

Quadcopter Construction for Unidentified Aerial Vehicle Investigation

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ASTR 202: Hands-on Planetary Exploration

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Table of Contents	Pages
<u>Drone Anatomy</u>	3
<u>Drone Frame Construction</u>	4
<u>Ordering Parts</u>	7
<u>Soldering Bullet Joints</u>	8
<u>Soldering T Connectors</u>	10
<u>Soldering Practice</u>	12
<u>Testing Motors</u>	15
<u>Mock test flight</u>	17
<u>Remote Control Transmitter/ Receiver</u>	18
<u>Landing Gear</u>	22
<u>Looking for Screws, Soldering Bullet Connectors</u>	25
<u>Soldering wires on the ESC for Angel</u>	25
<u>Troubleshooting</u>	27
<u>Stitch Troubleshooting Cont...</u>	28
<u>Stitch not lifting off</u>	32
<u>More troubleshooting</u>	35
<u>Test day with sensors</u>	38
<u>Lift-Off!!! (with a jiggle)</u>	43
<u>Damage Control</u>	44
<u>Field trip to Robo Lab (Olin College)</u>	45
<u>PID Tuning</u>	47
<u>PID Tuning contd...</u>	47
<u>Final Troubleshooting</u>	49
<u>Endnotes</u>	53

March 11, 2023: Drone Anatomy and Construction

In order to start building the drone I started looking into the anatomy of a drone during the week. In general a drone requires these components:

- Frame: is the main body of the drone that houses all the components that go on the drone. It is usually made out of carbon fiber because it is a light yet strong metal
- Flight controller: this is the brain of the drone, and it calculates how fast your motors should spin by taking your control input (from the receiver) and angle of the drone (from the gyros, accelerators and IMUs onboard) into account and sends signals to ESCs
- Electric speed controllers (ESC): varies the speed and direction of our motor speed. It usually has one input from the battery and four motor driver outputs. I have found out that they are prone to burn out quickly if we hook up the motors wrong so it's best to buy more than one although we only need one
- Power distribution board (PDB): distributes power from the battery to the ESC
- Motors: along with propellers produce lift force as they spin allowing the drone to fly
- Propellers: attach onto the motors
- Battery: power source for the flight controller and other electronics on board the drone; usually made of LiPo (Lithium Polymer) and are rechargeable
- Receiver and transmitter: establish connection between the drone and the pilot to allow flight control

In addition to these components, our drone has

- FPV (first person view camera): allows real time video stream for steering and navigation
- VTX: a video transmitter that sends the camera data to our ground station computer, phone or tablet, etc.
- LiPo battery charger

More on what the flight controller has for making the drone **balanced and stable**:
[\(source\)](#)

- Gyro stabilization provides flight navigation information to the central flight control systems. It detects changes in the position of a drone and compensates for it
- A flight controller uses IMU (inertial measurement unit) data about the drone's current position then sends new data to ESC
- IMU detects the current rate of acceleration using one or more accelerometers to find current position (basically has motion data)
- We can buy IMU chips with built in accelerometers and gyros (which is what we ended up ordering)
- It is advantageous to buy a six-axis gyro stabilization: 3D gyro + 3D accelerometer (more stable for 3D imagery and easier to fly). The

accelerometer measures the static acceleration (due to gravity) and the dynamic acceleration. This helps figure out the tilt angle of the drone and the way it is moving. It also helps make sharp turns

In our case, the [SpeedyBee F7 flight controller](#) we chose has the ESC and PDB integrated into it so there was no need to buy those separately. We are also using an existing frame from Happy Model's Drone Kit (HMF U580).

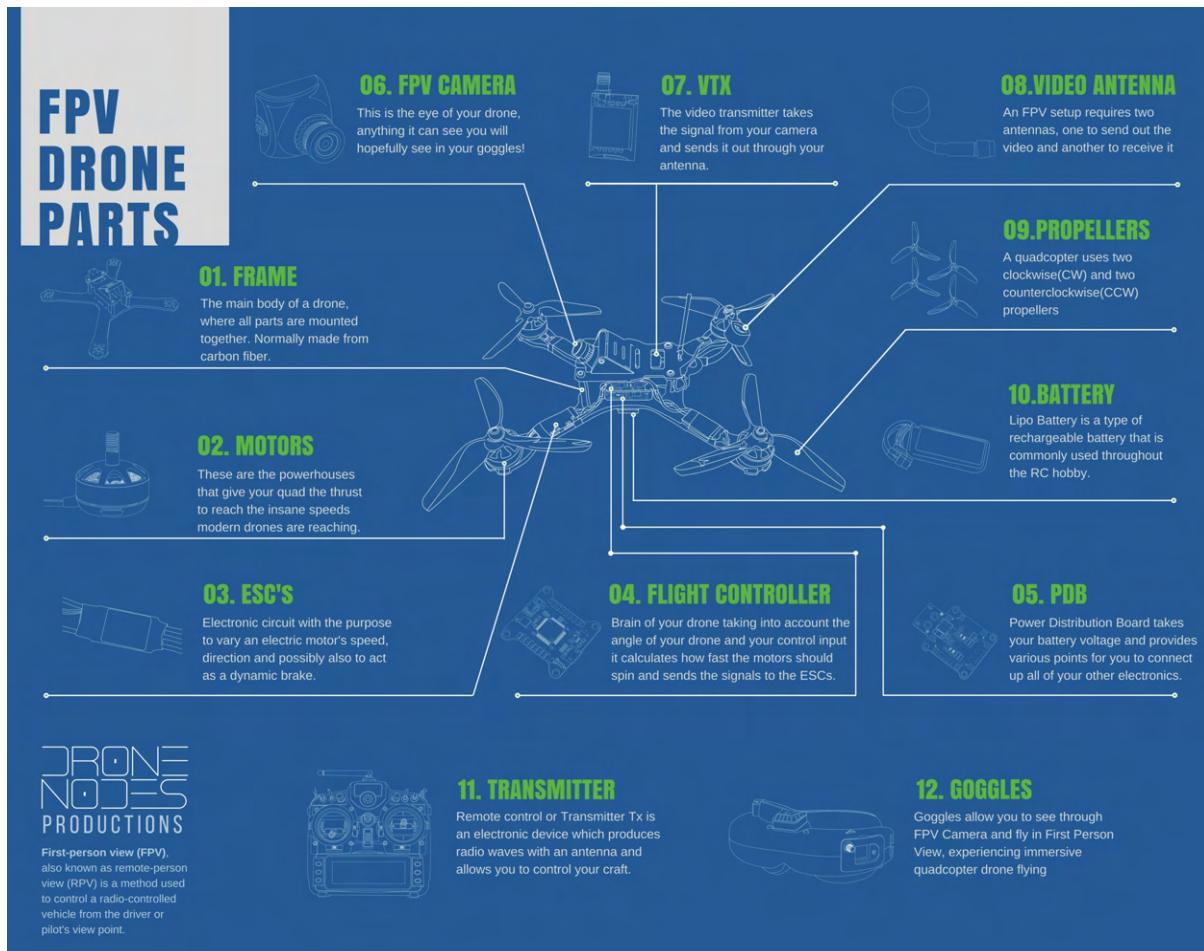
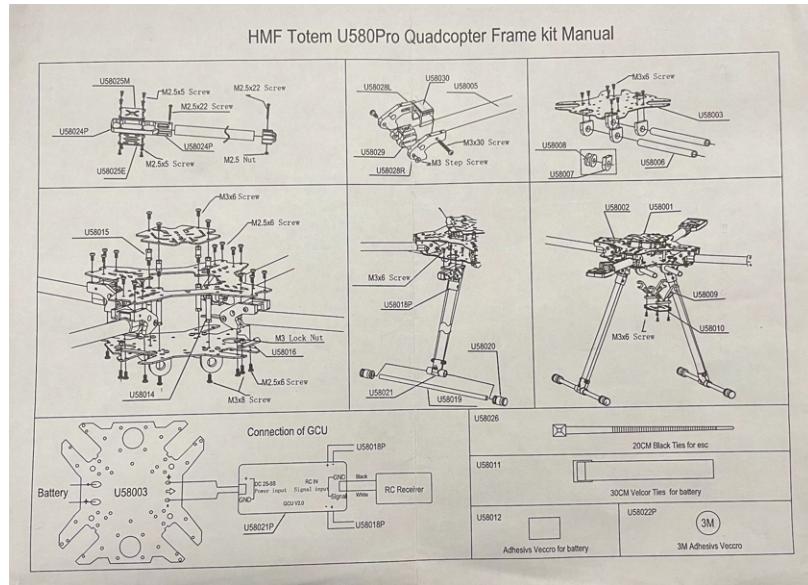


Fig. 1.0 Drone anatomy, [source](#)

Construction of the Drone Frame

Here is the manual and parts list I used to construct the frame one part at a time.



HMF U580PRO Quadcopter Frame Kit pack list			
Pack No.	DESC	QTY	Spare part No.
1	Up board	1	U58001
	Center board	1	U58002
	Bottom board	1	U58003
2	Screws Pack No.2	1	U58004
	16mm Carbon Fiber Tube(Arm)	4	U58005
	10mm Aluminum tube	2	U58006
	10mm tube fixed holder	4	U58007
	10mm damping ring	4	U58008
	10mm suspension hook Sets	1	U58009
	Battery mounted board	1	U58010
	30cm Velcro Ties	1	U58011
	Adhesive Velcro	1	U58012
3	Screws Pack No.3	2	U58013
	M3*30 Aluminum pillar	4	U58014
	M3*15+6 Aluminum pillar	4	U58015
	Tube Fixed paddles	4	U58016
4	Screws Pack No.4	1	U58017
	Retractable landing gear (Leg)	2	U58018P
	10mm Carbon Fiber tube (Leg)	2	U58019
	10mm Silicone Plug	4	U58020
	GCU control unit for Retractable landing gear	1	U58021P
5	3M Double-sided adhesive(1pcs)	1	U58022P
	Screws Pack No.5	1	U58023
	CNC Aluminum Motor mount holder 2Black+2Red	4	U58024P
	Carbon fiber motor mount board	4	U58025M
	Carbon fiber ESC mount board	4	U58025E
	20cm Black Ties	8	U58026
6	Screws Pack No.6	1	U58027
	J-shaped Aluminum parts Left	4	U58028L
	J-shaped Aluminum parts Right	4	U58028R
	16mm folding tube holder	4	U58029
	16mm C-shaped positioning Seat Holder	4	U58030
Screw pack2	M3*6 Screw (13pcs)		
Screw pack3	M3*6 Screw (5pcs)+M3*8 Screw(9pcs)+M3 Lock Nut(6pcs)		
Screw pack4	M3*6 Screw(9pcs)		
Screw pack5	M2.5*5 Screw(32pcs)+M2.5*22 Screw(4pcs)		
Screw pack6	M2.5*6 Screw(24pcs)+M2.5*22 Screw(4pcs)+M3*30 Screw(4pcs)+M3 Step screw(8pcs)+M2.5 Nut(4pcs)		

Fig. 1.2 HMF drone frame manual (top image) and parts list (bottom image)

My team and I had begun building out part of the arms using the kit during class that week. So, I started off by looking at the pieces we already constructed and made sure we were using all the parts and screws. I was initially confused with the naming convention for screws, so I looked those up first. [Source](#) I consulted.

- For metric screws, the name starts off with M and then has numbers, if it's imperial then we have fractional numbers starting off or has a fixed number between #0 to #10 for unified screws in inches.
 - Ex: #4-40 x 0.5, $\frac{1}{4}$ -20 x $\frac{5}{8}$, and M3-0.5x10
- The first number indicates the main diameter (thread to thread), the second number is the number of pitches and the third is the length of the screw (thread length).
 - For the first example it has a #4 diameter, 40 pitches in one inch, and is $\frac{1}{2}$ an inch in length.
 - Second example has $\frac{1}{4}$ diameter and 20 pitches per inch with $\frac{5}{8}$ of an inch length.
 - Third example is a 3mm diameter metric screw with pitches every 0.5 mm and has a 10mm length.

Having that in mind, if in our manual it says M2.5x5, it means it is a metric screw with 2.5 mm diameter and 5 mm length. I measured and verified that before moving onto using them. After that I pretty much followed the manual along with the pack list to build the rest of the drone frame.

Cautionary tips:

- Be careful with tightening the screws, especially the standoffs. I took a wrench and tried to tighten one of them and the screw embedded into one of the standoffs (part U58014, refer to Fig. 1.1b).
- In general, don't tighten all the screws for the central part of the frame (where the bottom, middle, top plates join) because you wouldn't need to unscrew everything in order to fit the motor cables and the flight controller.

I didn't assemble the landing gear because it came in the kit already retracted. Later, Sydney figured out that we need to connect it to one of the ports on the receiver and the battery in order to have it at 90 degree orientation like this:

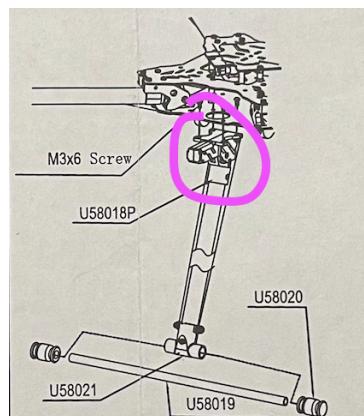
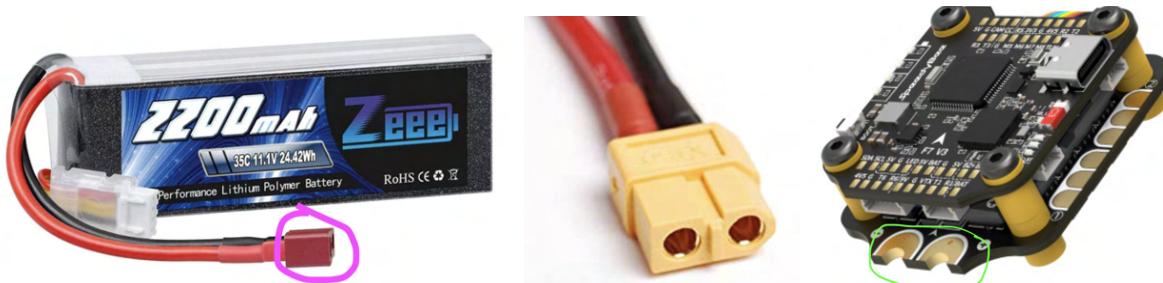


Fig. 1.3 The landing gear 90 degree orientation (circled in pink)

March 13, 2023: Ordering Parts

Spent some time in class validating parts we need to order for the second drone. Our second drone will have cameras similar to the first one but is mainly being built from a [3D model](#) Emma Silbeck found online. Both drones will have different sensors on them.

Katie Shaw and I were mostly ordering connectors to plug into the battery and figuring out what parts get soldered where. Our battery came with female T connectors and the flight controller came with XT60 power cable and thanks to our awesome TA, Nora Hoch, it came to our attention that we need more connectors in order to connect the battery with the flight controller. See images below to visualize the parts we are trying to wire together.



(a) Our LiPo battery with female T connectors (b) XT60 power cable (c) Flight controller
Fig. 1.4 The battery (a) has to connect with the power cable (b) which is connected to (c)

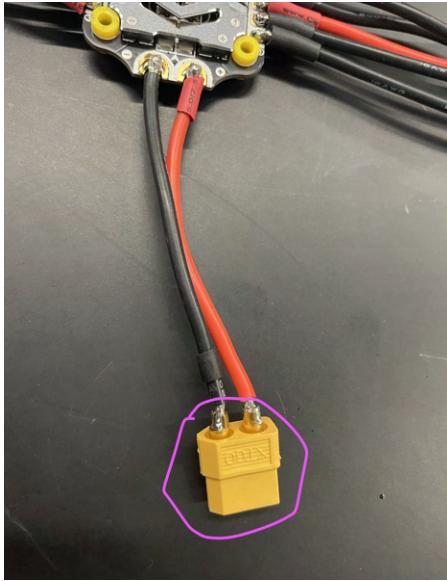
As you can see from Fig 1.4, connecting the female battery connector with the XT60 power cable that is soldered to the flight controller is not practical without additional wires or connectors. Therefore, we ordered male T connectors (Fig. 1.5) with hopes of soldering wires onto them on one side and connecting it the female battery connectors on the other side.



Fig. 1.5 Female-Male T connectors

I am going explain the final configuration:

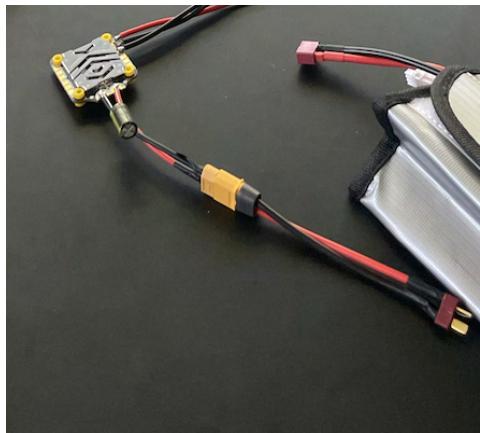
- 1) Soldered 16 gauge red and black wires to the flight controller pads (specifically the ESC) and compatible XT60 connectors we took from the observatory. See Fig.1.6 (b)
- 2) Soldered male T connectors to the XT60 power cord that came with the flight controller (specifically the ESC). See Fig.1.6 (b)



(a) XT60 connector-to-flight controller connection
Tconnector connection



(b) XT60 power chord to
Tconnector connection



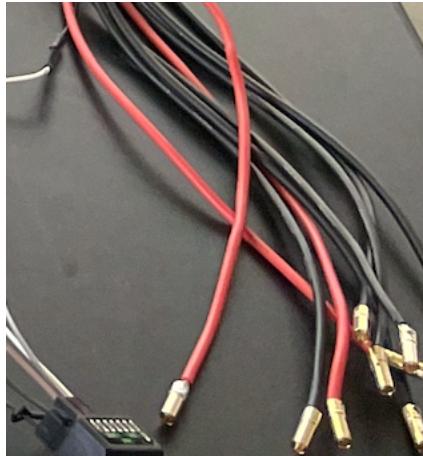
(c) Final configuration of the battery to flight controller configuration
Fig. 1.6 Battery to flight controller wiring process

The final configuration and the soldered wires you see in these images were taken at a later time. We did the soldering at a later time as well (see the notes on March 18, 2023 for more information).

March 16, 2023: **Soldering Bullet Joints**

On this day, Katie and I spent some more time preparing the parts we need in order to wire up the motors and start testing. After reading the motor wire gauge, which is 14 gage, we went to the science center to look for wires of similar capacity. We checked the We-Lab first, then our physics lab in the E-wing of the second floor. We then found a pair of 16 gage wires from our beloved Professor James Battat. After making our way back to the lab we measured optimal wire length for the

motor to the flight controller connection and soldered some bullet joints on to them. These joints connect to the brushless motors we had and help us establish an electrical connection to power the motors up.



(a) Wire soldered to bullet joints



(b) Female-male bullet joints

Fig. 1.6 Battery to flight controller wiring process

Something important and new I also learned that day is how dangerous LiPo batteries are. According to the information Sydney found, LiPo batteries are prone to explode, if they are shorted or wired wrong. There is a specific way to handle these batteries in general. LiPo batteries need to be ([source](#)):

- Kept at a specific voltage (3.8V) so that they don't go bad.
- Stored in a fireproof place or in LiPo Safe pack which comes with the battery. It's made of a fire resistant material and used to hold the batteries when charging (Fig. 1.7)
- Stored at room temperature.



Fig. 1.7 LiPo battery stored in LiPo Safe pack

March 18, 2023: Soldering T connectors

Sydney, Katie and I met on Saturday with the goal of working on

- Wiring the motors to the flight controller
- Wiring the battery onto the flight controller
- Figuring out the receiver and transmitter connection
- Testing out the motors

Since the T connectors we ordered for the batteries had arrived, we started off with soldering a pair of red and black wires -on the XT60 Power Chord- to one side of the connectors. These male connectors will then easily plug into the female T connectors on the battery.



Fig. 1.8 Wires-T-connector that plug into the LiPo battery

Then we used one of the XT60 connectors we found in the observatory and soldered another set of red and black wires onto it and soldered the other side of the wires to the flight controller. We also soldered a capacitor on the flight controller but the connection wasn't good so I will be working on that on Thursday (20th of March).



Fig. 1.9 TX60 connectors to flight controller wiring

Afterwards, Katie and I took turns in soldering wires on the bullet connectors for the motors. The goal was to connect the motors to the ESC but our motors came with wires soldered to male bullet connectors (see Fig 2.0). As a solution, we soldered wires onto female bullet connectors one side and soldered the other end to the ESC (more on this in Section 2 of my [Technical Supplements document](#)). See Fig 1.6 b) to remind yourself what the female-male bullet connectors look like.

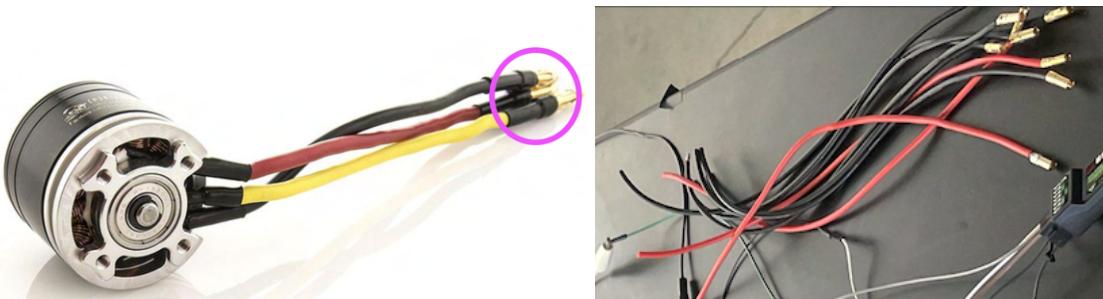


Fig. 2.0 [Motors similar to ours](#) with the male connectors circled (img to the left); wires we soldered to female bullet connectors (img to the right)

Katie found us [this video](#) so we leveraged the tricks the YouTuber mentions there to solder the joints well. (More on the process in the Soldering Standalone Bullet Connectors section of the [Technical Supplements](#)).

Thereafter, we tried soldering the 16 gauge wires for the motors onto the flight controller but since its pads were not holding the soldered joint, we left it for another time. In parallel to all of this, we were working on understanding and connecting the receiver to the flight controller and then binding the transmitter to the receiver. See Section 3.2 on binding in my [technical supplements](#) in Drone Transmitter and Receiver: Radio Control section.

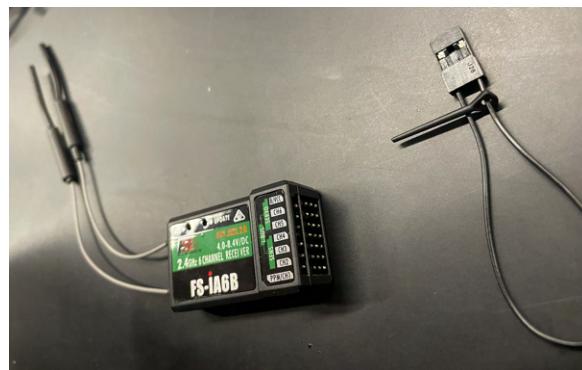


Fig. 2.1 Receiver (to the left) and binding key (to the right)



Fig. 2.2 Remote Control Transmitter

March 20, 2023: Soldering Practice

On this day, I spent most of my time practicing how to solder on the ESC using an electronic board that is also tricky to solder onto. After showing our professor (Wes) how we have been having trouble soldering such high gauge wires onto the ESC pads, he suggested a couple of things as a solution. Here is what I did, as per his suggestions.

- I looked for and found a [YouTube video](#) that walked me through how to solder on the SpeedyBee ESC pads.
- I stripped the 16 gauge wires we had a bit longer to twist the ends. Then, I practiced the techniques the YouTuber mentioned with a solderable breadboard (see Fig 2.4) that Wes gave me.

More information on how to solder on the SpeedyBee ESC is included in Section 1 of my [technical supplements](#). However, I will walk you through the general idea by going over how I practiced on a separate board.

1. I turned my soldering iron on and set it to the highest heat. I used a flat tip soldering iron to transfer heat to a bigger surface area.
2. As the iron was heating up, I put on safety eyeglasses and a face mask because I was working with leaded solder, which I recommend you should use. Leaded solder sticks more easily on these boards compared to the Lead-free solder.
3. I stripped the ends of my wires long enough and twisted the ends. Then I used helping hands to hold a pair of wires and started tinning them (wetting the ends with solder). Stop and move on once you have a decent amount of solder on the wires, do NOT put a lot of solder on them.



Fig. 2.3 Tinning wire ends with solder

4. I dabbed the soldering board with a heat flux pen and dabbed clean the soldering iron. I wet the bottom tip of the iron with solder and put it on the board. I removed the iron once a blob of solder formed on the board and after it solidified, dabbed it with heat flux.

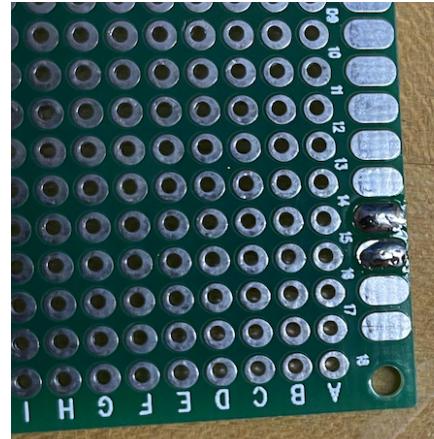


Fig. 2.4 Forming solder blobs on the pads to solder wires onto them next

On this step, I positioned the soldering iron in a way so that I do not solder two pads together. There's not much space between the pads so you need to be careful.

5. I used my helping hands to hold the wires down on the blot I just made in step 4 and cleaned my soldering iron. I then got some solder on the bottom tip of the iron and put it on top of the wire I am holding down on the board. When the solder melts through the wire, I remove my iron quickly and let it cool off as it forms a solid joint. I tugged on it to make sure it was not coming off.

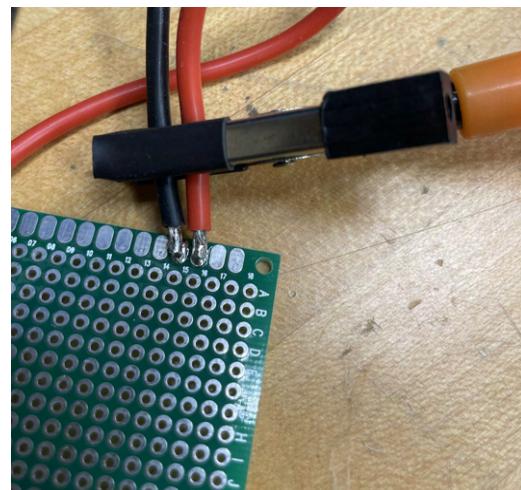


Fig. 2.5 Using helping hands to hold wires down on the board for solder

6. In doing this, I also practiced not to leave the soldering iron on the board longer than necessary because I would need that to avoid frying the circuit inside the ESC when I start soldering there.

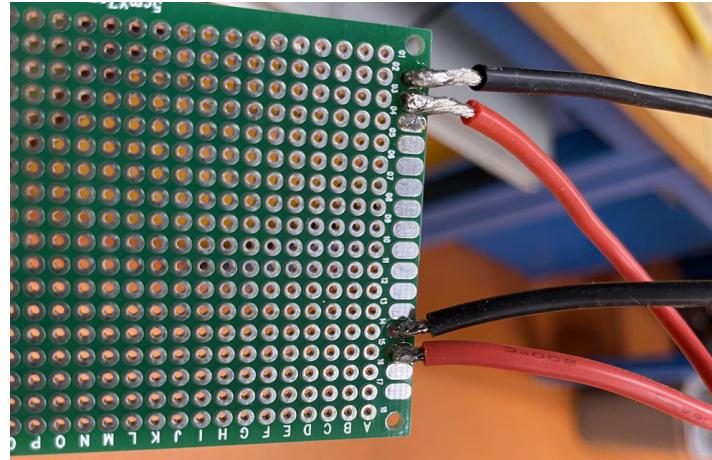


Fig. 2.6 Four successfully soldered wires on the solderable breadboard

After practicing the soldering technique this way on a couple of wires during class time, I prepped and started soldering on the ESCs themselves in the afternoon/evening using the wiring diagram I found on the SpeedyBee Manual (see Fig. 2.7). Check the technical supplement section to follow along the process or see Figure 1.6 for the final product. I then spent some time heat shrinking every exposed joint we had for the drone (including the battery wiring we went over on [March 18, 2023](#)). In addition, I also soldered a capacitor on the battery power cable we soldered on the ESC (see Fig. 1.9). It is a 1000uF low ESR capacitor that came with the flight controller stack. It prevents instantaneous voltage spikes from burning up our flight controller stack (Page 11, [SpeedyBee F7 Flight Controller Manual](#)).

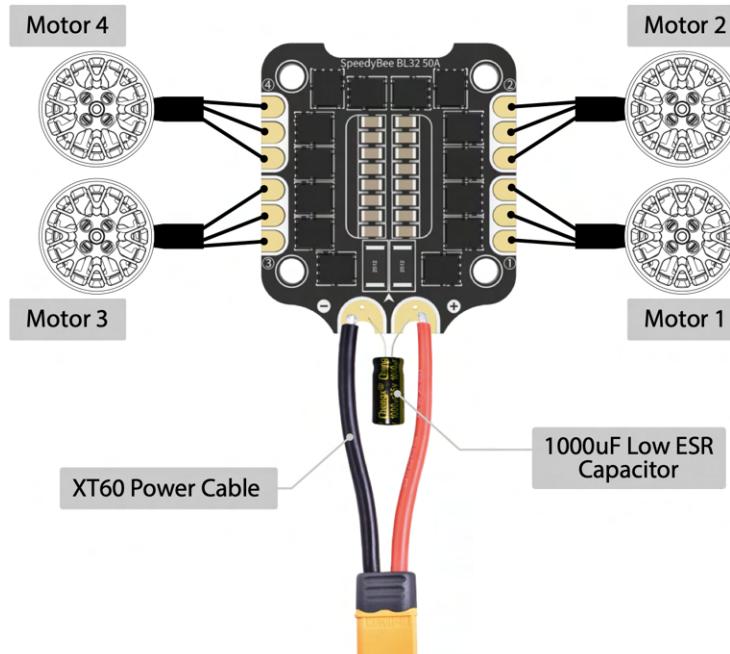


Fig. 2.7 SpeedyBee wiring diagram for motors and battery (source: [speedybee manual](#))

March 24, 2023: Testing Motors

Katie and I had not made it to class on Thursday so we met at 8 am the next day to work more on the first drone. One of the capacitor legs had been giving me a hard time on [Monday \(03/20\)](#) so I soldered that properly first. While I was doing that, Katie went to the Machine Shop to ask Larry for replacement screws or stand offs I broke. After that, Katie and I started off by testing each of the motors using the SpeedyBee App we downloaded from the app store. Each motor worked!! This means that our circuit configuration was connected properly and I managed not to fry the electronics inside the ESC.

We then disassembled the drone arms and put the three motor wires (with one side soldered on the ESCs) through the arms and connected the female bullet connectors to their male counterparts. Once we did that for all four motors, we screwed the arms onto the drone frame plates (see Fig. 2.8 for final result). Next steps will be mounting the propellers and testing. We held off on that because one of the propellers that were ordered was wrong.

Updates on the screw that broke off: Larry got the screw that broke off in the standoff out. That eliminated the need to find another suitable standoff. He also cut the head of one 3mm screw for us which means we can screw that into two standoffs at the top and bottom! We left that for the coming week as well.

A timelapse [video](#) of me and Katie working on assembling the frame. In addition, when Katie and I were trying to finish screwing the arms into the plates, we realized that three M3 screws were missing. Replacing those was left as a task for next week.

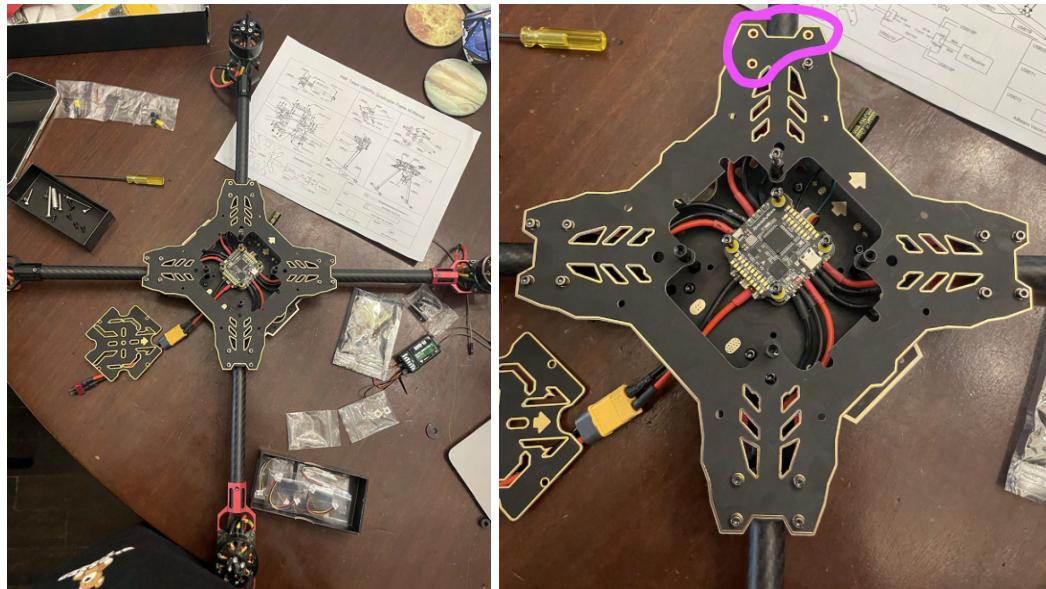


Fig. 2.8 Drone frame assembled with motors (top image); zoomed in picture to show the circuitry for the motors and battery with the three screws that were missing circled in pink (bottom image)

April 05, 2023: Mock Flight Testing

Today, I met with drone buddy Katie with the main goal of testing the drone with the propellers added and the batteries doubled. Last time we tested the motors, we connected only one of the LiPo batteries to the flight controller, we then turned on and off each motor one at a time. This time however, we connected the two LiPo batteries in series and then tested all four motors together. To connect the two batteries in series, Katie made an excellent wire connection for us to use. Here is what we did:

- Started off today's work with screwing in the top plate. We had left that from last week because we didn't have the replacement until Larry helped us. The blind screw went through the middle plate of the frame and held the bottom and top standoff together. Then the top plate was fixed atop the top standoffs.
- Once we got that all in, we tried to find replacement screws for the three M3 screws that were misplaced. After hunting down Prof. Katie Hall in science center, she gave us a box full of screws so we replaced the ones we lost.
- We also screwed the landing gears into the frame and zip tied the flight controller on the top plate.
- We put two batteries into the LiPo Safe Pack and zip tied it under the bottom plate. We didn't take the batteries out because we didn't want to risk starting a fire especially since the batteries are being connected in series. This method is not the most adequate because it makes the drone tip over on one side and unstable.
- We prepared for testing by getting a fire extinguisher in case of fire and working gloves for holding the drone in case of an emergency. We tied a string around each drone arm and then to a hollow concrete block in order to prevent it from tipping over.

During our test, we turned on each motor at a decent speed so that it wouldn't hover. Each motor turned on and nothing caught on fire so the mock test was successful. We left some tasks for tomorrow and the rest of the week.

- We need to connect the receiver to the flight controller and use the transmitter to remotely control the drone. Solder the electrical connections after we make sure that the wiring works.
- Connect the landing gear to the receiver and control the landing gear at will
- We need to 3D print an enclosure for the LiPo batteries. The current orientation is not stable and if we remove it we risk crashing the drone with the batteries at the bottom. (stretch goal)

April 06, 2023: Remote Control Transmitter/ Receiver

Today my partner Katie and I covered a lot of grounds for the remote control. There was frustration, excitement, exhaustion, etc but we were able to control the motors remotely from the transmitter before calling it a day at midnight. In the morning during class, until Katie came to class I was looking at 3D models for an enclosure she and I previously mentioned about printing for the LiPo batteries. I was able to get [this](#) from Thingiverse. In the upcoming days after we get the drone flight ready, we are planning on adjusting the dimensions to fit our two LiPo batteries and printing it. Some considerations to make is making it **fire safe/ heat resistant**. Perhaps we can stitch a fire resistant material inside of the enclosure?

During class time, another thing we tried was wiring the receiver. Our starting point was the two pictures that Sydney sent us ([source used](#)), which I will paste below.

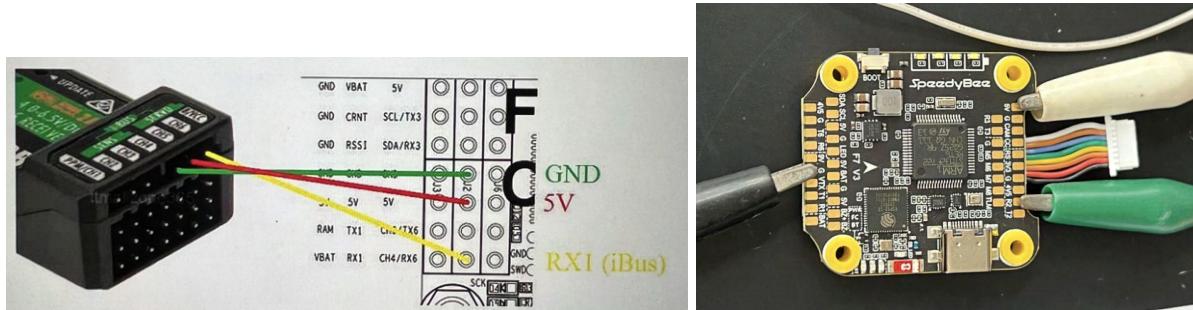


Fig. 2.9 First iteration of wiring for the receiver

We did not want to solder the wires onto the flight controller just yet so we used banana plugs to form the connections. The three wires (banana plugs) connected to the flight controller were connected to the servo of the i-BUS on the receiver (see Fig. 3.0)

- Green GND wire on CH5 (left image) to the black wire (right image)
- Red 5V wire on CH6 (left image) to the white wire (right image)
- Yellow RX1 wire on B/VCC (left image) to green wire on R2 (right image)

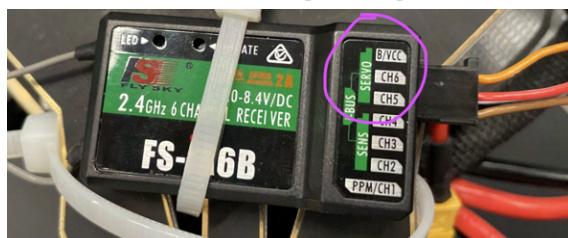


Fig. 3.0 Servo channels circled in pink on the FS-iA6B receiver

Here is how Stitch looks at this point:

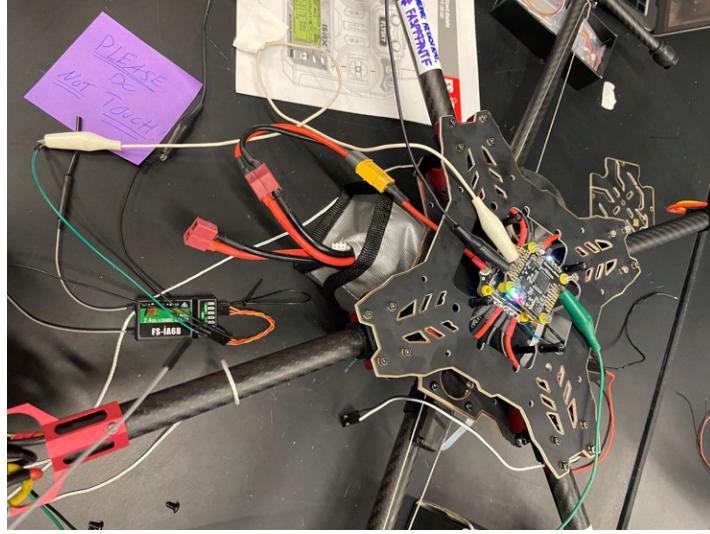


Fig. 3.1 Stitch with its LiPo batteries ziptied to the bottom and banana plugs connected to the flight controller for remote control

Transmitter/Receiver Configuration

In this process, It was both our first time so we had to figure out what everything did and how it worked on remote control as we went. After binding the transmitter to the receiver again (following the instructions outlined on March 18's entry on [Process of Binding Receiver and Transmitter](#)), we started to configure the transmitter (the entire process is outlined in my [technical supplements](#) under section 3.3 Transmitter configuration). We essentially set the output mode in the RX Setup to be PWM with a S.BUS serial output. We turned on all of the AUX channels and set them up: CH5 - SWA, CH6 - SWB, CH7 - SWC, CH8 - SWD, CH9 - VRA, and CH10 - VRB (see Fig. 3.2 below). [This](#) is the video I used to understand the different channels and how to set them up on the transmitter. Later in the day, we set CH5 to be our switch for arming the motors.



Fig. 3.2 Transmitter with channels labeled.

We initially had a hard time getting the SpeedyBee app to respond to the commands we are sending the transmitter. After configuring the transmitter, we knew the channels were set to the correct switches because there's an option to display this in the transmitter itself. We also know that the [gyro on the flight controller](#) is responding to us moving the drone. This means the drone is communicating with the flight controller but not the transmitter, and so we tried moving the banana plugs to ensure electrical connectivity. Because the pads on the flight controller are very small, it was a painstaking process to make sure the bananas are on the correct pads and are not touching adjacent pads. This and changing one of the plugs (coming from the receiver) from R2 back to R1 (had changed it during troubleshooting) on the flight controller helped! Once we got to see the channels changing values on the Speedybee as we played with the channels on the transmitter (see [video](#)), we then moved onto controlling motors using the transmitter.

After searching online for a suitable video to guide us in doing this, we found this useful [video](#). We had removed the propellers from the drone as we were doing this. I will outline the general steps we took now (one can do this on either the mobile or desktop app).

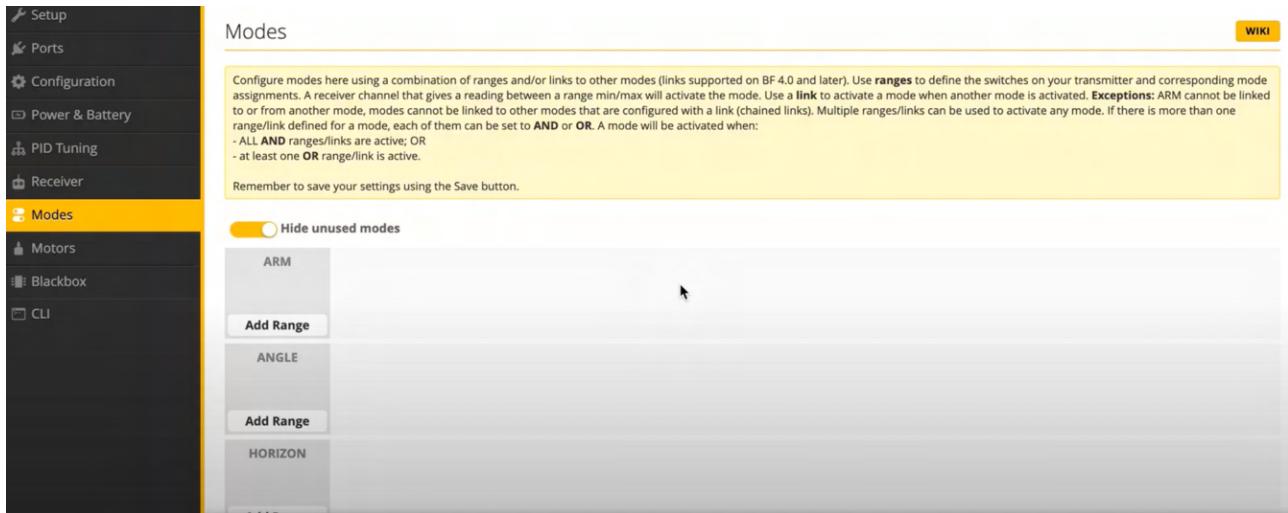
Arming the Motors

1. If you haven't already, in the transmitter turn on the AUX channels and set the CH5 (AUX 1 on betaflight) to SWA. This is the channel we will be using to arm or disarm the drone motors. If you don't know how to do this, see the steps outlined to achieve this in section 3.3 of my [technical supplements document](#).
2. Bind the receiver to the transmitter, make sure the transmitter recognizes the receiver. If the display on your transmitter is similar to the image below, then the receiver is not paired with it yet. Once it does, you will see "RX. ..." or something similar written under where it says "TX. ..." right now.

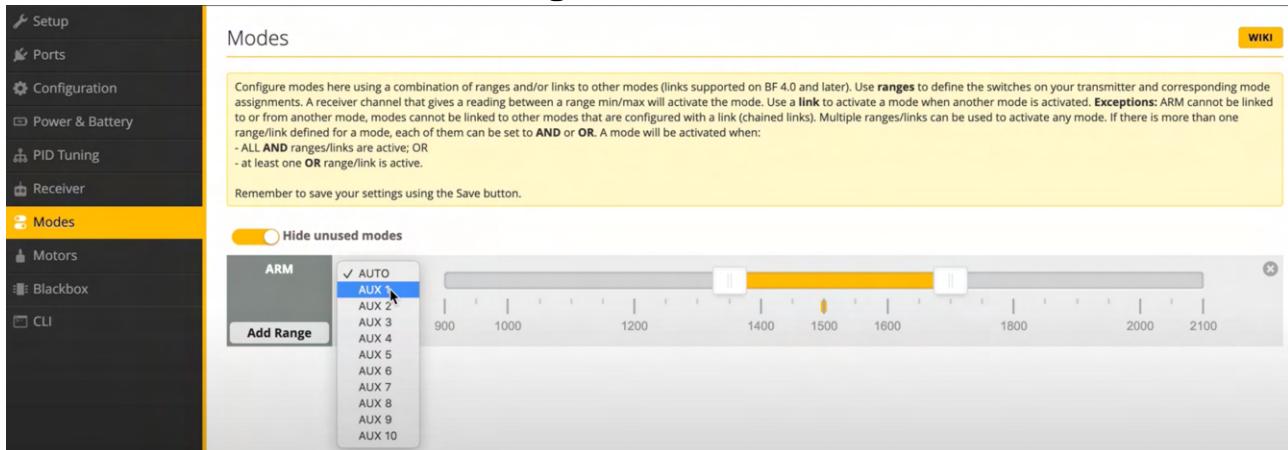


Fig. 3.3 Viewing transmitter display when turned on (not bound to a receiver)

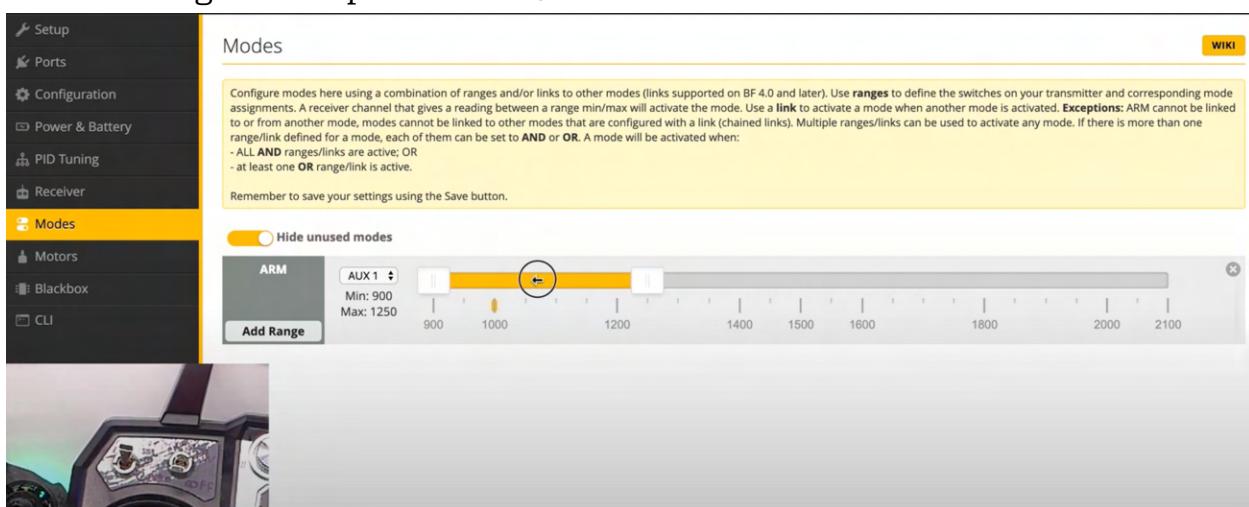
3. Go to the "port" tab on the app and make sure it's set on UART 1.
4. Navigate to the modes tab on the betaflight app (either mobile or desktop).



a) Go to ARM and click “Add Range”

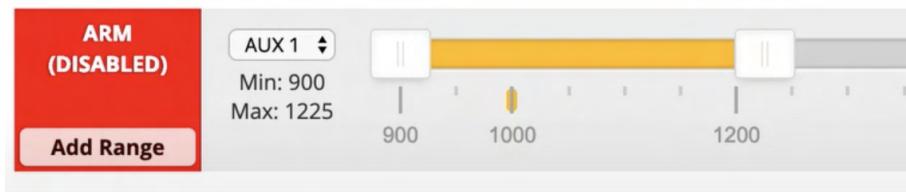


b) Change AUTO to AUX 1 in the drop down menu. As stated in step 1, AUX 1 on betaflight corresponds to CH5 or SWA on the transmitter.



c) The yellow tick mark (on 1000 in this image) switches between ~1000 and ~2000 as you flip CH5 up and down. In order to set the “ON” and “OFF” state,

we choose which orientation we would like the switch to be in (on the transmitter) when we turn it on then drag the yellow bar on top of the tick mark. For us it's OFF (transmitter SWA is flipped down) when the tick mark is on ~1000.



- d) Click Save (or Save and Reboot on the mobile app) and then try arming it using the transmitter (flipping the switch up). This should result in what you see in the image above.
5. Go to Motors tab and enable “motor test mode notice” then press save. Sometimes you might need to re-enable it after it reboots.
** **sanity check** ** at this point in the setup tab, under “info” you should see that the “Arming Disable Flags” says “arming allowed”.
Now you can flip CH5 (or SWA) and the motors should spin! At first it wasn’t working for us until we flipped the servo wires connecting the receiver to the flight controller.

April 10, 2023: Landing Gear

In the first portion of class, Katie and I took a pause from working on Stitch because we realized that we need a license to fly it for our testflights. So we went to the Federal Aviation Administration website that Emma found for us and took the [Recreational UAS \(Unmanned Aerial Systems\) Safety Test](#). It was structured like a module where you read and get tested as you go. After doing that, I got my license and went into reading the ChatGPT paper Wes gave us.

I have heard about the capabilities of this Open AI tools from numerous friends who utilize it a lot but I hadn't considered using it up until this point. Perhaps because of my upbringing, I had a tainted view of the platform as something that will make me lazy/ loose my intelligence. However, after reading the paper and participating in the ChatGPT talk Wes facilitated for us, my mind has been more open to the idea of exploring the tool more. I realized that like any other tool, you can use this to benefit or harm yourself. I can make ChatGPT explain concepts for me, help me brainstorm solutions to projects I have been stuck on (just like how I would ask a professor for help), etc. That coupled with a discipline of not allowing it to do all your work is a powerful combination that my mind was exposed to that day.

After the conversation, Katie, Sydney and I tried to figure out the landing gear. We watched numerous YT videos on how to use landing gear servos on Flysky (our transmitter). We set channel 6 to SWB (see section 3.3 of my [technical](#)

[supplements document](#)) to turn the landing gear servos on and off but it wouldn't work. Sydney tried switching the order of the wires going from the servo to the receiver(see Fig. 3.4). We even undid the screws (pointed with a green arrow in Fig. 3.4) on the landing gear to mechanically straighten it but none of these worked. Since we are under a time crunch, we removed the landing gear entirely and tried to find other replacements.

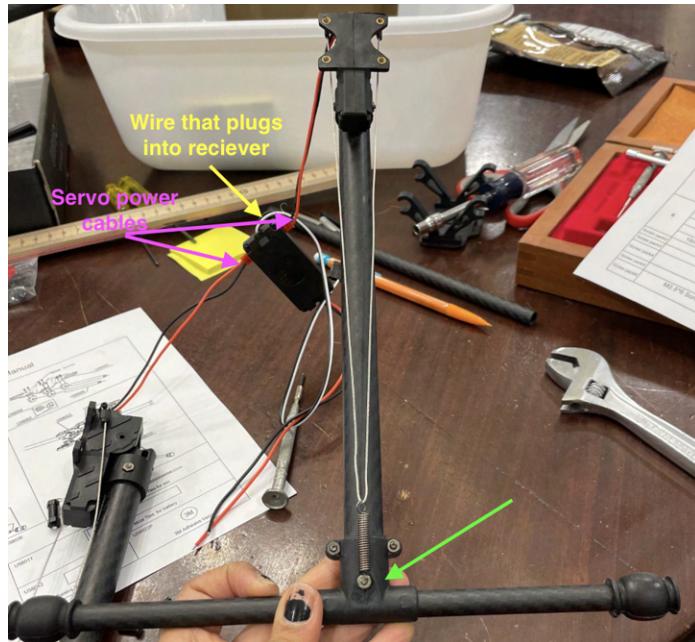


Fig. 3.4 Landing gear

We folded rigid wires (L shape) and tried fixing them onto the drone. The drone wobbled a lot because the wires were not rigid enough to keep Stitch balanced in place. We then tried winding thin strips of scrim cloth around the landing gear (after removing the top) in order to glue it and hold it in place on Stitch in the hole pointed out by the green arrow in Fig. 3.5.

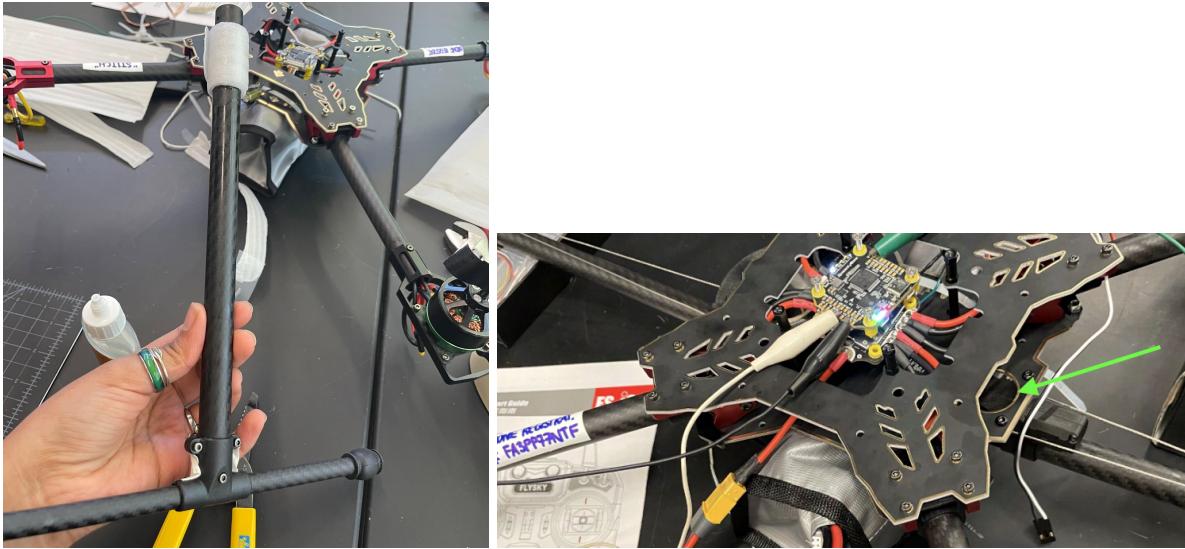


Fig. 3.5 Scrim cloth wound around the landing gear (left image); hole for the landing gear pointed out with a green arrow (right image)

Despite our efforts in making the cloth fit tightly inside the hole, the glue wasn't holding and the drone still wobbled a lot. We realized that this wasn't going to work so we cut out a hole into a small cardboard box and put Stitch in it. This would give us a temporary solution to the landing gear issue as it is more stable compared to what we tried thus far and it protected the battery pack from damage when we start our test flights. You will see our team working on Stitch in the image below and notice that Stitch is in a cardboard box.



Fig. 3.6 Stitch in a cardboard box landing gear

Aftwards the last thing I did for the day was soldering the receiver connection. Since we figured out what pads we need to solder onto in the flight controller (5V, GND, and R1), I went to the soldering station and soldered. Zoë wanted to learn how to solder so she was shadowing me as I soldered these three wires. I put heat shrink on the wires and soldered one side of the wires on the flight controller and soldered male servo connectors on the other side (see left image in Fig. 3.7). The goal was to connect it to a female servo wire (right image in Fig. 3.7)

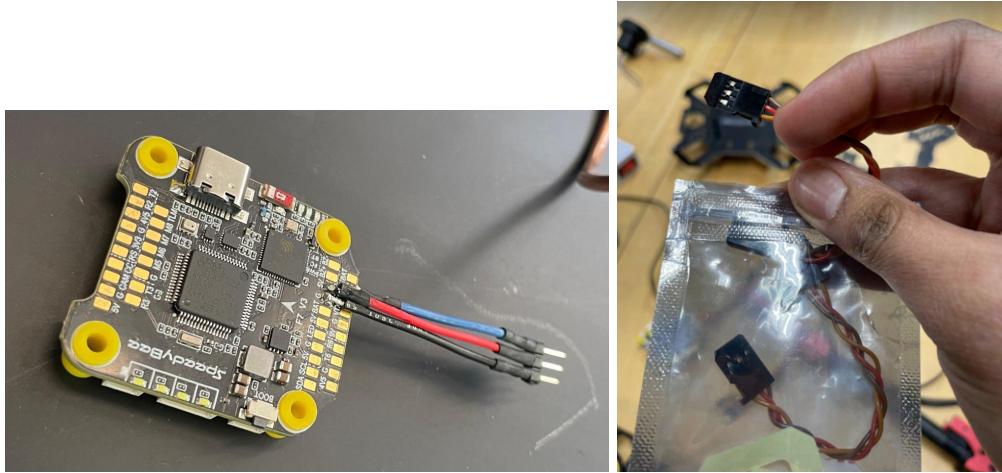


Fig. 3.7 Wires soldered on flight controller (left image); servo female wires (right image)

Around 3 pm, we went to the athletic fields to test Stitch. As I armed the motors using the transmitter, the arms started vibrating so some of the screws were shaken off. The motor was almost unbolted completely from the arms so I turned it off and we went back to the observatory.

April 13, 2023: Looking for Screws, Soldering Bullet Connectors

This day, many of our teammates were out sick so I started off by counting how many of the screws we had/ how many more we needed. Nora helped us find some of the screws on the grass the previous day but we had about four M2.5 screws missing. We were able to replace all the screws we missed but the M2.5 ones. We looked in the observatory, in the science center, and at Olin to no avail. So I looked up the ones we needed and sent it to Zoë, our project manager, in order to purchase some online.

In the second half of class, I guided Zoë as she soldered bullet connectors for our second drone: Angel. We followed the steps I outlined in Section 2.0 my [technical supplements document](#). These are cables that we will plug into the motors (see Fig. 3.8). They are then soldered onto the flight controller.

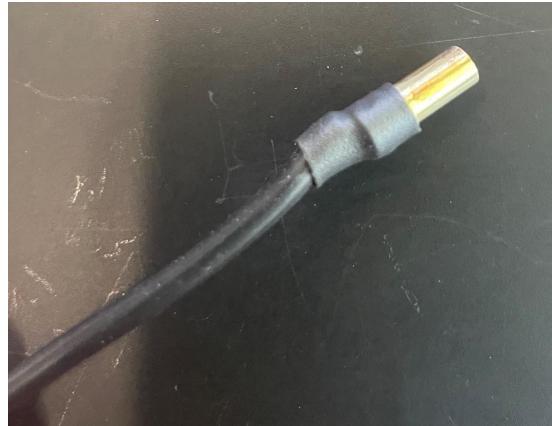


Fig. 3.8 Soldered bullet connectors encased in heat shrink

At one point, Zoë had to leave to talk to Wes so Emma and I finished soldering the rest of the wires to the bullet connectors (3 for each motor so 12 wires in total).

April 18, 2023: **Soldering wires on the ESC for Angel**

I spent my time soldering wires on the flight controller ESC for Angel today. When putting the wires into the drone frame to get it solder ready, my teammates unknowingly had cut the “excess” wires. Because the wires are now short, getting the wires from all four motors to reach the flight controller in the middle of the frame was hard. This considerably prolonged the amount of time needed to finish this task, however it was done in the end (see Fig. 3.9)

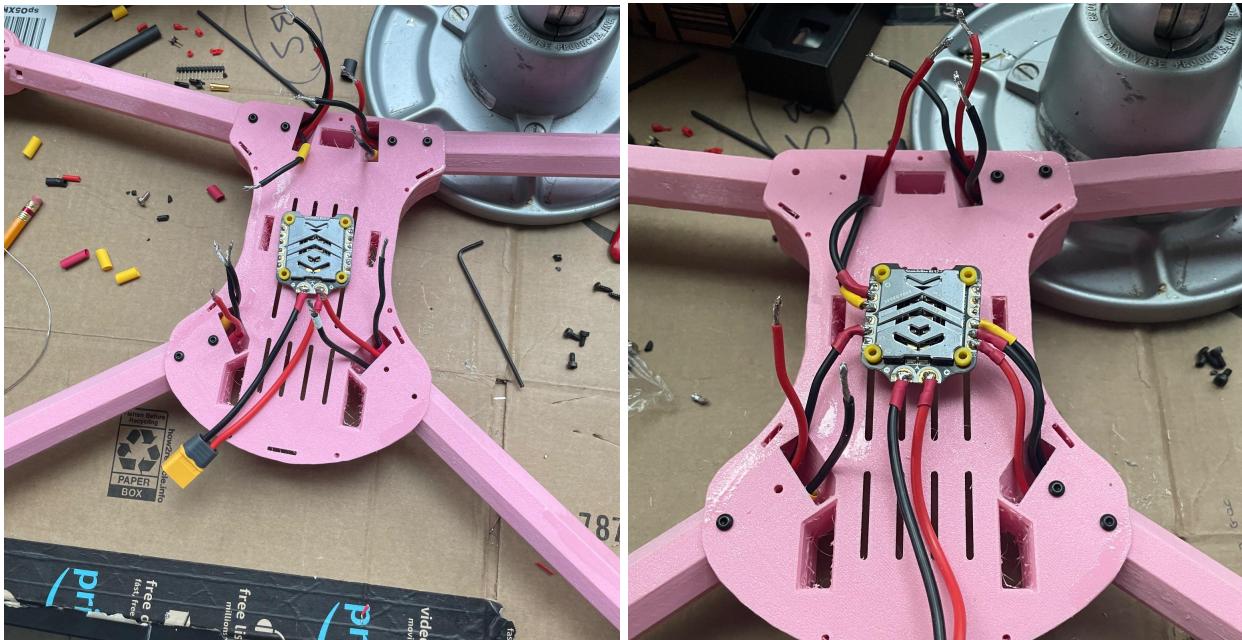


Fig. 3.9 Preparing motor wires to solder on the ESC (left image); soldering on the ESC (right image)

The wires sticking out of the frame in the image to the left (Fig. 3.9) are the wires tinted and ready to be soldered on the ESC. I first made sure what each wire was connected to on the motor and double checked with the wiring diagram in the SpeedyBee manual (see Fig. 2.7). Then after I knew which wire is soldered on which pad on the ESC, I tried to find a spot for the flight controller on the frame where the wires from all the motors would reach it. Then I soldered the wires for the motors diagonal from each other, one at a time as depicted in the image to the right in Fig. 3.9. Look at image below to see end result.

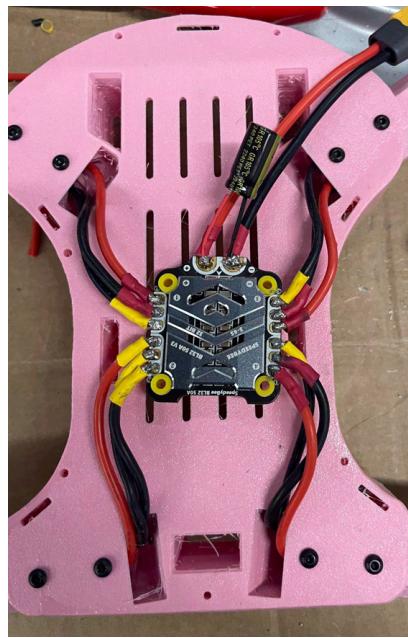


Fig. 4.0 All motor wires soldered and encased in heat shrink on the Electronic Speed Controller (ESC)

April 20, 2023: Troubleshooting

Katie and I convened today to go over our observations from the test flight on and troubleshoot. Here are the problems:

1. As we lowered the throttle down, the motor speed was not returning to a lower speed that it started off at.
2. The motor speeds did not match even though we were incrementally raising the throttle for all four at the same time.

Here are possible errors a solutions to solve these issues:

1. Receiver not working? No, we checked the speedybee app and the throttle changes in the app as we changed it on the joystick. The motor speeds seem to be responding well on the app.
2. Current draw perhaps non-uniform for different throttle speeds? Yes, it is different.

Though we didn't get our answer right away, this investigation made us realize that the motors are not starting at the same speed (saw this in the app). We

then went to the 12in telescope dome and tested the motors again while monitoring the speedybee app. Our observations are as follows:

- Motor 2 was rotating at a different speed compared to the other motors (audibly sounds different)
- Going in hand with that, motor 2 was not as warm as the other 3
- When we tilted the drone with our hands, the motor speeds changed (were more leveled out at some tilts)
- Some of the motors were vibrating and making weird noise
- We then started to think, could this be an issue with the gyroscope? Wiring?
- We tested each motor or turned them on individually one at a time on the speedybee app and each one went to the fullest capacity. We then turned on and increased throttle on all motors (using the master switch pointed, see Fig. 4.1)

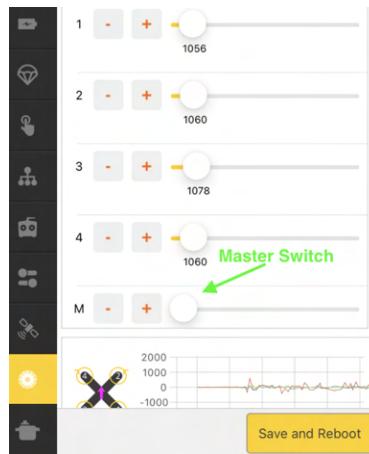


Fig. 4.1 Increasing motor speeds on the SpeedyBee app using the master switch

At one point in our tests, we tried to cut communication between the transmitter and the receiver and it didn't work. Though we turned the transmitter off, the motors were still running and this made us realize that the failsafe we set on the transmitter was not working. Lucky when we tested, we didn't have the propellers on so we just went and unplugged the flight controller from the batteries.

April 24, 2023: Stitch Troubleshooting Cont...

Coming into class this morning, there were a lot of issues we needed to solve. Here are the two main concerns:

- 1) **Difference in Motor Speed.** Stitch's motors were not all running at the same speed (though they were supposed to be on the same throttle).
- 2) **Failsafe.** The motors won't turn off as turn the switch (channel 5) off and the emergency failsafe we configured into the transmitter was not kicking in even after cutting connection between stitch and the transmitter.

We had a few hypotheses as to why these things were happening but it wasn't until we had a brief discussion with Professor Watters (Wes) that we had a clear idea of things to test in order to troubleshoot.

Here are our hypothesis/ discussion for the issue of motor speed difference:

- There might be an issue with the notion of attitude in the flight controller (gyroscope, accelerometer) or its readings?
- Gyroscope not stable?
 - Flight controller not fixed to the frame (was just hanging in the middle of the frame for multiple tests we conducted).
 - Do we need a different landing gear? Could the cardboard be messing up with the gyro readings because it is not stable?



Fig. 4.2 Stitch inside a cardboard box

- Faulty transmitter?

Here is our discussion for the failsafe issue:

- We now know that it's not a flight controller vs motor communication issue because we have tested each motor individually (and together) using the SpeedyBee app
- We also know that each motor is working correctly because when we tested the motors together on the app, they didn't show noticeable audible nor visible difference in speed.

We didn't have a working thesis of why the failsafe didn't work in mind. So we just decided to at least test again by altering different variables based off of the discussion points for the motor speed difference issue. I will first outline what steps (not necessarily in chronological order) we took then go over our results.

- We took the drone out of the cardboard we had it in and removed the LiPo batteries from the bottom. This was done to solve the stability issue, we wanted the drone to be sitting on a stable stand (the cardboard was not sturdy enough to be stable while the LiPo battery pack made the entire drone tilt). We thus used the four notches protruding from the bottom of the frame to keep the drone stable on the ground (pointed out by yellow arrows in Fig. 4.3)



Fig. 4.3 Stitch sitting on the LiPo battery pack, tilted to the side (top image); curved hollow notches we used for keeping the drone stable on the ground pointed out by yellow arrows.

- We then unscrewed the top plate and inspected the electrical joints to make sure everything was still intact. We then screwed the top plate back and zip tied the flight controller to the top plate. This was done to further ensure stability for the gyro readings and so that the flight controller can stay in the same reference frame as the drone body itself.
- Katie and I then went to the 12-in historic telescope dome and started testing our drone. After connecting to the flight controller on the SpeedyBee app, we noticed that the IMU of the drone reading shows that the drone is tilted. So we started off our testing by first calibrating the accelerometer onboard the drone through the app (see image below)

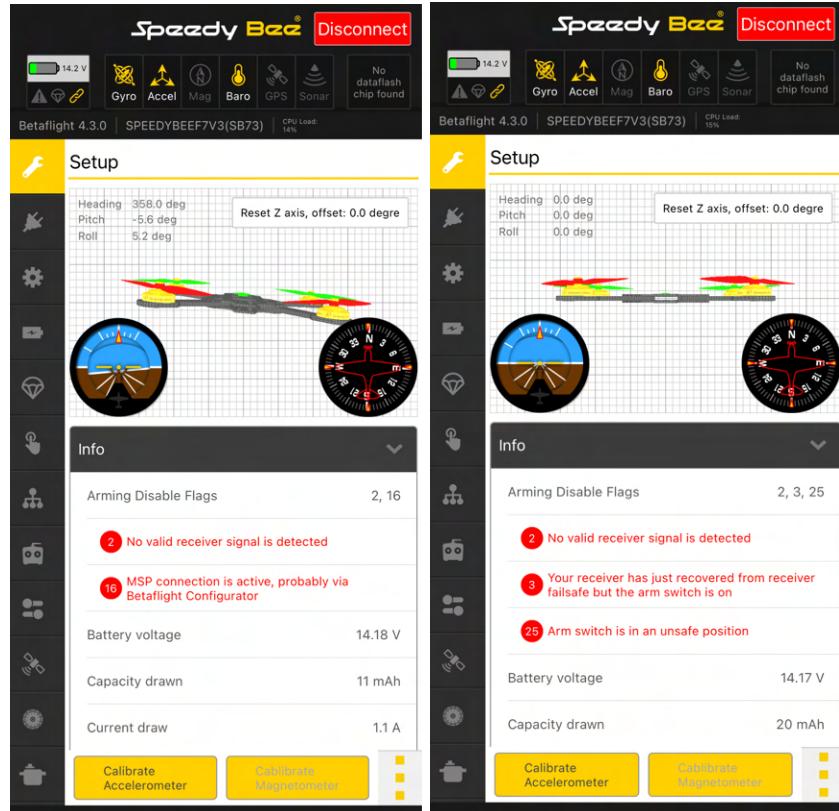


Fig. 4.4 Screenshots taken from SpeedyBee app during accelerometer calibration

We then followed our usual testing procedure of binding the transmitter to the receiver, occasionally arming the motors through the app, and turning on the motors using channel 5 on the transmitter. This testing was successful and proved our hypothesis for the motor speed difference correct! Through this test we also solved the failsafe issue. Here are the results:

- Once we had calibrated the accelerometer, the motors seemed to be running at the same speed and we confirmed this on the app. Here are two screenshots I took of the app in the motors tab for how the motor speeds look like. The first image shows that all four motors run at the same speed (same throttle) and second image shows how they vary when the drone starts to shake and move as we increase the throttle (which we assume is due to the gyro readings being different due to the drone's movement).

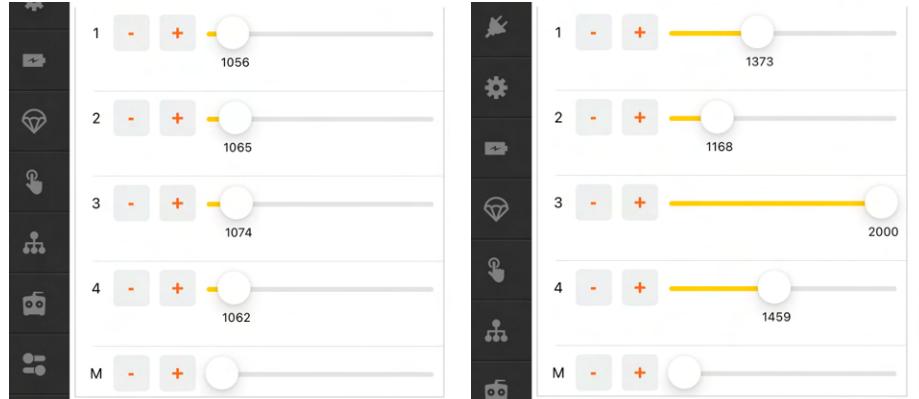


Fig. 4.5 Equal motor speeds at low throttle (left image); motor speed levels are different as throttle is increased (right image)

- This result shows us that removing the cardboard box from the bottom and placing the drone on stable stands in addition to zip tying the flight controller to the top drone frame all reinforce stability to the gyro. This stability leads to having our motors run at the same speed as the drone doesn't think it is tilting and needs to readjust etc by varying the motor speeds.
- In addition to this, during our test, we also noticed that the motor on/off switch on channel 5 was working perfectly and the failsafe was kicking in as we turn off communication from the transmitter. This we assumed was due to the fact that the drone was not receiving multiple commands from different sources (the SpeedyBee app + transmitter). We validated this by testing multiple times without interfering with the transmitter commands using the app.

Empowered by such a successful test (that solved both of the issues we had been struggling with), Katie and I went back to the project room and deciding to get our drone ready for field testing. For this the main challenge was to find a landing gear or get the landing gear that came with the drone frame to work. This was the next important step because we can't keep the drone stable on the LiPo battery pack without tilting. And if we remove the battery pack from the bottom, we need to find a place for it somewhere else.

Landing Gear

This is when Katie urged that we keep working on the servo landing gear that came with the frame. We needed a stable landing gear that could hold the weight so we divided and conquered it. I went to solder the landing gear's live and ground wires to 5V and GND pads on the flight controller, respectively while Katie kept playing with the transmitter configuration for the landing gear. We connected the wire going from the landing gear to the transmitter and tried testing to see if it was working. After multiple tests, Katie had the important realization that maybe we should try having the output mode of the transmitter in the RX setup be PWM

instead of PPM. And that worked!!! It also makes total sense because PWM sends voltage in certain time intervals allowing the servo to deploy the landing gear.

April 27, 2023: Stitch not lifting off

Initial hypothesis as to why Stitch is not taking off:

- Drone might be too heavy
- There's an operational limit to the motors (perhaps on the SpeedyBee app) that we were not aware of
 - We can check the current draw of the motors to see if they are at their capacity
- Maybe the calculation for the motor to weight (thrust) ratio was miscalculated initially

We first started exploring the lift capacity of the drone by redoing the [drone calculation](#). This calculator can be used to figure out which motors one can use for a drone. The variables are **weight** (drone weight, battery weight, equipment weight, and total weight) and **thrust** (thrust-to-weight ratio, number of motors, total thrust, and thrust per motor). We weighed Stitch on a scale we borrowed from the physics department and got 2124 g for the total drone weight. We estimated 100 g for the equipment and we know that the battery weighs 500g. Inputting these points into the calculator we got a 2,124 g thrust per motor for a 4:1 thrust-to-weight ratio. Here's a screenshot of the results from the drone calculator:

Weight	Thrust
Drone weight	1,524 g
Battery weight	500 g
Equipment weight	100 g
Total weight	2,124 g
Thrust-to-weight ratio	4 : 1
Number of motors	4
Total thrust	8496 g
Thrust per motor	2,124 g

Fig. 4.6 Calculating Drone weight to thrust ratio

I didn't understand what a thrust to weight ratio is so after looking it up, we learned that it means the number of motors we have for the drone. Got this assumption from the **thrust formula**: $\text{thrust} = (4/1) \times \text{total weight} = \text{thrust/motor}$; where 4/1 is the thrust to weight ratio.

Using the information we got from the calculator, we planned to cross check with the specifications of the cobra motor (from the [datasheet](#)). The datasheet predicted that our motors would have 1645 g of thrust per motor for our 13x4-E propellor size. Below is a screenshot of the specs we were looking at for the motor in addition to the datasheet.

Cobra 3510/20 Motor Specifications	
Stator Diameter	35.0 mm (1.378 in)
Stator Thickness	10.0 mm (0.394 in)
Number of Stator Slots	12
Number of Magnet Poles	14
Motor Wind	20 Turn Delta
Motor Kv Value	1000 RPM per Volt
No Load Current (Io)	1.06 Amps @ 14 Volts
Motor Resistance (Rm) per Phase	0.060 Ohms
Motor Resistance (Rm) Phase to Phase	0.040 Ohms
Maximum Continuous Current	32 Amps
Max Continuous Power (3-cell Li-Po)	350 Watts
Max Continuous Power (4-cell Li-Po)	470 Watts
Max Continuous Power (5-cell Li-Po)	590 Watts
Motor Weight	141 grams (4.97 oz.)
Outside Diameter	43.0 mm (1.693 in.)

Fig. 4.7 Cobra Motor Specifications

This table tells us the expected current draw for the motors which is 1.06 Amps at 14 V and from the SpeebyBee app, we confirmed this was true. Total voltage from the battery is 14.17 V as expected as well. See screenshot taken from the app below (important info highlighted in pink):

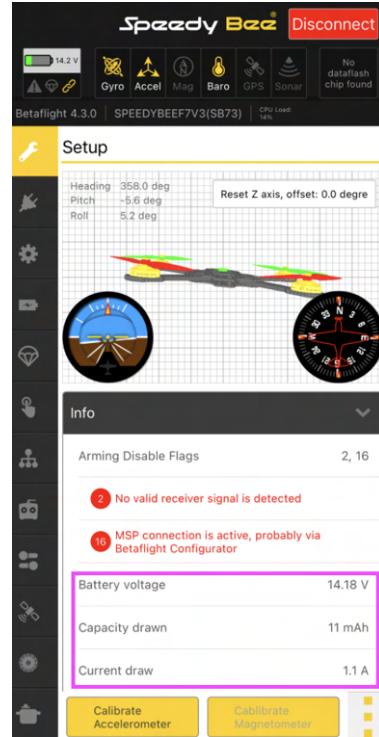


Fig. 4.8 Investigating current draw in SpeebyBee app

Having gathered all this information, we didn't know how to proceed just yet so we went outside to test the directions of the propellers again just in case. Motors 1 and 4 seem to be spinning in the cw direction while 2 and 3 also spinned

in the ccw direction (see motor numbers in Fig. 4.9 below, taken from the motor tab on the SpeedyBee app).

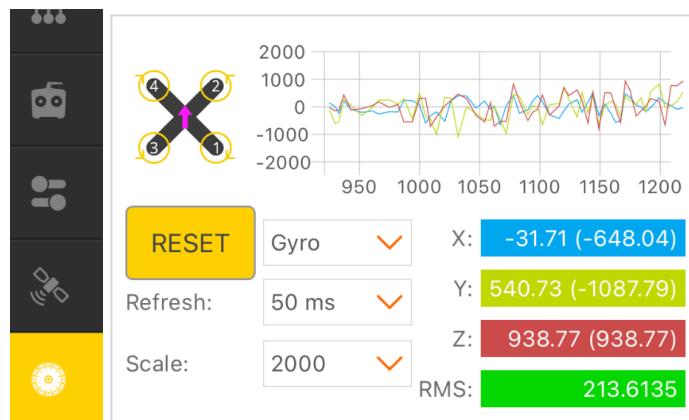


Fig.4.9 Direction of motors depicted on SpeedyBee app

Our eureka moment was when Katie made the important observation the motors should not be spinning in the directions they are currently spinning in. This was due to the fact that the correct propellers were not on the correct motors. Meaning to produce lyft (push air down): the propellers on motors need to have an orientation that lets them push air down (the lifted part of the blades needs to lead the motion of the propellers). See image below to visualize this. Props should be oriented such a way for motors 2 and 3 as depicted in the image to the left while the props for motors 1 and 4 are oriented the way it is depicted in image to the right.



Fig. 5.0 Proper direction of propellers to generate lyft

Drone is tilting so we didn't feel comfortable trying to set it at full throttle and get it to lift off. We attempted to increase the throttle and it keeps tipping over!

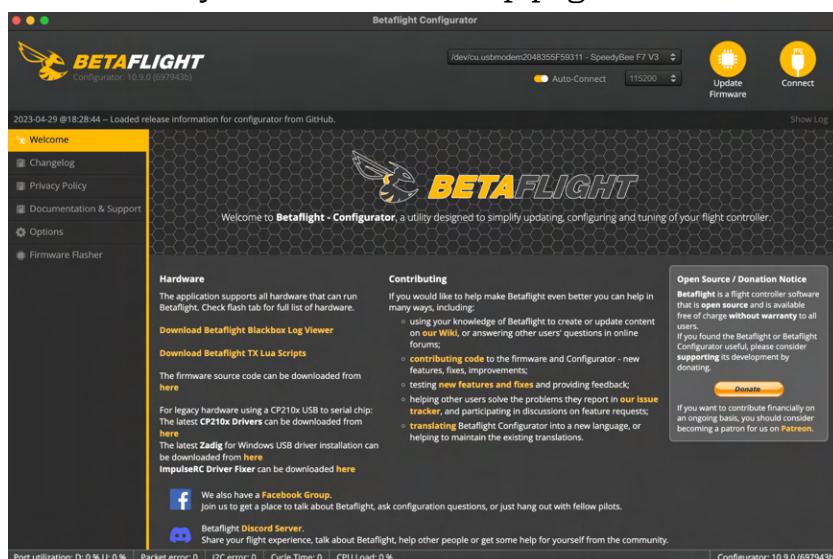
April 28, 2023: More troubleshooting

I went to Olin and talked to one of the students I know in my Robotics class as both my professors were busy. He works on a drone project in the robotics lab at Olin. He suggested things that we already tried such as propellor direction, motor direction, etc. He also suspected that perhaps one of our motors is not producing lift (not pushing the air down). So we checked this by checking the air movement under and on top of the propellers (with caution of course). All the motors seem to be pushing the air down.

We then found online that sometimes drones tilt during liftoff because one of the motors might be defected. This was one of the hypothesis we had initially but we ruled it out because when we ran the motors using the speedybee app they had an audibly similar rotational speed. I guess it makes sense that it wasn't that easy to just rule out without any quantitative analysis. We ruled it out based on qualitative measurement initially. We decided to make different measurements to see whether it is one of the motors that were caused an issue due to some kind of defect. Going back to the source Katie found online, we checked to see if one of the motors were not warm, after running them all at the same speed for a certain period of time. We ran the motors at full throttle without the propellers on for a while but we didn't notice any difference. I was surprised to see this because I recall telling Katie that one of the motors (motor 2, or Stitch) was not warm compared to the others in one of our previous tests (a while back).

Then we tried to find other ways to quantitatively measure the difference between motors (if there is any) so I downloaded betaflight on my laptop and we played around with it to see what values we can measure quantitatively to analyze the difference between the motors.

- There is a USB-C port on the flight controller so we connected our laptop through a cable. You will see the screen below (image to the left) and once you click "connect" you land on the setup page.



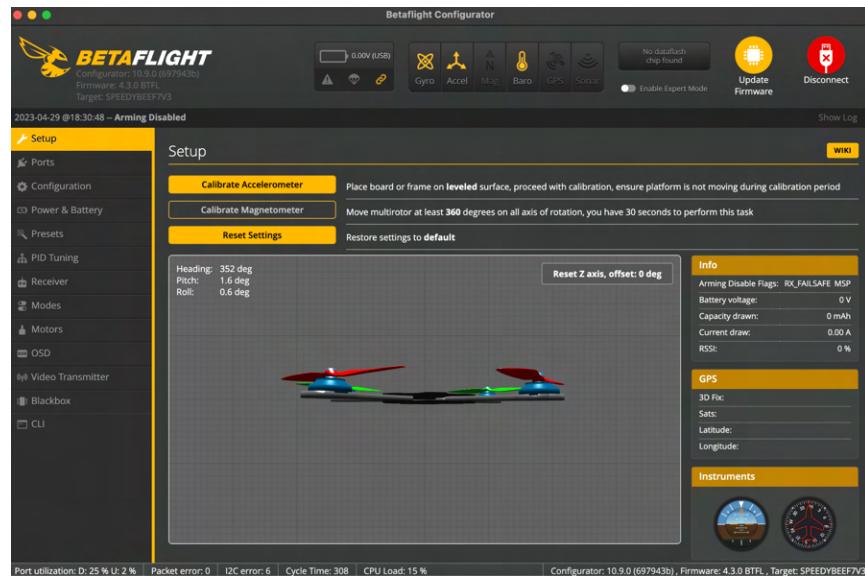


Fig. 5.1 Using betaflight computer app to connect (top image); setup page (bottom image)

- The app has the features that the mobile app has but has an easier UX to use. Back to our quantitative measurement though, one idea we had was measuring amperage. We turned each motor on, set it at a certain level (1828) and measured the amperage reading one by one. To do this, go to the motors tab on the betaflight app then click the “I understand this” button and then you can manually turn the motors on, one by one (or together through the master switch) to the right bottom side of the screen.

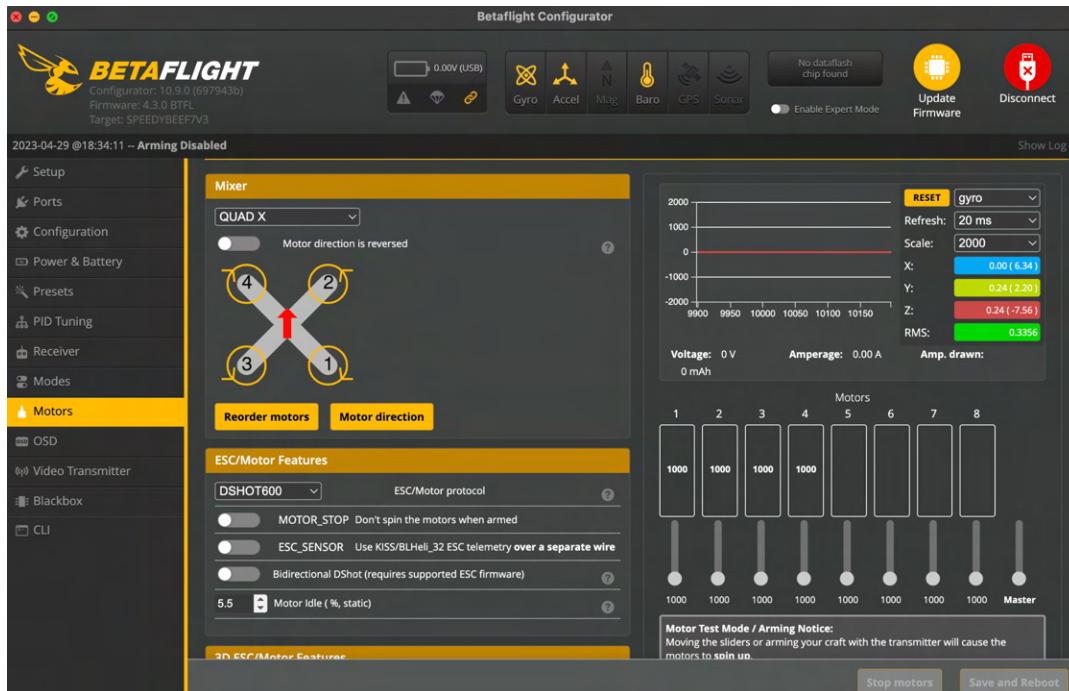


Fig. 5.2 Motors tab in betaflight

- Here are our measurements: (you can find amperage right under the graph to the right side of the screen).

Motor Number	Amperage Reading
1	1.89 ± 0.02 A
2	1.77 ± 0.04 A
3	1.91 ± 0.03 A
4	1.93 ± 0.03 A

The amperage readings here show that perhaps the second motor could be the defected motor because its current draw is lower (though not by much). This coincides with what we observe when testing the drone, the drone keeps tilting towards motor 2 (Stitch). We didn't do more tests to get more readindgs in order to verify this though (which I am realized now we should have done).

Then we waned to see what the amperage and motor speed readings are when we use the transmitter so while the drone is still attached to the laptop and the propellors are off, we armed the motors using the transmitter and noticed something unexpected and just very confusing. Motor three was overshooting! (see screenshot I took of this below). I have uploaded a [video](#) here.



Fig. 5.3 One of the motors overshooting as I arm the motors on the transmitter

With some google search we found out that this was expected when motors are bench tested with propellers off. This happens because the PID controller is trying to adjust the motor speeds based off the vibration of the flight controller. It cannot adjust itself as it is not hovering so the feedback loop makes it overshoot and we are seeing that in the third motor here.

After that we decided to do one hover test (a test to see if it can hover) by increasing the motor speed manually using a master switch on the speedybee app and then call it a day. As we were walking outside we realized that this method won't allow the flight controller to use its PID algorithm. Since we are setting the speeds of the motors to the same value, it won't let the flight controller tune its speed. We tested it either way and confirmed our suspicion, and Stitch continued to tilt so we cleaned up and called it a day around 11 pm.

One thing I forgot to mention is that we asked chatgpt¹ for more things to consider or troubleshoot. It mentioned that we should make sure the "motor mixing" setting on the betaflight app matches with the frame we are using. I didn't understand how we could do that initially but the options we had was either QUAD X or QUAD X 1234. The difference is in the ordering of the motors. Katie and I tried both settings to see if it changed anything but no, Stitch tilts. We were also hoping to see if changing it to QUAD X 1234 would tilt it to the same motor 2 or not in order to see if it was really a defect on that motor's part. However it didn't tilt to that side this time.

April 29, 2023: Test day with sensors

Came in in the morning today and worked with Sydney, Zoë and Katie to test our drones and sensors. I first helped my teammates hook up different sensors on board stitch. I fixed a raspberry pi, needed to mount the IMU and photogrammetry camera, on the top plate of the drone. Sydney ziptied the portable battery that powers the Pi to one side of the drone and on the other side, I ziptied the photogrammetry camera. Zoë and I then ziptied and taped the IMU top of that camera. We put the radio receiver on angel because we ran out of space on stitch and went out for testing. Here's what the drones looked like:

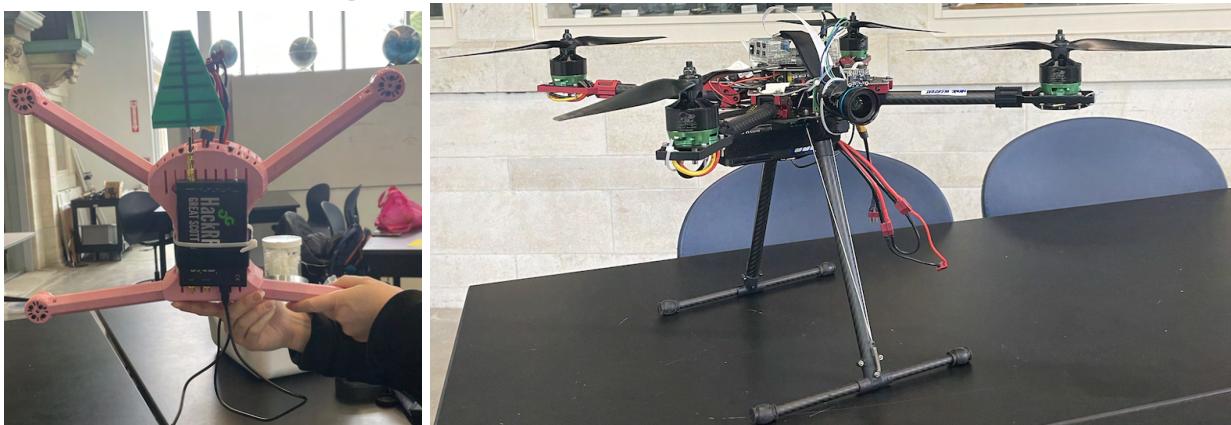


Fig. 5.4 The two drones: Angel (to the left) and Stitch (to the right)

While the sensors were being prepared, Katie and I were bouncing ideas off of one another about the tilting issue we have been having on Stitch. One thing we

were deciding whether we can rule out or not was the motor defect hypothesis. We were exploring this the day before (check 28/04 entry) and the amperage reading we had was challenging us from ruling out motor defect as one hypothesis. So we took one more reading and checked to see if motor 2 was still drawing less current. Here's what our results are (new test written in purple and first test we did the night before logged in red).

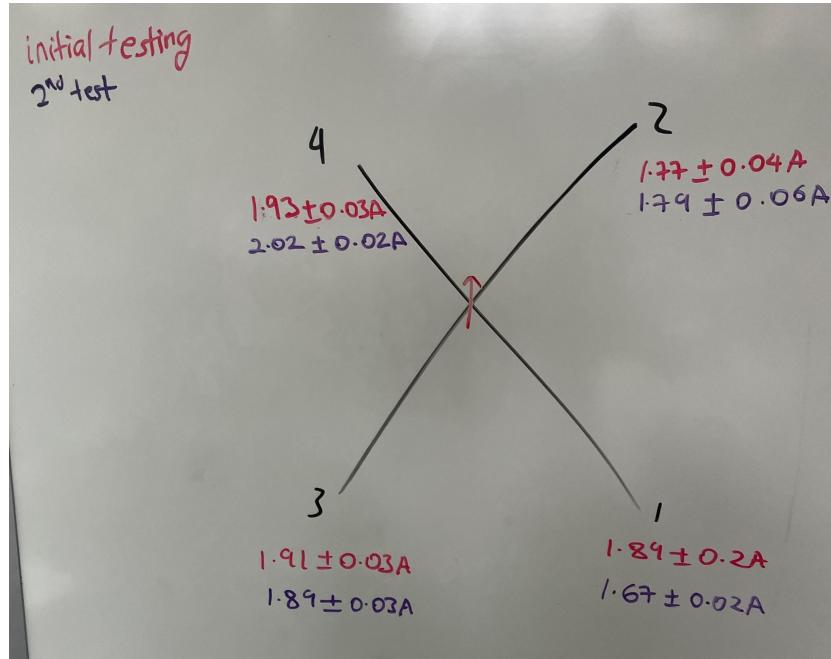


Fig. 5.5 Amperage reading of the motors in two tests

The amperage readings for each motor (at 1828 or the level we had it on yesterday) is different and not close to one another. We don't know how what is causing them to behave this way so we left it at that and started testing.

Our teammates were ready to test the sensors and motors of the drone (for Stitch) at this point so we went outside to do so. Stitch was tilting still as we didn't solve that yet so we instead ran with the drone to get good data for the IMU. Later we confirmed that the data was collected well so we ended our test there around noon.

Side Note:

- Last night (28/04) Katie and I were trying to figure out what motor mixing setting to use in betaflight. I figured out that ours is QUAD X by looking at the motor order on the flight controller.

Came back after lunch and checked if motors are soldered on the right place on the flight controller. Seems like everything on that end is good. See the arrows pointing up in the pictures below.

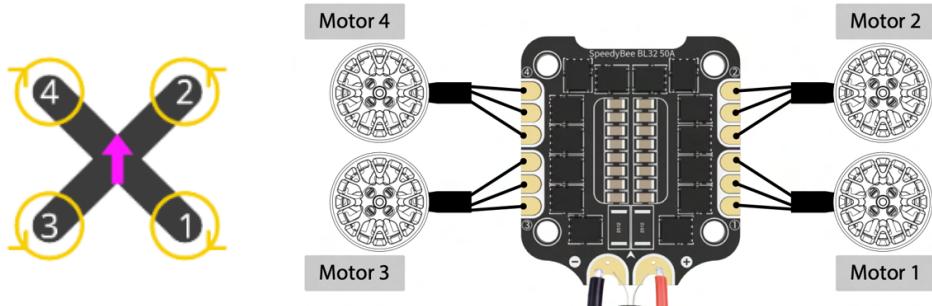


Fig. 5.6 Motor Numbering for Quad X (left image) and Speedybee motor wiring diagram (right image)

However, what it shows on betaflight appears to be wrong. Betaflight thinks that the drone is pointed where the arrow on the sticky note is pointing in the image below (which is to the left). On the other hand, the actual arrow on the frame (and in turn the flight controller) is pointing upward. So I checked the configuration tab on betafight and changed the yaw back to 0 degree. It was set on 90 degrees (maybe it got messed up when Katie and I were playing with it last night).

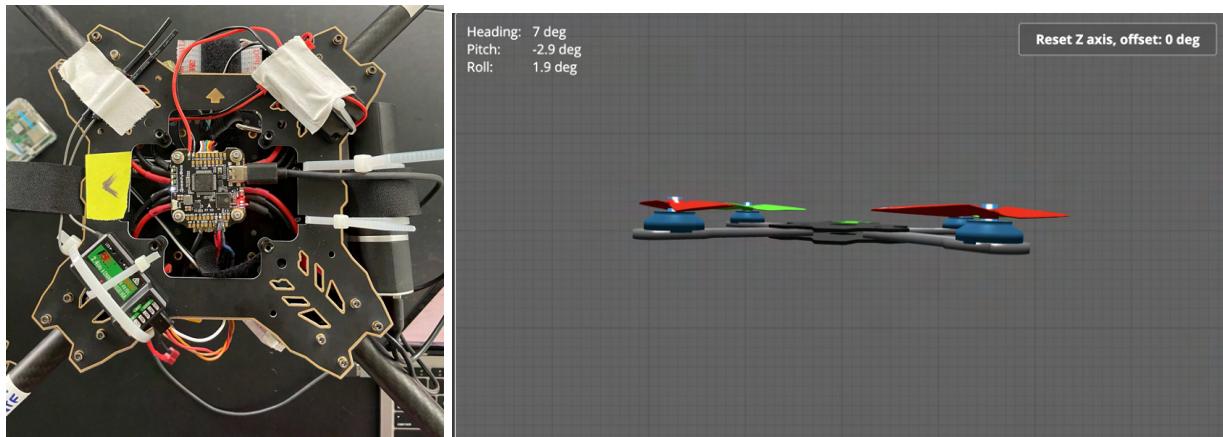


Fig. 5.7 Physical drone vs what we see on the app

Here's where I changed the setting on betaflight, then I clicked save and reboot at the bottom.

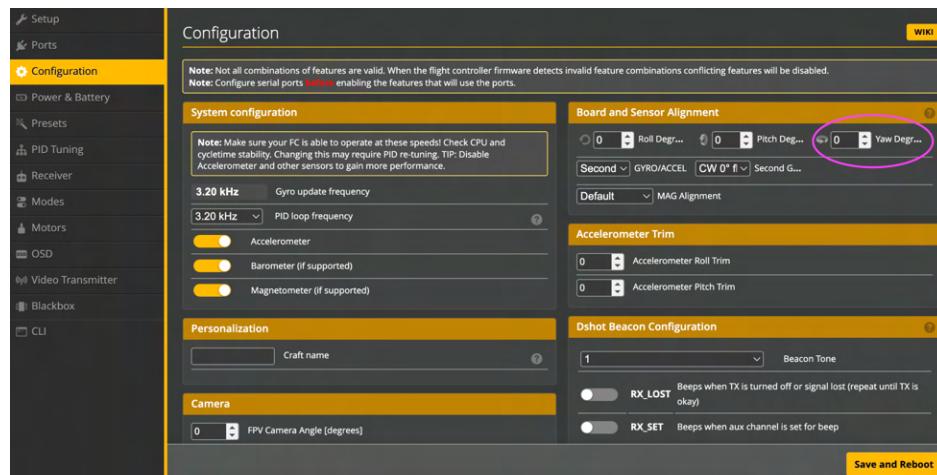


Fig. 5.8 Yaw setting (circled in pink) in betaflight

I called Wes and while I was showing him how we have been testing so far, he noted that the way we have been carrying out the calibration is wrong. The drone ended up tilting still during the test so we started exploring the calibration method more intently.

- The way Katie and I have been testing the drone so far involves clicking the calibration button every time we test (be it on level or unlevel surface). I hadn't thought about this until Wes caught it but what we have been doing doesn't make sense. For example we have been testing on the observatory hill most of the time and everytime we calibrate it there, we have been telling the drone that it is perpendicular to the gravitational field of the Earth. However this is not true because we have mostly been testing it on unlevel surface.
- Wes explained this to me and he said we need to calibrate the accelerometer on a level surface first then use that calibration for testing (and not recalibrate on uneven surface). **This tells us that the orientation of the frame is perpendicular to the gravitational field and orientation of the flight controller with respect to the frame that we used during calibration should stay rigid.** In other words, we cannot have the orientation of the flight controller change with respect to the frame, or else we have to recalibrate. I also did a google search to validate this and on a Setup Tab [configuration wiki](#) that betaflight provided, it is clearly stated that we need to calibrate the drone accelerometer on a level surface. See image below to view the calibration instructions.

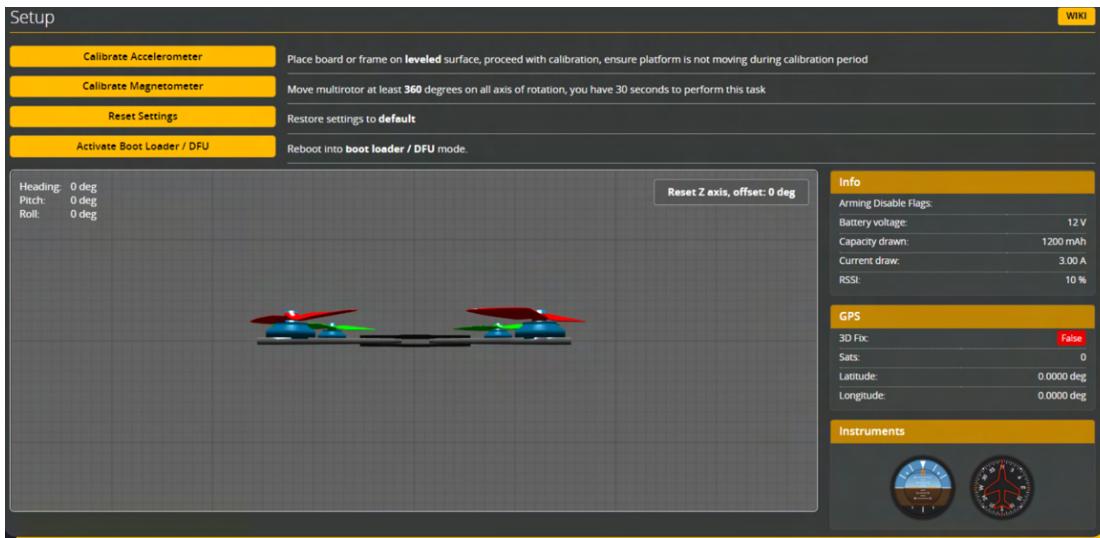


Fig. 5.9 Calibration settings (in setup page) on betaflight

- Having this in mind, I tried to find a level surface using a bubble level then I placed the drone there and put the bubble level on top. I first made sure that the flight controller was fixed flush to the top plate (used a velcro, with the metal in the velcro facing downward for ease of bubble level use). The screws on top of the plate didn't let the bubble sit on top easily either so I put a paper in between them and continued to find a suitable place for the

drone to be leveled out. Level is when the three bubbles are all in the middle (circled pointed out with yellow arrows in the image below).



Fig. 6.0 Using bubble level tool to find level orientation for Stitch

- After following that process of calibration, I tested it again and it kept tilting. I tried moving the batteries to counterbalance the movement and still kept tilting. Having tried all of these I have adjourned for the day!
- **One important thing to note was that this time, the drone was not tilting to motor 2 (Stitch) in fact it was tilting in the opposite direction.** This I think confirms that it is not a motor issue. Aside from calibration, the only major thing I changed today was the yaw (heading) by 90 degrees and that means now another motor is being commanded to overshoot (at least that's my assumption). It is not a motor issue, it has to be a command issue (either within the transmitter or the flight controller itself). Maybe the PID controller is not working correctly either due to settings issue or due to the flight controller being fried!!). Another measurement that was done today earlier when Katie was here was measuring the amperage of each motor. This also now confirms that it is not a motor issue.

- I realized that the motor mixing is on QUAD X 1234 so I changed this back to QUAD X and rebooted.

May 01, 2023: Lift-Off!!! (with a jiggle)

I left on Saturday by changing the settings on the drone as it was too dark to test at the time, After presentation on Monday the first thing we did was test the drone. It was still tilting but I had a feeling that it was the center of mass because I had left the battery slanted off too much from the center last time (see video [here](#)). We played around with the center of mass of the drone (meaning shifted the battery around here and there using a string to test the tilt of the drone in the air each time) for a while then went outside to test it (see image below).



Fig. 6.1 Katie holding Stitch with a string to find the center of mass

The grass is not level so we tried looking for level grass as it was still affecting the drone (made it tilt a lot). We tried to get it to lift off at the observatory hill (on the small pouches of grass) but we didn't want to risk crashing the drone since the asphalt is so nearby and we had a feeling it was trying to lyft so we went to the arboretum.

There we turned it on, and slowly started to increase the throttle. On the first try we got it to lift off a little but since we weren't expecting that we disarmed the motors quickly and the drone flipped over. It was not a harsh landing as it didn't even lift up more than a foot or two so we didn't damage anything. Encouraged by this, we started filming this time, found an even more level ground and started testing again. Before we armed the motors, we noticed a wind blowing in a certain direction. I will paste the video link [here](#) to help visualize what happened. Essentially though, the drone lifted off, drifted (in the direction of the wind, might be a coincidence or not) and was jiggling. Katie disarmed it quickly and it landed a bit more violently. We checked to see the damage and it was only the capacitor that came off and small piece of the frame (right under the arm) that

broke off. Though we damaged it a little, it **lifted off!!** Our hypothesis as to why it was jiggling was that maybe it has something to do with the PID tuning.

May 02, 2023: Damage Control

Katie and I came in the next day after lunch and started doing some repairs on Stitch. Katie took on soldering the capacitor onto the wires that it broke off of. Meanwhile I went to Larry Knowles, Wellesley's machinist, to drill holes into the top plate of the frame. The way we have the drone now, if you move the flight controller, the gyro orientation with respect to the frame is changed and that defeats the purpose of calibrating the accelerometer. The flight controller needs to be fixed to the frame so that after we calibrate the accelerometer, the gyro orientation won't be easy to interfere with.

Larry measured the flight controller side to side and divided by half to get the center. He also measured the diameter of the screw that goes into the flight controller. Then Larry inputted these values into the mill and drilled four holes into the top plate (where the red dots are in the image below).

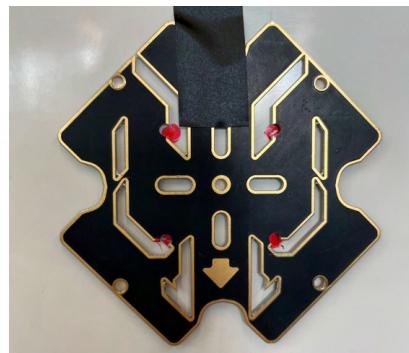


Fig. 6.2 Holes drilled into the top plate to secure the flight controller

I thanked him and went back to the obs where I found Katie who finished soldering the capacitor. We found a suitable spot and zip tied the capacitor in the interior of the frame. We have it right next to one of the arms (see image below). This was in order to prevent it from jiggling and breaking off again.

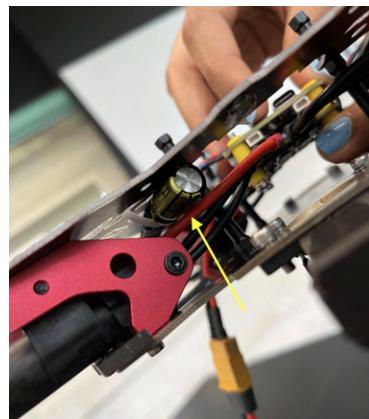


Fig. 6.3 Capacitor zip tied under the middle plate (pointed out with a yellow arrow)

After that we started fixing the flight controller stack onto the top plate by using screws and bolts. One side of the flight controller has a USB-C cable port so flushing the flight controller tightly to the top plate was not possible. We also wanted this stack to be level so we used washers on the two screws opposite to the side of USB-C port (see image below). We then bolted the top plate into the rest of the drone frame.

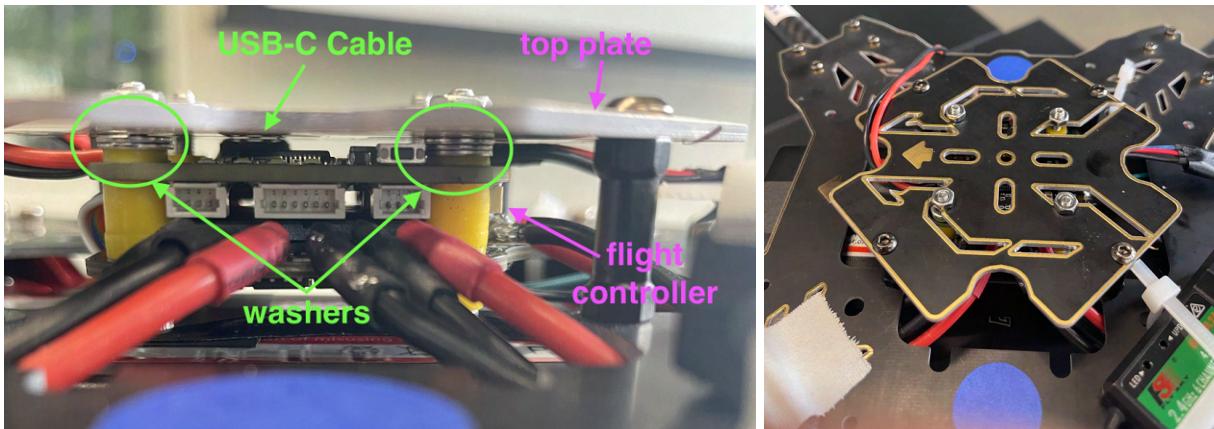


Fig. 6.4 Using washers to set a level gap between the top plate and the flight controller (left image); flight controller secured on the top plate using four screws and nuts

We eye balled whether the flight controller is level compared to the top plate and secured it with bolts. We then put a bubble level ontop of the drone and calibrated the accelerometer once we leveled it out. Afterwards, we found a spot to put the batteries (one inside the frame and one under the bottom plate). We used multiple velcros to secure them in place then left it at that for the day. I had scheduled a meeting with Professor David Barret (Dave) at Olin College for us the following day. He is a roboticist with decades of experience and knows how to work with drones really well so we were hoping to get some guidance on how to get Stitch up in the air and hover without jiggling.

May 03, 2023: Field trip to Robo Lab (Olin College)

Katie and I met the following day at 8:30 in the morning at the observatory to make any last minute adjustments and test one more time before heading to Olin for our meeting with Dave. Stitch still lifted off like last time but had a bit more harsh landing and was a bit more unstable. One of the landing gears broke as it crashed to the ground. [Here's](#) the video we took. We used gaffer tape to stitch the leg (no pun intended) and went to Olin.

Dave first took a look at the leg and once he finished his examination, he suggested we use epoxy. We showed him the video we took of the test we had just done and told him that we were thinking about using a hot glue gun to fix the leg. He said that won't hold so before we even came to talk about what we came for, we first went into fixing the landing gear. Dave gave us epoxy, alcohol (to clean the leg/ joint that shattered), and some gloves. He then walked us through the steps we needed to take in order to epoxy the leg (see section 4 on How to Epoxy in my

[technical supplements document](#)). We left the epoxy on the landing gear to set on the table and went to the room next door (the main robo lab).



Fig. 6.5 The epoxied fractured landing gear joint (left image); a picture of me using a wooden stirrer to put epoxy on the joint (right image)

Dave thought it was necessary to learn how to fly a drone he gave us some flight lessons. He took two small drones, gave us their controllers, and told us to fly them (see image below and [this](#) video).



Fig. 6.6 Mini drones Dave used to teach me and Katie how to fly drones

Then diagnosed the drone with him, he saw the video and asked about the propellers etc. then recommended that we tune the PID. we haven't told the flight controller anything about the drone frame (model) we are using nor have we adjusted the gains according to the weight of the drone or size of the props. He suggested we watch a video on youtube about tuning PID on betaflight (maybe for a Holybro 500, which is a famous research drone similar to the one we have). He suggested we tie the drone down to four cinder blocks (and four strings) to keep it from lifting over a foot and test, tune, test, tune, etc.

May 04, 2023: PID Tuning

This day, I spent most of my time trying to understand PID Tuning. From [this](#) video:

In betaflight PID-F controller: P-proportional; I-integral; D-derivative; F-Feedforward

- Feedforward allows sharp turns and improve setpoint tracking
- Setpoint is what you command the drone to do (input from sticks * rates in betaflight)

The PID-F Controller

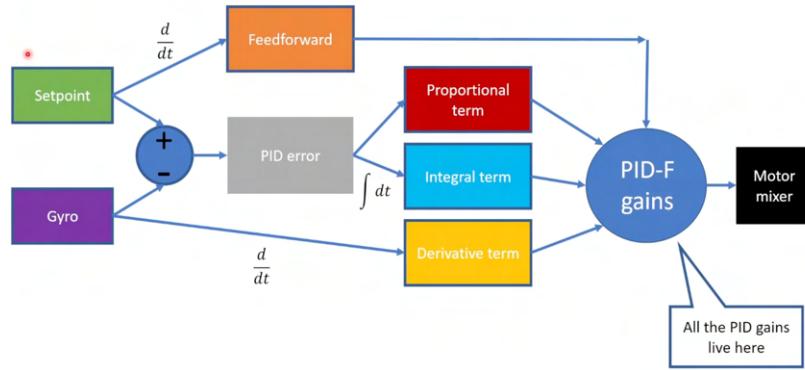


Fig. 6.7 PID controller

In the CLI, set these to get maximum capacity of the PID

```
set pidsum_limit = 1000  
set pidsum_limit_yaw = 1000  
save
```

May 05, 2023: PID Tuning Cont...

- Select preset (something to do with radio communication frequency). *How do we know what modes to select? What RC link speed etc?*
 - Change RC_Link to the mode you have. The drone will fly if you don't set this but it will fly better if you do
 - RC_smoothing. Smoothing stick input (adding latency) vs gittering (less latency). For the former, pick a lower Hz while a higher Hz for the latter one.
- Go to the motors tab and enable Bidirectional Dshot (allows us to use RPM filtering, targets the RPM that the motors are making and is effective to get the quad flying better). Check if the ESC supports it, ours does.
 - Input poles (if you don't know it count (the magnets) from inside the motor)

- Filtering: makes the drone run better otherwise there's a risk of smoking the motors, having them shake etc. the goal is to have as less filtering as possible, this reduces the latency in the PID loop.
 - Since we have RPM filtering active, we go in the filtering section and disable gyro lowpass 1.
 - The ADC filter in the transmitter needs to be off as well

Information above is from [this](#) video. Later Katie and I tied Stitch's arms to four cinder blocks.



Fig. 6.8 Stitch's four arms tied down to cinder blocks with heavy duty strings

Throughout this process, we were trying out different things but we were in uncharted territory so we weren't able to get far in the little time we had.

- Increased the D gain to max (1.40). We hoped it would jiggle less but we couldn't tell because it was tied to a string (catching it with too much force, momentum?)
- Played with preset, watched videos, couldn't find flysky on RC link
- Turned on the bidirectional Dshot and turned the gyro lowpass 1 off
- We increased the tracking (P and I gain). The idea was make it lift up a bit smoother but we quickly shut it off because we couldn't tell if it would have not jiggled had it been left on longer

At this point in the night, the grass was wet so we stopped in order to prevent the electronics from getting wet.

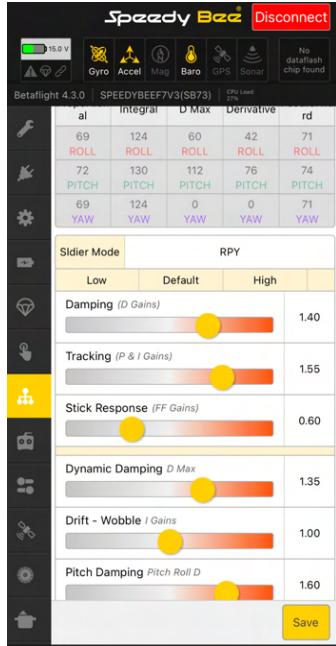


Fig. 6.9 PID gains in SpeedyBee

May 06, 2023: Final Troubleshooting

Resuming from where we left off yesterday, Katie and I decided to head to the arboretum and test the changes we made to the PID gains. We had somewhat of a stable liftoff (see [this](#) video). However when we retrieved it, we noticed that the arm that broke off during the test on May 3rd was no longer holding in the makeshift spot we had for it. As we armed the motors, the lift causes that broken arm to lift off more and vibrate exceedingly. When I say the arm broke off, the bottom plate holding the arm (bolted down) simple broke off leaving nothing to hold the arm down.

Katie and I spent a considerable amount of time trying to figure out a suitable way to attach it. First we tried to drill a hole into a spare plate we had left in from the kit. We went to the basement in the observatory to look for a power drill. We mistakenly thought that a dremel we found was a power drill. However we later found what we were looking for (see image below) and we tried to drill a hole into the plate but for some reason that didn't work. It seemed like it didn't have enough power. Therefore we resorted to using a superglue (we couldn't find an epoxy). It says once we apply it, we have to leave it on for about 2 hours for it to dry. We got some gloves on, wet the surface being glued, put glue on to the surface and held it in place with clamps.



a. Power drill



b. Gorilla superglue



c. Stitch's glued arm held in place with two clamps

d. Closeup image of the arms

Fig. 7.0 Methods pursued to fix the arms

After clamping it together for about 3 hours, we came back and tested it.

[Here's](#) a video we took. Though it lifted off, it jiggled a little and got caught into a tree nearby. Here's a picture of Emma taking the drone off from the tree:



Fig. 7.1 Emma getting Stitch off a tree

We played with the PID gains a bit more (increased the master multiplier for example) and tested but to no avail. In the last few tests, the drone started to crash land by itself as the failsafe kicked in (for a reason I still do not understand). We have come far in isolating the issues that have been causing Stitch to not liftoff, jiggle, and crash. We have troubleshooted through numerous problems and I am proud of what all of us have accomplished thus far. Due to lack of time and depth of knowledge, have not been able to adjust the PID gains (an algorithm inside the flight controller that adjusts motor speeds based of sensor readings) for our drone. However, this presents as an opportunity perhaps for a future team to iterate on.



Fig. 7.2 Stitch without sensors

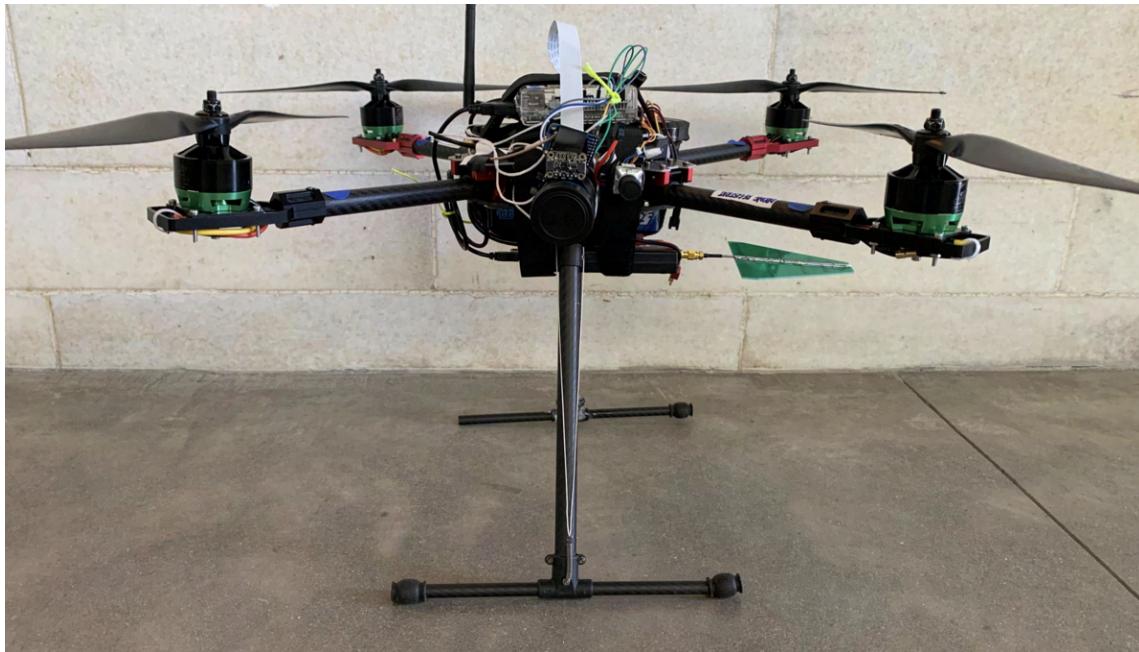


Fig. 7.3 Stitch after sensors are integrated, final image taken.

Endnotes

Me: I built a quadcopter drone with F7 speedy bee flight controller. we are remotely controlling it using flysky transmitter and an FS-iA6B receiver. when we turn all the motors on using beta flight and increase the throttle, all of them increase at the same rate. However, if we use the transmitter to increase the throttle, the drone starts to tilt towards one of the motors (each time). How should we solve this?

ChatGPT

It sounds like you might be experiencing a problem with your drone's calibration or motor mixing.

Here are a few things you can try to troubleshoot the issue:

1. Calibrate your accelerometer: First, make sure that your accelerometer is properly calibrated. In Betaflight, go to the "Setup" tab and select "Calibrate Accelerometer." Make sure that your drone is level when you calibrate it, and follow the on-screen instructions.
2. Check your motor mixing: Make sure that your motor mixing is correct. In Betaflight, go to the "Configuration" tab and make sure that the motor order is correct for your specific quadcopter frame. You can also check your motor output by going to the "Motors" tab and increasing the throttle for each motor one at a time. Make sure that each motor is spinning in the correct direction and at the same rate.
3. Adjust your PID settings: If your drone is still tilting, you may need to adjust your PID settings. PID stands for proportional, integral, and derivative, which are parameters that help to control the stability of your quadcopter. In Betaflight, go to the "PID Tuning" tab and adjust the values until your drone is stable. Be careful not to make drastic changes, as this could cause your drone to become unstable.
4. Check your transmitter and receiver: Make sure that your transmitter and receiver are properly paired and that your transmitter is sending the correct signals to your drone. You can check this by going to the "Receiver" tab in Betaflight and making sure that the channels are being correctly mapped.
5. Balance your propellers: If none of the above solutions work, try balancing your propellers. Imbalanced propellers can cause your drone to tilt in one direction. You can balance your propellers by using a propeller balancer or by sanding down the heavier side of the propeller.

Hopefully, one of these solutions will help to fix the problem with your drone tilting. Good luck!

Me: on the second bullet, you said try motor mixing. How do I know what orders are correct for the drone I am using

ChatGPT

The motor order for your drone depends on the specific frame you are using. You can find the correct motor order for your frame by checking the documentation that came with your drone, or by doing a quick online search.

Once you have determined the correct motor order, you can update the motor mixing settings in Betaflight. Here's how:

1. Connect your drone to your computer via USB.
2. Open Betaflight and go to the "Configuration" tab.
3. Under "Airframe," select the correct frame type for your drone.
4. Under "Motors," select the correct motor count for your drone.
5. Under "Motor Output," select the "Custom" option.

6. In the "Custom Motor Mixer" section, you can adjust the motor output for each motor. Use the "Motor" drop-down menu to select each motor, and then adjust the "Value" slider to set the correct motor output.
7. Once you have adjusted the motor output for each motor, click the "Save and Reboot" button to save your changes.

After updating your motor mixing settings, you can check your motor output in the "Motors" tab to make sure that each motor is spinning in the correct direction and at the same rate. If you need to make further adjustments, you can do so in the "Custom Motor Mixer" section.

Me: ok that didn't help, it is still tilting. for the third bullet point what settings do you want me to adjust on PID

ChatGPT

When adjusting PID settings, it's important to make small changes and test your drone's stability after each adjustment. Here are some general guidelines for adjusting your PID settings:

1. Start with the default PID settings in Betaflight.
2. Increase the "P" value for the roll, pitch, and yaw axis until your drone starts to oscillate. Then, decrease the value slightly until the oscillations stop.
3. Increase the "I" value until your drone stops drifting or oscillating slowly. Be careful not to increase the "I" value too much, as this can cause your drone to become unstable.
4. Increase the "D" value until your drone responds quickly and smoothly to changes in the throttle or control inputs.
5. Test your drone's stability by flying it in a safe, open area. If your drone is still tilting, adjust the PID values accordingly and continue testing.

Remember that every drone is different, and the optimal PID values for your drone will depend on factors such as weight, motor configuration, and flight style. It may take some trial and error to find the best PID settings for your drone, so be patient and persistent in your testing.