Team Hermes Final Report: CVS Drone Delivery System

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Chapter 1: Introduction

Introduction

Design methodology provides a structured approach to the design process that enables designers to effectively and efficiently create innovative and effective solutions to a wide range of design problems. Design methodology provides designers with a framework for defining requirements and constraints, generating and evaluating ideas, developing prototypes and models, and testing and refining designs. By following a structured design methodology, designers can ensure that their designs meet the needs of users, are technically feasible, and can be produced and delivered within the required timeframe and budget. The primary objective of this report is to document and showcase how we were able to design, prototype, and test a proof-of-concept drone delivery system under a $250 budget for low-volume delivery for the CVS on Guadalupe Street near UT Campus.

Chapter 2: Task Clarification

Introduction

In this project, we will be designing and constructing a proof of concept prototype delivery drone for the CVS located on Guadalupe St. to deliver items to students living within a mile of the store. Students' busy schedules mean that making a purposeful trip to convenience and utility stores on and around the UT campus to pick up one or two items is inefficient. This affects not only the student, but the store, which loses a potential customer. Although convenience stores such as CVS and Walgreens offer a ground delivery option for their products through DoorDash, this delivery system proves ineffective where there is limited road access and large pedestrian flux. Drones offer a unique opportunity for fast delivery and accessibility. After interviewing UT students and CVS employees, our team discovered a need for a drone that could deliver small-volume convenience store products. In a mutually beneficial exchange, CVS would implement such technology to assist customers, who would pay a premium for convenience. CVS was selected as the primary customer, as they will ultimately receive the completed drone. After conducting interviews with CVS employees, our team concluded that a drone should be durable against regular wear, require minimal repairs, have a small take-off and landing footprint, and be controllable without requiring the drone to remain in line-of-sight of the operator. For the initial phase of this project, we conducted background research on drone delivery systems and gauged customer interest by interviewing our target audience. Synthesizing observations from these interviews, we created a categorized needs list. These needs were examined by constructing a House of Quality to introduce engineering specifications.

Background Research

Drone delivery has become more prevalent in the past 8 years (Team Omnibeat, 2018) and appears to be growing still, as evidenced by the fact that Amazon, Walmart, and Walgeens, all major retailers, have all invested in the technology. Amazon has created numerous iterations for their delivery drones with a variety of different styles. For example, Amazon's MK4 drone model, a multirotor hexacopter, was the first concept that was used to fulfill Amazon orders in 2022 ("Amazon Prime Air", 2022). However, they have also experimented with other drone designs, such as its hybrid drone, the MK23, which is "designed specifically for the dual capability of vertical take-off and landing, like a helicopter, and winged-forward flight, like an airplane" (Appendix AC). Though Amazon might be at the forefront of drone delivery, we hope to fill a smaller niche. Amazon aims to deliver packages up to 5 pounds to anyone who pays for Prime Air, where the delivery has a drop of 12 ft. We will aim to build a drone that is intended to deliver single-item/small payloads up to 2 pounds to college students around the UT campus area.

At the moment, our target customer, CVS, is not engaging with drone delivery. However, they do provide 1 to 2 day shipping and on-demand delivery. The on-demand delivery "will occur within four hours of the order being placed". With the 1 to 2 day shipping method, "orders placed from Monday through Thursday will be delivered in 1 to 2 days, while orders placed on Friday or Saturday will arrive on Monday and Tuesday," respectively. Using a drone to deliver small packages from CVS would fill the gaps in delivery times, as the person delivering the item would not have to leave the store. This means that CVS would be able to quickly deliver small packages to customers at any point during the week, including Sundays, when delivery is typically not done.

Drone delivery might be the future of high speed shipping; however, there are issues that must be overcome to utilize this method of delivery. Firstly, the drone needs to be resilient to weather conditions such as harsh wind and precipitation. This can be combated by using robust materials for the frame and providing protection for the propellers. An additional concern is the avoidance of birds and animals to protect wildlife and the drone. To avoid these situations, the pilot can use a first-person view (FPV) camera to maneuver the drone accordingly. Moreover, drone delivery can only be completed for local customers due to the limited range of the transmitter on the flight controller. Finally, the drone must abide by federal and local aviation regulations. Drones pose a safety liability if the pilot loses control. We will prioritize ensuring an effective range of operation via experimental trials and communication with public safety experts.

Customer Needs Analysis

In early discussions, we found that a common problem faced by students in the UT Campus area is that going to the convenience store is still inconvenient, especially when the customer needs only a few items. Given this, we chose to interview convenience store employees as potential drone operators and convenience store customers - the majority of whom are students - as delivery recipients. We interviewed a CVS store manager and a UT student and CVS storefront employee. This allowed us to capture a representative breadth of views from within CVS. We also interviewed students with varied modes of transport and locations of residence to collect a diverse sample of responses.

We gathered data for customer needs analysis mainly through surveys and interviews. Our team created two online surveys - one for drone pilots and one for recipients. The pilot survey asked the user about their prior drone experience, busiest work hours, willingness to learn about new technologies, and challenges with existing delivery procedures. The recipient interview includes questions about the user's housing type, distance from the store, mode of transportation, and shopping habits (Appendix B). Interviews were recorded for posterity with the interviewee's consent, and hand-written notes were taken as needed throughout the interview.

Pilot interviewees varied considerably in their familiarity with drones, as Joel was "not sure" about an ideal drone's features, whereas Ricardo had flown drones before and had stronger opinions. However, both stated that it was important for the drone to be compact enough to be handled by one person and easy to carry indoors. Both expressed a concern over the feasibility of launching the drone from the street level due to heavy pedestrian and vehicle traffic, which would be a liability. This concern arises mainly due to this store's particular location, but could inform metrics such as the drone's takeoff and landing time - faster times will be more ideal. Joel welcomed the idea of a delivery drone, and stated that it would be appropriate for delivering the categories of items that we anticipated - i.e., individual snacks, drinks, medication, small cosmetics, and contraception. Ricardo stated that it could be burdensome for employees to learn how to pilot and maintain a drone, so we interpreted this as a need for the drone to be easy to pilot and simple to repair with common tools. This need can be further interpreted to include that the drone should be stable in flight, have a simple control interface, and ideally have some autonomous capabilities to reduce pilot effort.

Recipient interviewees unanimously expressed the importance of having a delivery location within close proximity to their home. Recipients largely preferred a no-contact drone delivery, where the package would be dropped off in a secure location without requiring recipient interaction. Just as with ground delivery, they could attend to their own duties and retrieve the package from the delivery address at their convenience. Most recipients did not have reservations about the safety of drones, but some expressed concerns of the drone being an obstruction to pedestrians, vehicles, and wildlife around campus. The biggest concern for recipients was ensuring that the package remained intact during drop-off and potential collisions. They mentioned that they would like to receive regular updates on the progress of their delivery, with many proposing text alerts at the time of delivery completion.

Studying the interpreted needs allowed us to categorize the needs into five sections: time, user interface/user experience (UI/UX), safety, drone capabilities, and size. With the raw customer statements and categories, we established the relative importance of each sub-section based on the frequency that it was mentioned across the 11 total customer interviews. The same process was repeated with the pilot interviews, whereafter the needs lists were combined into one document. The weighted and categorized needs list is featured in Appendix D, with greater weight values representing higher priorities. The list demonstrates that the drone's ability to safely navigate small spaces is of highest priority.

Engineering Specifications

We synthesized the House of Quality and customer needs list into an engineering specifications list (Appendix F). Each requirement was categorized as a demand or wish based on the importance stressed during the interview. Furthermore, we identified a mode of measurement and a threshold value to definitively determine whether a requirement has been satisfied. For instance, a concern expressed by CVS employees was carrying the drone inside and outside of the building. As such, we determined the largest dimension of the drone should be less than 36'' so that it can fit through a standard doorway. Its measurement mode would be a tape measure. This example is simpler than other specifications, as some require experimental trials. Some of these trials may be supplanted by computer simulations due to time constraints. Subjective metrics such as building instruction clarity are structured through customer trials, where user feedback will be translated into points on a rubric to rank responses objectively.

Generally, we factored the needs of the CVS employees into our design considerations more than the preferences of students, as CVS employees would be maintaining the drone. As this drone must be able to be replicated as a weekend project, we expect to design unique parts tailored to our drone's function. As having an easily repairable drone was mentioned as a customer need, our drone aims to have no more than three unique (off-the-shelf) subcomponents. Both students and CVS employees stressed the importance of a reliable payload system. As the end goal is to eliminate the chance of an unsuccessful delivery, we set realistic markers as a 1 mile radius delivery and a 0.5lb package weight limit. What we considered to be realistic goals were influenced by the budget and time span allotted for this project.

Problem Statement

Our mission is to provide a quick and efficient last-mile delivery service to students located near UT Austin campus. We aim to create a drone delivery system to complete low-volume delivery orders from CVS to students living at UT Austin. For the scope of this project, we will limit drone deliveries to within a 1 kilometer radius from the CVS located on 2402 Guadalupe St b, Austin, TX 78705.

Chapter 3: Conceptual Design

Functional Modeling

Our team employed two functional models to aid in concept generation: a black box model (Appendix G, Figure G1) and a function tree (Appendix G, Figure G2). The black box model includes the specific inputs and outputs of our drone system with the overall function being product delivery. Once the black box model was created, we extrapolated its contents to create a function tree to structure the entire process behind our drone delivery system.

To select specific inputs and outputs of our black box model, we first identified the overall function of our system and what it must do: it must deliver a product. Once we selected delivering a product as our black box function, we defined the system boundary to be the drone itself and the package. For example, a remote controller or digital display would not be a part of the system since they are not in physical contact with the drone. We chose this as our system boundary to have reasonable inputs and outputs. If we had included the pilot and controller within the system, the black box model would be inadequate since it would not correctly account for the informational input of the pilot.

After defining the system boundary, we divided the inputs and outputs of the black box in three forms: (1) energy, (2) materials, and (3) information/signals. Regarding energy inputs, we concluded that the drone would receive electrical energy in some form of a battery, solar power, or other mechanical power. The output of this electrical energy would result in torque output to drive the components to run the system, heat loss to the environment, sound from various sources like the propeller or motor, and light due to headlights or light emitting diode (LED) lights that will be mounted on the drone. For material input and output, we decided that we would exclusively be receiving the payload (CVS product order) from a CVS employee and delivering or "outputting" it to a customer. Thus, the only material that comes in and out of the drone control volume would be the product that is being delivered. For informational input, we deduced that we would only receive information in two ways: sensory information from the environment and control input from the pilot. In turn, the control and sensory information would be outputted as movement information to control the drone and telemetry data to constantly assess the drone's condition.

Upon completion of the black box model, we structured a function tree from the black box model to gain a better understanding of the different sub-functions within the overall function of the drone system. We structured our sub-function of delivering the product based on the three forms of the black box: energy, material, and information. In regards to energy, we included four sub-functions: import energy, store energy, convert energy into usable mechanical energy, and convert energy into light. For material use, we created a sub-function called "transport payload." Within this sub-function, we accounted for different methods of transporting the product such as a clasp mechanism, velcro, a lidded box, and a claw. In terms of informational inputs and outputs, we created a "perform telemetry" sub-function to gather any data related to the drone. This sub-function would account for the input of sensory information which would then coordinate with the movement of the drone. Underneath the "perform telemetry" sub-function, we added in components to account for measurement of altitude, measurement of temperature, measurement of position, capturing of images, processing of data, and transmitting data. We believe listing these components helped us in idea generation and in thinking exhaustively about everything needed to create the drone.

The combination of sub-functions of "transporting payload" and "performing telemetry" are the most likely to benefit most from idea generation because there are a plethora of methods to perform these functions. The team immediately thought of four different ways to transport a payload: a clasp mechanism, velcro, a lidded box, and a claw. There could be more ideas generated given additional time. Performing telemetry would also benefit greatly from creative idea generation because of the six different components within its function. For each component, each group member could draft a few unique ways to achieve the component function.

Creative Idea Generation

For concept generation, each member individually chose an idea generation method of their preference. We then used the 6-3-5 idea generation method as a team to build upon each member's initial ideas. On the individual level, the two methods used were mind mapping and design analogy. For the members that chose to do mind mapping, a wide range of drone design areas were explored, such as drone frame, payload structures, and customer interaction (see Appendix H). The design analogy method was more specialized, and members that chose this generation method focused on specific areas of the drone. For example, various propeller shapes and lift mechanism ideas took inspiration from components in the natural world or existing flight technology (see Appendix I). Due to the large breadth of unique concepts generated by each member from both mind mapping and design analogy, our team was able to bring many ideas into the 6-3-5 method.

The 6-3-5 idea generation exercise was highly effective in providing a foundation for our idea generation, as we had a bank of ideas to pull from. Each member's unique perspective can be seen by the diverse range of ideas in Appendix J. For instance, the quadcopter frame is mentioned in Figure J1 where there is also a suggestion to extend the frame around the propellers to provide support. This would add extra protection while giving the drone a more structured build.

One idea that was consistent in many of the 6-3-5 sketches was the quadcopter drone type. This drone design offers the user the most control, thanks to the ease of using a camera. Another potential idea that we developed was the use of a payload clasp. This clasp would latch onto the payload from both sides and hold it in place throughout the flight. Once the drone reaches its destination, the customer would release the clasp to receive the payload. This idea was further expanded upon as another team member suggested having an automatic system to release the package for contactless delivery, eliminating the risk of customers interacting with the drone during delivery.

Prior Art

After generating ideas on our own, we searched prior art to identify additional ideas, especially for flight control and payload transport subsystems. A promising multi-functional solution is a flight controller (FC), a circuit board equipped with sensors specialized for enabling drone flight. Most FCs have basic sensors like gyroscopes and accelerometers, while others may include sensors like barometers and compasses. While the FC on its own addresses some of our subsystem functions (like motion control and sensing), it can also serve as a hub for additional drone peripherals like global positioning systems (GPS), lights, servos, and more (Liang, 2023). Additionally, many FCs are compatible with existing flight control firmware. Adopting existing firmware (as opposed to developing proprietary software) may be preferable to the end user, as they will have access to a wealth of documentation and an active community of other drone users (Betaflight, n.d.).

Another solution that could supplement the functions of the FC is the Raspberry Pi (RPi), a wireless-capable, single-board computer that runs a custom Linux-based OS. Almost all drones incorporate FCs, but not all drones use RP, as this varies based on the drone's intended use. Drone builds including RPi typically use it to implement complex procedures such as object recognition or autonomous flight (Garg, 2022). In contrast, most builds in the FPV drone hobbyist community use only an FC, as these types of drones are manually piloted and optimized for agility. (Whiffles, 2018).

We also researched existing concepts for payload release mechanisms. Tethers are a common design seen in patents for drone payload subsystems such as the Amazon delivery drone (Appendix K, Figure K1). When implemented, tethers reduce the impact experienced by the payload and allow the drone to remain farther away from people, which reduces noise and increases privacy (Daleo, 2022). However, the tether is susceptible to swinging the package due to heavy wind or sharp changes in the drone's flight path, which could be a cause for concern for the customer. From a maintenance perspective, the tether would have to be inspected each use and replaced often to ensure a secure delivery and avoid any liability of the package falling. Additionally, if the tether gets caught during the dismount, The tether would need to be manually addressed, which reduces the efficiency of the system.

Clasps/latch mechanisms represent another class of possible payload release mechanisms. In actuality, clasps can be used in conjunction with tethers as seen in the system portrayed in Appendix K, Figure K2, where the clasp provides support, only releasing when it is time for the payload to be lowered via tether. Latches do not constrain the payload as much as clasps during transit, but are mechanically simpler, and in their most minimal form can consist of a motor, arm, and rod. This research, combined with our idea generation, served as the basis for the array of solutions we used in our morph matrix.

Morph Matrix and Design Concepts

We translated our functional modeling and concept generation into a morphological matrix, where ideas were organized by sub-function. Additionally, the concepts were organized physically as either mechanical, electrical, light, fluid, or miscellaneous. In accordance with these categories, our ideas for importing energy included a mechanical hand crank, electric charging, solar panels, and a wind turbine. After populating the matrix, each team member selected a distinct combination of elements to form their drone, intentionally varying the energy import and payload mechanisms. The six resulting concepts are described in Appendix L and below.

Our 'hand crank quadcopter' concept allows the user to quickly generate energy using a hand crank which is then stored in a torsional spring. Once wound, the stored energy in the spring would be used to drive a central shaft that is connected to a planetary gear train that powers the four blades. The drone also includes a squirrel cage generator, which is connected to the bottom of the central shaft and used to power the flight stack controller, (laser imaging detection and ranging) LIDAR, and a radio transmitter and receiver that are used for communication. The drone carries the payload using a hook that would support the handles of the CVS bag in flight. Once the drone reaches the customer, the drone would use a pulley system to lower the payload safely to the ground.

The 'brushed motor and claw quadcopter' is powered by DC brushed motors and a rechargeable Lithium-Polymer battery, which are commonly used for their high power output (Di Maria, 2019). This drone features a moving camera and headlights with an RPi -Arduino processing system, making for a customizable user interface. The payload would be transported by a claw apparatus, like those in claw machines, which would be adjustable but might place restrictions on the size and weight of the payload.

The ‘solar-powered drone’ concept features small solar panels on the drone body that will power four servo motors, headlights, a GPS tracking system, and a fixed IR camera. The payload would be secured in a quadcopter frame with a lidded box that allows the package to be easily removed by the customer.

Our ‘helium concept’ incorporates a helium balloon attached to a quadcopter drone frame to provide lift. The balloon allows us to passively lower the effective weight, reducing motor energy consumption. However, it may be challenging to secure the balloon to the frame. Additionally, the balloon must be large to provide any appreciable amount of lift, which conflicts with the customer’s desire for a compact drone.

The ‘wind quadcopter’ concept utilizes a wind generator and stores energy in a flywheel mechanism. It converts energy using a brushed motor and distributes it to the following components: collision avoidance lights, a sonar sensor plugin, a radio transmitter and controller, and a moving camera. Using a wind generator to generate energy and a flywheel mechanism to store energy are challenging due to the limitations of energy storage of the flywheel to sufficiently power onboard electronics.

Pugh Chart

We used a Pugh chart (Appendix N) to compare our six different concepts with one another. From these six concepts, we selected three to serve as baseline datum. The three baselines were chosen on the basis of being the most realistic to produce according to the following criteria. We formed criteria for the Pugh chart using our engineering specifications list. We standardized the specifications so each concept’s performance could be quantified and easily compared. For total cost and weight calculations, we selected materials for each design and summed their respective prices and weights (Appendix O). We additionally calculated the available energy storage of each concept, as well as the stress experienced by the payload carrying mechanism. We assigned each concept an ease-of-use score, which is a qualitative metric on a 1-10 scale that describes how difficult the drone is to pilot (Appendix N, Figure N1).

The 'hand crank quadcopter' has one of the lowest horizontal areas and cross-sectional areas of our six concepts, which likens it to greater flight stability and easy storage. However, it is not easy to pilot using LIDAR. The spring, shaft, and gears require additional maintenance time, both of which would be strenuous to our customer, CVS. Additionally, the custom torsional spring required to store enough energy to be usable as a power source and the design's LIDAR requirements far surpass this project's budget. The helium drone outranked every concept in terms of weight and cost, as much of the drone's volume is attributed to a helium balloon. However, a helium balloon is not a sustainable source of gravity compensation and may not be easily refillable. The 'clasp quadcopter' is most similar to conventional hobby drones, which do not not require as much build time or maintenance time as our alternative ideas. Its use of carbon fiber and wood makes it a relatively lightweight option and the use of an IR camera makes it harder to pilot than a traditional FPV camera and is extremely costly. Due to our inability to find an IR camera on the market within reason of our budget, the cost was left off in the budget calculations for the quadcopter clasp concept, and the camera was abandoned altogether.

The 'brushed motor and claw quadcopter' and 'claw quadcopter's' weight and size are both within target range, and the design is notable for its high energy storage capacity. The integration of features including a RPi, Arduino, and moving camera quickly made this design an expensive option that exceeds our budget. Moreover, the clasp mechanism is connected to the drone via small pins, which augment the stress experienced by the pins with heavy payloads. The 'solar-powered drone' design with a lidded box for the payload allows for the stress to be more evenly distributed along the bottom box surface area. However, the box adds a sufficient amount of weight and size to the drone frame. The solar panels have low power output and are an unreliable source of energy that restricts flight to specific times and weather conditions. Lastly, the 'wind quadcopter' experiences one of the lowest payload stresses of all the designs. While it generates an adequate amount of energy, the weight of a wind turbine and its dependency on weather conditions raises concerns of its reliability.

The three baselines were the ‘helium drone’, ‘brushed motor and claw quadcopter’, and ‘clasp quadcopter’, which were all associated with an electric charging method. We found this aspect of their designs to be the most realistic, as successfully storing enough mechanical energy - as with the ‘hand crank quadcopter’ - would not be feasible given our budget. Specifically, the costs associated with a battery are much less than the costs of constructing a powerful, compact mechanical energy generation system. Additionally, implementing a solar panel on a small scale did not appear as feasible as conventional rechargeable batteries. While the ‘wind quadcopter’ has potential to generate sufficient energy, its weight places an unreasonable load on the drone which ultimately worsens its performance. Of the three datum selected, the ‘helium drone’ was eliminated due to its low rankings in the Pugh chart. While effective cost-wise and weight-wise, it is bulky and risks being disrupted by crosswinds and sharp objects. Additionally, it performed no better than alternative designs at generating energy, making the volume an unfavorable tradeoff. The ‘helium drone’ ranked the lowest of all concepts in both Pugh charts where it was not a baseline. While the ‘solar-powered drone’, ‘wind quadcopter’, and ‘hand crank quadcopter’ proved advantageous in minimizing the stress experienced by the drone, they were outperformed by both the ‘brushed motor and claw quadcopter’ and ‘clasp quadcopter’ in weight and cost, metrics for which we had established cutoffs. Again, we note that the cost of the IR camera was not included in the calculations of the ‘clasp quadcopter’ due to its price. Similarly, the IR camera cost within the ‘solar-powered drone’ was replaced with the cost of a simple fixed camera.

Between the remaining ‘brushed motor and claw quadcopter’ and ‘clasp quadcopter concept’, we find the former to be the first choice in one Pugh chart, while the latter is the top contender in two Pugh charts. The ‘clasp quadcopter’ most differs from the brushed motor in regard to the payload mechanism. While the clasp supports the payload from two sides, the ‘brushed motor and claw quadcopter’ uses a claw to wrap around the entire payload. The claw mechanism does not provide much security for larger payloads due to its smaller size and greater experienced stress. A component analysis reveals that brushless motors are more efficient and easier to maintain than brushed motors (Millett, 2022), which improves the drone flight time and user maintenance time. In this category, the ‘clasp quadcopter’ is preferable to the ‘brushed motor and claw quadcopter’. While the ‘brushed motor and claw quadcopter’ weighed less than the ‘clasp quadcopter’, they both weighed under the 4 lb standard established by the team, making weight a less contentious point. All the above factors considered, we decided to proceed with the ‘clasp quadcopter’ drone for prototyping.

Upon determining our final concept, we referred to our prior art and background research to consider implementing minor changes that would improve the weaknesses of the current design. According to the Pugh chart, the ‘clasp quadcopter’ could benefit from an increased energy capacity and cost reduction. Much of these concerns are relevant to component selection. For instance, the energy capacity greatly varies depending on a battery’s voltage and charge, which can be recalculated after deciding the ideal flight time and package load. From preliminary cost estimates, it is difficult to stay under budget, even without autonomous flight options. Therefore, we will focus on finding the most suitable flight controller to reduce costs, and omit the RPi. In its current design, the ‘clasp quadcopter’ weighs more than the brushed motor and claw quadcopter. This can easily be balanced by utilizing low-density materials, such as carbon fiber and wood planks, over acrylic.

Low-Resolution Prototype

Our low-resolution prototype models the ‘clasp quadcopter’ with accessible materials including cardboard and tape (Appendix P). The primary feature we sought to highlight was the structure of the drone frame, which embodies a hybrid X shape. We modeled each of the propellers to have three blades with rounded tips. The fixed camera will be positioned on the front of the drone, flanked by headlights. The underside of the drone supports the clasp apparatus, while the top houses the battery and electronic components. Each corner of the drone is attached to a leg, which supports the grounded drone. The low-resolution prototype allowed us to visualize the overall dimensions of the drone, and to anticipate where potential structural weaknesses may arise. Additionally, the prototype allowed us to investigate if all the components needed in the structure of the drone will be feasible to produce in the given build timeline.

Next Steps

To further develop and validate our leading concept, we will take a three-pronged approach: CAD modeling, cost and ordering projection, and further idea generation. The first challenge we currently face is determining whether the geometry of our current design is dynamically stable. To eliminate this uncertainty, we will begin modeling our leading concept within SolidWorks to understand its physical constraints. Additionally, we must find components that fit our budget constraints while ensuring their timely delivery within the next project review. We have noted the cost of various components within the "back of envelope" cost projections (Appendix O), which are yet to be finalized. The third challenge we face is finding a clasping mechanism that adheres to the concerns noted in the customer surveys and analysis. As customers preferred to not directly interact with the drone, we are considering creating a clasp that can retract on command to drop off products. We will use another form of idea generation to brainstorm potential solutions as we initiate the next phase of our project.

Chapter 4: Embodiment Design and Prototyping

Introduction

In this section, we present the updates made to our selected concept after evaluating the feasibility of our concept within the scope of the project. We outline our approach to manufacturing, guided by design principles including Design for Assembly (DfA) and Design for Environment (DfE) that drove the evolution of our drone. Through multiple prototypes, we used experimental and simulation data to examine the advantages of pursuing new designs. We explored ways to improve our drone performance while aligning with customer needs, as in creating a contact-free delivery system and user friendly controller setup. In the end, we constructed an efficient, compact drone that successfully completes the last mile delivery of small volume packages.

Leading Concept

We concluded our concept generation phase by selecting the 'clasp quadcopter' as the base design, featured in Appendix M, Figure M5. In this concept variant, the x-shaped quadcopter would be supported by four legs which would allow it to be deployed from and land on any flat surface. The remote controller would allow the pilot to control the drone's flight and payload deployment. The drone's payload subsystem was an expandable clasp that would grip a box from both sides and then be expanded to release the box. The drone featured a flight stack controller, which would handle the data processing needed to communicate with the motors. The IR camera was abandoned in the concept generation phase, so we continued with a fixed camera positioned at the front of the drone. The FPV camera connects with a receiver to transmit a live video feed onto a smartphone app, which the pilot can view to navigate the drone. At this stage, we established that the payload mechanism would be custom designed.

Prior to constructing CAD models, we created a dimensioned sketch to determine the optimal layout of parts. This provided us with an estimate of the required size of the frame. Once we felt confident about our design, we recreated the sketch as an assembly in Solidworks. This program offered great flexibility in simulating various arrangements with our custom made CAD parts. While the concept sketches feature a hybrid-x shaped chassis, we converted this to a hybrid-H shape due to the ease of designing such a frame in Solidworks (Appendix R, Figure R1). We created a bracket for the pin and hook mechanism, as well as a servo enclosure. This motivated us to create an enclosure for the camera. We attached legs onto each corner of the frame through slots in the frame (Appendix S, Figure S1).

Our background research corroborated that retractable clasps are commonly used to carry payload in commercial delivery drones. However, given time and budgetary constraints, automating such a system seemed beyond the purview of this project. This system sounded promising if customers were to manually retrieve their box from the drone, but conflicted with our goal of contact free delivery. As such, we opted for a turning hook and pin system that would release packages without customer intervention (Appendix S, Figure S2). We arrived at this design by referring back to our concept generation and combining principles of a pulley and motor hook. This design was more compact and involved fewer moving parts than the clasp.

The electronic setup remained constant, with the four brushless motors being powered by a rechargeable battery and flight stack controller. We paid close attention to the weight and size of each component, as balancing the drone would be critical for stable flight. Initial ideas included an LED which would indicate battery life, send alerts at critically low levels, and send alerts of delivery completion. We downscaled these telemetry options after realizing our time had more productive uses aside from implementing additional sensors and programming that did not necessarily affect the flight of the drone. This question of time constraints also prompted us to remove the safety lights and collision avoidance lights from the prototype.

Failure Modes and Effects Analysis

We evaluated our system through a Failure Modes and Effects Analysis (FMEA) which highlights the ways we could identify and repair our drone if it were to experience a failure. Our FMEA chart (Appendix T) categorizes each component failure as critical, major, key, or significant. They are each assigned an occurrence frequency, severity rating, and detection rating between 1-10. They are additionally given a risk priority from 1-1000, which is a product of the occurrence frequency, severity rating, and detection rating. We found the most correctable failure to be a battery failure, as the battery could easily be recharged before the next delivery. Additionally, we identified propeller breakage to be the easiest to detect of all potential failures, as a visual inspection would suffice. The electronic components would require a closer look to identify signs of part failure, but these signs would be recognizable once familiarized with operating the drone. A critical takeaway from this chart was that a failure in any of the components would result in a failure of the delivery, as either the payload or the chassis would incur damage from dropping. We looked for ways to minimize the severity of a potential failure by physically bolstering the design, although the interconnected nature of the drone made this challenging.

In particular, we had concerns of the payload mechanism failing as its success depended on the interlocking of small, moving parts. This could result in the pilot being unable to attach the package, or the package not releasing at the time of delivery. While this failure could be attributed to a mechanical deformation in the hook, we found it can also be caused by a signal error between the flight stack and servo motor. More importantly, the stress experienced by the pin could cause deformation that would warrant replacement of the part. We prepared to design parts with chamfered edges and larger surface areas to better distribute stress. Additionally, we considered installing 3D printed shields around each component as a precautionary measure.

Experimentation

From our customer needs analysis, customers placed an emphasis on quick, contactless delivery. Therefore the focus of experimentation was to test quickness and efficiency of the delivery by measuring three total responses. To test quickness, we measured two responses: total time of flight in seconds and the average horizontal speed during the flight in meters per second. To test efficiency, we measured the drop success rate where a successful drop is defined as the drone delivering the payload within a targeted radius of approximately 28 centimeters with no damage to the drone or package. We denoted a successful drop with a +1 and a failed drop with a -1.

We identified three control variables: mass of payload, thrust of the motor, and landing option. Each control variable had two levels: low and high (Appendix W, Table W1). Denoted as X1, the mass was measured in terms of packs of gum where the low level is one pack of gum (14 grams) and the high level is three packs of gum (42 grams). Denoted as X2, the thrust of the motor was measured as a percentage of the motor's total possible output where the low level was 30% thrust and the high level was 100% thrust. To calibrate the thrust, we utilized a load cell and set a marker of what position the corresponding control rod on the remote controller was at. For instance, the low level of 30% thrust corresponded to the control rod being at a 54° angle while the high level of 100% corresponded to the control rod being at a 172° angle. Denoted as X3, the landing option variable was used to determine which type of landing would be quicker and more efficient in terms of drop success where the low level was defined as landing on the ground and releasing the payload while the high level was defined as hovering approximately 1 foot (30.48 centimeters) above the target and releasing the payload from the air.

We identified various noise factors such as: outdoor wind speed, heat from the sunlight, and potential precipitation. To mitigate these factors, we chose to conduct the experimental trials when the wind was low and the weather conditions were cloudy and without chances of precipitation. For added consistency, we chose to have only one person throughout the testing process to pilot the drone to mitigate human error.

For the procedure of the experiment, we chose the setting of the experiment to be the flat and grassy field where the final demonstration would take place (field between EER and GLT). Two members were present with the roles of being the pilot and the cameraman, respectively. The goal of the pilot is to deliver the payload from a starting position 30 feet (9.14 meters) away from the drop off location and return to the starting position. We chose a fixed distance of 30 feet because it was perfectly in the frame of the cameraman, and we decided that any longer distance would result in too much time spent in experimentation since the drone has to cover more ground. The goal of the cameraman is to record each trial starting when the drone begins levitating and ending when the drone returns to the starting position after delivering the package. The materials in the experiment included: the drone, the remote controller, three packs of gum to vary the mass of the payload, and confetti markers to denote the target circle. From the video recordings of each trial, we were able to measure the total flight time and the time to cover the horizontal distance. With the time to cover the horizontal distance, we divided 9.14 meters by this time to calculate the average horizontal speed to get to the drop off location in meters per second. We conducted the first trial with all of the control variables set to the low level and proceeded to cover every variation of the 2 levels for 3 control variables with 3 repeated trials for each variation resulting in 24 total trials.

The six notable results of the experiment were as follows: (1) a heavier payload resulted in longer average flight times and slower average horizontal speeds, (2) the mass of the payload did not have a significant effect on the drop success rate, (3) the landing option of hovering and then releasing the payload from the air resulted in faster total flight times and faster horizontal speeds but less reliable drop rates, (4) higher thrust resulted in faster flight times and faster horizontal speeds but less reliable drop rates, (5) thrust was the most statistically significant factor on average horizontal speed and total flight time with an R^2 equal to 0.742 and 0.363, (6) the only other statistically relevant factor was the landing option variable on the total flight time with an R^2 value of 0.339 while other factors for all responses had R^2 values less than 0.100 (Appendix W, Figures W13-15). From the results of the experiment, we determined that we could improve upon our drone by creating a sturdier, more centered frame in order to properly carry heavier payloads since the drone could easily handle the higher mass level of three packs of gum without a significant detrimental impact on drop success. Furthermore, we gathered that the thrust and landing option were the most significant factors when it came to drop success, so we decided that it was optimal to pilot the drone at 65% thrust and deliver the payload while hovering. This provides the pilot with the best control over the drone, higher chances of successful deliveries, and contactless deliveries for customer satisfaction.

Simulation

When determining the optimal material to construct our frame out of, we factored weight, strength, and cost into our consideration. Our initial concern with ⅛’’ wood was that while it was the most inexpensive option, it was the most likely to deflect or even fail. In Solidworks, we performed finite element analysis on a ⅛” wood frame (Appendix U). The material properties for plywood were sourced from the MatWeb database. We supported the frame by the motor screw holes and applied a uniform 10N force across the surface of the frame. 10 N was the estimated weight of flight components with the payload. These settings simulate the weight of the flight components and a small payload acting on the drone while it is hovering in place. The simulation revealed that a deflection of 0.26 mm would occur in the center of the frame - barely visible but possibly enough to affect flight dynamics. To avoid the risk of deflection, we opted for ¼” plywood, which was the next size available.

Updated Leading Concept

One notable change in the design of the drone was expanding the chassis to be multilayered. While the initial prototype housed all the components on a single layer of wood, we found that this arrangement would offset the center of gravity due to the weight of the battery relative to other parts. To remedy this, the current drone design consists of a base layer as well as two stories atop the central body. (Appendix Y). Having a smaller frame proves advantageous in reducing the moment of inertia, which lessens the likelihood of the drone flipping. The tiered structure houses the flight controller, while the cross arm is responsible for the four motors. The battery is zip tied onto the top tier. The multi-tiered design is not only more compact than our previous iteration, but is modular as well. The screw holes of each layer are strategically aligned such that another cross arm could easily be added to the existing frame. If a user was looking to increase the motor's thrust, they could simply screw on an additional cross arm complete with motors.

These changes also enable us to compact the payload mechanism into a single part, which results in a mechanical advantage for the servo motor arm. Rather than being partly stratified between the side and bottom of the frame, the new payload system is consolidated onto one plane as shown in Appendix Y, Figure Y2. The servo horn was also adjusted to allow for a greater range of motion for the pin. Having a single part responsible for payload minimizes the risk posed with several moving elements. Specifically, it allows for the pin to move more smoothly through the bracket. We observed a much greater payload drop success rate after consolidating the payload system.

Additionally, we redesigned the legs of the drone to increase their surface area. While the original wooden legs provided the advantage of height, allowing for the drone to land before releasing the payload, the flat pieces of wood did not offer stability. We added L-shaped feet onto the legs in aims of distributing impact, thereby preventing the legs from breaking. The current iteration of legs pictured in Appendix Y, Figure Y3 significantly softens the drone's landing.

Design for Manufacturing, Design for Assembly

We employed DfA and Design for Manufacturing (DfM) to optimize our manufacturing plan. A significant factor we considered early in the process was the layout of components, which can be seen in our CAD model in Appendix R. Besides the necessity of symmetry for weight distribution, the identical placement of motors and legs eliminates concerns of using the incorrect side of the frame. Larger components such as the battery, flight controller, and receiver were strategically arranged to maintain the drone's balance. However, the battery is not screwed onto the board, so the frame will incur minimal damage if it is mispositioned. We ensured all the parts on the drone had partial enclosure, rather than being fully encased, for ease of access. The two stories of the drone chassis are connected via standoffs to leave a majority of the body open. All parts, except for the payload release bracket, are mounted on the top of each layer for increased visibility. One way in which we reduced costs was designing any 3D printed supports to feature screw holes matching those of our electronic parts. This way, we could use the screws provided by these parts instead of purchasing additional screws elsewhere.

Ease of manufacturing was the leading reason behind selecting wood as the sole material for the frame. Verifying the 3D geometry of the chassis would have required a considerable amount of time if it was to be 3D printed. We used a laser cutting machine, which required minimal time to produce a frame of our drone's size. This process is advantageous in that each layer of the frame can be machined as one piece and requires limited manual assembly. Moreover, wood planks are relatively inexpensive compared to acrylic and carbon fiber, both of which are typically found in drone projects.

Sustainability

All of our electronics were sourced online from Amazon and shipped altogether, saving the need for multiple trips to various stores. The use of a rechargeable battery over single use batteries saves us from frequently disposing of batteries, which contain environmental toxins. We purchased propellers made of polycarbonate, which is a fully recyclable plastic.

The drone frame is constructed entirely of wood, with the addition of brass spacers. The camera and motor accessories and payload brackets were 3D printed from PLA filament. Both wood and PLA are plant based, biodegradable sources. Even while laser cutting the wood, we were keen on using as much of a given board as possible, so as to not create scraps. The legs were originally created out of wood, but we found a way to reuse our brass spacers as legs and repurpose the wood as leg pads. However, these legs were much shorter than the original wood pieces, which would limit the size of our payload. Our workaround to this issue was having the drone release the package while still flying, instead of landing it beforehand. When the drone is in the air, there are no restrictions to the size of the payload.

Final FMEA

Revisiting our initial FMEA chart, we sought to diversify our remedial methods and tailor the process controls to every component. Originally, every subcomponent was suggested to have a physical shield, which would address physical damage but not electrical failures. We included specific measures to address both physical and electrical sources of failure, rather than listing broad solutions that could be applied to any part. Additionally, we found that redesigning the legs and payload provided enough stability to no longer warrant the installation of shields.

As we experimented, we understood the importance of proper landing gear. Specifically, we observed that the drone would incur physical damage if it was to have poorly attached legs. Therefore, we added legs as a component onto the FMEA chart and classified it as ‘key’. The initial landing gear was designed to absorb hard landings and distribute weight evenly, allowing us to reduce its occurrence frequency to 2/10. In the original payload system, slight deformations in the pin and bracket created inconsistencies in the system’s performance. We resolved these issues by redesigning the entire subsystem and reduced its occurrence frequency to 1/10 (Appendix Z). The reduction in both of these subsystems’ occurrence ratings were justified during test flights, as the payload mechanism never malfunctioned and the landing gear broke once out of an estimated 35 flight tests.

To lower the risk of electrical hardware failure, the final design implements three strategies to mitigate failure: heat shrink at wire solder joints, installing the battery platform over the flight stack to protect it from direct collisions, and using zip ties to arrest the wires to the frame. We made sure to keep wires loose but secure even in rough landings (Appendix Z).

Final Drawings, Bill of Materials, and Budget

Our drone successfully achieves its purpose of completing last-mile deliveries while costing less than $250. Since the budget was one of the biggest constraints of this project, we methodically planned what items to purchase and listed them in the bill of materials (BOM) (Appendix V, Figure V1). We initially listed every component our drone would require, and gradually removed items which we would design rather than purchase. We considered whether to purchase or design propellers and opted to purchase them as they fit within the budget and would greatly increase the probability of our drone succeeding. 3D printing propellers posed the risk of failure due to surface imperfections and the specificity of aerodynamic geometry. As such, we decided propellers were a worthwhile purchase. Components such as the battery, flight stack controller, and motors were clear candidates for purchase, as they would be incredibly difficult to create ourselves. In the BOM, we included costs of laser cutting and 3D printing, although these services are free of cost to students. The main difference between our BOM and budget is the inclusion of miscellaneous materials such as screws and zipties. Since our team members already owned these common items, we did not add these costs into our BOM. However, we factored them into the budget to accurately reflect the cost of fully building the drone from scratch.

DIY Manufacturing Instructions

We documented how to build the drone such that one would be able to complete the project in less than a weekend (Appendix AA). We created thorough instructions on how to connect electrical fixtures, assuming that the user has already purchased the required electronics. The document is organized chronologically and divided into sections so the user may follow the instructions as a tutorial. The first three sections - Electronics hardware setup, 3D printing, and laser cutting - may be performed in any order, although we found the listed order to be the most time efficient. We would provide the user CAD files of our custom made parts, to allow them to focus on manufacturing rather than designing.

Final Discussion

Over the process of conducting background research and customer needs analysis, we determined the key features desired by the users of our drone delivery service. As we quantified these needs into engineering specifications, we brainstormed ideas that could creatively achieve these needs. With a multitude of concepts generated, we gravitated towards selecting the most feasible and relevant concept, the ‘clasp quadcopter’. Once this concept was selected for prototyping, we continued iterating designs to improve the drone. While the ‘clasp quadcopter’ proved the most efficient with its brushless motor and flight stack configuration, the applicability of the clasp mechanism was questionable. At this stage, we proposed changes to the concept that we felt aligned better with our established customer needs. In order to effectively plan our manufacturing phase, we prioritized creating those components deemed necessary to the drone’s function of flying. Namely, functions such as GPS tracking and battery progress were abandoned as we allocated more time to improving the existing drone design. Our philosophy was to produce a reliable drone with as minimal parts as possible.

The standout feature of our drone is its modularity. The frame was intentionally designed to be stackable, so that layers could be removed and added as desired by the user. Our components are easy to replace as they are contained within a single enclosure, such as for the camera and payload bracket. If these parts required modification, the user could easily swap them out.

We successfully fulfilled customer requirements by implementing a contact-free delivery system. The evolution of our payload from a bracket to a claw to a pin and hook demonstrates how we transitioned relying on prior art to designing our own system. This system is fairly unconventional for a delivery drone, and required repetitive testing for it to work consistently.

In the future, we would pursue auxiliary telemetry features such as GPS and battery updates. Such features are compatible with our current flight stack, and would require only a few electronic modules to complete. These features, along with the camera, would offer the pilots transparency on the status of the drone. The team considered incorporating a payload drop notification which would alert the pilot when the package is safe to release. This would be achieved through a sonar sensor that records the height from the ground, and sends a message when the drone is within a certain proximity. The exact value of this height would need to be determined by testing payload drops at varied heights.

Additionally, we could design shields for our propellers and battery as planned in the FMEA. Many customers voiced concerns of drones harming wildlife, whereby propeller guards would offer an extra degree of safety. The FAA requires all commercial drones to have anti collision lights. Given a greater budget, we would retrofit the drone with collision avoidance lights and nighttime lights to improve the safety factor. While there are many ways to go before registering a drone with the FAA, tailoring our design to comply with existing regulations improves the product for our customers and for hobbyists building our drone as a project.

Chapter 5: Conclusion

Conclusion

Designing a drone delivery service for CVS presented a unique challenge as undergraduate senior mechanical engineering students. This project required a holistic approach that considers not only the technical aspects of drone design, but also the logistics of delivery operations. Throughout this design methodology class, we have learned how to systematically approach a problem and develop a prototype that meets the needs of the client. The successful completion of this project has not only demonstrated our technical skills but also taught us to work collaboratively, think critically, and innovate for future endeavors. Ultimately, the drone delivery service has the potential to revolutionize the retail industry by providing fast, efficient, and contactless delivery options for consumers.

Chapter 6: Contributions

Ishan - Frame Redesign, Manufacturing/Assembly, soldering, software debugging/flight controller setup, and final CAD Assembly

Patrick: FMEA, DOE Data Collection, final prototyping and debugging of frame, payload mechanism, and landing gear.

Calvin: Early version CAD Assembly, Frame redesign, Payload Mechanism redesign, created technical documentation, managed part logistics

Ron - Led Design of Experiments and performed statistical analysis. Generated main effect plots. Created presentation slides, script and directed rehearsal.

Kavi - Modeled camera enclosure, lead writer on Final Report.

Vivian - Frame modeling. Created presentation slides. Created illustrations for earlier report sections.

We have determined that everyone has contributed equally to the project based on their strengths.

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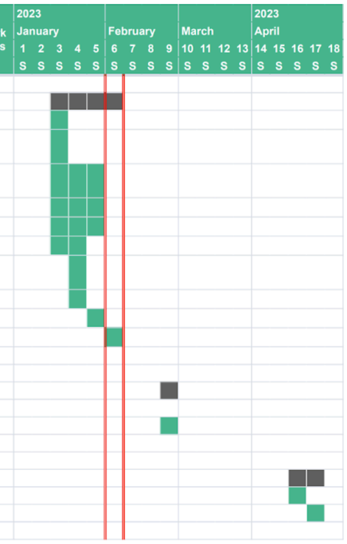
Appendices

Appendix A

Initial Gantt Chart and Task List

ID	Work Breakdown Structure	Start	End	Person	Progress	Dependency	Days	Work Days
1	Phase One	1/18/2023	2/6/2023		43%		20	14
1.1	Develop a Gantt chart Phase C	1/18/2023	1/18/2023	Whole Team	100%		1	1
1.2	Develop interview questionnaire	1/18/2023	1/20/2023	Whole Team	100%		3	3
1.3	Gather background information on your project	1/18/2023	2/3/2023	Whole Team	0%		17	13
1.4	Customer interviews	1/18/2023	1/30/2023	Vivian, Ron, Kav	100%		13	9
1.5	pilot interviews	1/18/2023	1/30/2023	Patrick, Calvin	100%		13	9
1.6	needs analysis research	1/18/2023	1/23/2023	Whole Team	0%		6	4
1.7	Translate customer needs into engineering requirements	1/23/2023	1/28/2023	Whole Team	0%		6	5
1.8	Make a product requirements li	1/23/2023	1/28/2023	Whole Team	0%		6	5
1.9	Write a problem statement	2/3/2023	2/3/2023	Whole Team	0%		1	1
1.10	Project Proposal	2/6/2023	2/6/2023	Whole Team			1	1
2	Phase Two	3/3/2023	3/3/2023		0%		1	1
2.1	Project Design Review	3/3/2023	3/3/2023	Whole Team			1	1
3	Phase Three	4/17/2023	4/24/2023		0%		8	6
3.1	Final Presentation	4/17/2023	4/21/2023	Whole Team	0%		5	5
3.2	Final Report	4/24/2023	4/24/2023	Whole Team			1	1



Appendix B

Pre-Interview Survey

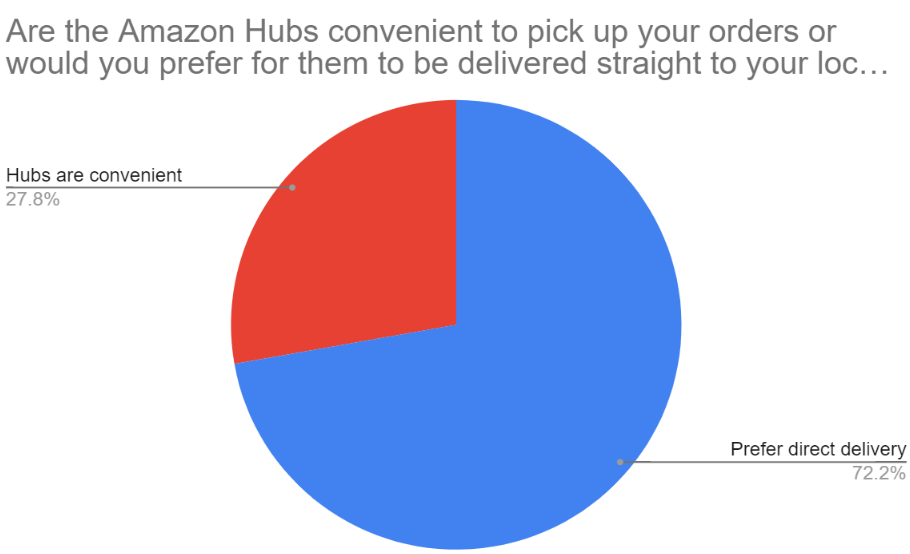


Figure B1. Delivery Preference Responses (Unfiltered)

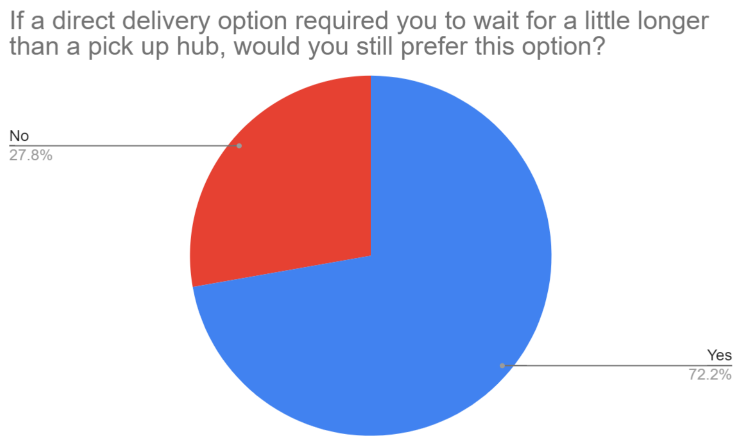


Figure B3. Wait Time Responses (Unfiltered)

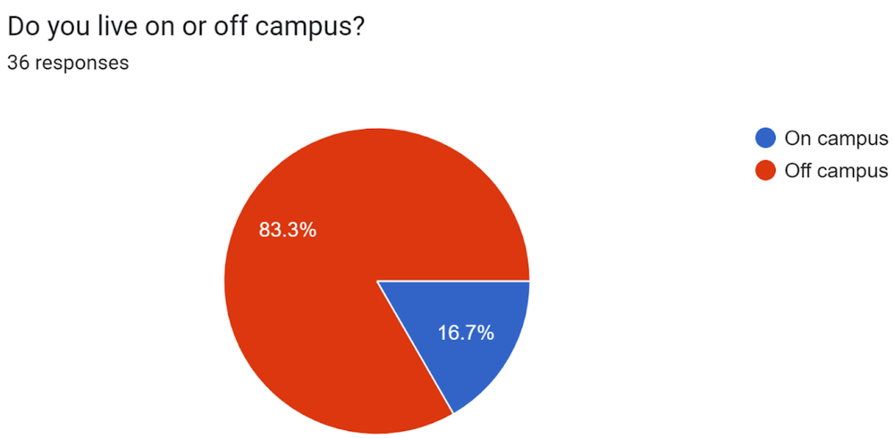


Figure B4. Residence Responses

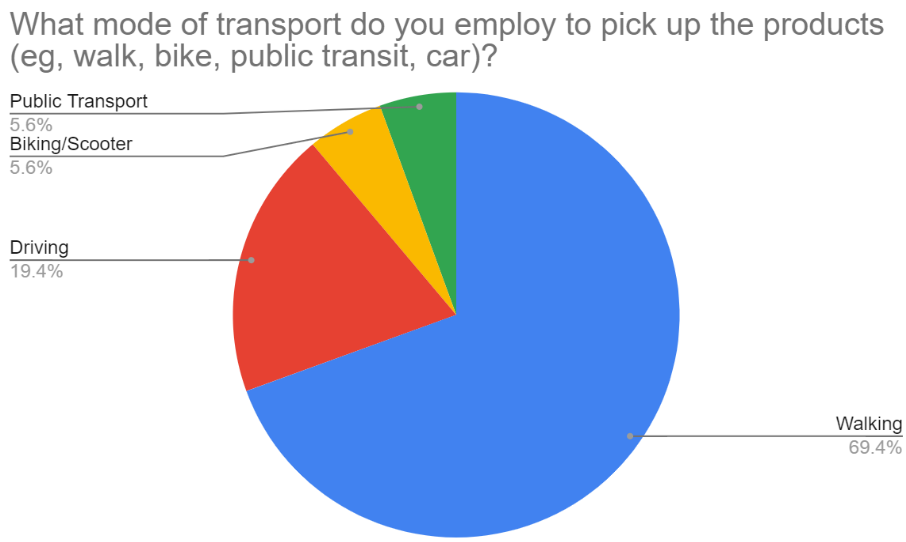


Figure B5. Mode of Transportation Responses

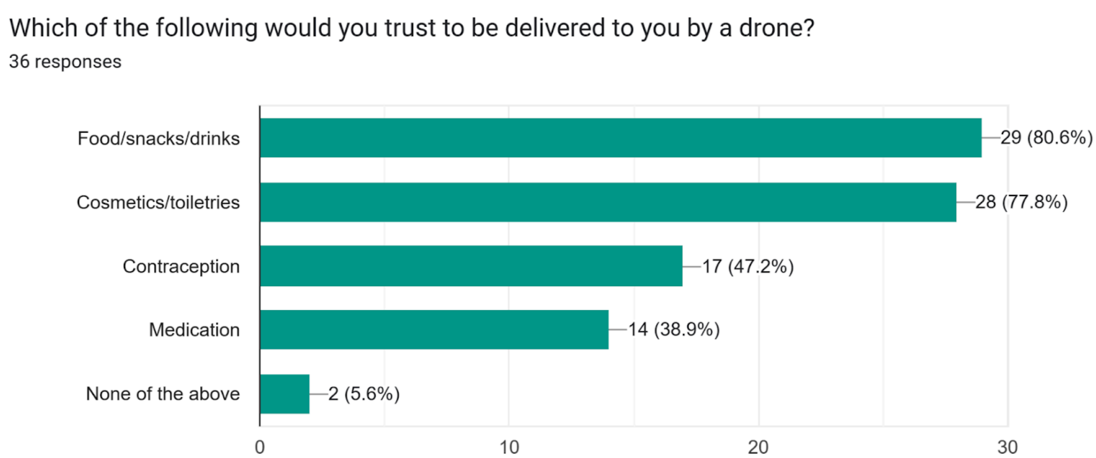


Figure B6. Item Selection Responses

Appendix C

Recipient Interviews

Interviewee: **Caitlin M., 4th year Mechanical Engineering**

QUESTION	CUSTOMER STATEMENT	INTERPRETED NEED
Walk me through what you imagine this delivery/drone interaction might look like.	"I see it being like Uber Eats but without the tip part, because there's no driver. Since it's a drone, it kind of removes the problem of whether a driver will or will not pick up the order. I'm thinking the drone is coming from some kind of hub or warehouse, like Amazon, and it calculates the distance of the closest hub to you. It might give you an estimated time and cost." "I feel like it might be hard for it to come up to the doors. Maybe there's something like an Ikea pop-out storage box that attaches to the mailbox that the drone can lower the package into." "I could access this service through an app or web."	Low cost, accessible, tracking system, ease of delivery
Do you have any experience with drones?	"My brother uses drones in filming, and I helped him test it out when he initially got it. I would be standing under it in case it malfunctioned or fell. It was a very expensive camera drone, so I imagine it's a little different than a hardy delivery drone." "Mostly very comfortable approaching a drone, unless it looks very industrial."	Sturdy, non-intimidating look
Based on the earlier drone images and your own experience, what are your likes and dislikes?	"The controller that was used for it had a very nice screen. That wouldn't be as big of a thing for this case, but it had a tracking for altitude and distance. I could see this technology being used for places like Pizza Hut that can track and display order status like when it's been placed, if it's on the way, the customer seeing what the drone sees."	Tracking system
How do you typically find out about new services around/on campus?	"Favor, specifically, has all the blue stickers everywhere. But mostly word of mouth."	Reliability
Anything else that was not addressed by the form or interview?	"Nope, the Google form was nice and thorough!"	

Interviewee: **Jordan S., 3rd year Mechanical Engineering**

QUESTION	CUSTOMER STATEMENT	INTERPRETED NEED

Walk me through what you imagine this delivery/drone interaction might look like.	"Go to the store website and then select a drone delivery option after checkout. Then, probably put in a timeslot for the delivery like asap or a designated time. I live in a condo, so I'm not really sure where the drone would drop off. You need to punch in something to get inside, so maybe just outside the building, but I'm not sure if that's safe or ideal." "Hopefully the drone would just lower, slowly. It should probably sit down on the ground, release the thing, and then fly back up." "Maybe access by calling or emailing the service, whichever is easiest for the consumer."	Reliable drop-off location, safe product landing, accessible
Have you used a drone before?	"Yea, my brother had a drone when he was like 10 or something. He flew it on the beach, and there was a lot of sand everywhere. The thing about it is that it kind of ran out of battery pretty quickly." "Comfortable approaching a drone as long as it has been tested beforehand."	Reliable, safe to environment
Based on the earlier drone images and your own experience, what are your likes and dislikes?	"Not too worried about battery time as a consumer. I liked that the drone had a follow feature that would follow you around, but I don't know how practical that is for delivery. Maybe it could locate the person, but it has to know which person it is."	Tracking system
How do you typically find out about new services around/on campus?	"Merch, free merch. I get a lot of GoPuff merch and ads on my phone and at the games."	Bribe (with free merch)
Anything else that was not addressed by the form or interview?	"I was in the store recently and I needed some face wash, and I went to CVS like a week ago. That thing was kind of heavy, so would that be a problem for the drone?"	Robust

Interviewee: **Riya Patel, 3rd year Chemical Engineering**

QUESTION	CUSTOMER STATEMENT	INTERPRETED NEED
Walk me through what you imagine this delivery/drone interaction might look like.	“The first thing that comes to mind is that a lot of times when I am studying late at night, I want coffee, snacks, and other stuff like that. At times like 10 or 11 PM, I don’t have those things at my apartment, and I don’t feel like walking to a convenient store. So I could definitely see myself using that service then. Also, I could see myself using the service when I am running late or am going somewhere and want a quick drink like Gatorade. It would be nice if the drone could deliver what I want as I am getting ready. It would also be nice if the drone delivery service was interfaced with an existing app like CVS or Uber.”	Convenient, accessible, integrated use with existing technology, ease of delivery
Do you have any experience with drones?	“I have only heard of Amazon Prime Air but don’t have any personal experiences with anything drone related.”	Educate customers about drones before delivering
Based on the earlier drone images and your own experience, what are your likes and dislikes?	“It looks like the propeller designs that are closed-loop seem safer than those with exposed wings/propellers. I am not a mechanical engineer, so I don’t know how easy that is to implement but the closed-loop designs look safer to the untrained eye! The white drone designs also seem more aesthetic which could play a factor for customers. As for some dislikes, I would be concerned about if a drone dies and hits me or a pedestrian. I think finding ways to mitigate that is necessary for a service like this. Another thing to think about is to make sure that the package can only be accessed to the person ordering it - you don’t want someone else to steal it just because it was dropped off at some location by the drone.”	Ensured safety of propellers, white design for aesthetic purposes, educate customers before delivery, safety of package to the customer

How do you typically find out about new services around/on campus?	“Usually through social media or word of mouth. For example, I heard of Fetti through my friends and started going on Fetti’s instead of Lyft or Uber rides because my friends influenced me to go with them and because it seemed cooler. I think this service could grow the same way by presenting the service as cool, sleek and convenient for people.”	Aesthetic, convenient
Anything else that was not addressed by the form or interview?	“I think the form mentioned this, but I would be willing to pay 10% for a delivery fee since the volume of the order is low. In my head, I would only be paying like 20 cents for a $2 coffee to get it delivered to my door which is worth it to me!"	Reliability on low cost/low volume deliveries to not pay as much total cost for delivery

Interviewee: **Evandhika Bimaputra, 4th year BHP + Philosophy + Math**

QUESTION	CUSTOMER STATEMENT	INTERPRETED NEED
Walk me through what you imagine this delivery/drone interaction might look like.	“The way that I am thinking about such a drone delivery service is trifold: order, delivery, and feedback. Within the ordering stage, I imagine myself ordering my groceries through a mobile application. Once the order is received, it will be processed through the system and leads into the next stage. The delivery stage is where the drone will be mobilized and delivered to my doorstep. I anticipate that there will be a unique code designated for my order to ensure anti-theft measures. Once I have received my delivery from the drone, I will inspect the contents of the package to justify my feedback on the application or company I ordered from.”	Convenient user interface, tracking system, safety of package that is being delivered

Have you used a drone before?	"When I was in New York over the summer, I had the opportunity to pilot my friend's drone in Central Park. However, I do not have any experience with existing drone delivery systems like Amazon Prime Air."	Educate customers about drones before delivering
Based on the earlier drone images and your own experience, what are your likes and dislikes?	"To be honest, I just want my package to be delivered as fast as possible, so I don't really care about how the drone appears to me. One concern I have is the safety of the package the drone is carrying as well as the environment around the drone. I do not want the drone to run into a tree, hit a pedestrian's head, and break what I ordered."	Quick delivery, safety concerns for the package and environment
How do you typically find out about new services around/on campus?	"I typically see posters in elevators in West Campus apartments which force me to pay attention since there is nothing else to do in elevators."	Market with fliers in West Campus apartments
Anything else that was not addressed by the form or interview?	"I believe a great idea for drone delivery in West Campus or urban areas like New York City would be to deliver to customers' windows to make it even more convenient."	Convenience through direct window delivery

Interviewee: **Tay Nguyen, 4th year Civil Engineering**

QUESTION	CUSTOMER STATEMENT	INTERPRETED NEED
Walk me through how you see yourself using the product and how you would access it	Place an order on an app like the Target app. There is an option for delivery, pickup, ship to store, so there could be another tab for drones. Want to get updated when it's time to go downstairs and pick up the order. 15-20 minutes or so as expected delivery.	Cohesive order -> delivery process

How often could you see yourself using this service?	Goes to convenience stores to pick up NyQuil, bandages, but these are not items that are frequently purchased. Does not visit unless there is an urgent situation, so the delivery makes sense with the urgency. Buying groceries are more common for interviewee, would use drone delivery for produce. Is not scared of drones or approaching them to retrieve item from bag.	Low need for direct delivery
Based on the images we saw earlier, what are some likes and dislikes about using a drone delivery system	Hasn't used drones, but has seen Chick-Fil-A drones. Likes: the convenience Dislikes: Doesn't know the infrastructure behind how they move. Might be obstructions for people walking or buses. How to navigate trees? Not a big concern, but with west campus homeless people / drunk people might abuse it potentially	Main doubt is drone crashing (infrastructure safety over personal safety concerns)
How do you typically find out about new services around/on campus?	Having friends use something/word of mouth is significant attribute Goes for brands that can do one job really well and consistently, like MetroBike Social media presence is also bonus, but not primary motivator	Reliability
Anything else that was not addressed by the form?	Thinks drones are interesting, thinks college audience is ideal for delivery as people are very likely to put aside cost for convenience.	
Ranking/This or That	**Convenience vs. safety** Convenience **Cost vs. immediacy** Cost **Cost vs. product integrity** Product integrity **Out of all options** Convenience is most important	Convenience triumphs, safety not a large concern

Interviewee: **Axel Puebla, 3rd year Aerospace Engineering**

QUESTION	CUSTOMER STATEMENT	INTERPRETED NEED
Walk me through how you see yourself using the product -> how you would access it	Ideal process would be placing an order on the website, going about their day. Wants box to be placed in balcony. The drone should leave the package there and fly off. If the interview weren't to have a balcony, then a pick up spot (like Amazon Hub) would be another option.	Drone is self sufficient, does not require customer presence
How often could you see yourself using this service?	Somewhat. Interviewee is usually on the campus area, so walking to CVS is not a huge trip. They also have a car, so picking up items is usually not a hassle.	Moderate need for direct delivery
Based on the images we saw earlier, what are some likes and dislikes about using a drone delivery system	Dislikes: If the drone experiences a crash, the package may be lost or destroyed. Likes: navigates west campus quickly, since the road conditions are usually changing often.	Assurance of damage-free delivery
How do you typically find out about new services around/on campus?	Flyers or word of mouth. Says recommendations from friends are the strongest motivator in purchasing a product/service.	
Ranking/This or That	• Convenience or cost: cost • Safety or immediacy: safety • Safety or cost: cost • Immediacy or convenience: convenience	Cost triumphs convenience and safety

Interviewee: **Minh Quan Duong, 1st year Chemical Engineering**

QUESTION	CUSTOMER STATEMENT	INTERPRETED NEED
Walk me through how you see yourself using the product -> how you would access it	Get confirmation that order is received, get tracking code to check delivery process. Send regular updates on progress of delivery. The drone should deliver the product without intervention.	Regular information sent to customer
How often could you see yourself using this service?	Not often, does not like spending money. Interviewee plans purchases ahead, says it eliminates the reliance on delivery.	Low cost
Based on the images we saw earlier, what are some likes and dislikes about using a drone delivery system	Likes: efficient Dislikes: Tradeoffs from size; if the drone is too large, it will deliver the product in an exposed manner. But if drone is smaller, it restricts the carrying capacity	Package should be securely stored
How do you typically find out about new services around/on campus?	Social media piques interest…there are many interactive features	
Ranking/This or That	● Convenience or cost: cost ● Product integrity or immediacy: product integrity ● Product Integrity or cost: safety	Product integrity triumphs

Appendix D

Customer Needs List

Category	Customer Needs	Weights (1-5)*
Time	The drone must take off and land quickly.	3
	The user should be able to load the payload quickly.	3
User Interface / Recipient Experience (UI/UX)	The user interface must be intuitive for those piloting the drone.	4
	The recipient should not have to touch or interact with the body of the drone to receive their delivery.	3
	One person should be able to easily load the drone payload.	3
	It would be nice if the drone integrates with existing store technology and infrastructure.	2
Safety	The drone should have safety features to avoid collisions.	4
Drone Capabilities	The drone must be able to take off and land in small spaces.	5
	The drone should be able to complete a round-trip delivery of up to 2km.	4
	The drone must be durable and function after regular wear and tear.	4
	Drone must be able to be controlled without visual line of sight.	4
	The drone must be able to be repaired by the user without the use of specialized tools.	4

Size	Drone should be able to be carried by one person	3
	The unloaded drone should be easily storable while not in use	3
	The unloaded drone must be able to fit through a typical door.	5

Appendix E

House of Quality

What		Relative Importance	Time to take off time bewteen 1-3 seconds from turning on power	Energy to secure payload = 5 newtons -15 newtons	Energy to detach payload = 5 newtons - 15 newtons	Avg. width of door frame (under 762 mm)	Maximum weight	onboard camera (>=24 FPS capture	Drop test from varying heights with store packaging (0.15m,0.3m,0.6m,1m)	Control system (PID controller) (update time ~= 500 milliseconds)	Drop test and latch cycling with storage enclosure (0.15m,0.3m,0.6m,1m)	Test remote control/receiver in urban conditions for interference issues at 200m,400m,600m,800m, and, 1000m (remote will broadcast @ 2.4 GHz or 5GHz)	Number of unique subcomponets (3-	Material used with high durablity and toughness (frame = Young's modulus range 100GPa-180GPa. Drone houng = Young's modulus of 1GPa-3GPa)	Thrust-to-weight ratio
	Direction of Improvement		←	←		→									
	Units		seconds	N	N	m	N	FPS	m	milliseconds	m	m	N/A	GPa	N
Time	Drone should be able to start/ take off quickly	3		X	X		X								
Time	Quickly secure and detach payload	3		✓	✓										
Time		0													
(UI/UX)	Easy to use drone control interface	0						?							
(UI/UX)	Recipient receives delivery without contacting drone	0						✓							
(UI/UX)		0													
Safety	Collision avoidance	0						✓							
Safety	Package remains intact during drop-off	0							✓						
Safety	Secure package storage area	0									✓				
Drone Capabilities	Stable (no drift) while flying/landing/taking off	5	?				✓			✓					
Drone Capabilities	Capable of a delivery radius of 1km	4					X								
Drone Capabilities	Drone must be operable without visual line of sight	4						✓				✓			
Drone Capabilities	Easily repairable with common tools	4											✓		
Drone Capabilities	Made of durable material that's resistant to wear anc	4												✓	
Size	Small enough for one person to carry														
Size	Storable on a shelf					✓									
Size	Fit through a typical door					✓									
	Target		1	10	10	0.762	1.8	24 FPS	no damage that	500	no damage to	1000	3	frame = 1400.	

How +

Appendix F

Engineering Specifications

Category	Demand/ Wish	Customer Need	Design Requirement	Verification Method
Architecture	D	Compact size	Smallest dimension must not exceed 36 inches, horizontal surface area less than 4 sqft	Solidworks measurement
	W	Stable in flight	Aerodynamic, balanced	CFD, CG analysis in Solidworks
	D	Lightweight	Unloaded weight less than 4 lbs	Solidworks measurement
	D	Durable	Able to carry out a delivery after dropped from 2 ft (no flight essential components fail)	FEA
Setup	D	Clear building instructions	Instruction clarity score greater than 4	Instruction clarity scale (1-5)
	W	Short build time	Can build in one weekend	Consumer trials
Maintenance	D	Easily repairable	Uses common tools; disassembly takes less than 3 hours	Consumer trials
	W	Short energy import time	Stored usable energy capacity should go from 20% to 80% in 15 minutes.	Prototype trials
Safety	W	Protected from moving parts	Contact in horizontal plane does not result in damage to either moving parts or obstacle	Prototype trial, simulation
	W	Safe even if connection lost	Loss of connection results in return to origin or safe landing	Prototype trial
Capabilities	D	Sufficient range	Minimum 2 km round trip	Power calculations from energy storage device + motor combo

Category	Demand/ Wish	Customer Need	Design Requirement	Verification Method
	D	Can see the drones surroundings	Can avoid obstacles with vision only	Prototype trials
	D	Easy to deliver package accurately	Deliver package within a 1m diameter target with no more than moderate (4-6) difficulty	Consumer trial, Perceived Exertion scale
	D	Can carry various sized items	Payload securing mechanism can carry items up to a cubic foot.	Solidworks measurement
	D	Can carry items weighing up to a bottled drink	Can support package weights less than 0.5 lb	Thrust calculations
	W	Take off quickly	Motors generate enough thrust for lift off within 10 s	Thrust calculation from motor specs
	D	Drone is operable without direct line of sight	Pilot receives real-time position data AND/OR live video	Prototype trials
	W	Can fly at night	Delivery fulfillment rate of at least 70% of that of daytime after sunset	Prototype trials
Cost	D	Inexpensive	Costs less than $250	Bill of materials

Table F1. Engineering Specifications List

Appendix G

Functional Models

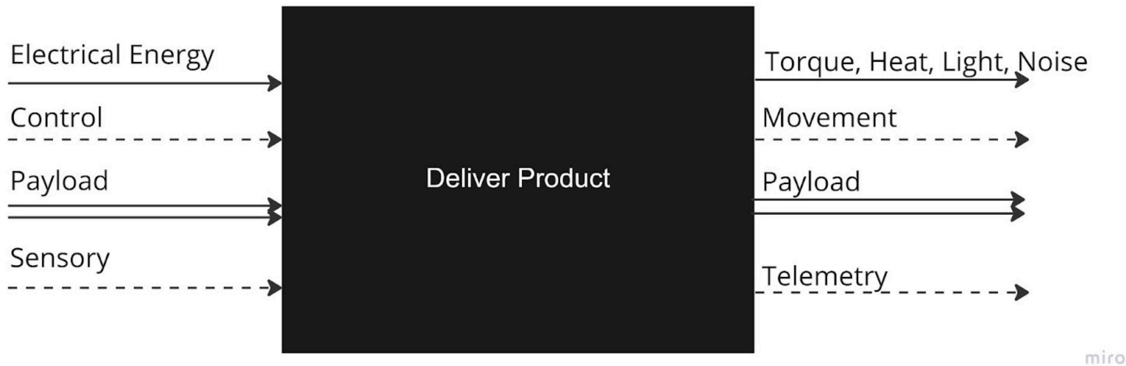


Figure G1. System-level Black Box Diagram

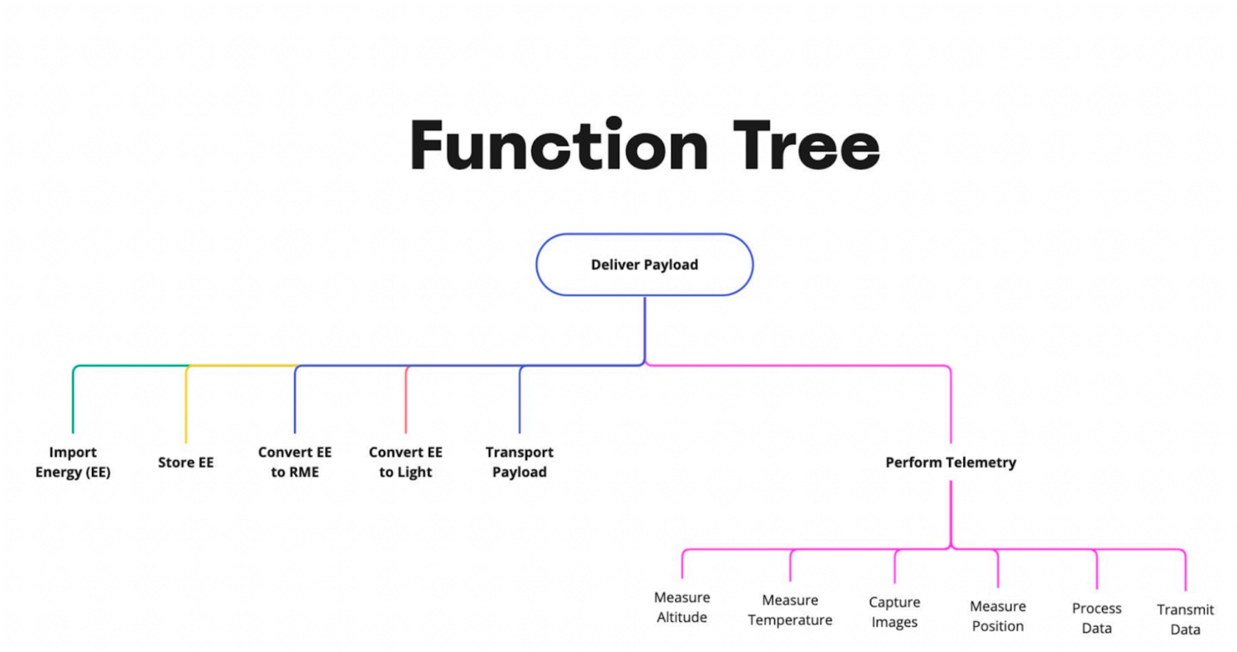


Figure G2. Function Tree Diagram

Appendix H

Idea Generation: Mind Mapping

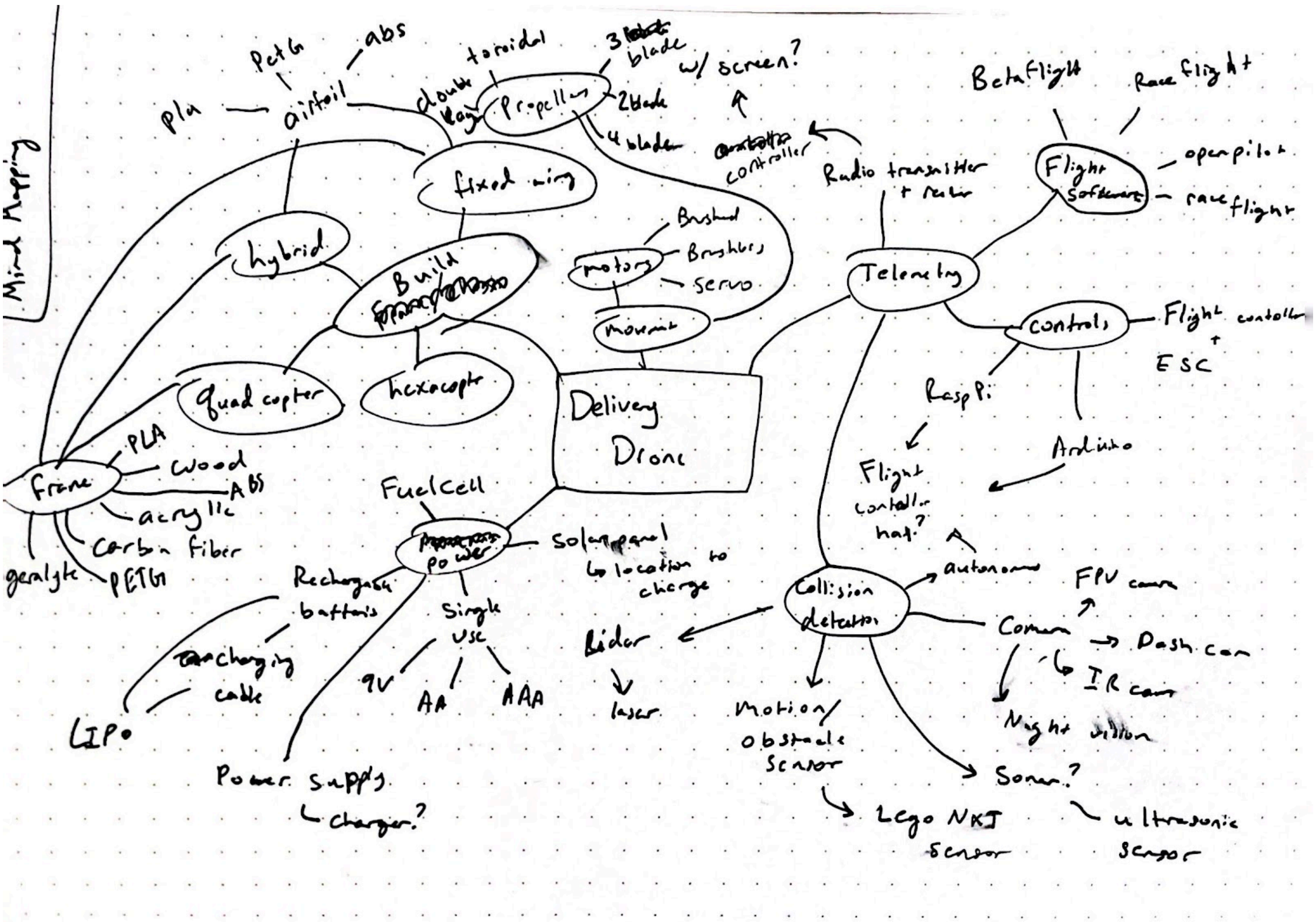


Figure H1. Ishan’s Mind Map

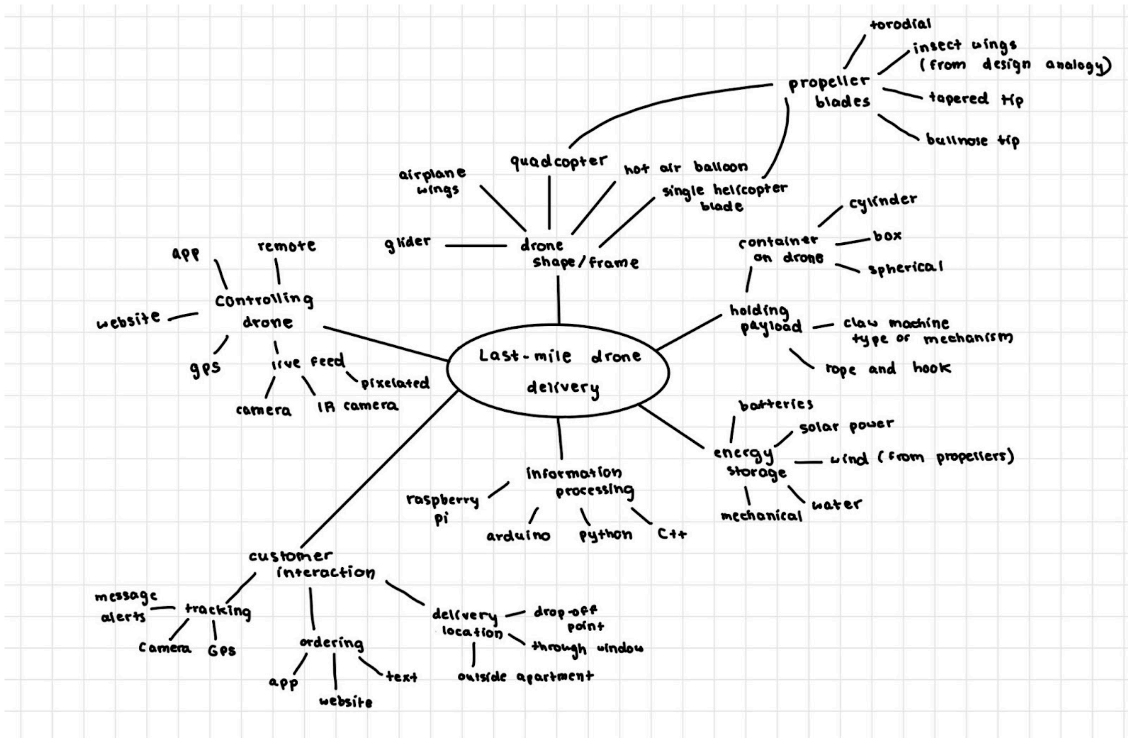


Figure H2. Vivian's Mind Map

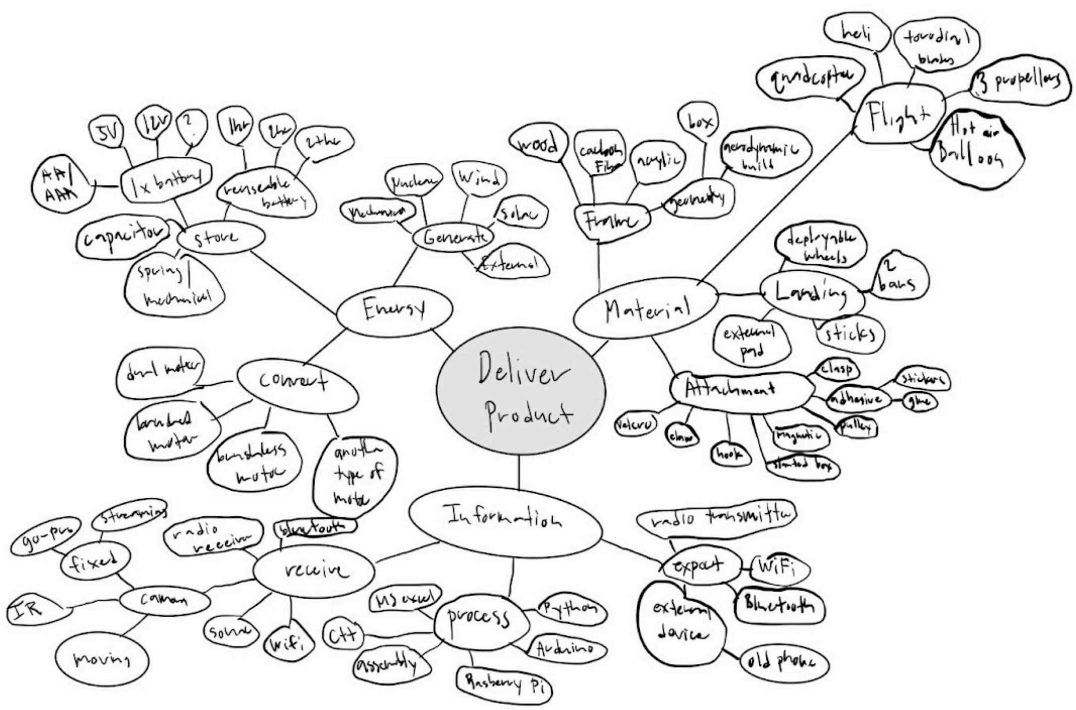


Figure H3. Ron's Mind Map

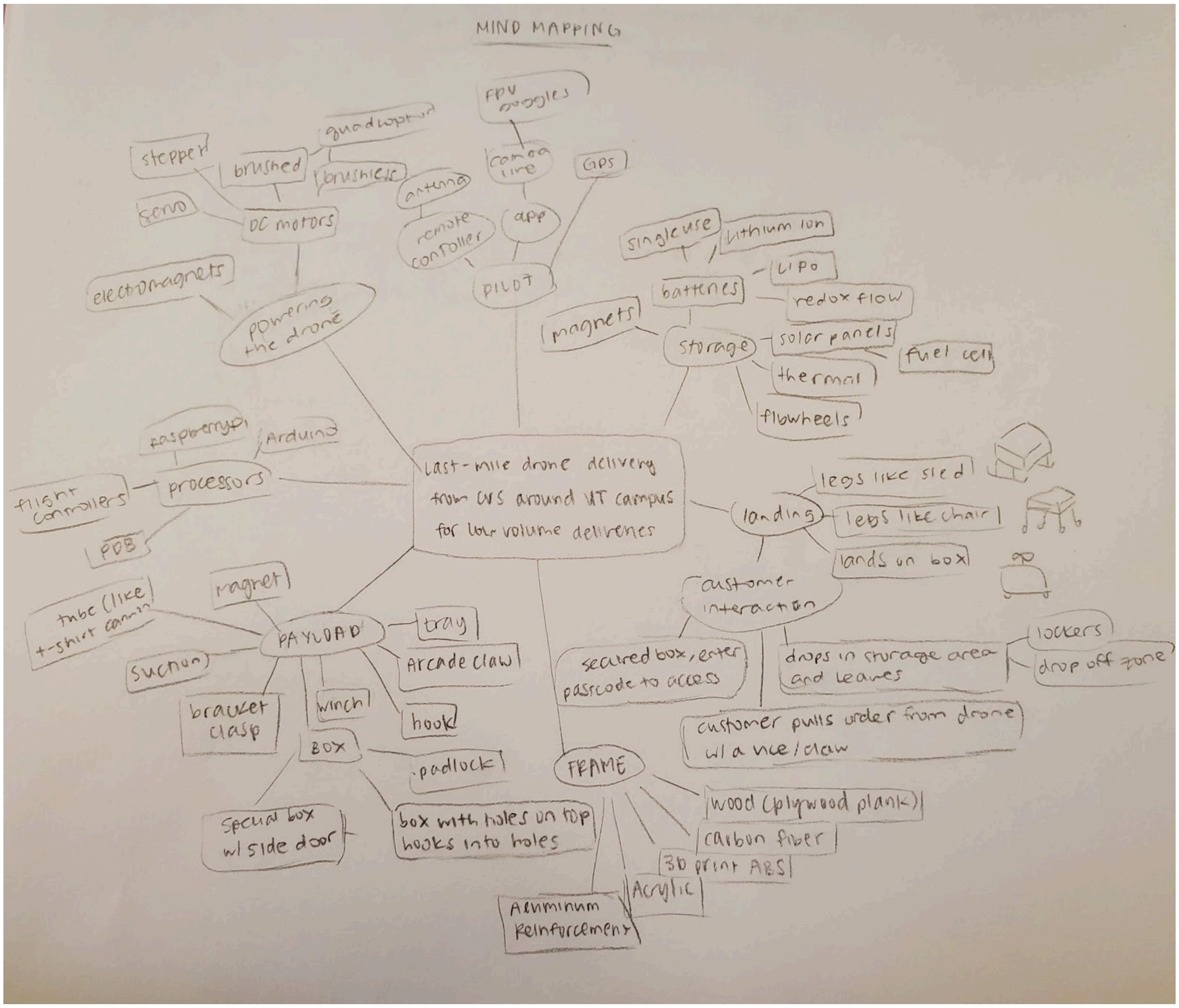


Figure H4. Kavi’s Mind Map

Appendix I

Idea Generation: Design Analogy

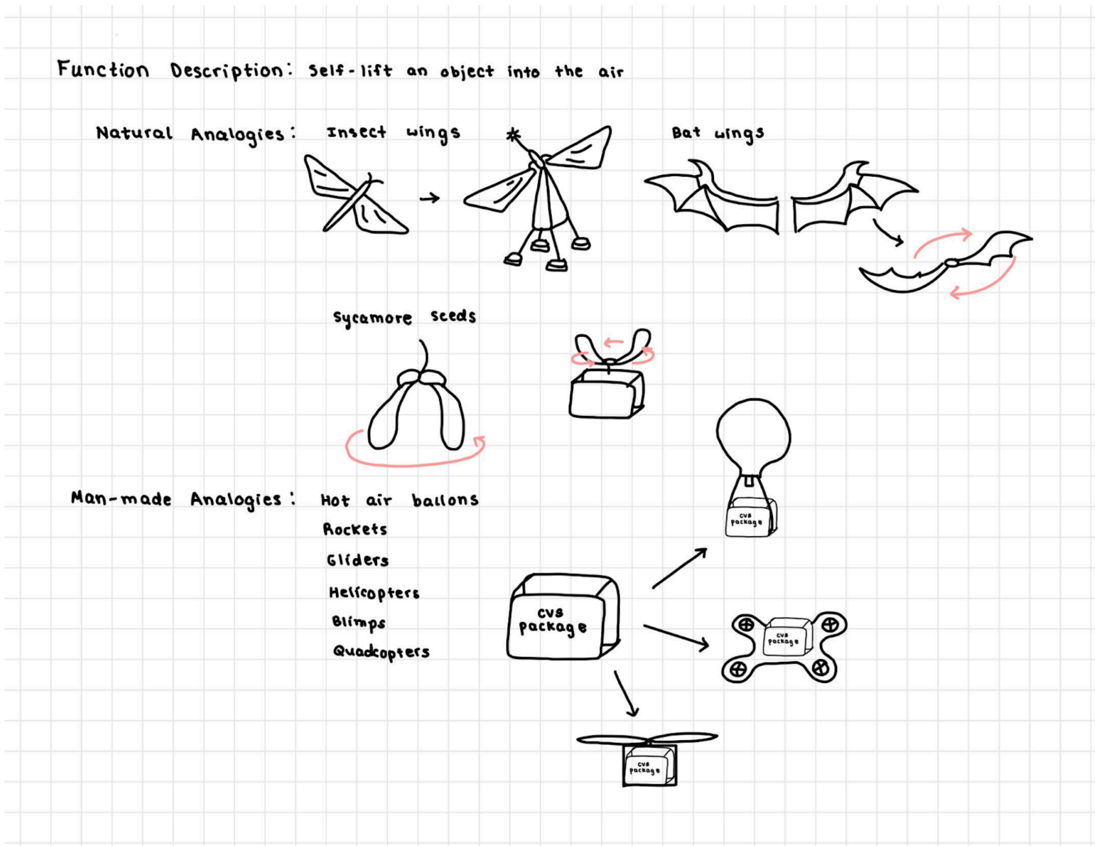


Figure I1. Vivian's Design Analogy

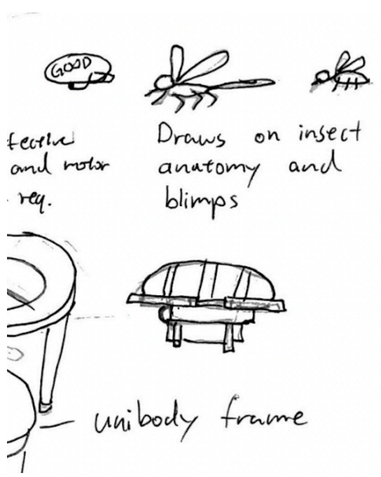


Figure I2. Calvin's Design Analogy

Appendix J

Idea Generation: 6-3-5 Method

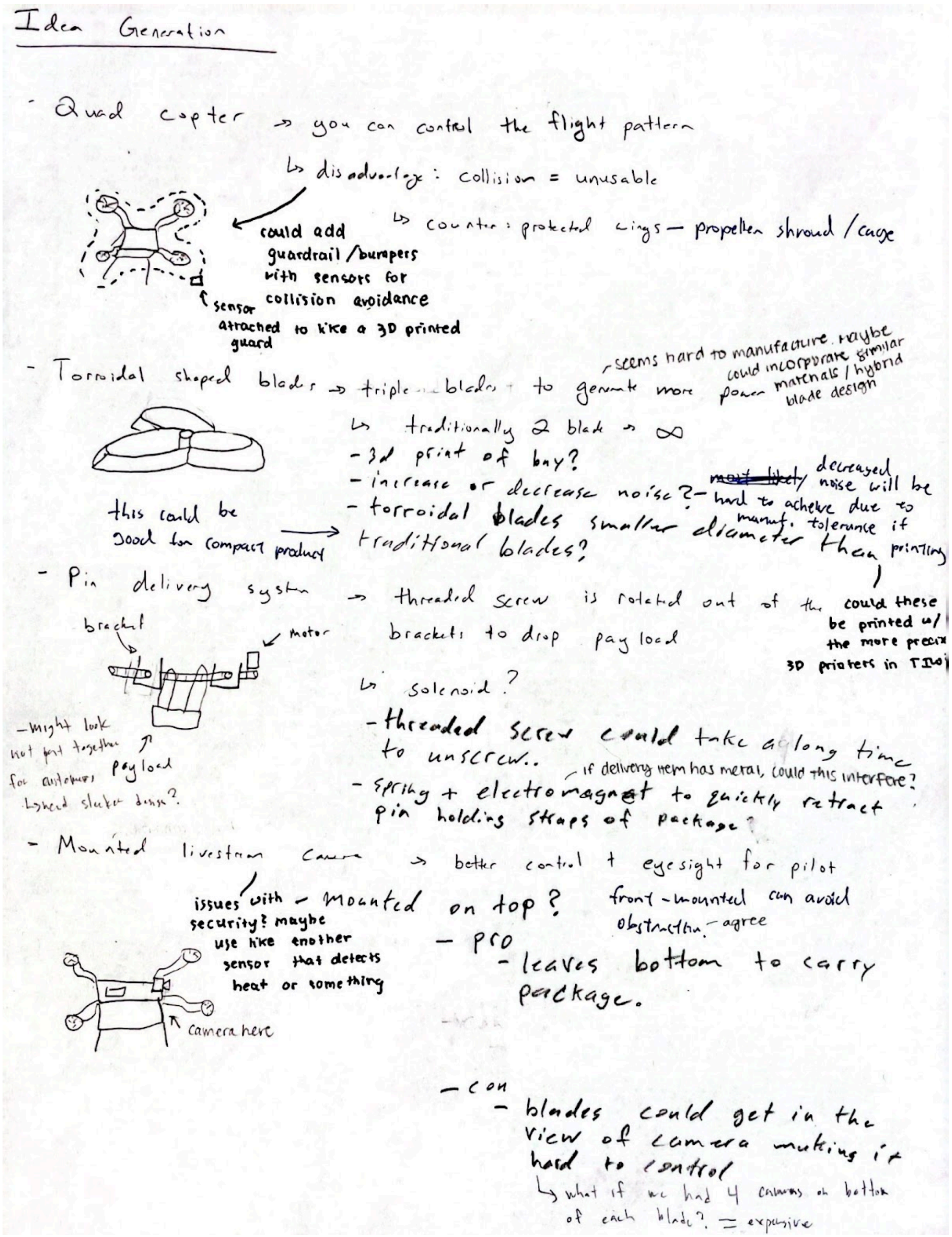


Figure J1. Ishan’s 6-3-5

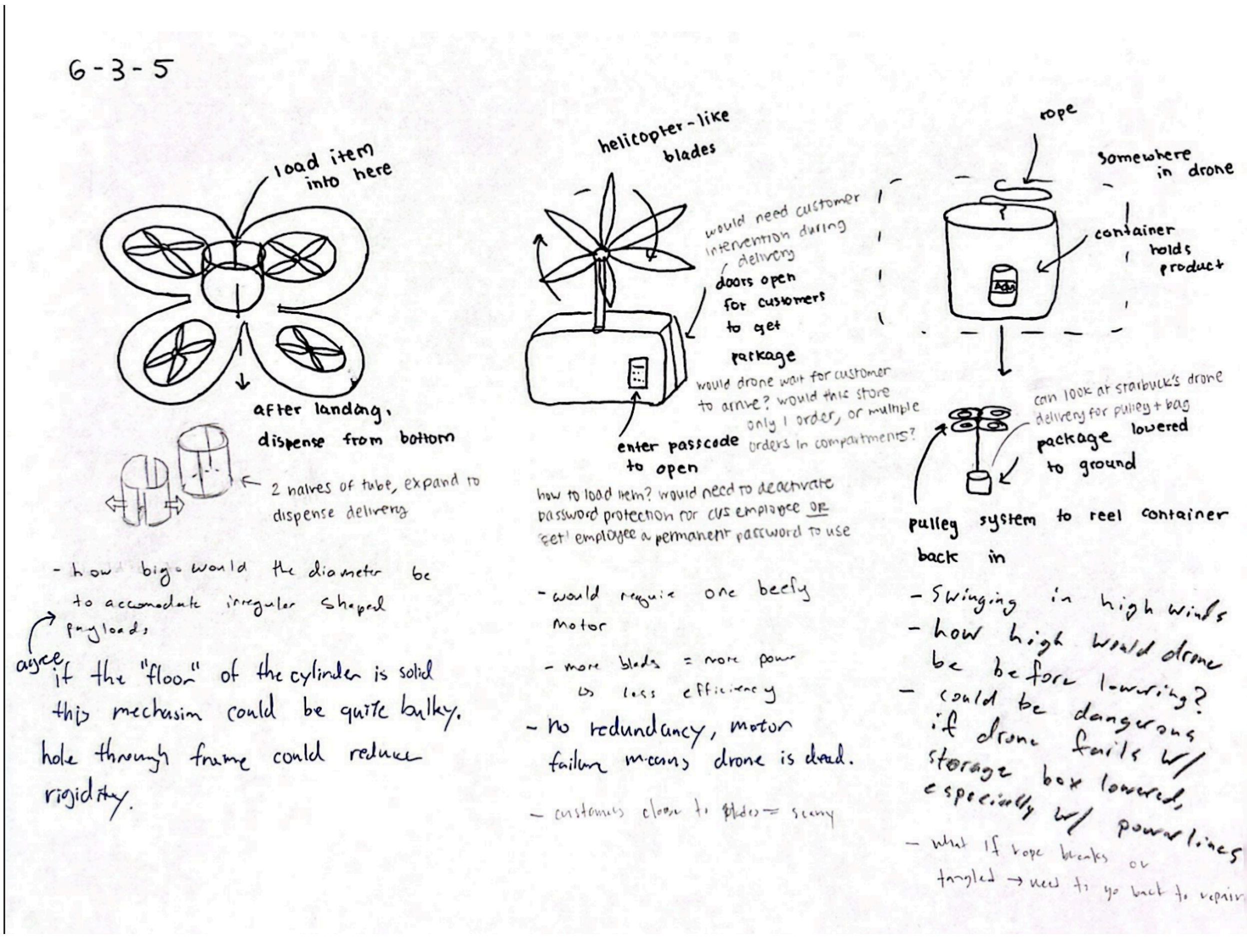


Figure J2. Vivian's 6-3-5

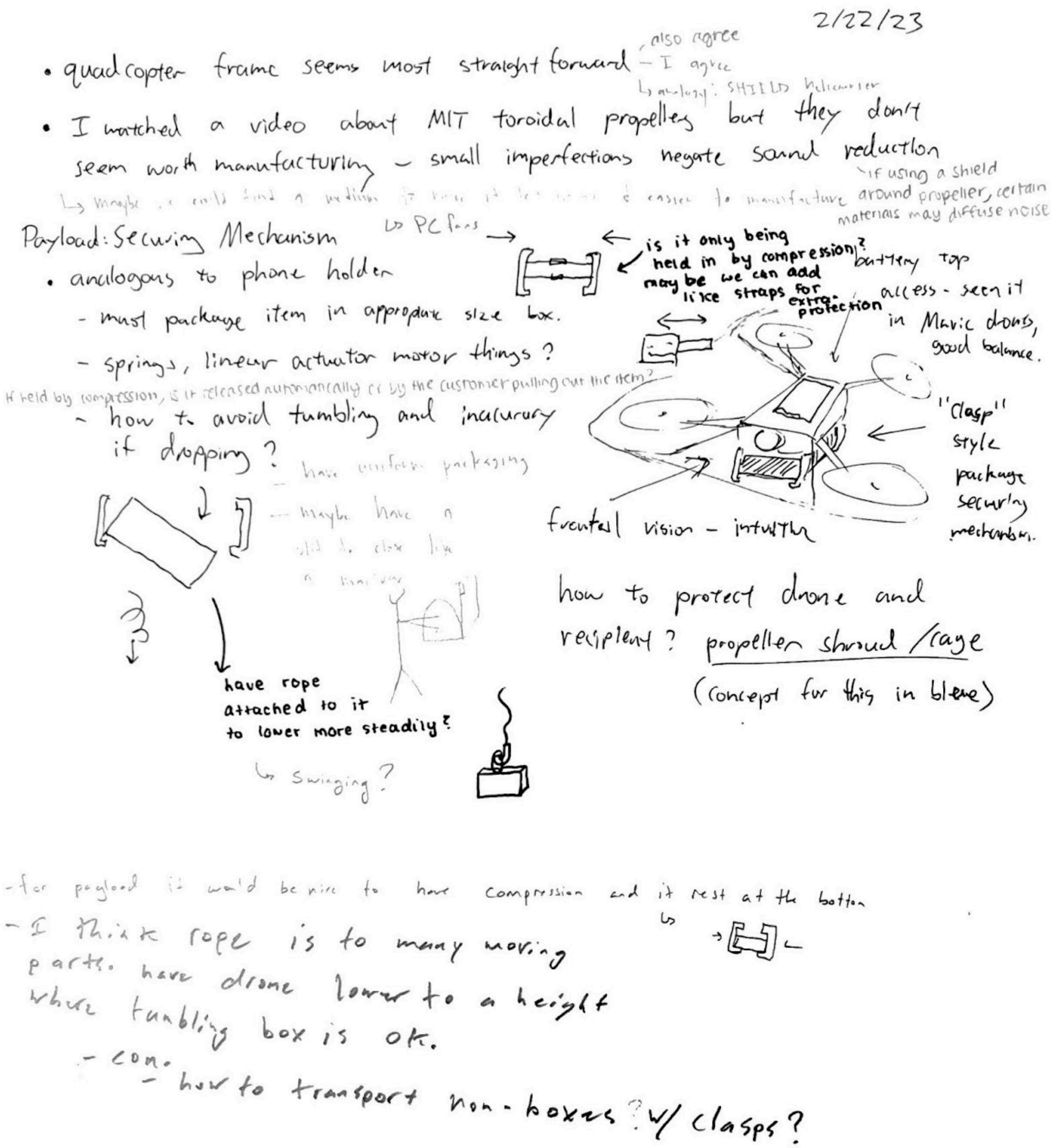


Figure J3. Calvin's 6-3-5

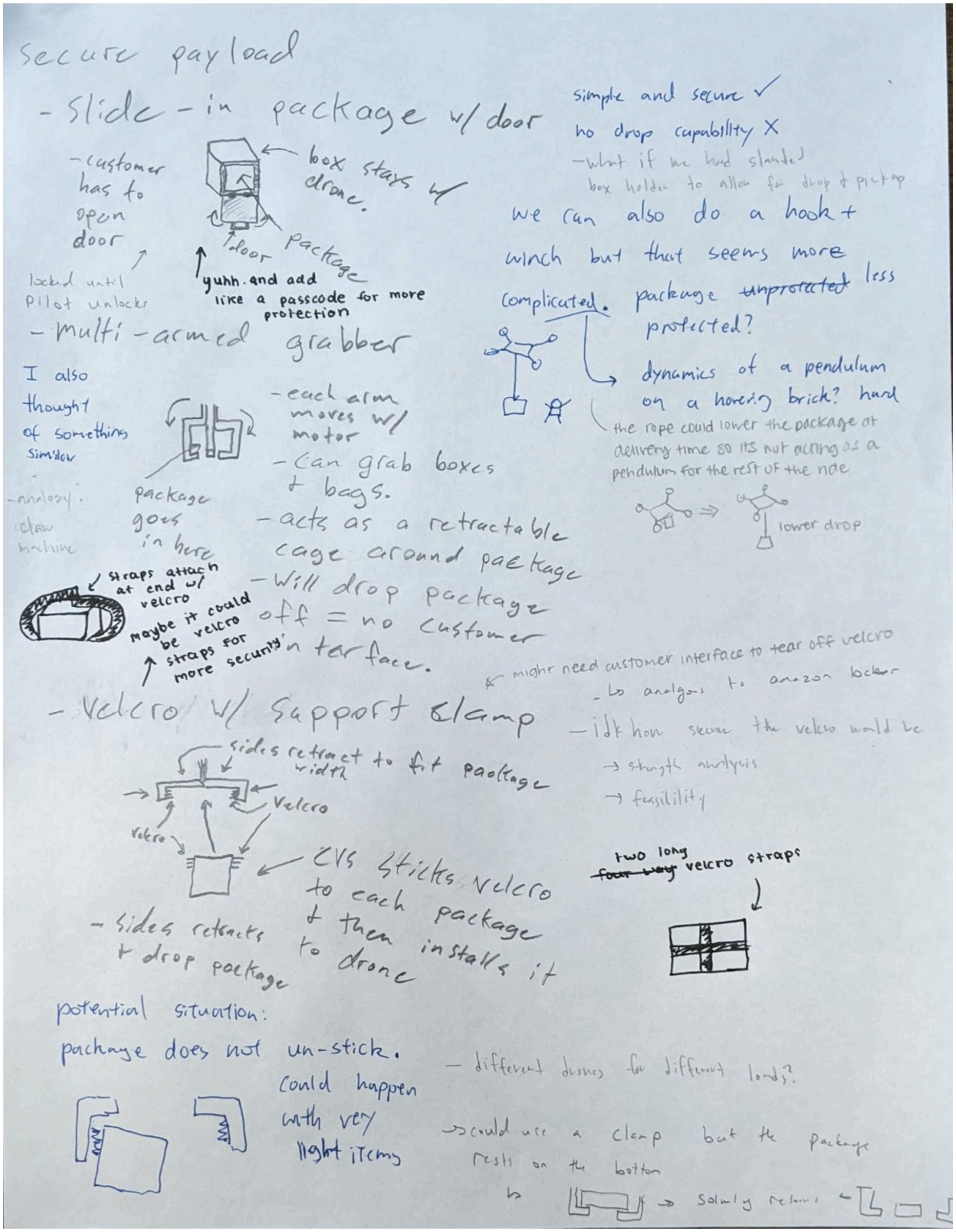


Figure J4. Patrick’s 6-3-5

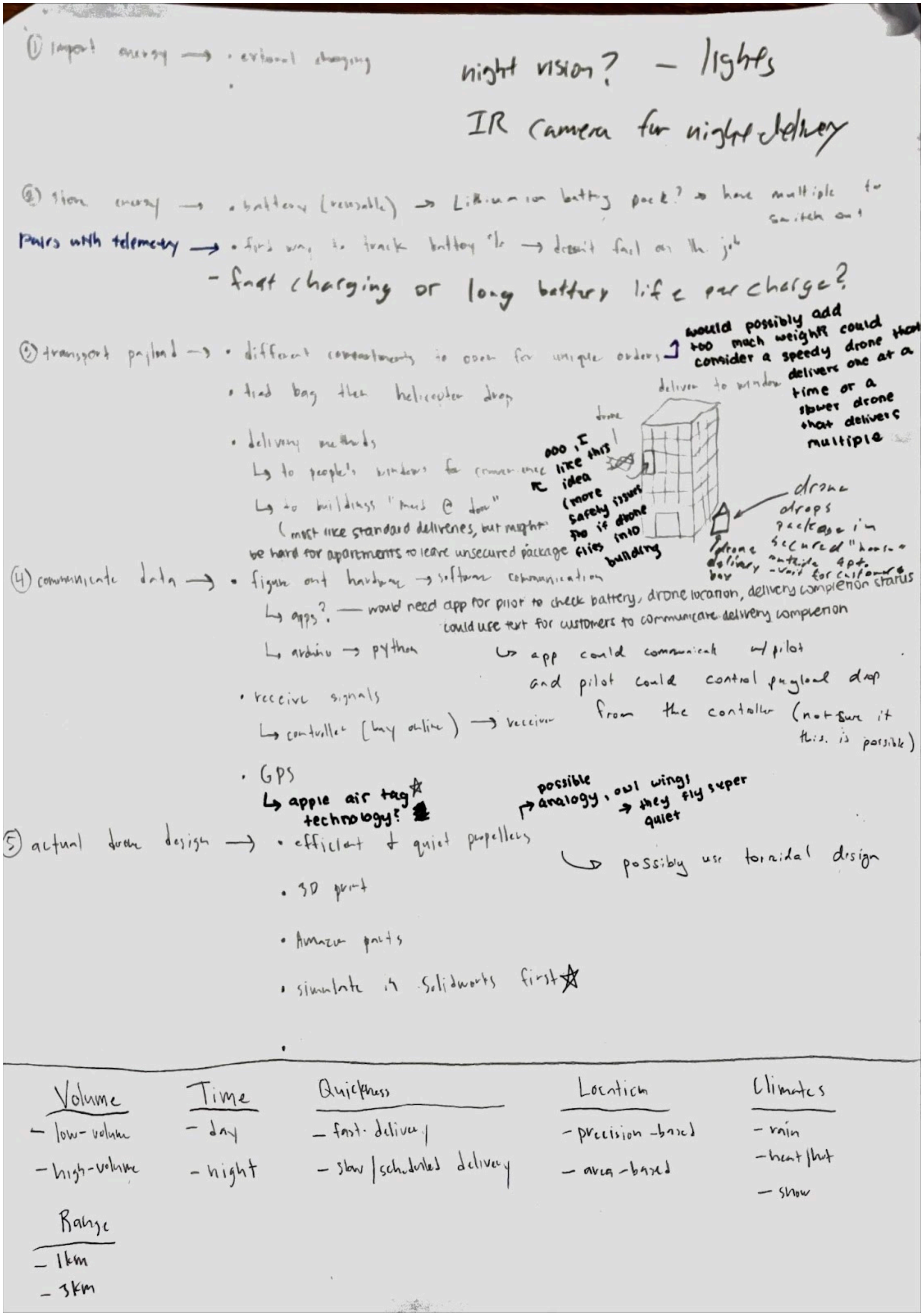


Figure J5. Ron’s 6-3-5

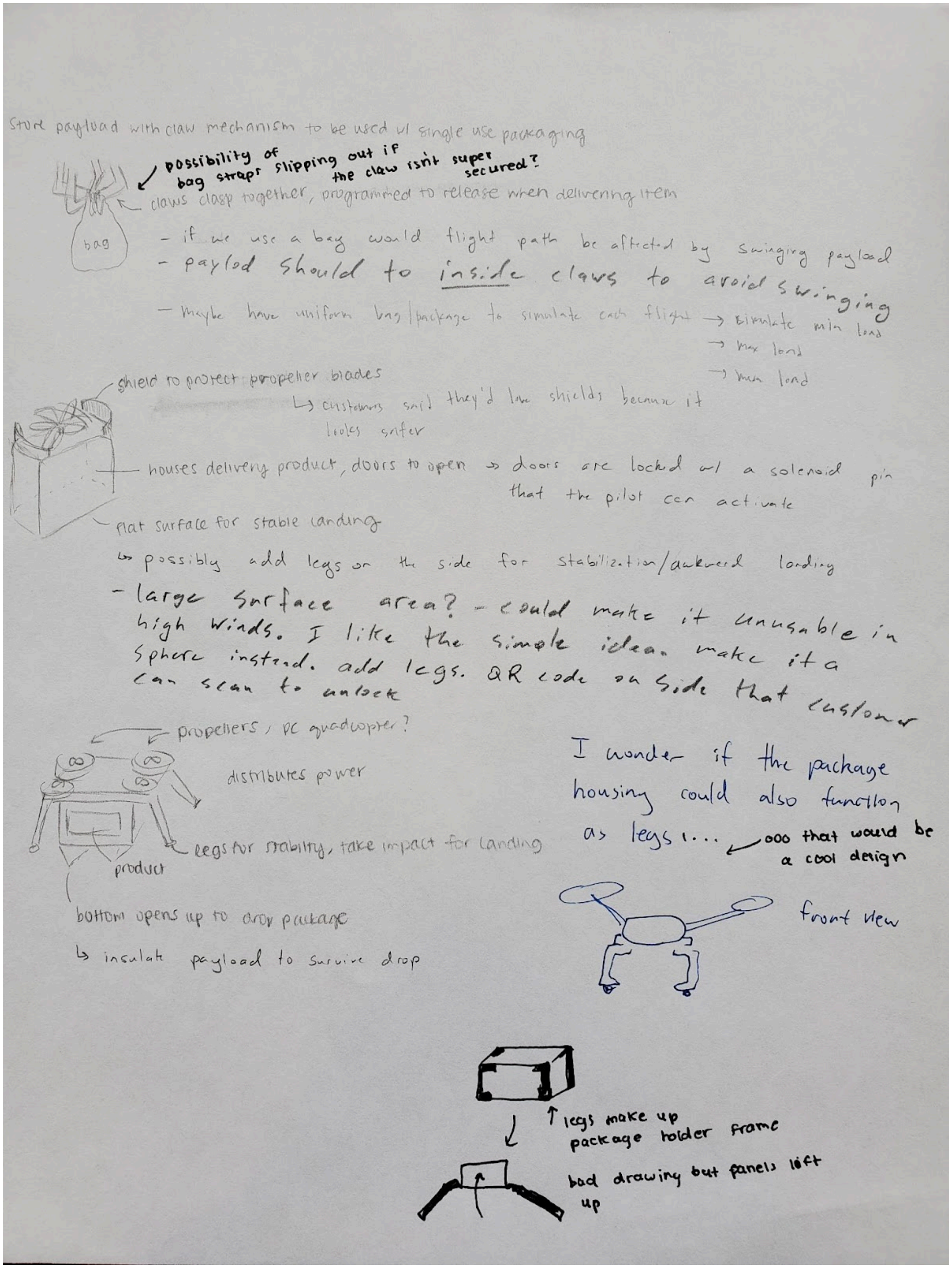


Figure J6. Kavi's 6-3-5

Appendix K

Prior Art

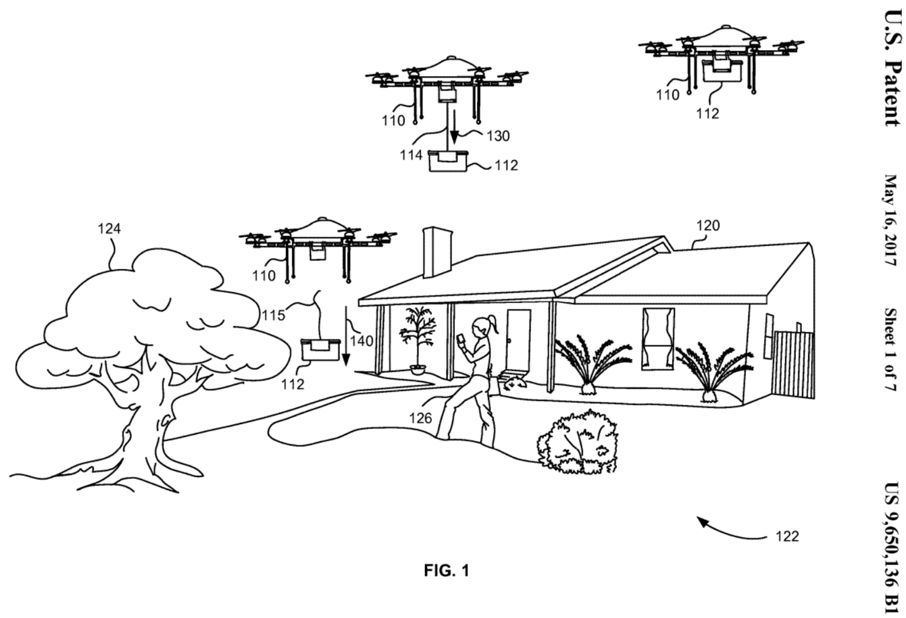


Figure K1. Illustration of Amazon's drone delivery system that lowers a payload using a tether before severing it to release the payload (Haskin et al., 2017).

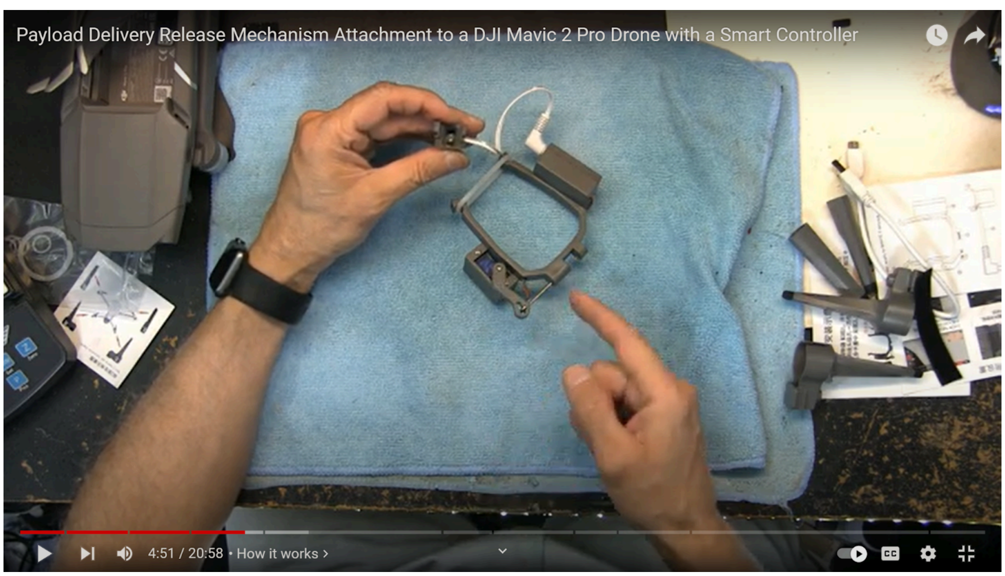


Figure K2. Latch-type payload release mechanism (Technology Tips, 2020).

Appendix L

Morph Matrix

Table L1. Morph Matrix

Morphological Matrix					
Energy → / **Sub-Functions ↓**	**Mechanical**	**Electrical**	**Light**	**Fluid**	**Misc.**
Import Energy	Hand Crank	External Charging	Solar Panels	Wind Turbine	
Store Energy	Spring	Single Use Batteries			Propane
	Flywheel	Rechargeable Batteries			Fuel Cell
Convert Energy to:	Servo Motor			Helium	
	clasp quadcopter			Hot Air	
	Brushed Motor				
	Linear Actuator				
			Collision Avoidance Lights		
			Headlights		
Secure Payload	Clasp / Vice				
	Pulley and Fastener				
	Lidded Box				
	Velcro				
	Grasping Claw				
Perform Telemetry	Altimeter				
	Sonar				
		GPS			

		Raspberry Pi/Arduino			
		Flight Controller Stack			
		Radio Transmitter/Controller			
			IR Camera		
			LiDAR		
			Fixed Camera(s)		
			Moving Camera		
					Thermal Sensor

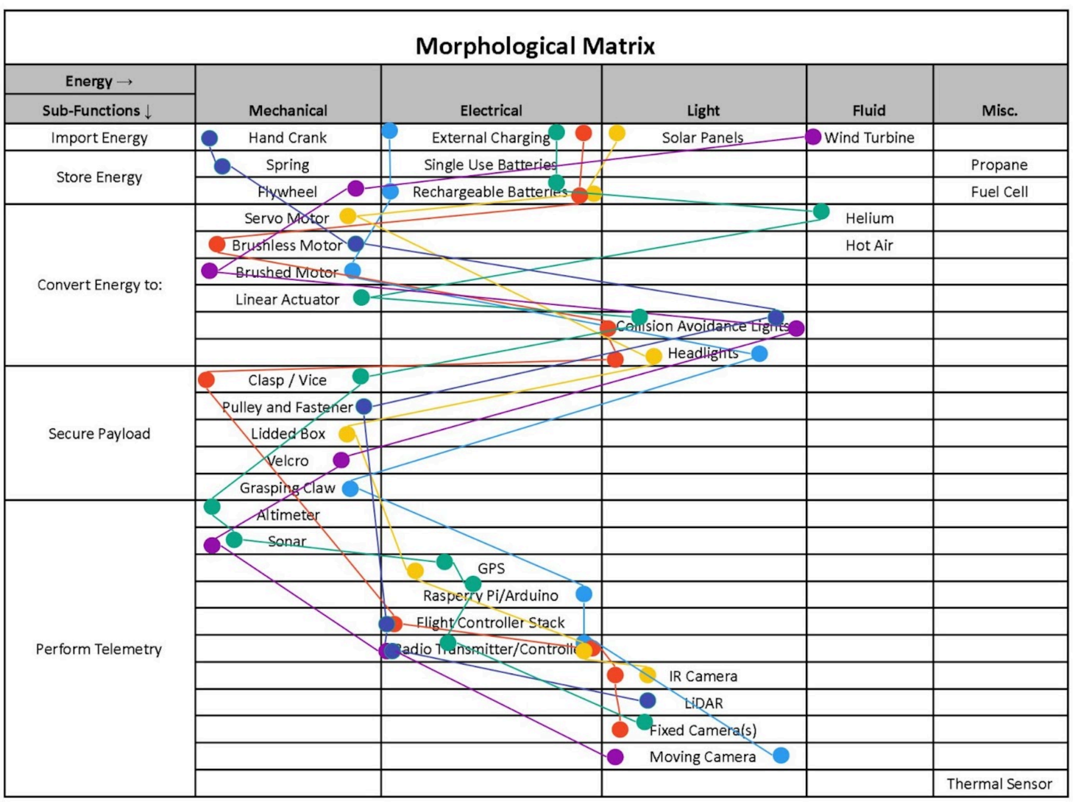


Figure L1. Morph Matrix with Selections

Table L2. Expanded Concept Description

Concept Name	Description
Hand Crank Quadcopter	Hand crank, spring, clasp quadcopter, collision avoidance lights, pulley and fastener, flight controller stack, radio transmitter and controller, LiDAR
Brushed Motor and Claw Quadcopter	External charging, rechargeable batteries, brushed motor, headlights, grasping claw, RaspberryPi + Arduino, transmitter and controller, moving camera
Helium Drone	External charging, rechargeable batteries, helium, linear actuator, clasp/vice, altimeter, sonar, GPS, RaspberryPi + Arduino, transmitter and controller, fixed camera
Clasp Quadcopter	External charging, rechargeable batteries, brushless motor, collision avoidance lights, headlights, clasp/vice, flight controller stack, transmitter and controller, IR camera, fixed camera
Solar-Powered drone	Solar panels, rechargeable batteries, servo motor, headlights, lidded box, GPS, transmitter and controller, IR camera
Wind Quadcopter	Wind turbine, flywheel, brushed motor, collision avoidance lights, velcro, sonar, transmitter and controller, moving camera

Appendix M

Design Concept Sketches

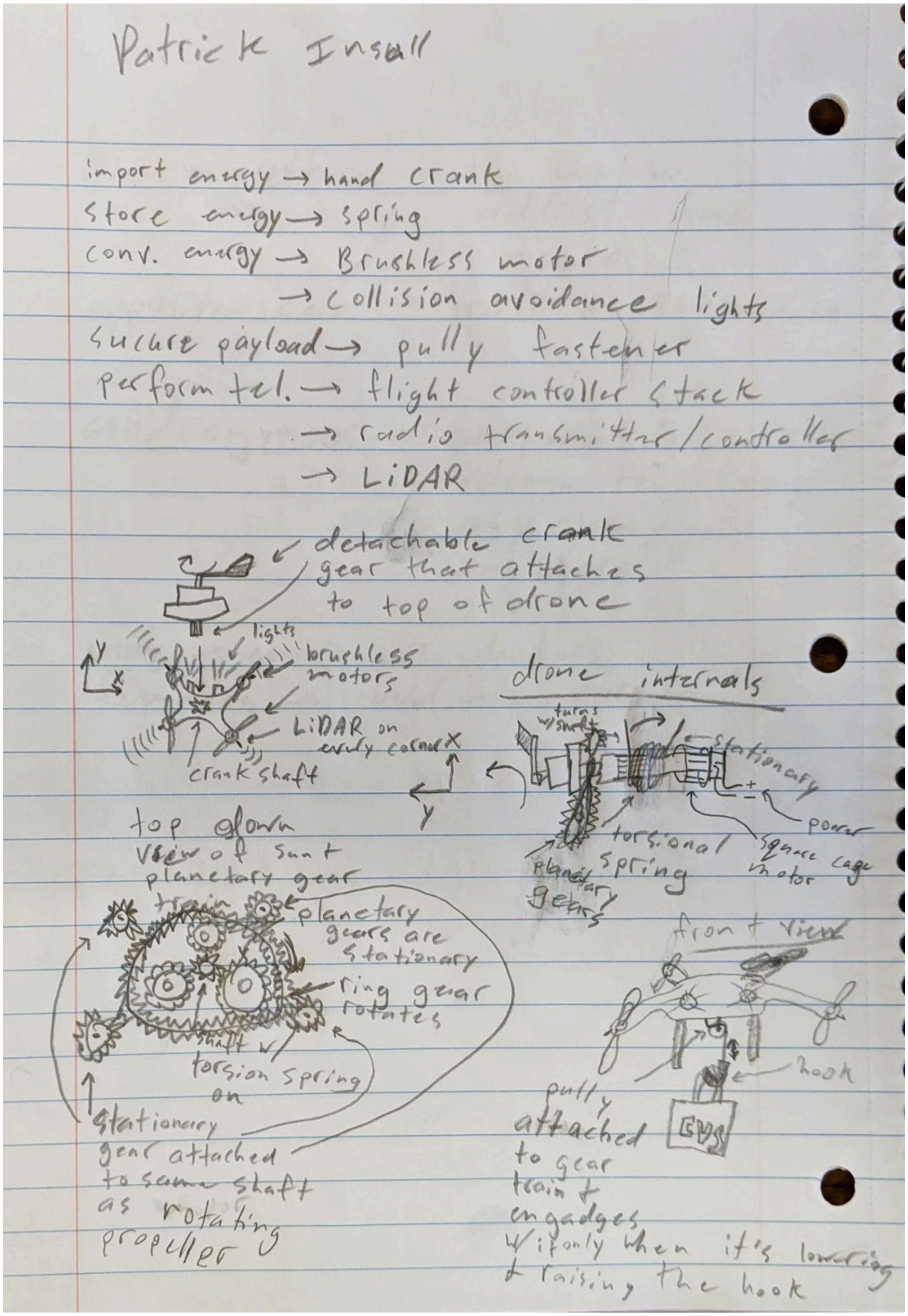


Figure M1. Hand Crank Quadcopter Design Concept Sketch Pt. 1

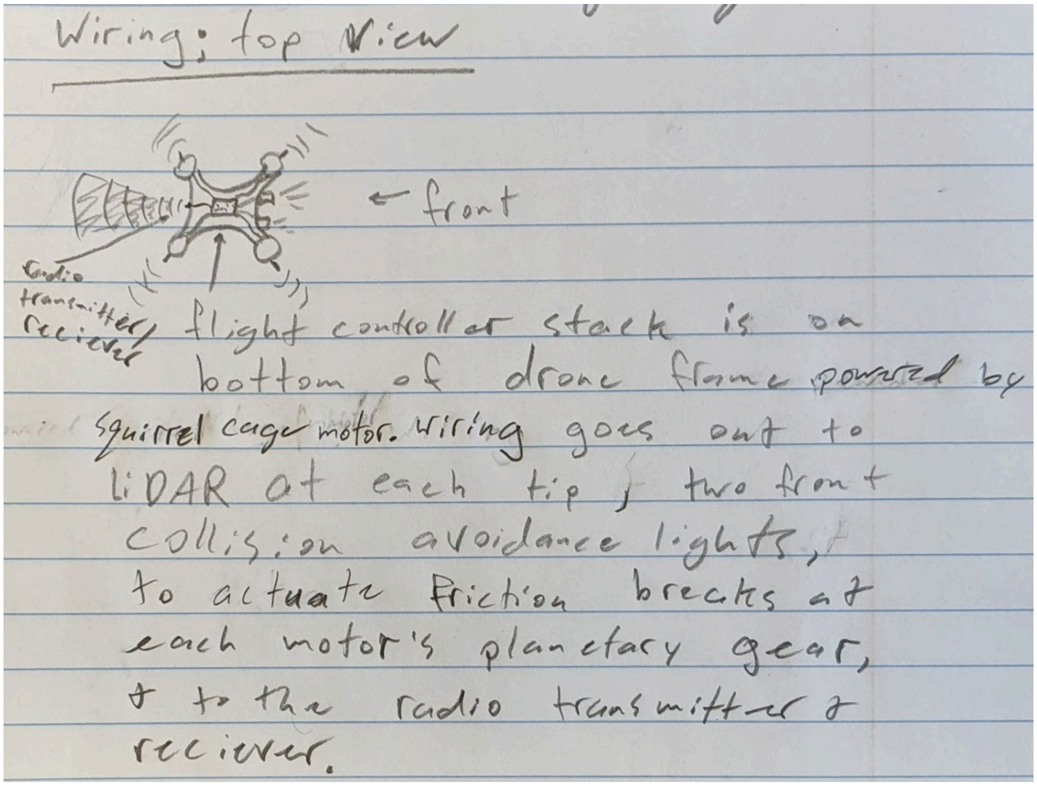


Figure M2. Hand Crank Quadcopter Design Concept Sketch Pt. 2

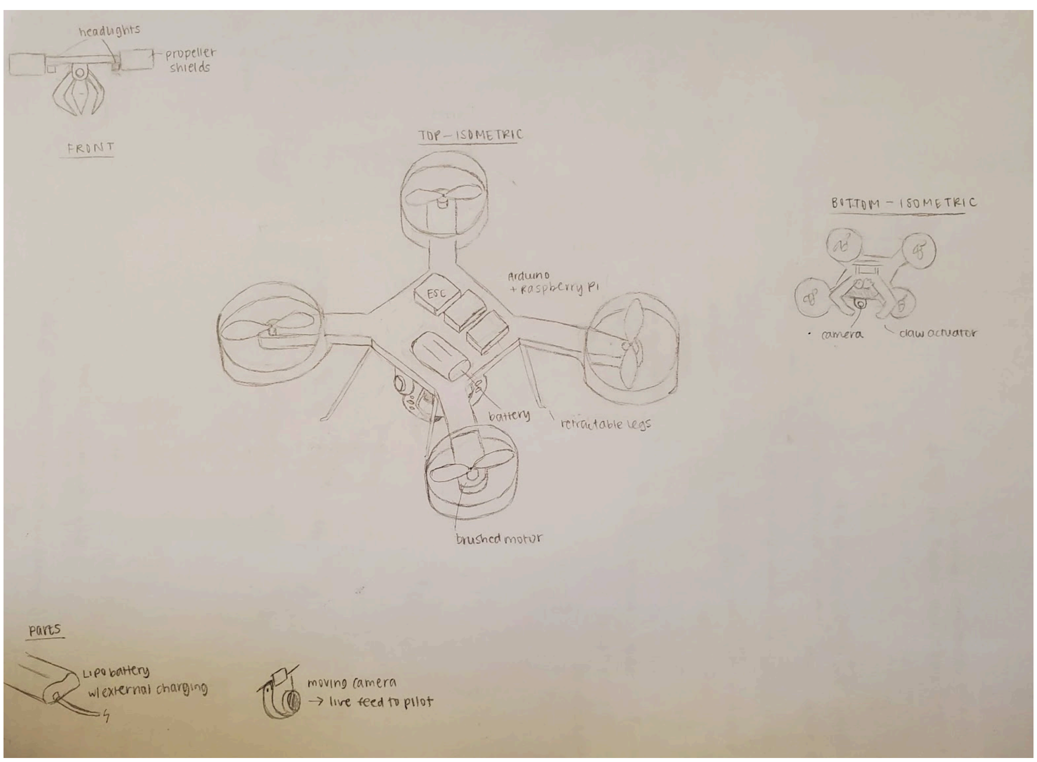


Figure M3. Claw + Moving Camera Quadcopter Design Concept Sketch

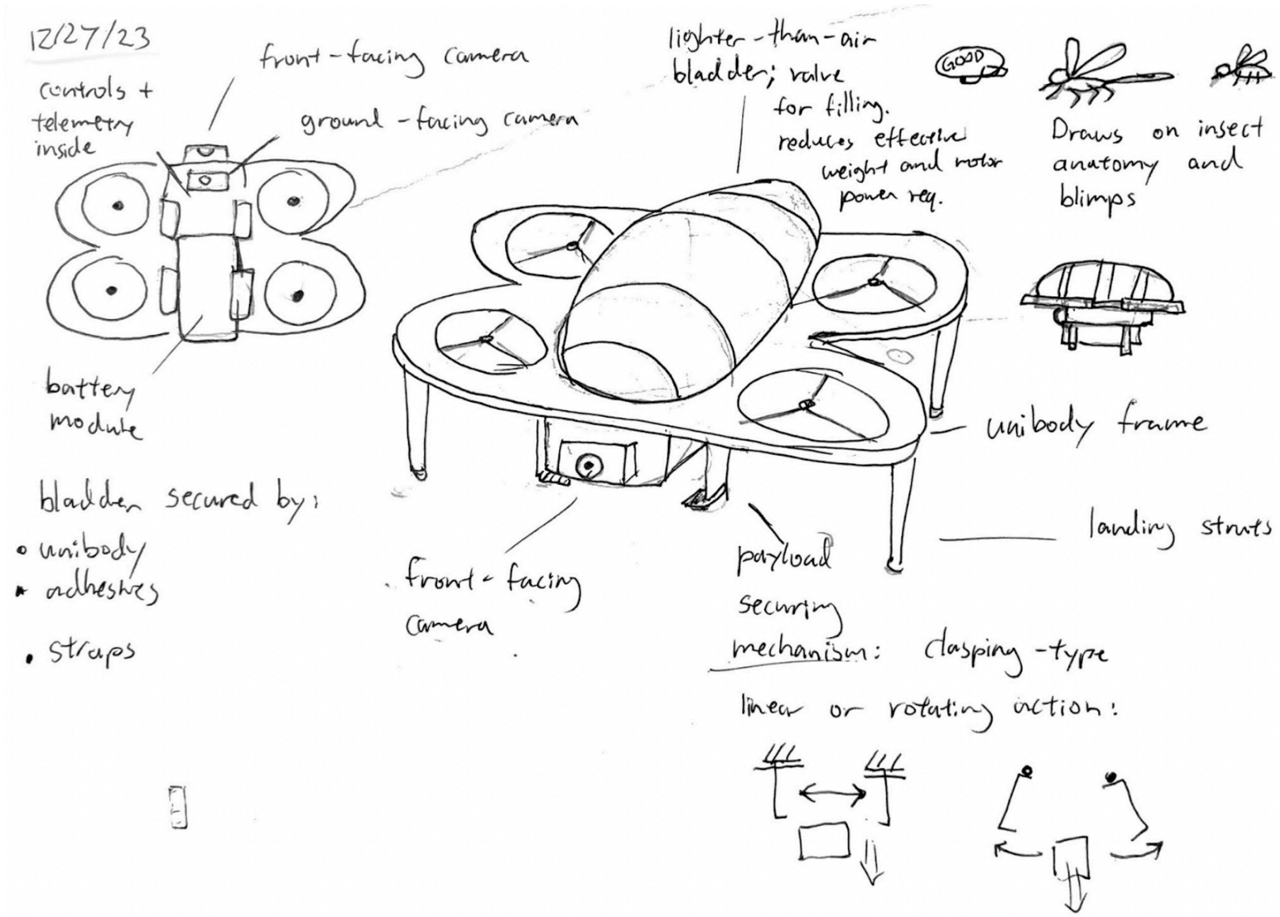


Figure M4. Calvin - Helium Design Concept Sketch

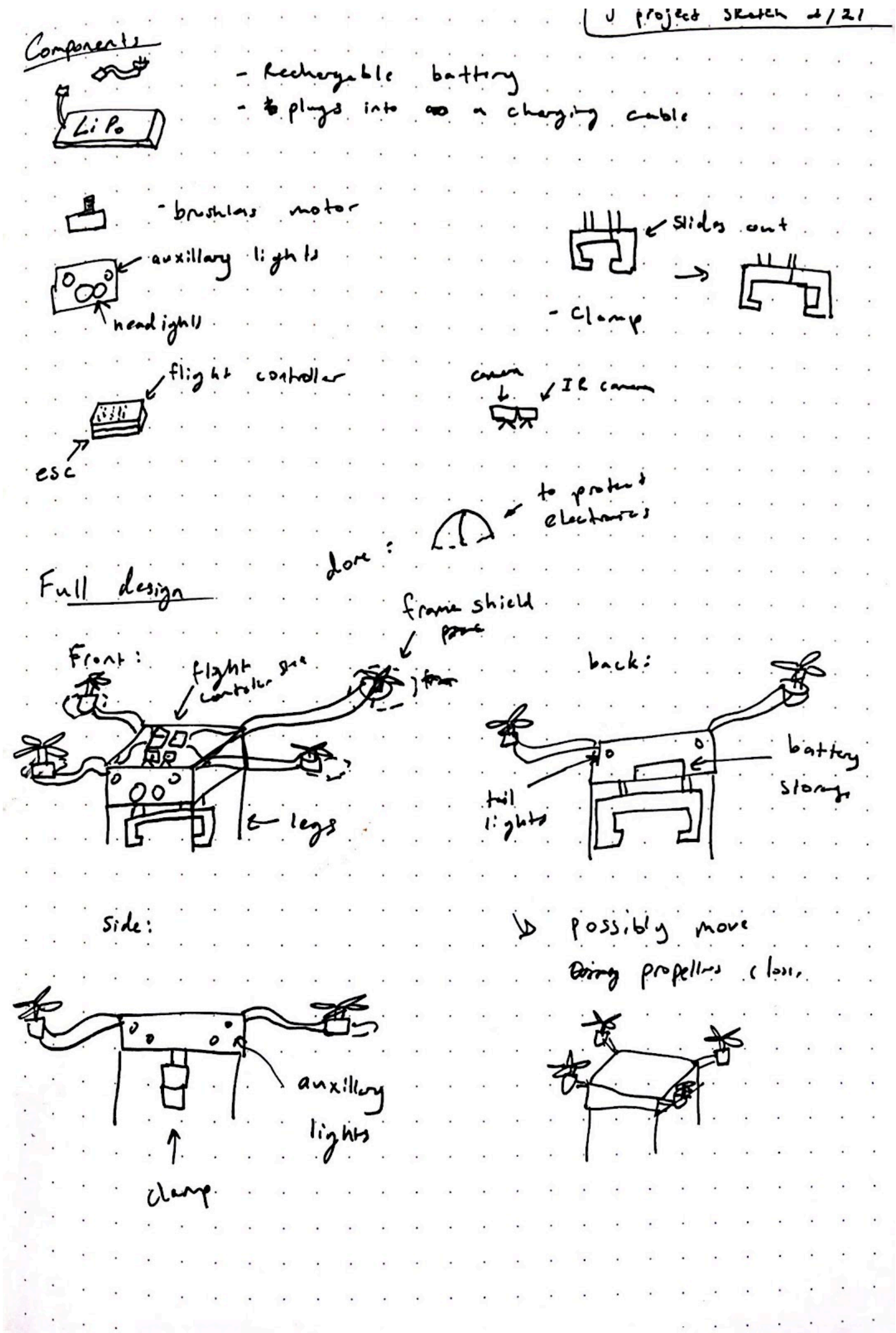


Figure M5. Clasp Quadcopter Design Concept Sketch

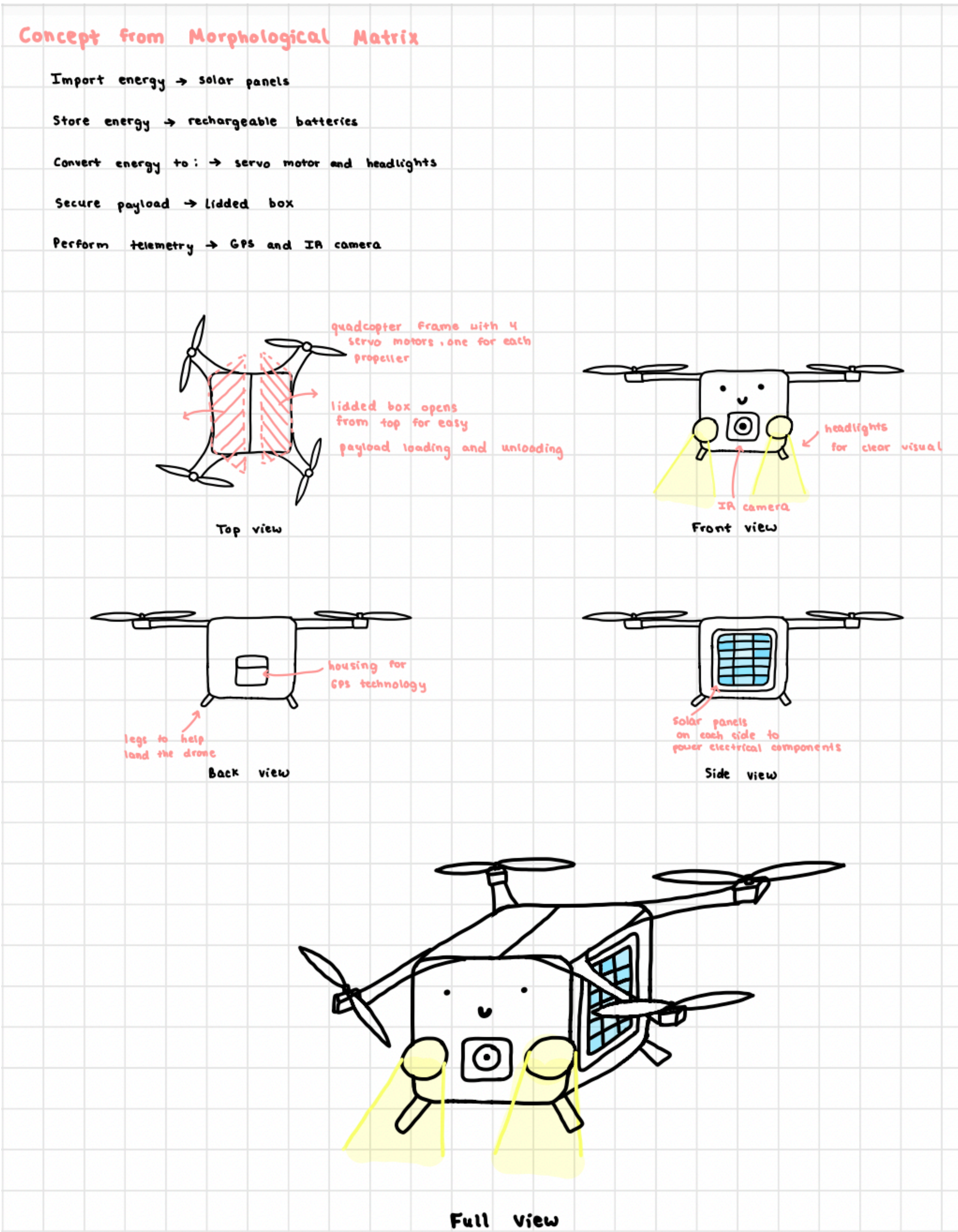


Figure M6. Solar-Powered Drone Design Concept Sketch

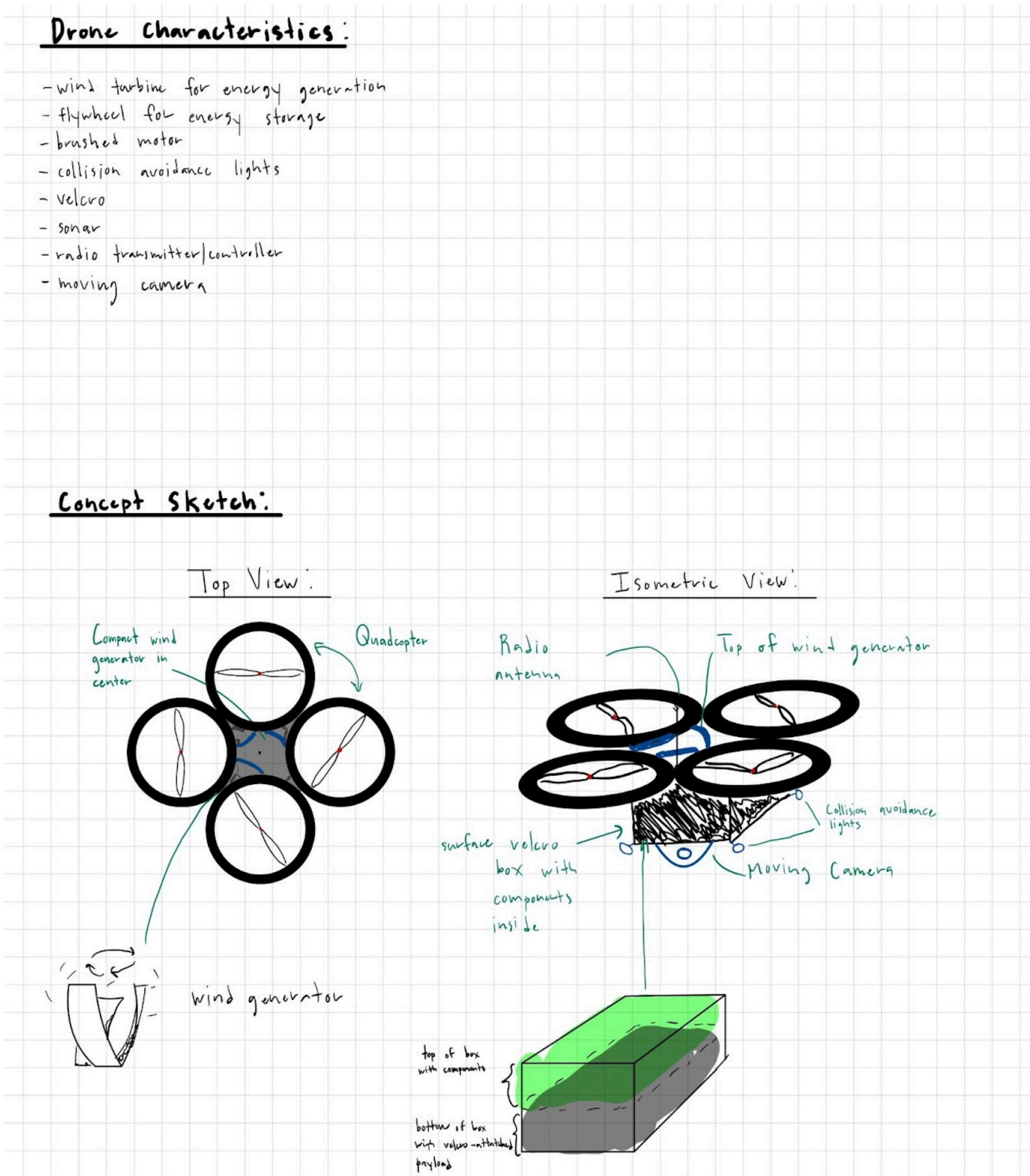


Figure M7. Wind Quadcopter Concept Sketch

Appendix N

Pugh Chart

Table N1. Pugh Chart Using Brushed Motor and Claw Quadcopter as Datum

		Alternatives							
Criteria	Baseline	Hand Crank Quadcopter	Brushless Motor + Claw Quadcopter	Helium Quadcopter	Clasp Quadcopter	Solar Quadcopter	Wind Quadcopter	Totals	Rank
Weight (lb)	0	–	0	+	–	–	–	-2	7
Horizontal Area (ft^2)	0	+	0	–	+	+	+	2	1
Maintenance Time (hours/year)	0	–	0	–	–	0	–	-4	8
Cost ($)	0	0	0	+	+	–	–	1	4
Available energy (J)	0	–	0	–	–	–	–	-4	8
Ease of use for pilot (1-10 on Perceived Exertion Scale)	0	–	0	–	0	–	0	-2	6
Maximum stress experienced as a result of .5lb payload (lb/in^2)	0	+	0	–	+	+	+	2	1
Combined cross sectional area (in^2)	0	+	0	–	+	+	+	2	1
Build time (hours)	0	0	0	–	+	–	–	-1	5
	Totals	-1		-5	2	-2	-2		
	Rank	2		5	1	3	3		

Table N2. Pugh Chart Using Helium Drone as Datum

		Alternatives							
Criteria	Baseline	Hand Crank Quadcopter	Brushless Motor + Claw Quadcopter	Helium Quadcopter	Clasp Quadcopter	Solar Quadcopter	Wind Quadcopter	Totals	Rank
Weight (lb)	0	–	–	0	–	–	–	-4	8
Horizontal Area (ft^2)	0	+	+	0	+	+	+	4	1
Maintenance Time (hours/year)	0	–	+	0	+	+	–	0	7
Cost ($)	0	–	–	0	–	–	–	-4	8
Available energy (J)	0	+	+	0	+	–	–	2	3
Ease of use for pilot (1-10 on Perceived Exertion Scale)	0	–	+	0	0	0	0	0	6
Maximum stress experienced for .5lb payload (lb/in^2)	0	–	+	0	+	+	+	2	3
Combined cross sectional area (in^2)	0	+	+	0	+	+	+	4	1
Build time (hours)	0	+	0	0	+	–	–	1	5
	Totals	-1	4		4	0	-2		
	Rank	4	1		1	3	5		

Table N3. Pugh Chart Using Clasp Quadcopter as Datum

		Alternatives							
Criteria	Baseline	Hand Crank Quadcopter	Brushless Motor + Claw Quadcopter	Helium Quadcopter	Clasp Quadcopter	Solar Quadcopter	Wind Quadcopter	Totals	Rank
Weight (lb)	0	–	+	+	0	–	–	0	1
Horizontal Area (ft^2)	0	+	–	–	0	–	–	-2	5
Maintenance Time (hours/year)	0	–	0	–	0	0	–	-3	8
Cost ($)	0	–	–	+	0	–	–	-2	5
Available energy (J)	0	+	0	–	0	–	–	-1	3
Ease of use for pilot (1-10 on Perceived Exertion Scale)	0	–	+	0	0	+	–	-1	3
Maximum stress experienced for .5lb payload (lb/in^2)	0	+	–	–	0	+	+	0	1
Combined cross sectional area (in^2)	0	–	–	–	0	+	+	-2	5
Build time (hours)	0	–	0	–	0	–	–	-3	8
	Totals	-3	-2	-4		-2	-5		
	Rank	3	1	4		2	5		

Table N4. Perceived Exertion scale

Magnitude	Difficulty of Piloting the Drone
10	Impossible to control
9	Very difficult to maintain control
7-8	Frustrating, requires unbroken focus to maintain control
4-6	Moderately challenging, can converse with some pauses while piloting

2-3	Lightly challenging, can hold conversation uninterrupted while piloting
1	Requires hardly any effort

Appendix O

Back-of-the-Envelope Calculations

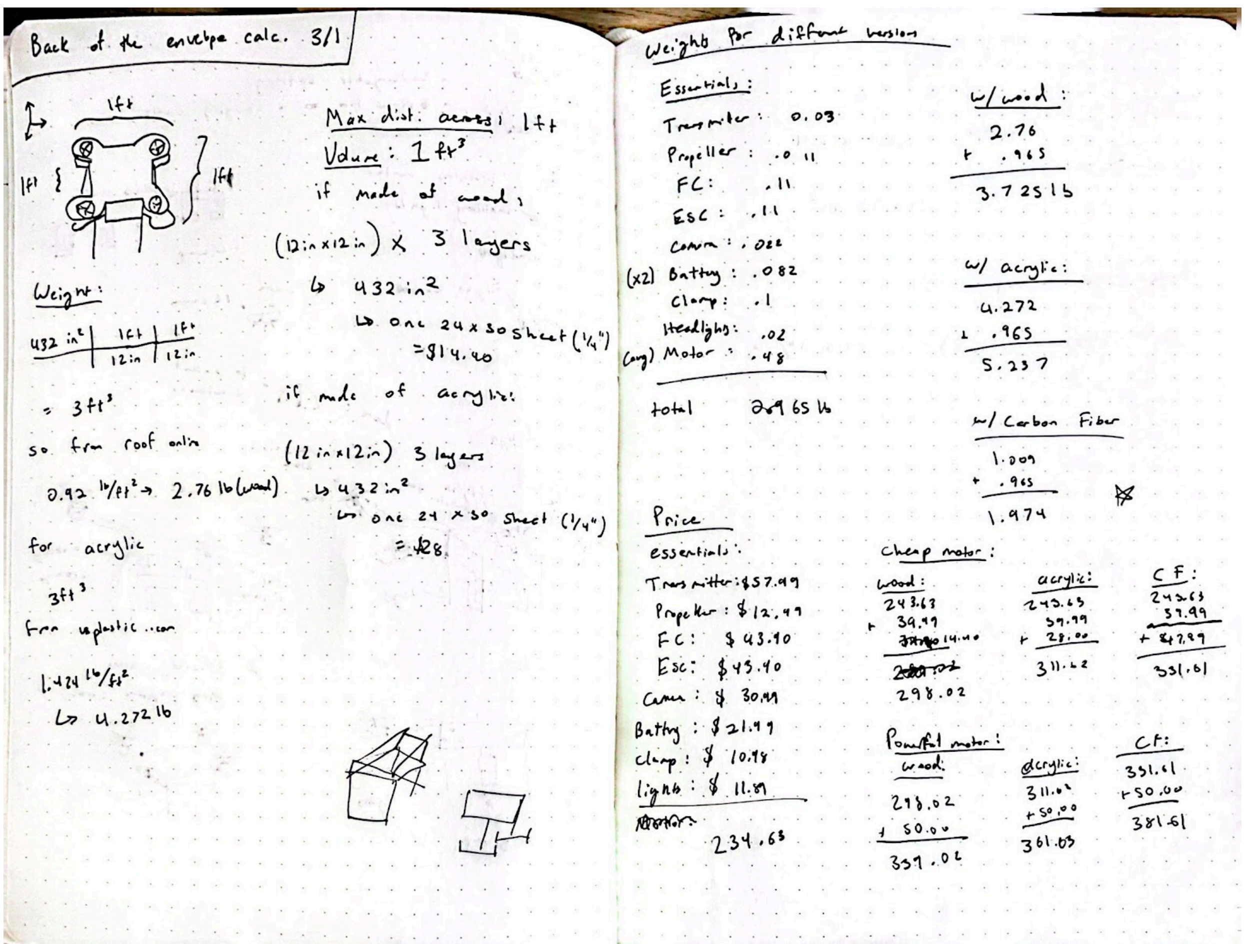


Figure O1. Clasp concept Back of the Envelope Calculations

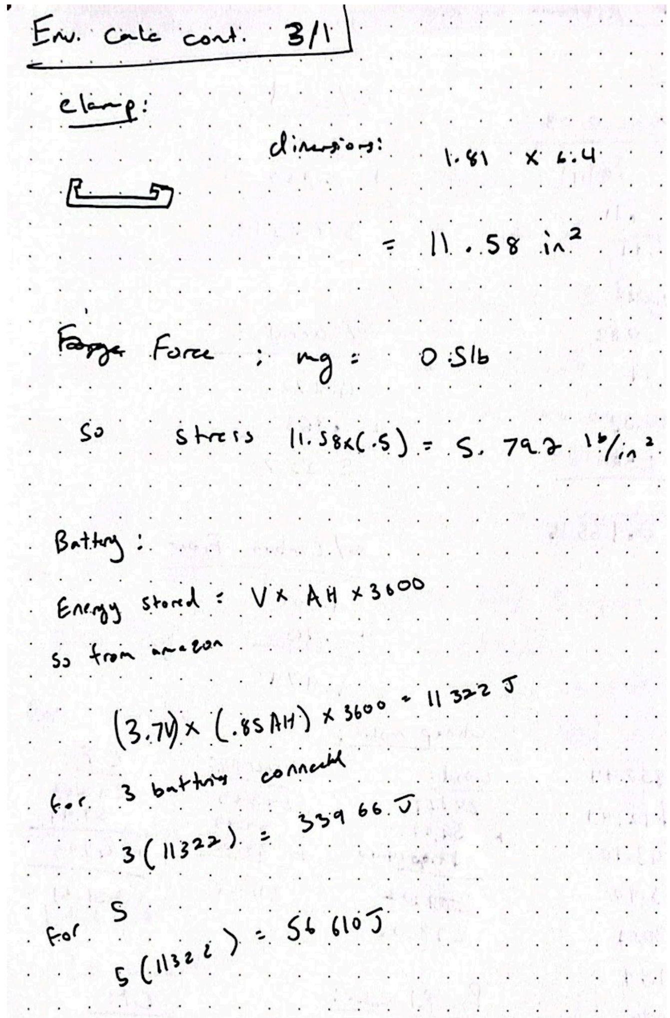


Figure O2. Clasp concept Back of the Envelope Calculations continued

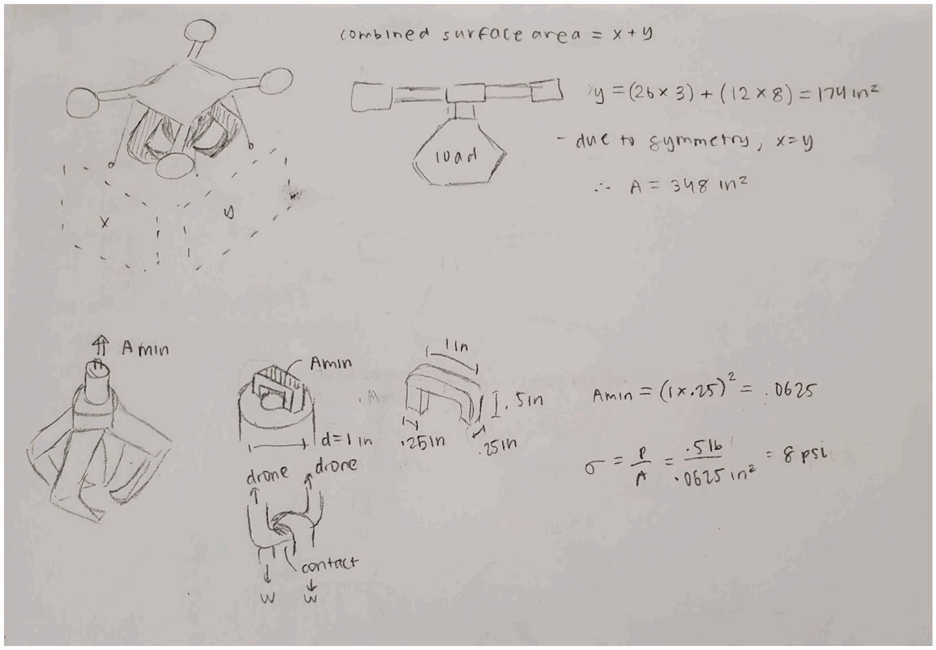


Figure O3. Calculations for brushed motor and claw concept

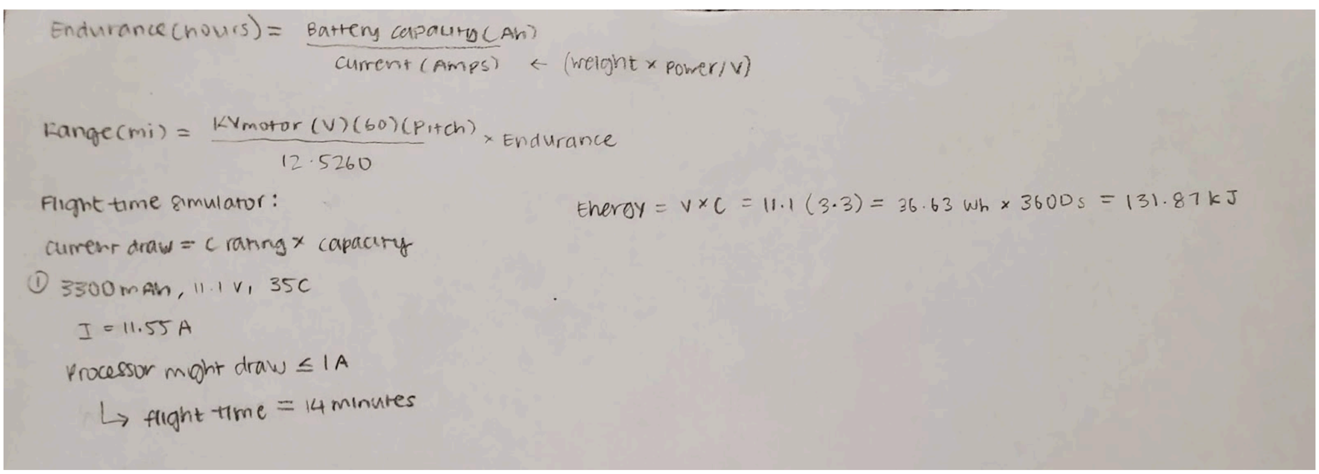


Figure O4. Calculations for brushed motor and claw concept

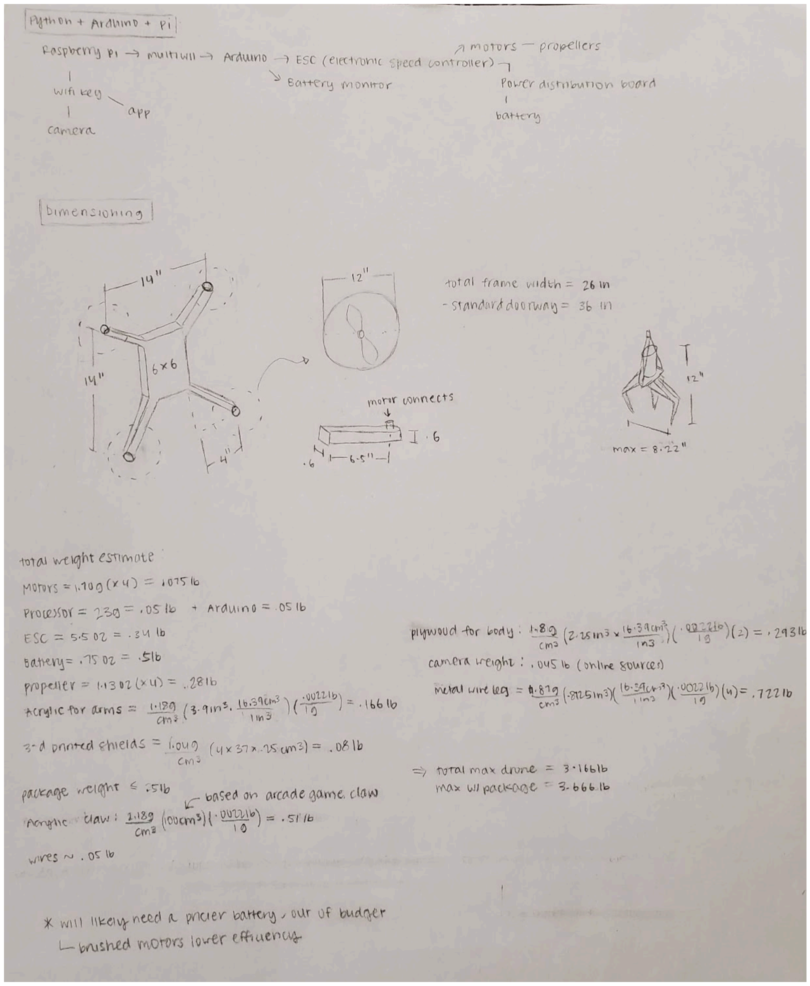


Figure O5. Calculations for brushed motor and claw concept

Table O1. Cost estimate for Claw Concept

Item	Cost
4 DC brushed motors	$16
Raspberry Pi model B: (Re-sale)	$70
rechargeable battery LiPo	$40
ESC	$17
Arduino Uno	$29

camera	$35
Power Distribution Board	$30
Wood for body	$16
Acrylic for body	$12
Remote controller	$39
TOTAL	$304.00
* wood and acrylic costs estimated with Texas Inventionworks	

Table O2. Maintenance Estimate for Claw Concept

Task	Frequency	Time per year
Wipe down camera	1 min/week	.86 hours
Wipe down chassis	3 min/week	2.6 hours
Inspect propellers	1 min/week	.86 hours
Replacing screws	10 min/ 2 years	.08 hours
Replacing motors	15 min/5 years	.05 hours
Updating firmware	1 hour /3 years	.33 hours
Replacing propellers	15 min/1 year	.25 hours
Total yearly maintenance:		**5.03 hours**

Back of envelope calcs.

Stored energy-
If the K value of the torsional spring was 50 Nm/rad and it was still rotated 10 times, the energy stored in the spring would be:

$\theta = 2\pi * 10 = 20\pi$ radians

$E = (1/2) * 50$ Nm/rad $* (20\pi \text{ radians})^2$
$= (1/2) * 50$ Nm/rad $* 400\pi^2$
$= 10{,}000\pi^2$ Joules
$\approx 98{,}960.2$ Joules

Cross sectional area-
Front of drone-

Assume bag attached to drone has area of 1.25 ft^2 and front of drone has area of 1 ft^2

1 ft = 0.3048 m

Therefore:

$1.25 \text{ ft}^2 = 1.25 * (0.3048 \text{ m/ft})^2 = 0.11613 \text{ m}^2$
$1 \text{ ft}^2 = 1 * (0.3048 \text{ m/ft})^2 = 0.09290 \text{ m}^2$

$0.11613 \text{ m}^2 + 0.09290 \text{ m}^2 = 0.20903 \text{ m}^2$

$0.20903 \text{ m}^2 * 10.76391 \text{ ft}^2/\text{m}^2 =$ **2.250 ft^2**

Stress felt on carrying mechanism as a result of 0.5lbs-
Assumptions- hook material = steal, effected area is 0.1550 square inches, force=0.5lb.
To calculate stress, we divide the force by the area.

Figure O6. Calculations for Spring + LiDAR + Flight Stack Concept Pt. 1

Horizontal Area

Assuming that the drone has a rectangular shape with a length-to-width ratio of 2:1

Length = diagonal size / sqrt(5) ≈ 305 mm (12.01 inches)
Width = Length / 2 ≈ 152.5 mm (6.00 inches)
Area = Length x Width ≈ 46,412.5 mm^2 = **(71.96 in^2)**

Drone weight
Gears will be made from material with density close to acrylic and all gears can be made from a sheet of 14x14x0.33 inches of the material. = 64.68in^3 = 1059.9153cm^2

Weight (gears)= 1059.9153cm^3*1.18g/cm^3=1250.700054gs
Weight (motors) = 8-20 grams (pick 13 grams) = 13*4=52grams
Weight (spring)=

Length of wire = Number of coils * Wire circumference
Wire circumference = π * Wire diameter

Number of coils = 10
Wire diameter = 0.5 cm

Wire circumference = π * 0.5 cm = 1.57 cm
Length of wire = 10 * 1.57 cm = 15.7 cm
Volume = π/4 * (Outer diameter^2 - Inner diameter^2) * Length of spring
Inner diameter = 5 cm - 10 * 0.5 cm = 0 cm (assuming the spring has no space between the coils)
Outer diameter = 5 cm
Length of spring = Wire diameter * Number of coils = 0.5 cm * 10 = 5 cm

Volume = π/4 * (5 cm^2 - 0 cm^2) * 5 cm = 98.17 cm^3

Assuming the spring is made of steel with a density of 7.85 g/cm^3, we can calculate the weight of the spring:

Weight = Volume * Density * 1 kg/1000 g

Density of steel = 7.85 g/cm^3
Weight = 98.17 cm^3 * 7.85 g/cm^3 * 1 kg/1000 g = 768 grams

Flight stack = 9grams
LiDAR= 75 grams

total= 2154.700054 g / 453.59237 = **4.75 lbs**

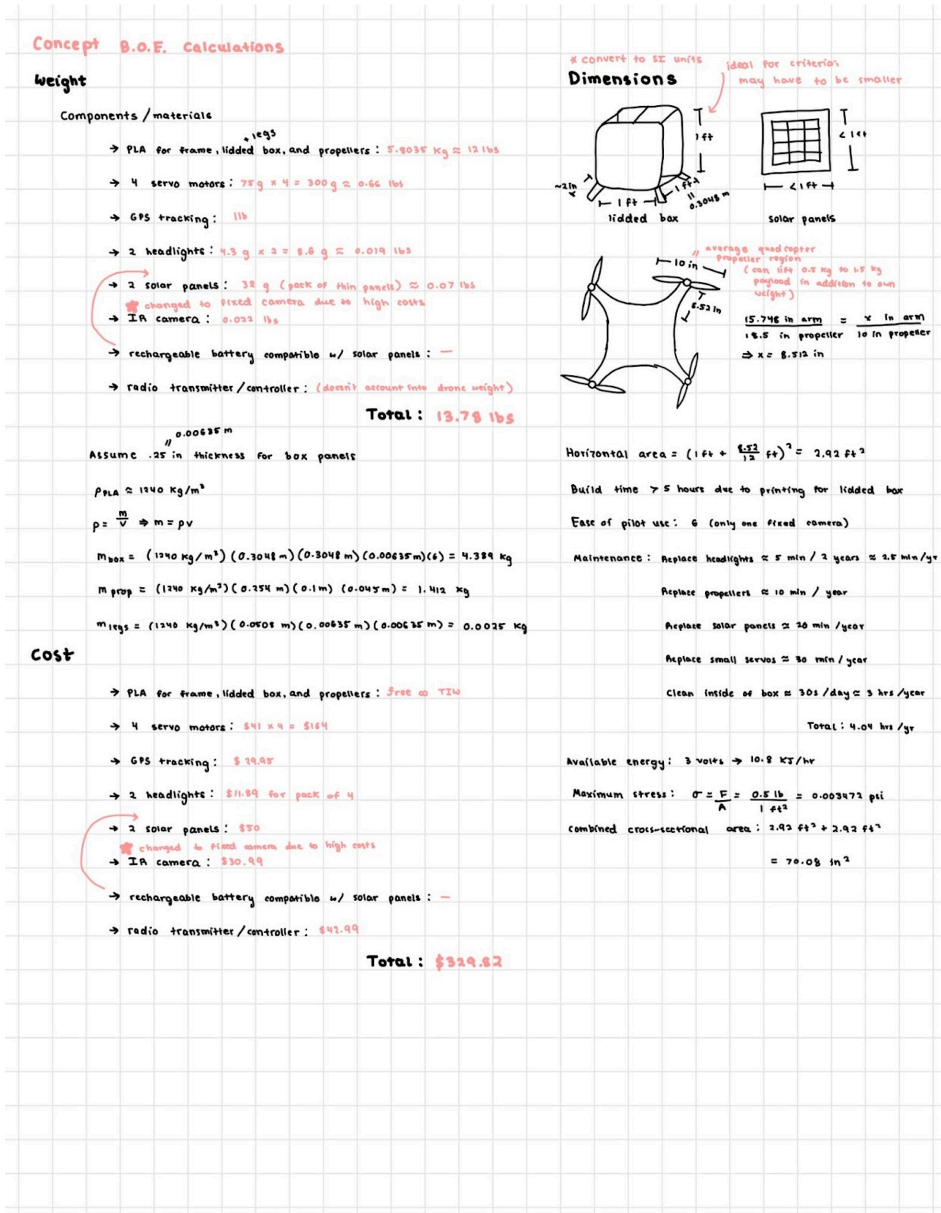
Figure O7. Calculations for Spring + LiDAR + Flight Stack Concept Pt. 2

Table O3. Calculations for Spring + LiDAR + Flight Stack Concept Pt. 3

Component	Quantity	Cost $	Reference
GARMIN LIDAR-LITE V3	2	130	https://www.flyability.com/lidar-drone#:~:text=This%20LiDAR%20sensor%20detects%20targets,more%20about%20the%20Leddartech%20VU8
EMAX RS1106 II 6000 KV Micro Brushless Motor	4	12.99	https://www.readymaderc.com/products/details/emax-rs1106-6000-kv-micro-brushless-motor-?gclid=CjwKCAiAjPyfBhBMEiwAB2CCIozvEWmnJhcMZ1CIgmcKeGZyc4TSE7TKMZCBs-8oCgbNcC4vQ9wa7RoC74kQAvD_BwE#features-tab
SpeedyBee F405 V3 BLS 3-6S 30x30 Stack/Combo (F405 FC / 8Bit 50A 4in1 ESC)	1	69.99	https://www.racedayquads.com/products/speedybee-f405-v3-bls-3-6s-30x30-stack-combo-f405-fc-50a-4in1-esc?currency=USD&variant=39970450079857&

			gclid=CjwKCAiAjPyfBhBMEiwAB2CCIvvyko7ld0aCxWR6hXYD8xNmLKICu-MD7MmxgDIO1gw7zP4HhdmewBoCbW4QAvD_BwE
YUNEEC H520/TYPHOON H + (PLUS) TRI-COLOR LIGHT CIRCUIT BOARD (YUNH520121SVC)	1	9.99	https://www.vertigodrones.com/Yuneec-H520Typhoon-H-Plus-Tri-Color-Light-Circuit-Board-YUNH520121SVC_p_1713.html?gclid=CjwKCAiAjPyfBhBMEiwAB2CCIm1R4IAmJmDtnT1OW8BkVSm7ctsy--sH8NRMsB_jVZhJMW5pr2ic4hoCJEsQAvD_BwE
DTXMX Flysky FS-i6X 2.4G 10CH Radio Transmitter and Receiver iA10B RC Controller for Airplane Helicopter FPV Drone RC Boat	1	57.99	https://www.amazon.com/DTXMX-Transmitter-Receiver-Controller-Helicopter/dp/B0B3T2R65X/ref=sr_1_1_sspa?keywords=Drone+Receiver&qid=1677700908&sr=8-1-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyP

			UEyVk4xQTRKR1kwQTgmZW5jcnlwdGVkSWQ9QTAwODI1NjkyTTRWQTBCWDhNQUhHJmVuY3J5cHRlZEFkSWQ9QTA3MTY1NjQxM041WTVSTzk2OURLJndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ==
Spring, Torsion	1	132.36	https://www.zoro.com/bk-industries-bki-spring-torsion-s0071/i/G602236880/?recommended=true
Frame (Carbon Fiber)	1	47.99	https://www.amazon.com/Readytosky-Quadcopter-Stretch-Version-Landing/dp/B01N0AX1MZ/ref=sr_1_5?crid=1MUH5D0BN5RQN&keywords=S500+quadcopter+frame&qid=1677618832&sprefix=s500+quadcopter+frame%2Caps%2C127&sr=8-5
Total		$630.28	



Concept B.O.E. Calculations

Weight

Components / materials

→ PLA for frame, lidded box, and propellers (+ legs): 5.8035 Kg ≈ 12 lbs

→ 4 servo motors: 75 g × 4 = 300 g ≈ 0.66 lbs

→ GPS tracking: 1 lb

→ 2 headlights: 4.3 g × 2 = 8.6 g ≈ 0.019 lbs

→ 2 solar panels: 32 g (pack of thin panels) ≈ 0.07 lbs

changed to fixed camera due to high costs

→ IR camera: 0.022 lbs

→ rechargeable battery compatible w/ solar panels: —

→ radio transmitter / controller: (doesn't account into drone weight)

Total: 13.78 lbs

Assume .25 in (= 0.00635 m) thickness for box panels

$\rho_{PLA} \approx 1240\ kg/m^3$

$\rho = \frac{m}{V} \Rightarrow m = \rho V$

$m_{box} = (1240\ kg/m^3)(0.3048\ m)(0.3048\ m)(0.00635\ m)(6) = 4.389\ kg$

$m_{prop} = (1240\ kg/m^3)(0.254\ m)(0.1\ m)(0.045\ m) = 1.412\ kg$

$m_{legs} = (1240\ kg/m^3)(0.0508\ m)(0.00635\ m)(0.00635\ m) = 0.0025\ kg$

Cost

→ PLA for frame, lidded box, and propellers: free @ TIW

→ 4 servo motors: \$41 × 4 = \$164

→ GPS tracking: \$29.95

→ 2 headlights: \$11.89 for pack of 4

→ 2 solar panels: \$50

changed to fixed camera due to high costs

→ IR camera: \$30.99

→ rechargeable battery compatible w/ solar panels: —

→ radio transmitter / controller: \$42.99

Total: \$329.82

* convert to SI units

Dimensions

ideal for criteria; may have to be smaller

1 ft
~2 in
1 ft
1 ft = 0.3048 m
lidded box

< 1 ft
< 1 ft
solar panels

10 in
8.52 in
// average quadcopter propeller region (can lift 0.5 kg to 1.5 kg payload in addition to own weight)

$\frac{15.748\ in\ arm}{18.5\ in\ propeller} = \frac{x\ in\ arm}{10\ in\ propeller}$

$\Rightarrow x = 8.512\ in$

Horizontal area $= (1\ ft + \frac{8.52}{12}\ ft)^2 = 2.92\ ft^2$

Build time > 5 hours due to printing for lidded box

Ease of pilot use: 6 (only one fixed camera)

Maintenance: Replace headlights ≈ 5 min / 2 years ≈ 2.5 min/yr

Replace propellers ≈ 10 min / year

Replace solar panels ≈ 20 min / year

Replace small servos ≈ 30 min / year

Clean inside of box ≈ 30 s / day ≈ 3 hrs / year

Total: 4.04 hrs / yr

Available energy: 3 volts → 10.8 KJ/hr

Maximum stress: $\sigma = \frac{F}{A} = \frac{0.5\ lb}{1\ ft^2} = 0.003472\ psi$

combined cross-sectional area: $2.92\ ft^2 + 2.92\ ft^2$

$= 70.08\ in^2$

Figure O8. Calculations for solar-powered drone concept

Back of Envelope Calculations for Helium Concept – Calvin Guo

Build Time

We made a rough, standardized estimate that the user can build the drone in about six hours over a weekend. Since this concept incorporates a balloon, which may be awkward to handle and secure within a frame, we added one hour of time to consider the difficulty.

Table O3. Maintenance Time for BlimpCopter Concept

Task ≈ Time per task	**Time per year**
Replace propellers ≈ 5 min / month	60 min/ yr
Replace balloon ≈ 10 min / month	120 min / yr
Plug in or replace battery ≈ 1 min / day	365 min / yr
Inspect camera lens ≈ 1 min / day	365 min / yr
Inspect fasteners and hardware ≈ 5 min / month	60 min / yr
Total	**16 hr / yr**

Weight

Table O4. Cost Estimate for BlimpCopter

Component	**Estimated Weight**
1/8” Ash Wood, 8” x 24”	200g
Camera	50g
Battery	854g
Propellers	5g
Raspberry Pi Model B+	50g
Weather balloon	5g
Motors	300g
Drone transmitter	5g
Screws, nuts, bolts, etc.	40g
Total	1509 g

Values were approximated using common household items, or drawn from the references in Table I3 if available. The estimated total weight is 1509 g, or 3.33 lbs. Assuming the inflated helium balloon provides 2lb of lift, then the effective weight of the drone is 1.33 lb.

Size

Since this concept incorporates a balloon to provide lift, we will assume that we attach a volume of helium that results in 2 lb of lift (that is, 50% the target maximum unloaded drone weight, 4 lb.). For a one cubic foot helium filled balloon, gravity pulls down on the helium with a force of 0.0114 pounds while the air pushes up with a force equal to the weight of the air the helium displaced, or 0.0807 pounds. The difference in the up and down force is 0.069 pounds.

Therefore, to lift 2 pounds, we will need a balloon with a volume of 28 cubic feet. This translates to a sphere with a diameter of 3.8 feet. We assume that this balloon is the most significant contributor to the cross-sectional area. Thus, 3.8 ft is used as the value for a rectangular bounding box for the following values.

Horizontal Area

$(3.8 \text{ ft})^2 = 14.44 \text{ ft}^2$

Combined Cross-Sectional Area

$2 * 14.44 \text{ ft}^2 = 28.88 \text{ ft}^2$

Maximum Stress in Payload Mechanism

Assume that the payload is 0.5 lb., and that four servo arms are under tension, bearing the weight of the payload. We assume that there are four servo arms attached to the payload securing arms. The servos for our project will be quite small, so the combined cross-sectional area of the four servo arms is assumed to be (3 x 6)4 mm. The resulting stress is about 0.31 MPa or 45 psi.

Pilot Ease of Use

6: moderately challenging. This concept only incorporates a single fixed camera which would make it difficult for the pilot to verify that the payload has made it to the target. However, the reduced effective weight of the drone may assist in an easier takeoff and landing.

Cost Estimate

Table O5. Cost estimate for BlimpCopter concept.

Component	**Quantity**	**Cost $**	**Reference**
1/8” Ash Wood, 8” x 24”	2	39.14	ash wood from hardwood supplier
Camera	1	25	Raspberry Pi Camera module
Battery	1	13	Amazon - 650 mAh drone battery
Brushless motors	4	39.99	Amazon - Brushless Motor Set
Propellers	4	11.99	Amazon - Drone Propeller set
Raspberry Pi Model B+	1	29.95	Adafruit Raspberry Pi Model B
Weather balloon	1	10	Scientific sales - Weather Balloon

Servo motor	4	19.99	Amazon - Servo Set
Drone transmitter	1	52.97	Amazon - Transmitter & Controller
Screws, nuts, bolts, etc.	20	10	
Total		**$252.03**	

Back of Envelope Calculations for Wind Quadcopter Concept - RonGabriel Maninang

All back of envelope calculations are summarized in the table in the page below. Links to source information can be found at each keyword.

To find weight, I simply looked at the specified weight in the corresponding link. You can easily access the information/website where I found all of my information with each component. For the horizontal area, I only included the largest possible horizontal area out of all of the components since that would overshadow the rest of the other horizontal areas. I found the horizontal area of the flywheel to be the largest at 1.77ft^2 where I derived from the dimensions given on Amazon. For maintenance time, I estimated how long it would take to repair each component. For cost, I simply put down the cost of each component based on the cost given on Amazon. For the available energy, I had to search up how to calculate the energy that can be stored in a flywheel based on material, geometry, and angular velocity of the brushed motor. I used the website linked on “Available Energy [J]” in the table below and performed the following calculations:

*E = I * angular velocity^2*

I = kmr^2

k = 0.3 since it's flat disk with center hole

m = 3.1 lb

r = .5 inches

I = 0.2325lbin^2 = 6.8e-5kgm^2

angular velocity from motor = 49000RPM = 5131.267995 rad/s

E = 1791.45 Joules

For ease of use, I estimated the perceived exertion on a scale from 1-10. I only ranked components that could potentially affect the pilot’s performance and delivery. For example, using a moving camera on a moving drone would be a 6, in my opinion, because you would have to pilot the drone and move the camera at the same time which would require the movement of two different systems. Then, I selected the maximum perceived exertion value across the components because that would hinder the rest of the pilot’s experience. For the maximum stress calculation, I used the area of the frame:

Stress = 0.5lb / bottom area of the frame

*bottom area of frame =(11.42*7.09)in^2*

Stress = 0.006 psi

For the combined cross sectional area, I used the frame dimensions in the x and y dimensions only to yield an area of 43.68in^2. For build time, I estimated how long it would take to build/install/incorporate each component to the overall build. I estimated that my total build time would take the longest out of all of the concepts because of the wind generator and flywheel.

Table O6: Back of Envelope Calculations for Wind Quadcopter Concept

Component	Weight [lb]	Horizontal Area [ft^2]	Maintenance Time [hours/year]	Cost [$]	Available Energy [J]	Ease of use for pilot [1-10 on Perceived Exertion Scale]	Maximum Stress from 0.5 lb Payload [lb/in^2]	Combined Cross Sectional Area [in^2]	Build Time [hours]
Wind Turbine	3	-	2.5	249.99	-	-	-	-	2
Flywheel	3.1	1.77	4	55.78	1791.45	-	-	-	2.5
Brushed Motor	0.03	-	1.5	18.99	-	-	-	-	.5
Collision Avoidance Lights	0.01	-	0.5	23.99	-	1	-	-	0.05
Velcro	0.3	-	1.5	19.88	-	5		-	0.05
Sonar Sensor	0.017	-	1	18.99	-	1	-	-	0.05
Radio Transmitter /Controller	1.43 (0.09 contrib	-	1	52.97	-	1	-	-	0.1

	uting)								
Moving Camera	0.02	-	1	129.00	-	1	-	-	0.2
Frame	1	-	3	47.89	-	1	0.006	43.68	1
Other	1	-	.5	30.00	-	1	-	-	1
Total	8.567	1.77	16.5	647.48	1791.45	6	0.006	43.68	7.45

Table O7: Cost Estimate Table for Clasp Quadcopter concept

Item	Link	Price	Weight (lb)
Frame (Wood)	Source: TexasInventionWorks Calculations: Roof Online	$14.40	2.76
Frame (Acrylic)	Source: TexasInventionWorks Calculations: US Plastic	$28	4.272
Frame (Carbon Fiber)	Link	$47.99	1.009

Transmitter (without controller)	Link	$19.99	0.09
Transmitter (with Controller)	Link	$57.99	0.03
Propeller 3 wing	Link	$12.99	.011
Propellers 2 wing	Link	$21.99	.15
Flight Controller	Link	$43.90	.11
ESC	Link	$43.90	.11
Day and Night Camera	Link	$30.99	.022
Dipole Camera	Link	$17.99	0.0075
Battery (2 pack and no charger) (11 V)	Link	$33.99	0.295419
Battery (3.7 V) with charger (5 pack)	Link	$21.99	.041
Ipad Clamp	Link	$10.98	0.1
Delivery system	Link	$34.43	.29
Head Lights	Link	$11.89	.02

Motors (cheaper option)	Link	$39.99	.42
High thrust motors	Link	$89	.55

Table O7: Design Justification for Clasp Quadcopter Concept

Weight (lb)	**3.725 lbs.** This weight corresponds to the calculations that use baltic birch plywood for the frame. With the acrylic frame, the weight comes out to 5.237 lb. The carbon fiber frame come out to 1.974 lb.
Horizontal Area (ft^2)	**1 ft^2.** This is an ideal vision for the drone as it would compactly fit within one cubic food. However, Once a payload is attached the size of the drone might change as it would be dependent on the size of the package that it is carrying.
Maintenance Time (hours/year)	**6.5 hours/yr.** The frame would need to be replaced quarterly as the daily stress would wear out the wood. If the customer is provided with the vector file for the frame, they would be able to laser cut the file within half an hour. They would just need to assemble the components together which would take another hour.
Cost ($)	**Total= $298.02.** See back of the envelope calcultions
Available energy (KJ)	**33,966 Joules**. See back of envelope calculations.
Ease of use for pilot (1-10 on Perceived Exertion Scale)	**5**. The main difficulty would be learning how to fly the drone. Once, the employee has flight experience, the system becomes much easier to use.
Maximum stress experienced as a result of .5lb payload (lb/in^2)	**5.792 psi**. (check back of envelope calc.)
Combined cross sectional area (in^2)	**2ft^2.** The front and horizontal faces are both 1ft by 1ft.
Build time (hours)	**3 hours**. The electronics will be the biggest obstacle as the wired connections need to be secured which will take approximately 1 hour. Once this is complete, assembling the frame and putting the subsystems together should take the remaining time.

Appendix P

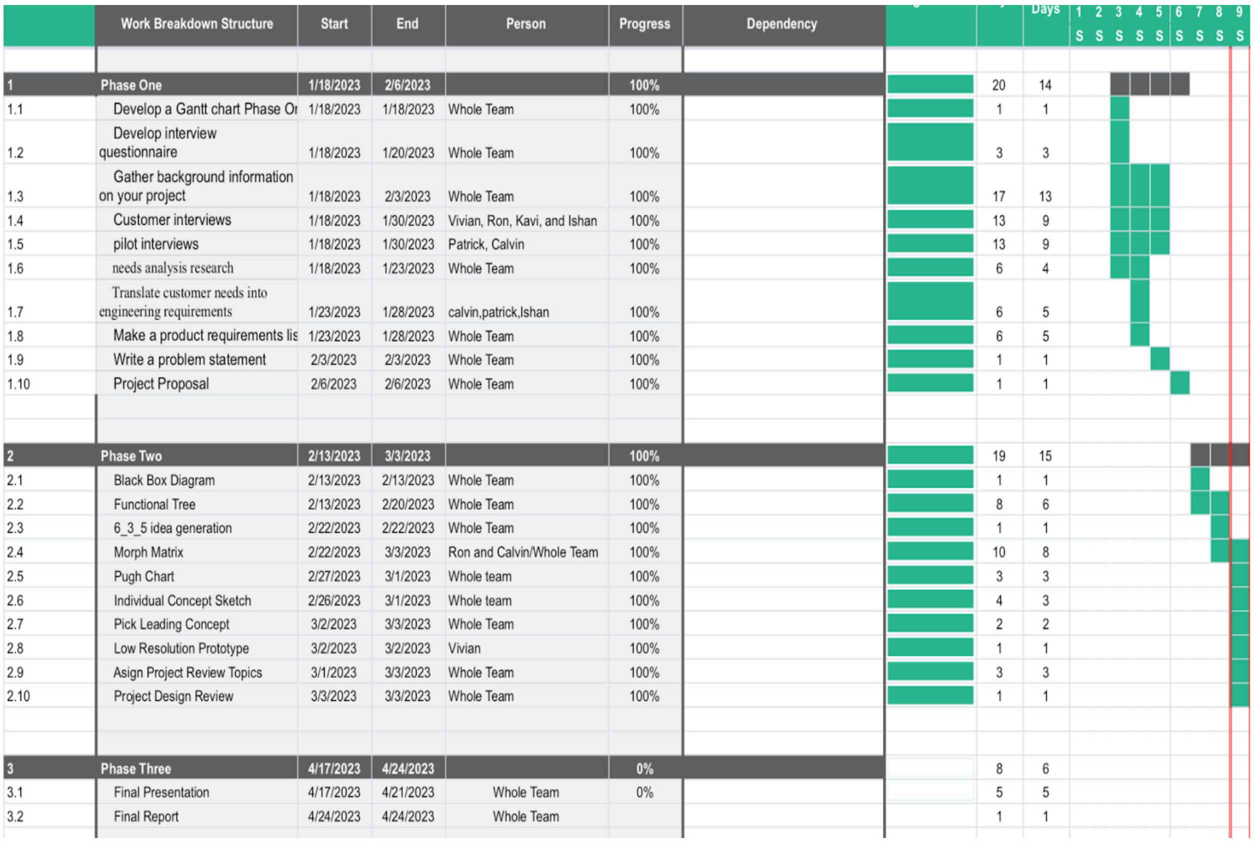
Low Resolution Prototype

Figure P1. Low Resolution Prototype (Top View)

Figure P2. Low Resolution Prototype (Front View)

Appendix Q

Gantt Chart / Task List



	Work Breakdown Structure	Start	End	Person	Progress	Dependency		Days
1	Phase One	1/18/2023	2/6/2023		100%		20	14
1.1	Develop a Gantt chart Phase O	1/18/2023	1/18/2023	Whole Team	100%		1	1
1.2	Develop interview questionnaire	1/18/2023	1/20/2023	Whole Team	100%		3	3
1.3	Gather background information on your project	1/18/2023	2/3/2023	Whole Team	100%		17	13
1.4	Customer interviews	1/18/2023	1/30/2023	Vivian, Ron, Kavi, and Ishan	100%		13	9
1.5	pilot interviews	1/18/2023	1/30/2023	Patrick, Calvin	100%		13	9
1.6	needs analysis research	1/18/2023	1/23/2023	Whole Team	100%		6	4
1.7	Translate customer needs into engineering requirements	1/23/2023	1/28/2023	calvin,patrick,Ishan	100%		6	5
1.8	Make a product requirements lis	1/23/2023	1/28/2023	Whole Team	100%		6	5
1.9	Write a problem statement	2/3/2023	2/3/2023	Whole Team	100%		1	1
1.10	Project Proposal	2/6/2023	2/6/2023	Whole Team	100%		1	1
2	Phase Two	2/13/2023	3/3/2023		100%		19	15
2.1	Black Box Diagram	2/13/2023	2/13/2023	Whole Team	100%		1	1
2.2	Functional Tree	2/13/2023	2/20/2023	Whole Team	100%		8	6
2.3	6_3_5 idea generation	2/22/2023	2/22/2023	Whole Team	100%		1	1
2.4	Morph Matrix	2/22/2023	3/3/2023	Ron and Calvin/Whole Team	100%		10	8
2.5	Pugh Chart	2/27/2023	3/1/2023	Whole team	100%		3	3
2.6	Individual Concept Sketch	2/26/2023	3/1/2023	Whole team	100%		4	3
2.7	Pick Leading Concept	3/2/2023	3/3/2023	Whole Team	100%		2	2
2.8	Low Resolution Prototype	3/2/2023	3/2/2023	Vivian	100%		1	1
2.9	Asign Project Review Topics	3/1/2023	3/3/2023	Whole Team	100%		3	3
2.10	Project Design Review	3/3/2023	3/3/2023	Whole Team	100%		1	1
3	Phase Three	4/17/2023	4/24/2023		0%		8	6
3.1	Final Presentation	4/17/2023	4/21/2023	Whole Team	0%		5	5
3.2	Final Report	4/24/2023	4/24/2023	Whole Team			1	1

Figure Q1. Phase 2 Gantt Chart

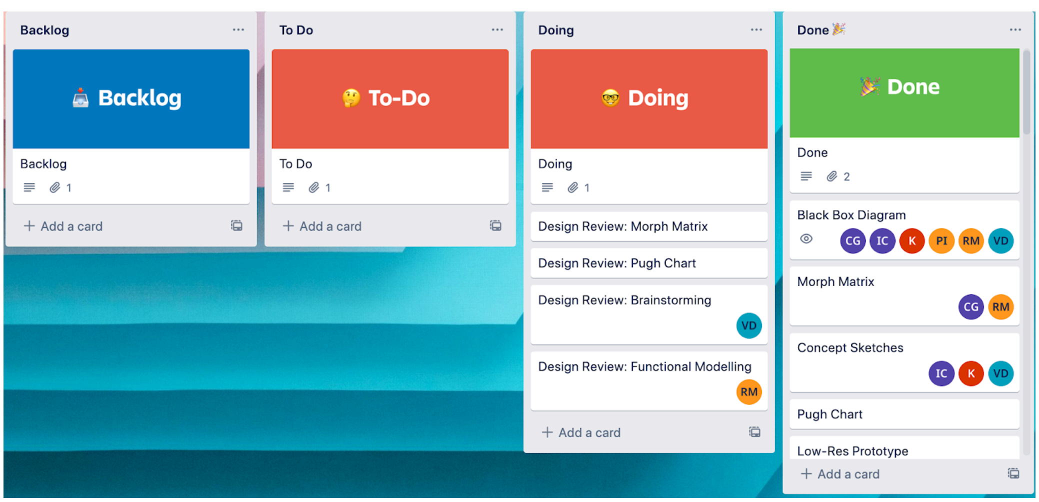


Figure Q2. Phase 2 Task List

Appendix R

Leading Concept Models

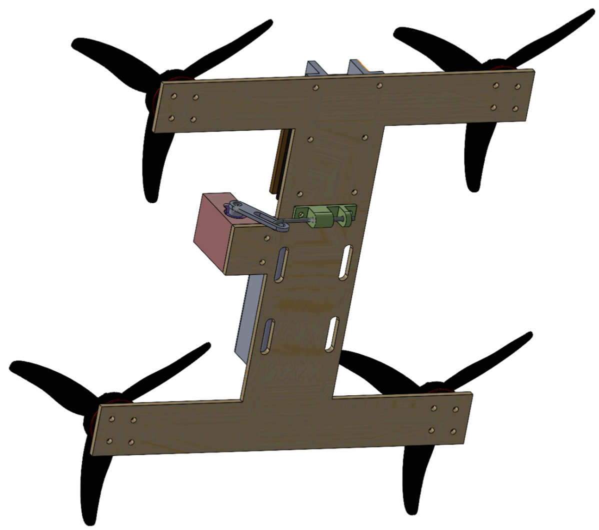


Figure R1. Initial CAD Model

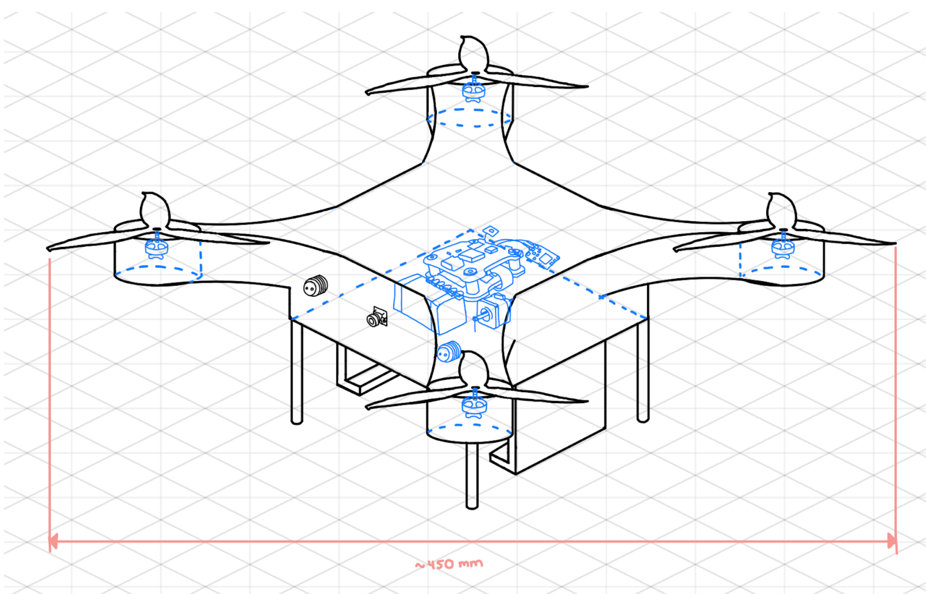


Figure R2. Dimensioned Concept Sketch

Appendix S

Manufacturing

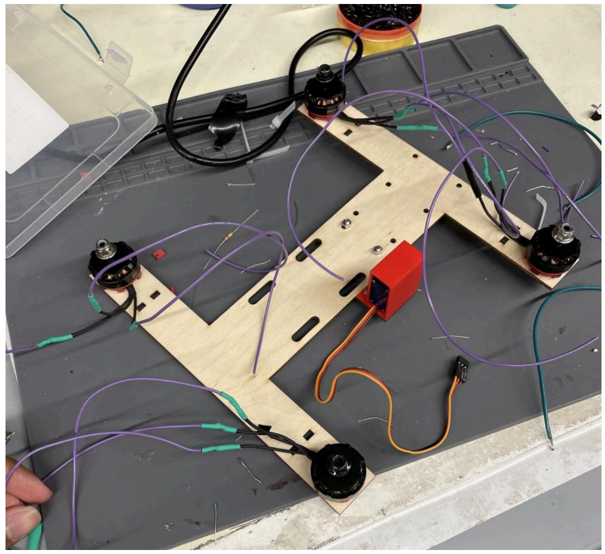


Figure S1. Laser Cut Frame

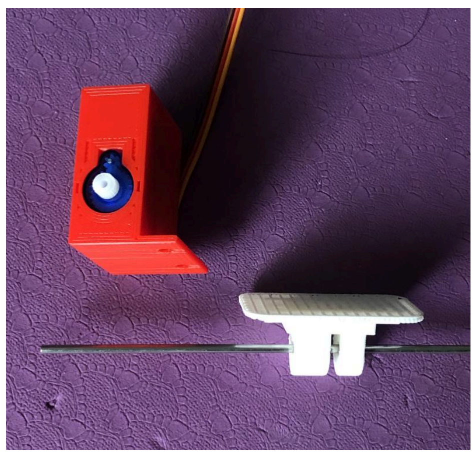


Figure S2. 3D Printed Payload Mechanism

Figure S4. Laser Cut Legs

Appendix T

Initial FMEA

Component & Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity Rating (1-10)	Classification (critical, key, major, or significant)	Potential Cause(s)/ Mechanism(s) of Failure	Occurence Frequency (1-10)	Current Process Controls	Detection Rating (1-10)	Risk Priority Number (1-1000)	Recommended Action(s)	Responsibility and Target Completion Date
Brushless Motors	Motor stops rotating	incorrect installation	10	critical	physical wear, loose wiring, overvoltage	3	operator inspects motors before every flight	7	210	motor brakets that prevents movement while in storage	calvin- 4/7
LiPo Battery	Battery dies	drone looses power while in flight	10	critical	water/weather damage, over heating	3	operator checks LED lights on flight controller before each flight	7	210	protective guard that prevents battery movement but still allows for airflow.	patrick- 4/7
RC Transmitter	RC transmitter stops transmitting information	drone does not communicate with remote/pilot	10	critical	drone out of range, faulty wiring, damage due to crashing	2	operator checks functionality before every flight	2	40	test connectivity in flight delivery radius and identify dead zones.	ron- 4/7
Propellers	propellers breaks	loss of flight stablity or total loss of flight capacity	9	critical	collision, high wind speeds, extreme weather conditions	4	visual/physical inspection	9	324	propeller shields	vivian - 4/7
Flight Stack	short circuits	loss of some or all control of the drone	10	critical	rain, hot/cold weather, incorrect installation	2	run control tests	5	100	frame hood/shield that prevents vibration, shift in position	Ishan - 4/7
Payload Mechanism	pin gets stuck	payload isn't dropped off	6	key	loose motor connection, wear in the pin bracket, stress from payload	7	test the efficacy of the pin when inserting the payload	8	336	end of pin is tapered so it can slide in even if it is slightly misaligned. lubrication	kavi- 4/7

Appendix U

Simulations

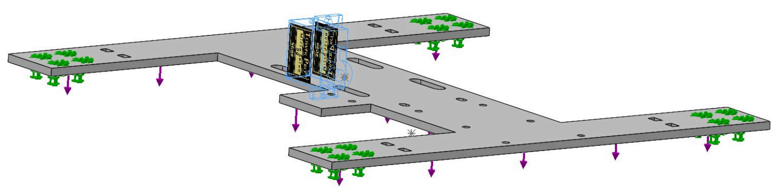


Figure U1. Frame FEA Support and Force Conditions

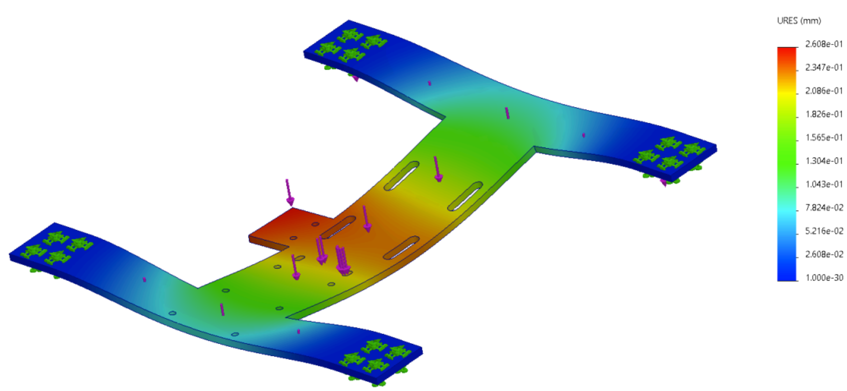


Figure U2. Frame FEA Deflection Results

Appendix V

Financials

Bill of Materials

Name	Needed	Source	Price Per Unit	Total Price	Finished / Procured?
		Total Price (sum of all):		$ 243.05	
Frame, Enclosures					
Wood Frame	1	TIW	$ 3.50	$ 3.50	Procured
3D Printed Enclosures	3	TIW	$ 0.20	$ 0.60	Procured
Flight Control, Communication					
Battery	1	https://www.amazon.com/gp/product/B0784BB8	$ 19.13	$ 19.13	Procured
Brushless motors	1	https://www.amazon.com/gp/product/B088NGC	$ 36.99	$ 36.99	Procured
Propellers	4	https://www.amazon.com/iFlight-Tri-Blades-Prop	$ 0.84	$ 3.36	Procured
Camera	1	Camera	$ 17.99	$ 17.99	Procured
Receiver	1	Receiver	$ 32.99	$ 32.99	Procured
Transmitter + reciever +	1	https://www.amazon.com/FLYSKY-Transmitter-C	$ 51.50	$ 51.50	Procured
FC + ESC Stack	1	https://www.amazon.com/SpeedyBee-Flight-Cor	$ 75.99	$ 75.99	Procured
Payload Mechanism					
Metal Rod	1	https://www.amazon.com/dp/B07B6MFB3N?ref=ppx_yo	$ 1.00	$ 1.00	Procured

Figure V1. Bill of Materials

Budget

Name	Needed	Source	Price Per Unit	Total Price	Finished / Procured?
		Total Price (sum of all):		$ 248.90	
Frame, Enclosures					
Wood Frame	1	TIW	$ 3.50	$ 3.50	Procured
3D Printed Enclosures	3	TIW	$ 0.20	$ 0.60	Procured
Flight Control, Communication					
Battery	1	https://www.amazon.com/gp/product/B0784BB8	$ 19.13	$ 19.13	Procured
Brushless motors	1	https://www.amazon.com/gp/product/B088NGC	$ 36.99	$ 36.99	Procured
Propellers	4	https://www.amazon.com/iFlight-Tri-Blades-Prop	$ 0.84	$ 3.36	Procured
Camera	1	Camera	$ 17.99	$ 17.99	Procured
Receiver	1	Receiver	$ 32.99	$ 32.99	Procured
Transmitter + reciever +	1	https://www.amazon.com/FLYSKY-Transmitter-C	$ 51.50	$ 51.50	Procured
FC + ESC Stack	1	https://www.amazon.com/SpeedyBee-Flight-Cor	$ 75.99	$ 75.99	Procured
Payload Mechanism					
Micro Servo	1	https://www.amazon.com/Micro-Servos-Helicopt	$ 2.33	$ 2.33	Procured
Metal Rod	1	https://www.amazon.com/dp/B07B6MFB3N?ref=ppx_yo	$ 1.00	$ 1.00	Procured
Fasteners					
M3 Screws	50		0.03	$ 1.50	Procured
Hex Standoffs	20		0.03	$ 0.60	Procured
Zip ties	7		0.06	$ 0.42	Procured
Velcro tape	2		$ 0.50	$ 1.00	Procured

Figure V2. Budget

Appendix W

Design of Experiment

Table W1. 3 Control Factors, 2 Levels

Control Factor	**Low Level (-)**	**High Level (+)**
X1 (mass of payload)	1 pack of gum	3 packs of gym
X2 (thrust of motor)	30% thrust	90% thrust
X3 (landing option)	Ground landing	Hovering landing

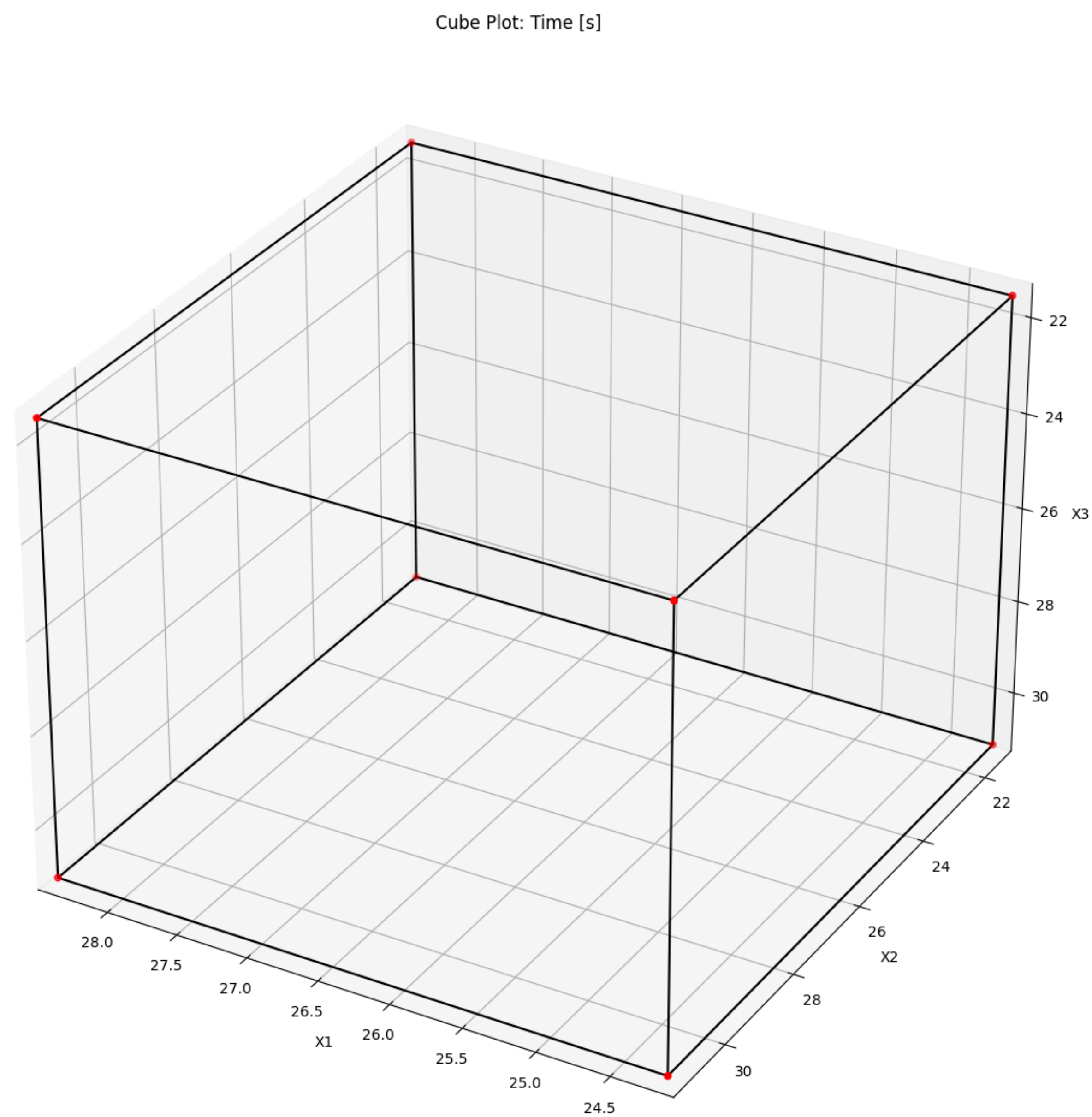


Figure W1. Cube Plot with Time

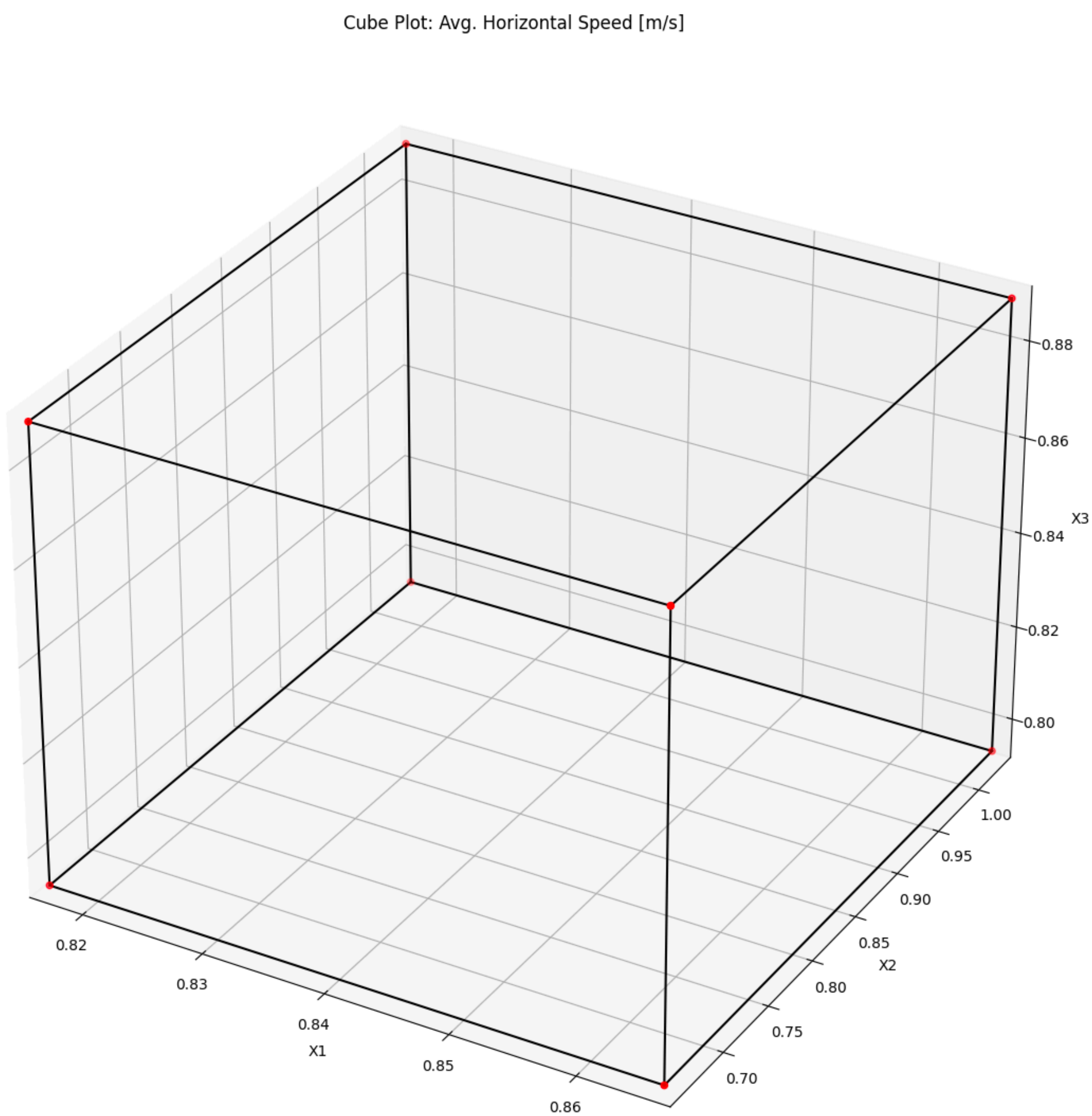


Figure W2. Cube Plot with Average Horizontal Speed

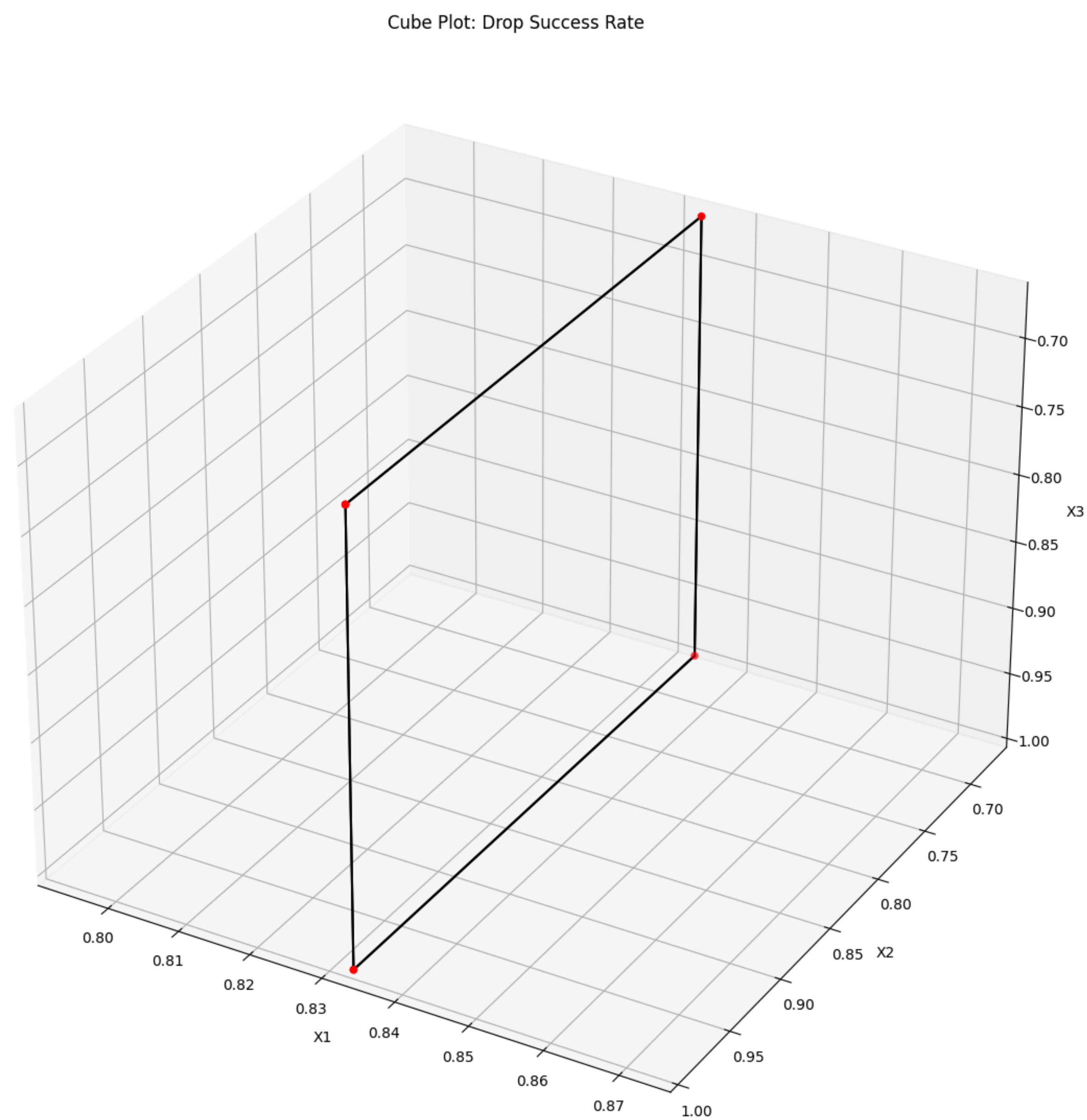


Figure W3. Cube Plot with Drop Success Rate

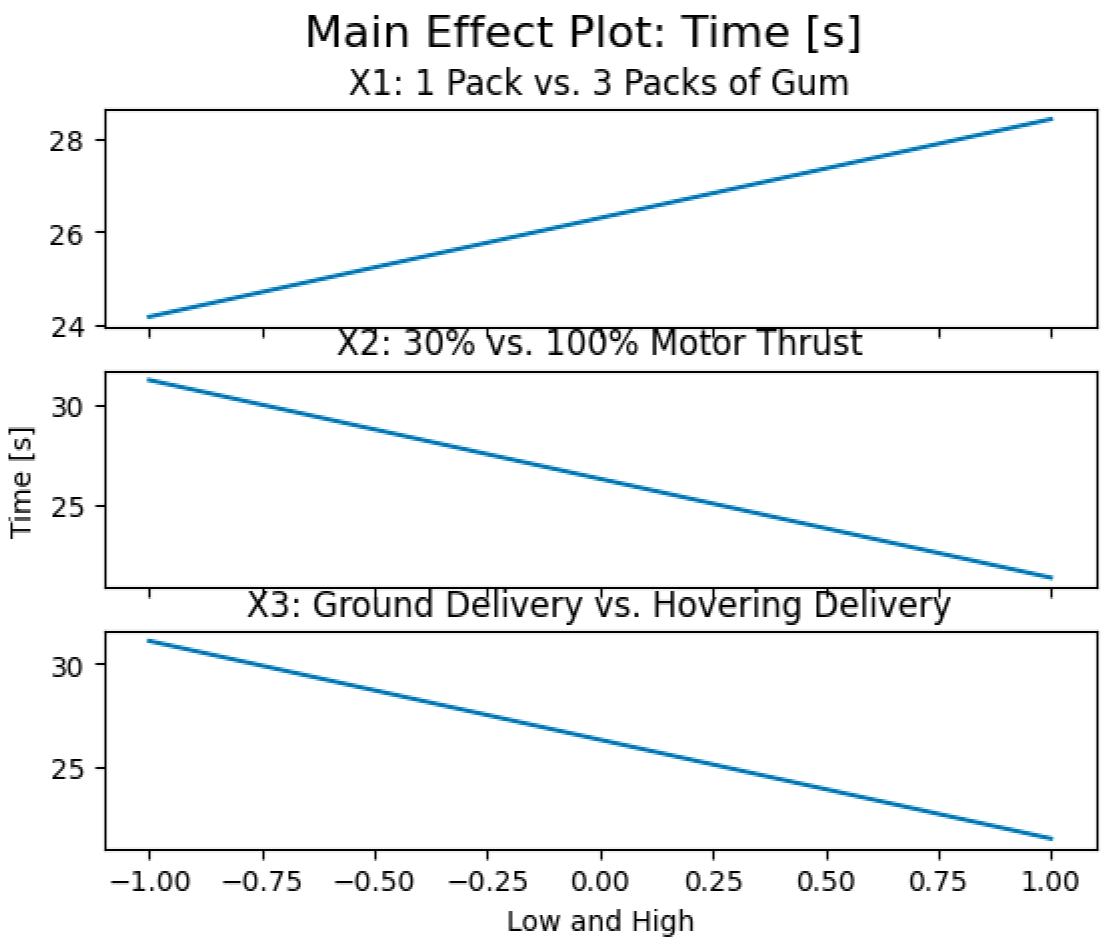


Figure W4. Main Effect Plot: Time

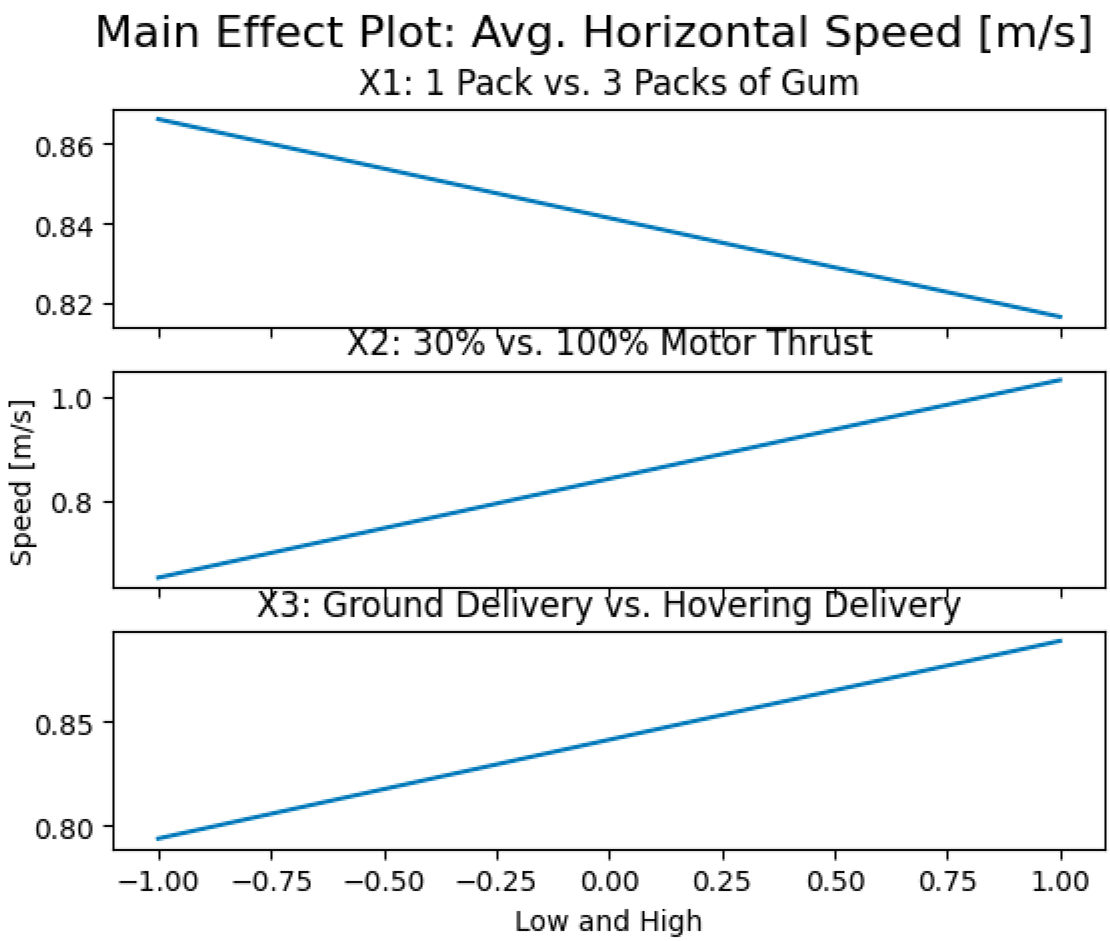


Figure W5. Main Effect Plot: Average Horizontal Speed

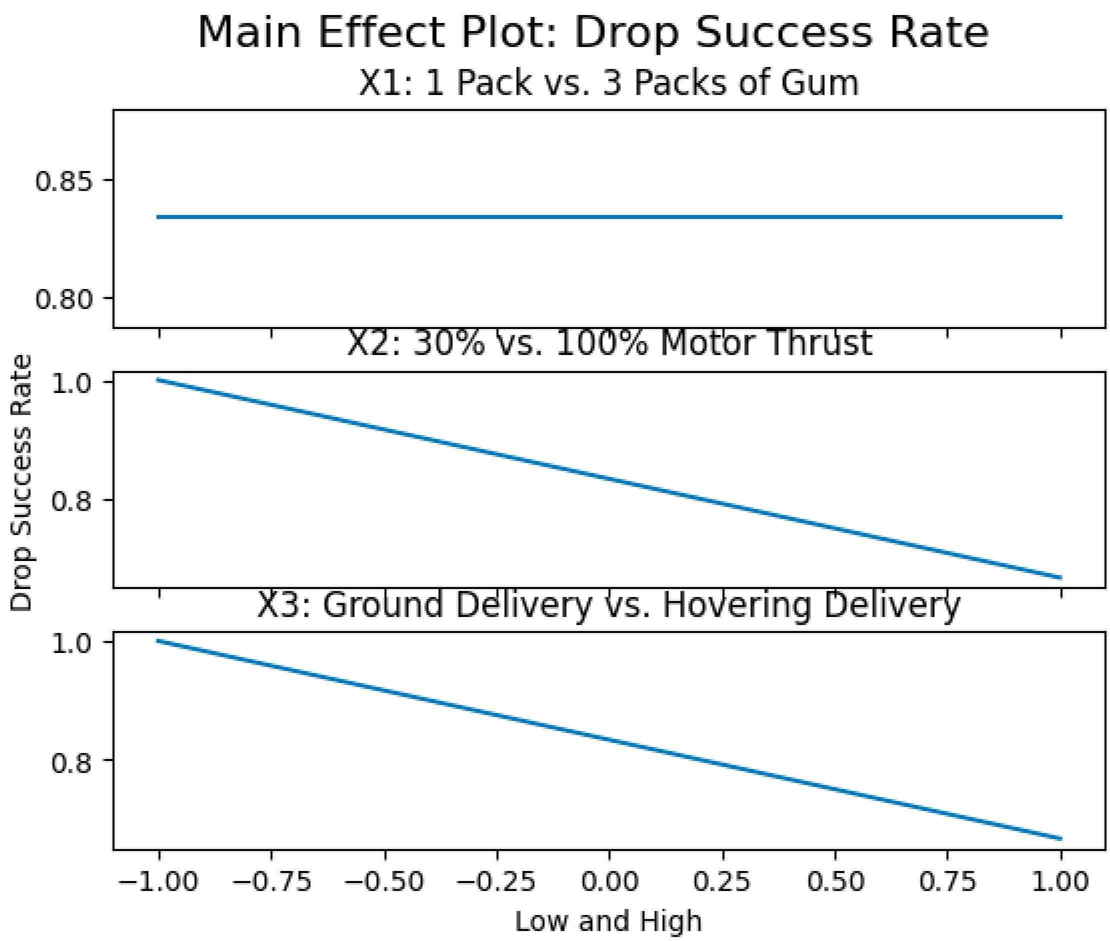


Figure W6. Main Effect Plot: Drop Success Rate

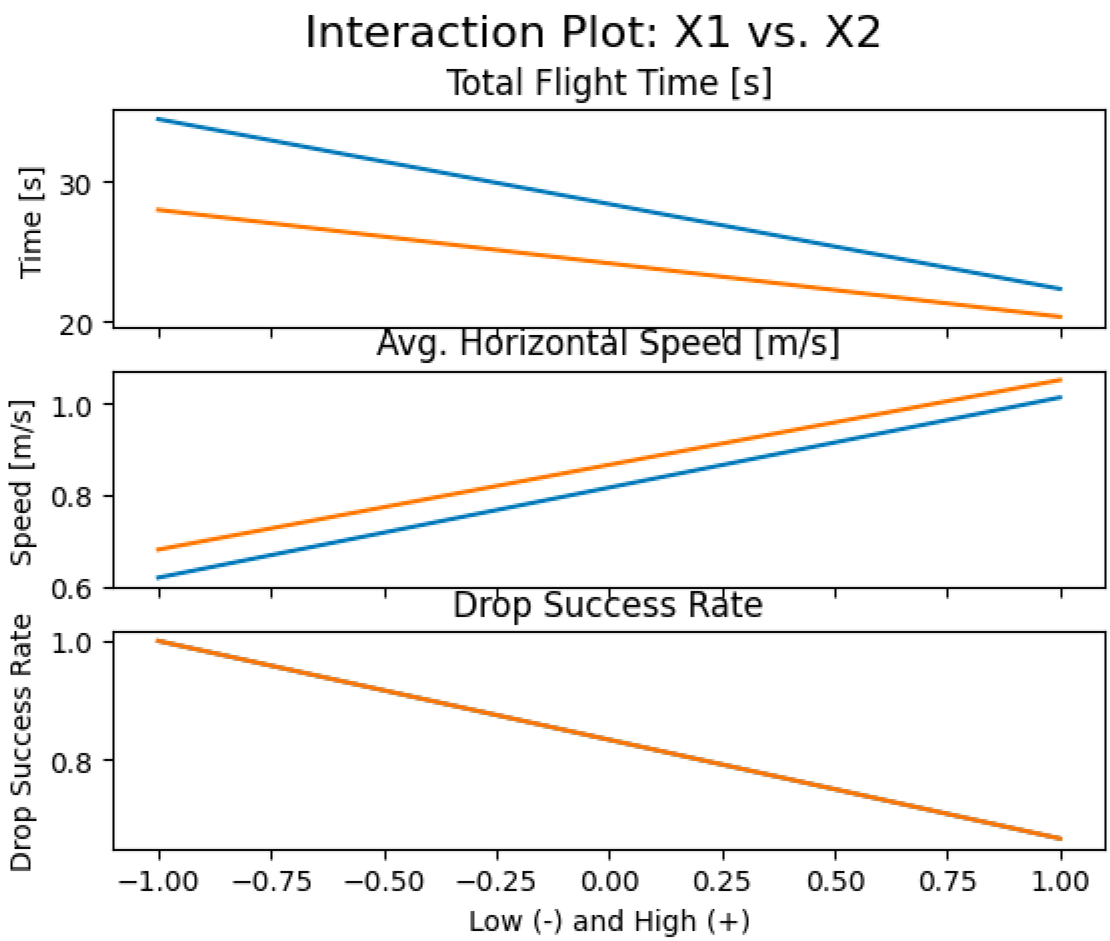


Figure W7. Interaction Plot: X1 (mass) vs. X2 (thrust)

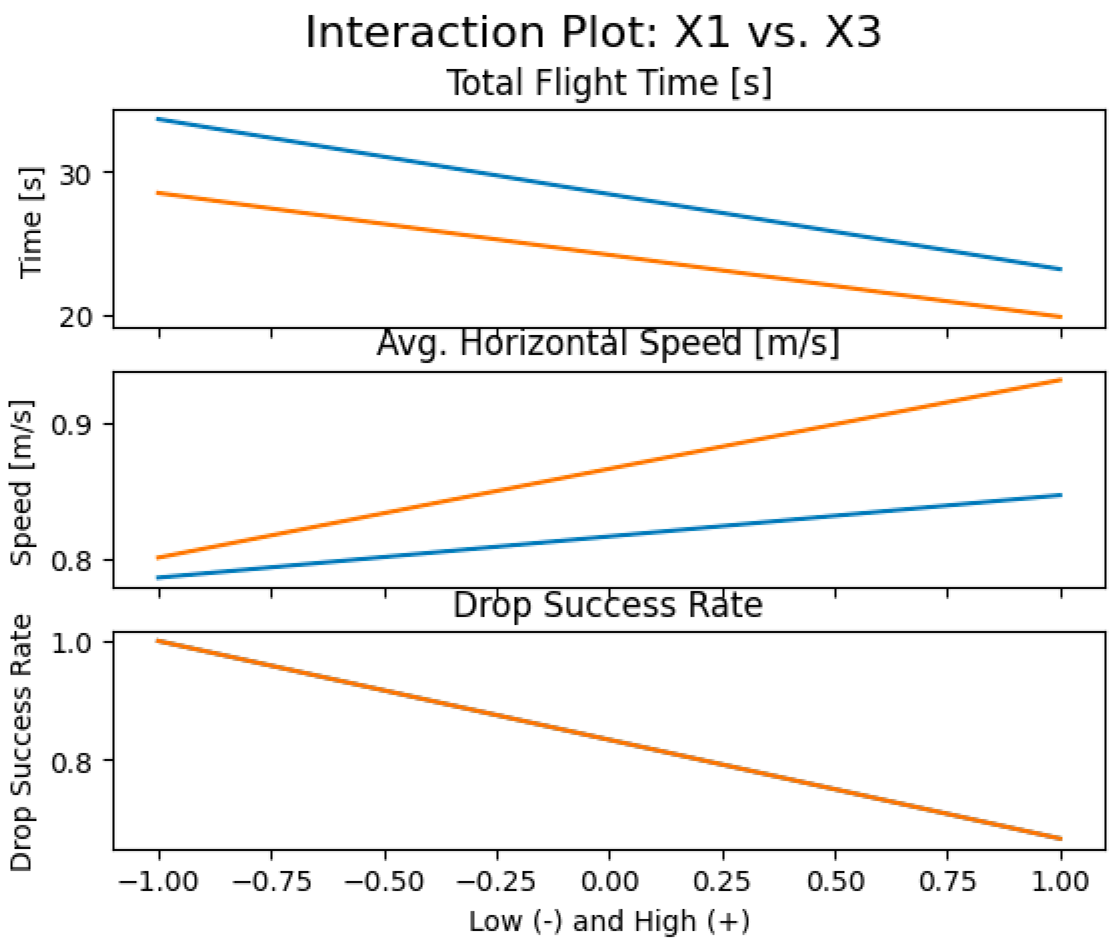


Figure W8. Interaction Plot: X1 (mass) vs. X3 (landing)

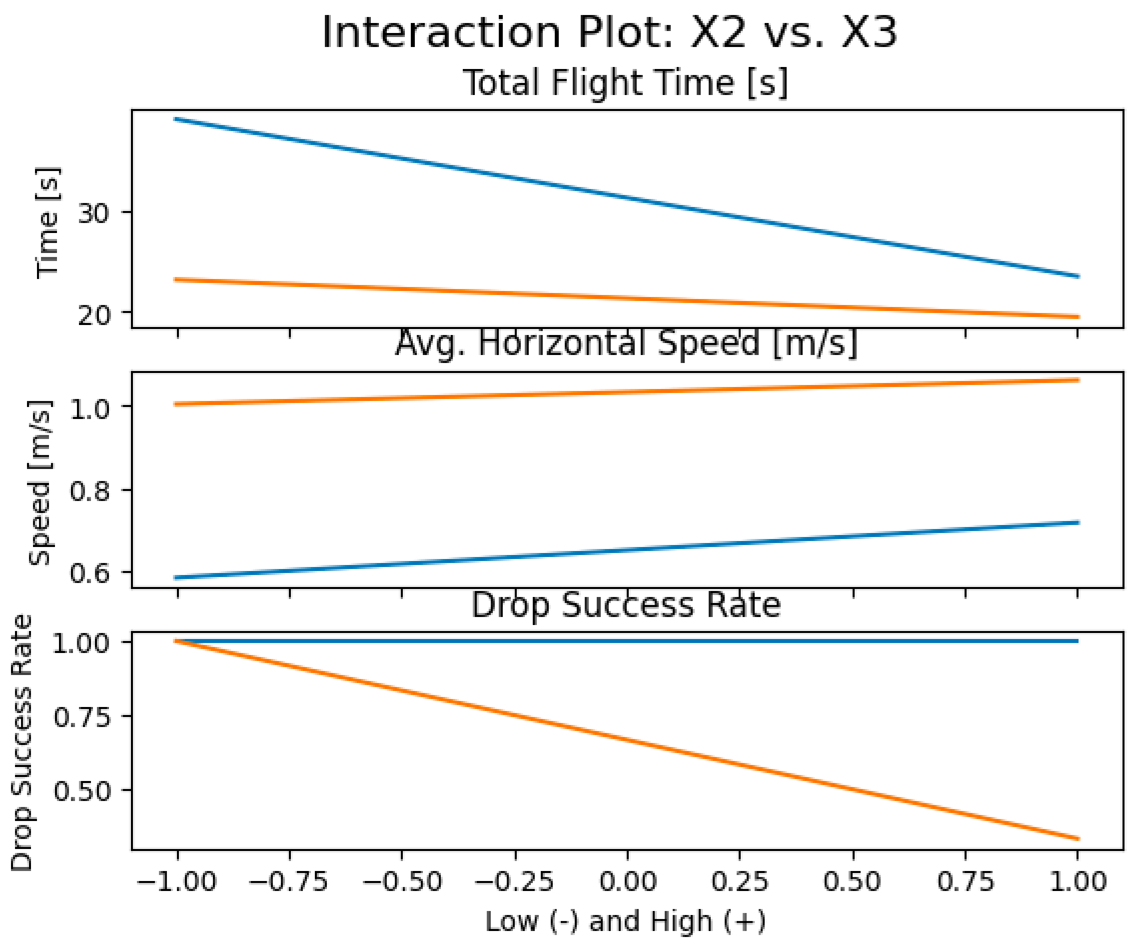


Figure W9. Interaction Plot: X2 (thrust) vs. X3 (landing)

	sum_sq	df	F	PR(>F)
x1	108.375000	1.0	5.772304	0.026108
x2	590.041667	1.0	31.426986	0.000017
x3	551.041667	1.0	29.349756	0.000027
Residual	375.500000	20.0	NaN	NaN

Figure W10. ANOVA Analysis: Time Response

	sum_sq	df	F	PR(>F)
x1	0.014811	1.0	1.264950	2.740338e-01
x2	0.874783	1.0	74.712000	3.456283e-08
x3	0.054831	1.0	4.682913	4.274202e-02
Residual	0.234175	20.0	NaN	NaN

Figure W11. ANOVA Analysis: Speed Response

	sum_sq	df	F	PR(>F)
x1	2.958228e-31	1.0	9.860761e-31	1.000000
x2	6.666667e-01	1.0	2.222222e+00	0.151641
x3	6.666667e-01	1.0	2.222222e+00	0.151641
Residual	6.000000e+00	20.0	NaN	NaN

Figure W12. ANOVA Analysis: Drop Rate Success Response

```
                            OLS Regression Results
================================================================================
Dep. Variable:     Total Flight Time (s)   R-squared:                       0.067
Model:                               OLS   Adj. R-squared:                  0.024
Method:                    Least Squares   F-statistic:                     1.572
Date:                   Tue, 25 Apr 2023   Prob (F-statistic):              0.223
Time:                           02:09:37   Log-Likelihood:                -83.808
No. Observations:                     24   AIC:                             171.6
Df Residuals:                         22   BIC:                             174.0
Df Model:                              1
Covariance Type:               nonrobust
====================================================================================
                       coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------------
const               26.2917      1.695     15.513      0.000      22.777      29.806
x1 -- A (Payload)   -2.1250      1.695     -1.254      0.223      -5.640       1.390
==============================================================================
Omnibus:                        6.954   Durbin-Watson:                   1.008
Prob(Omnibus):                  0.031   Jarque-Bera (JB):                5.417
Skew:                           1.151   Prob(JB):                       0.0666
Kurtosis:                       3.339   Cond. No.                         1.00
==============================================================================
```

```
                            OLS Regression Results
================================================================================
Dep. Variable:     Total Flight Time (s)   R-squared:                       0.363
Model:                               OLS   Adj. R-squared:                  0.334
Method:                    Least Squares   F-statistic:                     12.54
Date:                   Tue, 25 Apr 2023   Prob (F-statistic):            0.00183
Time:                           02:09:58   Log-Likelihood:                -79.223
No. Observations:                     24   AIC:                             162.4
Df Residuals:                         22   BIC:                             164.8
Df Model:                              1
Covariance Type:               nonrobust
====================================================================================
                      coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------------
const              26.2917      1.400     18.779      0.000      23.388      29.195
x2 -- B (Thrust)   -4.9583      1.400     -3.542      0.002      -7.862      -2.055
==============================================================================
Omnibus:                        4.746   Durbin-Watson:                   0.887
Prob(Omnibus):                  0.093   Jarque-Bera (JB):                2.795
Skew:                           0.682   Prob(JB):                        0.247
Kurtosis:                       3.968   Cond. No.                         1.00
==============================================================================
```

```
                            OLS Regression Results
==============================================================================
Dep. Variable:     Total Flight Time (s)   R-squared:                       0.339
Model:                               OLS   Adj. R-squared:                  0.309
Method:                    Least Squares   F-statistic:                     11.29
Date:                   Tue, 25 Apr 2023   Prob (F-statistic):            0.00283
Time:                           02:10:39   Log-Likelihood:                -79.667
No. Observations:                     24   AIC:                             163.3
Df Residuals:                         22   BIC:                             165.7
Df Model:                              1
Covariance Type:               nonrobust
==================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
----------------------------------------------------------------------------------
const                26.2917      1.426     18.435      0.000      23.334      29.249
x3 -- C (Landing)    -4.7917      1.426     -3.360      0.003      -7.749      -1.834
==============================================================================
Omnibus:                        4.499   Durbin-Watson:                   1.283
Prob(Omnibus):                  0.105   Jarque-Bera (JB):                2.659
Skew:                           0.733   Prob(JB):                        0.265
Kurtosis:                       3.716   Cond. No.                         1.00
==============================================================================
```

Figure W13. Regression Results with Total Flight Time Response

```
                             OLS Regression Results
=====================================================================================================
Dep. Variable:     Average Horizontal Speed [m/s]   R-squared:                       0.013
Model:                                        OLS   Adj. R-squared:                 -0.032
Method:                             Least Squares   F-statistic:                    0.2800
Date:                            Tue, 25 Apr 2023   Prob (F-statistic):              0.602
Time:                                    02:13:55   Log-Likelihood:                 2.2620
No. Observations:                              24   AIC:                           -0.5239
Df Residuals:                                  22   BIC:                             1.832
Df Model:                                       1
Covariance Type:                        nonrobust
=====================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const                 0.8414      0.047     17.922      0.000       0.744       0.939
x1 -- A (Payload)     0.0248      0.047      0.529      0.602      -0.073       0.122
==============================================================================
Omnibus:                        1.343   Durbin-Watson:                   1.563
Prob(Omnibus):                  0.511   Jarque-Bera (JB):                1.173
Skew:                          -0.380   Prob(JB):                        0.556
Kurtosis:                       2.229   Cond. No.                         1.00
==============================================================================
```

```
                             OLS Regression Results
=====================================================================================================
Dep. Variable:     Average Horizontal Speed [m/s]   R-squared:                       0.742
Model:                                        OLS   Adj. R-squared:                  0.731
Method:                             Least Squares   F-statistic:                     63.34
Date:                            Tue, 25 Apr 2023   Prob (F-statistic):           6.43e-08
Time:                                    02:14:09   Log-Likelihood:                 18.378
No. Observations:                              24   AIC:                            -32.76
Df Residuals:                                  22   BIC:                            -30.40
Df Model:                                       1
Covariance Type:                        nonrobust
=====================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const                 0.8414      0.024     35.076      0.000       0.792       0.891
x2 -- B (Thrust)      0.1909      0.024      7.959      0.000       0.141       0.241
==============================================================================
Omnibus:                        8.489   Durbin-Watson:                   1.828
Prob(Omnibus):                  0.014   Jarque-Bera (JB):                6.364
Skew:                          -1.016   Prob(JB):                       0.0415
Kurtosis:                       4.494   Cond. No.                         1.00
==============================================================================
```

```
                                OLS Regression Results
==========================================================================================
Dep. Variable:     Average Horizontal Speed [m/s]   R-squared:                       0.047
Model:                                        OLS   Adj. R-squared:                  0.003
Method:                             Least Squares   F-statistic:                     1.073
Date:                            Tue, 25 Apr 2023   Prob (F-statistic):              0.311
Time:                                    02:14:24   Log-Likelihood:                 2.6819
No. Observations:                              24   AIC:                            -1.364
Df Residuals:                                  22   BIC:                            0.9924
Df Model:                                       1
Covariance Type:                        nonrobust
=====================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const                 0.8414      0.046     18.238      0.000       0.746       0.937
x3 -- C (Landing)     0.0478      0.046      1.036      0.311      -0.048       0.143
==============================================================================
Omnibus:                        1.652   Durbin-Watson:                   1.610
Prob(Omnibus):                  0.438   Jarque-Bera (JB):                1.176
Skew:                          -0.288   Prob(JB):                        0.556
Kurtosis:                       2.081   Cond. No.                         1.00
==============================================================================
```

Figure W14. Regression Results with Average Horizontal Speed Response

```
                            OLS Regression Results
==============================================================================
Dep. Variable:           Drop Success   R-squared:                       0.000
Model:                            OLS   Adj. R-squared:                 -0.045
Method:                 Least Squares   F-statistic:                 2.665e-15
Date:                Tue, 25 Apr 2023   Prob (F-statistic):               1.00
Time:                        02:15:20   Log-Likelihood:                -19.827
No. Observations:                  24   AIC:                             43.65
Df Residuals:                      22   BIC:                             46.01
Df Model:                           1
Covariance Type:            nonrobust
====================================================================================
                       coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------------
const                0.8333      0.118      7.071      0.000       0.589       1.078
x1 -- A (Payload) -7.633e-17     0.118  -6.48e-16      1.000      -0.244       0.244
==============================================================================
Omnibus:                       36.794   Durbin-Watson:                   1.636
Prob(Omnibus):                  0.000   Jarque-Bera (JB):               86.645
Skew:                          -3.015   Prob(JB):                     1.53e-19
Kurtosis:                      10.091   Cond. No.                         1.00
==============================================================================
```

```
                            OLS Regression Results
==============================================================================
Dep. Variable:           Drop Success   R-squared:                       0.091
Model:                            OLS   Adj. R-squared:                  0.050
Method:                 Least Squares   F-statistic:                     2.200
Date:                Tue, 25 Apr 2023   Prob (F-statistic):              0.152
Time:                        02:15:37   Log-Likelihood:                -18.683
No. Observations:                  24   AIC:                             41.37
Df Residuals:                      22   BIC:                             43.72
Df Model:                           1
Covariance Type:            nonrobust
===================================================================================
                      coef    std err          t      P>|t|      [0.025      0.975]
-----------------------------------------------------------------------------------
const               0.8333      0.112      7.416      0.000       0.600       1.066
x2 -- B (Thrust)   -0.1667      0.112     -1.483      0.152      -0.400       0.066
==============================================================================
Omnibus:                       30.021   Durbin-Watson:                   1.717
Prob(Omnibus):                  0.000   Jarque-Bera (JB):               54.760
Skew:                          -2.530   Prob(JB):                     1.29e-12
Kurtosis:                       8.400   Cond. No.                         1.00
==============================================================================
```

```
                            OLS Regression Results
==============================================================================
Dep. Variable:           Drop Success   R-squared:                       0.091
Model:                            OLS   Adj. R-squared:                  0.050
Method:                 Least Squares   F-statistic:                     2.200
Date:                Tue, 25 Apr 2023   Prob (F-statistic):              0.152
Time:                        02:15:50   Log-Likelihood:                -18.683
No. Observations:                  24   AIC:                             41.37
Df Residuals:                      22   BIC:                             43.72
Df Model:                           1
Covariance Type:            nonrobust
=====================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const                 0.8333      0.112      7.416      0.000       0.600       1.066
x3 -- C (Landing)    -0.1667      0.112     -1.483      0.152      -0.400       0.066
==============================================================================
Omnibus:                       30.021   Durbin-Watson:                   1.650
Prob(Omnibus):                  0.000   Jarque-Bera (JB):               54.760
Skew:                          -2.530   Prob(JB):                     1.29e-12
Kurtosis:                       8.400   Cond. No.                         1.00
==============================================================================
```

Figure W15. Regression Results with Drop Success Rate Response

Appendix X

Updated Leading Concept

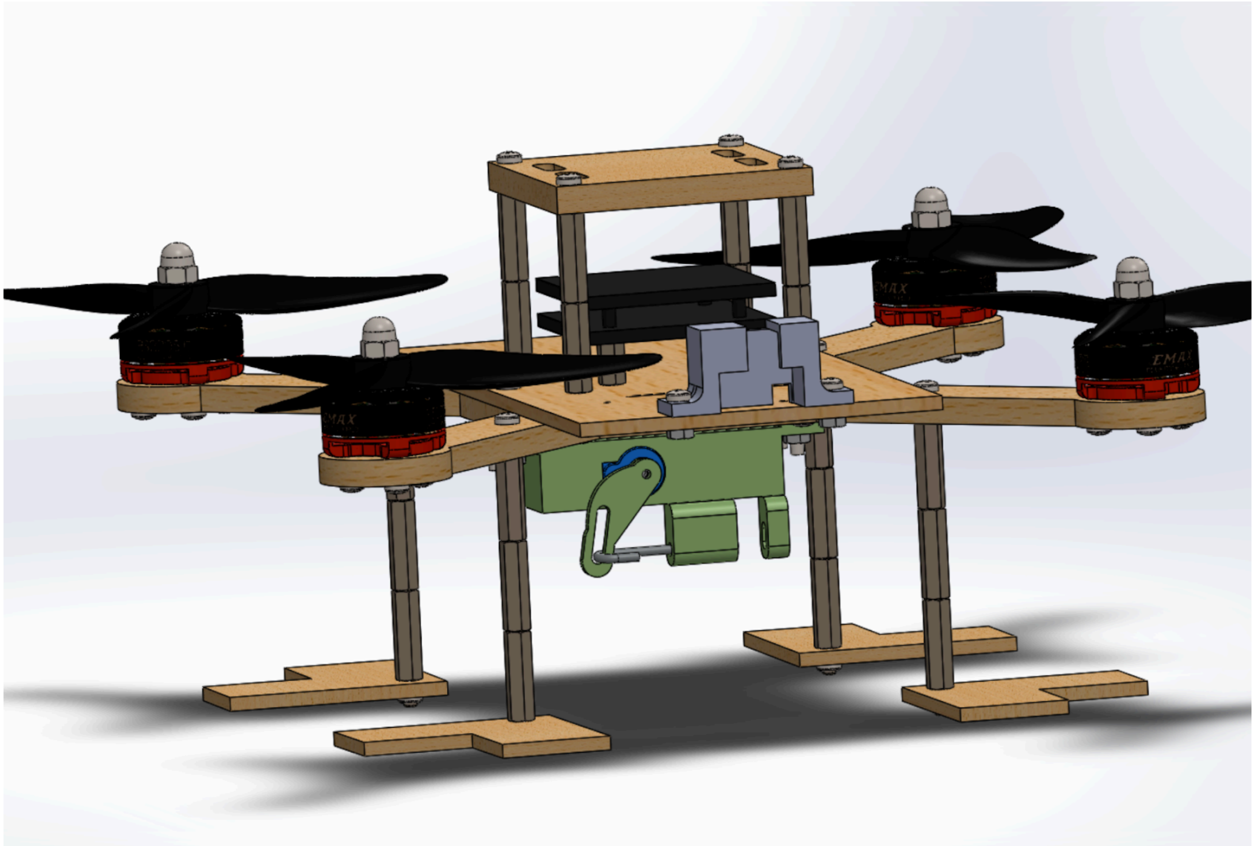


Figure X1. Updated CAD Assembly

Appendix Y

Final Prototype

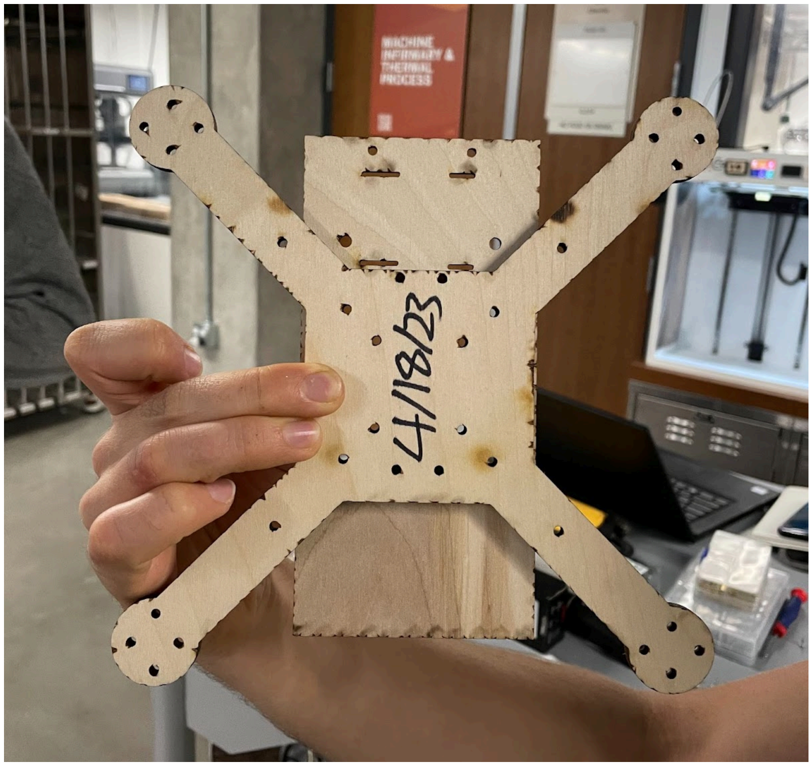


Figure Y1. Updated Frame

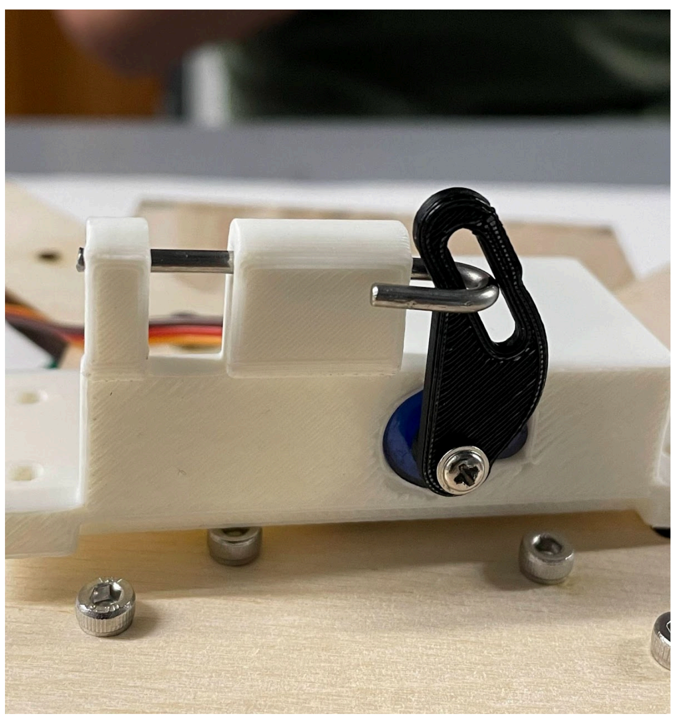


Figure Y2. Updated Payload Mechanism

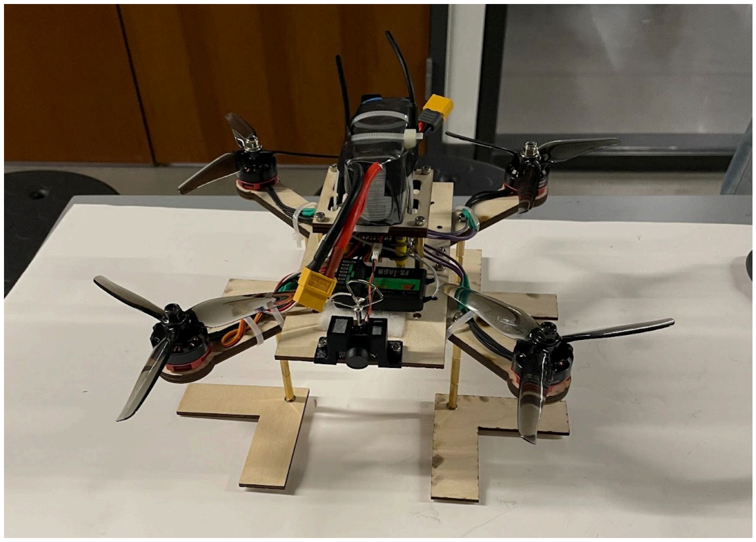


Figure Y3. Final Assembly

Appendix Z

Final FMEA

Component & Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity Rating (1-10)	Classification (critical, key, major, or significant)	Potential Cause(s)/ Mechanism(s) of Failure	Occurence Frequency (1-10)	Current Process Controls	Detection Rating (1-10)	Risk Priority Number (1-1000)	Recommended Action(s)
Brushless Motors	Motor stops rotating	Incorrect installation	10	Critical	Physical wear, loose wiring, overvoltage	3	Operator inspects motors before every flight	7	210	Motor brackets that prevent movement while in storage
LiPo Battery	Battery dies	Drone loses power while in flight	10	Critical	Water/weather damage, over heating, not charged before launching drone	3	Pilot charges the battery after every flight	7	210	Check the charge level before and after deploying the drone
RC Transmitter	RC transmitter stops transmitting information	Drone does not communicate with remote/pilot	10	Critical	Drone out of range, faulty wiring, damage due to crashing	2	Operator checks functionality before every flight	2	40	Test connectivity in flight delivery radius and identify dead zones
Propellers	Propellers break	Loss of flight stablity or total loss of flight capacity	9	Critical	Collision, high wind speeds, extreme weather conditions	4	Visual/physical inspection	9	324	Propeller shields
Flight Stack	Short circuits	Loss of some or all control of the drone	10	Critical	Rain, hot/cold weather, incorrect installation	2	Run control tests	3	60	Tape down wires to minimize movement, cover flight stack with another layer of wood
Payload Mechanism	Pin gets stuck	Payload is not dropped off	5	Key	Loose motor connection, wear in the pin bracket, stress from payload	1	Test the efficacy of the pin when inserting the payload	7	35	Resizing holes of pin bracket. Don't have payload exceed max allowable weight
Legs	One or more legs/feet collapse/bend	Drone cannot land without incurring damage	5	Key	Collision, payload interference, uneven landing	2	Operator inspects each leg's integrity before every flight, checks ground area	7	70	Design legs with feet that evenly spreads and absorbs landing load

Appendix AA

Build Instructions

Materials:

- 1 SpeedyBee FC stack (includes flight controller and ESC)
- 35V 1000uF low ESR capacitor
- 1 14.8V Lipo battery pack

- 1 FPV receiver
- 1 Transmitter controller
- 1 micro FPV camera
- 4 Tri-blade propellers
- 4 2300KV Brushless motors
- 1 2mm stainless steel metal rod
- Velcro tape (10 in)
- 4 Zip ties
- Electrical tape
- 4 20mm M3 screws
- 6 10mm M3 screws
- 4 10mm female standoffs
- 12 15mm M3 screws
- 4 6mm M3 screws
- 3 20mm male standoffs
- 1 20mm female standoff
- 1 15mm female standoff
- 4 M3 nuts
- ⅛" plywood board
- ¼" plywood board

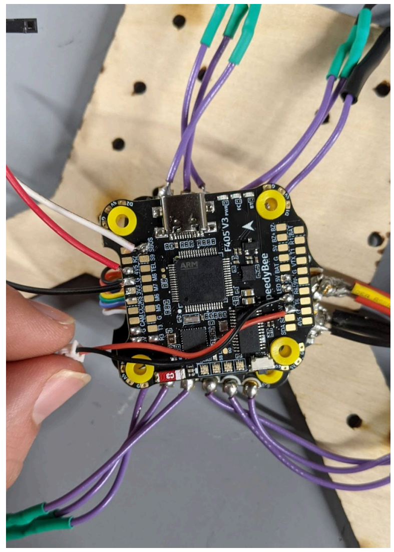
Tools:

- 3D printer
- Laser cutter
- Screwdriver
- Soldering iron

- Wrench

Electronics Hardware Setup

1. Solder XT60 cable from the battery to ESC pads
2. Solder capacitor to ESC
3. Solder motor leads to ESC
    a. Trim or extend motor leads according to length of motor arms
    b. Beginning at one end of the ESC, Line up the motor leads to the ESC pads.
    c. Without crossing the leads, solder in order.
4. Solder receiver wires to Flight controller
    a. Solder red wire to 4V5
    b. Solder black wire to Ground
    c. Solder white (signal) to SBUS
    d. Make sure to use connectors with female ends
5. Solder FPV camera wires to the FC
    a. Solder black wire to ground
    b. Red to any 5V pad
6. Connect the ESC and FC with the included rainbow-colored 8-pin connector



FC connections

Laser-cut Parts

1. Download the PDF / drawing files
2. Cut the motor cross arms and battery platform from ¼ " plywood
3. Cut the flight deck from ⅛" plywood
4. Inspect hole alignment on each laser-cut part, ensuring that holes match and the M3 screws can fit through them

Assemble Frame

1. Line up the flight deck and motor cross arms.
2. Place the soldered electronics on the flight deck
    a. Make sure that the front (the notched face/rainbow) of the FC faces the front of the frame.
    b. The front of the frame is marked by four slots.
3. Connect the flight stack.

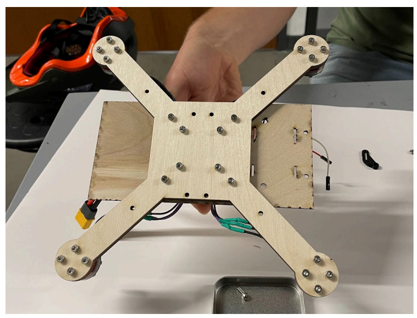
a. Thread four 20mm M3 screws through the flight stack holes and screw into 10mm female standoffs underneath.

b. Align the hex standoffs with the innermost square of holes.

c. Using four 15mm M3 screws, secure the hex standoffs by screwing through both the flight deck and motor cross arm layers.

4. Secure the motors to the holes at the end of the motor cross arms.

    a. Using four 6mm M3 screws per motor.



Cross arm and flight deck assembly

5. Screw two male 20mm standoffs to a 20mm female standoff. This is now a single landing leg.

    a. Assemble four landing legs. Make sure to screw the standoffs very tightly together.

    b. Using 10mm M3 screws, attach the legs to the bottom of the frame cross arms at the outermost set of holes.

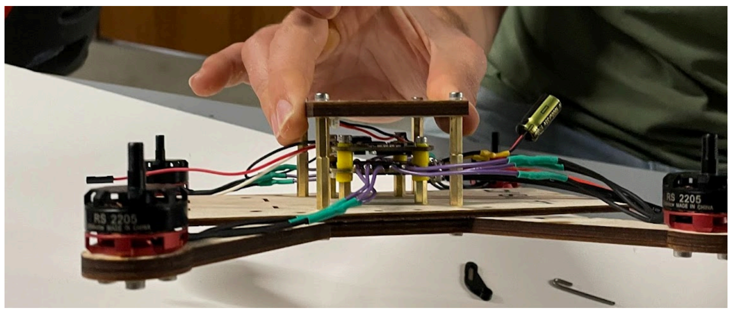
6. Screw a double-ended female 15mm hex standoff to a male 20mm standoff. This is now a battery platform leg.

    a. Assemble four battery platform legs.

    b. Screw the battery platform legs to the holes in the battery platform using four 10mm M3 screws.

    c. Screw the battery platform legs to the second ring of screw holes on the motor cross arms using four 15mm M3 screws.

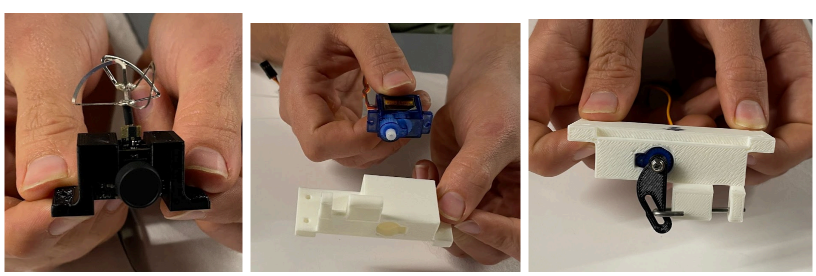
Battery platform



Full assembly of frame

3D-Print Parts

1. Download the included STL files
2. Print the camera enclosure, payload bracket, and servo arm with a FDM printer
3. Remove supports (if supports were used during printing)



3D printed parts: camera enclosure, payload bracket, servo arm

Assemble Payload Mechanism

1. Snap the servo into the payload mechanism bracket.
2. Slide the straight part of the rod into the payload bracket holes.
3. Thread the hooked portion of the rod through the servo arm slot.
4. Press the servo arm onto the servo shaft.
    a. Make sure that the tip of the servo arm is just touching the payload bracket
5. Screw the 5mm Phillips wood screw through the servo arm into the servo shaft
6. Attach the combined payload mechanism to the motor cross arms at the widest pair of holes on the frame
    a. Use four 15mm M3 screws and four M3 nuts.

Install Receiver

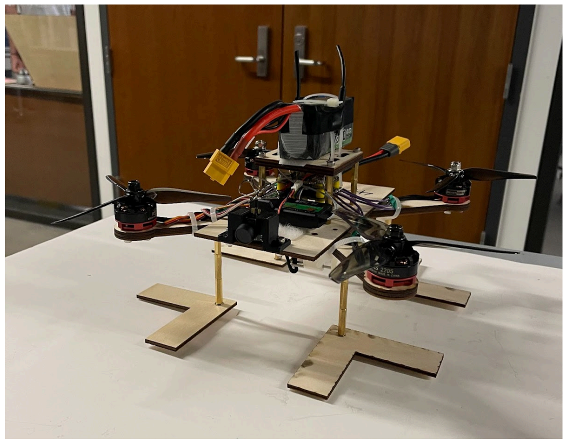
1. Cut velcro tape to the length of the receiver.
2. Place one half of the velcro tape between the four slots on the flight deck.
    a. Place the other on the receiver base.
    b. Attach the receiver.
3. Secure the receiver by binding zip ties through the slots.
4. Thread the receiver antenna through the battery platform's slots.
    a. This will be secured in the next step.

Install Battery

1. Place velcro tape on battery in this orientation <picture>
    a. Place velcro tape on the battery platform.
2. Place the battery on the platform and secure it by placing zip ties through the slots.
    a. Secure the receiver antenna by threading them underneath the zip ties.

Install Camera

1. Fit the camera into the camera enclosure and thread the power cable through the slot.
2. Use 10mm M3 screws and nuts to attach the camera enclosure to the front-most holes on the flight deck.



Final assembly

Appendix AB

Final Gantt Chart and Task List

ID	Work Breakdown Structure	Start	End	Person	Progress	Days	Work Days
1	Phase One	1/18/2023	2/6/2023		100%	20	14
1.1	Develop a Gantt chart Phase One	1/18/2023	1/18/2023	Whole Team	100%	1	1
1.2	Develop interview questionnaire	1/18/2023	1/20/2023	Whole Team	100%	3	3
1.3	Gather background information on your project	1/18/2023	2/3/2023	Whole Team	100%	17	13
1.4	Customer interviews	1/18/2023	1/30/2023	Vivian, Ron, Kavi, and Ishan	100%	13	9
1.5	pilot interviews	1/18/2023	1/30/2023	Patrick, Calvin	100%	13	9
1.6	needs analysis research	1/18/2023	1/23/2023	Whole Team	100%	6	4
1.7	Translate customer needs into engineering requirements	1/23/2023	1/28/2023	calvin,patrick,Ishan	100%	6	5
1.8	Make a product requirements list	1/23/2023	1/28/2023	Whole Team	100%	6	5
1.9	Write a problem statement	2/3/2023	2/3/2023	Whole Team	100%	1	1
1.10	Project Proposal	2/6/2023	2/6/2023	Whole Team	100%	1	1
2	Phase Two	2/13/2023	3/3/2023		100%	19	15
2.1	Black Box Diagram	2/13/2023	2/13/2023	Whole Team	100%	1	1
2.2	Functional Tree	2/13/2023	2/20/2023	Whole Team	100%	8	6
2.3	6_3_5 idea generation	2/22/2023	2/22/2023	Whole Team	100%	1	1
2.4	Morph Matrix	2/22/2023	3/3/2023	Ron and Calvin/Whole Team	100%	10	8
2.5	Pugh Chart	2/27/2023	3/1/2023	Whole team	100%	3	3
2.6	Individual Concept Sketch	2/26/2023	3/1/2023	Whole team	100%	4	3
2.7	Pick Leading Concept	3/2/2023	3/3/2023	Whole Team	100%	2	2
2.8	Low Resolution Prototype	3/2/2023	3/2/2023	Vivian	100%	1	1
2.9	Asign Project Review Topics	3/1/2023	3/3/2023	Whole Team	100%	3	3
2.10	Project Design Review	3/3/2023	3/3/2023	Whole Team	100%	1	1

3	Phase Three	3/3/2023	4/24/2023		100%		53	37
3.1	Design Review: Functional Modelling	3/3/2023	3/3/2023	Whole Team	100%		1	1
3.2	Design Review: Brainstorming	3/3/2023	3/3/2023	Whole Team	100%		1	1
3.3	Sketch drone frame - initial design	3/6/2023	3/10/2023	Vivian	100%		5	5
3.4	Create BOM	3/6/2023	3/14/2023	Whole Team	100%		9	7
3.5	Battery, motor choice	3/6/2023	3/18/2023	Patrick and Calvin	100%		13	10
3.6	Payload mechanism component	3/6/2023	3/21/2023	Calvin and Kavi	100%		16	12
3.7	Camera choice	3/6/2023	3/20/2023	Ron And Ishan	100%		15	11
3.8	Order Parts All Parts	3/6/2023	4/16/2023	Calvin, Patrick, Ishan	100%		42	30
3.9	Extend Motor Cables	3/28/2023	3/31/2023	Ishan	100%		4	4
3.10	Design Frame Version 1	3/28/2023	4/11/2023	Calvin, Vivian	100%		15	11
3.11	Design Payload mechanism Version 1	3/28/2023	4/11/2023	Calvin, Kavi, Patrick	100%		15	11
3.12	BetaFlight Servo Control	3/28/2023	4/14/2023	Ishan	100%		18	14
3.13	Order Pin / Latch Material For Payload System	3/28/2023	4/4/2023	Calvin	100%		8	6
3.14	DOE	3/29/2023	4/23/2023	Ron, Vivian, Patrick, Calvin	100%		26	18
3.15	Design Landing Gear/Legs	3/29/2023	4/16/2023	Patrick, Calvin, Ishan	100%		19	13
3.16	FMEA	3/29/2023	4/23/2023	Patrick	100%		26	18
3.17	Legs/Landing Gear Version 1	3/29/2023	4/11/2023	Patrick, Cavlin	100%		14	10
3.18	Electronics	4/19/2023	4/24/2023	Ishan	100%		6	4
3.19	Design Legs/landing Gear	4/12/2023	4/24/2023	Calvin, Ishan, Patrick	100%		13	9
3.20	Mile Stone Check 3	4/12/2023	4/12/2023	Whole Team	100%		1	1
3.21	Design Frame Final Version	4/5/2023	4/16/2023	Calvin, Patrick, Ishan	100%		12	8
3.22	Design Payload Mechanism Final Version	4/5/2023	4/16/2023	Calvin, Patrick, Ishan	100%		12	8
3.23	Drone Prototyping	4/10/2023	4/18/2023	Calvin, Patrick, Ishan	100%		9	7
3.24	Final Presentation Slides	4/10/2023	4/18/2023	Ron + Whole Team	100%		9	7
3.25	Assemble Final Prototype	4/18/2023	4/18/2023	Patrick, Calvin, Ishan	100%		1	1
3.26	Final Test Flight	4/18/2023	4/18/2023	Patrick, Calvin, Ishan	100%		1	1
3.27	Practice Final Presentation	4/18/2023	4/19/2023	Whole Team	100%		2	2
3.28	DOE Tests	4/19/2023	4/22/2023	Patrick and Calvin	100%		4	3
3.29	Final Report	4/15/2023	4/24/2023	Kavi, Vivian + Whole team	100%		10	6

Appendix AC

Amazon Air MK23