Flight Dynamics Analysis
Quadcopter - P15230

Introduction

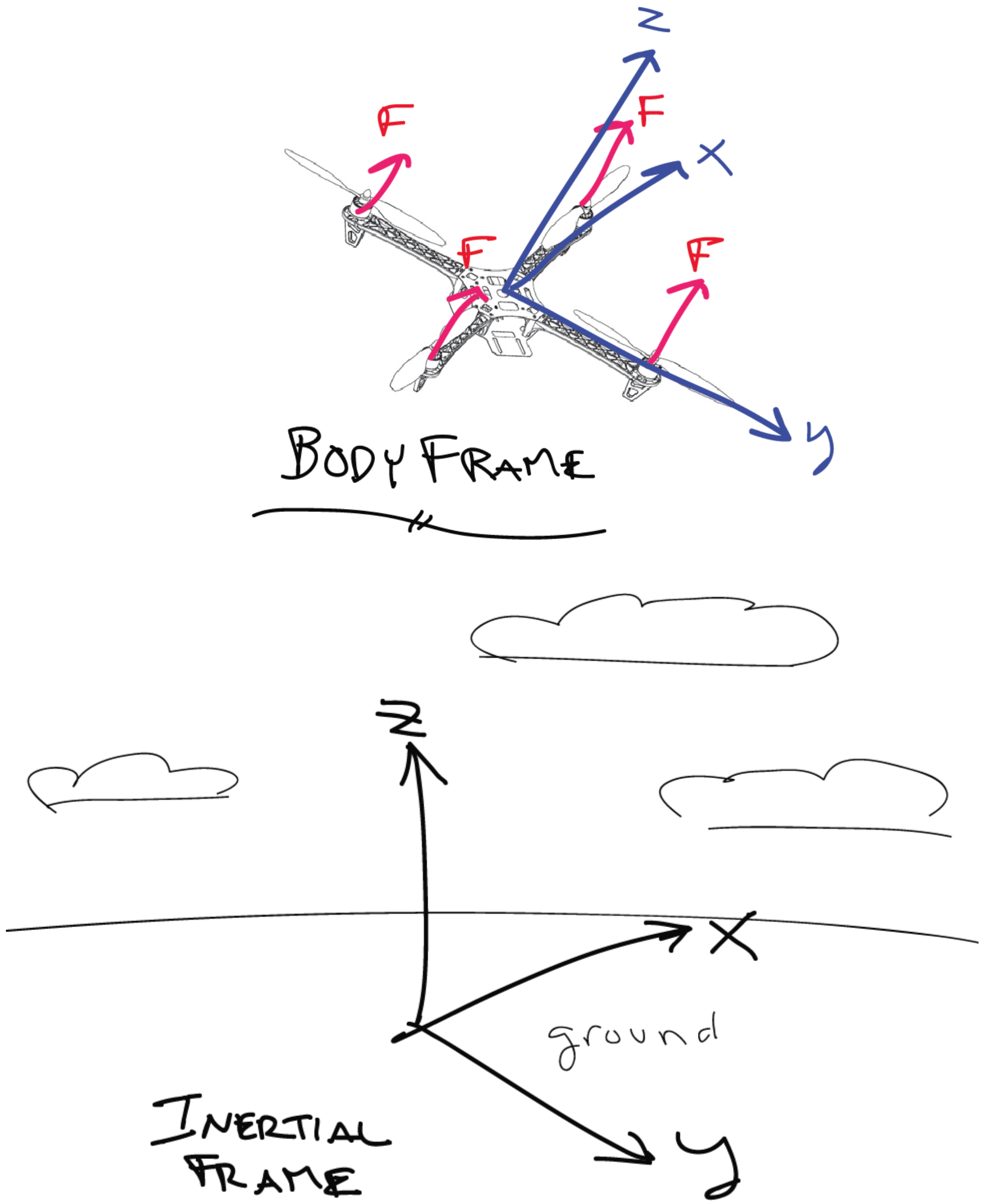

Figure 1: Coordinate system referenced in flight dynamic motion

All general flight dynamic equations can be derived using these two frames of reference, one from a fixed orientation on the ground below the craft and a dynamic coordinate system that moves through pitch, roll and yaw with the UAS. Flight dynamics for pitch, roll and yaw in this system have been previously calculated and are already integrated into the flight controller that will map UAS telemetry in real time and feedback that information to the overbearing code that determines the crafts flight plan.

This analysis will mainly look into motor selection based on what is needed for overall lift, and propeller selection for motor efficiency.

Motor Power Derivation

$$\tau = K_t(I - I_0) \qquad ...(1)$$

Calculating for brushless motor torque where I is the input current to the motor and I_0 is the current when no load is occurring on the motor. K_t is the torque proportionality constant.

$$V = IR_m + K_v\omega \qquad …(2)$$

Here, V is the voltage drop across the motor with R_m being the motor resistance, omega is the motor angular velocity, and K_v is a proportionality constant due to reverse EMF generated per motor RPM.

$$P = IV = \frac{(\tau + K_t I_0)(K_t I_0 R_m + \tau R_m + K_t K_v \omega)}{K_t^2} \qquad …(3)$$

Equations for torque and motor voltage drop can now be used to calculate the power required by each motor, which is further simplified below.

$$P \approx \frac{(\tau + K_t I_0) K_v \omega}{K_t} \qquad …(4)$$

Resistance can be neglected as it should be small so the equation simplifies to the above.

$$P \approx \frac{K_v}{K_t}\omega \qquad …(5)$$

Finally, it can be assumed that $K_t I_0$ is << torque, since I_0 is the current occurring when there is no load, and thus is small in the case of the quadcopter under power, giving us the final equation for power (5).

It can now be seen that power required by each motor is strongly influenced by the rate at which it is turning and the reverse EMF back on the motor generated from the drag force on propeller blades moving through the air. This concludes that we should look into slower RPM motors and focus on propeller efficiencies.

Motor Selection

There are many motors out there on the market to consider for multi-rotor application. Specifications per each motor to be considered are; kV, max current (A), output shaft diameter, weight, thrust, Li-Po(2S-4S) and suggested propeller to match the motor. Multi-rotor brushless motors range from 600-1200kV with lower kV ratings being able to turn a larger propeller, which is good for lift; kV=RPM/Voltage. So say you have a 3S(11.1v) battery and a 980kV motor, the maximum RPM for the motor with no load would be 980*11.1=10,878 RPM. RPM will naturally drop when propellers are added to each motor, and motor suggested propellers should be taken into consideration.

With consideration of the current frame to be in use for our design, the DJI F450, the DJI 2212 motors can be selected for use. They are rated for 920 RPM/V and can turn either an 8in or 10in propeller, in addition to being compatible with both an 18A and 30A speed controller. These motors are rated for using either 2S or 3S Li-Po batteries, the later will most likely be selected for longer flight times and higher propeller RPM; 920 RPM/V * 11.1V = 10,212 RPM unloaded! Under load for continuous rating, ~75% no load RPM, the motor should be running at about 7,659 RPM. In terms of final calculated lift attributed to all four motors, it needs to be approximately twice that of the total weight of the UAS.

Propeller Selection

When looking at propellers, prop diameter and prop pitch are the two main specifications to focus on. The higher the prop pitch, to a certain point, the higher the thrust as the propeller is able to travel a further distance per each revolution. Both propeller diameter and pitch, though, need to be correlated back to the kV rating of the motor which will determine if the motor can turn a certain diameter propeller. It is wise to stick to motor suggested propellers for now, and due to their availability and generally low cost, tests for power consumption vs lift, propeller diameter vs lift and propeller pitch vs lift may be performed at a later date using a test bench set up to truly determine the best propeller to fit our end goal through experimental testing.

Quadcopter Motion Control

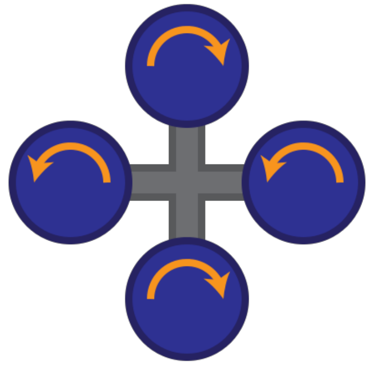

Figure 2: Level hover or change in altitude by adjusting thrust to all motors equally.

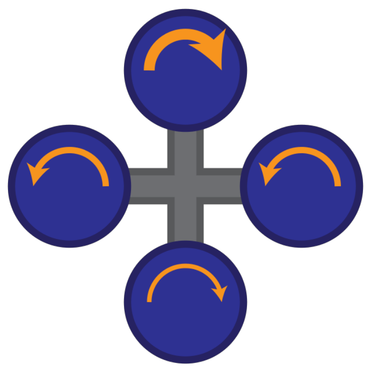

Figure 3: Control of pitch and roll through increasing thrust on one motor and decreasing on its diametrically opposite motor.

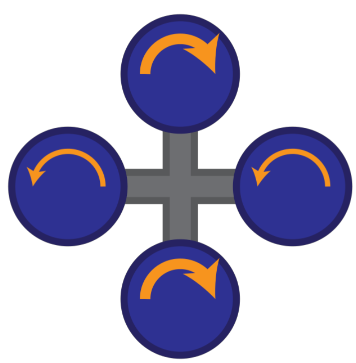

Figure 4: Control of yaw through increasing thrust of two motors rotating in same direction equally.

For example, if the pilot of the UAS would like for the craft to yaw counter clockwise, thrust would be increased for the motor pair rotating in the clockwise direction, while thrust is decreased for the motor pair rotating in the counterclockwise direction to retain altitude. This rotation in the counterclockwise direction is accomplished through higher torque due to the clockwise motor pair producing a moment in the counterclockwise direction onto the airframe.

Moving Forward…

<u>Testing for propeller efficiency</u>

MATERIALS:

1. DJI 2212 motor
2. 30A speed controller
3. 3S (11.1V) Battery
4. Variety of propellers
    4.1. 8” & 10” diameter propellers
    4.2. range of pitches from ~3 to ~6
5. Digital scale
6. Digital multimeter
7. Weight

TEST SET UP: