DESIGNING A DRONE

Built for EFFICIENCY
DURABILIY
POWER
SPEED

And how you can too.

by Jack Curtis

The Designer.

Jack Curtis, Lake Forest College class of '23, is a physics major, adventurer, athlete, and passionate drone enthusiast. From middle school to senior year of college, Jack has honed his skills in designing, building, and flying several drones that have each built upon the last.

Driven by a curiosity for the intersection of physics, engineering, and design, Jack embarked on a journey to explore the vast world of drone design. Through countless hours of research, hands-on experimentation, and collaboration with experts, he has gained comprehensive knowledge in various aspects of drone construction, materials, and intelligent design.

In addition to practical expertise, Jack has also expanded into academics to deepen his understanding of drones. His project in Advanced Applied 3D Design and Fabrication provided insights into the creative aspects of drone aesthetics and 3D printing. Furthermore, his time spent in a physics research project advised by Dr. Nathan Mueggenburg allowed him to apply trends from scientific experimentation to develop smarter and more efficient drone designs.

Through this magazine, Jack aims to share his experiences, knowledge, and passion for building and designing drones with fellow physics majors, aspiring drone builders, and curious readers. He believes that drones have the potential to revolutionize various industries and inspire new engineers and designers.

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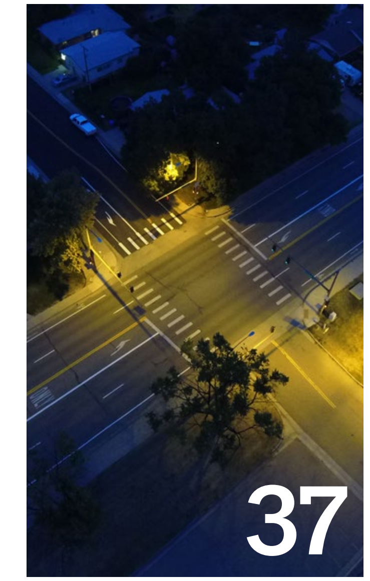
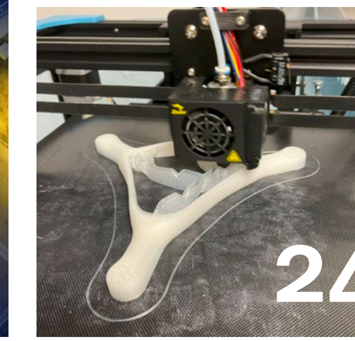
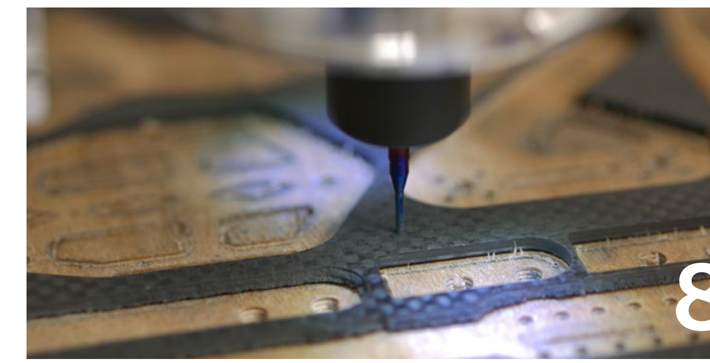




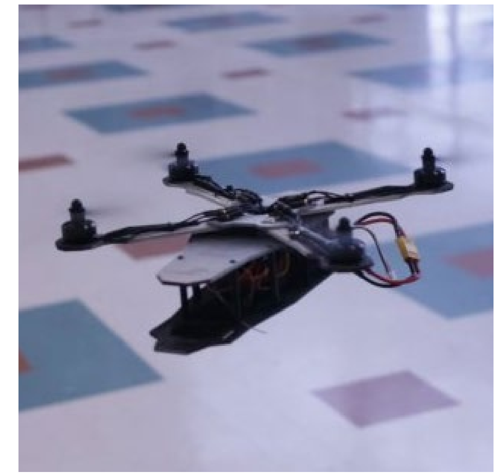


PAST WORK

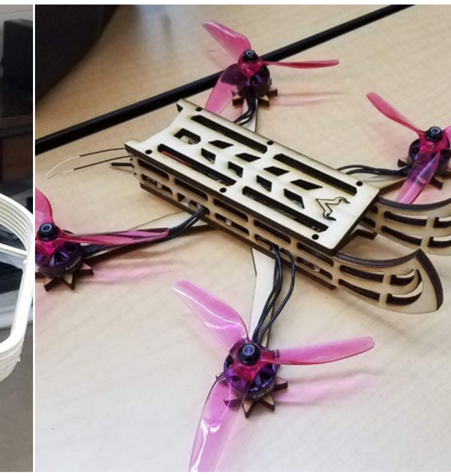
Lemorange takes flight! It was clunky, unstable, and slow due to the early hobby flight controllers and lack of electronics designed specifially for quadcoptors.

The "Vespula" was a major leap forward in both technology and design. Drone hardware got smaller and so did this one moving to nimble 5 inch propellers. It was foldable too!

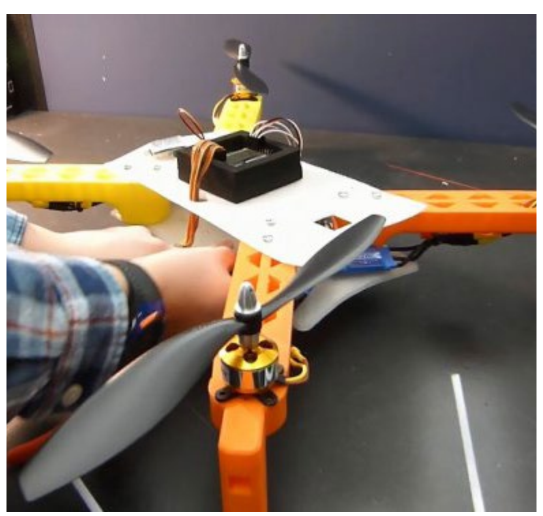
After stable test flights proving its durability, Vespula iterates into its final design, the "Yellow Jacket." Seen here flying through my middle school cafeteria.



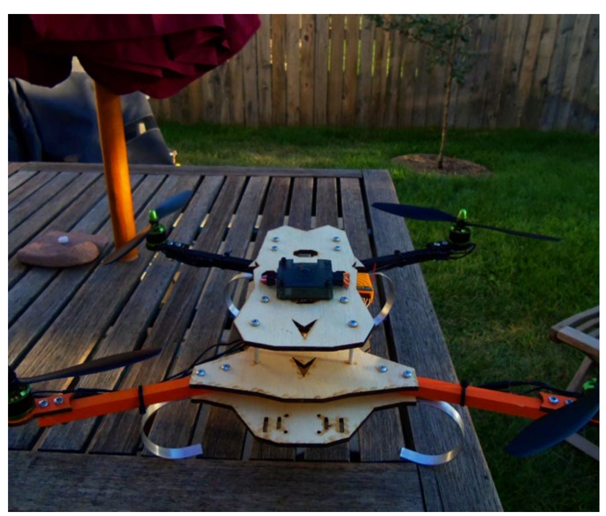
Bringing drones to my high school, I led a team to win a $5000 grant to design a search and rescue drone system. These were the first prototypes. On the left is an idea for a drone with detachable motor pods. The right features wooden struts to protect a thermal camera.



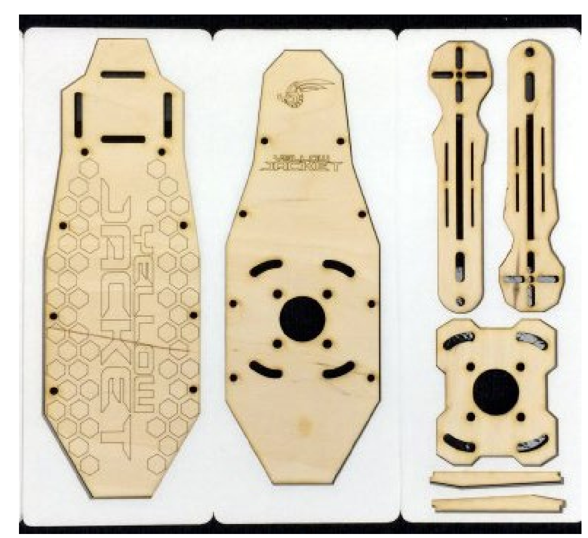
2014 — 2015 — 2018 — 2019



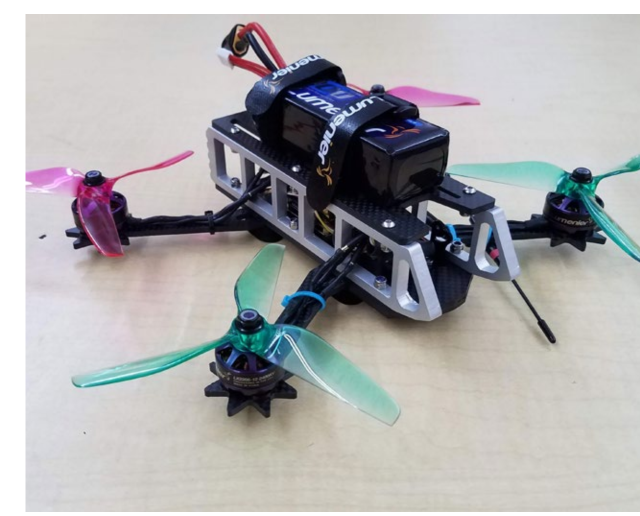
My first design in a middle school club, the "Lemorange" for its yellow and orange 3D-printed arms, had massive 10 inch props spinning on model airplane motors to lift this heavy goliath.



Exploring different materials, this copter was designed in 2D CAD and lasercut out of plywood. It suffered many of the same problems as Lemorange and was almost uncontrollable in flight.



With the easy manufacturing of laser cut wood, the Yellow Jacket is turned into a kit and sold to hobbyists around the world via the club's website.



My final prototype for the search and rescue project was machined out of carbon fiber and aerospace aluminum for a rugged, crash-proof drone that had a range of 10 miles.

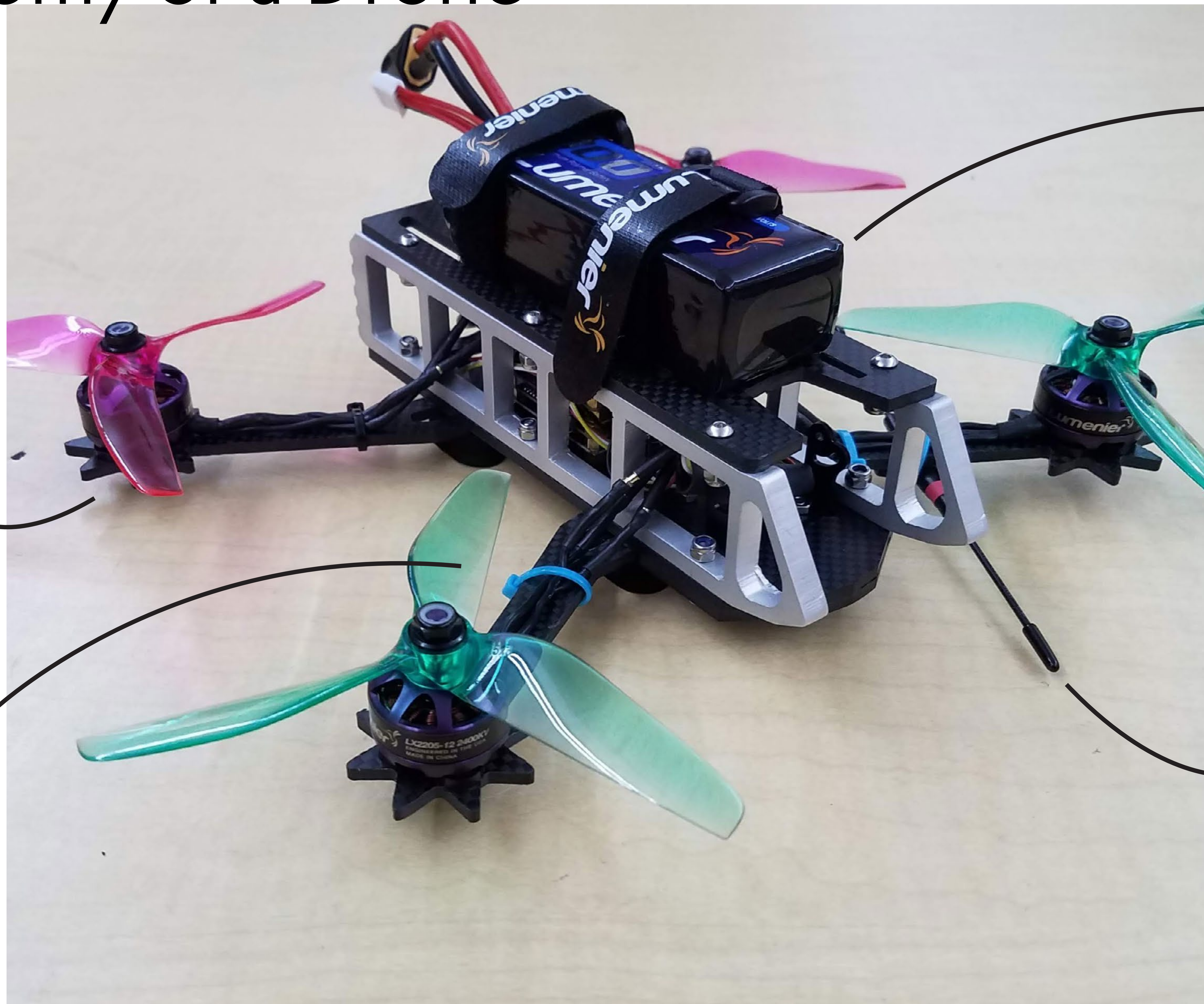
Evolution of Drone Design

Anatomy of a Drone

Racing drones are built on carbon fiber frames that are usually a handfull of flat, cutout pieces that screw together. Because the frames are cut and not machined at different depths, only simple 2-dimensional plans made in CAD are required to design them.

Motors attach to propellers to provide lift. Most drones have 4 props. The new one's I designed have 6, and while this is less common, many large photography drones feature 6 or even 8 for stable, heavy-lift operation. Drones designed to be electric air taxis have even more.

Arms extend from the main body to support the motors and keep the propellers clear of everything. Modern drone motors are brushless which are known for their rapid acceleration and high accuracy. They have three wires that connect to a speed controller in the central body.

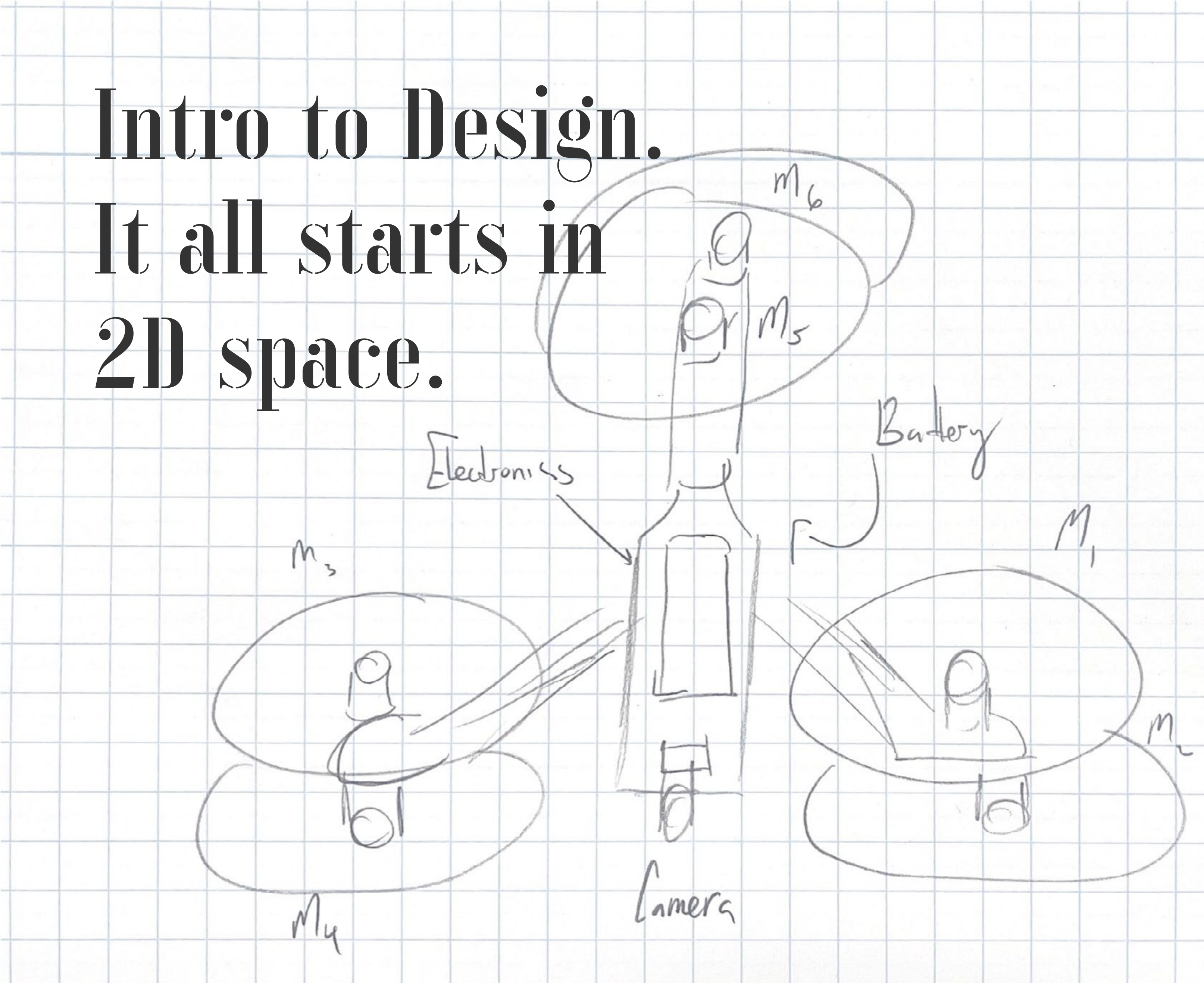


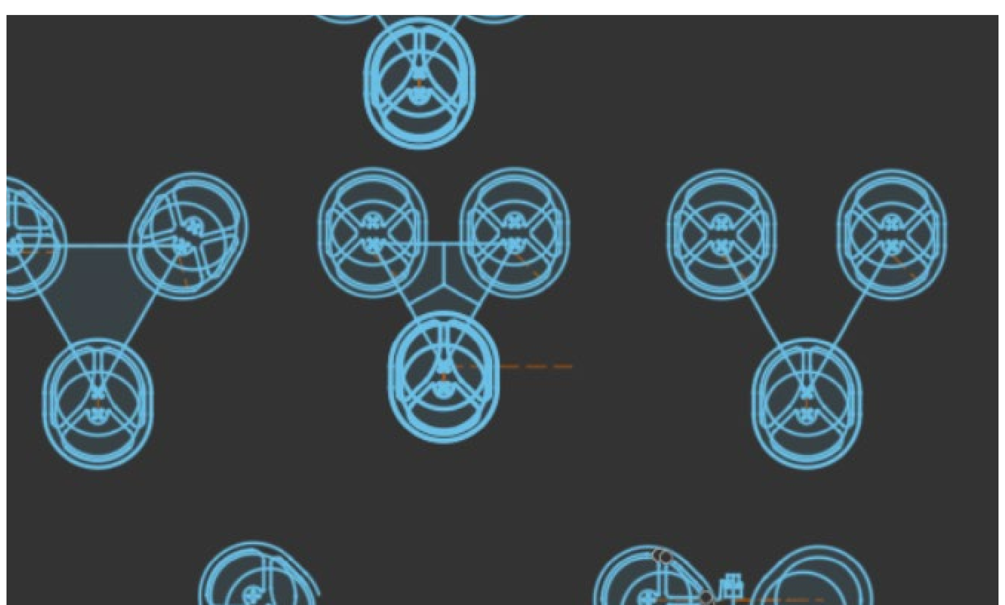
Batteries are either top mounted or bottom-mounted depending on the design of the frame. They are the heaviest component and have a large part in determining how fast a drone flies as well as the duration and flight characteristics due to the tradeoffs between weight, voltage, and discharge rate.

The center of the drone contains the brains of the operation, a flight controller. This is a circuit board with accelerometers, gyroscopes, compasses, and other chips to handle the incoming controls from the pilot and outputing appropriate signals to each motor's throttle. This output is handled by speed controllers, in this case a 4-in-one board for each of the 4 motors. It distributes power from the battery to all electrical components and handles each motor's controls.

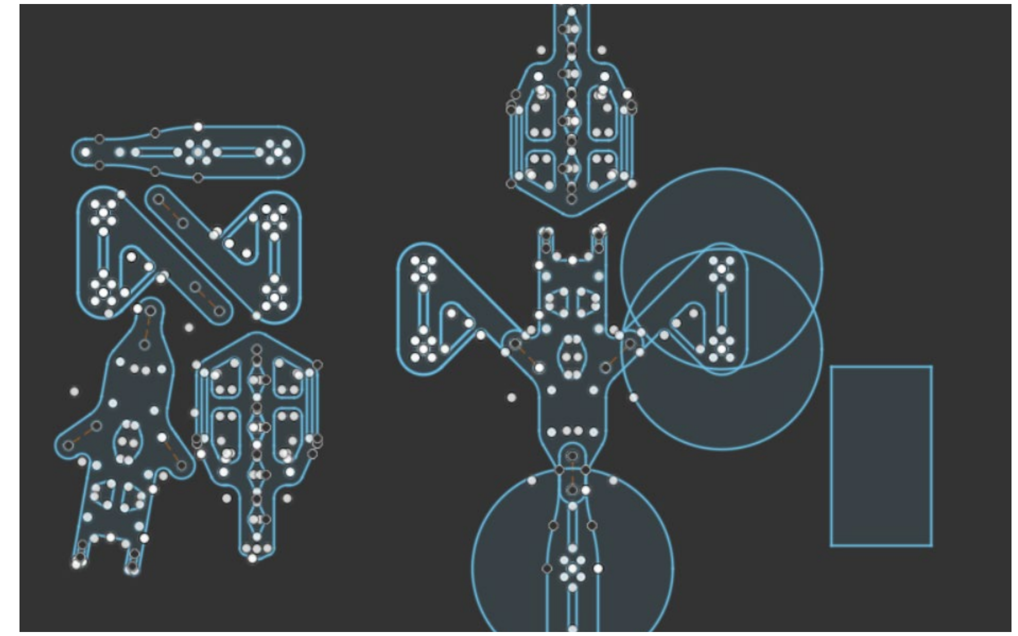
All racing drones need to communicate with a pilot since they aren't autonomous. This antenna is attached to a 2.4 GHz reciever, which recieves all commands from a remote control that serves as the transmitter.

Intro to Design. It all starts in 2D space.

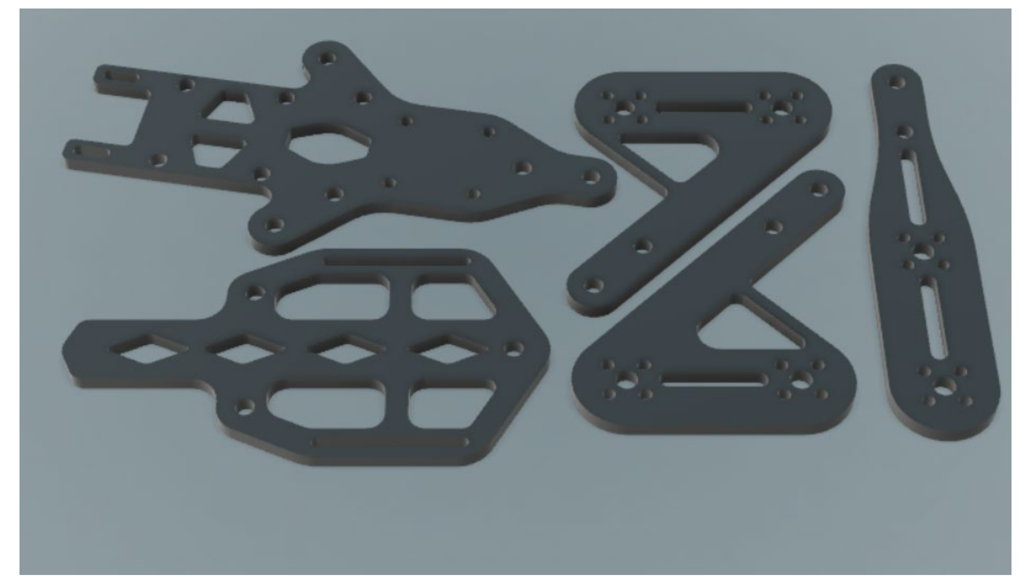




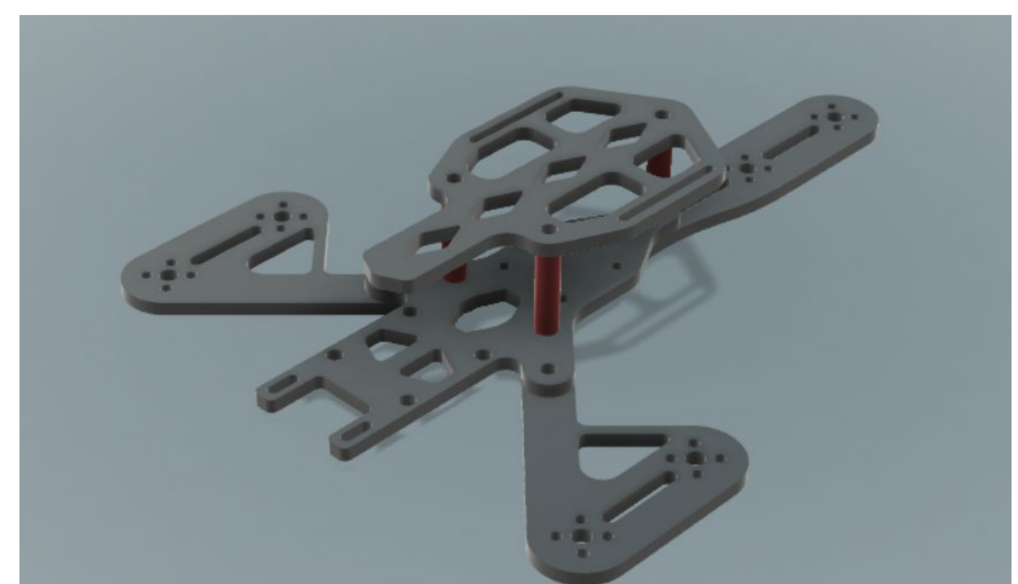
Designing these 2D drone frames is easier than it seems. Fusion 360 is my go to CAD program because it has everything I need and is easy to get a student license for. Follow a few basic tutorials, or just hit "Create Sketch" and start playing. Draw a simple sketch. Lay out the motor mounting points, the size of their propellers, and all of the mounting points of any electronics. Make dozens of iterations until you find something that you like.



Design a couple of layers to your frames where spacers can later create stacks that protect your frame and give your drone more real estate to mount electronics.
To make sure all the holes line up, move the parts around. On the left of this image, I have all my individual plates. On the right, they're layed out to how the frame will look when assembled. You can do this later in 3D, but checking now saves some time later.

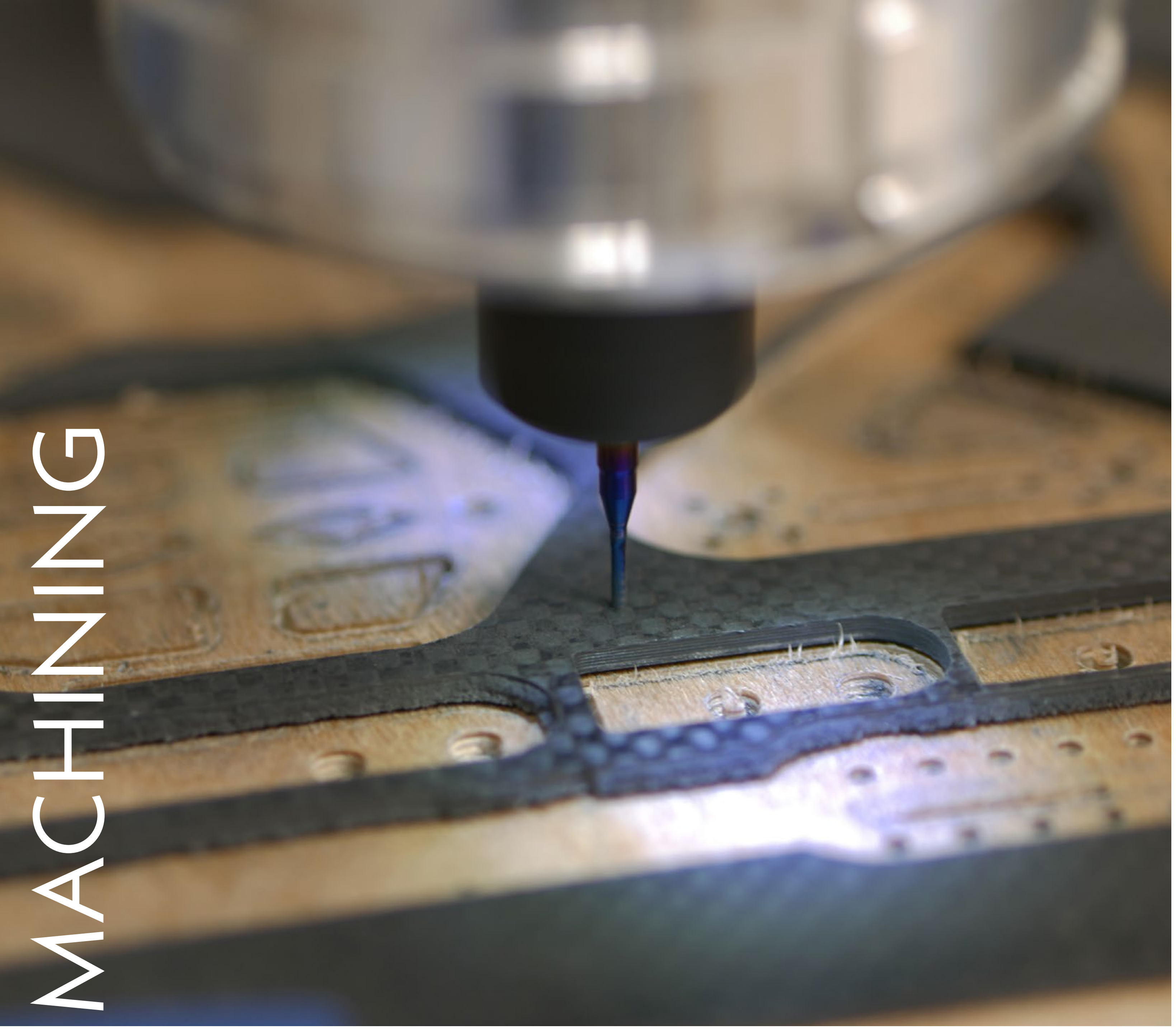


Expand into 3D! Once you like your design, hit "Finish Sketch" and extrude the shapes up to the width of your material. In my case, I'm using 2 mm thick carbon fiber plates so this is the width I'm setting. This is how my finished parts will look after they are cut out on the CNC mill. If you want to laser cut instead (suitable for wood or plastic), only 2D sketches will be needed.



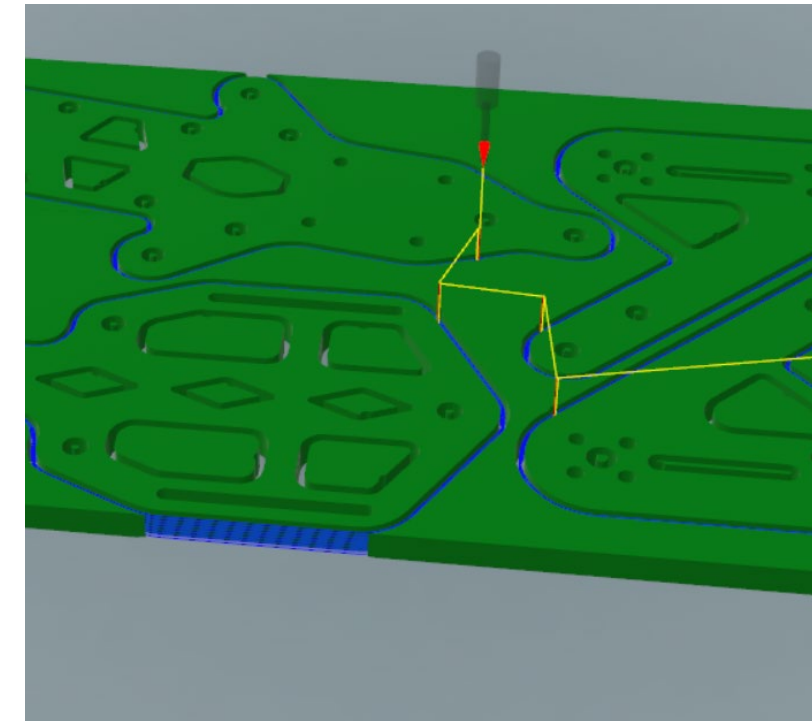
Now I can move all the parts around and put them into place. I also added the spacers by creating new sketches on top of one of the plates, drawing a circle, and extruding the column upwards.

CNC MACHINING

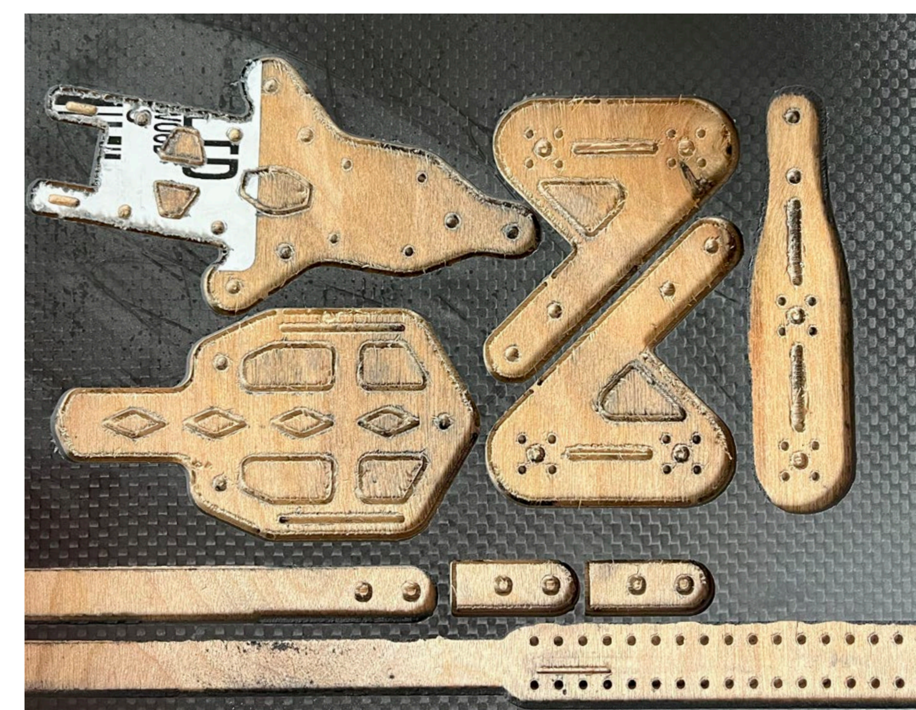


Carbon fiber. High strength, low weight. Its a standard in the aerospace industry and the go-to for racing drones. To make a frame out of it, you're going to need a CNC machine. Its a drill that moves in three directions and even carbon fiber can't stand up to the ceramic-coated carbide drill bit spinning at 10,000 RPM. You can find these machines in many makerspaces, universities, and shops, but you might need to supply the specialized bit designed for carbon.

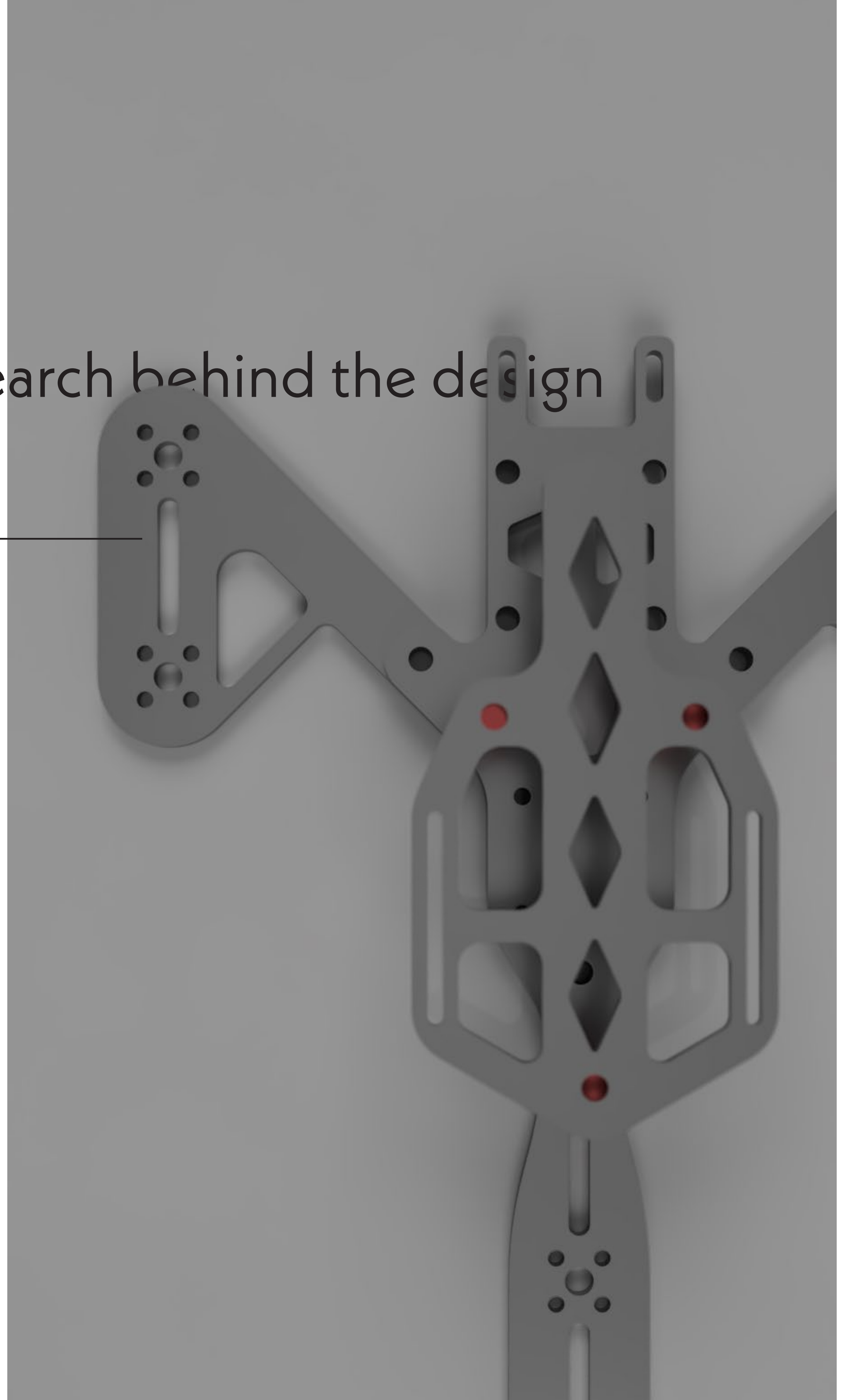
After you design your model, you need to create G-code that tells the CNC machine how to cut it. In Fusion 360, this can by done by going to the "Manufacturing" tab, inputing the specifications of your machine and material, and then generating different tool paths for the drill bit to follow. Here I use a "Bore" to drill all the holes, a "2D contour" to cut the interior paths, and another to cut out the outside of the parts. Make sure to look at each setting and cut at multiple depths so the CNC cuts gradually downwards and not all at once. Also make sure your cutting bit is small enough to mill all the hole. I use a 1.2 mm bit for everything.



The pieces are cut from the carbon sheet to reveal a wooden spoilboard below (scrap wood to protect the CNC table). Here I set the depth of the material a bit too low shown by the deep cuts into the wood. Deeper is usually better than too shallow though because any warping in the carbon sheet can lead to pieces that aren't cut all the way through.



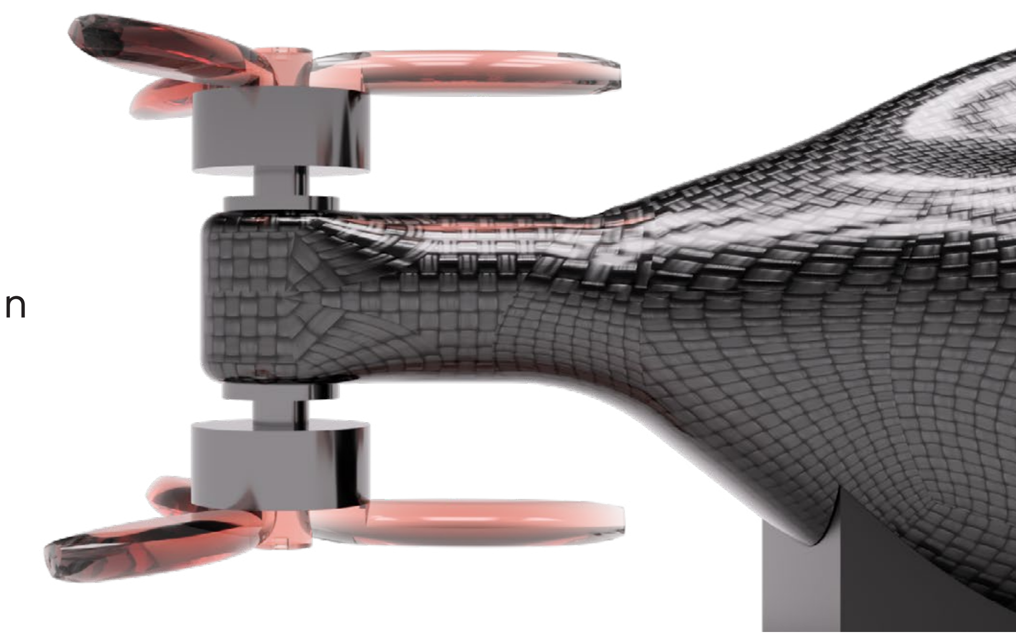
The research behind the design



What's with this separation between each pair of motors? The Ghost design had motor pairs on top of one another, this drone is to test something new.

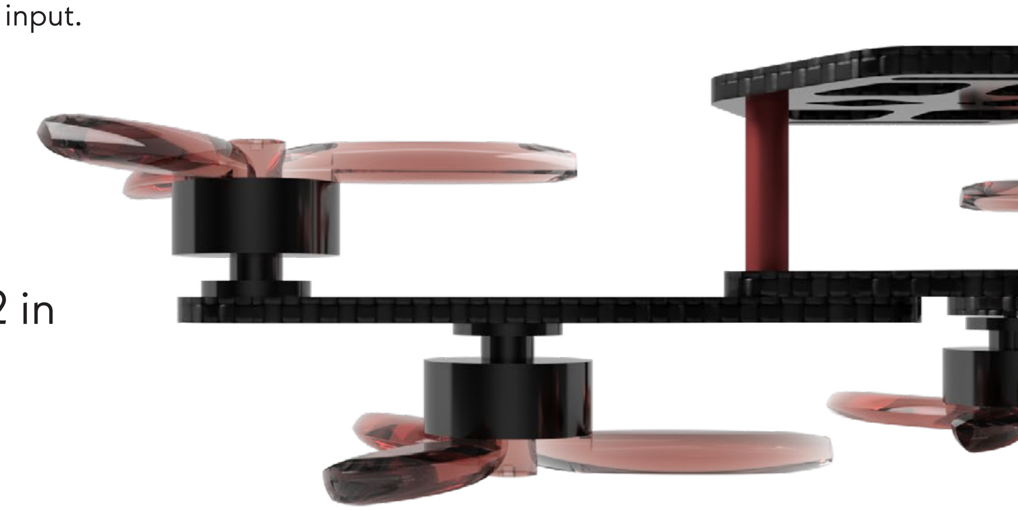
Coaxial motors, when two motors are in line with one another on the same axis, are more compact, allow for reduncany if one motor fails or loses a prop, and have a higher thrust in a 6-motor setup (hexacopter) when compared to the standard 4-motor (quadcopter) setup. But compared to a hexacopter that has evenly spread out motors, the coaxial is less efficient.

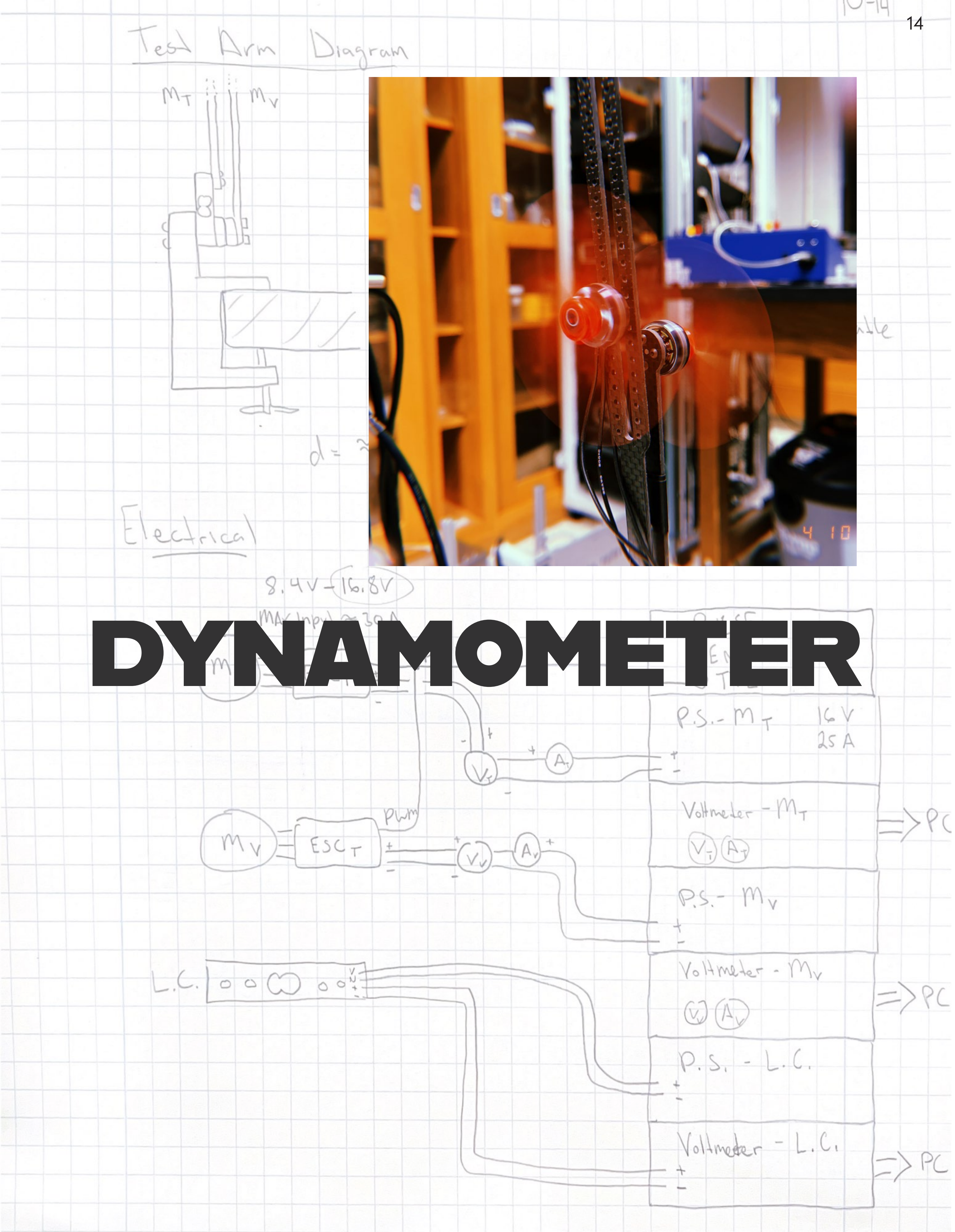
Offset = 0 in



Despite their advantages, coaxial motors generate a significant amount of drag due to the interaction between the two propeller streams, which can reduce the overall efficiency of the system. The goal of this research was to see if an offset in the pair of motors would increase the efficiency of the bottom motor, that is, the amount of thrust generated at a given power input.

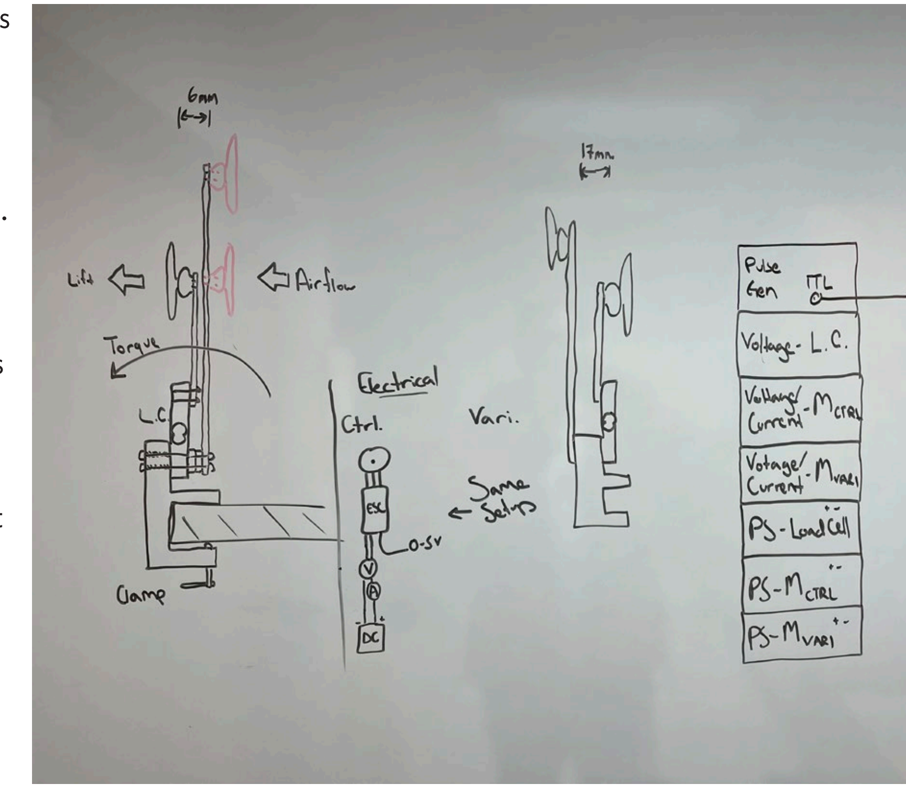
Offset = 1.2 in

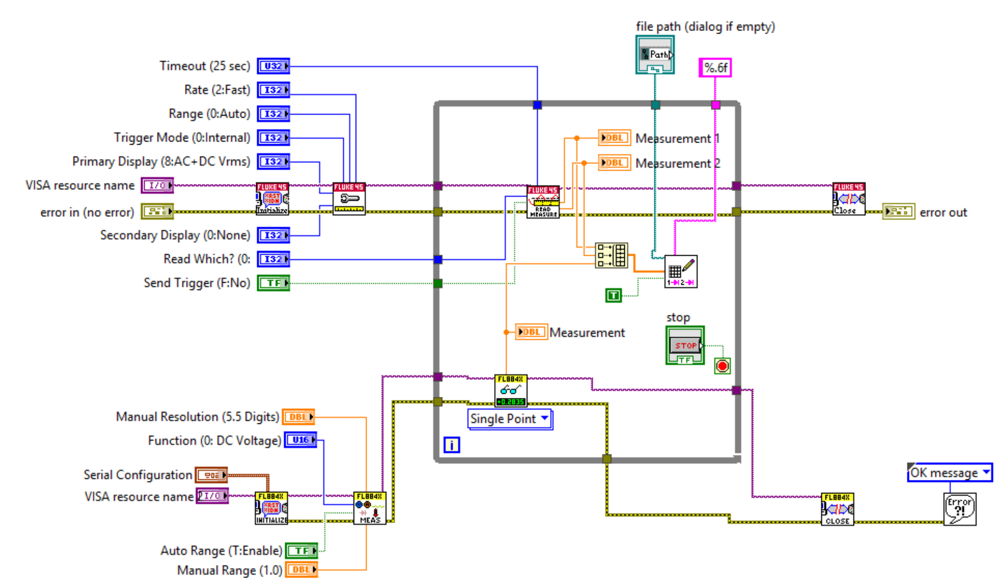




DYNAMOMETER

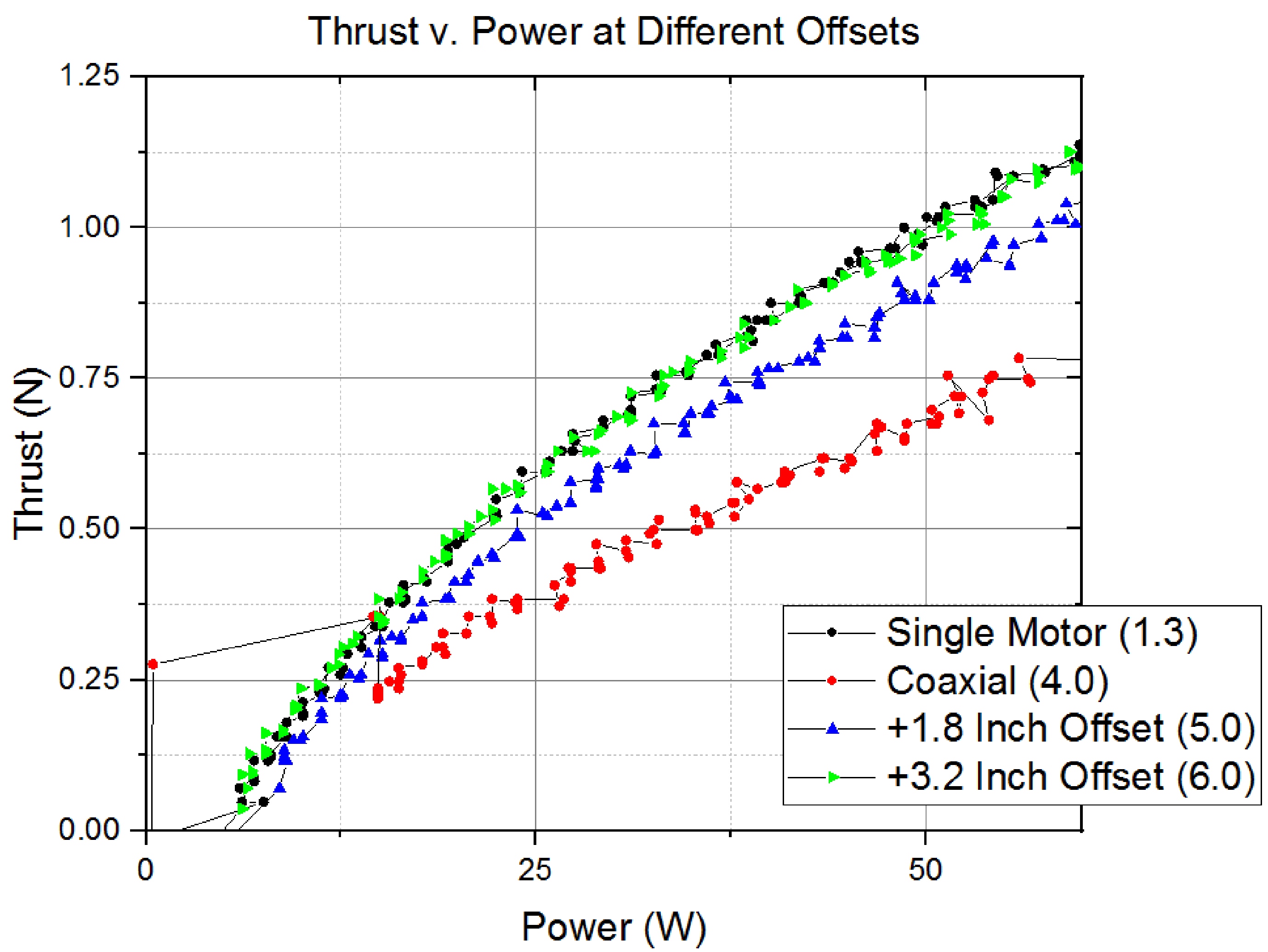
I designed this experimental appartatus called a dynamometer for testing the efficiency of one downwind motor in relation to the offset of the second up-wind motor. Both motors are set to the same voltage and the same throttle. The thrust of the fixed, down-wind motor is then measured using the load cell (L.C in the diagram on the right). Power being used by the fixed motor is also measured on a digital multimeter by simultaniously measuring voltage and current. If the offset is zero, the variable, up-wind motor is right in front of the fixed, and the thrust is lower. If the offset is 3+ inches, the diameter of the propellers, then the variable motor is 100% offset from the fixed and the thrust is higher. Left is a photo of the motors in opperation with an offset of 0.6 inches.





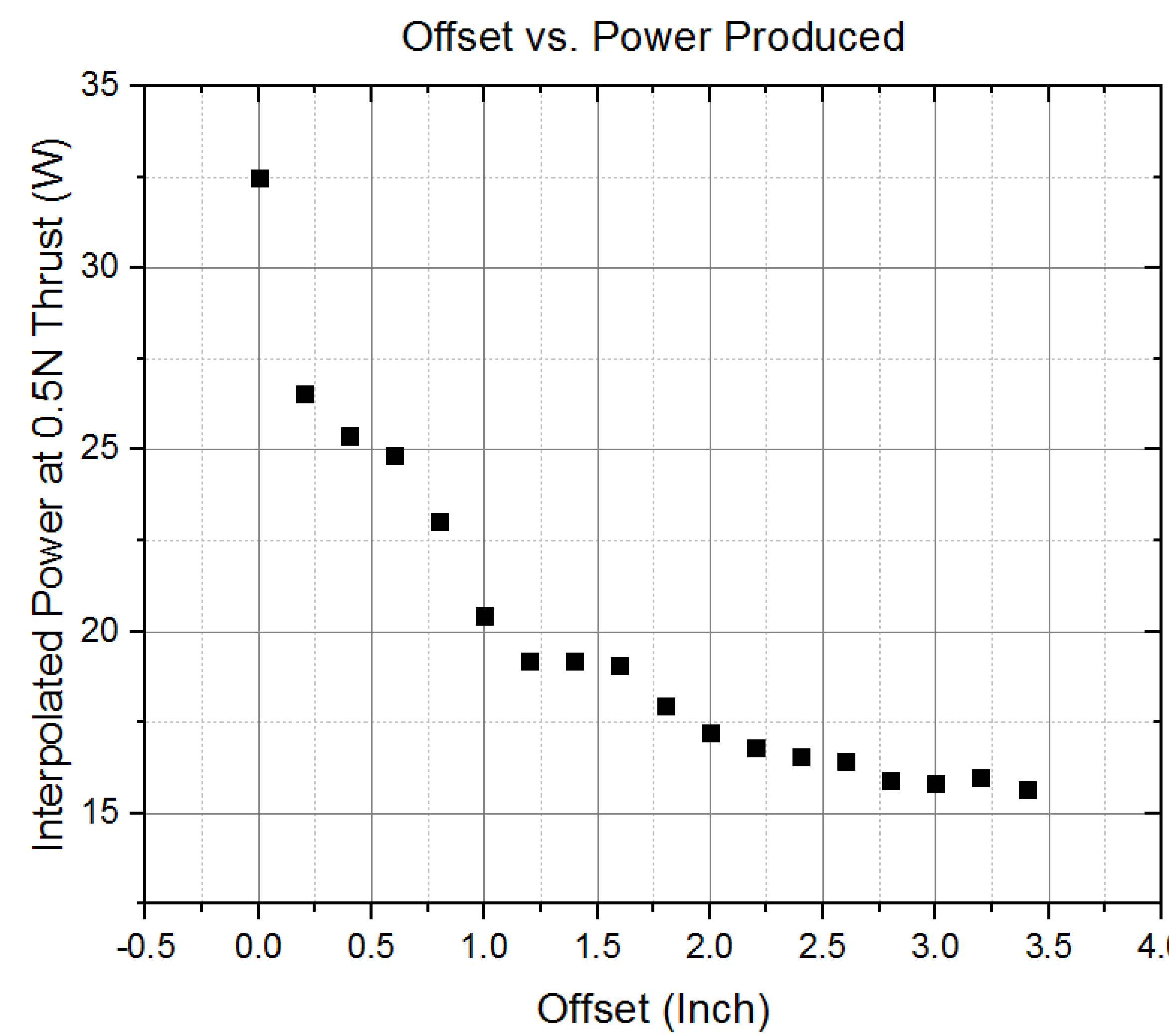
In order to get a curve relating power to thrust, both values would need to be measured simultaneously along a range of different throttle inputs. The only way to measure all values at the same time is to automate it. To read the values and record them into a spreadsheet, the LabView program on the right was written to continuously measure the thrust, voltage, and power of the fixed test motor. Now I could run the program, ramp up the throttle on the motors, stop the program, and analyze the data in excel for thrust vs power.

The Results



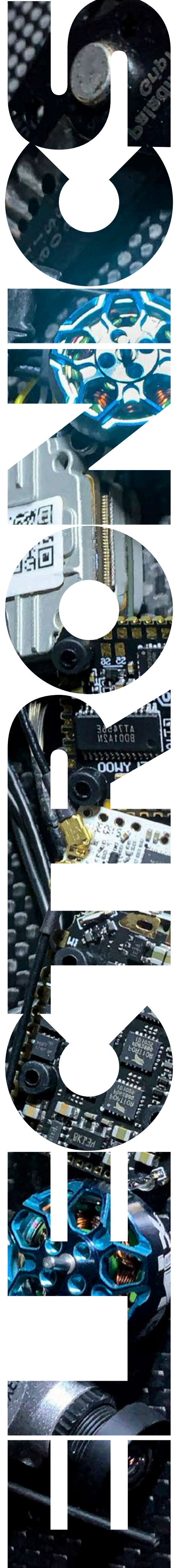
This graph compares the Power vs. Thrust with the two motors arranged in coaxial (0 inch offset), 1.8 inch offset, 3.2 inch offset, and with only the fixed single motor running. When the variable motor is offset by 3.2 inches, completely shifted off of the fixed propeller, it produces roughly the same thrust at any given power as a single motor operating with no interference.

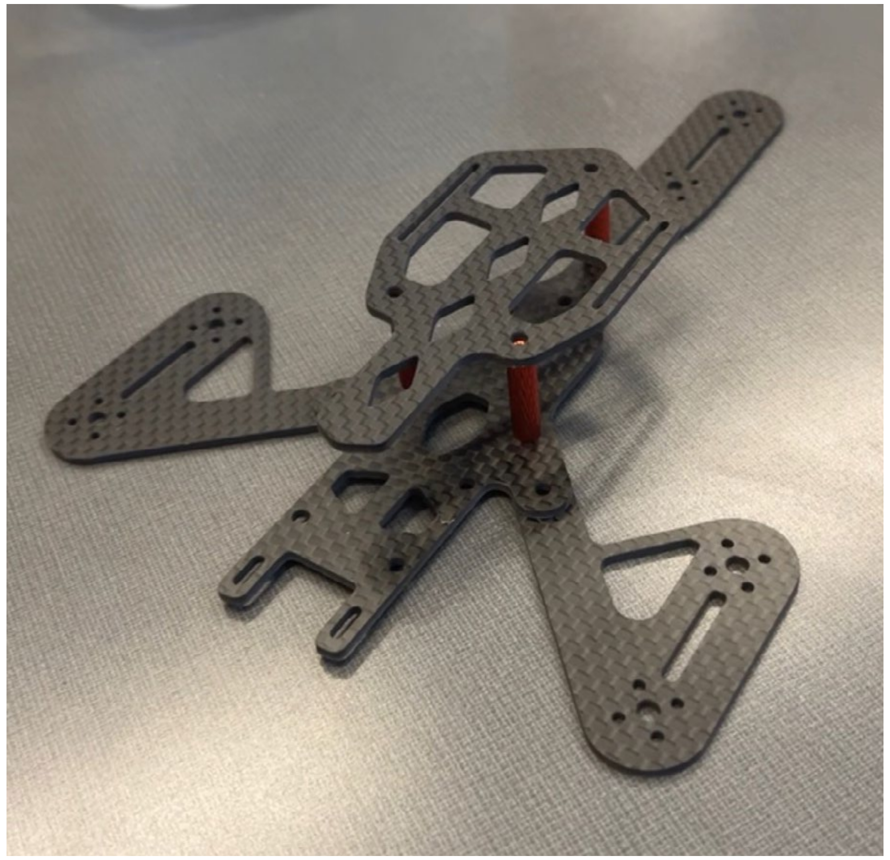
On the other hand, the coaxial setup shows a significant drop in efficiency where at any given power, the thrust is around 25% less than the fully offset 3.2 inch. At 1.8 inches, where a little over half of the propellers are overlapping, there is a slight drop in efficiency, but not nearly as much as coaxial. This indicates the potential of an offset.



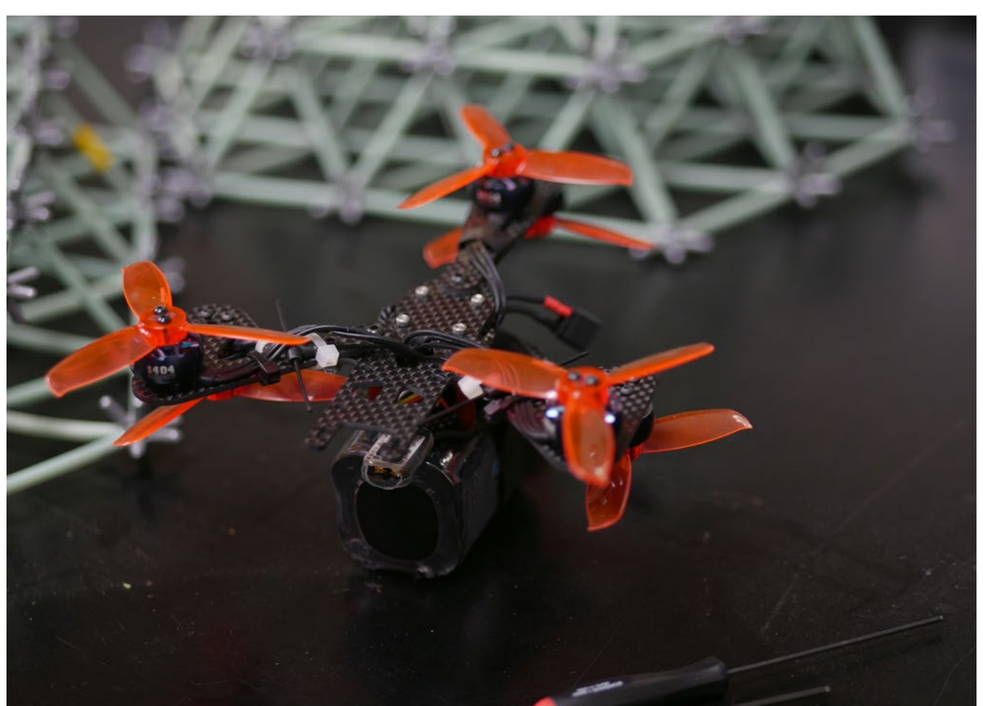
To compare each of the offset distances that the dynamometer is capable of measuring, power needed to be compared at some fixed thrust value. The approximate all up weight of the test drone was set at 250g, a standard target weight in the industry due to FAA registration. It was then divided by 6 to see what the load on each motor is during hovering (where the force of lift is equal to the force of gravity) and converted into N, newtons, rounded to 0.5 N. To get the power required for the motor to produce this thrust, each offset was interpolated at 0.5 N with multiple trials to create the graph above. This graph indicates that at low offsets, the increase in efficiency from each step is significant, but drops off at 1.2 - 1.6 inches over a plateau.

Because of this, a 1.2 inch offset between each motor pair was selected for the final design to maximize both efficiency and compactness.





Above is the CNC machined test drone all assembled. The offset was designed into this, but in order for it to be a successful proof of concept, it needed to be assembled with electronics and capable of stable flight since it is unclear how an offset will affect flight characteristics. Below is the fully assembled and soldered test drone.



Selecting the ideal components is its own research project, and it's important.

Picking motors is somewhat subjective. It depends on desired flight characteristics, battery voltage, and propeller size. Motors are measured in the size of the stator, the main cylindrical body that controls their power output, as well as KV, the number of revolutions per minute (rpm) a motor turns when 1V (one volt) is applied without any load (e.g., propeller) attached to the motor. With smaller propellers, larger KV's are usually used to make them spin faster. These large KV, small motors spin at high RPM but have low torque, so they can't effectively turn large propellers. The general rules of thumb are:

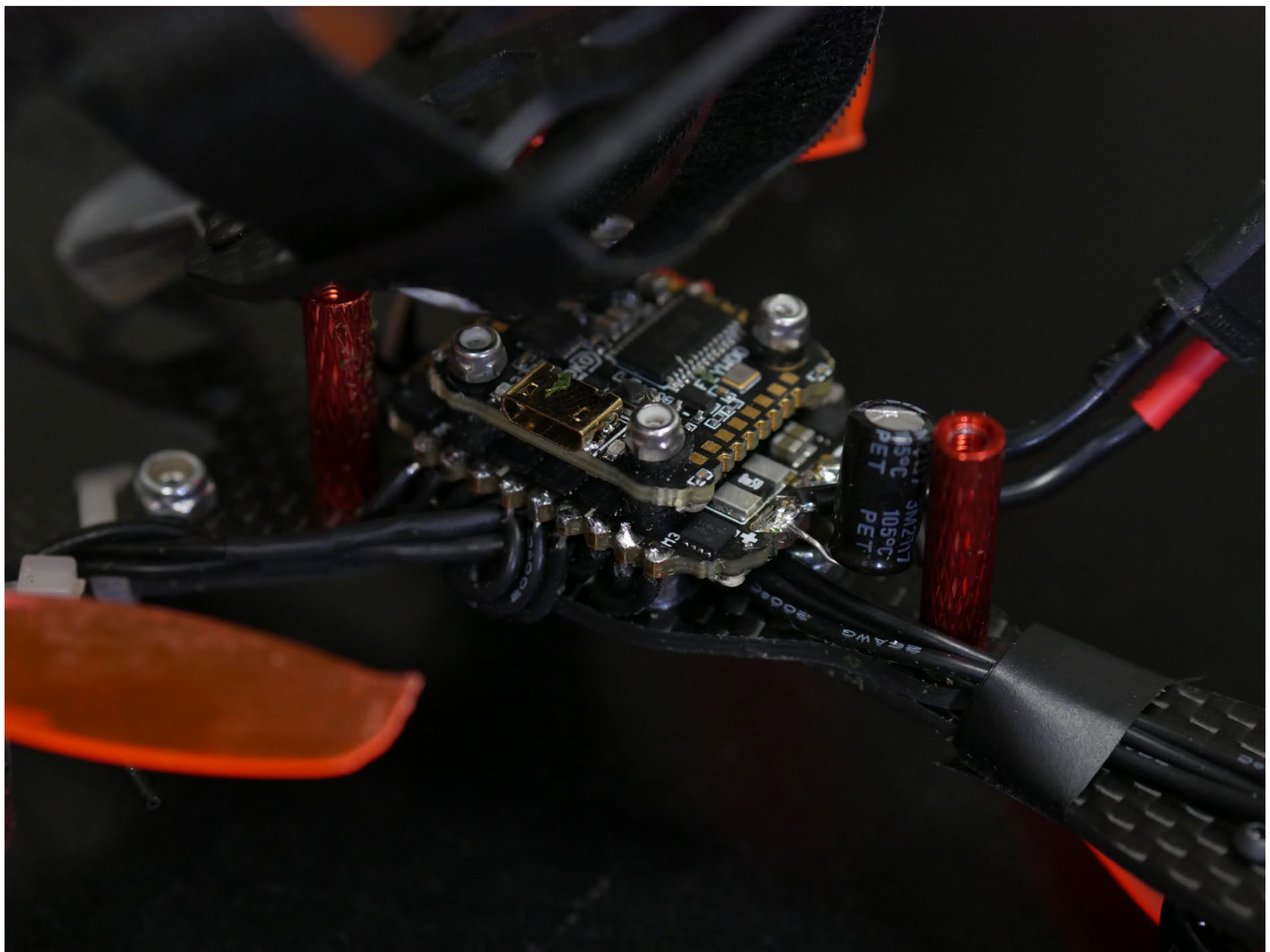
2-3 inch prop: 3200 KV and higher
4 inch: 2600 KV - 3000 KV
5 inch: 2300 KV - 2600 KV
6 inch: 2000 KV - 2300 KV
7 inch 1200 KV - 1600 KV

For reference, I chose the iFlight Xing2 1404 4600KV. 1404 here is the stator size. They might be a little too high KV, but these motors have titanium parts, smooth bearings, and great performance.

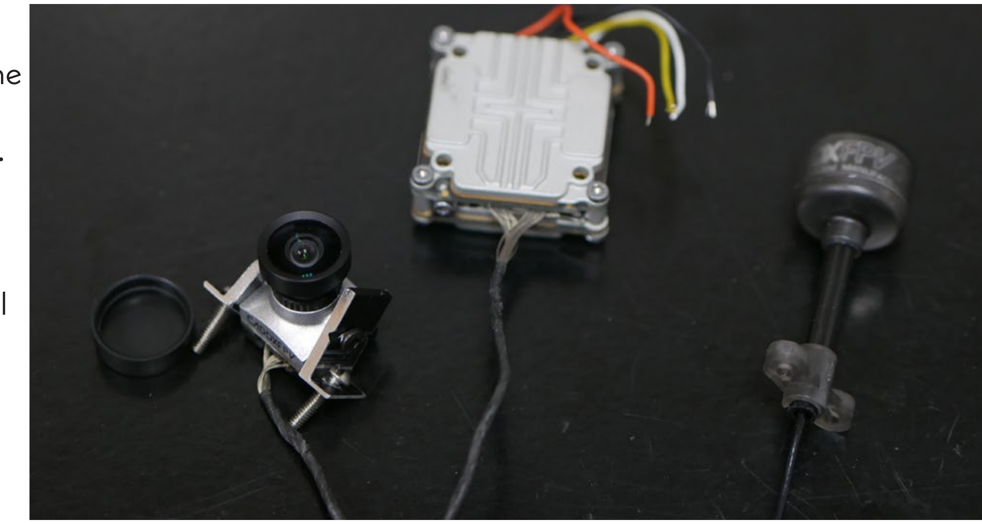
For the battery there are two ways to go, Lithium Polymer (Li-Po) for higher performance and racing, and Lithium Ion (Li-Ion) for slower speeds but longer flight times. Then there's the cell count, which determines voltage, and the capacity, measured in mAH. For most 3 inch drones, the batteries are 3 to 4 cells and 1000 to 1600 mAH depending on weight and flight time. Since I have 6 motors, I went for a 4 cell pack because of the voltage required by the speed controllers and Li-Ion for a long flight.

ELECTRONICS

Below is the flight controller (FC) and motor speed controller (ESC) stack. When selecting these components, I recommend buying the two as an integrated stack, rather than individual components. This simplifies the build process and reduces the chances of weird incompatability issues. The two main considerations are size of the boards to fit into your frame, voltage input (if you need higher cell support for racing), and current output of the speed controllers. I chose the only micro hexacoptor capable stack which made the process simple, but quadcoptors have hundreds of options. My speed controller takes up to a 4 cell and delivers up to 12 A to each motor which is plenty for a 3 inch build.



To fly from the perspective of the drone, you need a camera with a video transmitter and goggles. This allows for a VR-like experience that makes the hobby of drone racing so exciting. The only real option is the DJI digital cameras and goggles. They film and stream video from several miles away in HD. If you have a very small drone (sub 2 inch), you might consider an analog video setup.



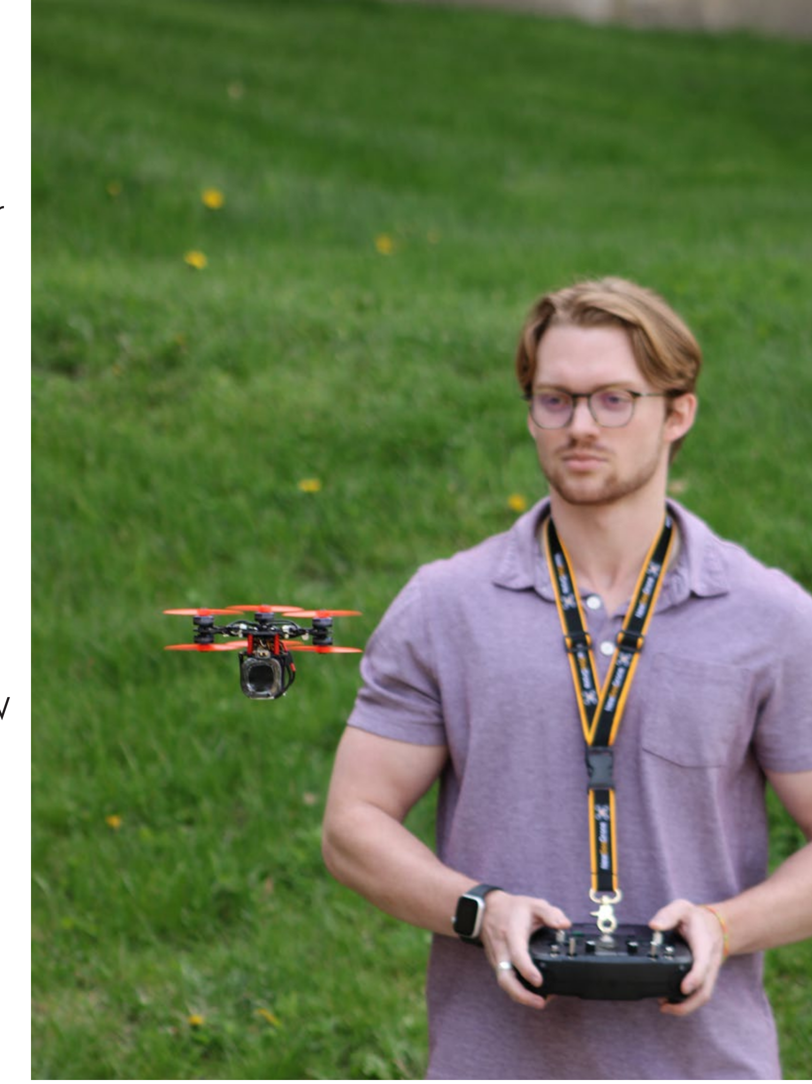
For the radio control, you need a transmitter, like the TBS Mambo seen below, and a small reciever that goes on the drone and recieves all the controls you're sending it. There are a lot of options here but the main ones are TBS, FrSky, RadioMaster, and DJI radios that work with the DJI video systems (this would be the simplest option). I chose TBS (Team Black Sheep) because I've used their radio equipment before and they deliver exceptional range and quality. Get the same brand for radio and reciever to ensure that they communicate on the same protocol.

LIFT OFF!

With all the electronics assembled, the only next step is to send the drone on its maiden flight. Despite an unconventional layout, the test drone flew great. Lots of power, long flight times, and high level's of responsiveness. Best of all, I didn't crash it and nothing broke!

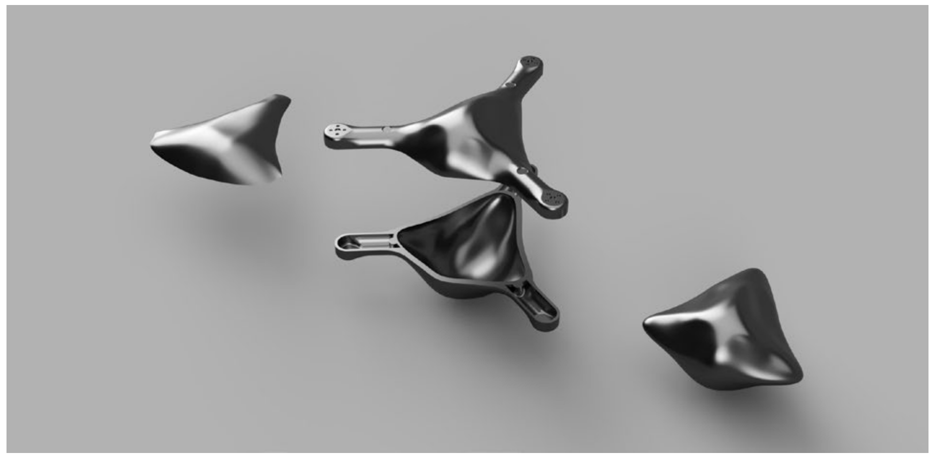
Before the first flight, a couple of things need to be checked:

1. Enter the Betaflight configurator (software that runs on flight controllers) to ensure that everything is showing up correctly. See a Betaflight tutorial online.
2. Power up the drone without props attached. Make sure the transmitter connects and all the motors are spinning the right directions. See online for motor directions for your setup.
3. Attach propellers correctly. Double check the CW and CCW directions each one.
4. Secure all bolts such that no components come lose.
5. Check that the failsafe feature works by turning off the transmitter when connected to the drone, it should disarm.
6. Arm the drone and without the throttle up, slightly push the pitch and roll controls to make sure the drone responds correctly.
7. Take off!



It may be worth while investing in a FPV flight simulator when starting out. These racing drones have very little stabalization, are highly sensitive, and very unforgiving. The fly like missiles and when control is lost, it's hard to regain. I always start slow with a new build and slowly push open its flight envelope. If you're flying line of sight like I was, never lose track of the drone or its orientation. If flying with goggle (FPV), its good practice to always have a spotter oversee the drone. Be sure to follow all FAA and local regulations when flying.

Extrude. Revolve. Sweep. Loft.
3D DESIGN



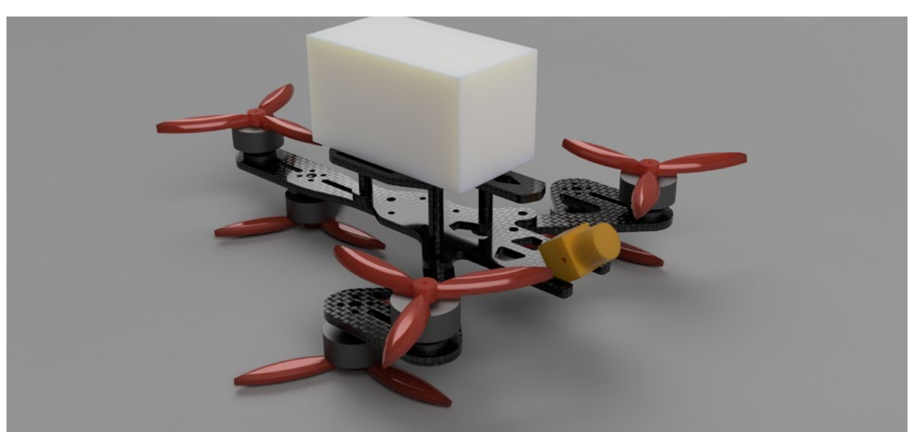
I wanted to learn about 3-dimensional CAD and design through the process of creating a forged carbon fiber drone (see page 30-31). I have had extensive experience with 2D CAD design since I first learned the DraftSight program back in middle school to make laser-cut wooden quadcopters. The goal for this project was to expand upon this by designing complex forms that could house delicate racing drone electronics.

In the drone indusry, almost all of the racing drones are built on plates of carbon fiber. Some commercial drones, like the popular DJI Mavic series, are injection molded plastic. The designs for these drones are far more complex, requiring large teams of engineers rather than a couple hobbyists. But besides their complexity, a 3D form also allows for more creative opportunity, expression, and new manufacturing techniques.

The best way to get better is to keep creating new sketches, hitting "save-as" to try something new, and exploring how each and every tool works.

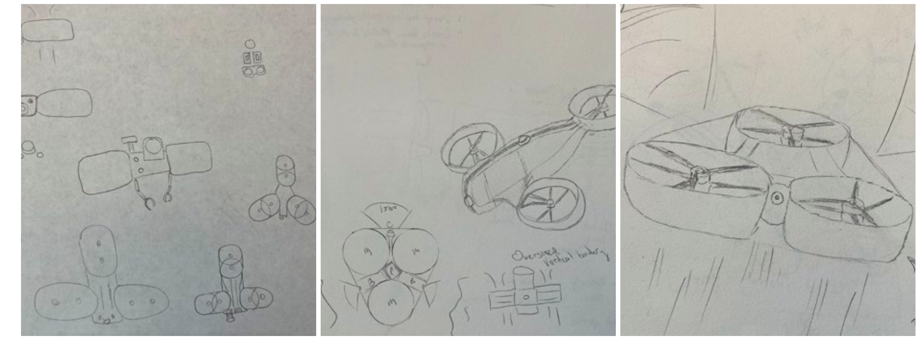
The most helpful thing is to model absolutely all of the components. Every motor, screw, propellor, speed controller, the camera, the battery, etc. Then lay it out in 3D space. Doing so allows for fewer prototypes and fewer errors. It's been the biggest lesson for me to learn when batteries become an after thought and are strapped to the bottom or when my flight controllers have almost no clearance space for the wiring.

3D is hard. In the image above, I was developing a new prototype for my design class. Because I wanted the body to be smooth and aerodynamic, there are no flat faces to create sketches on. When you need to cut holes or extrude new spaces, offset planes and complex construction geometry have to be implemented. CAD, like Blender or Photoshop often has a dozen ways to accomplish any task, so when things don't work, keep going and try something new.



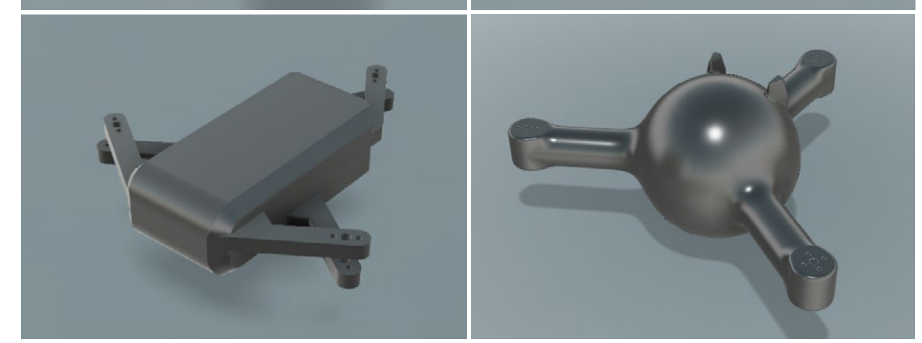
Above: a render of my final research test drone with the modeled motors, battery, and camera to make sure everything is clear of the 6 propellors.

The process starts the same as 2D...



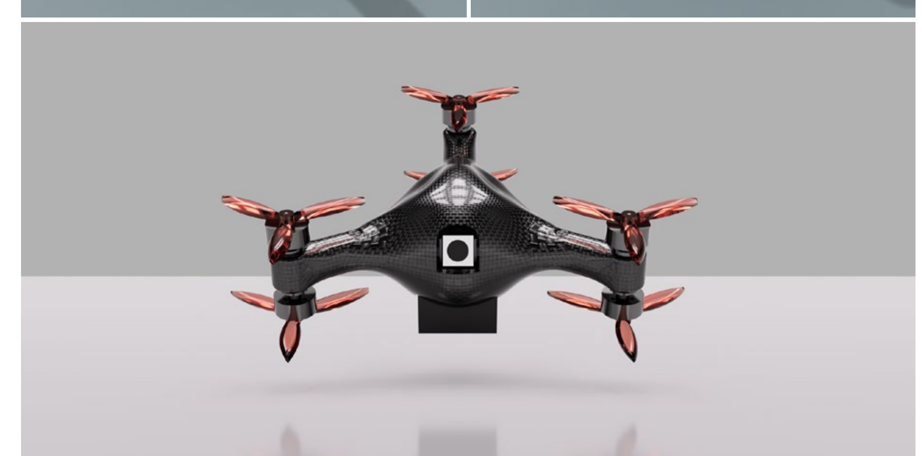
Sketches

3D Sketches

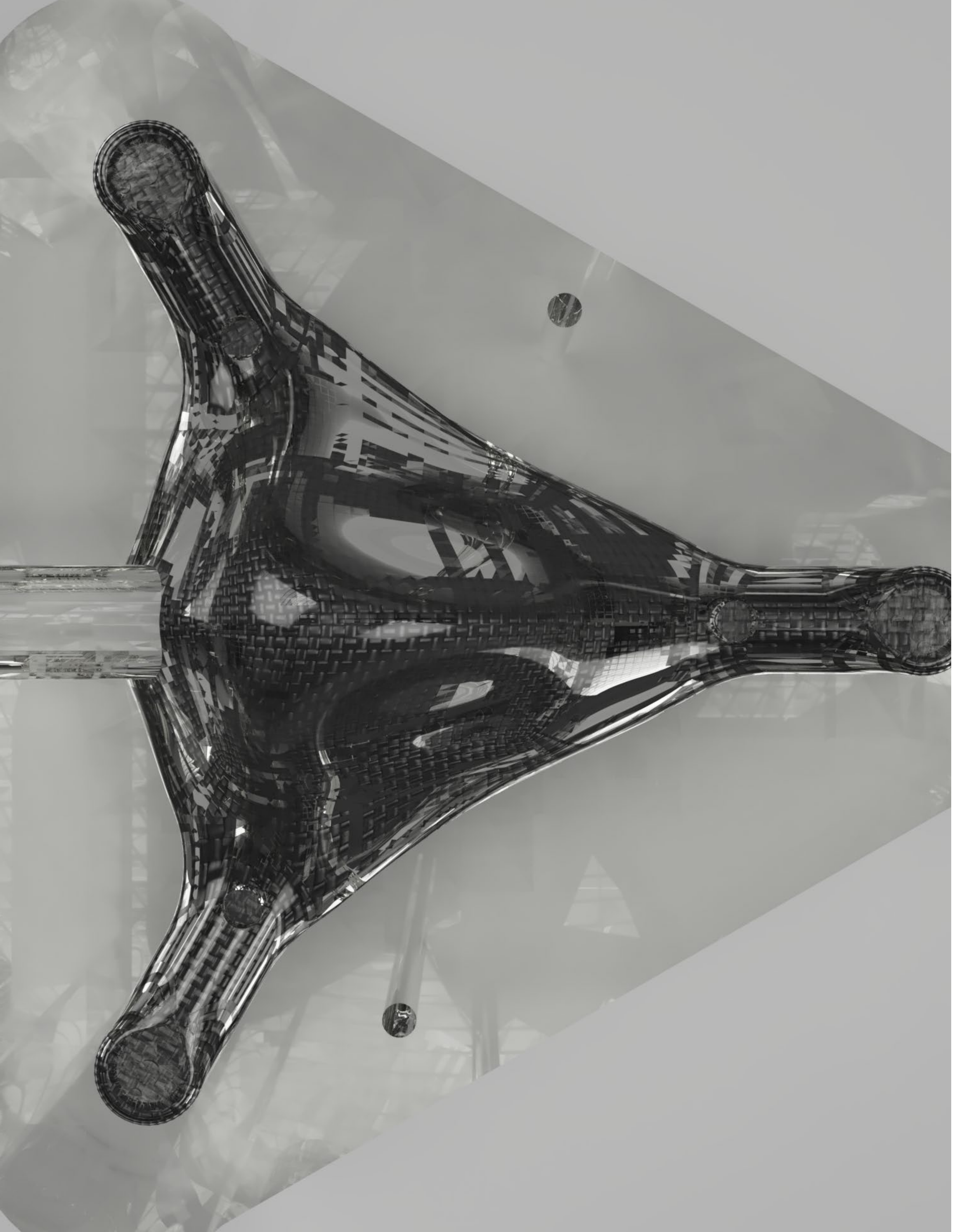


Prototypes

Refine

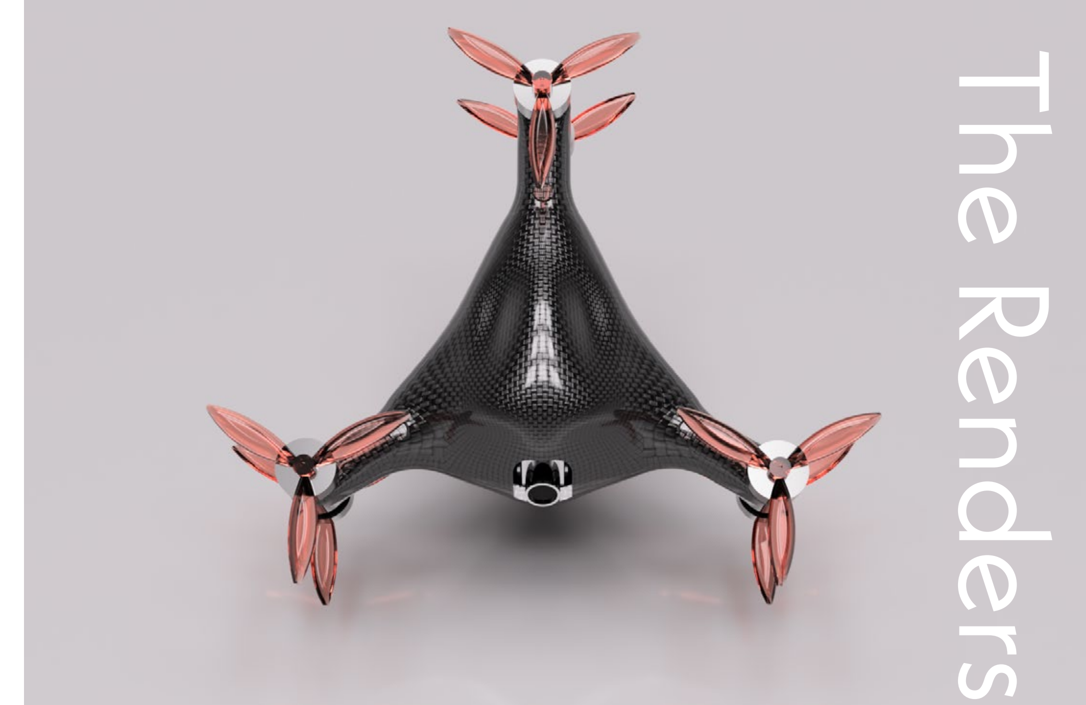


Final



The Renders

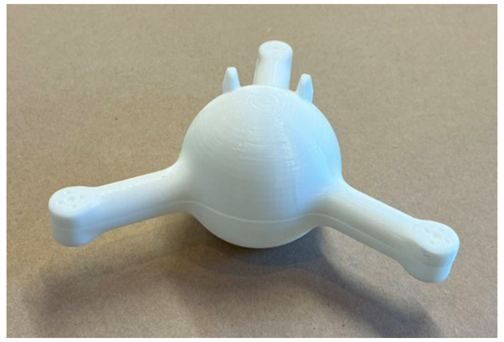
Renders are important in design. I'm able to get a clear idea of how the materials will look together and how light will interact with it, making it important for both aesthetics and a final check before prototyping. They're also useful to show potential investors and customers while the final product is finishing development. These were made in Fusion 360 using the "Render" tab.

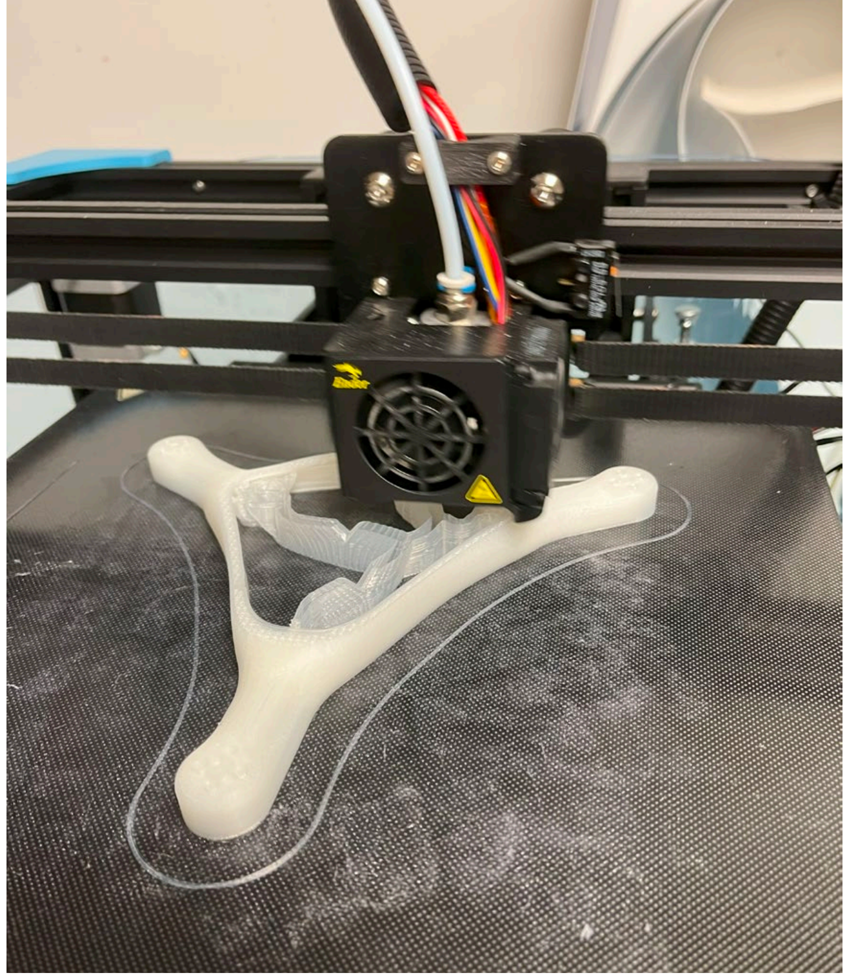


3D printing has revolutionized the way drone parts can be created, enabling designers to easily produce complex shapes and geometries that were previously impossible with traditional manufacturing methods. In a few hours, I could make a functional prototype out of strong PETG plastic. Fusion 360 makes it easy to export an STL (mesh) file that then goes into any 3D slicer. I used Ultimaker Cura to convert the STL model into a file that the 3D printer can use. Having everything modeled in CAD is great, but it doesn't compare to holding a full scale model in your hand.

Imaged on the left is the "Tree" support structure I generated in Cura to prevent the part from warping or collapsing during the print.

Below are two of my prototypes. "Sputnik" on the bottom lead to the more complex, strong, and aesthetic "Ghost" on top that was my final model.





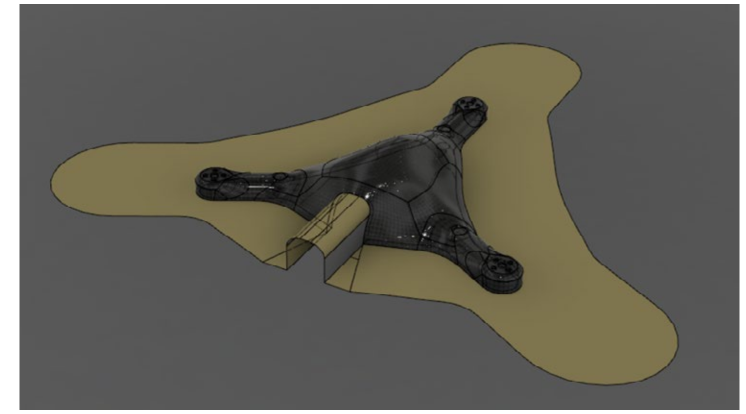
3D Printing.

What about 3D shapes made out of carbon fiber? Enter...

FORGED CARBON FIBER

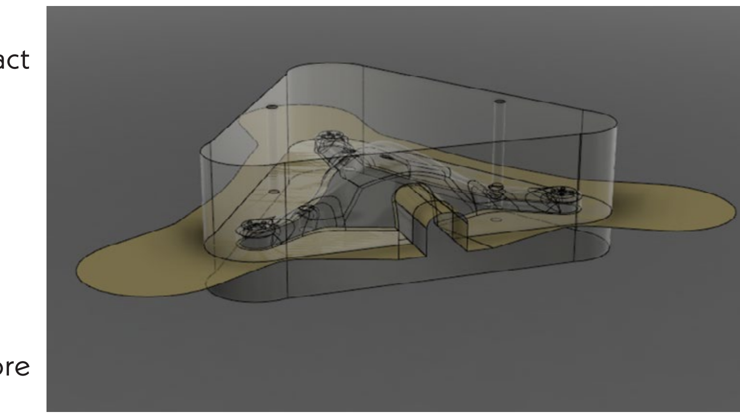
This is an amazing material created by compressing layers of chopped carbon fibers with epoxy resin. Because the fibers are sprinkled in randomly, the material is strong in all directions. I have always wanted to experiment with it, but been intimidated by the process, thinking it was reserved for professionals with high end equipment. On the contrary, it can be made with a 3D printed mold to make anything you desire incredibly strong, light, and beautiful. Pictured to the right is a closeup of the top half of the Ghost design forged in a 3D printed mold (you can even see the layers of the 3D print imprinted in the part). I added in copper leaf to give it the orange pops of color.

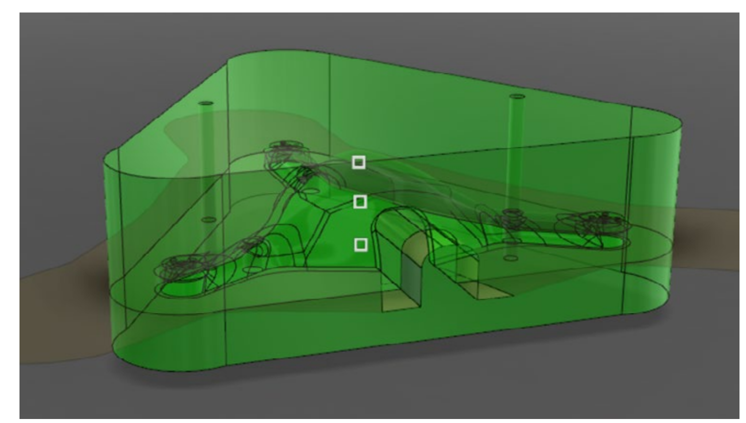
First, you need the mold.



Designing the mold to forge the carbon fiber parts is a challenge in itself. Shapes that are simple with symmetric geometry and convex parts are easy. This drone design has a concave shell, so the mold needs to have a core and a cavity that push the fibers from above and on the inside of the part. See the two halves of the mold (in red) in the images on the previous page.

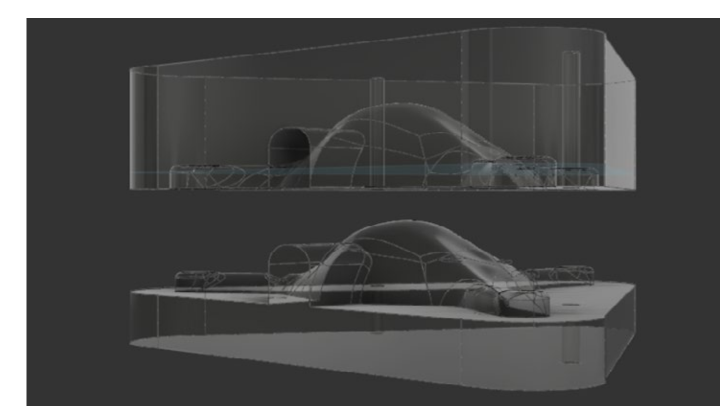
To start, I made a triangular prism for the mold body and used the "Combine"-subtract function with the drone part inside to create the cavity. The yellow-beige in the image above is a surface that extends from the part's splitting plane outwards. To the right, see how the the surface is designed to extend beyond the mold. The surface creates what is called a non-planar parting line because it parts the mold body in a more complex path than a simple plane can.





On the left, the non-planar parting line splits the mold (now in green) using the "Boundary-Fill" command. Getting the surfaces to meet the cavity bounds at all points took about 10 attempts, redrawing new surfaces with different techniques. I almost gave up on this because of how fickle it was. What I was left with is below. A split core and cavity compression mold.

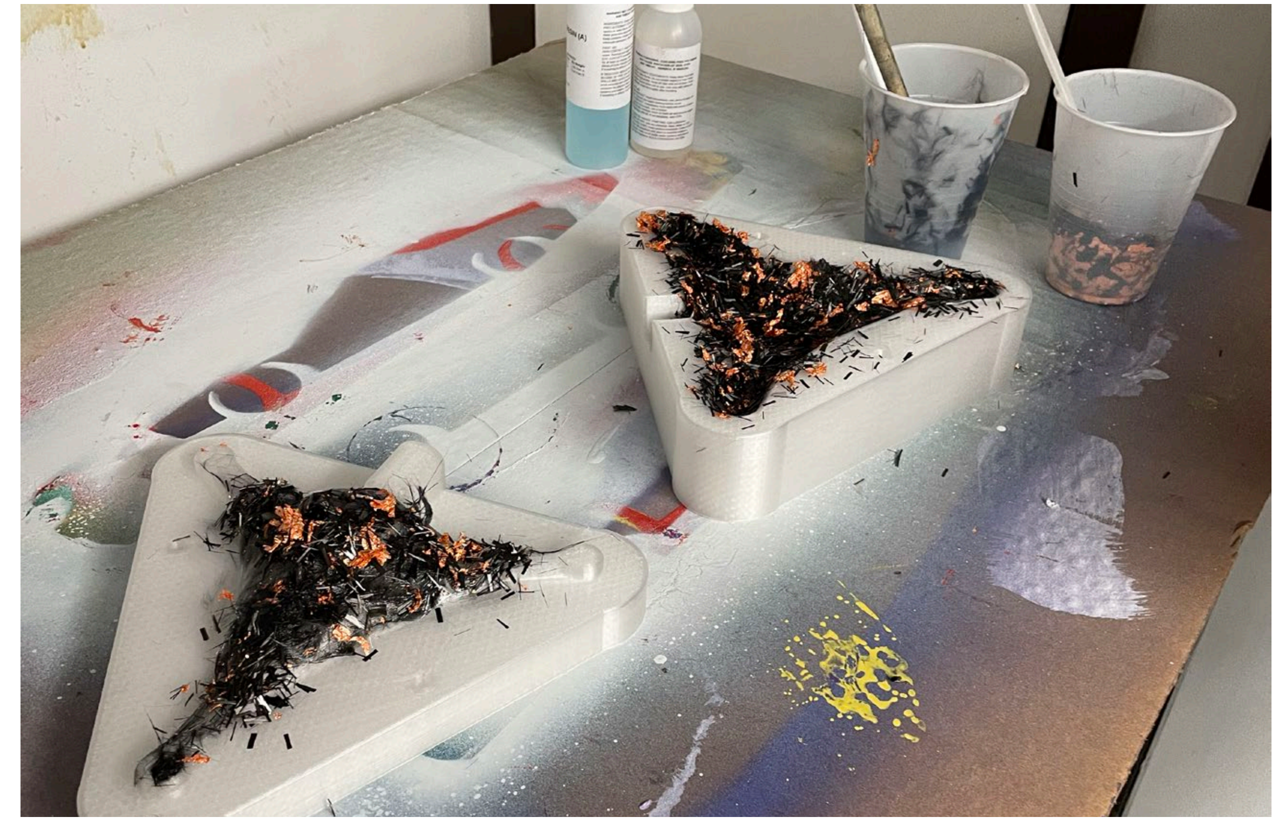
Some parts will be easier than others. I watched several tutorials on creating "Non-Planar Parting Lines" and "Core and Cavity Molds" in Fusion 360 to help me. When one technique didn't work, I made a new parting line with new surfaces, until it finally did. If you're successful, you'll be left with 2 pieces that come together with a cavity in the middle for the part.



Print.
Wax.
Layer.
Cast.
Wait.

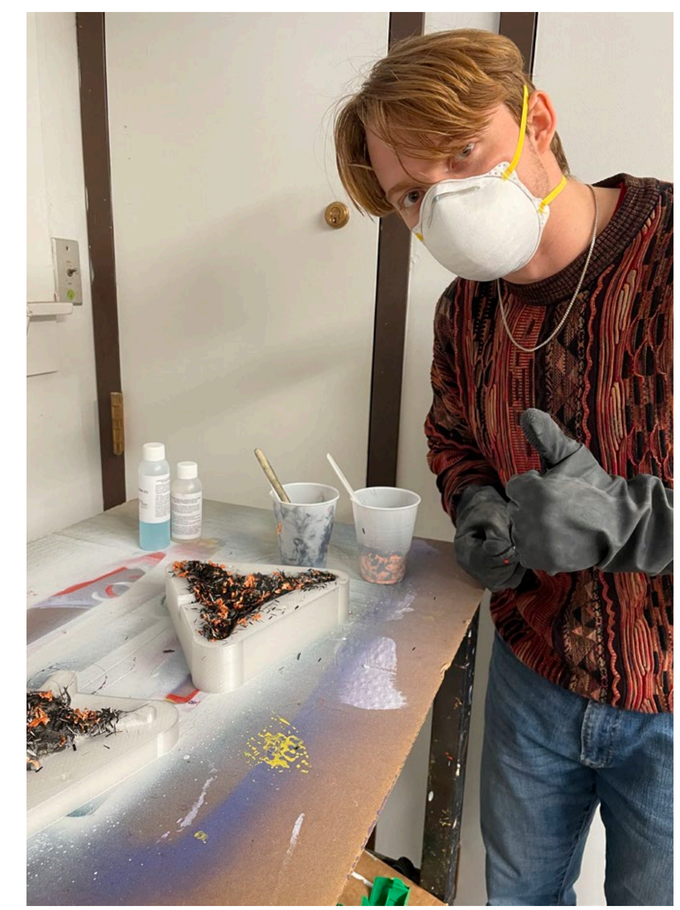
This is the final 3D printed mold using PETG plastic in a 40% infill. The article I followed, "How to Compression Mould Forged Carbon Fibre Components" by EasyCompostites, suggests using much higher infill, close to 75%, but that would have taken considerably longer and used more filament than I had. At 40% with a robust Gyroid infill setting, it's still very strong.

To prepare for casting, a mold release agent is required to separate the part from the mold after it's reopened. This is sprayed to coat every surface, waiting to dry, and reapplying a couple times before any epoxy or carbon is added. See page 36 for the importance of this coating.



The next step is adding the epoxy and carbon fiber. I bought a forged carbon fiber development kit from Amazon for this process. Optional for aesthetics, I began the preparation by pouring some of the loose carbon fibers into a cup and adding a generous amount of genuine copper leaf, stiring thouroghly. The leaf is so thin that this takes longer than I expected. Also, add way more copper than you think for it to be visible in the finished product. Since it's so thin and light, you can't really go wrong.

Next, mix the 2-part epoxy hardener and resin and keep in mind that once combined, you have about 30 minutes of working time because it starts to stiffen up. Brush a generous layer of epoxy to the mold, add some of the carbon mix, add more epoxy, and repeat. The article suggests weighing material to know exactly how much of each needs to be added into the cavity, but we didn't have a scale and went by eye. Since its going to be compressed, add way more than you think.



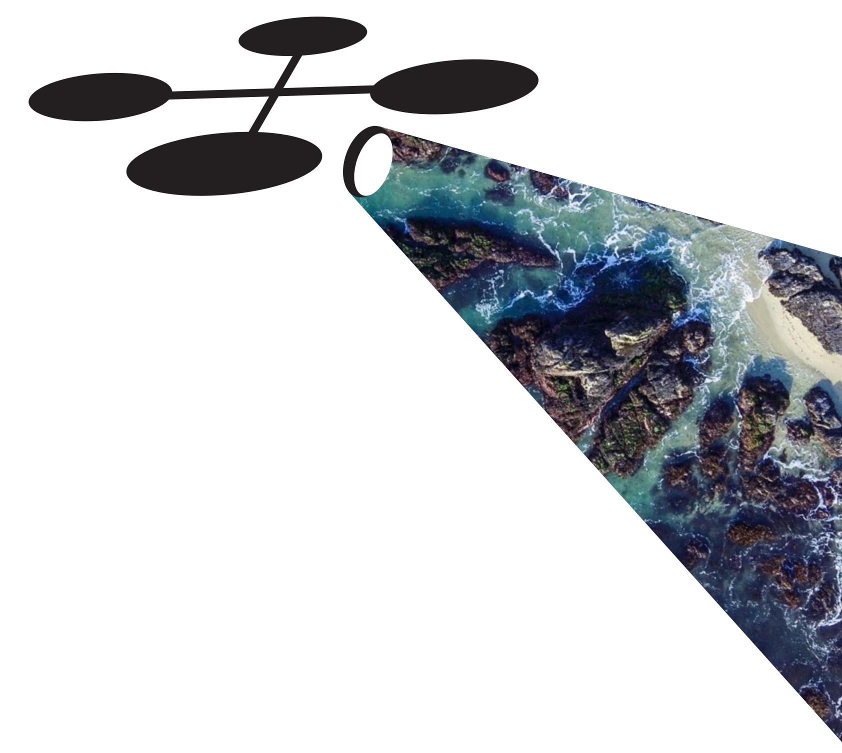
STUCK!

The result of the casting. The piece was unable to be removed from the cavity, and I tried all sorts of things. Aggressive hammering to the other side, pulling with plyers, even drilling from the other side to hammer a pin through to pop it out. It was stuck.

I thought of 3 likely reasons for this: using the wrong mold release agent (I couldn't find the exact one from the article in US stores), too much epoxy, and 3D print layers in the mold creating a strong binding to the part. Things to try next time: using proper mold release wax, weighing the epoxy and carbon for a proper ratio, and making a resin mold instead of a 3D printed one. The resin molds are more time consuming to make but last considerable longer. The best possible mold would be milled out of solid aluminum or steel but this is obviously more expensive. Not great for prototyping, necessary for manufacturing.

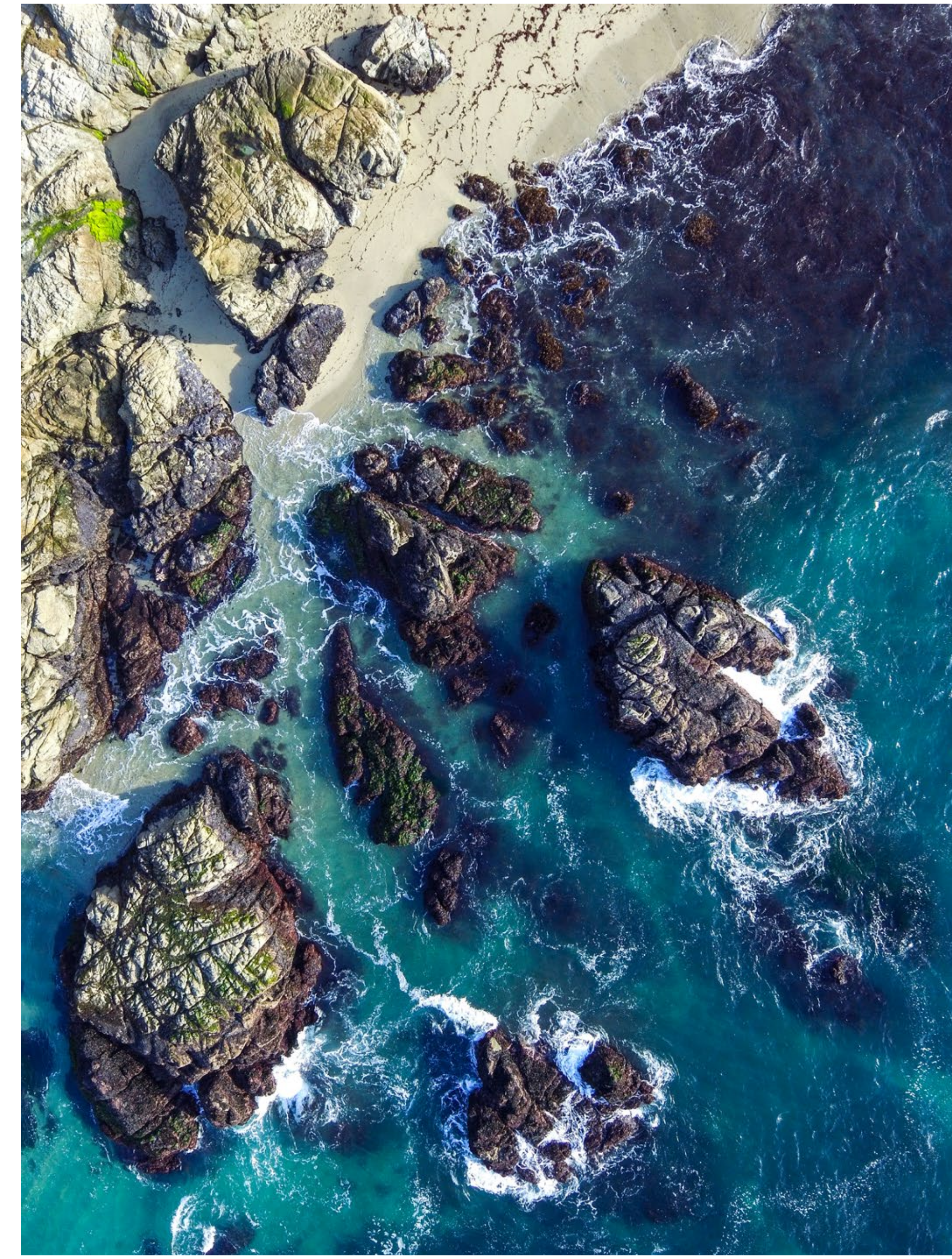
Through the Lens →

Photography from the skies is one of the reasons drones hold such fascination.

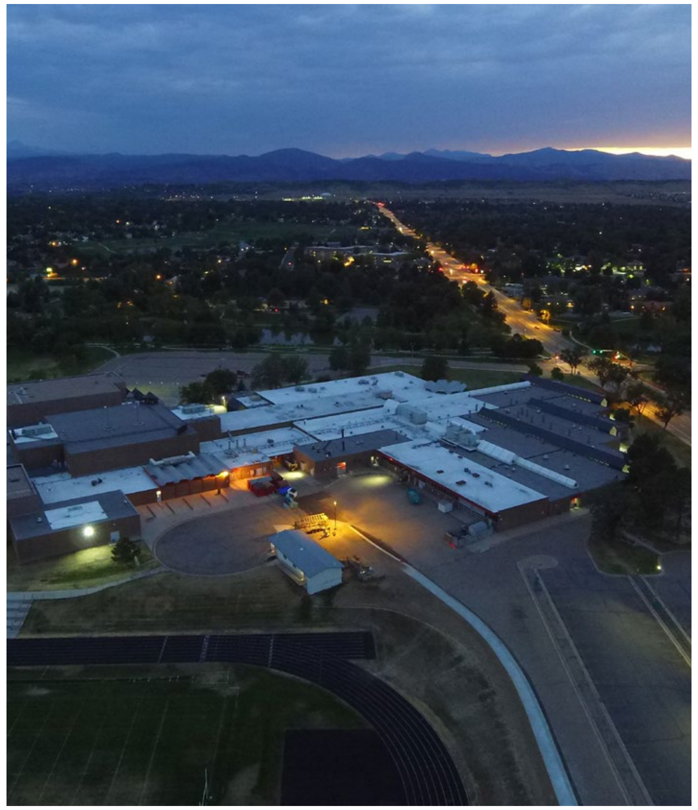


Through the Lens

I took these photos on a DJI Phantom 3. Built around a camera, the drone has 3-axis stabalization and a large imaging sensor, making it ideal for shots like this. This was taken in Bodega Bay iust north of San Francisco.



This photo isn't possible on a racing drone. The 3-axis gimble can tilt the camera down while an enhanced flight stabalization and GPS-lock keeps the drone steady in high winds that blow in from the Pacific. That said, this drone can't do what my design can either. It's considerable slower, full of limitations to keep it tame, and incapable of aerobatic maneuvers. I wouldn't want to crash this one either.



These 3 shots were taken over my high school. Even at dusk, the small aerial camera picks up on all the little details of our world that we can't normally see. The streetlights, which look mundane at eye level, create fascinating intermittent patches of amber as they lead towards the mountains. Even the top of my school becomes curious with the countless peculiar rooftops and odd stitching together of many different renovations over the years.

I was flying about 700 meters above the ocean looking North along the coast. The coastline here shrinks away as the drone reaches heights comparable to only an airplane or perhaps a few high-acheiving birds. The incredible scale that can be viewed from up here is what's amazing. When I was flying over the ocean, I was nervous but in awe of the expanse visible on my phone connected to the remote controller that streams video to me over a mile away. All the cars, the people, the noise, it doesn't exist up here.

Next Steps

I intend to continue pushing the flight envelope of the test drone and see how it compares to the flight of a conventional 3 inch quadcopter and hexacoptor. With this comes PID tuning. This is the process of tuning the response of the controls and accelerometer signals to the individual motor outputs. Because the preprogrammed settings for the 6-in-1 flight controller are designed for a conventional hexacoptor and not the coaxial with a offset, there may be improvements to be made in flight handling.
Additionally, the 3D Ghost design is yet to yield a successful forged carbon fiber prototype. I'd like to modify this design with the 1.2 inch offset from the test drone while maintaining the benefits of a molded shell construction. Not only does this design have potential for a virtually unbreakable structure, but the aerodynamic benefits from a shell and efficiency improvements from an offset give this design potential. The concepts can also be expanded into a coaxial octocoptor (8 motors) or drones with larger propellers to see what their ideal offset is, 30%, 40%, 50% of the prop diameter? Does this trend continue?
Next year, I'm starting a PhD in Aerospace Engineering at the University of Florida to research the intelligent decision making of swarms of robots and drones, expanding into their autonomy.

Acknowledgements

I thank Dr. Michael Kash for his support as the Chair of the Lake Forest College Physics department to fund the research of the test drone prototype. It is a rare occasion that one can approach a professor with a proposition for such an experiment, which the department has no history of researching, and have this be funded with no hesitation. I'm very grateful for this oppertunity.
Dr. Nathan Mueggenburg is my research advisor. His support was critical for managing the experimental process of the coaxial offset reserach. Desiging an experimental process was new to me and his guidance allowed me to reach clear conclusions.
Lastly, Dr. David Sanchez Burr of the Art department helped me through the 3D printing and molding processes while exploring the 3D design components of the Ghost prototype.

Contact Info

Please reach out with any questions, comments, or interests in drone design, my processes, etc. I'd be happy to help anyone with this hobby because it can be tricky yet so incredibly rewarding to take on. Cheers!

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