Using the Engineering Design Process

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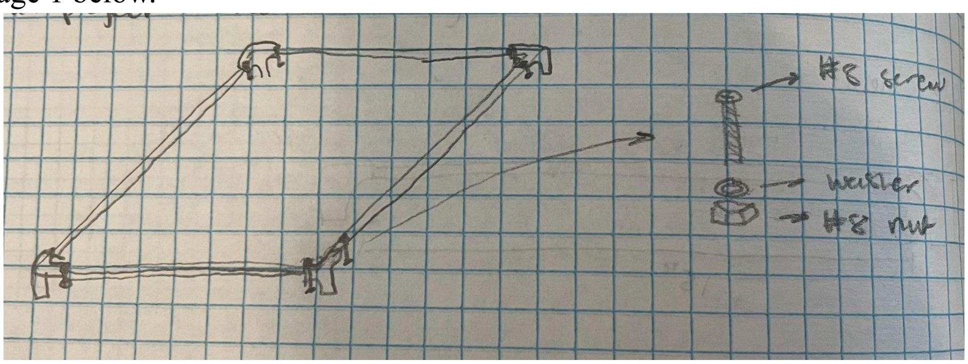
Introduction

At the beginning of the semester we were assigned the task of creating a quadcopter using the engineering design process. The goal was to take an assortment of parts and construct them in a way that made a functional quadcopter. This project was open ended meaning that there were many ways to build the quadcopter but there were some designs that may prove more efficient than others. The process started by researching what quadcopters are and the essential parts to making one functional. Once a list of the needed parts was created, we then started to brainstorm ideas for the design of our frame by looking up several different designs and considering the benefits of each. After seeing our given materials, the design was chosen and we began to construct the frame. This process of asking, researching, designing, executing, testing, revising, and communicating our results was continued throughout the build with other components like the flight controller stack, motors, motor mounts, receiver, and transmitter as we continued in the pursuit of a functional quadcopter. All of our findings about the materials used, how the quadcopter was constructed, and what we learned along the way are included below.

Build Process

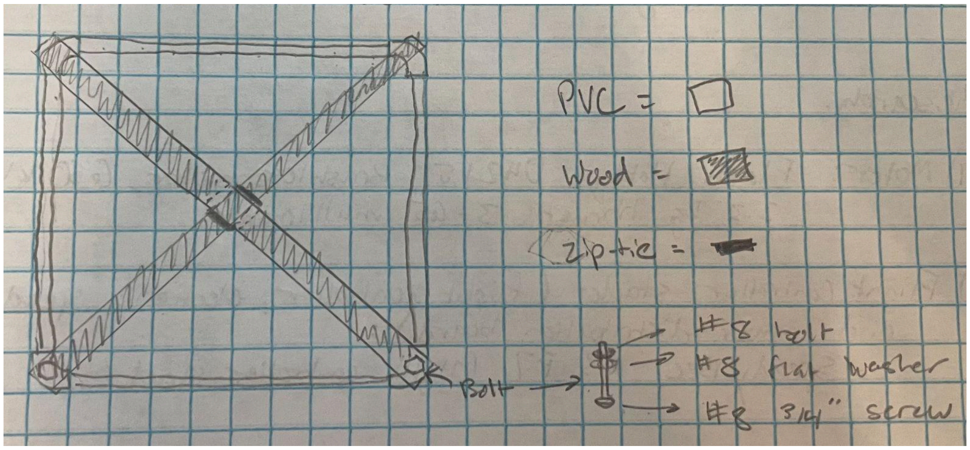
After researching quadcopters, a square design was decided on by our team and we began construction. Our frame was built out of ½ inch pvc pipe selected for its strength and weight. The PVC was placed in a square design using 3-way elbow fittings in the corners of the square to connect the sides and used the third side as landing gear to give us space off the ground as can be seen in image 1 below.



[1]

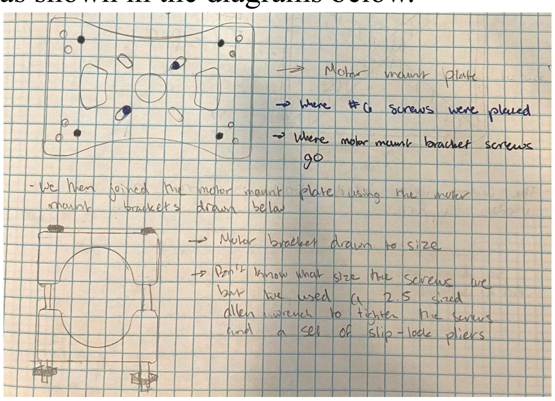
Since we were counting on twelve inch propellers, we needed to allow for at least twelve inches between the corners of the frame so that the propellers would not collide, but the PVC sides sit three-fourths of an inch inside the fitting, so we decided to 16.5 inches to create a width of 15 inches in between the corners. The ends of the PVC pipes where secured to the elbow fittings by vertical placing a #8, one and a half inch long screw through the overlap of the PVC pipe and the elbow fitting. A 5/32 inch drill bit was used to drill a pilot hole for the screw making sure that the bit was drilled in vertically. A lock nut washer and a #8 nut were attached on the bottom of the screw to secure the PVC to the corners. The end of a spade bit was used to create a divot in the elbow fitting so that the drill bit would not slip when the pilot hole was drilled for the screws. Cross supports were then added to the frame spanning from each corner to its opposite in an “x” pattern using one inch wide wood painting sticks cut to 26 inch sections with a hand saw while the paint stick was held against the table. The paint sticks were secured to the corners using a ¾ inch #8 screw with a flat washer and #8 bolts on top to make the tightening process easier. The overlapping wood in the center was secured using zip-ties as shown in Image 2.

[1] Image 1 - the outside of pvc frame

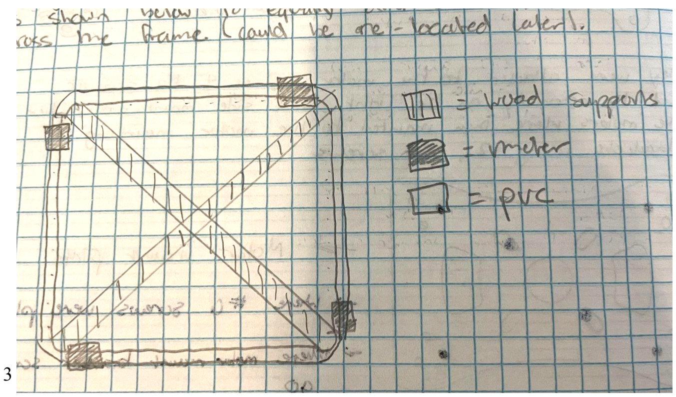


[2]

After completing this phase of building, the frame was weighed and found to be 1lbs and 9.4 oz which was far below our max weight since each of our motors was regulated to carry 3 lbs each. After completing the frame we began to work on adding the motors to the frame. Our team was given four Flash Hobby D4215, Brushless motors that can spin at 650 kV and are capable of creating 3.3 lbs of thrust. The recommended propeller size for the motors was 8-12 inches of which we planned to use 12 inch propellers since our frame was rather large. To attach the motor to the frame, two motor mount brackets were used to connect the motor mount plate to the frame as shown in the diagrams below.



[3]



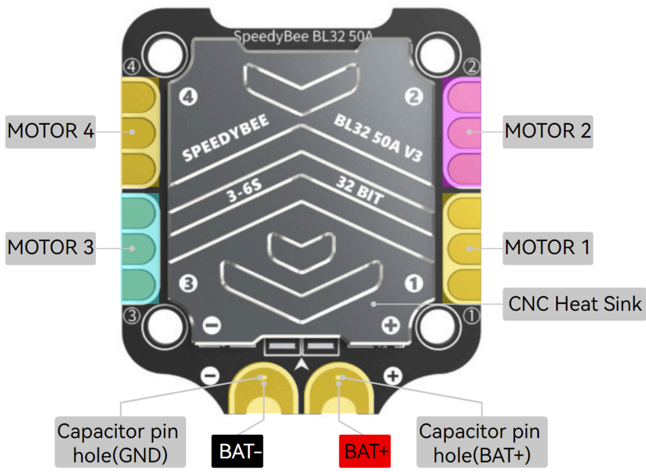
[4]

Since the motor mounting brackets were too large for the half inch PVC pipe, we attached small pieces of rubber to the PVC where all 8 motor mounting brackets were placed to make the diameter of the PVC larger and provide traction so the bracket would be less likely to move in flight. After all eight brackets were added to the frame our team then attached the motors to the motor mount plate and then attached each plate to brackets using the screw placement shown in the diagram above. Once the motors were attached to the frame, our team began working on integrating the SpeedyBee stack.

A SpeedyBee F7 V3 BL32 50A 30x30 Stack for the flight controller (FC) and electronic speed controllers (ESC) for our quadcopter. This integrated system reduces the amount of soldering needed to connect the motors and receiver to the ESC as well as including many features like visual audio capabilities, bluetooth, and the ability to support more than 4 motors

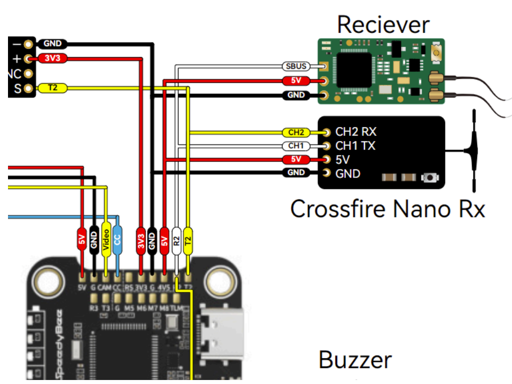
[2] Image 2 - frame with wooden cross supports
[3] Image 3 - motor mount brackets and motor mount plates
[4] Image 4 - location where the motors where mounted

which would allow us to enhance the quadcopter in the future. All the specs of the stack are included in the user manual attached below (Reference 6). The 1000 uF capacitor provided with the stack was attached to the capacitor pin holes making sure to check for correct polarity. The leads for the battery were then connected to the battery leads. The four motors were attached to the ESC in the configuration below using 3 inch sections 18 AWG wire with a quarter inch stripped off to solder to the ESC. All tweleve (one wire per pad) of these 3 inch wires were then connected to the motor leads using wire nuts and electrical tape. Afterwards, all leads were checked for continuity using a voltmeter. The stack was then attached to the frame by drilling pilot holes in the overlap of the paint sticks and then threading the screws provided with the SpeedyBee stack in all four corners.



[5]

After the motors were connected to the ESC, our team began working on attaching the receiver to the FC. A RadioMaster R86C receiver was connected to the FC using the diagram in the manual making sure to connect the SBUS, 5V, and ground wires to their correct terminals.



[6]

Next, our team began to arm the RadioMaster TX16S radio transmitter to the receiver using reference 7 as a guide. Once the receiver was installed and the transmitter was set up, our team began to troubleshoot the reason why the input from our transmitter was not starting up the motors. The application software BetaFlight (reference 8) was used to track what input the FC was receiving from the transmitter and that our arming switches were working correctly. After hours of problem solving we concluded that the error was occurring somewhere between the

[5] Image 5 from reference 6 - ESC with locations of motor leads
[6] Image 6 from reference 6 - diagram to connect receiver to FC

connection of the FC to the ESC output since the FC was receiving the correct input from the transmitter but no outputting power to the motors as expected. We went back and researched different ways to update firmware, recalibrate the ESC's, and confirm that the receiver was correctly connected to the transmitter. After several hours of testing our motors began to spin when the arm switch was on and the FC was not connected to the computer through the USB-C cable or connected to a phone via bluetooth. Our group came to the realization that the SpeedyBee stack must have a failsafe not allowing power output while an external device was connected to the flight controller.

Materials Used

1. Hardware used:
    a. Flight Controller/Electronic Speed Controller: SpeedyBee F7 V3 BL32 50A 30x30 Stack
    b. Motors: Flash Hobby D4215-650kv, 2.3 KW horsepower, 3-6S multicore (11.1-22.2V) brushless motors
    c. Transmitter: RadioMaster TX16S MKII 2.4GHz 16CH Radio Transmitter
    d. Receiver: RadioMaster R86C receiver
    e. Battery: HRB 3300mAh 60C Li-Poly Battery
    f. Motor mount plates: Hobbypower 3k Cf Motor Mount Plate for 16mm 22mm 25mm Arm Tube Quadcopter Multirotor
    g. Motor mount brackets: CNC Alloy 25mm Tube Boom Mount Motor Clamp for DIY RC Quadcopter Hexacopter
    h. Propellers: Nylon black 12 inch propellers with 4.5 degree pitch
2. Tools used:
    a. Hand tools
        i. Screw drivers
        ii. Crescent wrench
        iii. Electrical wire strippers
        iv. Scissors
        v. Magnifying glass
        vi. Allen wrenches
        vii. Electric drill
        viii. Hand saw
        ix. Soldering iron
        x. Helping hands
        xi. Box knife
        xii. Drill bit set
    b. Multimeter
    c. Computers
    d. Scale
3. Fasteners
    e. Electrical tape
    f. #8 1 ½ inch screws
    g. #8 ¾ inch screws
    h. #8 nuts
    i. Wire nuts

4. Frame
    a. ½ inch PVC
    b. ½ inch 3-way PVC elbow fittings
    c. 1 inch wide wooden paint sticks

Discussion

There is a lot of reflection and evaluation that goes into building and operating a functional quadcopters including communication within the team and resilience when faced with obstacles in the physical construction of the quadcopter. While we were not able to get our quadcopter operational until the last week of the lab, it was clear that controls on the quadcopter were very sensitive and needed a great deal of technical skill to fly safely. Our team was able to learn a lot about the non-operation of the quadcopter as we spent the vast majority of our time trying to get our build off the ground. There are various methods of troubleshooting when the quadcopter was not operational, including checking electrical connections, confirming compatibility of the receiver and transmitter, and verifying the FC is executing the desired output. Sometimes our team had to go back to square one and do research all over again just to confirm our initial understanding was correct. Another problem our team ran into was soldering since all our team members were not technically proficient and one small mistake could lead to a fatal short in the board. Because of this, our team had to re-soldering many connections that could have been fixed on the first try had we been more patient when initially creating connections. Another challenge we faced was communicating, especially when a team member was not there for the lab. To make the most of our combined efforts, it was important to communicate our research, mistakes, and how problems were solved so time was not wasted. Our team knew that with the final weight of the prototype being 3lbs and 0.8oz without the battery and the motors rated at 650 kV (which means it spins 650 times for each volt that the motors receive) the drone should fly given the power to the motors. This was why it was so satisfying when we finally saw the motors spin.

Conclusion

Reflecting on our semester of using the engineering design process, there were some things that could have been done differently to improve our build and efficiency if our team was to attempt this project again. When soldering our motors, if we had taken the time to properly connect our soldering joints, it would have saved us several hours of reconnecting broken joints. Our lab time could also have been improved early in the semester by doing more detailed research beforehand allowing us to better handle challenges in the lab due to a greater understanding of our materials. However, our group excelled in keeping detailed records in our lab manuals which helped us stay focused on the next step. Also, our team always made sure to keep our materials organized so they would be readily accessible for the next lab. If we were to add anything to the quadcopter, our group would create a covering for the SpeedyBee stack to protect it from being hit during flight as well as building a structure to hold the battery under the frame. Another feature that would be helpful would be LED's to make the quadcopter more visible during flight. Our group was able to communicate and use each other's strengths to help the team while allowing our partner to help us in the things we were not proficient in. Meeting more outside of the lab could have helped us solve problems quicker and made sure all members of the team were up to date on the most recent discoveries. Our group learned early on in the build the importance of practical skills when it came to soldering and how valuable it is to have someone who is proficient in this skill to evaluate your work. It became clear as the lab progressed that there was still much to learn in practical skill especially related to electrical connections and software of the SpeedyBee stack. Overall, this project was a great way to work through the engineering design process and show resilience when problems arose.

References

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2. How to connect a motor to the ESC and power cable (XT60): https://www.youtube.com/watch?v=m4EmrIO4uOk
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8. BetaFlight Download page: https://github.com/betaflight/betaflight-configurator/releases/tag/10.9.0