Spring 2021

DJI Drone Modification

Sean Lacey

Seth Mancuso

Bryce McKenzie

DJI Drone Modification

Sean Lacey, Seth Mancuso, Bryce McKenzie, Tyler Reis

Department of Mechanical Engineering

Honors Research Project

Submitted to

The Williams Honors College
The University of Akron

Approved:

Date: 4-20-21
Honors Project Sponsor (signed)

DAVID M. PETERS
Honors Project Sponsor (printed)

Date: 4/20/21
Reader (signed)

DANIEL S. LACEY
Reader (printed)

Date: 4/20/21
Reader (signed)

DAVID LESHOCK
Reader (printed)

Accepted:

Date: 4/20/2021
Honors Department Advisor (signed)

Gopal Nadkarni
Honors Department Advisor (printed)

Date: 4/20/2021
Department Chair (signed)

Sergio Felicelli
Department Chair (printed)

DJI DRONE MODIFICATION

By

Sean Lacey

Seth Mancuso

Bryce McKenzie

Tyler Reis

Final Report for 4600:402-461 and 4600:402-497

Faculty Advisor: David Peters

Honors Faculty Advisor: David Peters

Reader 1: David Leshock

Reader 2: Daniel Lacey

May 2021

Project Number: 10

Table of Contents

Abstract

For this project, we set out to create a lightweight carrying case that would be mounted to a DJI Phantom 3. This case is designed to transport small packages, such as medications, from a delivery vehicle to their final destination. Based on our maximum drone lifting capacity of 600 grams, our case, servomotor, and contents had to weigh less than or equal to that value. The coronavirus pandemic has led to an increase in contactless delivery options along with the push for immunocompromised people to avoid contact with people that may be sick. Our product would help transport necessary supplies to those that have a difficulty leaving their homes to get them. We also envision the case to be scalable based on the size and lifting capacity of the drone. We used multiple design revisions to create our ideal design. This design has two release mechanisms; a manual option with a sliding clip and a powered option with a servomotor that is integrated into the control of the drone. To integrate additional servo inputs to the drone, we need a NAZA-M Lite flight controller. Since our drone did not come standard with this flight controller, we chose to forgo these changes to the drone and to explain how the flight controller would be integrated and programmed. Our final design reflects this change, but still includes the cut out for the servomotor on the front side. Our prototype combines the manual release mechanism and the powered release mechanism. The servomotor can be added, and the manual clip can be moved to the open position to create the powered release. Future designs would remove the manual clip to create the powered release. When our final design and testing were complete, we completed a product that met our initial goals and was fully functional in testing.

Introduction

The goal of our project is to create an aerodynamic capsule that can transport small packages from a delivery vehicle to a designated drop off location using the method of contactless delivery. The vision behind product is to provide a wide range of customers a safe and efficient delivery service for essential products such as cold and flu medicine, birth control, and prescription medication. The coronavirus pandemic has led to an increased focus on staying home if you don’t feel well. We hope to help those that don’t feel well to get the supplies and medications they need while not risking their health or the health of others. We envision this will be useful for delivery companies during neighborhood or townhome routes with many drop off points within a one to two-mile radius. The size and range of the drone will determine the size of the transportation capsule. Our design will be scalable for larger drones and larger carrying capacities. The drone we used is the DJI Phantom 3, which has a specified weight of 1216 grams. According to the DJI Forum, tests have been done with a Phantom 3 lifting 800 additional grams, but only for a short period of time. Upon further research, we determined that our recommended cargo load is between 500 and 600 grams under ideal conditions. This equates to 1.32 pounds or 21.16 ounces. According to Statistica, 52% of packages in 2019 were less than 500 grams. This presents a wide range of deliverable products for future renditions, though we focused on medications for our project. The lifting capacity is our number one functional requirement. DJI currently does not sell any carrying attachments for the Phantom 3 or 4. We found some other attachments for sale such as the Drone Sky Hook, but none were like a carrying case. Our project scope involved designing and 3D printing various case designs, testing their functionality in terms of carrying products, then testing them on the drone based on their ease of attachment and how they impact the drone’s flight. We completed multiple concept sketches and design renditions to create our final design.

Design

Design Background

We completed modifications on our DJI Phantom 3 to add a cargo case under the landing gear. The vision of this case was to transport small packages weighing 500 grams or less. This weight requirement is based on the payload of our specific drone. We envision that our case design and functionality can be scaled to larger drone models that can lift more weight. During our detailed proposal stage, we created our first concept sketch which is shown below in Figure 1. Our concept design revisions were based on this initial sketch, but we made numerous changes and improvements.

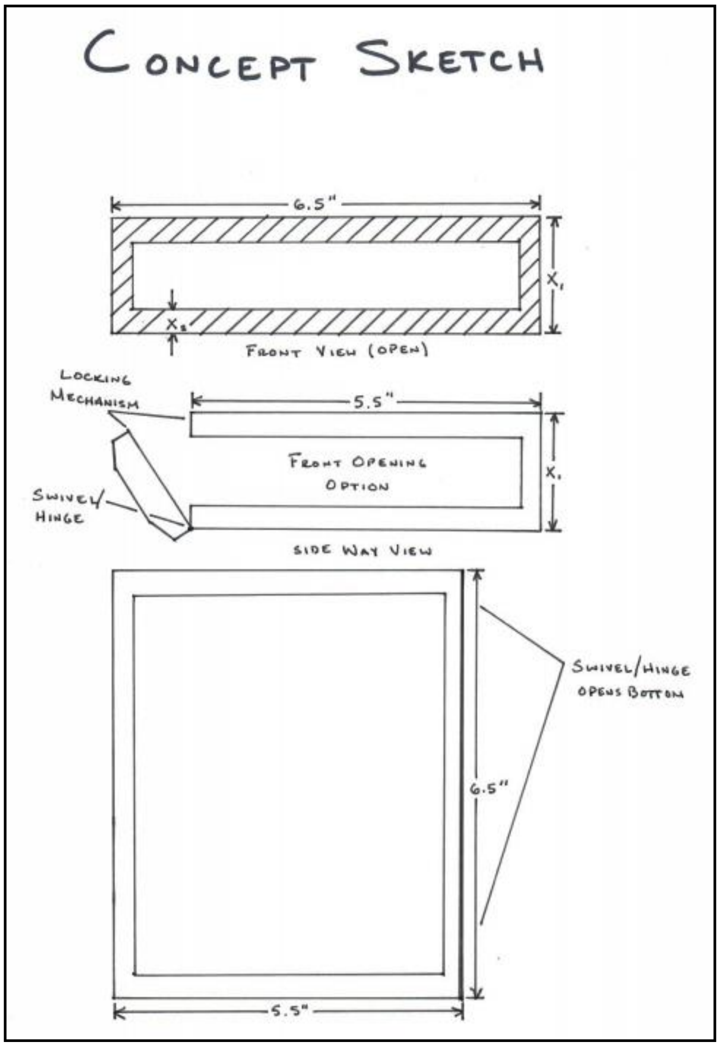

Figure 1: Initial Concept Sketch - Sean

Sean designed the initial concept sketch shown above. His design uses a rectangular case with a length and width that is the same as that of the drone landing gear. His design shows two opening methods. The first is on the side, which utilizes a smaller door. For this method to work, the contents either must be physically removed from the case by a person once the drone has landed, or the contents would roll or slide out of the case as the drone is tilted forward, relying on gravity and the momentum of the drone. The second opening method features a bottom door which would allow the contents to fall out of the case due to gravity. For this to work, the drone would hover six to ten inches above the drop location, then allow the contents to fall out once the door is released.

We researched numerous medication packages and designs to refine our case sizing. We also obtained old pill bottles and used the measurements to create a baseline for our case size.

Initial Concept Designs

Within our group, Sean, Seth, and Bryce all created concept designs. Sean's design is shown in Figure 1 above, while Seth's is shown in Figure 2 and Bryce's is shown in Figures 3 and 4 below. The designs were numbered one through three, with Sean being one, Seth being two, and Bryce being three and we created a morphological table to vote on the characteristics of each. Our voting criteria and table are shown below in the Design Decision Making section. While the designs all had the same general idea, there were some differences in the structure of the release mechanism and the positioning of the door.

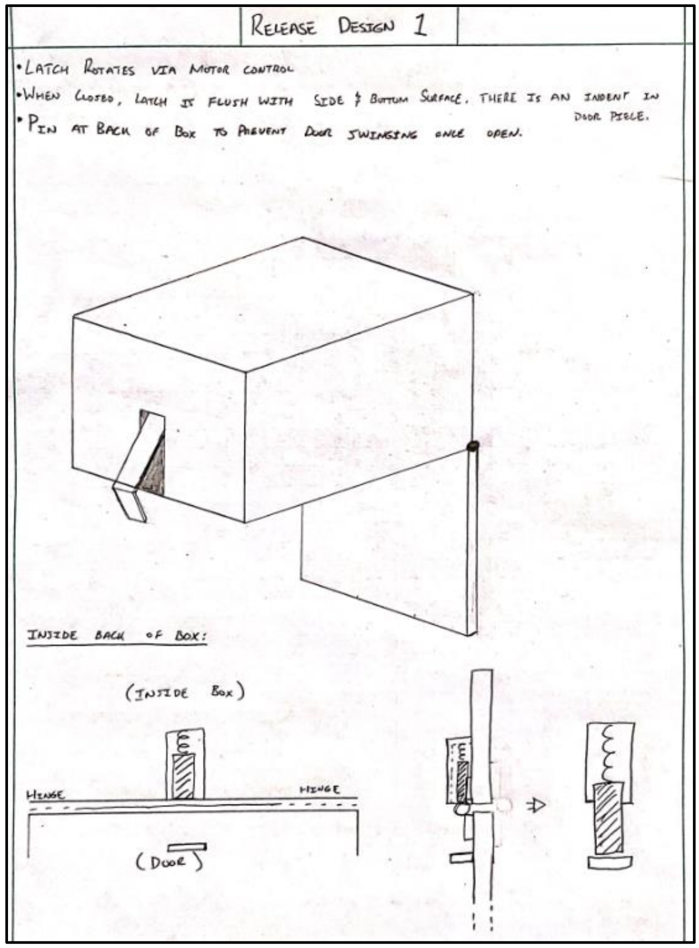

Figure 2 – Initial Concept Sketch – Seth

For Seth’s initial design of the release mechanism the attention was on keeping the box aerodynamically favorable, while maintaining functionality, as well as keeping the components small and light weight. First, the latch is oriented such that it is fully flush with the surfaces on the side of the box, and bottom of the lid. Then when the motor turns, the latch lets go of the door which swings open. However, because we do not want the door flapping around during the delivery and on the return flight, a spring-pin mechanism has been created to lock the door in the downward position. While not necessarily favorable to fly with a large flat surface area, it is better than having the door swinging, disturbing the center of gravity of the drone, and causing it to crash. For this initial design drawing, no dimensions were provided. This is intentionally done so that Tyler could design it in the rendered model small enough to fit together, while watching the effect of the latch size on weight. More accurate dimensions would be specified with the next iteration.

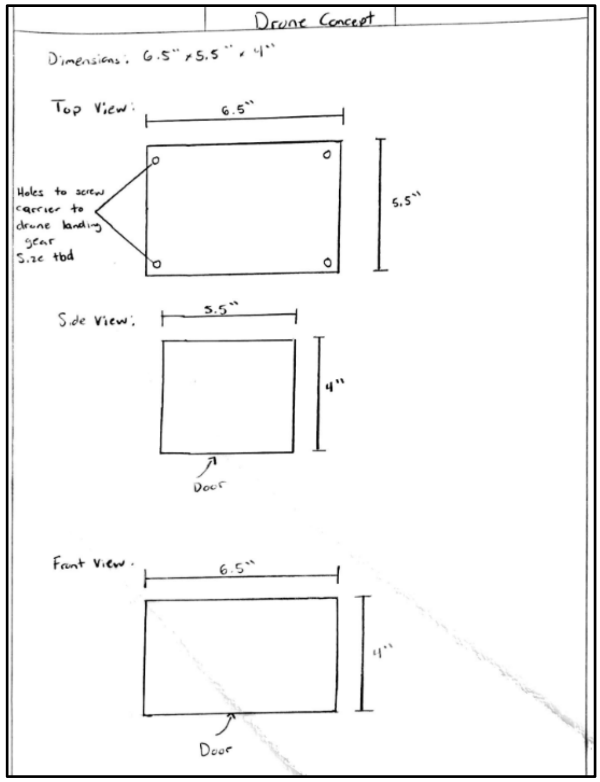

Figure 3 – Initial Concept Sketch – Bryce

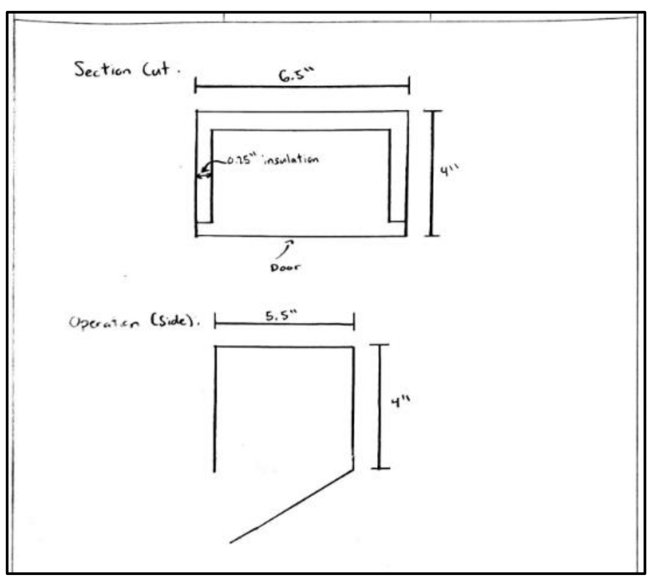

Figure 4 – Initial Concept Sketch – Bryce

For this initial concept sketch of the box, as seen in Figures 3 and 4, Bryce wanted to keep it simple and avoid as many moving parts as possible. To do this, he received the dimensions of the landing gear of the drone from Sean and made the box dimensions match so that we could simply screw the box to the bottom of the landing gear. We then made the height of the box 4 inches to accommodate for most sizes of pill bottles. When designing the door, Bryce thought a simple trap door design would work well with Seth's latch door design, and it minimized moving parts such as rotating or tipping the box the release the contents inside. Once Bryce had this design sketch, it was then passed over to Tyler so he could modify it into a 3-D design for printing.

Design Decision Making

Based on the components of each design, we created a morphological table to vote on the functions of each design that we liked the most. Our key components were case structure, door position, release mechanism, case size, and ease of operation.

Decision Matrix					
Concept Design 1					
Voting	**Case Structure**	**Door Position**	**Release Mechanism**	**Case Size**	**Ease of Operation**
Bryce	5	3	3	4	4
Sean	5	3	3	5	4
Seth	5	3	4	3	4
Tyler	5	4	3	5	4
Total	5	3.25	3.25	4.25	4
Concept Design 2					
Voting	**Case Structure**	**Door Position**	**Release Mechanism**	**Case Size**	**Ease of Operation**
Bryce	5	4	2	3	3
Sean	5	5	2	4	3
Seth	5	4	3	3	3
Tyler	5	4	3	3	3
Total	5	4.25	2.5	3.25	3
Concept Design 3					
Voting	**Case Structure**	**Door Position**	**Release Mechanism**	**Case Size**	**Ease of Operation**
Bryce	5	5	4	4	4
Sean	5	5	3	4	4
Seth	5	5	3	3	4
Tyler	5	4	3	5	4
Total	5	4.75	3.25	4	4

Based on the results of our decision matrix, we combined our highest rated features into our group concept design. We liked the idea of the door on the bottom of the case as we could use gravity to allow the contents to be released. We also adjusted the release mechanism to integrate the manual version as well as the servomotor release. The manual version is most like concept design one's release mechanism. Our initial CAD design is shown below in Images 1 through 6.

Design Revisions

We anticipated multiple revisions of this design based on the results of the 3-D printing and the integration of the servomotor. Images of the CAD design, the printing process, and the case attached to the drone are shown below. Our initial idea for connecting the case to the drone landing gear involved small screw-in clips. After researching and creating a mock sketch of the clips, we determined that using a bracket system would be a better idea. These brackets are also shown below in the images. Our first CAD design is shown in Images 1 through 6.

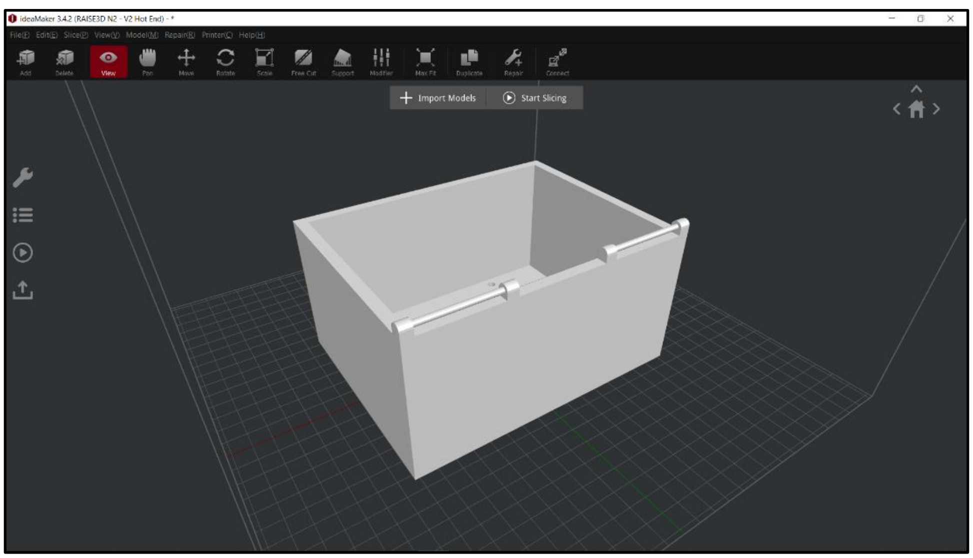

Image 1 – Case Design ISO View – Tyler

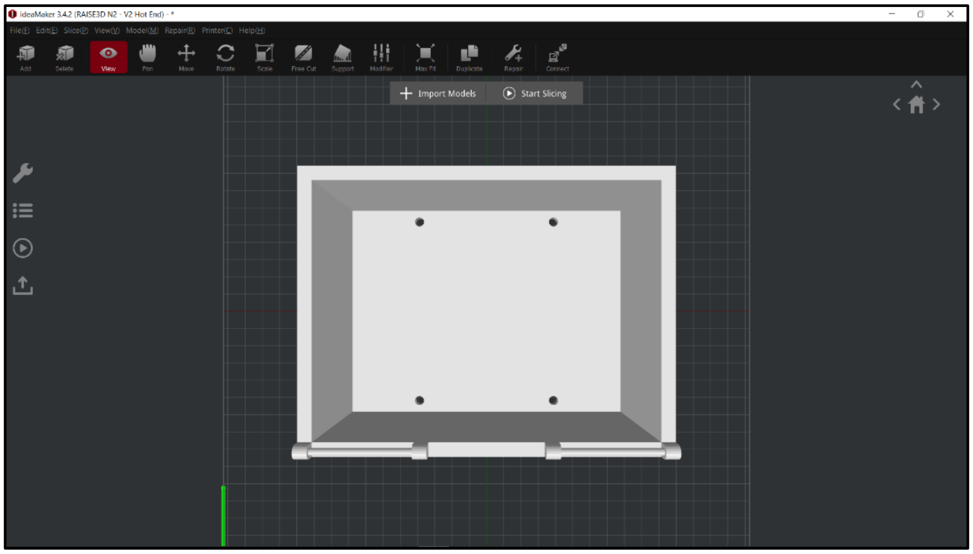

Image 2 – Case Design Top View – Tyler

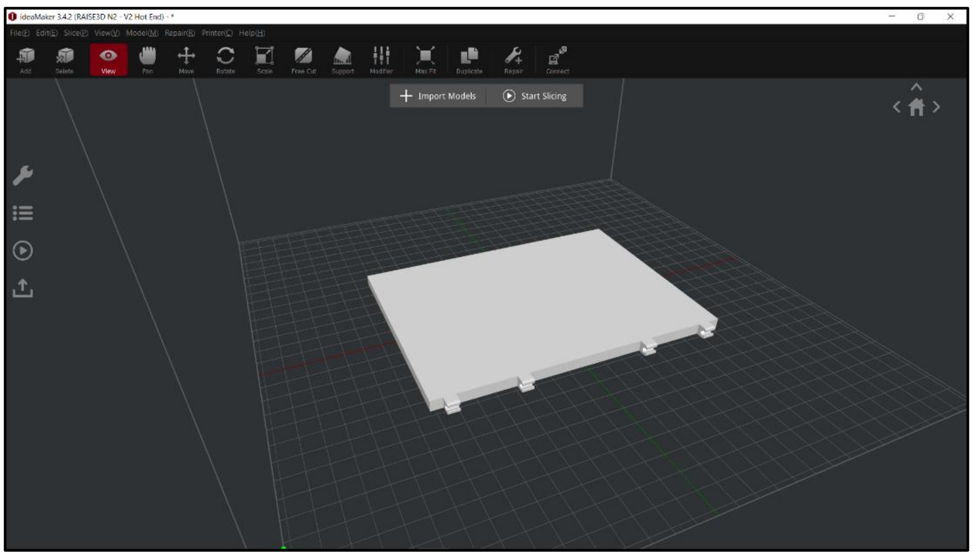

Image 3 – Door Design ISO View – Tyler

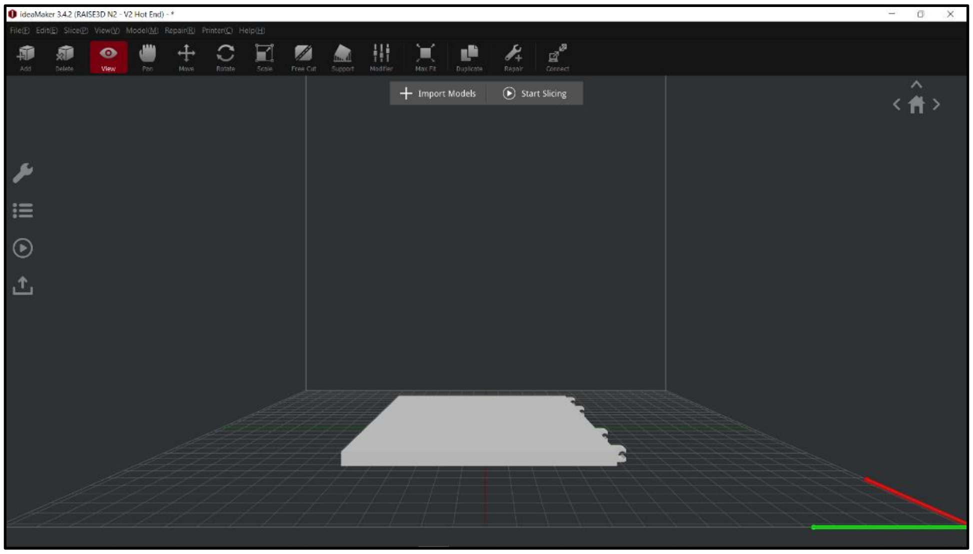

Image 4 – Door Design Side View – Tyler

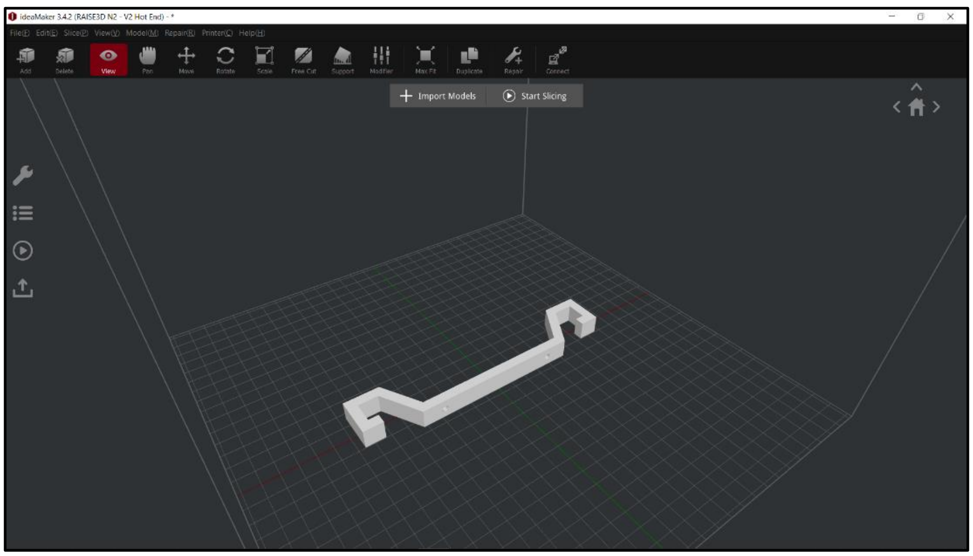

Image 5 – Mounting Bracket ISO View – Tyler

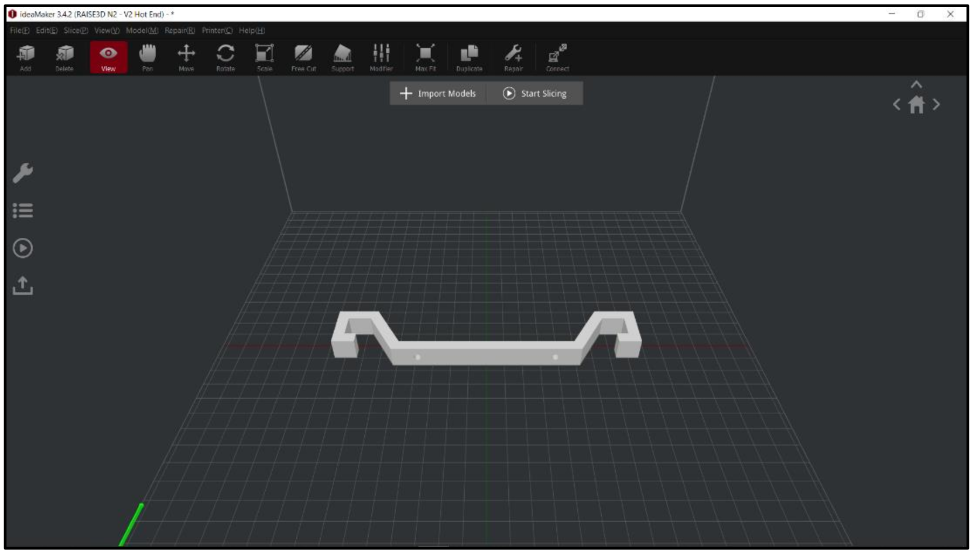

Image 6 – Mounting Bracket Front View – Tyler

Our 3D printed parts were then assembled and attached to the drone. This is shown in Image 7. We used #10 self-tapping screws to connect the brackets to the case. The brackets then use tension to remain attached to the drone landing gear.

Image 7 – Assembled Case and Brackets

With revision 0, we were planning on integrating the 25 kg DSServo digital servomotor shown in Image 8. Upon further research and after taking apart the drone, we found out that the Phantom 3 does not come standard with the DJI NAZA-M Lite Flight Controller. This NAZA controller is shown in Image 9. This model flight controller was originally standard on the Phantom 1 and it allows direct integration of servo inputs to be programmed to functions on the controller.

Image 8 – DSServo Digital Servo

Image 9 – NAZA-M Lite Flight Controller

The current controller was unable to handle the additional input that the servo would provide, so the only option for this integration would be adding the NAZA controller. To add the NASA controller, the circuit board would have to be modified and the drone's controllability would need to be reprogrammed. Since the drone is Sean's personal property and due to the cost of the controller, we decided to forgo replacing the controller and use a manual approach for the release. We also created a second case option which includes the servomotor integration, and we explain below how this would integrate with the drone if the NAZA controller were installed.

Revision 1 takes these changes into account and shows both the manual release, and the servomotor release options. We used our learnings from the first revision to make improvements for this round. In the first print, the case had a slight warp on the mounting surface, so that was corrected. Our initial sketches of the two release mechanisms are shown below in Figures 5 and 6.

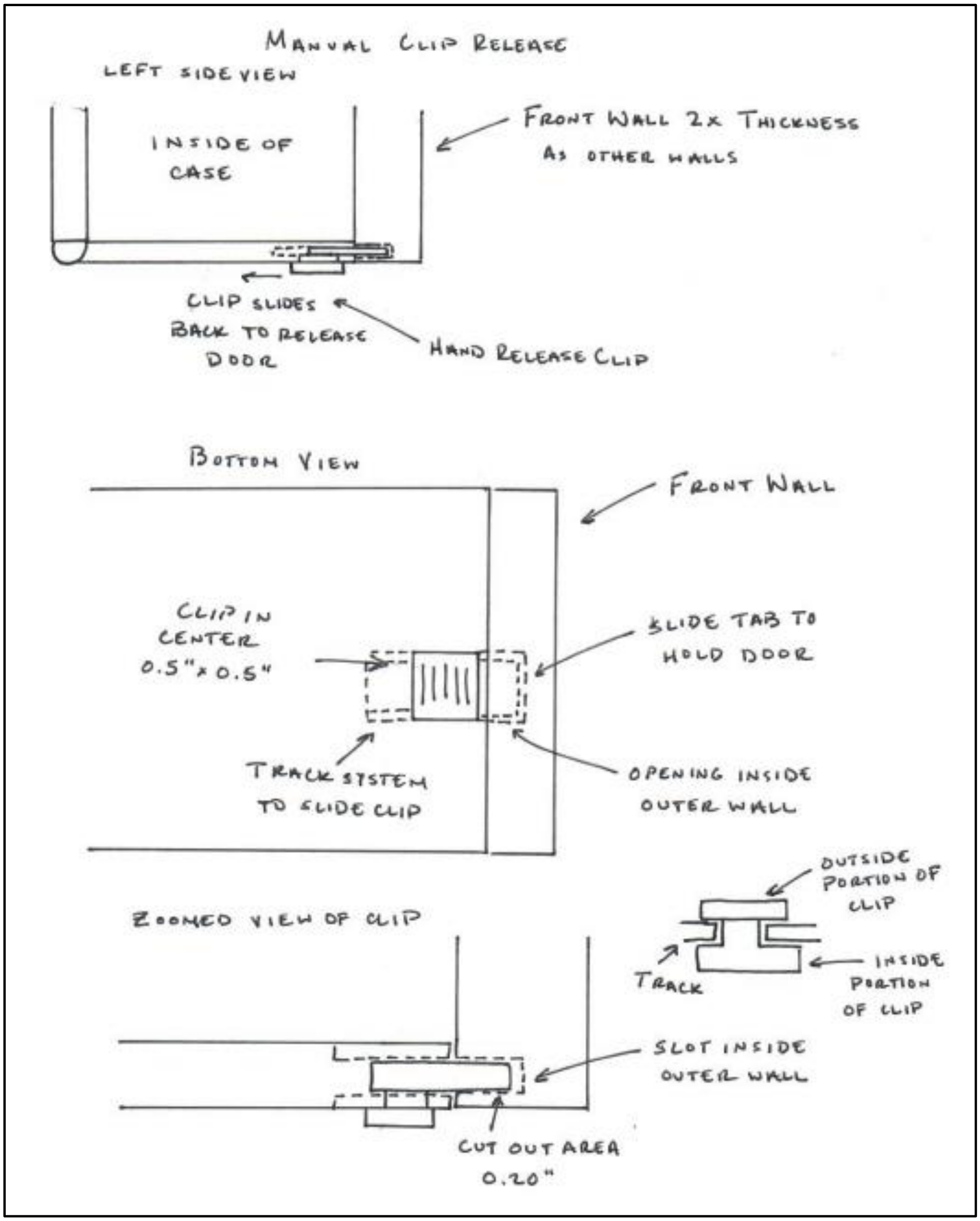

Figure 5 – Manual Release Design

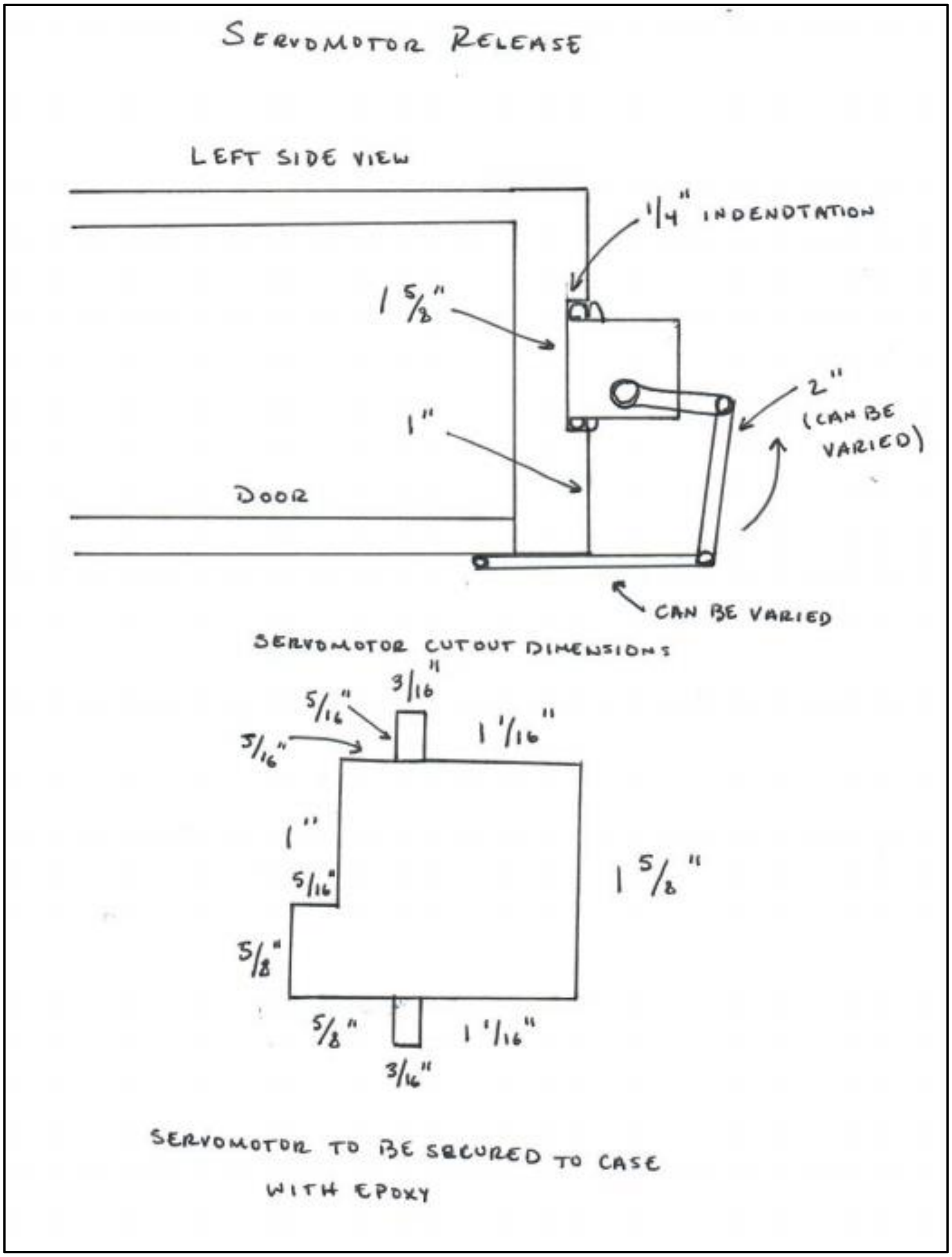

Figure 6 – Servomotor Release Design

From these initial sketches, we made slight adjustments during the CAD design stage which are shown below in Images 10 through 15.

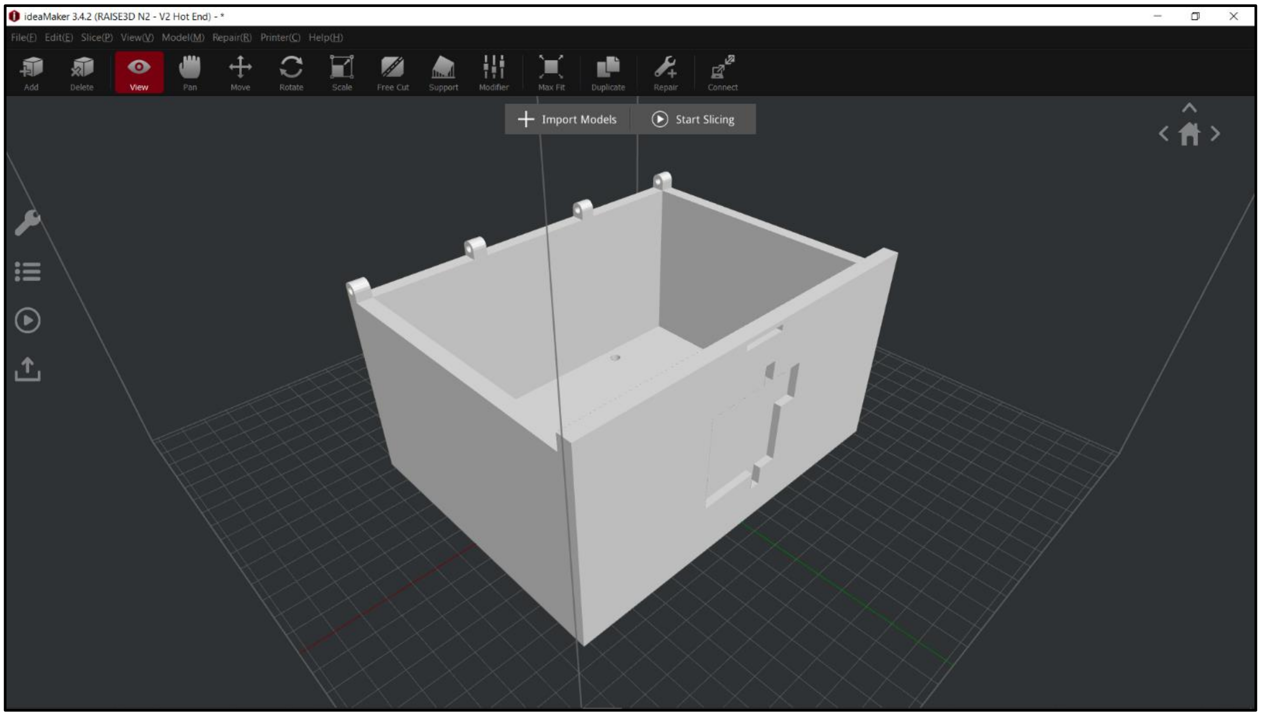

Image 10 – Case Design Rev1 ISO View – Tyler

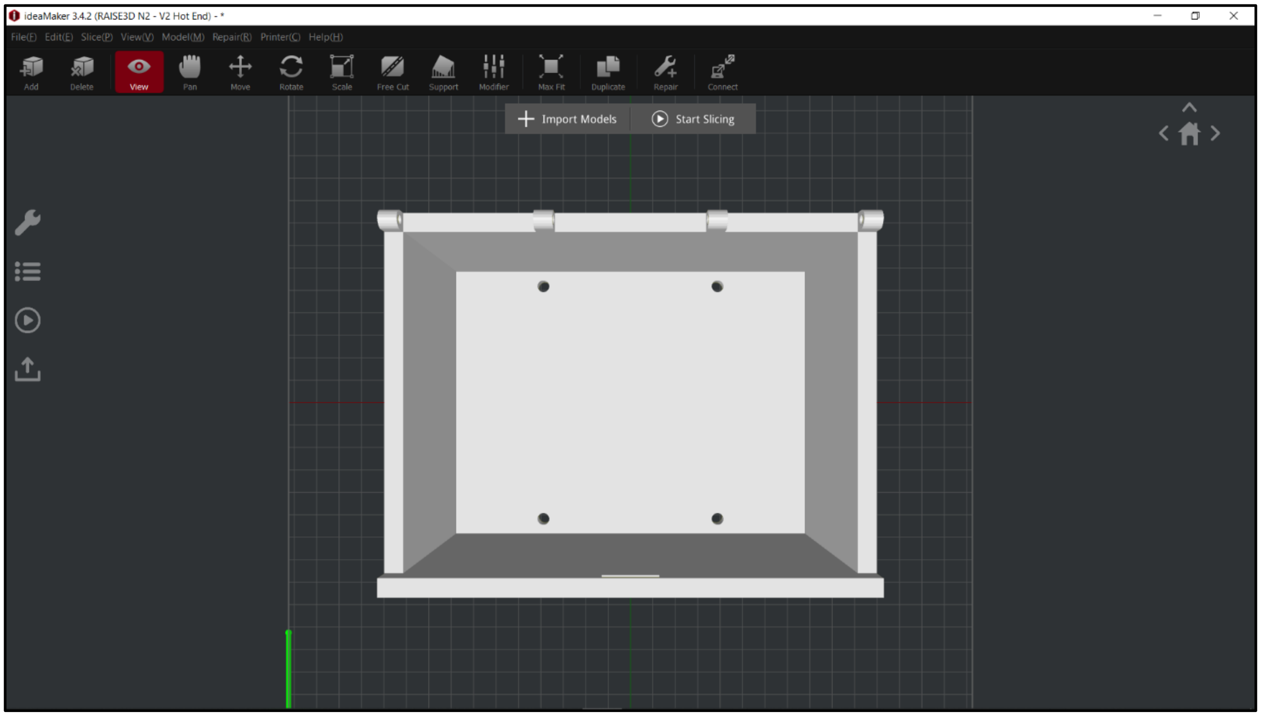

Image 11 – Case Design Rev1 Top View – Tyler

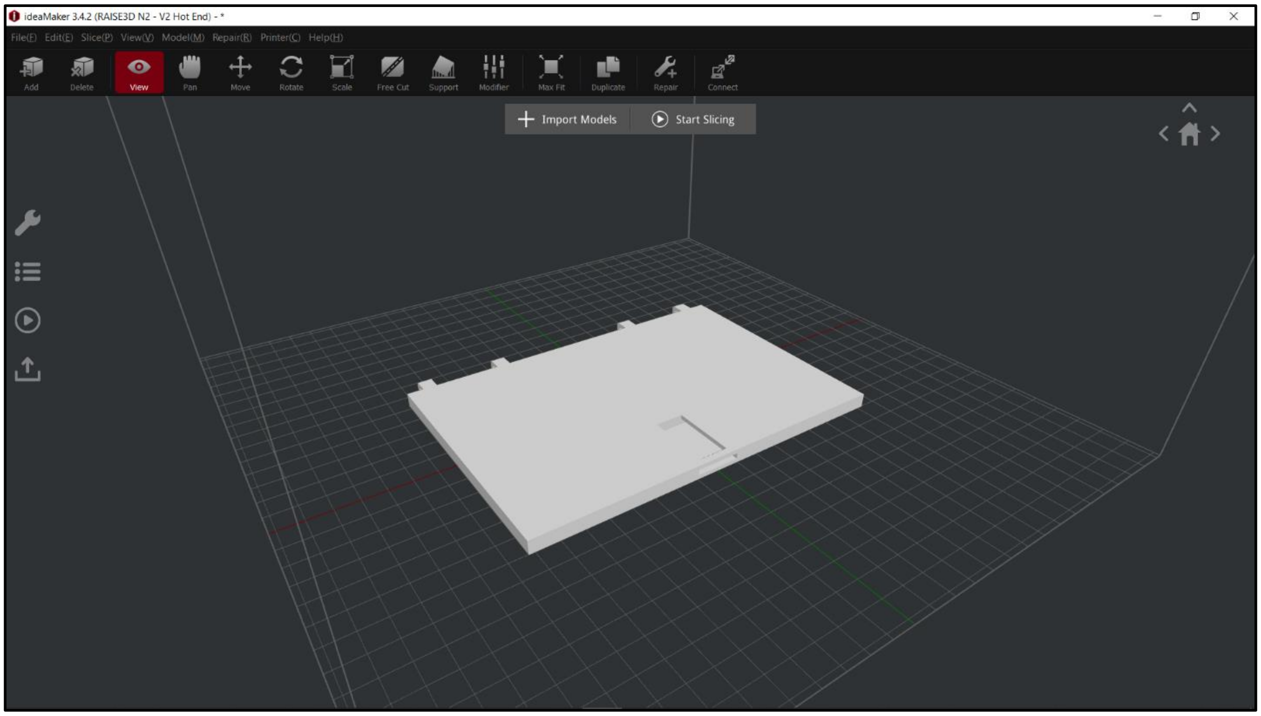

Image 12 – Door Design Rev1 ISO View – Tyler

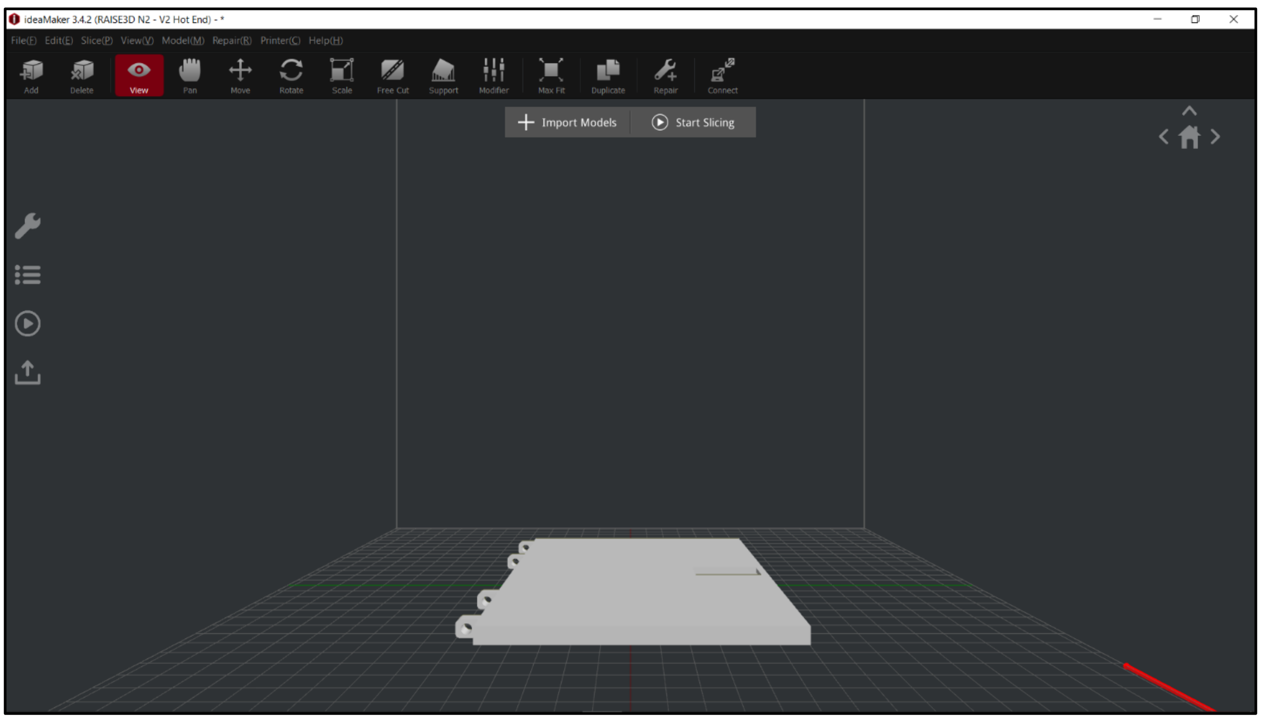

Image 13 – Door Design Rev1 Side View – Tyler

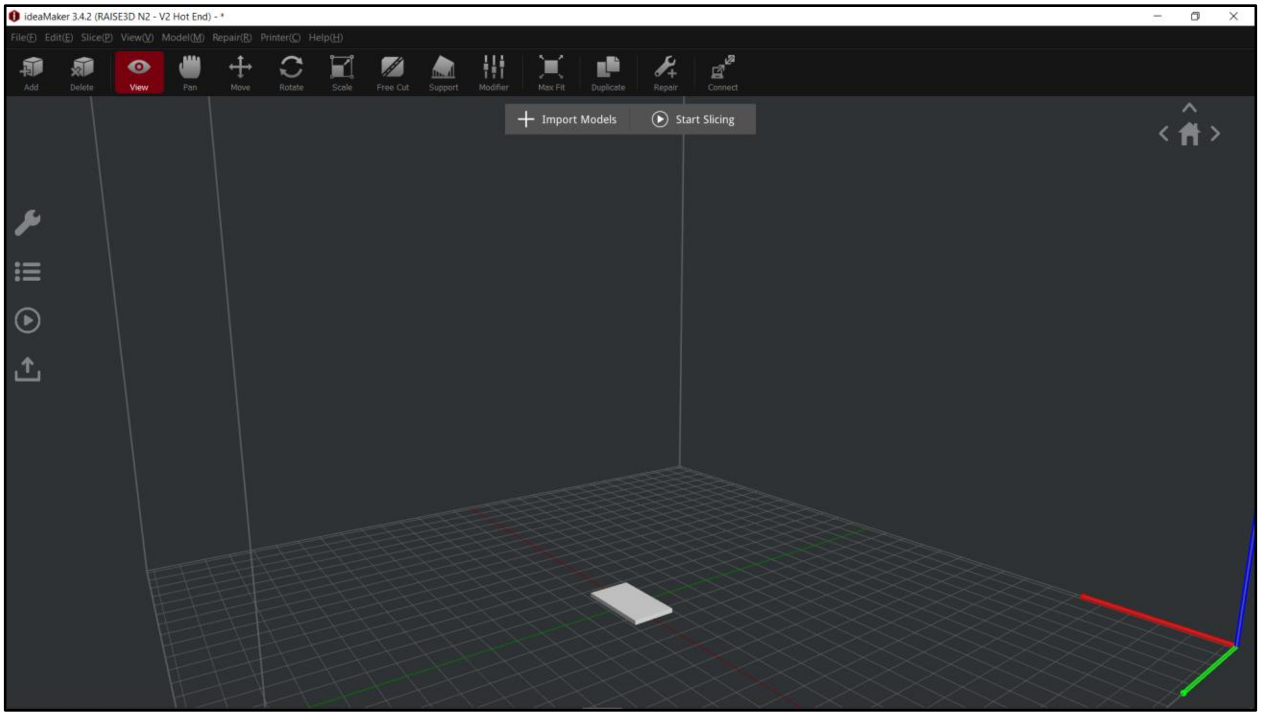

Image 14 – Clip Slide ISO View – Tyler

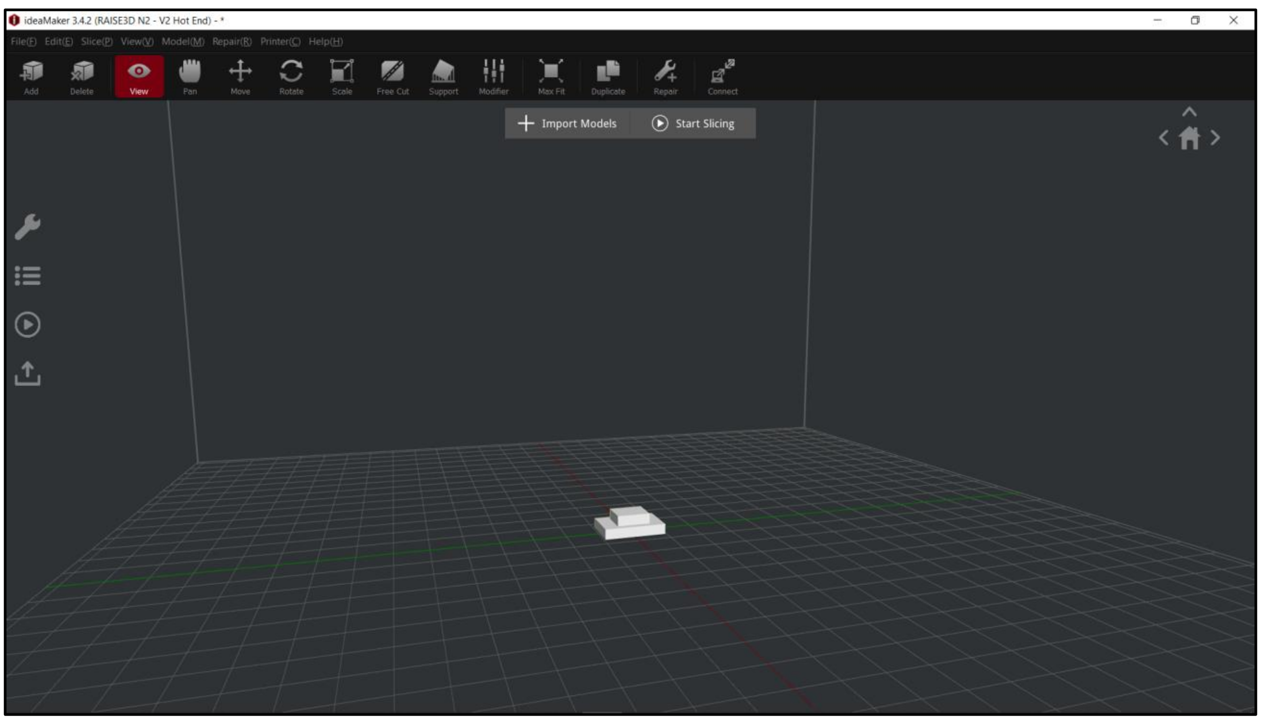

Image 15 – Clip Thumb Rest ISO View – Tyler

The top mounting brackets were not revised because the fit was exactly what we were looking for. Only the drone door and box had been revised to make up revision 1, along with the creation of the clip and clip thumb rest. The clip was only added to serve a manual function to our design after the group decision to replace the servo motor. We also added the mounting area for the servomotor. This allows our prototype to show both the manual and powered release mechanisms.

Both revisions were printed with the same settings on a Tevo Tornado and spliced in IdeaMaker. For both prints we used a 0.3mm layer height and 5% infill density printed at 210°C with a 60°C bed temperature. Both prints were from the same 1 kg spool of Hatchbox 1.75mm (+/- 0.03 mm) white PLA. Before printing each revision, the build plate was leveled and kept at a paper sheet thickness from the printing nozzle. Because the first model had warping, the first revision was printed with a ten-layer wide brim and a temporary enclosure was placed over top of the printer to reduce rapid cooling.

Final Design

Based on the functionality of revision one, we determined that it met our product specifications. This was also confirmed during our testing process. This process is described below in the Final Product Testing section. This final revision showcases the manual release and the powered release mechanisms. The manual release incorporates a small clip on the bottom of the box. To lock, the clip slides into the outside wall of the case. The powered release has a servomotor cutout on the front side. The servomotor is mounted in this location and is secured with epoxy. Image 10 above shows the location and construction of the servo cutout. A linkage is then attached to the servo motor which will secure the door closed. When the servomotor is activated, the linkage will rotate away from the door, causing it to open and the contents to be released onto the drop zone.

In revision one, we upgraded the door hinge mechanism from printed clips to a more secure steel rod construction. This will give the door a longer life-cycle than the previous design. The design shows four connection points on each the case and the door that are 1/8" in diameter. Since the mounting brackets fit perfectly in our initial design, we did not make any changes. We used #10 ½” self-tapping screws to connect the mounting brackets to the case. The screws are threaded from the inside of the case, so they are not visible from the outside. We kept the same dimensions as the previous design as it met our weight requirements. Our total weight of the final design was 334.3 grams. This was a difference of 30.5 grams from our initial design, which weighed in at 364.8 grams. Our final design is shown attached to the drone in image 16, 17, and 18 below.

Image 16 – Assembled Case Front View

Image 17 – Assembled Case Side View

Image 18 – Attached Servomotor Front View

Design Verification

NAZA-M Lite Flight Controller Integration

The NAZA-M Lite is DJI's most cost-effective solution for custom drone flight controllers. According to DJI's website, the M Lite is a simplified version of the NAZA-M, but it still possesses its high reliability and stability. The M Lite contains inner damping, controllers, 3-axis gyroscope, 3-axis accelerometer, and barometer functions. It can also measure flying altitude and attitude, which makes it useful for autopilot control. The NAZA-M Lite first came standard on the DJI Phantom 1 but was then replaced with a less customizable controller on the following models, including the Phantom 3 that we used. Both types of controllers allow the same functions and flight modes, but the newer model does not allow any added inputs. Since our Phantom 3 has the newer model controller, we will explain how the NAZA-M Lite would have been integrated into our system if we were to have added it.

There are two versions of the NAZA-M Lite. Version 1 is what we are basing the integration on. The full package for both versions can be purchased on Amazon. The version 1 package includes the flight controller, GPS sensor, remote LED connector, VU (Versatile Unit), and servo wiring connectors. The version 2 model contains the same components but with upgraded technology and programming.

This controller can be retrofitted to a DJI drone or used for a custom drone construction. The weight of the components of the control system are as follows. The controller is 25 grams, the GPS is 21.3 grams, and the VU is 20 grams. This flight controller uses servo wiring to connect to the rotor motors, in contrast to the circuit board wiring on our drone. To simplify the installation, the current circuit board can be replaced with a simplified version. For the operation of the case itself, the manual release would require the drone to be landed and powered off. Once the propellers stop moving, the drone can be picked up and the contents of the case can be released. For the servomotor release, the drone will hover about a foot over the drop zone. When it is in this position, the servomotor will be activated by the controller, which will cause the lever to move away from the door, thus releasing the contents onto the drop location. Figure 7 below shows the assembly diagram for the controller, given that DJI motors are used. The controller has eight inputs on the left side, along with an LED and expansion input. The expansion input is used for the GPS/compass and the LED input connects to the versatile unit, which controls the LEDs. The receiver or controller will connect to inputs A, E, T, R, and U, while inputs X2 is used for the Futaba S-Bus protocol and X3 is linked back to the VU. Since X1 is the only available input, we would use it to plug the release servo into. X2 uses Futaba S-BUS, which is a serial protocol that controls the servomotors. This protocol has up to 16 proportional and two-digit channels available.

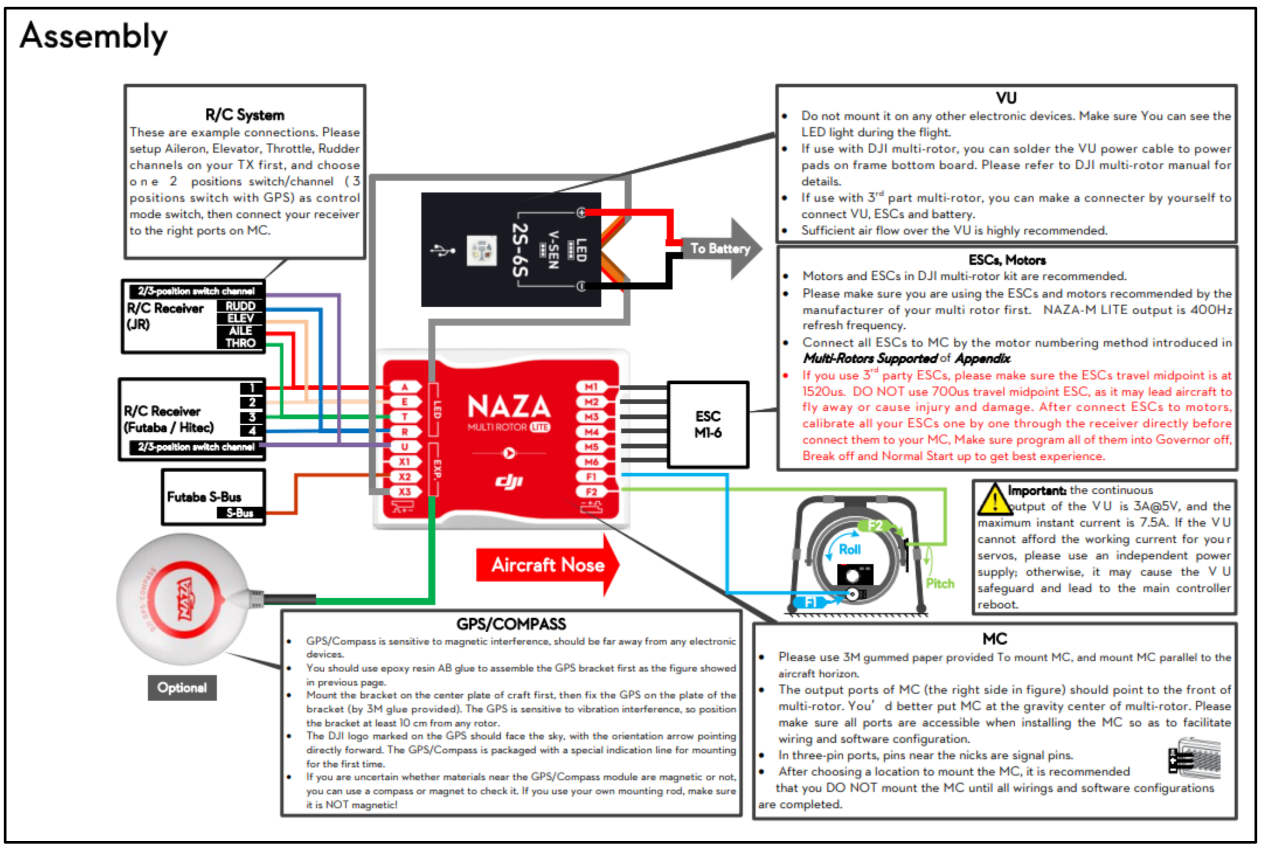

Figure 7 – NAZA-M Lite Assembly Diagram

The right or front side of the controller has inputs M1, M2, M3, M4, M5, M6, F1, and F2. The M inputs are used for the motors. This controller can handle up to six motors. In our case, we would only have four connected, so that would leave us with M5 and M6 open. The motors use an ESC, which is an electronic speed controller. The ESC is used to make sure all motors are operating at the same speed. This ensures stable flight and proper motor operation. The ESC and motors must be manufacturer compatible. It is recommended to use DJI brand ESC and motors. Inputs F1 and F2 are used for the gimbal control. F1 controls the roll and F2 controls the pitch. Two servos are used within the gimbal.

Once all inputs are connected, the DJI NAZA-M Lite Assistant software will be used to set up the inputs and assign them to controller functions. A DJI brand of custom controller can be used. During the setup, the controller will be connected to a computer through a Micro-USB cable. Once the software is downloaded and started up, the constraints can be set using the view tab. This is shown in Figure 8. The channel monitor will communicate with the controller to recognize the active channels.

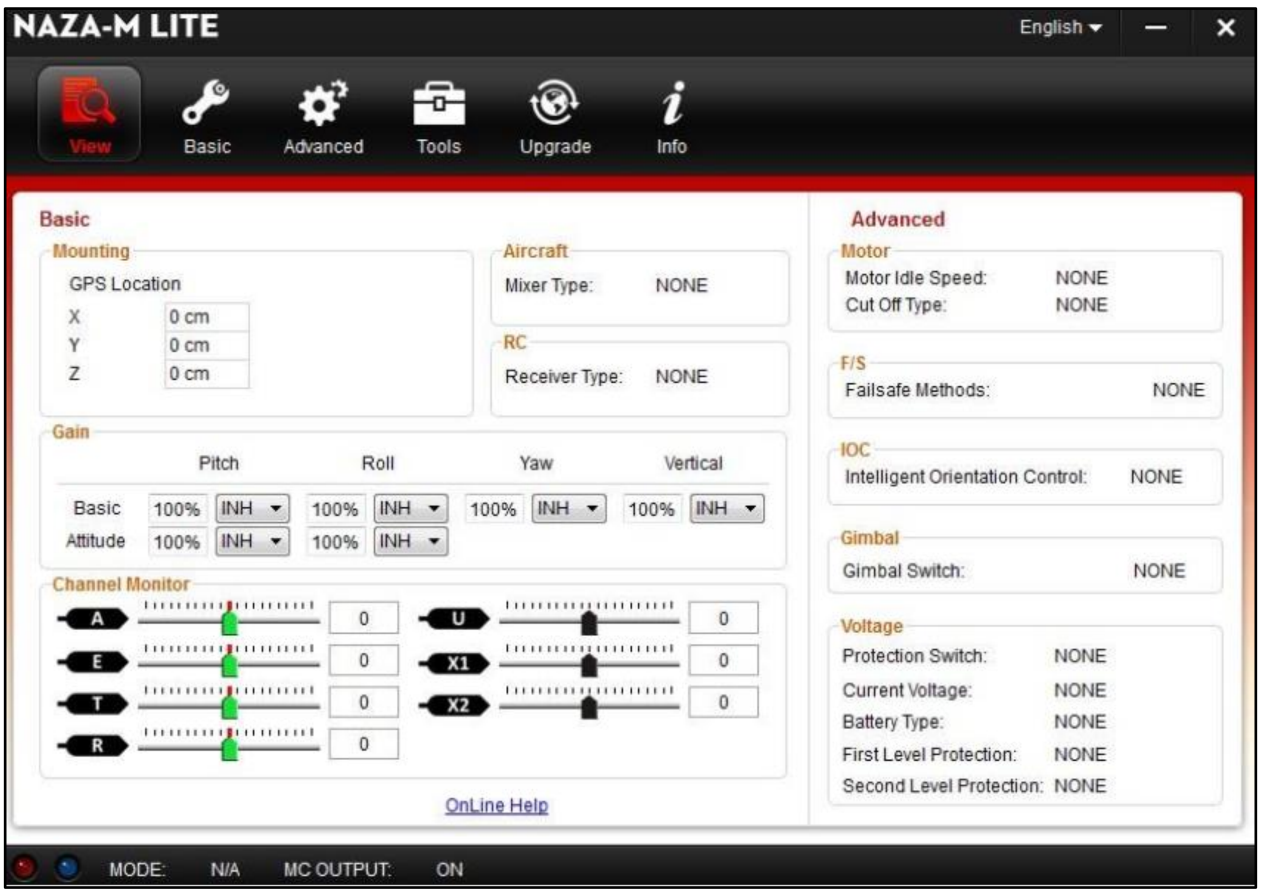

Figure 8 – NAZA-M Lite Software View Tab

If a firmware update is needed, connect the controller to your computer with a Micro-USB cable. Run the software and select the upgrade. Once the upgrade is complete, you can click OK and cycle the power of the unit after five seconds. Once this is complete, you can move on with the programming. The Basic tab has four subtabs. The aircraft subtab is used to determine what mixer type is being used. This references the number of motors and orientation of the drone. In our case, we have a four motor, X type. Next, the mounting subtab references the controller orientation. The goal is to have the NAZA controller at the exact center of gravity of the drone. The RC subtab delegates the calibration of the command sticks on the handheld controller. On the handheld controller, you'll move the joysticks vertically and horizontally to observe the response on the screen. It should be observed that the calibration bar remains at the zero point when the joysticks are unmoved. Adjusting the calibration bar will lead to uncontrolled movement by the drone and the motors.

On the DJI Phantom 3 handheld controller, there are two switches, one in the upper right corner (S1) and one in the upper left corner (S2). S1 is primarily used to toggle between flight modes. S2 is used to initiate Smart Return to Home. To operate our release servomotor, we will be replacing the Smart RTH function with the X1 servo control function. Since this is a 3-position switch, we will be able to open, stop, and close the latch. This is achieved on the RC subtab by linking switch S2 with input X1.

Next, the gain subtab is used to determine the response between the handheld controller function and the drone operation. The default sets the basic gain at 100% for the pitch, roll, yaw, and 50% for the vertical. The altitude gain is set at 40% for the pitch and roll. These settings work well for standard DJI motors. If a different brand motor is being used, test the drone's response based on different set points. If there is a delay in the response, meaning the pitch joystick is 100% forward and is then released, but the drone takes a few seconds to return to a hover, the basic gain will need to be increased. Start by increasing the basic gain by 10%-15% until the response to nearly immediate. Increasing the gain too will cause vibration and potential loss of control. If the attitude response is slow, follow the same procedure with the attitude gain.

Once the basic settings have been adjusted, we move on to the advanced settings. Under the advanced tab, there are five subtabs labeled: motor, F/S, IOC, gimbal, and voltage. The motor tab controls the motor idle speed and the motor cut off. This is shown in Figure 9. The idle speed determines the speed the motors will idle at before the drone takes off. The operating manual encourages this to be set at the maximum position of “recommended”. The recommended selection translates into 7% of the motor’s total speed, while the low translates to 3% and the high translates to 11%. The cut off type determines how the motors will be stopped. “Immediately” means that once the motors start and the throttle stick is above 10%, the motors will not stop immediately unless the throttle stick is back under 10%. The motors can also be restarted if the throttle stick is pushed over 10% within five seconds of the motors being stopped. Intelligent means that the motors can only be stopped by executing a combination stick control, such as pressing both joysticks 45 degrees towards the center of the controller. Intelligent cut off is recommended.

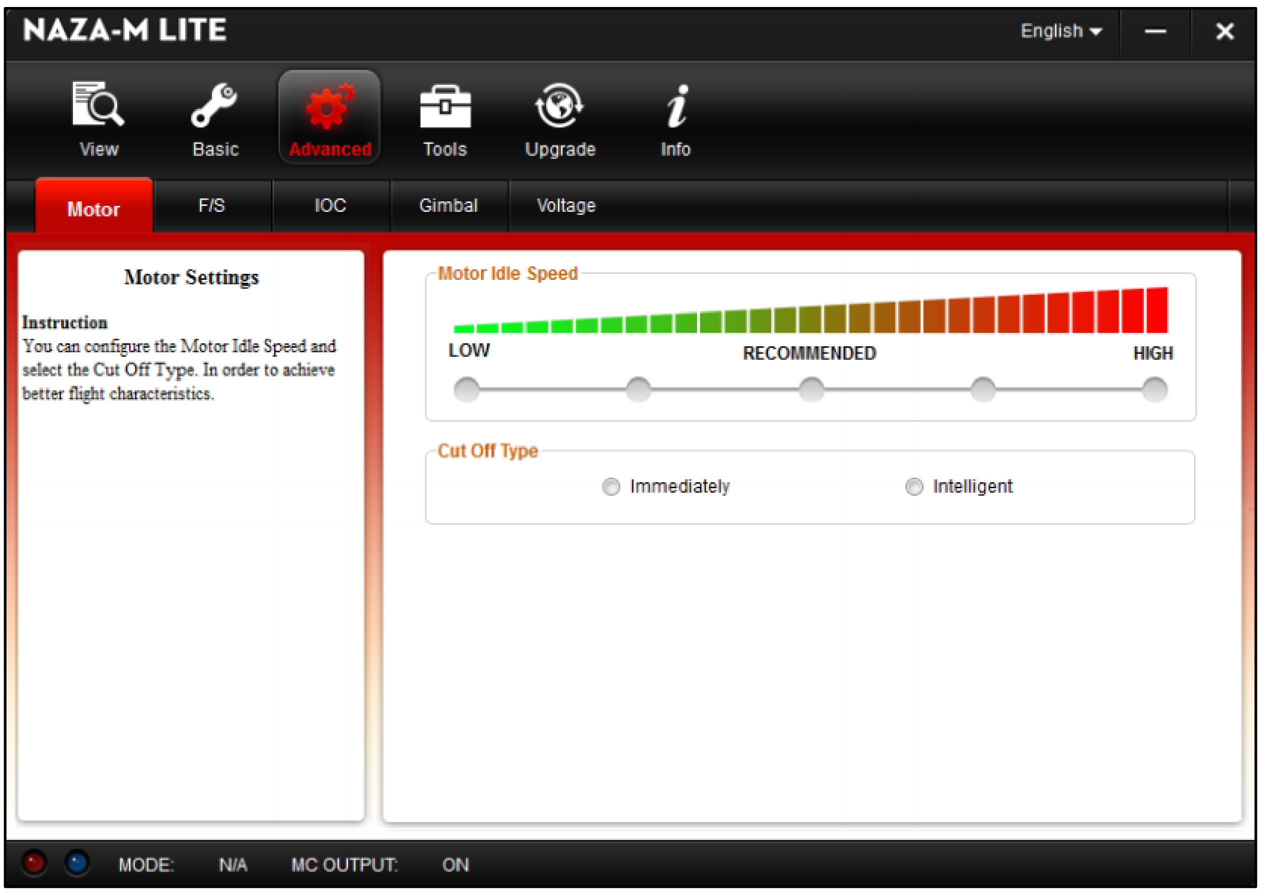

Figure 9 – NAZA-M Lite Software Advanced Tab

The F/S subtab determines the failsafe method. Failsafe occurs when the drone is out of range of the handheld controller, the transmitter is down, or one of the A, E, T, R, or U channels loses connection with the flight controller. There are two failsafe methods, landing and go-home and landing. The landing method will land the drone in the current location after six seconds of hovering. The go-home and landing method will set a home point upon takeover then return the drone to that home point. Typically, go-home and landing is the better option, but it depends on your flight use. This function can also be cancelled on your phone as the drone is returning home.

The rest of the advanced setting can be left at defaults if DJI products are being used. If a different brand gimbal or battery is being used, the gimbal and voltage subtabs may need adjusted. Once the programming has been completed, the NAZA-M Lite software can be closed, and the handheld controller can be unplugged. The drone is now ready for the preflight checks. These preflight checks will confirm that the flight controller was connected correctly and that the handheld controller is properly communicating with the drone. Before firing up the motors, the gimbal roll and pitch can be tested with the rolling switch in the upper left corner of the handheld controller. Next, the motors can be started to idle through a combination stick control. Before elevating the drone to its desired altitude, it is recommended to run response checks with the joysticks. Make sure the drone responds as desired when at an altitude of three to six feet. The S2 switch can also be tested to confirm that the case release servomotor opens and closes as desired. Once all checks have been completed and the drone is operating properly, the cargo can be loaded into the case and the delivery can be made. If there are any issues with the control, the drone will need to be landed, powered down, and the NAZA software will need adjusted.

Design Testing

With each design revision, the product and the drone underwent testing. This consisted of testing the integration to the drone, both physically and electronically, the balancing and stability, and the flight testing. We needed to make sure the brackets connected to the landing gear properly and did not move based on the carrying load. In the case of using the NAZA-M controller, we needed to verify the electronics of the servomotor and the controller were communicating and operating properly. Once we determined that everything was operating properly pre-flight, we needed to complete our tests during flight. During the flight, the drone needs to remain balanced so that it does not drift in one direction based on the package weight. The case must not interfere with the drone's positioning or aerodynamics. To summarize the goal of the flight testing, the drone must operate as if the case was not attached.

Final Product Testing

For our final testing procedure, we observed the drone as it took off, gained elevation, flew horizontal, reduced elevation, hovered to release the contents, and then landed. During the test, our conditions were 65 °F, with a slight breeze around 8 MPH. The drone maintained its stability during the takeoff process, despite the breeze. We first observed it hovering at approximately ten feet. After hovering, we gained vertical elevation to about 70 feet. We then flew horizontally in various directions while using hard stops to shift the contents in the case. During the hard stops, the performance of the drone was not disturbed. We then flew it over our drop zone while maintaining the same elevation. Next, we decreased elevation until we were a couple of feet above the retrieval person. Our good friend Joe Krosse was kind enough to assist us as the retrieval person. He is shown in Image 20. While hovering, he was able to grab onto the case, open the door, retrieve the contents, and then close the door. Once the door was closed, the drone gained elevation and simulated flying back to its home point. This process was captured on the video that is shown in our presentation. Our final testing is also shown below in images 19 and 20.

We tested various loadings within the case. We tested the hovering ability with one, two, three, four, and five pill bottles. Our max lifting capacity during this test was determined to be 235 grams. We also tested the flight with the door left open. We did not experience any issues, even with the slight breeze. We did not deem it necessary to test the drone in adverse weather conditions due to the drone not being weather rated. In Sean's personal experience, he has flown the drone in wind speeds of 25 MPH and higher. This has made the drone operation difficult, but this would not affect the testing of our case. More details about this are listed below in the Uncertainties section. We also temporarily attached the servomotor with tape to test the impact of its weight. The drone was able to compensate for the weight difference and still stay balanced despite the increased front loading. This was reassuring as we previously had concerns that the servomotor would cause the drone to be unbalanced and drift. A diagram of our testing procedure is shown below in Figure 10.

Image 19 – Final Testing in Progress

Image 20 – Retrieval of Case Contents

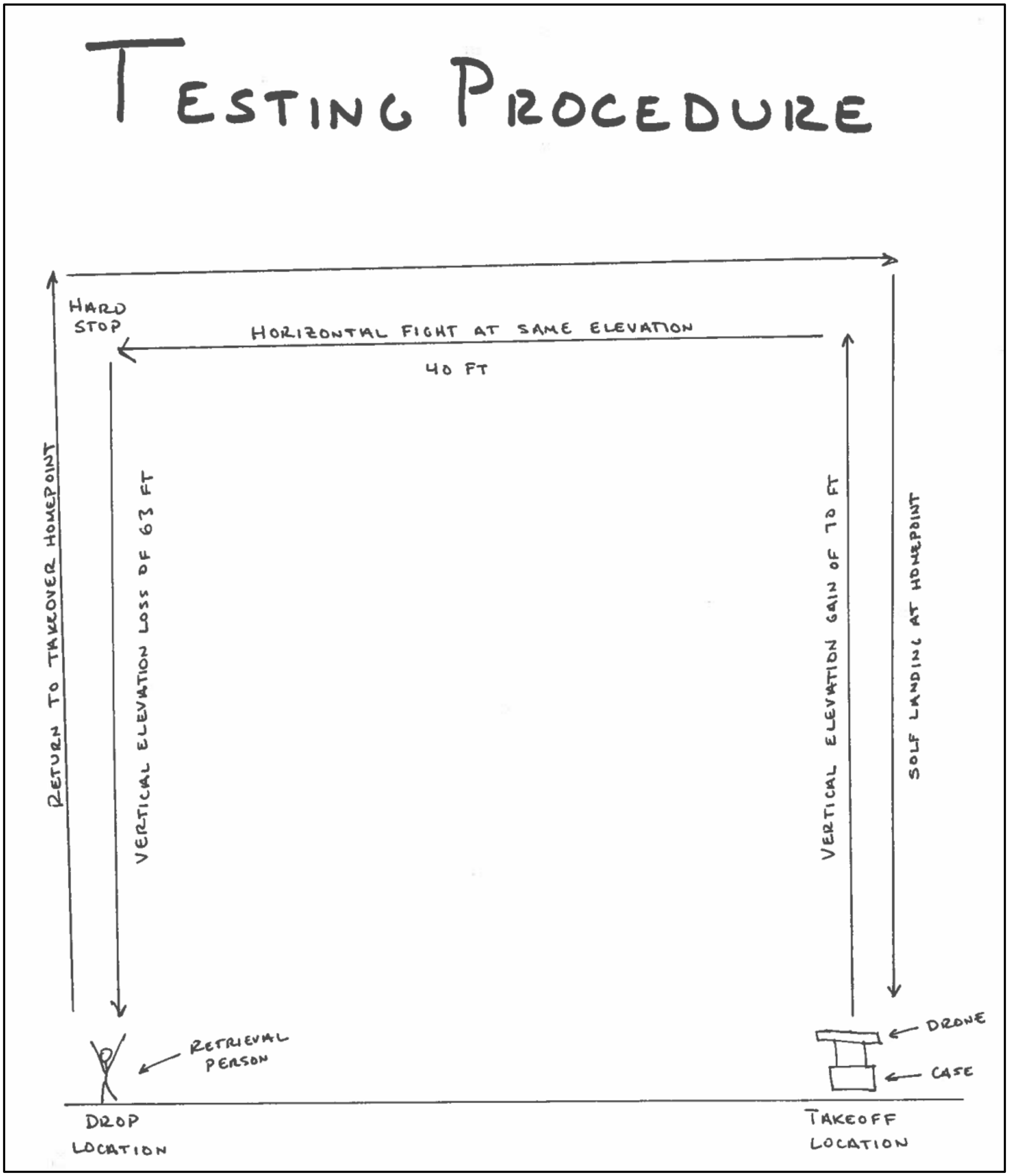

Figure 10 – Final Testing Procedure

In the creation and revisions of our design, we used multiple metrics to track our progress and gauge our success. These metrics are listed below along with their result.

1. Sean's Preliminary Drone Testing and Carrying Capacity Verification: Completed
2. Sean's Initial Concept Design: Completed
3. Seth's Initial Concept Design: Completed
4. Bryce's Initial Concept Design: Completed
5. Tyler's Initial CAD Design: Completed
6. Tyler's Initial 3D Print: Completed
7. Sean's Initial Design Testing: Completed
8. Servomotor Integration: Reevaluated
    a. Reevaluated on basis of rebuilding drone flight controller, circuit board, and motors. Not cost nor drone life effective. Manual release method proposed instead.
9. Group Concept Design Rev I (Manual Release Option): Completed
10. Tyler's CAD Design Rev I: Completed
11. Tyler's 3D Print Rev I: Completed
12. Group Design Verification: Completed
13. Sean's Final Design Testing: Completed
14. Group Project Report: Completed
15. Group Design Day Presentation: Completed

Based on these metrics and our completion of them, we consider this project to be a success. While we endured a roadblock in the servomotor integration, we reevaluated our situation and decided up on a manual release option. Future projects could involve building a drone from the ground up and integration a servomotor release mechanism.

Costs

Parts

Our project required a few minor purchases. These are described below along with their dollar amount. Our total part cost for this project was $93.49.

- DJI Phantom 3: $699.00
- New Pack of Propellers: $11.48
- New Landing Gear: $19.90
- PLA Printing Filament: $19.99
- 25 KG Digital Servomotor: $21.34
- #10 Self-Tapping Screws: $1.18
- 1/8” Steel Rod: $4.14
- Super Glue: $4.47
- Precision Screwdriver Set: $10.99

The drone was purchased by Sean before this project, so it does not function into our total costs. We only purchased one new pack of propellers during the project. The landing gear was also purchased prior to the project. Tyler had enough 3D printing filament for the entire project, so we did not have to purchase more. Besides the new propellers, our other costs were that of the servomotor, self-tapping screws, and the precision screwdriver set.

Labor

We based our labor costs off each of us making $100 an hour, as initially described in our detailed proposal. We budgeted 80 hours of work for this project. Based on that calculation, we each would have charged $8,000 for our work, totaling $32,000.00 in labor costs. Since we did not get paid for our work, this number does not factor into our total costs.

Conclusion

Accomplishments

Our goal for this project was to create a drone-mounted carrying case that could transport essential products, such as medicine, insulin, and personal care products to those that are vulnerable to COVID transmission. We envisioned this product as a form of contact-less delivery from a delivery service such as Amazon, USPS, or UPS. Given the capabilities of our drone, we set our targets on small items such as pill bottles, medicine boxes and small food products. We set out to make the operation of the case automatic in the sense that it would fully be controlled by the operator of the drone or even programmed into the drone autonomously.

In the end, we produced two options for the case. The manual version can be opened when the drone is hovering or when the drone has landed and is turned off. We also laid the groundwork for a servomotor-powered version that would be operated by a small servomotor that would be programmed into the drone's operating system. We successfully created a carrying case that was below our weight requirement and was large enough to carry a line of medicinal products. Based on this initial goal, we successfully created a carrying case that can be comfortably mounted to a consumer drone. We envision this to be a scalable product that can increase in size based on the model of the drone. We also learned about drone flight controllers and the programming of the DJI product line. This project allowed us to work through roadblocks and challenges, while helping us learn how to navigate a long-term design and production process. Because of this project, we will each be better engineers and better project leaders.

Uncertainties

The functionality of the case depends on the payload of the drone. Further advances in drone technology will allow the transportation of larger packages over further distances. We described the working conditions for our product as a resource for contactless destination delivery where a delivery truck parks in a central location in a residential neighborhood, then the drones are dispatched to deliver the packages to each house. One issue with this would be the storage of the drones within the delivery truck. Since the truck is already carrying a full load of packages, there is limited room for the drones. This storage could be accomplished by including a drone housing space on the roof of the vehicle, with a mechanism to load the package onto the drone, then to load the drone into the release space. The drone release space would also have to include docking stations where the drones can charge while idle. This would be necessary since the drones would have to operate for over ten hours a day.

Package quantities for delivery areas would determine the number of drones needed at one time. Each delivery vehicle may have a specific quantity of drones on board, so that would limit the number of packages that could be delivered at once. Advances in delivery vehicle design would integrate this function into the vehicle.

Weather conditions would impact the delivery ability as well. Most consumer drones are not rated to be used in harsh weather conditions. Rain, snow, and high winds would make delivery difficult. We can use epoxy or silicon to seal openings in high moisture penetration areas. Since the door is on the bottom of the case, it would not have a high penetration risk. The servo motor we used is specified to be water resistant. The weather rating of the drone would be determined by the manufacturer.

Design Challenges

Our two biggest challenges in our design was the weight carrying limit of the DJI Phantom 3 and the integration of the servomotor into the flight controller. For the weight limit, we could not add more than 600 grams to the drone. This included, the case, servomotor, and the contents of the case. Due to this, we focused on transporting smaller packages with the vision of expanding to larger packages with more powerful drones. We also decreased our case size slightly from our original plans. This size reduction still gave us ample room in the case for our target packages.

Secondly, the integration of the servomotor caused us to reevaluate our project goals. Originally, we were planning on fully controlling the release with the servomotor and a linkage. When we learned that our drone did not come standard with the proper flight controller, we decided to forgo this installation due to the cost of the controller, new circuit boards, new motors, and the risk of permanently damaging the drone. Instead, we explained how the integration would take place and how it would need to be programmed to properly function.

Going forward, our best option would be to build a drone from scratch so we could implement the functions we desired. This would be a longer process and would fall out of the scope of our project.

Ethical Considerations

The main ethical consideration would be that of patentability. If we wanted to get this project into the next phase, we would need to start by getting patents for our creation. For this, we can turn to the competition and see what they have patented. Big competitors that are breaking into drone delivery include Amazon and UPS, and Amazon has already obtained numerous patents over many aspects of a drone delivery system. Back in 2013, Amazon CEO Jeff Bezos announced PrimeAir, the Amazon drone delivery service, and shortly after the announcement, Amazon began filing for drone technology related patents. According to The Center for the Study of the Drone at Bard College, as of August 2017 Amazon has over 65 awarded patents, which encompasses a large array of drone technology and application.

Some of the patents Amazon procured are focused on the sensors and sensing abilities of the drone, and some others focus on the general practice of using a mobile distribution center for the release, return, and inventory of drone deliveries. Seeing these patents from Amazon, if we wanted to be competitive, we would need to patent our own ideas. Also, seeing the direction Amazon has gone with the delivery system, we could expand upon our own ideas and come up with personalized, original versions of their ideas. For instance, they were awarded a patent titled "Multi-use UAV docking station systems and methods." Creating a docking station for the charge and repair of drones is a brilliant idea, and if we could create our own methods, it could greatly help our project idea.

Another competitor that broke into the patent conversation was the United Parcel Service of America or UPS. In 2017, they filed for a patent titled, "Methods for Landing An Unmanned Aerial Vehicle." This patent describes the way UPS would use their vehicles as mobile distribution centers by putting racks on the roof of the vehicles for the drones to dock, pick-up, and distribute packages that were on the truck for delivery. This simple, yet ingenious idea would allow for faster deliveries times by drones and reduce time of travel for all deliveries.

Using the manual release mechanism, the best option would be for the drone to completely land, with the motors off, so there would be no safety concern of the blades cutting the person retrieving their package. This would differ from our testing procedure shown above. We still wanted to see how the drone would behave while hovering, as someone retrieved the package. The powered release mechanism would eliminate the need for this process.

Future Work

The vision behind our design is that it can be scaled based on the size of the drone and the size of the package. We foresee this being used to transport larger packages over larger distances. As drone technology evolves, there is more and more opportunity to increase the size and weight of possible deliveries. As of spring 2021, there is an $18,000 drone, the Freefly Alta 8, available on the market that has a payload capability of 20 pounds. This drone would be right in line with what we envisioned for our project, but the hefty price-tag was outside of our scope. On larger drones like the Alta 8, we envision a clamping system composed of four daisy-chained servomotors which would secure a package on each of the four edges. To release the package, the servomotors would work in unison to let go of the package, like how a claw releases its contents. Aside from carrying bigger, heavier things, upscaled models would overall be able to be utilized for a wider range of applications. Some models could be able to deliver beverages, like alcohol, or even groceries. As shown through the pandemic that started in early 2020, fully contactless delivery is becoming the next big thing, and with drones this is even more increasingly possible.

Another integration approach is the ability to carry multiple boxes with multiple contents and be able to drop them off independently. This idea was discussed throughout our group; however, we did not have to means to be able to accomplish for this project. The idea would be to snap together individual box and motor configurations into one piece and attach them to a drone. A control system would then need to be created to be able to open the boxes independently so that contents within each box could be delivered to multiple locations in one trip. With the payload capacities being increased as stated in the previous paragraph, this is another route that this idea could go in the future.

Our final idea for a future direction of this project would be a more recreational, fun approach. These drones, with their delivery capabilities, could become a new type of drone racing, where competitors pick up packages and race through a timed course to deliver them to certain locations past obstacles. Even though racing the drones does not necessarily have an impact on any worldly needs, by racing the drones, a drive to optimize and redesign the drones could be created, thus directly benefiting the impact this project could have on the actual delivery side.

References

“Alta 8.” *Freefly Store*, store.freeflysystems.com/products/alta-8?variant=18143788999.

DJI. *NAZA-M Lite User Manual V2.00*. DJI, Apr. 2014, dl.djicdn.com/downloads/naza-m%20lite/en/NAZA-M%20LITE_User_Manual_v2.00_en.pdf.

DJI. *Phantom 3 Standard User Manual V1.4*. DJI, July 2017, dl.djicdn.com/downloads/phantom_3/User%20Manual/Phantom_3_Standard_User_Manual_v1.4_en.pdf.

Forum, Dji. “How Much Weight Can My Phantom 3 Standard Lift?” *DJI FORUM*, forum.dji.com/thread-50131-1-1.html.

Gartmann, Uwe. “Futaba S-BUS Controlled by Mbed.” *Mbed*, 8 Mar. 2012, os.mbed.com/users/Digixx/notebook/futaba-s-bus-controlled-by-mbed/.

Michel, Arthur Holland. “Amazon's Drone Patents.” The Center for the Study of the Drone, Bard College, Sept. 2017, dronecenter.bard.edu/files/2017/09/CSD-Amazons-Drone-Patents-1.pdf.

“Naza-M Lite - DJI.” *DJI Official*, www.dji.com/naza-m-lite.

“Naza-M Lite - Videos: DJI.” *CreateDJI*, www.dji.com/naza-m-lite/video_v1-doc.

Appendices

Metrics for Success

Our goal for this project is to create an aerodynamic capsule that can transport small packages from a delivery vehicle to a designated drop off location using the method of contactless delivery. Our metrics for success were the following. Design and 3-D print a lightweight carrying case that can transport small packages to their final deliver destination. Add an additional load between 500 and 600 grams to the drone while maintaining proper flight behavior. Integrate a manual and powered release mechanism for opening the case and delivering its contents. Based on those metrics, we believe that we have met our goals and consider this project to be a success.

Acknowledgments

Throughout our project, we received assistance from various people. Without their help and advice, this project would have been much more difficult. We would like to thank Dave Peters, Zach Owen, Joe Krosse, David Leshock, and Dan Lacey for their assistance during our project. We would also like to thank all our professors throughout our time at the University of Akron. The groundwork that they laid was immensely helpful throughout our college careers and in this project. The project wraps up what has been a great five years for each of us and we are proud to have been a part of the University of Akron. Go Zips!