PROPULSION SYSTEM SELECTION FOR AN INDIGENOUS MULTIROTOR (WITH EMPHASIS ON QUADCOPTER)

The propulsion system of a multirotor comprises of the motors, battery, Electronic Speed Controllers (ESCs), propellers and the power distribution board. For a successful flight of the copter in air, it is crucial that an appropriate combination of the same be adopted keeping in mind all target parameters such as **weight optimisation, copter stability along with agility, endurance**, specific purposes such as FPV etc.

Many factors govern the selection of each of these components and many of them are interdependent on one another, where one changes with another. Since there is no well-defined method, we start by making certain assumptions in the beginning, analysing and enhancing each component till the whole system fits in. This paper explores in detail the factors which help one choose an optimal and effective system.

MOTOR SELECTION

Throughout the UAV field, BLDC motors is the widely accepted class of motors used. Brushless motors turn a lot quicker and utilise less power at the same speed relative to DC motors. Unlike DC motors, they don’t lose power in the brush-transition, which makes them durable and robust. For quadcopters of larger sizes, we mostly use outrunners.

The major factors to be considered for the motor selection are the **frame size, thrust** required by the quadcopter, the **KV rating** and the **power** required during one complete flight.

FRAME SIZE

The frame size ascertains the class of quadcopters it belongs to, whether it is a FPV racing quadcopter, indoor flying, aerial cinematography, surveillance or other special purpose copters.

Generally, quadcopter sizes with wheelbase 150-300 mm serve as good racing quads and 400-700 form the larger class of quads, which could be used for a variety of purposes. Once we have a particular frame size according to our use, we can get its weight which would help in the GTOW estimation (explained ahead). This also gives us an idea of the size of motors and propellers to be used. Furthermore, we can assume suitable reference COTS quadcopters, according to our frame sizes for the purpose of comparison.

KV (velocity constant)

The velocity constant KV is an important parameter of the brushless DC motors. It gives the revolutions per minute per volt (rpm/Volt) of the motor when no propeller is loaded. Larger motors usually are powerful than smaller motors due to the greater torque they have available to spin propellers. Naturally, the size of the propeller is in accordance with that of the motor, larger motors with larger propellers and viceversa. There is a simple logic here- **A low kV motor can spin a larger propeller, and a high kV motor can spin smaller propellers**. Large props can generate more thrust, hence lifting more weight; they have smaller kV ratings. Small props can spin faster, and hence make smaller quadcopters easier to manoeuvre; they have higher kV ratings. For example, I'd use 800-1200kV motors on a quad of size 450-600 mm, but 2000-2400 kV motors on quads of size 250 – 300 mm. also, as the size increases, the weight of motors also increases, so a balance has to be struck between the two.

THRUST

The relationship between the motor and thrust is important to understand. The four motors together produce a thrust which balances the weight and provides the necessary force for acceleration in the desired direction. We need to choose a motor which can give the required amount of thrust to take-off and keep the quadcopter in the air. Thrust can be estimated by taking a suitable Thrust: Weight (T/W) ratio if the weight (GTOW) is known.

WEIGHT ESTIMATION

This is the **gross total weight before take-off**. It includes the summation of the weights of the frame, landing gear, motors, batteries, ESCs, Power Distribution Board, propellers, Flight controller system, GPS, transmitter, camera and gimbal(if any), wires, etc. Since many of these aren't known initially, we can take an approximate estimate, subject to change as we proceed on deciding each component.

We already know the weight of the frame and landing gear. Since we know a frame size and a kV range, we can compare datasets of various motors having the required kV rating, referring to quads having same sizes as the one we are going to design. This gives a rough estimate of the weight of each motor.

A look at the data-sheets of these motors mostly shows recommended batteries to be used with them. You will understand more about battery assumption after reading the section on battery selection. The weight of the flight controller and camera you intend to use are available online. Rough estimates of the ESC and PDP can be taken. Keep a buffer of 100 gm for the propeller, wires etc. hence the GTOW can be calculated.

THRUST/WEIGHT RATIO

To keep a 1 kg quad in the air, we need 1 kg of thrust. So, to be able to lift a 1 kg quad in the air, while leaving some room for manoeuvrability, it is good practice to keep your thrust in the range of 1.7-2.3 kg. This means that applying 50% thrust will allow your quad to hover in the air, increasing this will take it higher, and lowering this will bring it down. The 2:1 T/W ratio is commonly used for quads. For racing quadcopters, this ratio can be increased as per need, with those having ratios above 2:1 ideal for acrobatics.

Though a higher T/W ratio gives flexibility to for acrobatics, it becomes harder for the pilot to control the quad, making it difficult for amateurs to fly it successfully. This is because the throttle stick has a wide range of offerable values and the multirotor becomes sensitive to the abrupt throttle changes that could be made by the pilot. For example, in a 3:1 ratio, at 33% throttle the quadcopter can be easily hovered and manoeuvred and sudden jumps to 70% or above throttle might make the copter uncontrollable.

POWER

The power consumed by all four motors during flight is the most important factor which limits our motor finalisation decision. This an estimate of the power P=**F.V** used by the quadcopter motors as a whole.

Using the GTOW and thrust ratio at 3 different stages of flight- take-off, hover and landing, the thrust (F) can be calculated and multiplied with the average speed of ascend, hover and descend. This when added gives the total power.

MAXIMISING ENDURANCE

It’s hard to determine flight time on a quadcopter without actually testing it, because it depends on many factors: average flying speed, battery, motor/propeller efficiency, payload, wind speed etc. However there are ways you can maximize your flight time in the air. Generally, low KV motors with large propellers have higher efficiency and can carry larger battery, and thus longer flight time. Brushless motors and propellers tend to have the worst efficiency at maximum throttle, and higher efficiency at lower throttle.
Therefore flying around fast, doing acrobatics etc., will use more power thus shorter flight time. But with proper analysis, a battery which provides a reasonably long flight time can be selected for all quad types.

BATTERY SELECTION

The number of cells (**s-rating**), **mAh rating** and the **C-rating** are the necessary battery specifications.

The battery's capacity is defined in mAh. MAh means milli-Ampere per hour. A battery with a 1000mAh capacity can deliver 1 Ampere (1000mA/1000) for 1 hour. The C-rating or battery discharge rate is a measure of the, maximum current that can be drawn from the battery. If a battery has a C rating of 45/70 C, 45 is the normal discharge rate and 70 is the burst rate which can be used only for a period of 10 seconds in most cases.

Using the mAh and discharge rate, we can calculate the amperage of the battery. This is basically the amount of current that can be drawn with the time for which it can be drawn. a battery having 2200 mAh, 35/70 C gives a maximum discharge rate of 2.2*35=77 A. It supplies a constant 2.2 amperes for an hour. But if 20 A was drawn from the same, the flight time would reduce to 6.6 minutes.

The number of cells controls the voltage (hence power), while the endurance is controlled by the mAh. The discharge rate should be above a certain value or else the battery will get discharged quickly. The weight of the battery increases by the addition of extra cells as well as increasing the capacity of the battery (mAh). In order to increase flight time, we have to be careful. Too heavy, it won't make much difference to the endurance; too light, it won't keep the quad in the air for long.

ESC SELECTION

The amps the motor pulls will give you an idea of the ESC to be used. The ESCs are connected to the batteries via the power distribution board within the multirotor frame. Most ESCs come with a battery eliminator circuit (BEC) which acts as a voltage regulator, allowing other electronic components like the flight controller and receiver to power up without connecting them directly to a battery.

They come with specific amperage ratings, and are pre-programmed with one out of two major firmwares – BLHeli or SimonK. The SimonK firmware is widely claimed to be superior, and allows quicker response times and more stable flights.

The amperage rating needs to be **1.2 to 1.5 times** the maximum current rating of any of the motors, so that any peak current requirements of the quadcopter (during take-off or quick manoeuvres) can easily be taken care of, without overheating or burning of the ESCs. The power distribution boards are also chosen according to the amperage.

PROPELLERS

The motor datasheets give a fair idea of the propellers that are used with them. Before shortlisting any propeller, it is advisable to check that it is in accordance with the frame size. Changing the diameter or pitch, effects the power and T/W ratio.

ANALYSIS AND SELECTION USING E-CALC

We have covered all the factors that affect battery and motor selection. By now, we can shortlist a few motors and batteries according to the availability and cost effectiveness. But we need a method to analyse the combinations and validate which one gives the desired results. **For this we use a software called e-calc.** for exclusive use of the features, one needs to buy it.

Under the quadcopter calculator, we feed all the details asked- from motor and battery chosen to model weight (with or without drive) and frame size. **Figure 1.1** shows one such calculation.

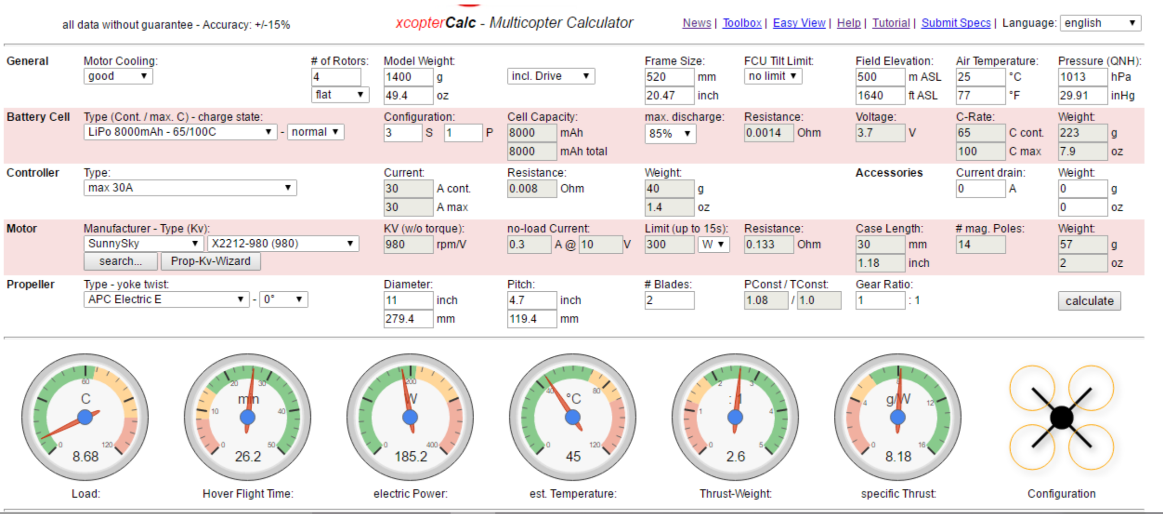

Figure 1.1

As in the above example, the meters at the bottom show the calculated parameters that we had to optimize as a part of the aim. As mentioned earlier, by merely varying the propeller parameters, we can considerably change the power and T/W. we can change our battery mAh ratings and observe the changes in flight time. An important point to note is that as we change our components, we must keep track of the changes in the model weight. One can use the model weight without drive feature which calculates the weight of drive on its own. If the maximum power supplied overshoots the motor limits, it displays an error message as in the figure 1.2.

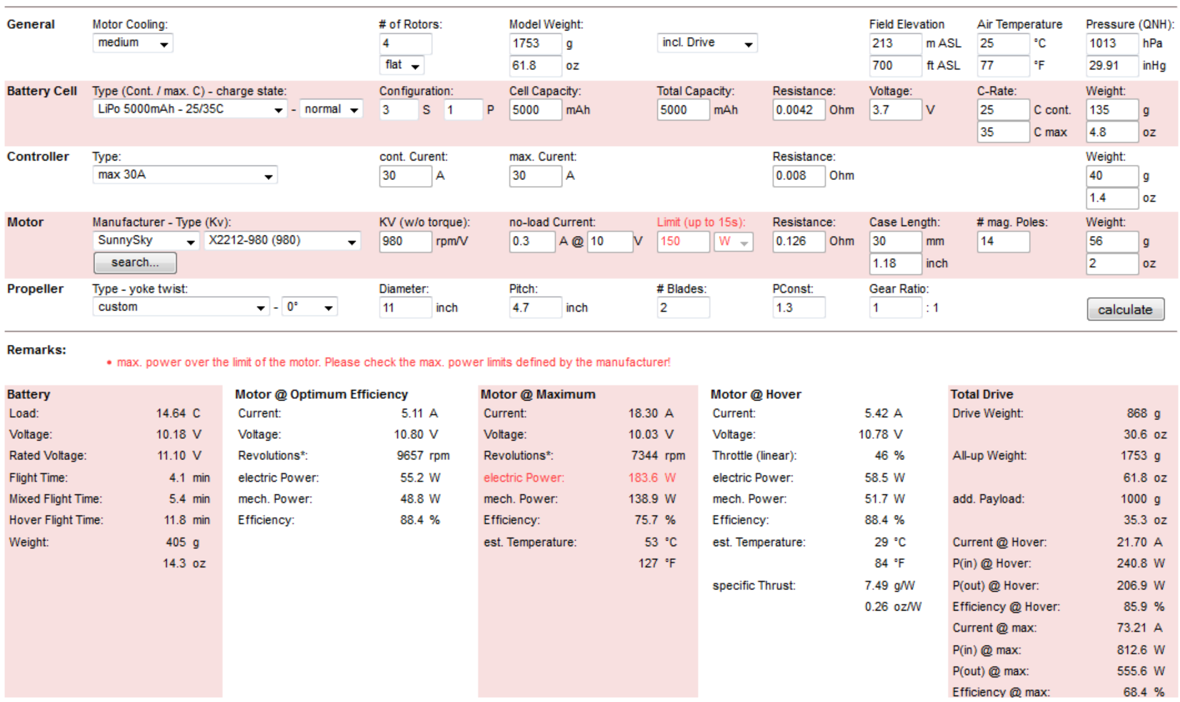

Figure 1.2

Using ecalc, prepare a data sheet of the various combinations and finalise the one that suits you best. A sample data set is shown in figure 1.3.

	MOTOR	kV	GTOW	battery cells	battery mah / C rating	PROPELLER	PROP COMPANY	T/W	POWER	HOVER TIME(min)
1	MOTOR	kV	GTOW	battery cells	battery mah / C rating	PROPELLER	PROP COMPANY	T/W	POWER	HOVER TIME(min)
2	SUNNYSKY X2212	980	1400	3	5000 mah, 65/100 C	10 x 4.7	APC ELECTRIC E	2.2	146	15.5
3			1400	3	8000 mah, 65/100 C	10 x 4.7	APC ELECTRIC E	2.2	150	24.9
4			1400	3	8000 mah, 65/100 C	11 X 4.7	APC ELECTRIC E	2.7	188	26.5
5			1400	3	8000 mah, 65/100 C	11 X 4	APC ELECTRIC E	2.6	172	27
6	TIGER MT-4006-13	740	1400	4	5000 mah, 65/100 C	10 x 4.7	APC ELECTRIC E	2.5	176	21
7			1400	4	8000 mah, 65/100 C	10 x 4.7	APC ELECTRIC E	2.5	180	34
8			1400	4	5000 mah, 65/100 C	10 X 4	APC ELECTRIC E	2.3	158	21
9			1500	4	5000 mah, 65/100 C	10 X 4.7	APC ELECTRIC E	2.3	177	19
10			1500	4	5000 mah, 65/100 C	10 X 4	APC ELECTRIC E	2.2	158	19
11	SCORPION S11-2212(V2)	885	1500	3	8000 mah, 65/100 C	11 X 4.7	APC ELECTRIC E	2.1	150	14
12	SCORPION S11-2212(V2)	960	1500	3	8000 mah, 65/100 C	11 X 4.7	APC ELECTRIC E	2.3	177	23

ESTIMATED GTOW : 1400-1500 gm
WHEELBASE: 520 mm
ESC USED: 30 A
REQUIRED : 18-26 min flight time
150-180 W power
2.1- 2.5 THRUST/WEIGHT RATIO

The above table gives various combinations for a comprehensive propulsion system for the quadcopter to be designed. It has been prepared according to the base models, by changing the battery cells, mah, propeller size, each of the four motors has been analysed to give the optimum values of requirements.
The final selection is subject to availablility and cost of desired components.

Figure 1.3

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