FlyMi assignment report

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1 Introduction

The following information is given:

- Maximum total weight of 10kg.
- Structural mass is 35%-50% of total weight.
- Minimum payload weight of 1.25kg.
- Takeoff is to be completed in a 10x10 m area.
- Flight of at least 15 minutes.
- After landing battery capacity should be 20%.
- Maximum speed is 50kts.

I then made the following assumptions:

- Structural mass weighs 50% of maximum allowed, with the UAV weighing the maximum allowed.[1]
- Budget for parts is unlimited.[2]
- The UAV takes only the minimum cargo possible.
- The UAV is flown in cruise at maximum $E = 25.5$, takeoff is performed at $C_{Lmax} = 1.46$ with corresponding drag coefficient $C_{D,CLmax} = 0.061$.[3]
- There are no space constraints for batteries and motor dimensions.
- Wing shape is rectangular with $b = 3.7m$ and $c = 0.15m$, wing height is $h = 0.2m$ and wing efficiency factor $e = 0.8$.[4]
- Rolling resistance between UAV wheels and dirt surface is $\mu_r = 0.1$.[5]

[1] I am assuming the worst case scenario, more assumptions about saving weight will be made after motor selection is further perfected.
[2] Again, more assumptions will be made later.
[3] I took this value from last year's FlyMi assignment where the polar curve for a similar UAV was given.
[4] Based off my estimations taken by observing FlyMi's Nyx UAV in person.
[5] I got this from Anderson's *Introduction to flight*, see note number 6.

2 Initial calculations

First of all I calculated the peak thrust required to perform the takeoff in the given distance. I started by calculating the takeoff speed:

$$V_S = \sqrt{\frac{Q}{\frac{1}{2}\rho S C_{Lmax}}}.$$

Numerical value is $V_S = 14\frac{m}{s}$.

There are three main forces acting on the aircraft during takeoff: thrust from the engines, rolling resistance and air resistance. Rolling resistance is given by

$$R = \mu_r(W - L).$$

The complete formula for air resistance is

$$D = \frac{1}{2}\rho V_S^2 S \left(C_{D,0} + \phi \frac{C_L^2}{\pi e \lambda} \right)$$

where

$$\phi = \frac{(16h/b)^2}{1 + (16h/b)^2}.$$

Summing forces parallel to the ground and employing Newton's second law:

$$F = T - D - R = T - \left(\frac{1}{2}\rho V_S^2 S \left(C_{D,0} + \phi \frac{C_L^2}{\pi e \lambda} \right) \right) - \mu_r(W - L) = m\frac{dV}{dt}$$

where T is the thrust value I had to calculate.

To accurately calculate the value I had to integrate numerically this last equation, however it was a difficult task. Looking for some help with this integration, I turned to J. D. Anderson's *Introduction to Flight*.[6] The textbook suggested that, since both D and L are proportional to the dynamic pressure, their algebraic sum can be considered constant. To account for small calculation discrepancies with this method, it also suggested to consider a liftoff velocity 20 percent higher than the stalling velocity. The author says to calculate the average lift and drag at a velocity of $0.7V_{LO}$. So the complete equation is:

$$\frac{1.44V_S^2(Q/g)}{2\{T - [D + \mu_r(W - L)]_{0.7V_{LO}}\}}.$$

Therefore, the minimum thrust required for the initial acceleration is $T = 106.4N$.[7]

Energy required for the takeoff roll is:

$$E_{TO} = T d_{max}.$$

I also calculated the air resistance for cruise flight, assuming that most of the flight is conducted at maximum efficiency conditions:

$$D = \frac{Q}{E}.$$

[6] Anderson J.D. Jr. *Introdution to flight.* McGraw-Hill, New York, Ninth edition. In particular I'm referring to chapter 6, section 15 "*Elements of Airplane Performance, Takeoff Performance*".

[7] Of all the manoeuvers, the short takeoff is the one which requires the most thrust, therefore a motor capable of fulfilling this requirement will be able to perform all of the other manoeuvers.

With that value, energy required for cruise flight is:

$$E_R = D_{cruise} V_{max} t_{flight}.$$

I then added the two energy values together.
To that value I added an additional 40% divided as follows:

- 20% to comply to the rules regarding after landing battery capacity.
- An additional 20% to account for internal parts friction and dissipation, manoeuvered flight and wind during the competition (not accounted in my calculations), as well as a safety margin for any calculation errors.

The total energy calculated is $E_{Tot} = 1.23 * 10^5 J$.

Having calculated these values, I was ready to start choosing batteries and motors.

3 Battery

I prioritized the choice of batteries so that later I would have the exact value of the maximum possible weight for the motors.

First of all I converted the total energy value found above from Joules to Watt-hours:

$$1.23 * 10^5 J = 34Wh.$$

With that number in mind, I started searching the internet for a battery that would fit the energy requirement.[8]

I then found the "Tattu R-Line 22.2V 2200mAh 6S 95C Lipo Battery" [9] as the best compromise between energy and weight.

The battery has the following characteristics:

- 22.2V voltage.
- 2200mAh capacity.
- 321g weight.

I was now ready to start selecting the motors.

[8] I did not check for voltage compatibility between the battery and the motor because I assumed that there would eventually be an electrical circuit/controller to take care of that.

[9] https://gensace.de/collections/tattu-r-line/products/tattu-r-line-22-2v-2200mah-6s-95c-lipo-battery-with-xt60-plug

4 Motor

First of all I calculated the maximum allowed weight for the motor/motors (the choice between single and multiple motors will be made later).
Considering:

- 5kg structural weight.
- 1.25kg payload weight.
- 0.321kg battery weight.

The maximum possible weight is 3.429kg.

First I converted the peak force required from Newtons into kilogram-force (the force unit used on the website): $106.4N = 10.8kgf$. I then manually filled a .dat table with the most important characteristics of the motors found on the website provided, leaving out the motors with too high or too low maximum thrust and/or weight.

Having imported the table into Matlab, I calculated which motor solutions were single-engine, which were double and which were triple, I then created a thrust vector and a weight vector to plot all of the motors into a graph.

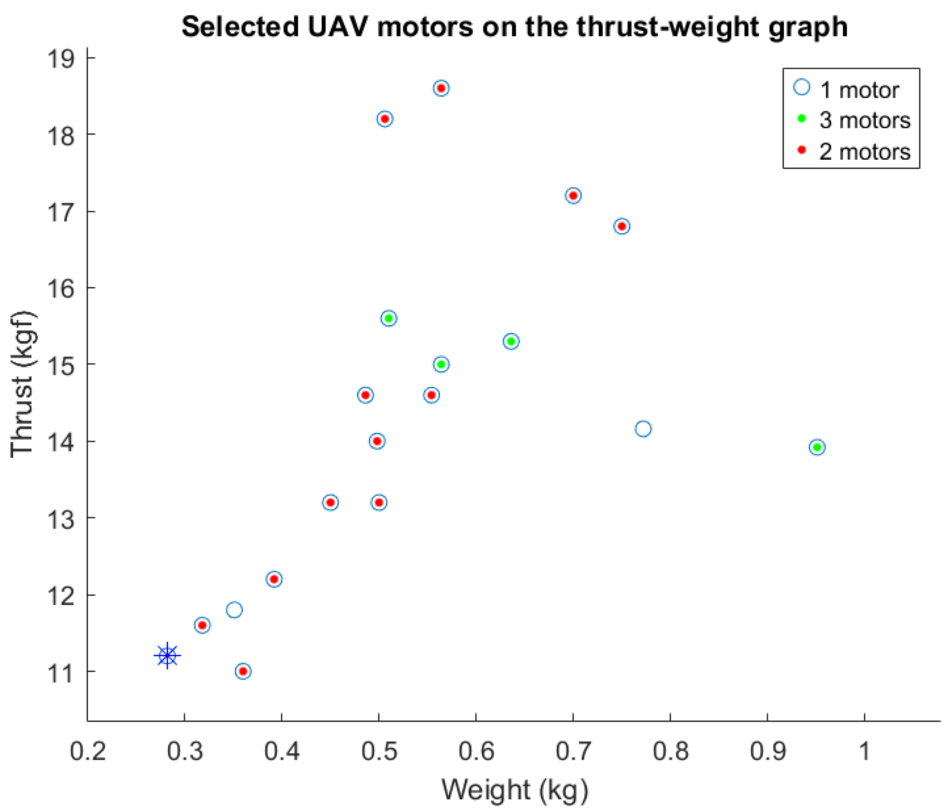

Figure 1: All motor solutions plotted onto the T/W graph.

By plotting this graph I found the best possible motor in terms of weight and thrust: ”U8 Lite L Efficiency Type UAV Motor KV110”, which weighs 282 grams and produces 11.2kgf of peak thrust (with the recommended G30*10.5 propeller).[10]

It’s interesting to note that, while the selected motor is intended for a single-engined configuration (highlited with a blue star in the graph), most of the other solutions with similar characteristics in terms of weight and thrust are intended for a double-engined solution. This means that, if the team wanted to design a double-motor UAV, there wouldn’t be much of a drawback in terms of weight. However I think the single engine solution is better, not only because of the lower weight, but also because it’s simpler and requires less wiring, therefore reducing cost and weight.

If, for some reason, the selected motor couldn’t fit onto the UAV, any other motor plotted close to the one selected would still be a good enough choice, though it would change the configuration from single to double-engined.

5 Final considerations

The calculations above are made from rudimentary data and spur-of-the-moment observations. More accurate results could have been obtained, had there been more precise data available. Despite this, the over-above results are a good starting point for the UAV initial dimensioning.

As for the motor data, instead of getting the numbers by hand from the website, I could have sketched an algorithm for a bot that would have done it for me, but I don’t have enough knowledge in that field. I don’t think I would have gotten much better results anyway, nor would I have saved much more time.

[10] https://store.tmotor.com/product/u8lite-l-kv100-u-efficiency.html