piezo sound pointer
- microSD card for high-rate logging throughout broadened timeframes

3.4.2 Battery eliminator boards

The expression "BEC", which represents Battery Elimination Circuit, has its foundations in gas planes. Since their primary purpose source was non-electric, they had a different (typically NiMH) battery to control the recipient and servos, which since those days customarily take around 4.8 to 6 volts. So when individuals turned over putting electric engines on airplane for push, the course of action remained something very similar for some time: A different enormous (and high-voltage) battery for fueling the primary engine, and a little, 5 volts battery for controlling the control gadgets, which couldn't take the higher voltage of the principle battery.

Along these lines, a BEC was a voltage controller that would dispense with that subsequent battery by giving managed capacity to the beneficiary and servos straightforwardly from the primary battery.

The least difficult BEC is a direct controller (now and again called LBEC), a gadget that drops the voltage of its yield by dropping the remainder of the voltage on a variable resistor that would scatter the force coursing through it. The issue with that will be that since it works by scattering the additional force, it's extremely wasteful when the voltage distinction is high: If you have a 12V fundamental battery and a 5V yield devouring 1A of current, the direct BEC should burn-through the other 7V and 1A of current and lose that to warm. In the event that you have a 16V battery, that is 11V*1A: more than twice the valuable force is simply lost to warm! And keeping in mind that you probably won't think often about the actual misfortune (the fundamental engine is presumably eating significantly more than that in any case), the way that the thing warms up like insane may be an issue.

So if your control gadgets and servos are adequately eager for power, you need an switching voltage controller or SBEC. Exchanging controllers convert voltages with scarcely any force misfortune, thus can give out heaps of amps without warming up something over the top. A characteristic disadvantage of these controllers is a somewhat swaying yield voltage (the specialized term for that is swell)

Various switchers smooth it out to changing degrees (perhaps the most ideal ways is to stick a different straight controller after the exchanging one), however it's generally still there even after smoothing. In any case, fundamental plane hardware (for example recipient and servos) ordinarily don't mind if there is any wave, as long as it's not very huge, so it was the most ideal choice for quite a while.

Incidentally came coordinating this controller into the ESC, since it gets battery power in any case, and in planes connects to the recipient with a 3-pin servo header, along these lines having the option to give directed force through that header. Along these lines, for a RC plane, having the BEC incorporated into your ESC implies wiping out an entire extra controller load up and not wiring anything to control your collector and servos: you just need to connect the ESC, and presto, all your gadgets have power.

For multi copters and multi-engine planes, this can get odd, as you have different ESCs, and each needs to give its own force. Furthermore, having different exchanging controllers attempt to yield to a similar spot can prompt... unforeseen outcomes. Conceivably (however improbable) even unstable, so flight regulators typically have their own BECs and ordinarily don't have pins/cushions for power on their engine associations, while greater planes will in general utilize an independent BEC.

Presently come the showcasing terms. An UBEC is a "Universal" or at times even "Ultimate" BEC. These are simply (ideally) great independent voltage controllers that can highlight greater accessible flows, higher productivity, better yield swell smoothing (some of the time through a direct controller), selectable voltages (5V or 12V, in some cases additionally 6 and 9V, or even the entire reach), better unwavering quality, and so forth

OPTO is the strangest of the pack. Actually, it means "opto coupler", which is a method of electrically confining your ESC from the other hardware completely. This can be helpful when managing extremely high voltages and additionally flows, as the voltage swell created in the force supply by the actual engines can be very high, particularly during quick RPM speed increase or slowing down, and can criticism to your control gadgets through one or the other force or ESC control wires. All things considered, this component is fundamentally unmistakable on the tremendous, blaring 80+ amp plane ESCs with radiators. Nonetheless, some quad copter ESCs are additionally known to have opto coupling. Since the mark of Opto is to not have your FC electrically associated with the ESC, it is for the most part fundamentally unrelated with having an inbuilt BEC in the ESC. Anyway available that is not generally the situation, and the term is regularly mistaken for different things even by the makers, so on the off chance that you see this stamping on an ESC it very well may be something different. A few models of ESC even utilize the word OPTO to show that they do have a locally available BEC

3.4.3 UART or Radio Controllers

UART is a shortening for Universal Asynchronous Receiver/Transmitter. The equipment sequential interface empowers fashioners to connect outside parts, similar to a Telemetry, to the robot sheets. It is beneficial to have more than one UART port, yet your robot board's plan directs this.

A Drone Radio Transmitter is an electronic gadget that utilizations radio signs to send orders remotely by means of a set radio recurrence over to the Radio Receiver, which is associated with the robot being distantly controlled. As such, the gadget makes an interpretation of the pilot's orders into the development of the multi rotor. A Drone Radio Transmitter communicates orders through channels. Each channel is an individual activity being shipped off the airplane.

- **Roll:** Moves your robot left or right noticeable all around, in a real sense "rolling" your robot.
- **Pitch:** Slants your robot forward or in reverse.
- **Yaw:** Pivots your robot clockwise or counterclockwise, permitting you to make circles or examples noticeable all around.

- **Choke:** Controls the measure of force shipped off your robot, which makes the robot speed up or more slow.

Radio Transmitters

OpenTX is an exceptionally configurable framework offering a lot of choices for a wide range of RC models. It is made by pilots considering pilots. Wi-Fi and Bluetooth have made it workable for drone producers to make gadget controls that sudden spike in demand for cell phones or tablets. Not simply a cell phone form of your RC transmitter, yet cutting edge controls.

Radio Receivers

A Radio Receiver is the gadget fit for getting orders from the Radio Transmitter, deciphering the sign by means of the flight regulator where those orders are changed over into explicit activities controlling the airplane. A Receiver should be viable with the Radio Transmitter which much of the time implies that a similar brand of Rx and Tx should be bought to set up a correspondence.

Frequencies should likewise be something very similar on both Rx and Tx. For example; a 2.4GHz Transmitter can just work with 2.4GHz Radio Receiver. Along these lines, while choosing your Drone Transmitter and Receiver, it is significant that they are viable with one another as far as recurrence and different boundaries. Likewise, it is vital that both the segments have the size and highlights as per the particulars required. It is prescribed to buy a great Radio transmitter with Receiver when heading out to fly your own robot as it is one of the parts that will keep going long enough

3.4.4 Firmware and software used in drones

You can fix different firmware on your robot sheets to accomplish various purposes and specializations. For example, iNav is produced in view of GPS applications, while KISS is appropriate for hustling. Segment four of this guide contains a definite conversation of the different robot board firmware for use. The software should be updated always for better safety and performance. Firmware is the product at the core of your robot. It controls everything from flight contributions to battery the executives and everything in the middle. So having state-of-the-art firmware is significant on the off chance that you are to work your robot securely and dependably.

In any case, checking for and applying firmware refreshes isn't a need for most administrators, who have different things to consider. Telling the significant specialists about flight movement and making reports for paying clients are undeniably more squeezing matters to most administrators than applying programming refreshes.

This frequently brings about refreshes being deferred to a later date, however for certain robots, this is a misstep since they will not permit you to fly before the update has been applied. Some robot pilots frequently get irritated by this safeguard system, asserting that it keeps them from working productively and causes shame before the client. However, actually firmware is so critical to the protected activity of your robot that it would be careless of a producer to permit an old or obsolete robot to continue to fly. Updates regularly fix messes with in flight adjustment calculations and battery the board which could without much of a stretch reason your robot to drop out of the sky.

This chapter concludes the most of the building process of this heavy lift multi rotor aircraft, as this chapter provides knowledge about various kind of motors and which motor is most suitable for drone making. Other than that this also helps us to know more about ESCs and how they function and what kind of propellers are there and how they affect the performance of the system. This also show us that how the battery configuration should be made to get the best result. Besides all these drive system component, this chapter also gives a brief summary of onboard electrical and electronic devices along with firmware which helps the aircraft to hover, stabilize, motion and how to operate the aircraft as how the rider wants it but with full safety.

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Chapter 4

Design optimization

There are many design parameters which should be considered while building a drone. Design parameter like propeller configuration, frame design, ducting of propeller, center of mass should be taken care of. In topic 3.5 all the parameters and optimizations are studies and the best result in conveyed.

4.1 Ducting

The effectiveness of float skilled Unmanned Aerial Vehicles (UAVs) can be improved by utilizing airplane arrangements with ducted (covered) propellers (rotors). For the assessment of propeller execution, the primary boundaries are pushed and power coefficients also, power stacking. To accomplish their ideal values, mathematical states of the internal and external surfaces of a conduit must be appropriately planned. In its fundamental structure, a part of the tube shaped pipe takes after a cambered airfoil. There are three mathematical highlights yielding execution gains of ducted propellers: appropriately planned bay speeding up the stream towards the rotor, a leeway among sharp edge and conduit improving tip stream, and veering diffuser area limiting the stream from constriction. Conduits can be depicted by the accompanying factors: internal distance across, absolute length, delta sweep, tip-to-cutting edge leeway, diffuser point, and length. They can be non-dimensional by the inward distance across of a conduit or the propeller width

4.1.1 Vortex generation

Adding a channel around propellers decreases the misfortunes produced by the tip vortices. Be that as it may, the elements of the pipe must be picked carefully to essentially improve the proficiency. It has been shown [3] that lessening the tip-freedom, which is the distance between the tip of the cutting edge and the pipe, will bring about more vulnerable vortices of more modest distance across. The tempestuous active energy brought about by the different vortices will hence diminish, prompting an increment in productivity. Notwithstanding, channel push and rotor push are influenced

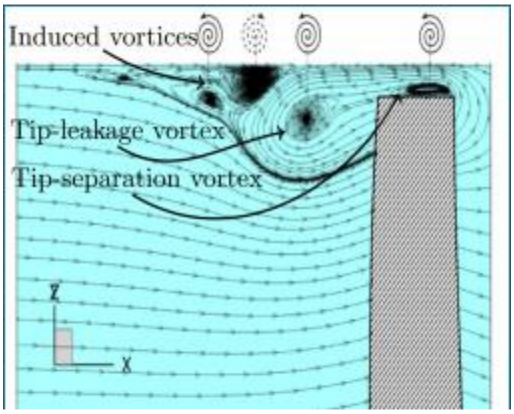

Figure 3.10 vortex generation at the propeller edge [17]

diversely by the diminished tip-leeway. While investigating the push created by the conduit and the rotor independently, it very well may be shown that, sometimes, marginally expanding the tip leeway can improve the rotor push. Figure 3.10 shows the distinctive vortices that show up around a ducted propeller.

4.1.2 Duct geometry

Ducting around any propeller works on Bernoulli’s principle. The surface area of the inner side of the ducting is greater than the outer side which makes an uplift force on the top of the duct body thus increasing the amount of total thrust.

Ducting has two main work to do, first is to cancel the vortex generation at the edges of the propellers and second is to increase the uplift force or thrust. As it is shown in figure 3.11, the space between the edge of the propeller and the inner surface of the duct body has minimum possible distance, thereby allowing no space for vortex generation and side by side helping to create more thrust.

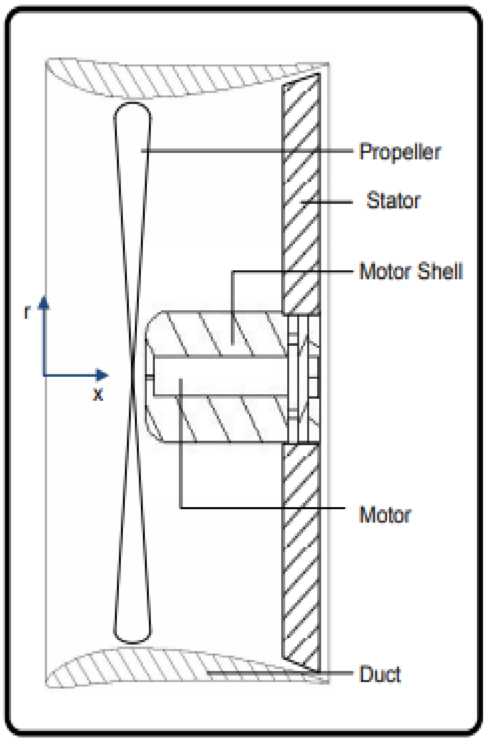

Figure 3.11 Duct geometry [18]

Figure 3.11, a duct geometry is shown for a single propeller and motor setup. The proposed idea is to do the same for all ten motor propeller setup for better efficiency.

4.2 Frame design

The frame design of this proposed prototype model is set with ten rotors as discussed above in this thesis report. While designing the frame the main focus should be on symmetry and the net angular momentum should be zero.

In case of coaxial rotors either one of the opposite rotor should move in clockwise direction or the other should move in counter clockwise so that the net angular momentum should be zero. Same is the case with non-coaxial rotors.

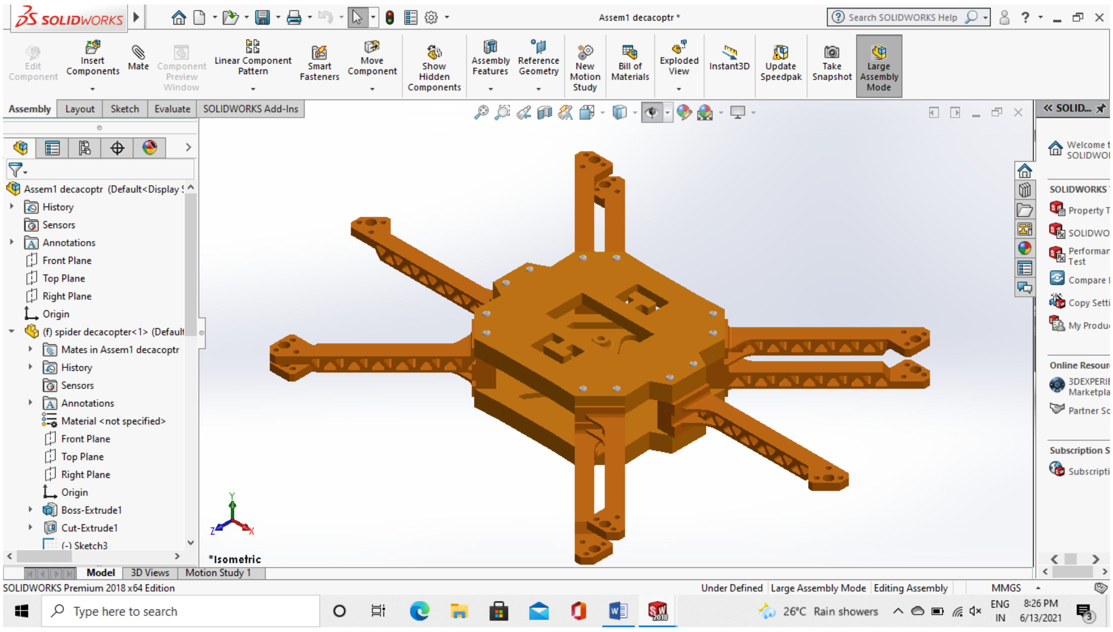

Figure 3.12 3D model design of prototype

The present design is made while keeping a skateboard in mind. For a drone with a human it will a hover board sort of thing in mind. As shown in figure 3.12 there are tem slots for motors in which 8 are coaxial and to motors which will work as booster rotors to get the extra thrust at the time of takeoff are arranged on the either side of the assembly. The design is totally symmetrical and a platform is made in the center of the assembly on which the rider can stand. In this way the weight would be distributed evenly and balancing would become easier. The material proposed for frame fabrication is carbon fiber, as it is 5 times stronger than steel and weighs extremely less. The frame design has been made on solidworks 2018 with all measurements and factors that can affect the performance of the aircraft.

This chapter describes the design parameters and design optimization techniques by which we can increase the total thrust of the aircraft. It elaborates the concept of voter generation at the edge of propeller blades and also provides the solution for this which is the process of ducting. Ducting not on makes the system more efficient but also helps to increase the total thrust. Besides this this chapter also give us the ides of prototype frame design and the composition material for frame fabrication.

Chapter 5

Result and Discussion

5.1 Calibration of the drive system

From the matter which discussed in previous sections, now a perfect and reliable combination of motors, propellers, ESCs, and batteries to lift a human can be executed. The details of these components as shown in Table 2, 3, 4, and 5.

Table 2. Selection of Appropriate Battery

Battery type	Li-Po
Capacity	8000mAh
Configuration	12S1P
Continuous/max discharge rate	15C/30C
Voltage per cell	3.7v
Battery voltage	44.4v
Weight	2200g

Suggested Battery: OKCELL 44.4V 12S 8000mAh

Table 3. Selection of Appropriate ESC

Peak ampere	275A
Max volt	51.8v (14S)
Programming support	Yes
BEC support	OPTO
Weight	456g

Suggested ESC: Turnigy D-lux 250A HV 14s 60v

Table 4. Selection of Appropriate Motor

KV	150
Max current	190A
Max voltage	14S/51.8v
Suggested ESC	250A 14S
Weight	2530g

Suggested Motor: Turnigy RotoMax 150cc Brushless Outrunner

Table 5. Selection of Appropriate Propeller

Composition	Carbon Fiber and Nylon composite
Size	32X11.5"
Max working rpm	4450rpm
Weight	197g

Suggested Propeller: Eolo carbon fiber reinforced nylon propellers 32X11.5

5.2 Load Calculations

The load calculation is done according to a ten-motor propulsion system (Decacoptor). The analysis is done in the multiple of 10.

Weight of motors 2530g X 10 = 25300g

Weight of propellers 197g X 10 = 1970g

Weight of ESCs 456g X 10 = 4560g

Weight of batteries 2200g X 10 = 22000g

The total weight of the drive system will be the sum of the above-calculated weights, that is, 25300g+1970g+4560g+22000g=52830g

Therefore, converting it into kilograms

52830g = 52.83kg ~ 53kg

The total weight of the drive system would be ~ 53kg payload

The maximum allowed weight of passenger along with the safety gears will be 100kg,

90kg + 10kg = 100kg

(human weight) + (safety gears)

Weight of frame

Considering the best material for frame fabrication, carbon fiber, the flexibility for frame weight is given up to ~20kg.

So, the total weight calculation for the take-off will be,

Table 6. Total weight of aircraft with the passenger.

Drive system	53kg
Payload	100kg
Frame	20kg
Total	173kg

For better understanding, the weight calculation is done in kilograms (kg). Still, the actual unit will be kilogram-force (FGF) as all the weight considered is exerting that much force on the Earth's surface, or in other words, gravity is pulling it to Earth's center.

Thrust generation

Thrust is the propulsive force of an aircraft. To hover an aircraft, the value of thrust should be greater than the force of attraction by the gravity on the aircraft.

With the drive system discussed in this Paper, throttle response concerning thrust generation is shown below in the table,

Table 7. Thrust generation w.r.t % throttle response.

Throttle (%)	Thrust (kgf)	Aircraft position
41.29	80	Grounded
43.54	90	
45.79	100	
49.98	120	
54.05	140	
56.90	160	
61.11	180	Take off
66.81	230	

The above table is constructed with the help fig 4. and the rpm of mentioned 150kV BLDC motor. The voltage obtained from one battery is 44.4v, and the kV rating of the motor is 150kV. So, the rpm of the motor can be calculated by multiplying the kV rating with the supplied voltage as,

$$150 \text{ X } 44.4 = 6660\text{rpm}$$

The throttle percentage and the thrust production corresponding to that were calculated by dividing the specified various rpm, which can be observed (in fig. 4) by the achieved rpm.

5.3 Conclusion

This thesis report covers a wide field of drone design and development, this report provides the best configuration of the drive system which is capable to lift a weight of maximum 230 kg with throttle limited to 66%, which is enough to lift a human weight along with the weight of aircraft. This thesis not only calibrates the drive system but also concludes all the aviation electronic and flight controller that stabilize the aircraft and firmware that can update the microcontroller regularly to provide a safe and controlled ride.

The followings are the conclusion of this thesis report:

1. Based on the above discussion and research, the calibration of the drive system concludes the specifications of the following components (components are in multiple of 10)

- 150 kv ORBLDC motors
- 12s 15C 8000mAh Li-Po batteries
- 275A ESCs
- 32X11.2 CF propeller blades

With the above specifications, following components for the drive system is suggested:

- Turnigy RotoMax 150cc Brushless Out runner
- OKCELL 44.4V 12S 8000mAh
- Turnigy D-lux 250A HV 14s 60v
- Eolo carbon fiber reinforced nylon propellers 32X11.5

2. Design parameters like frame design and ducting of propellers for better efficiency and increased thrust is also discussed in the above study with some productive conclusions. And the frame should be made of (carbon fiber) composite material.

3. The maximum weight that the proposed prototype can lift is 230 kg with throttle opened up to 66% only.

4. The above study configured an acute propulsion system because of the complexity of the demand of generation this much amount of thrust on battery power. This leads to some restriction and modifications, that is:

    - The throttle should be restricted to 66%, beyond that the risk of overheating or burning of ESCs and battery pack increases.
    - The switching frequency of ESCs should be reprogrammed from 8KHz to 12KHz

5. The best flight controller to operate ten motors and control the signal congestion for better stability is **Pixhawk 2.1 cube**, that comes with 32 bits cortex M4F processor and a GPS with fully configured IMU and support up to 12 channel radio transmission system.

6. After examining the complexity, the system's probable loads are concerned, and the weight of the frame is given flexibility up to 20kg and the total calculated weight of the onboard components is 53kg. So, the total weight of the super build aircraft would be 73kg.

7. The max allowed weight of the rider along with the safety gears is 90+10 kg.that is 90kg for the rider and 10 kg for the safety equipment.

8. The max payload and the aircraft's weight were calculated around 173kg (round off to 180kg), and the calibrated propulsion system can churn out a max thrust of 230kg, which is more than the requirement.

List of publication

Shreyansh Pandey, Ashutosh Chaudhary, Mr. B.N. Agrawal (2021)

CALIBRATION OF A DRIVE SYSTEM FOR A HUMAN-DRIVEN MUTI-ROTOR PROPULSION AIRCRAFT

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CALIBRATION OF A DRIVE SYSTEM FOR A HUMAN-DRIVEN MUTI-ROTOR PROPULSION AIRCRAFT

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Abstract

Road traffic and congestion control have always been an issue on Indian roads. Besides this, the burning of fossil fuels, environmental harm, and related problems are always there. To avoid this, aerial vehicles (drones) are among the best options to adopt and reduce road traffic. This paper aims to study and review the technologies for an aerial vehicle that can lift a human, i.e., a human-driven drone. Countries like the USA and China are already using big and small drones for delivery, surveillance, medical support, etc. This paper will try to upgrade the Unmanned Aerial Vehicle (UAV) system to a Manned Aerial Vehicle (MAV). The results reveal that ten 150kV outrunners BLDC motor propulsion systems (decacopter) with 12s Li-Po batteries with a 15C continuous discharge rate, 275A ESCs, and 32 x11.5inches, carbon fiber propeller blades can lift the aircraft aloft with a human weighing up to 90kg.

Keywords: UAV, Battery, Motor, Propeller, Li-ion, Li-Po, ESC, MATLAB

1. Introduction

There are different types of drones of various sizes that use different technologies and can counter different payloads based upon their size and drive system [1]. In large air crafts that are designed to lift a huge amount of load, the RF method is used to get the proper lift [2]. The use of electric drive system over fuel-based engines is clear in terms of stabilization and initial torque generation as electric motor provides better efficiency [3]. The size of the aircraft or the size of the propeller is the main consideration while developing a heavy-lift multirotor system as bigger propellers generate more thrust [4]. To get the desired thrust, the number of motors should also increase because a single electric motor can handle a certain amount of load. To build a heavy-lift multirotor propulsion system, the design should contain more than 6 motors along with large size propellers [5]. The selection of the components for a reliable drive system should be made in a way that none of the components will get any type of damage and prevent the overheating of the circuit boards and ESCs during the flight operation [6]. Brushless DC motors are more efficient as they have fewer contact points and can run at high rpm. The best suitable motor to drive large propeller blades is outrunner brushless DC (ORBLDC) as outrunner provides more torque than the inrunner BLDC motors [7]. The mass of the motor should be kept as low as possible to decrease the total weight of the aircraft [8]. Masses of other drive components are also a critical parameter to get the proper lift, masses of components should be kept to their minimum without compromising the work efficiency [9]. The design of the propeller should be in a way that it should create a minimum air vortex at the edges as it decreases the propeller efficiency [10]. After getting the perfect calibration, it is important to get accurate software for the programming part for stabilization and proper handling [11].

The present study aims to make a hoverboard type of frame design for drone. It is difficult but possible to make a drone that can lift a human. Therefore, a BLDC motor with proper kV and appropriate ESC and battery can get the correct rpm, and with propellers of effective pitch and length, can get the desired thrust force. Significant results of different research in this field have also taken into consideration to get the best possible products, and It is not possible to get the required thrust with just four to six motors, as the propeller length cannot be exceeded beyond a specific value, and so then the motors will not deliver enough torque to rotate the propeller.

2. Parts and Design Consideration

2.1 Existing propulsion systems

The required fuel fraction method or RF method is used in large-sized aircraft that use jet fuel or gas motors[12]. This method limits the size of the machine and components like transmission, rotor blades, driveshafts, thus reducing the GTOW (Gross Take-off Weight) with appropriate weight after calculation. This method is proposed only for the motor-based propulsion system, and no such process is proposed for electric propulsion systems though people are working on it. Ampatis worked on an approach that optimizes the data from the battery, ESCs, and motors to balance the payload and design of the system [5]. He defines the vehicle dimensions, motor dimensions, and battery weight. The authors also consider the effects of varying the number of motors on the design. Also presented are thoughts on the modelling of electrical propulsion systems.

Besides this, several tools are being used to calculate various parameters and ensure the proper working of an aerial vehicle. MATLAB and eCalc are the best combinations to motor a multirotor aircraft. Here, MATLAB is a programming platform explicitly designed for motors and scientists to analyse and design systems. It is a matrix-based language allowing the most natural expression of computational mathematics. And, when it comes to eCalc, Benito has well defined it in the study [11]. Its application in designing and calculating the flying time and endurance of the helicopter/multi-copter and some other computations is dependent on a specific set of inputs.

2.2 Design considerations of multirotor electric propulsion system

There are various considerations that the user in designing a multirotor UAV (Unmanned Aerial Vehicle). Still, in this paper, heavy-duty and heavy load carrying capacity drones have suggested the best configuration and design considerations that affect air time, payload capacity, and vehicle balancing.

2.3 Motor

Brushless DC motors are considered over traditional brushed DC motors for better efficiency and long lifetime. BLDC motor comes with two configurations: outrunner (OR) and inrunner (IR), define the position of stator and rotor. In IR motors, the armature runs on its axle and magnets (either permanent or electromagnet) and is positioned on the lateral side of the armature, considered stator. Whereas in the OR BLDC motor, the spinning part does not spin on the axle; instead, the whole outer magnets and the motor body rotate over the stator. Both OR and IR BLDC motors have similar efficiency with a slight difference depending upon the various dependencies.

The main difference between IR and OR BLDC motor is the torque generation. OR BLDC motors have greater torque output than IR BLDC motors [5]. This forces users to choose between the IR BLDC motor for modest builds (under 100g) and the OR BLDC motor for heavy use. That is why it uses OR BLDC in our project. There are two drive systems one is direct drive, and the other is gear drive. Gear drives are generally fitted inside the motor body, thus providing extra space to absorb crash energies. On the other hand, a direct-drive system is used when it needs instant torque and saves battery energy.

Motor parameters

The most critical and arguable parameter of motor selection is the kV of motor or speed constant. One kid is one revolution per minute on applying 1 volt to an unloaded motor. kV is in proportion to 2 Volt. 2 volts will rotate twice the value of kV. It is a rating that indicates how fast an unloaded motor will run when a certain amount of potential difference is created across it, and it is measured in RPM/V (Round Per Minute/Volt). The best output and most efficient result, kV of the motor and propeller, battery, and ESC (Electronic Speed Controller) should be selected carefully. Too high kV motor or too high voltage can damage the motor when the system is exposed to full throttle, affecting the motor's RPM and efficiency. Generally, for a heavy-duty build, a lower KV motor at high voltage is used in configuration with low pitch large propeller blades to get sufficient lift. And if a small-sized high pitch propeller is selected with high kV motors, it will be suitable for high-speed acrobatic drones.

According to Gur, the above figure shows that fewer kV motors have high mass and vice versa but it also shows that OR motors are more efficient than IR motors for heavy-duty and high voltage [8]. The graph shown below describes the relationship.

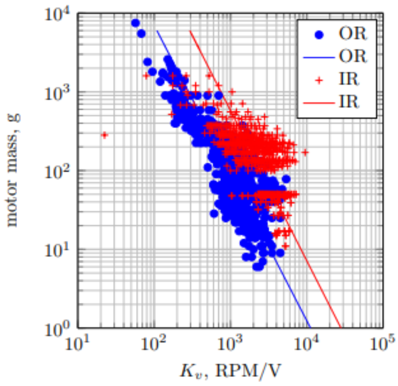

Fig. 1. OR and IR kV to mass relationship [9]

Fig 1. Show that per unit kV of IR motor is heavier than OR motor.

2.4 Battery

There are mainly two types of batteries used to build heavy-duty drones: Li-ion (Lithium-ion) battery and Li-Po (Lithium Polymer) battery.

Table 1. Comparison between Li-ion and Li-Po batteries.

Basis	**Li-ion**	**Li-Po**
Aging	Charging capacity degrades with time	Retain charging power better than Li-ion
Energy density	High energy density	Low as compared to Li-ion
Conversion rate	85-95%	75-85%
Safety	Volatile	Safe
Cost	Cheaper	Expensive by 30%
Weight	Heavy	Light weight
Charging time	Longer than Li-Po	Comparatively shorter

The above table shows how Li-Po batteries are more suitable in building a drone, whether it is a small one or a big one.

Battery parameters

a) **Battery capacity:** Battery capacity is the amount of energy that a battery can hold. It's the sum of the current drawn from the battery until the voltage drops to a specified point for each cell. It is measured in Amp hour (Ah) and milliampere-hour (mAh) for high-capacity batteries. Suppose you need 500 milliamps of current for 2 hours, then it should be of capacity shown below

$$500 \text{ (milliampere) X } 2 \text{ (hour)} = 1000 \text{ mAh}$$

But battery capacity majorly depends upon the discharge rate of the battery.

b) **Discharge rate:** Discharge rate (or C-rate) is the rate of current discharge from the battery. It is the continuous discharge rate that the battery can handle. For example, if a 5200mAh battery is used with a constant discharge rate of 40C, then the withdrawal current will be

$$5.2\text{(Ah) X } 40 = 208\text{A}$$

Some batteries have a continuous and maximum discharge rate (like 40C/80C), which is the maximum current that can be withdrawn.

c) **Configuration:** A battery is made up of several small cells. Each cell contains 3.3 to 3.7 volt. These cells are arranged in series to increase the voltage. This configuration is denoted by the letter "S." Like for a battery of 6 cells, it should be written as 6S1P. Where 6S denotes 6 number of cells and 1P denotes that they are connected in series.

Mass of the battery: Mass of the battery is increased as increase the number of cells. It can be understood by the graph represented below in figure 2.

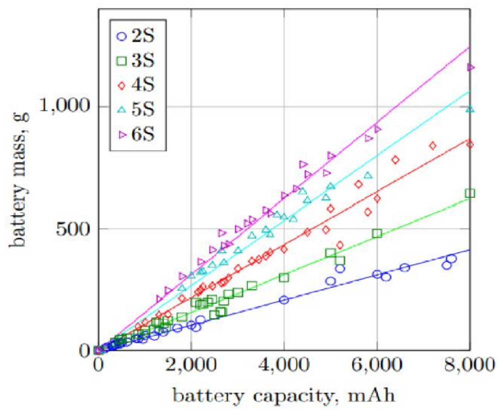

Fig. 2. Battery masses from 2S to 6S configuration [9]

In Fig.2, all batteries considered are of 1P configuration and show that the 6S structure is the heaviest and decreases and moves towards 2S. This result is demonstrated by considering 30 standard Li-Po batteries. If batteries of the same chemistry are taken, the mass is linear with the number of cells it contains.

2.5 Propeller

It is evident that to get an ample thrust, and the propeller span should be significant. And the pitch of the propeller should be adequately designed so that it can displace the maximum air and gain the best efficiency. When the length of the propeller is increased, the edges become soft and flexible (in plastic and nylon) hence creating an air vortex and affect the efficiency. Flexible in nature will change the angle of attack at the outer end of the blade, thus affecting the dynamic performance of the propeller. So, the composition material should be stiff enough for the large propellers to encounter deflection at the end. This effect is described thoroughly by Harrington in his work [10]. If the pitch and number of blades are increased in a propeller, it will displace more air, thus providing more thrust. But if kept on increasing the blades' speed, it will also increase the system's weight, and efficiency will decrease. The best way to increase the thrust without increasing the number is to increase the blade radius to the extent that the motors and other electronics can handle it.

Propeller parameters

Mass of the propeller should be carefully considered while building an aerial commuter and should minimize the weight to the best without compromising the efficiency and reliability. Dmitry has shown a relationship between the masses and the diameter of different compositions on propeller blades [9].

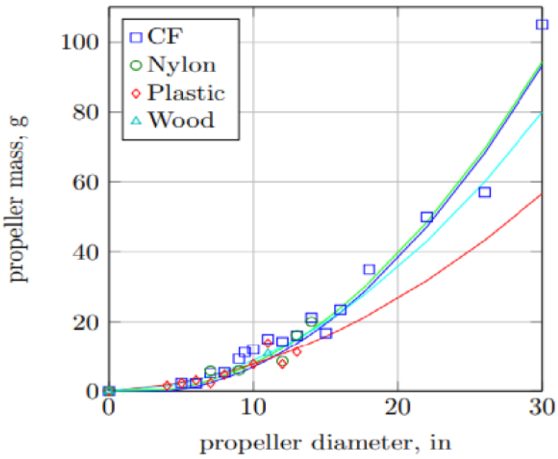

Fig. 3. Masses of different propeller with their diameters [9]

As here can be seen in Fig. 3, that carbon fiber (CF) is the only material that can be used for large propellers. Carbon fiber is five times stronger than steel that means it is stiff enough to counterbalance the air vortex generation at the edges. There are many manufacturers of propellers, but Eolo€ provides with best motoring designs with different test parameters. When driven at a maximum rpm of 4450, The propeller with 32 inches diameter and 11 inches pitch can produce thrust up to 23 kg.

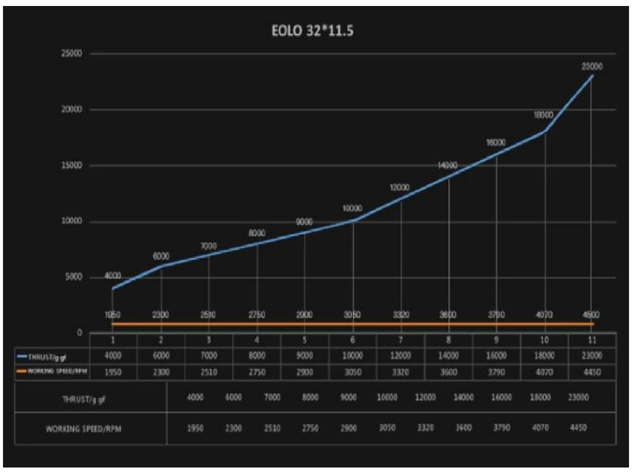

Fig. 4. Thrust w.r.t RPM graph for a 32x11.5 inches propeller (eolo-cn32-11-5-prop.htm)

The max operating speed of the propeller cannot exceed that means the system cannot be operated at full throttle. Otherwise, it will damage the blades as well as can damage the ESC.

2.6 ESC (Electronic Speed Controller)

Generally, the BLDC motor comes in a three-phase configuration as they are more efficient. And to run these motors, an electronic device must switch the current flow at a significant frequency to run the motor at high rpm. ESC is placed between the battery and the motor, takes power from the battery, and delivers it to the motor to require it. ESC works with PWM (Pulse Width Modulation) control signals. Onboard FETs (Field-effect Transistors) are used for switching circuits. Many ESC gives freedom to reprogram changing frequency in a range of 8 to 16 kHz to increase the rpm but at the cost of overheating FETs. Other avionics need less power to operate; BEC (Battery Eliminator Circuit) is used, but OPTO (Optoisolator) is used for better efficiency. OPTO isolates a low voltage power from the main power supply to protect the other electronics like the receiver and other control boards. OPTO inbuilt unit ESC and eliminate the use of BEC.

ESC parameters:

The main parameter is the ampere of the ESC. Motor, battery, and ESC work together, so it depends on the battery used here and the battery's discharge rate. Manufacturers provide the maximum ampere value that ESC can handle. For example, if a battery of 5200 mAh is taken with a discharge rate of 40C, then (5.2 X 40 = 208A) 208A will be the current output. ESC must handle the current up to and beyond 208A; otherwise, the FETs will overheat or can short also.

3. Result and Discussion

3.1 Calibration of the drive system

From the matter which discussed in previous sections, now a perfect and reliable combination of motors, propellers, ESCs, and batteries to lift a human can be executed. The details of these components as shown in Table 2, 3, 4, and 5.

Table 2. Selection of Appropriate Battery

Battery type	Li-Po
Capacity	8000mAh
Configuration	12S1P
Continuous/max discharge rate	15C/30C
Voltage per cell	3.7v
Battery voltage	44.4v
Weight	2200g

Suggested Battery: OKCELL 44.4V 12S 8000mAh

Table 3. Selection of Appropriate ESC

Peak ampere	275A
Max volt	51.8v (14S)
Programming support	Yes
BEC support	OPTO
Weight	456g

Suggested ESC: Turnigy D-lux 250A HV 14s 60v

Table 4. Selection of Appropriate Motor

KV	150
Max current	190A
Max voltage	14S/51.8v
Suggested ESC	250A 14S
Weight	2530g

Suggested Motor: Turnigy RotoMax 150cc Brushless Outrunner

Table 5. Selection of Appropriate Propeller

Composition	Carbon Fiber and Nylon composite
Size	32X11.5"
Max working rpm	4450rpm
Weight	197g

Suggested Propeller: Eolo carbon fiber reinforced nylon propellers 32X11.5

3.1 Load Calculations

The load calculation is done according to a ten-motor propulsion system (Decacoptor). The analysis is done in the multiple of 10.

Weight of motors 2530g X 10 = 25300g

Weight of propellers 197g X 10 = 1970g

Weight of ESCs 456g X 10 = 4560g

Weight of batteries 2200g X 10 = 22000g

The total weight of the drive system will be the sum of the above-calculated weights, that is,

25300g+1970g+4560g+22000g=52830g

Therefore, converting it into kilograms

52830g = 52.83kg ~ 53kg

The total weight of the drive system would be ~ 53kg payload

The maximum allowed weight of passenger along with the safety gears will be 100kg,

90kg + 10kg = 100kg

(human weight) + (safety gears)

Weight of frame

Considering the best material for frame fabrication, carbon fiber, the flexibility for frame weight is given up to ~20kg.

So, the total weight calculation for the take-off will be,

Table 6. Total weight of aircraft with the passenger.

Drive system	53kg
Payload	100kg
Frame	20kg
Total	173kg

For better understanding, the weight calculation is done in kilograms (kg). Still, the actual unit will be kilogram-force (FGF) as all the weight considered is exerting that much force on the Earth's surface, or in other words, gravity is pulling it to Earth's centre.

Thrust generation

Thrust is the propulsive force of an aircraft. To hover an aircraft, the value of thrust should be greater than the force of attraction by the gravity on the aircraft.

With the drive system discussed in this Paper, throttle response concerning thrust generation is shown below in the table,

Table 7. Thrust generation w.r.t % throttle response.

Throttle (%)	Thrust (kgf)	Aircraft position
41.29	80	Grounded
43.54	90	
45.79	100	
49.98	120	
54.05	140	
56.90	160	
61.11	180	Take off
66.81	230	

The above table is constructed with the help fig 4. and the rpm of mentioned 150kV BLDC motor. The voltage obtained from one battery is 44.4v, and the kV rating of the motor is 150kV. So, the rpm of the motor can be calculated by multiplying the kV rating with the supplied voltage as,

$$150 \text{ X } 44.4 = 6660\text{rpm}$$

The throttle percentage and the thrust production corresponding to that were calculated by dividing the specified various rpm, which can be observed (in fig. 4) by the achieved rpm.

Conclusion

This paper concluded as follows:

- Based on the above discussion and research, ten 150kV outrunners BLDC motor propulsion systems (decacopter) with 12s Li-Po batteries with a 15C continuous discharge rate, 275A ESCs, and 32 x11.5inches, carbon fiber propeller blades can lift the aircraft aloft with a human weighing up to 90kg.

- It became challenging to calibrate a proper propulsion system without damaging or burning the ESCs, motors, and wires while extracting the most controllable current and potential difference from the batteries.

- After examining the complexity, the system's probable loads are concerned, and the frame is given flexibility up to 20kg.

- The max payload and the aircraft's weight were calculated around 173kg (round off to 180kg), and the calibrated propulsion system can churn out a max thrust of 230kg, which is more than the requirement.

The throttle should be restricted to 65% otherwise motors can damage the propellers. The best suitable flight controller for discussed propulsion system would be **Pixhawk 2.1 flight controller.** And Frame the of aircraft should be made up of carbon fiber.

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