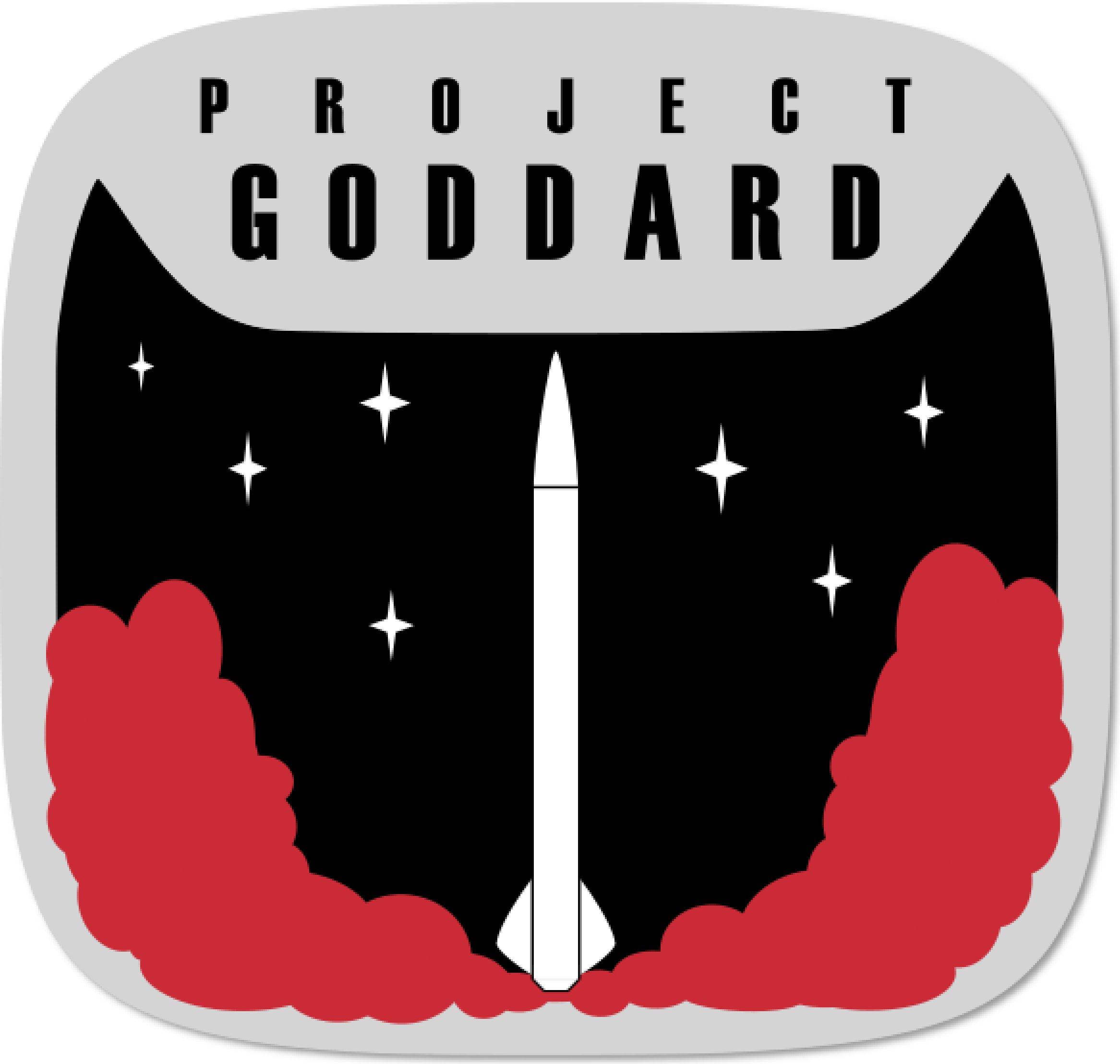
Worcester Polytechnic Institute

Flight Readiness Review



University Student Launch Initiative
March 2nd, 2020

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1.3 TERMINOLOGY

AGL	Above Ground Level
AIAA	American Institute of Aeronautics and Astronautics
AMW	Animal Motor Works, High Power Rocketry Supply Company
APCP	Ammonium Perchlorate Composite Propellant
BEC	Battery Eliminator Circuit
BS	Bachelor of Science
CAD	Computer Aided Design
CDR	Critical Design Review
CG	Center of Gravity
CNC	Computer Numerical Control
CP	Center of Pressure
CTI	Cesaroni Technologies Incorporated
DSRL	Driving, Stabilizing, Rotating, Lifting
EM	Electromagnetic
ESC	Electronic Speed Control
FAA	Federal Aviation Administration
FMEA	Failure Modes and Effects Analysis
FPV	First Person View
FRR	Flight Readiness Review
GPS	Global Positioning System
ID	Inside Diameter

LoRa	Long Range
LOS	line of sight
LRR	Launch Readiness Review
MQP	Major Qualifying Project, WPI Senior Capstone Project
MS	Master of Science
MSDS	Material Safety Data Sheet
NAR	National Association of Rocketry
NASA	National Aeronautics and Space Administration
OD	Outside Diameter
PDR	Preliminary Design Review
PETG	Polyethylene terephthalate, 3D Printer Filament
PLA	Polylactic Acid, 3D Printer Filament
PPE	Personal Protective Equipment
RAM	Random Access Memory
RC	Radio Control
RF	Radio Frequency
RSO	Range Safety Officer
SD	Secure Digital, Data Storage Standard
SGA	Student Government Association
STEM	Science Technology Engineering and Math
STEM	Science Technology Engineering and Mathematics
TRA	Tripoli Rocketry Association
TWR	Thrust to Weight Ratio
UAV	Unmanned Ariel Vehicle
USB	Universal Serial Bus, Data port standard
USLI	University Student Launch Initiative
WPI	Worcester Polytechnic Institute

2 SUMMARY

2.1 TEAM SUMMARY

2.1.1 Mission Statement

Through competing in University Student Launch Initiative (USLI), our team aims to help our members develop an understanding of teamwork, rocketry, robotics, and the engineering design processes and to share the knowledge we gain through this competition with our community to promote interest and excellence in Science, Technology, Engineering, and Math (STEM).

2.1.2 Team Leadership

The acting Executive Board is comprised of Captain Christian M. Schrader, Interim Rocket Lead Kirsten Bowers, and Interim Payload Lead Kevin Schultz. The Safety Officer is Veronika Karshina. The team is supported by our mentor, Jason Nadeau, and our University Advisor, Dr. John J. Blandino. Additional Officers and their details can be seen in Section 3.

2.2 LAUNCH VEHICLE SUMMARY

The launch vehicle has an overall length of 111 in, an outer diameter of 6.1 in and has a weight of 34.9 lb without the motor. The launch vehicle uses a Cesaroni Technology Inc. (CTI) L1050 solid rocket motor because of its 3.56 s burn time and total impulse of 3727.0 N*s. Designed to reach 4750 ft, the launch vehicle is now expected to reach 4088 ft.

The launch vehicle uses a 1515 rail and ascends to apogee where the ejection charge releases the drogue parachute and bundled main parachutes. The drogue diameter is 36 in, the upper main diameter is 120 in, and the lower main diameter is 132 in. The launch vehicle descends as a tethered whole under drogue until 700 ft. At 700 ft, a Tinder Rocketry Tender Descender separates the shock cord. The two bodies are no longer tethered to each other. At 600 ft, the Jolly Logic Chute Release on each main parachute releases its respective parachute. The main parachutes are open between 550 and 525 ft.

The launch vehicle's flight data will be recorded using StrattologgerCF in the electronics bay. The electronics bay will also contain the launch vehicle's batteries. Each body also contains its own Global Positioning System (GPS) tracker.

2.3 PAYLOAD SUMMARY

The goal of the payload is to mechanically retain and deploy an Unmanned Arial Vehicle (UAV) to collect a sample from a designated area. In order to perform this function, we have designed a lead screw driven retention system which orients and lift the UAV out of the rocket body and an unfolding drone capable of collecting a 15ml sample.

3 CHANGES MADE SINCE CDR

3.1 LAUNCH VEHICLE

3.1.1 Retention Bay Design Reconfigurations

The retention electronics bay underwent several design changes to improve accessibility, correct inconsistencies, and reduce weight. The CAD model was corrected to include two LiPo batteries, rather than one, because the altimeter needed be on a circuit independently powered from the servo. This helped keep the servo from conflicting with the other components and overdrawing power. The Battery Eliminator Circuit (BEC) model was relocated because the CAD model needed measurement modifications after the part was physically obtained. The position of the LoRa was relocated to improve ease of assembly. Furthermore, wire pathways were created in the 3D print to streamline connections between the Arduino and other electrical components. Minor amounts of material from the 3D print in the model were removed in locations where there were conflicting bodies. A 3D printed part was added beneath the radio antenna to act as a guide and protection for the wire coming off the antenna. Lastly, weight-reducing alterations were made to the carbon plate on which the 3D print is mounted.

3.1.2 Primary Electronics bay

3.1.2.1 Split Sled

The electronics bay sled holding the avionic board, Strattologger, and other electronical components was changed from one singular printed piece to two pieces. This was done to fit the print around aluminum spine, which underwent lightening alterations. Furthermore, this change helped improve the manufacturability of the sled and prevent bending the antenna wire to a degree that could potentially damage it. Numerous smaller enhancements were also made to electronics mounting features located on the sled

3.1.2.2 Ballast

The ballast system experienced a couple of changes in its design in order to improve ease of construction. The ballast core tube was changed so that it can be positively constrained between the electronics bay bulkhead and ballast cap without requiring the installation of numerous fasteners during the final assembly of the rocket. Additionally, a seal was added to the ballast system in order to increase protection of the electronics systems from gasses during deployment events.

The ballast cap is used as a rail button in order to keep the rocket within the specified weight limits. In order to do this, the bolt size on the ballast cap was increased to ¼” - 20.

3.1.2.3 Aluminum Spine

The ¼” - 28 on the aluminum spine was increased to a 5/16” - 24 bolt. This was done to ensure that the bolt tear out strength in the spine’s threads is adequate, without requiring specialty deep-hole tap tooling.

The weight of the aluminum spine was reduced to improve the overall weight of the launch vehicle. A finite element analysis was performed on the upgraded spine to ensure it could withstand any forces exerted on it.

3.1.3 Recovery System

The shock cord length from the lower bulkhead was extended to 520 in so that lower main parachute did not get tangled on a rail button or the lower airframe itself which would prevent tearing and possible unsuccessful parachute deployment. The shock cord between the lower main parachute and the drogue parachute was extended to 167 in to avoid tangling between the two. The upper parachute was changed to a 120 inches diameter chute while the lower parachute was changed to a 132 inches diameter chute.

3.1.4 Nose Cone

For safety reasons we have decided to change our nose cone. Although the use of our previous nose cone was a team derived requirement, the decision to change to our current nose cone was one made due to concerns of over stability, and to help reduce the weight of the vehicle. Our nose cone still constructed out of fiberglass but has an exposed length of 24in and a shoulder length of 5.5in. It has a mass of 28oz, which will help reduce the weight of the upper section of the launch vehicle. We chose to remain with fiberglass due to its high strength but to forgo the metal tip both for weight reduction and to reduce our off-rail stability to 2.6, well within the desired range of between 2 and 3.

3.2 PAYLOAD

Due to mistakes in calculations and modeling, the scissor lift was redesigned to only use one linear actuator instead of two. This resulted in the fixation of the actuator into a horizontal position with a clevis and link added to drive the scissor lift. In addition, the assembly was modified for all parts to lay flat when the lift is at its lowest position.

On the UAV, the flight controller is fully functional and configured using the Betaflight Software including safety switches programmed for different stages of the mission.

The landing legs on the UAV have been modified from the previous design of base mounted standoffs to posts mounted on the UAV’s folding arms which provides better stability for landing and helps retain the arms inside the rocket.

4 TEAM STRUCTURE

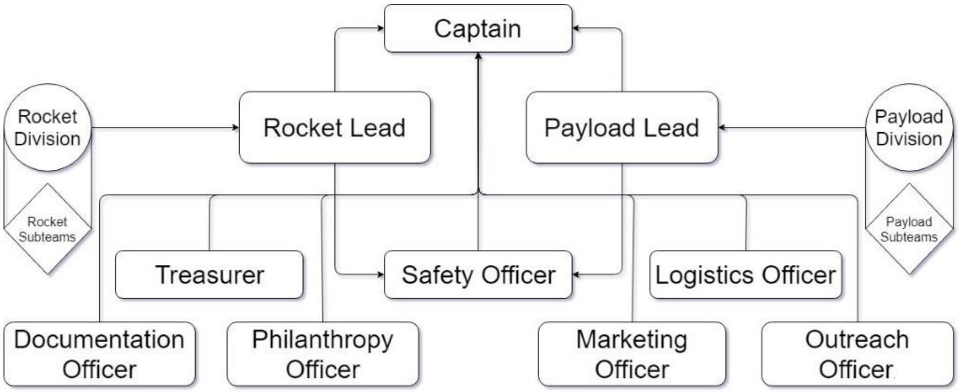

Figure 4-1 Chain of Command

4.1 EXECUTIVE BOARD

The team is led by the Executive Board which consists of the Captain, the Rocket Lead, and the Payload Lead. As the Rocket Lead and Payload Lead will both be leaving to complete school projects out of the country, the team has elected interim leads that will serve in their place for the rest of the competition.

4.1.1 Acting Executive Board Members

Christian M. Schrader, Captain, BS/MS Aerospace Engineering

(781) 290-3098, cmschrader@wpi.edu

Christian Maximilian Schrader is a Junior pursuing an Aerospace Engineering major and Computer Science minor. He currently has a level 1 high powered rocketry certification and is pursuing a level 2 certification. As Captain, his responsibilities include being a point of contact for the team, leading the Officer Board, and coordinating the team as a whole. This includes planning to ensure the team meets deadlines and ensuring the team follows competition regulations from NASA (National Aeronautics and Space Administration), WPI (Worcester Polytechnic Institute), and AIAA (American Institute of Aeronautics and Astronautics). His experience includes becoming an Eagle Scout, working as an Intern Group Lead at NASA Ames, and serving as the Safety Officer and Co-Founder on the team last year.

Kirsten Bowers, Interim Rocket Lead, BS Aerospace Engineering

(716) 255-3417, kmbowers@wpi.edu

Kirsten Bowers is a Sophomore in pursuit of an Aerospace Engineering major with an Electrical and Computer Engineering minor. As Interim Rocket Lead, her responsibilities consist of the execution of the design, construction, and documentation of the Launch Vehicle with input from the other officers and general team members while ensuring that the team has adequate knowledge through organized construction times, and aid in the construction. She is also responsible for leading sub teams within the Rocket Division during this process and communicating and collaborating with the Captain and Payload Lead or Interim. Her goal is to guide the project to fruition in the absence of the Rocket Lead. She currently has a level 1 high powered rocketry certification and is pursuing her level 2 certification. This, along with her experiences at Space Camp, various leadership programs, and being an active member on the team last year has provided her with the technical and leadership experience needed.

Kevin G. Schultz, Interim Payload Lead, Competition Pilot, BS/MS Aerospace Engineering.

(650)-279-8271, kschultz@wpi.edu

Kevin Gerald Schultz is a Freshmen pursuing a BS/MS in Aerospace Engineering. As Interim Payload Lead, Kevin is responsible for the coordination, development, and overall operation of the payload team. This consists of overseeing the progress and development made by numerous sub-teams of the overall payload. Kevin has previous leadership from previous engineering and project groups. He also has prior experience with Unmanned Aerial Vehicles (UAV) from personal projects has led him to be responsible for flying our UAV during competition.

4.1.2 Nonacting Executive Board Members

Sophie Balkind, Rocket Lead, BS/MS Aerospace Engineering

(978) 270-2900, sbalkind@wpi.edu

Sophie Balkind is a Junior Aerospace Engineering major with concentrations in both aeronautics and astronautics. She is currently pursuing her level 1 certification in high powered rocketry. As Rocket Lead, Sophie's responsibilities are to facilitate the design, construction, and documentation of the Launch Vehicle. She will lead the design of the launch vehicle with input from the other officers and general team members. When time for construction Sophie will ensure that the team has adequate knowledge through workshops, organize construction times, and aid in the actual construction. She is also responsible for leading sub teams within the Rocket Division and communicating with the captain and payload lead. Sophie's background participating in Sailbot provided her with a technical and competitive background. Her participation in Real World Design Challenge in high school also provided her with experience writing extensive technical reports.

Sophie will be leaving to complete her Junior year project in Worcester, England. The Interim Rocket Lead, Kirsten Bowers will serve in her stead.

Thierry de Crespigny, Payload Lead**,** BS/MS Aerospace Engineering

(650) 515-0615, tldecrespigny@wpi.edu

Thierry de Crespigny is a Junior Aerospace Engineering major with concentrations in both aeronautics and astronautics along with minoring in Robotics Engineering. He is currently pursuing his level 2 certification in high powered rocketry. As Payload Lead, Thierry's responsibilities are to facilitate the design, construction, and documentation of the payload. He will lead the design of the payload with input from the other officers and general team. During construction Thierry will ensure that the team has adequate knowledge through workshops, organize build and design times, and aid in the actual construction. He is also responsible for leading sub teams within the Payload Division and communicating with the captain and rocket lead. Thierry's background participating in Battle of the Rockets provided him with a technical and competitive background in designing and building payloads.

Thierry will be leaving to complete his Junior year project in Berlin, Germany. The Interim Payload Lead, Kevin Schultz will serve in his stead.

4.2 OFFICER BOARD

The team has an Officer Board, which is a superset of the Executive Board. In addition to the executives, the Officer Board contains Officers with special duties that are integral to the team's function.

4.2.1 Safety Officer

The role of the Safety Officer is to ensure the wellbeing of all people, objects, and facilities affected by the inherently dangerous task of manufacturing and launching a class 2 launch vehicle. Our Safety Officer, Veronika Karshina, will supervise a group of safety personnel drawn from every sub team of the WPI USLI team. The Safety Officer will examine the potential risks of using various hazardous materials or procedures and create a risk mitigation plan for each such instance. WPI USLI defines risks as follows:

- potential for bodily harm
- potential for damage/destruction of personal property
- potential for damage/destruction of equipment
- potential for damage/destruction of facilities
- Any other potential risk that the Safety Officer or Safety Personnel deems critical

In addition to risk definition and management, the Safety Officer must have in depth knowledge of NAR (National Association of Rocketry) High Powered Rocketry Code. It is the role of the Safety Officer to maintain compliance with this code as well as risk recognition and mitigation plans throughout the team. The Safety officer will complete this task by supervising a team of safety personnel that will be instructed in all relevant codes and plans. It will then be the safety personnel's' job to be present at all USLI event where potential risks could arise and ensure all codes/plans are followed during the duration of the event.

Lastly, it is the role of the Safety Officer to ensure that that all team members are versed in NAR High Powered Rocketry Code and with the safety procedures detailed above. This will be done through mandatory safety trainings, maintaining availability of safety personnel, written procedures/codes, and fostering a culture of asking clarifying questions regarding procedures, laws, regulations, or risks.

Veronika Karshina, Safety Officer, BS Aerospace Engineering

vkarshina@wpi.edu

Veronika Karshina is a Sophomore at WPI pursuing a Bachelor of Science in Aerospace Engineering with a minor in Computer Science. Currently pursuing her class 1 certification in high powered rocketry, Veronika has taken a principle of personal and social safety class in high school where part of the syllabus included safety procedures in case of dangerous chemicals release. Veronika has received a junior lifeguard training and was a counselor in training at a summer camp, where she got more training in first aid. Veronika Karshina was a member of WPI USLI team last year, where she was involved closely in the design, construction and launch of the rocket, learning safety principals along the way. All this training and skills gained from it make Veronika Karshina qualified to be Safety Officer of this team.

4.2.2 General Officers

Adrianne Curtis, Philanthropy Officer, BS Aerospace Engineering

(860) 930-4257, aecurtis@wpi.edu

The responsibilities of the philanthropy officer include:

- Creating a sponsorship package for potential sponsors
- Making connections with potential sponsors and gather sponsorship funds for the team
- Maintaining a positive relationship with sponsors

Christian M. Schrader, Documentation Officer, BS/MS Aerospace Engineering

(281) 290-3098, cmschrader@wpi.edu

The responsibilities of the documentations officer include:

- Compile all sections of the document
- Finalize all documents to NASA Student Launch Standards
- Ensure that documents are coherent, and the information contained is adequate

Note, the Documentation Officer elected for this year, Jeremiah Valero, had to step down.

Connor Walsh, Outreach Officer, BS Aerospace Engineering

(978) 846-5438, cwalsh@wpi.edu

The responsibilities of the outreach officer include:

- Setting educational engagement goals for the team
- Contacting and working with organizations and programs around WPI focused on STEM (Science Technology Engineering and Math) engagement for children and the community around Worcester
- Creating educational engagement activities for events throughout the year

Chris Renfro, Social Media Officer, BS Aerospace Engineering

(508) 365-8470, crenfro@wpi.edu

The responsibilities of the social media officer include:

- Responsible for the team’s social media presence, merchandise, and the website

Kirsten Bowers, Treasurer, BS Aerospace Engineering

(716) 255-3417, kmbowers@wpi.edu

The responsibilities of the treasurer include:

- Managing the budget and handling purchasing

Troy Otter, Logistics Officer, BS Aerospace Engineering

(508) 455-8828, tmotter@wpi.edu

The responsibilities of the logistics officer include:

- Coordinating transportation and lodging for the competition and test launches
- Facilitate spaces to store and build the launch vehicle

4.3 ADULT EDUCATORS

Jason Nadeau, Team Mentor, President of Lake Winnipesaukee High Powered Rocketry

(978) 761-9790, jabikeman@aim.com

John J. Blandino, University Advisor, Associate Professor of Mechanical Engineering at WPI.

(508) 831-6255, blandino@wpi.edu

4.4 GENERAL MEMBERS

The rest of the team is comprised of General Members, of which there are approximately 30. Each one is either part of the Rocket or Payload Division. Each division is further split into sub teams that are assigned responsibility for a specific subsystem.

5 VEHICLE CRITERIA

5.1 AIRFRAME

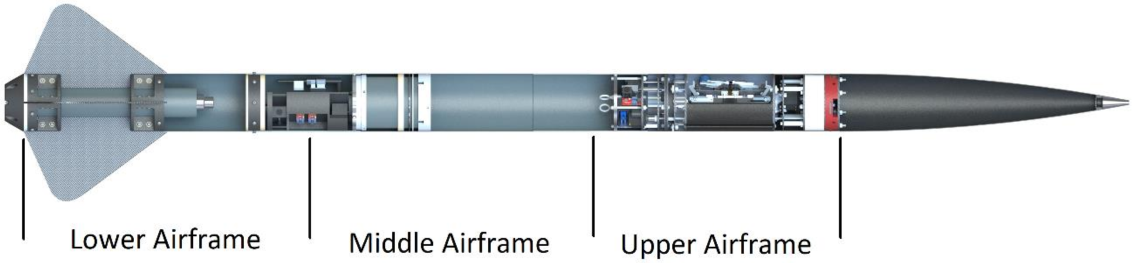

Figure 5-1 Launch Vehicle Cross Section.

The airframe is divided into three sections, the upper, middle and lower airframe so that all components are sufficiently accessible. The airframe has a diameter of 6.079in. The upper airframe is 26in and houses the selected payload with retention system and has a 6in coupler secured to the next section with shear pins. The coupler is open on the lower side, with a support ring, to store recovery such as the tender descender as well as connections to the shock cord/parachutes. There will be four slots in the upper airframe to allow the bolts that hold the payload in the nose cone to slide freely.

The middle airframe, at 30in, has a storage cavity for the recovery system and connects to the lower airframe via the electronics bay which bolts into both the middle and lower airframe. This airframe is the longest to maximize space for the shock cord, three parachutes, and half the electronics bay.

The lower airframe at a length of 29in houses the second half of the electronics bay and serves as an attachment point for the fin can and motor retention system.

To maintain pressure equilibrium in each close section, the launch vehicle has vent holes. There are four vent holes in total, each measuring 0.17in in diameter, that were drilled on the airframe to equalize the pressure to the exterior of the launch vehicle. Two of the vent holes, which are directly opposite each other, were drilled 10in above the bottom of the upper airframe and another two were drilled 10in below the top of the lower airframe. There are no vent holes in the middle airframe as the upper and middle airframes function as one pressure cavity.

Figure 5-2 From left to right, the lower airframe, middle airframe, and upper airframe.

Each section is constructed out of Blue Tube 2.0 due to its low cost and light weight as well as its high durability and resistance to abrasion. The criteria for material strength was based on NAR guidelines, where it states that the airframe of a rocket must be able to withstand forces 40-60 times the rocket's total weight. Additionally, we considered the extra stress on the airframe due to attachment points where we bolt through the airframe. Fiberglass was chosen as a solution to this problem. Traditionally, one layer would go on the interior and one on the exterior but doing this was incompatible with other design and material choices, such as the use of our nose cone and Blue Tube Inner Tube.

Two layers of 6 oz. fiberglass fabric sleeves were added to the exterior of the airframes to ensure that it can withstand the additional stress. In order to achieve this, first, epoxy coated each cut airframe section of Blue Tube 2.0 and a cylindroid piece of fiberglass was cut in order to cover the main airframe tube. Epoxy went over this, and then another fiberglass tube was added, and epoxy was placed over that. The fiberglass tube ends were tied off, as the fiberglass intentionally extended past the Blue Tube 2.0 by several inches. Tubular plastic shrink wrap was placed over the fiberglass and heated with a handheld heater such that the plastic wrap compressed the airframe. Next, the airframe went in an oven for about 24 hours so that the epoxy dried, creating a solid shell. When the airframe came out of the oven, the plastic wrap was cut off along with the fiberglass that extended past the airframe, which can be seen in Figure 5-3. Finally, the airframe got sanded to its proper size and to ensure that no shards existed to create a smooth surface, the final product of the lower is seen in Figure 5-4.

In addition to strengthening the airframe, the epoxy used in the layers of fiberglass waterproofs the airframe from potential inclement weather conditions at the launch site. Waterproofing the airframe is important to protect the structural integrity, electronic components, black powder charges, and parachutes, especially when launching in winter weather conditions.

Figure 5-3 Fiberglassed Airframe

Figure 5-4 Assembled Lower Airframe

5.1.1 Carbon Fiber Fins

The purpose of the fins is to provide stability across launch vehicle flights by adjusting the location of the center of pressure of the launch vehicle. A stable launch vehicle requires the center of pressure be located behind the center of gravity along the ram axis. The shape of our fins maximizes the surface area behind the center of gravity vehicle of the launch vehicle to affect the center of pressure in a desired manner to perfect the stability and avoid weather cocking, when a projectile is over stable and susceptible to turning into the wind.

The shape of the fin is considered a modified delta and is a Carbon Fibre Foam Composite Fin. The fin includes a rounded trailing corner, a leading edge, as well as sweeping the trailing edge to the rear of the rocket. These designs, along with the chamfering the leading outer edge of the rocket fin, to reduce the amount of drag and to achieve the desired stability. The leading edge of the fin is printed from PETG and is only required in the layup stage to provide the structure that will become the carbon fibre fin.

In order to carbon fibre, the fins, a fin template was laser cut from plywood and used to trace onto a foam base. Two fins were made at a time. The board was cleaned with acetone prior to construction of the fins and a rectangle of peel putty was put on the board in preparation for the vacuum bag. The center area of the rectangle was then waxed to prevent the fins from sticking to the board. The foam core was cut and the leading edge was placed along the foam core with space in between the two fins for the vacuum nozzle. Each fin and its leading edge were covered in a layer of epoxy. Layers of carbon fiber fabric were then prepared by covering them in epoxy. The fins were overlaid with 3 layers of carbon fiber on one side and smoothed out. Then, a layer of peel ply was placed down, followed by a layer of breather, and finally a layer of bleeder. The layering process can be seen in Figure 5-5. A small piece of bleeder was also folded and placed at the center. The vacuum nozzle was placed on top of the piece of bleeder, and a vacuum bag was placed on top. The peel putty was pressed down to seal the vacuum bag, and a small hole was cut in the center for the vacuum pump. The vacuum pump was attached to the board and sealed with more peel putty. The board was placed in the oven overnight while the epoxy cured and hardened. The fins were taken out of the vacuum bag and cut to shape using a Dremel in a well-ventilated area, with all members wearing safety glasses and masks. The edges of the fins were sanded to match each other and to fit into the fin can. This process was then repeated on the other side of each fin, creating four fins total which can be seen in Figure 5-6

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Figure 5-5 Fins being removed from vacuum bag.

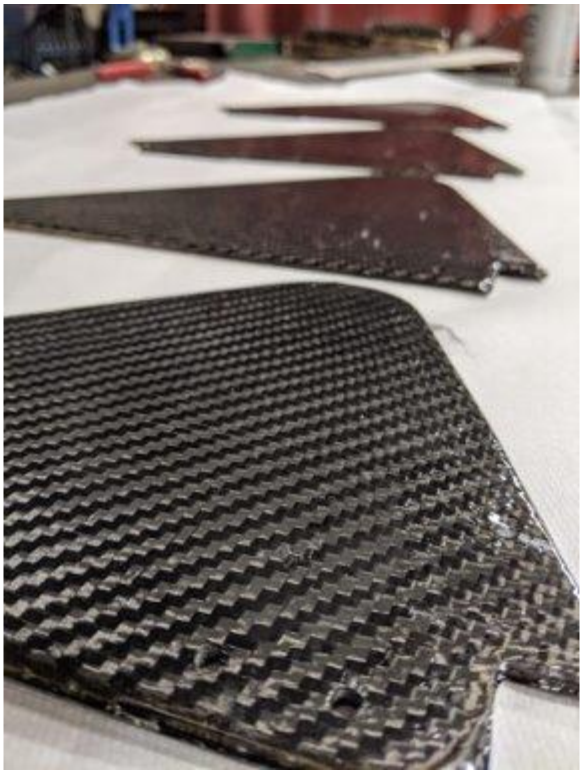


Figure 5-6 Fins with clear coat.

5.1.2 Nose Cone

For supersonic rockets, the ideal nosecone shape is conical, but at subsonic speeds the best shape is more rounded. Tangent ogive is one of the least drag shapes for a nose cone and is frequently used on high speed rockets. This shape has a pointed tip and rounded cone shape and is what our launch vehicle utilizes.

For safety reasons we have decided to change our nose cone. Although the use of our previous nose cone was a team derived requirement, the decision to change to our current nose cone was one made due to concerns of over stability, and to help reduce the weight of the vehicle. Our nose cone still constructed out of fiberglass but has an exposed length of 24in and a shoulder length of 5.5in. It has a mass of 28oz, which will help reduce the weight of the upper section of the launch vehicle. We chose to remain with fiberglass due to its high strength but to forgo the metal tip both for weight reduction and to reduce our off-rail stability to 2.6, well within the desired range of between 2 and 3.

The nosecone is directly integrated into the payload retention system with a threaded drive rod that is used to actively retain the nosecone. More details can be found in a latter section, where the retention system is detailed.

5.2 FIN CAN AND MOTOR RETENTION

The fin can hold the fins in place in the lower airframe, and also serves as the attachment point for the motor retention system to the rest of the vehicle. The main components of the fin can are the upper and lower fin brackets. These brackets include 4 sets of arms that bolt onto each fin with slots that extend into the body of the bracket to prevent shearing. The combination of the upper and lower fin bracket at the top and bottom of the fin can hold the fins in place, while also act as centering rings for the motor tube. This design includes captive hex nuts which allows the tail cone to be removed and reattached without removing the entire fin can from the airframe. This system allows for the fins to be removed and inspected after flight, as well as offers the possibility to easily replace the fins if needed. As an added benefit, the removable fins help to ease transportation of the vehicle to and from launch sites.

Figure 5-7 Fin Can Assembly

The motor retention system consists of the motor retention sleeve, motor retention flange, and thrust plate. This system of parts is made from 6061-T6 aluminum, used for its combination of strength, low density, cost effectiveness, and machinability, and are directly involved in securing the motor casing within the vehicle and transferring the thrust of the motor to the vehicle. The motor retention flange transfers the thrust of the motor to the thrust plate, which contacts the bottom of the lower airframe and eliminates the need for epoxied centering rings. A 3D printed tail cone lies below the thrust plate and around the motor retention sleeve. The tail cone reduces the base drag of the rocket and holds the motor retention sleeve flush against the thrust plate when the motor is not burning.

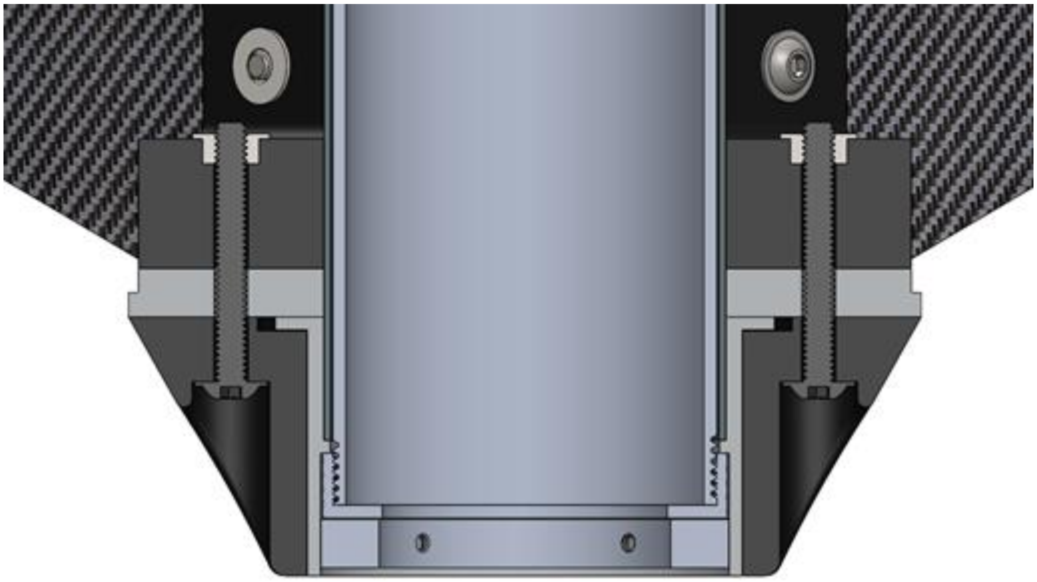


Figure 5-8: Cutaway View of Motor Retention System

Each component was manufactured according to the manufacturing information in Table 5.1.

Part	Quantity	Material	Manufacturer	Manufacturing Method
FIN BRACKET (Lower)	1	Nylon-X	Internal	3D Printing
FIN BRACKET (Upper)	1	Nylon-X	Internal	3D Printing
THRUST PLATE	1	6061-T6	Jones Machine Company	Machining
MOTOR RETENTION SLEEVE	1	6061-T6	Internal	Machining
TAIL CONE	1	PETG	Internal	3D Printing
MOTOR RETENTION FLANGE	1	6061-T6	Jones Machine Company	Machining

Table 5.1: Fin Can and Motor Retention Manufacturing

The fin brackets and tail cone were both printed on a Creality Ender 3, with a hardened hot end to be capable of printing with Nylon-X filament.

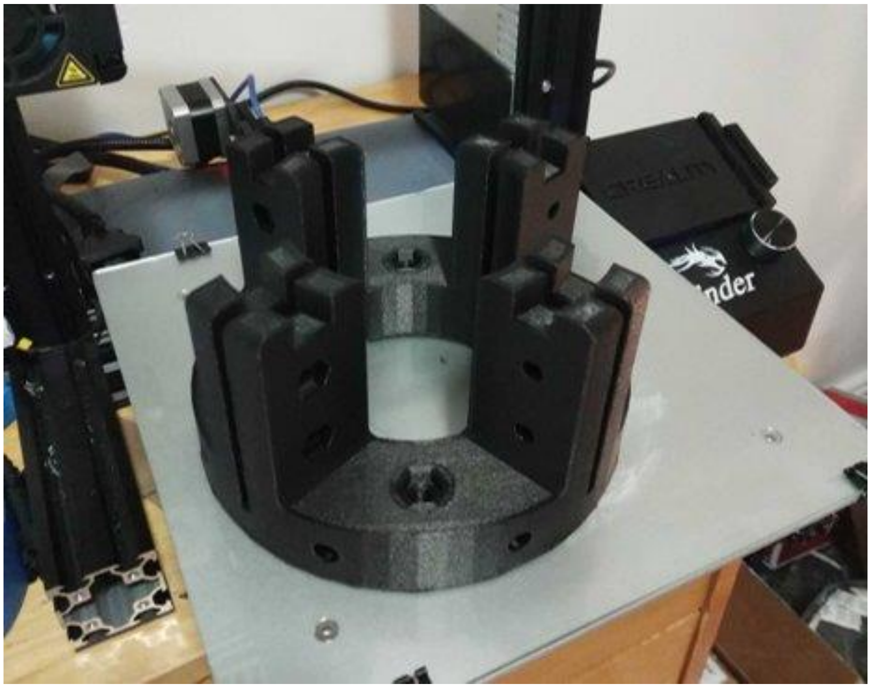


Figure 5-9: Printed Lower Fin Bracket

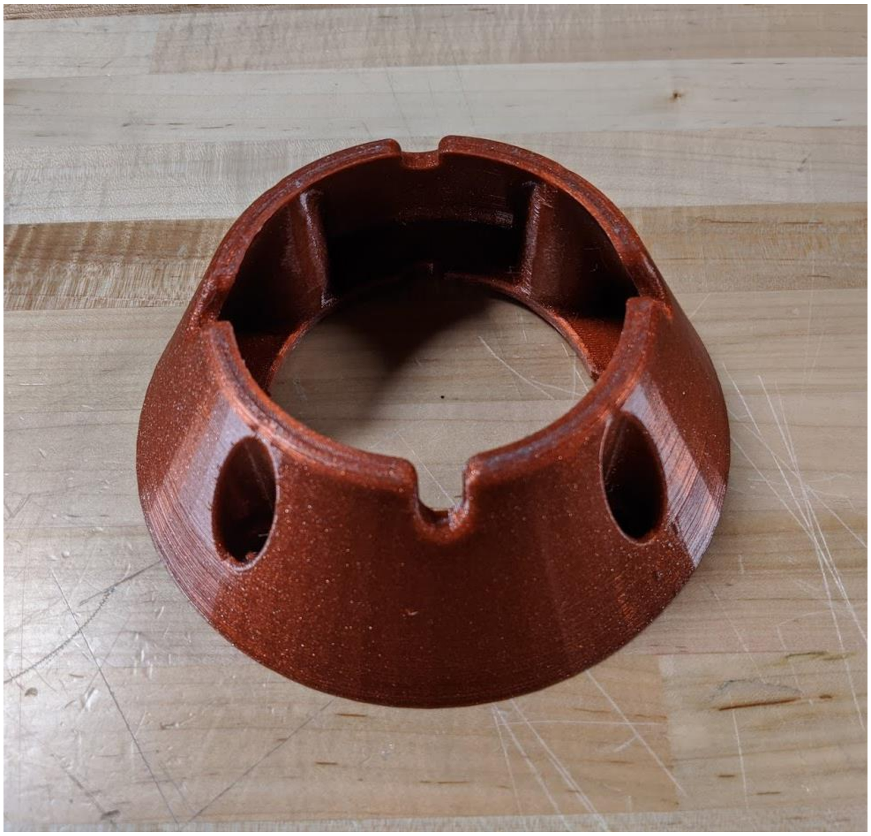


Figure 5-10: Printed Tail Cone

As can be seen in Figure 5-11, ¼-20 heat set inserts were pressed into the radial holes of each fin bracket using a soldering iron, and ¼-20 hex nuts were pressed into place in the countersinks on all other bolt holes. In addition, further 3D printed strengthening members were epoxied around the top of each bracket.

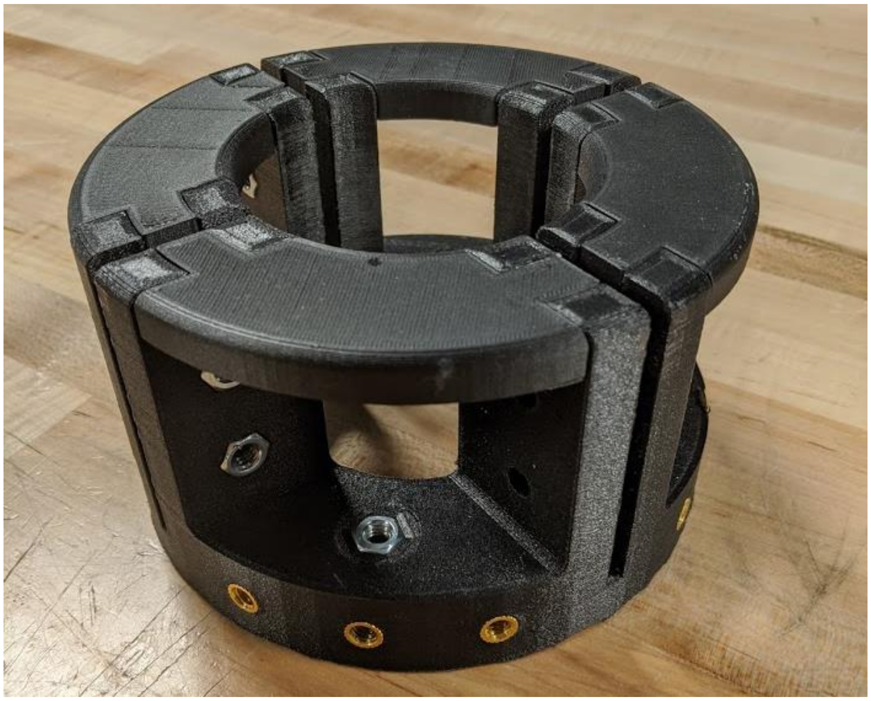


Figure 5-11: Assembled Lower Fin Bracket

Due to a lack of time for the manufacturing of every component, the thrust plate and retention flange were manufactured by our sponsor, Jones Machine Shop.

Figure 5-12: Completed Thrust Plate

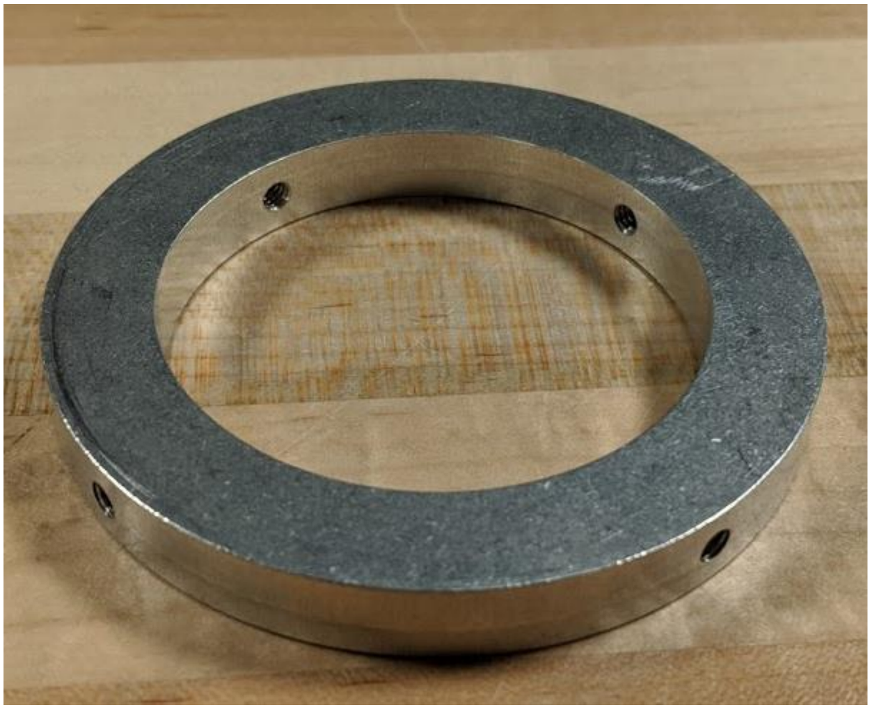


Figure 5-13: Completed Retention Flange

The motor retention sleeve, as seen in Figure 5-14, was manufactured in WPI's Washburn Machine Shops, on a Haas ST30-SSY CNC lathe, by members qualified to work with the machine.

Figure 5-14: Completed Motor Retention Sleeve

Assembly of the fin can and motor retention system was completed in the Foisie Makerspace and the Higgins MQP Lab. Since no epoxy is used in the structure, and no composite materials had to be cut or sanded, this work was completed quickly and safely.

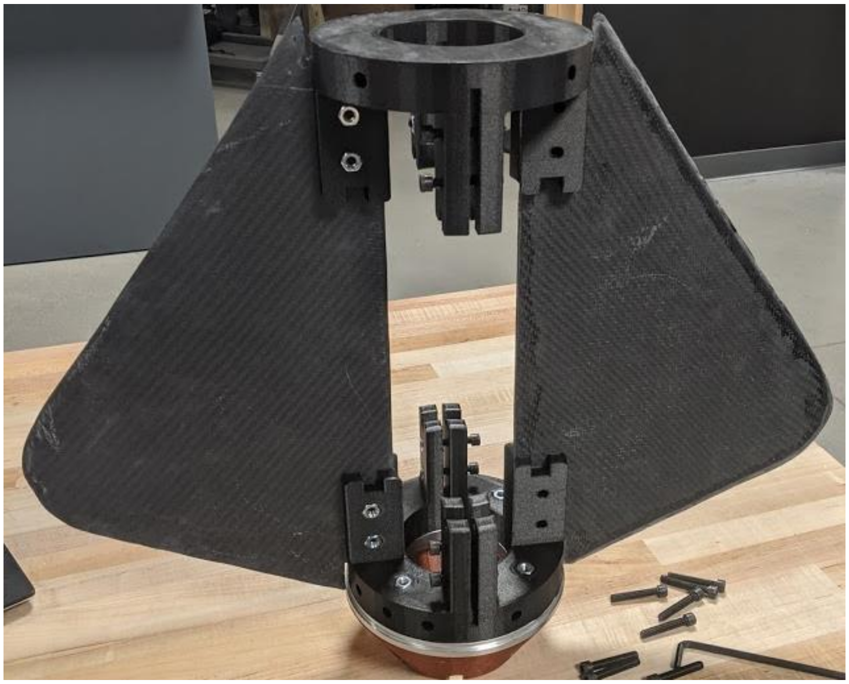


Figure 5-15: Partially Constructed Fin Can and Motor Retention System

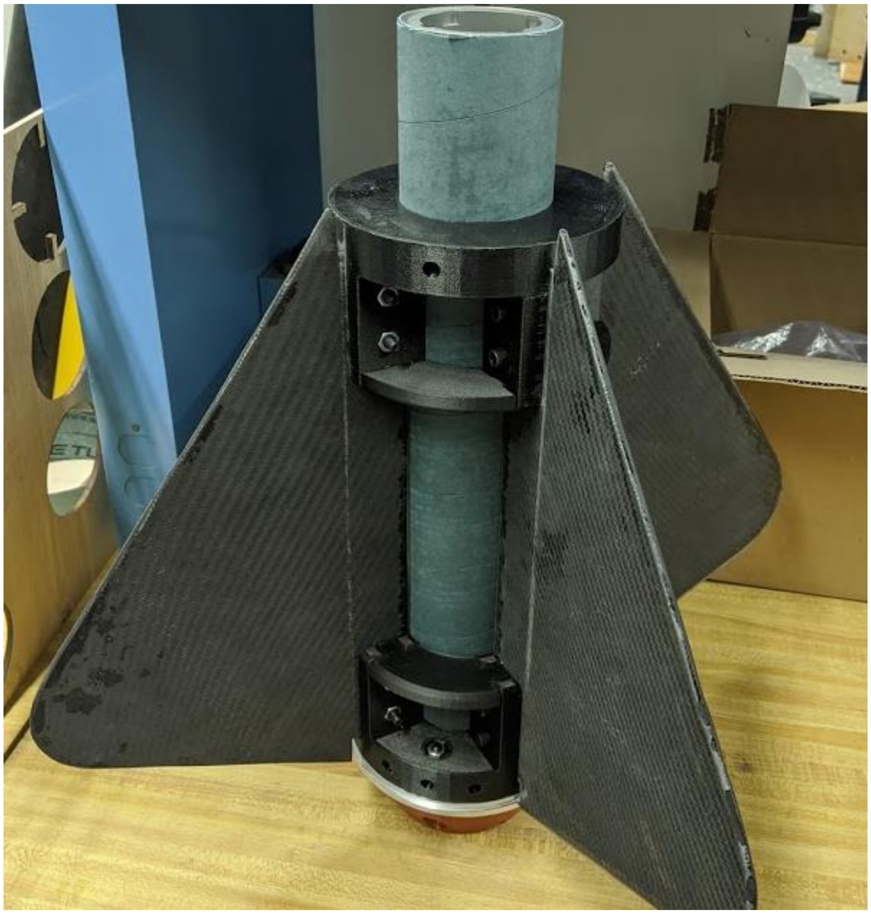


Figure 5-16: Fully Constructed Fin Can and Motor Retention System

5.3 ELECTRONICS BAY

Outside of the payload, which contains several electronic assemblies described in Section 6.2.5 to drive actuators associated with retention and deployment of the UAV, the rocket contains two primary electronics mounting bays, subsequently shortened as EBays. The primary EBay contains redundant barometric altimeters for tracking the rocket’s altitude, initial separation of the airframe, and deployment of the drogue parachutes. It also contains the rocket’s primary telemetry package, which records, transmits, and logs data about the rocket’s position and acceleration during flight. The secondary ebay, generally referred to as the retention bay, houses independent circuits associated with both the payload and recovery system, driving the tender descender which disconnects from the main rocket body during nominal flight as described in Section 5.6, enabling dedicated GPS tracking of this independent rocket section, providing controlled actuation to the retention lead screw, and transmitting wireless control signals to other electronic modules within the payload retention system.

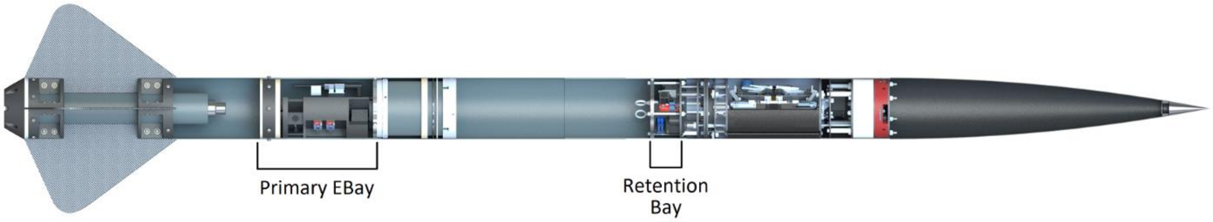


Figure 5-17 Location of the primary ebay and retention bay. The primary ebay spans the coupler which joins the lower and middle airframe, while the retention bay is recessed near the forwardmost point of the coupler which joins the upper airframe and payload to the rest of the rocket

5.3.1 Primary Electronics Bay Avionics

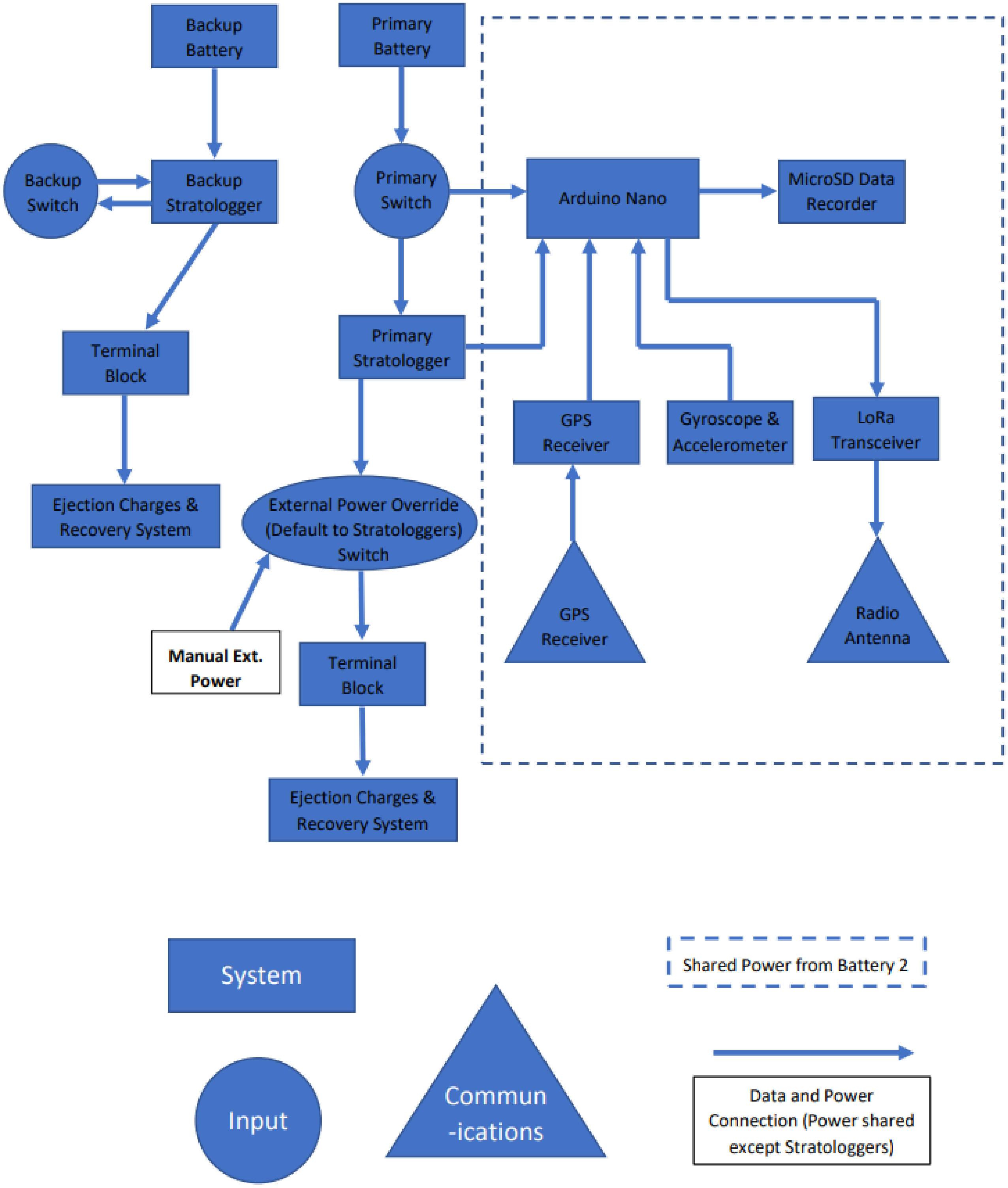


Figure 5-18 Connection block diagram showing all primary EBay elements

5.3.1.1 Deployment and Charges

The avionics design used in the full scale launch vehicle have been flight-proven in both the subscale and full scale test flights, in reliably and effectively deploying recovery devices, accurately tracking the rocket's altitude using barometric sensors, and avoiding any potentially unsafe unanticipated operation while on the ground. The primary tracking altimeter is a Perfectflite Strattologger CF, which is powered by a Turnigy Nano-tech two cell 370mah lithium polymer battery pack, connected via a JST-RCY connector rated for 10 amps at our operational voltage. The altimeter can be powered on while installed in the fully assembled rocket at the launch pad via a two-position locking rotary switch, which can be accessed when the rocket is fully assembled on the launch pad ready to fly, using one of the four atmospheric sampling holes described in Section 5.1. The power switch directly interrupts the circuit between the power port of the Strattologger and the battery. This enables the telemetry package (Section 5.3.1.3) to draw current off the power terminals of the primary Strattologger, without requiring an additional switch.

Figure 5-19 StrattologgerCF altimeter

The backup altimeter is also a Strattologger CF, chosen due to its aforementioned reliability, and to simplify programming of altimeters by only requiring team members learn one interface program. The backup altimeter is on its own independent circuit, with its own dedicated battery and rotary switch. Once again, the same model battery/switch are used, to reduce the number of tools required to activate the rocket and enable interchangeable spares. Because the backup circuit does not need to power any additional devices, the switch port on the Strattologger is used instead of interrupting the current pathway between battery and altimeter. Using two altimeters in this way provides redundancy to the drogue separation event in our recovery sequence.

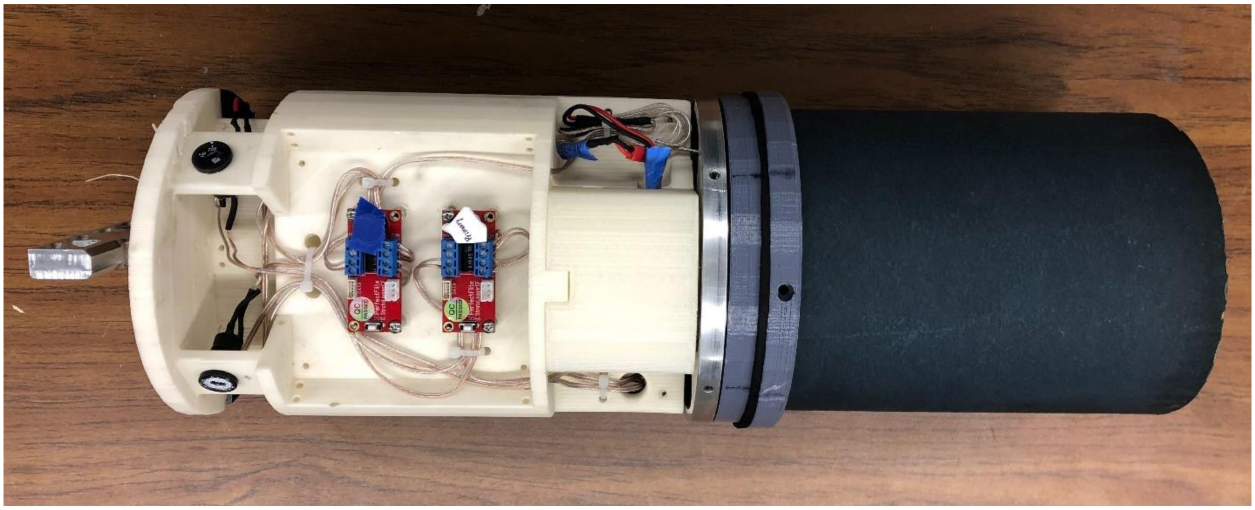


Figure 5-20 Strattologgers mounted to electronics bay. Rotary switches are visible at left for the main (top) and backup (bottom) Strattologgers. NOTE: EM/RF shielding assembly removed for clarity

Both Strattologgers only utilize the drogue output charge port during flight, as main parachute deployment and separation of the payload section from the recovery rigging are handled by the jolly logic chute releases (Section 5.6) and retention bay Strattologger (Section 5.4) respectively. The backup Strattologger is programmed to trigger its apogee charge on a 1.5 second delay, to prevent both charges from firing simultaneously and potentially damaging the recovery system through their combined force. The ejection charges are triggered using a low current e-match. Both deployment circuits use an indirect connection between the ematch and altimeter output, interrupted by a terminal block. This terminal block is mounted to the forward bulkhead assembly and has one side permanently wired to the deployment circuitry. Since the forward bulkhead is much more readily accessible than the small connectors on the Strattologger, this enables us to change out ematches between tests and flights much more quickly, with lower risk of wiring error.

Figure 5-21 Forward bulkhead of the electronics bay, showing permanently connected wires routed through the bulkhead to the Strattologgers. Open ends of the terminal blocks (bottom) are used as a connection point for charge e-matches.

The ematch is assembled into a black powder charge by our mentor, which consists of a cut off latex glove finger filled with an appropriate quantity of 3.31g black powder and sealed to the e-match using a zip tie and electrical tape. Additional wraps of electrical tape compact the powder and increase the burst pressure of the charge, ensuring that all powder is ignited before it is expelled from the charge. The charge is then mounted and captured within an aluminum ejection well, which directs the blast forward, dissipates heat, and prevents damage to other rocket components.

5.3.1.2 Ground Testing

A major issue discovered during our subscale test flight and assembly was the extreme difficulty involved in wiring an external trigger to perform ground tests of our recovery system deployment. In the subscale design, wires had to be carefully threaded from terminal blocks on the forward bulkhead through holes in the middle airframe as it was installed. This was a delicate, time consuming operation, which required several people to carefully maintain tension on the wires and monitor the recovery harness to avoid damaging the charges and took upwards of 30-40 minutes to perform per test.

The full-scale model features an improved design, which utilizes a double-pole-double-throw switch to select between one of two potential power supplied to feed power to the primary charge terminal block. Power can be routed to come either from the Strattologger, or from a JST-RCY power connector, with the unused power supply being left an open circuit. The JST-RCY power connector, which was chosen due to its availability and proven performance as the main battery connector in our electronics system, can be connected to an external power supply while the electronics bay is already fully installed in the assembled launch vehicle, including recovery rigging. This enables us to connect directly to the internal terminal block without cumbersome wire re-routing, and provide power to it without physically disconnecting any wires, and without risk of damaging the Strattologger by back-feeding current into it.

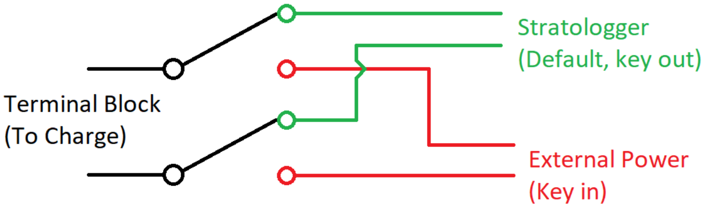


Figure 5-22 Wiring of the DPDT switch used to enable external power supply for ground testing. The charge output is always connected, the switch selects between internal or external power supply, leaving the unused supply an open circuit.

For the switch, a C&K YF21132C203NQ double pole double throw two position key lock switch was chosen. This switch was selected due to its relatively small size for a key lock switch, and its continuous power rating of 112 watts which is 1.94 times greater than the maximum power spikes we have observed in ejection tests even with sub-optimal, high current draw igniters. The key lock design was selected due to an attractive safety feature. It uses a key which is inserted through an airframe vent hole and is then rotated 90 degrees to actuate the switch. The key can only be removed in one of two positions, resulting in an obtrusive protrusion from the rocket in one mode. We configured the switch such that the key must be present in the TEST mode, and can be removed in FLIGHT mode, and added a high-visibility flag to the key, to ensure that the rocket cannot be flown with the power pathway between altimeter and charge inadvertently left open.

Figure 5-23 Key with remove before flight flag. Installation indicates that the electronics bay is in TEST mode. On the right: Power leads emerging from the external power port, in preparation for a ground test.

On the backup Strattologger, an equivalent system is not used, instead the Strattologger output is connected directly to the charge terminal block. This is to ensure that the backup system is as simple as possible to remove all potential failure points, and because dual charges do not add any functionality during ground tests – charges can be sized one at a time.

This system performed flawlessly during both testing and flight operations, enabling seamless switchover and triggering charges as intended in both modes.

5.3.1.3 Telemetry Package

In addition to its primary function in providing deployment functionality, the primary EBay also houses a telemetry package, which provides supplemental data about our flight performance. The telemetry package also interfaces with the data port of the primary Strattologger to receive a real-time stream of barometric altitude data. All data recorded by the telemetry package is transmitted to a ground tracking station via a 915MHz half-wave dipole antenna connected to a RFM95W LoRa (long range) radio transceiver. The LoRa, along with all other telemetry package components, interface with an Arduino Nano, which runs code to interface all components with one another. Other sources of data include a MPU-6050 inertial measurement unit, which provides three axis motion data, indicating the rocket's change in velocity and rotation, giving a clearer picture of its motion than could not be achieved only through barometric data. The telemetry package also houses a NEO-6MV2 GPS, which provides location tracking of the rocket body and will assist in locating it should it be lost from sight or drift a long distance. Finally, all data is recorded to a 32 gigabyte micro SD card using an Adafruit breakout board so that in the event of transmission failure data can be retrieved later from the rocket.

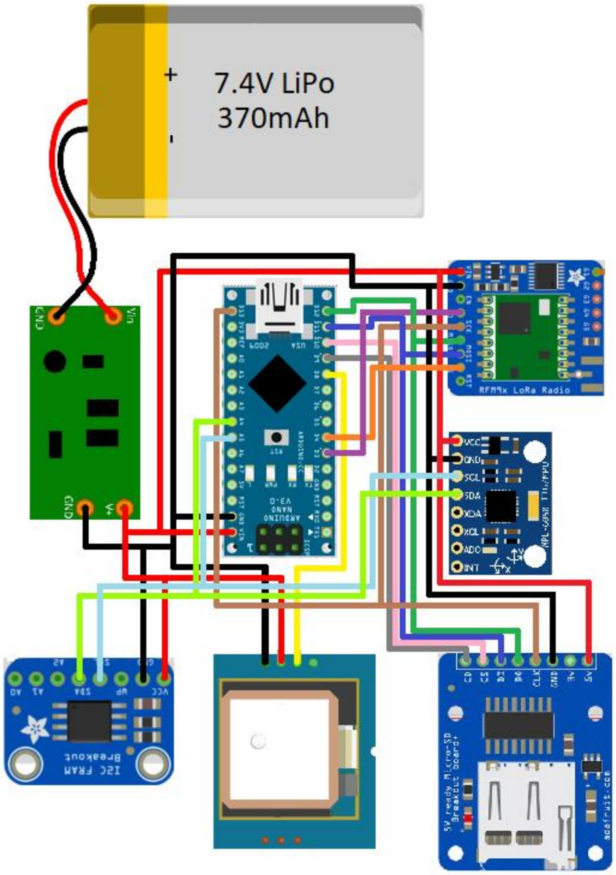


Figure 5-24 EBay telemetry package wiring schematic, including Arduino, GPS, LoRa, RAM breakout, and MPU 6050

The physical construction of the telemetry package was completed during the subscale build cycle. The same telemetry package flew on both our subscale and full-scale test flights. It performed without any problems on the subscale test. During our first full scale test, an assembly error discussed further in Section 7 prevented us from receiving data from the board. A minor modification to the mounting system, which will add additional protrusions to physically restrict components from inadvertently being plugged in in reverse, is planned before our full scale refight opportunity.

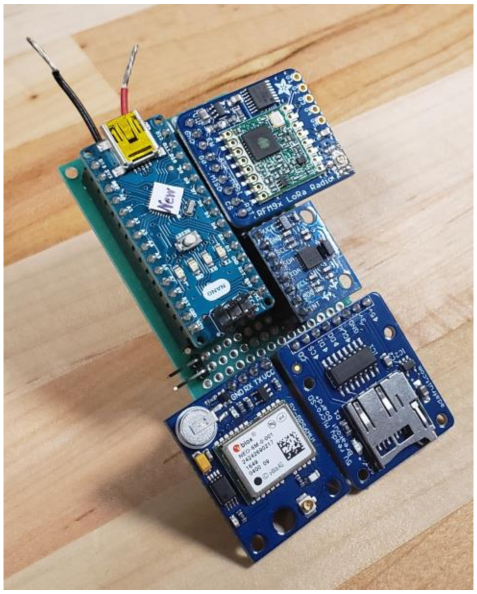


Figure 5-25 Assembled telemetry package

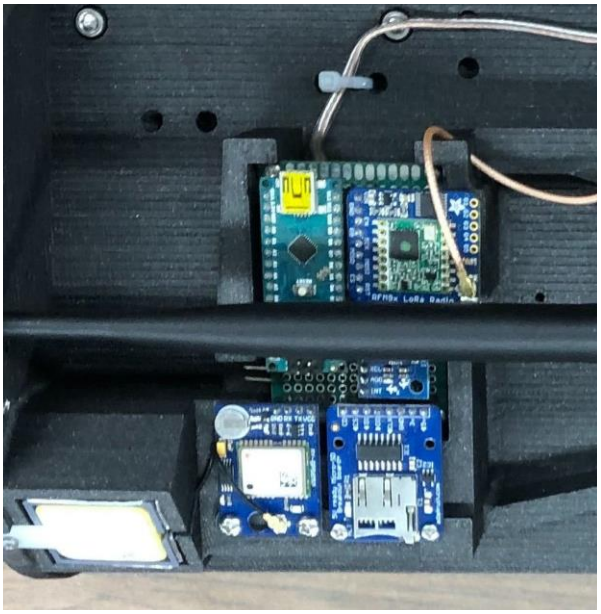


Figure 5-26 Telemetry package installed in the EBay sled

5.3.1.4 Structure

In addition to supporting various electrical components, the EBay serves a key role in the structure of the rocket. It sits at the joint between the lower and middle airframes and serves as the lower connection point for the recovery harness. Therefore, the electrical components must be masked within a coupler tube during flight, which makes maintenance difficult

The design developed for the subscale vehicle, in response to concerns over the structural integrity of our Preliminary Design Review (PDR) design, was originally intended to be scaled up to the full scale vehicle. It consisted of two printed PETG adapter rings with brass threaded inserts around their perimeter, meant to be installed in the airframe using a series of radial bolts. The forward bulkhead, made of ½” plywood, was rigidly connected to the forward ring via a series of through-bolts, such that a tension load would compressively deform the PETG adapter rather than inducing a tearout failure. However, this design in practice relied only on the forward bulkhead to dissipate tension loads, as the printed sled could not be relied on as a structural member.

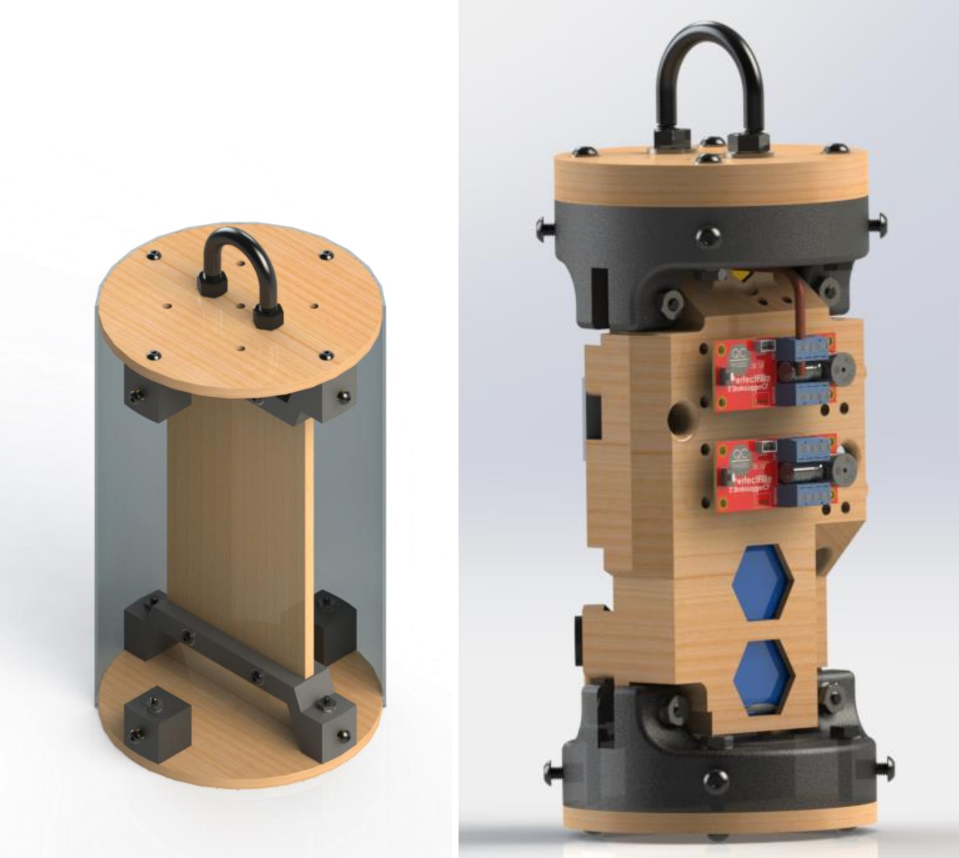


Figure 5-27 Left: PDR ebay, with inadequate structural integrity. Right: Subscale ebay, which distributed loading through the forward PETG ring, but left the aft bulkhead underutilized structurally.

In addition, we found that in practice, radial bolts used as the only means of securing the EBay in place was impractical from a maintainability perspective, if all bolts had to be installed and removed every time the ebay was installed. Inaccuracies in drilling matching holes in the airframe meant that despite the theoretical symmetry of the assembly, there was only one orientation which fit the parts correctly. The brass expansion threaded inserts chosen did not press fully into the printed parts in all cases, and sometimes developed a tendency to spin in their holes, making disassembly cumbersome. The soft material of the inserts was prone to stripping and cross-threading, particularly with repeated use. Assembly and disassembly of these components for ground test and flight greatly increased the time required to prepare our rocket for flight and pushed our flight near the end of the launch window.

Concerns about the increased loading concentrated on a single bulkhead on the full-scale design were planned to be addressed by increasing the bolt count, but this would have exacerbated the maintainability problem. Many aspects of the subscale ebay were a great success, and directly influenced the sled design. But it was determined that a new approach was needed for the full-scale design.

The design employed on the full-scale vehicle addresses the maintainability problem, while also distributing the loads equally between the forward and aft bulkheads. The design features a T-shaped aluminum spine, which distributes tensile loads applied by the recovery harness across both bulkheads.

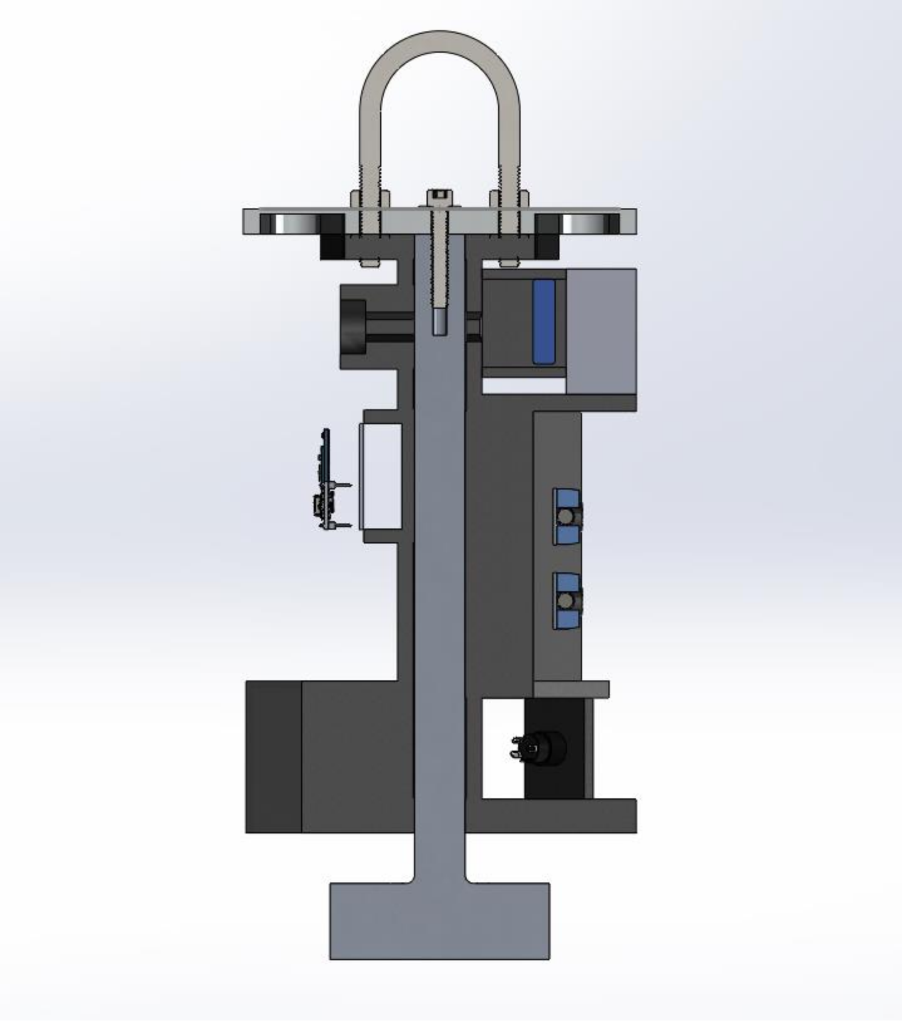


Figure 5-28 Cross-sectional view of the electronics bay sled, built around the aluminum spine. The T-shaped profile at the base is used to pull on the interior surface of the aft bulkhead

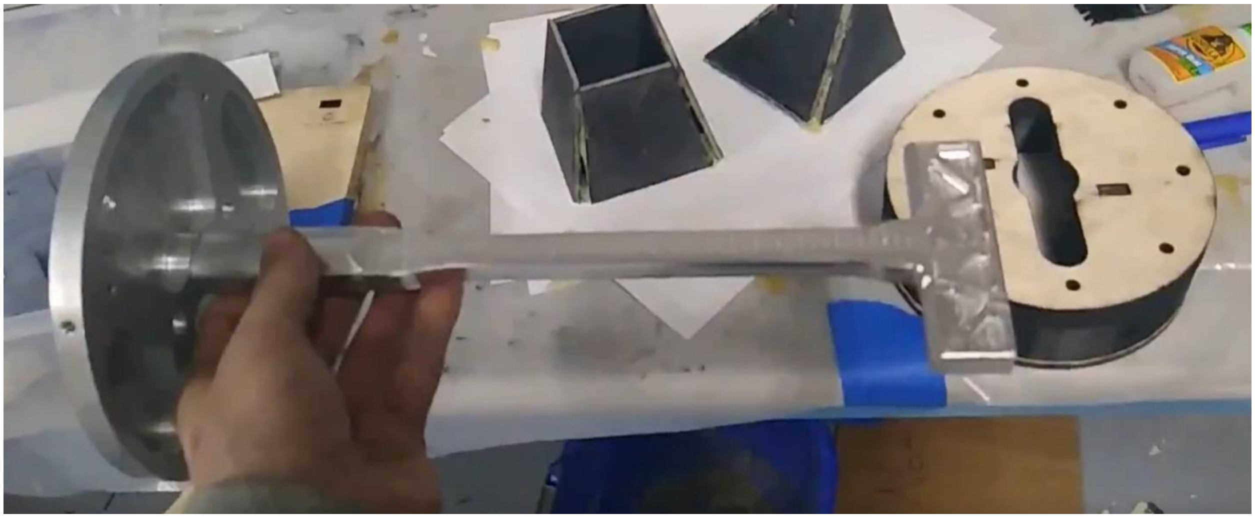


Figure 5-29 Forward bulkhead rigidly mounted to the aluminum spine

The aluminum spine is a twist-to-install design, allowing the forward bulkhead and sled to be removed without disconnecting the E-Bay coupler or aft bulkhead from the lower airframe. This design was implemented for an increased ease of launch day assembly and maintenance with half as many bolts required to fully assemble the launch vehicle. The aft bulkhead now consists of two layers of plywood, separated by a NylonX 3d printed piece used to house mounting holes to attach the bulkhead and coupler to the lower airframe. Because this connection is never broken during rocket assembly, and speed of assembly is now less of a concern, eight ¼” 20 bolts are used, ensuring that this connection would not fail under even extreme loads. The layers are connected together via eight 10-32 bolts with steel nylock nuts, such that no threaded inserts are loaded in tension as in the previous design.

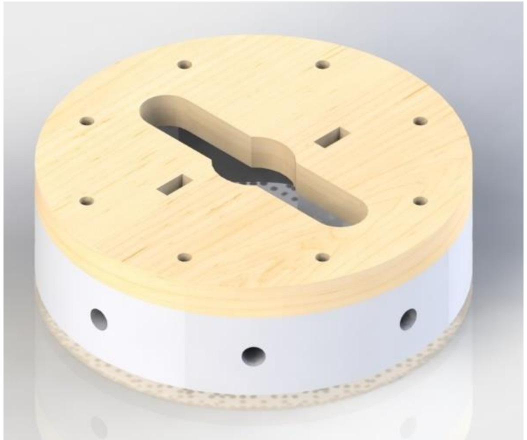


Figure 5-30 Aft bulkhead rendering, showing slot for aluminum spine insertion, compressive bolt holes which clamp the wood bulkheads around the printed body, and radial bolt holes which mount the bulkhead to the airframe.

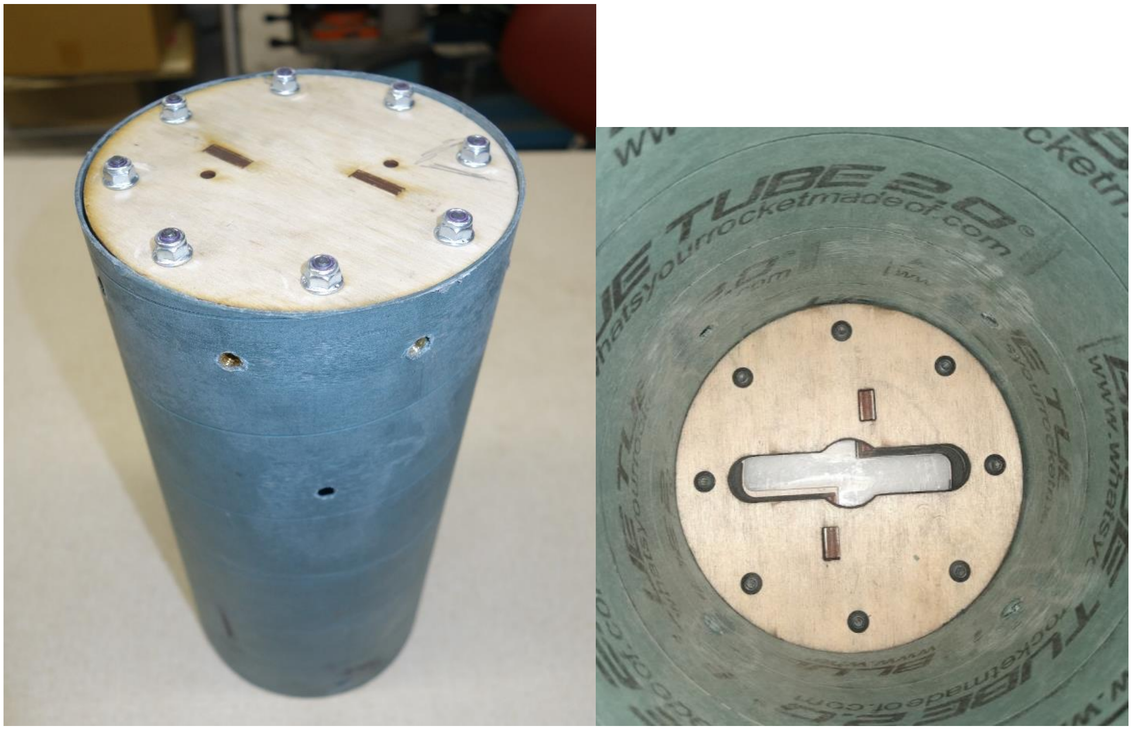


Figure 5-31 Left: Aft bulkhead at the base of the coupler tube, with brass threaded inserts. Right: Aft bulkhead viewed from above while installed, showing spine slot and Delrin skid plate.

To allow assembly and distribution of loading, the forwardmost plywood bulkhead features a slot, which allows the T-shaped profile at the base of the tension member to pass through the bulkhead. During insertion into the coupler, round sections built into the main electronics sled keeps the tension member centered on the slot. Once inserted, the entire forward bulkhead, sled, and tension member, are rotated clockwise 90 degrees, locking the T profile underneath the plywood bulkhead. The Ebay is locked in position rotationally at its base by reaction of the T-profile against vertical walls in the aft bulkheads 3d printed spacer piece, and permanently once installed in the rocket, as the four bolts threaded through the airframe into the forward bulkhead constrain the Ebay rotationally. Once installed, any tension load applied to the forward bulkhead causes the spine to pull upwards on the aft bulkhead, distributing the bulk of the load to the permanent connection made between the aft bulkhead and lower airframe.

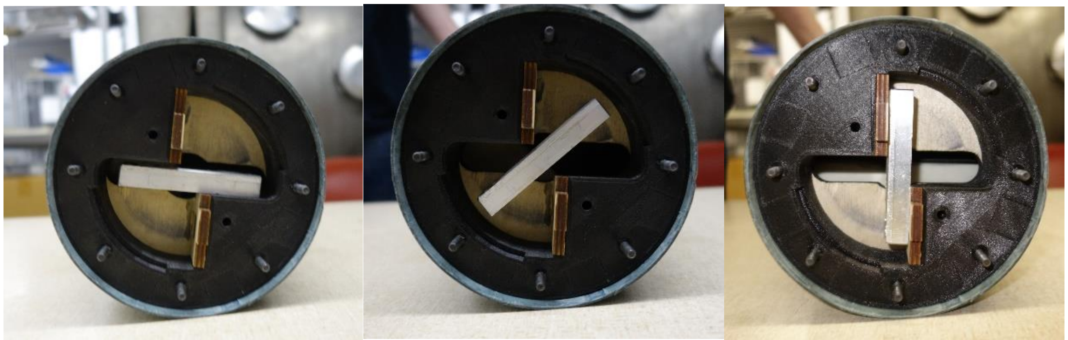


Figure 5-32 Assembly sequence, showing how the aluminum spine twists and locks into position within the printed core of the aft bulkhead. Lower plywood panel removed for clarity

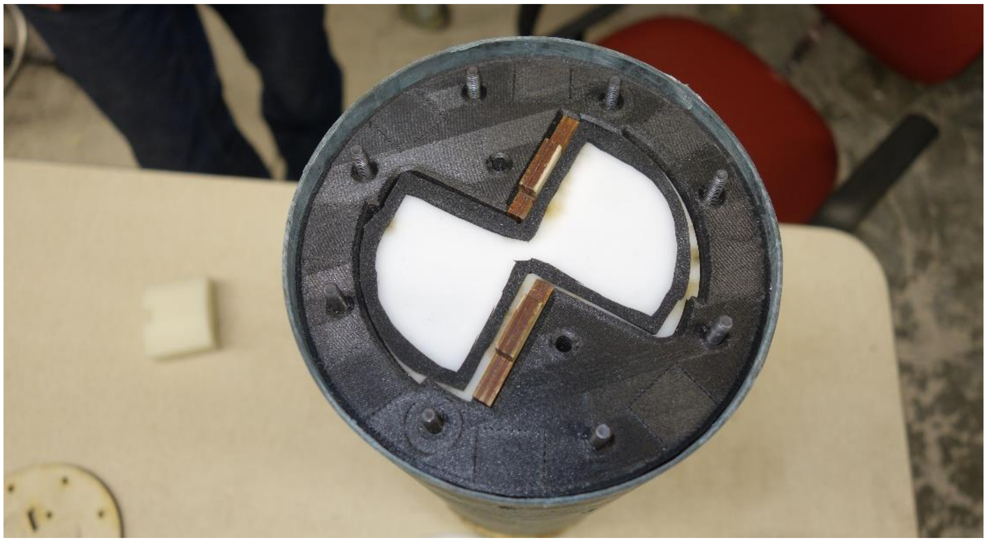
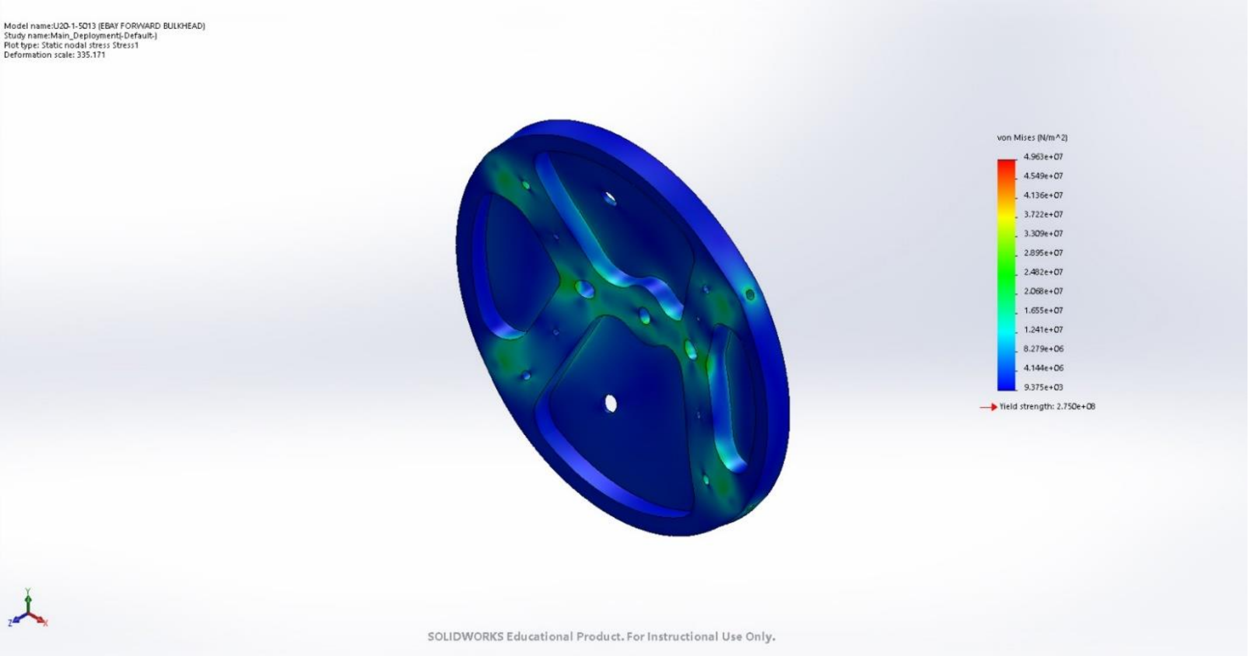


Figure 5-33 Clamped within the print structure: Delrin (white) skid plate, used to provide a smooth surface for rotation of the spine, and neoprene (black) compressive bowtie piece, which closes vertical alignment gaps and ensures that the spine is pressed against

Once twisted into place, the spine is locked in place using four radial bolts inserted into the forward bulkhead, which is built from 0.375” thick aluminium with a lightening webbing milled in the rear face. Since the bolts pass through the coupler tube as well as the middle airframe, the bulkhead/spine assembly is rotationally held in place. The radial bolts also provide a direct structural bridge between the forward bulkhead and the airframe, but for analytic purposes the bulk of the loading is assumed to pass through the spine and into the heavily reinforced aft bulkhead. Therefore, smaller/fewer fasteners can be used on the forward bulkhead, just four 8-32 bolts, to expediate assembly.

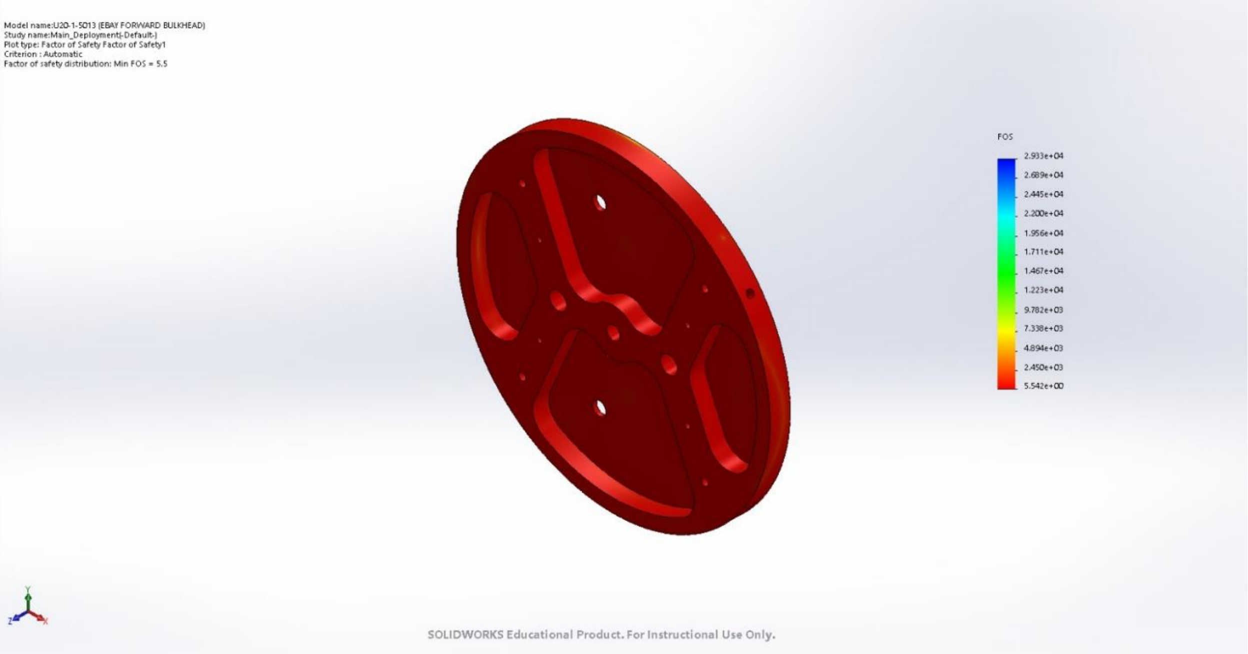
5.3.1.5 Analytics

The forward ebay bulkhead was simulated to ensure it would withstand ejection and parachute opening forces. Using a custom MATLAB program to simulate parachute opening, the maximum expected force was determined to be 921N at main parachute opening. As shown, the expected safety factor for this force on the bulkhead is 5.8. While a lighter design was considered, machining complications made this design acceptable.



Model name:U20-1-5013 (EBAY FORWARD BULKHEAD)
Study name:Main_Deployment(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 335.171

Figure 5-34 Finite Element Analysis of forward bulkhead, showing von mises stresses



Model name:U20-1-5013 (EBAY FORWARD BULKHEAD)
Study name:Main_Deployment(-Default-)
Plot type: Factor of Safety Factor of Safety1
Criterion : Automatic
Factor of safety distribution: Min FOS = 5.5

Figure 5-35 Finite Element Analysis of forward bulkhead, showing safety factor

A potential weak point in this system is the single-bolt threaded connection between the bulkhead and the spine. A tearout failure analysis was performed, using the equation

$$A_t = 0.7854 * (D - \frac{0.9743}{n})^2$$

to produce the equivalent shear area given a screw major diameter and thread count. 6061 aluminum has a shear strength of 30ksi, meaning that with an 1800N (404lb) load applied, there must be at least 0.013 square inches of equivalent shear area, or 0.039 square inches to achieve a safety factor of 3. For the original ¼-20 bolt, this formula gives a result of 0.03 square inches per inch of bot, requiring a 1.3 in deep thread to sufficiently support the loading. As we did not have access to deep-hole taps for thread engagement deeper than an inch, this bolt was increased in size to a 5/16-24 thread, which gives a safety factor of 4.46 when threaded an inch deep.

The spine was initially roughly designed and assumed by inspection to have adequate cross-sectional area to support tension loads applied, with the threaded connection being the failure point. However, as it became clear that the rocket needed to lose weight to meet our mission success criteria, the tension member was reduced in size, and further analyzed. A 1800N tensile load was assumed based on results from the MATLAB recovery system analysis. Solidworks finite element analysis was used to assess the impact that this load would have, and where material could safely be removed without impacting the part's safety factor. Much of its length was necked down to a ½" x ½" profile, while keeping a rounded, wider section around the threaded hole to eliminate thin regions around the highly stressed threads.

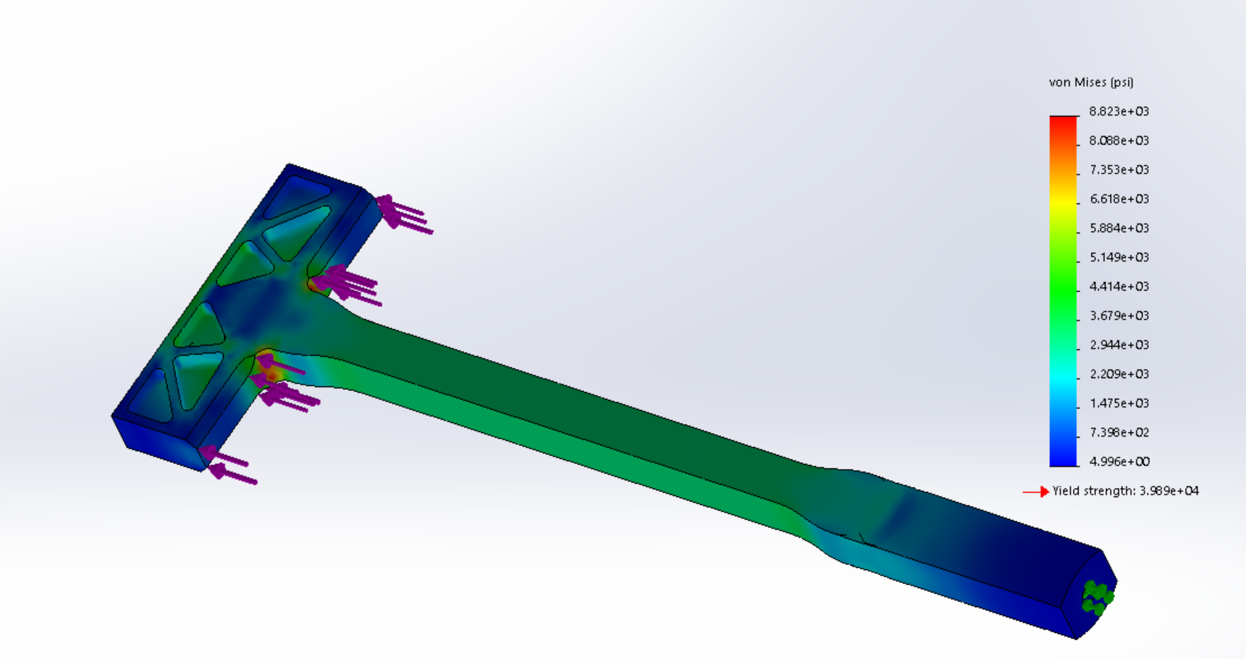


Figure 5-36 Finite Element Analysis of spine, showing von mises stresses. The most highly stressed regions are at the stress concentrations where the T profile begins, and, hidden, within the hole.

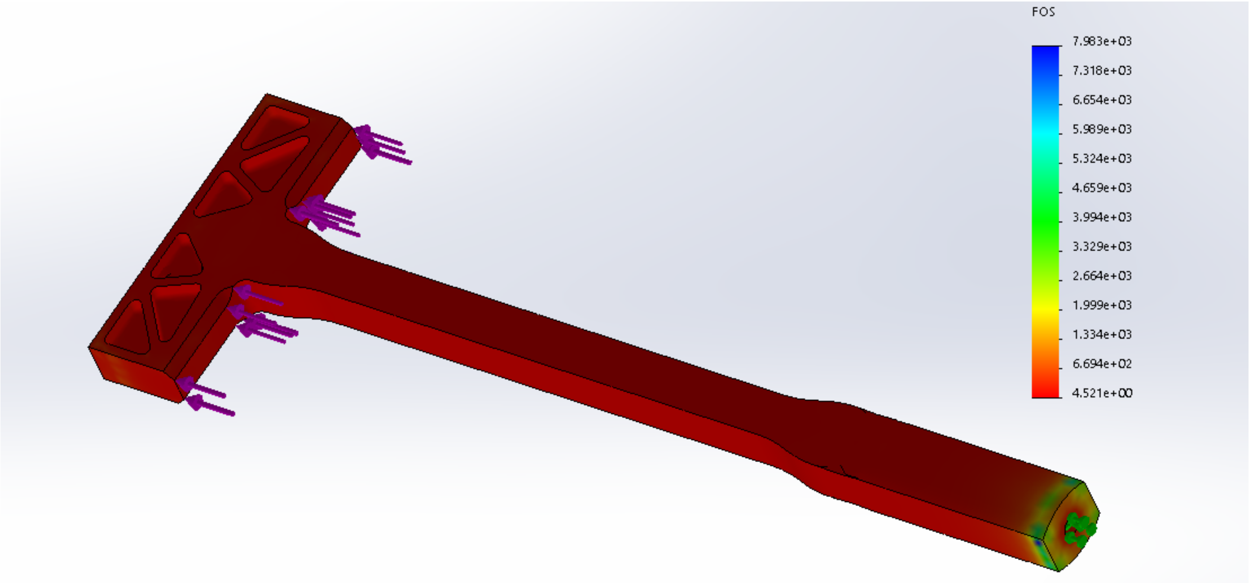


Figure 5-37 Yield factor of safety for the above simulation, showing a minimum value of 4.5.

5.3.1.6 Manufacturing

Manufacturing of electronic bay structural components occurred in the weeks leading up to the full scale test flight, and is summarized in the below table

Part	Quantity	Material	Manufacturer	Manufacturing Method
ALUMINUM SPINE	2 (1 spare)	6061-T6 Aluminum	Internal	Machining, HAAS Minimill
FORWARD BULKHEAD	1	6061-T6 Aluminum	Jones Machine Company	Machining
AFT BULKHEAD FORWARD PLATE	2 (1 spare)	½” 9-ply plywood	Internal	PLS 6.60 Laser Cutter
AFT BULKHEAD BODY	1	NylonX	Internal	3D PRINTING
AFT BULKHEAD LOWER PLATE	1	¼” 5-ply plywood	Internal	PLS 6.60 Laser Cutter
AFT BULKHEAD ALIGNMENT PLATES	2	¼” 5-ply plywood	Internal	PLS 6.60 Laser Cutter
AFT BULKHEAD SKID PLATE	2 (1 spare)	1/8” Delrin	Internal	PLS 6.60 Laser Cutter
AFT BULKHEAD SPRING BOWTIE	1	1/8” Neoprene	Internal	Manually cut
EBAY COUPLER TUBE	1	6” BlueTube 2.0 coupler	Internal	Horizontal Bandsaw, manually drilled/sanded to finish

Table 5.2 Primary electronic bay components.

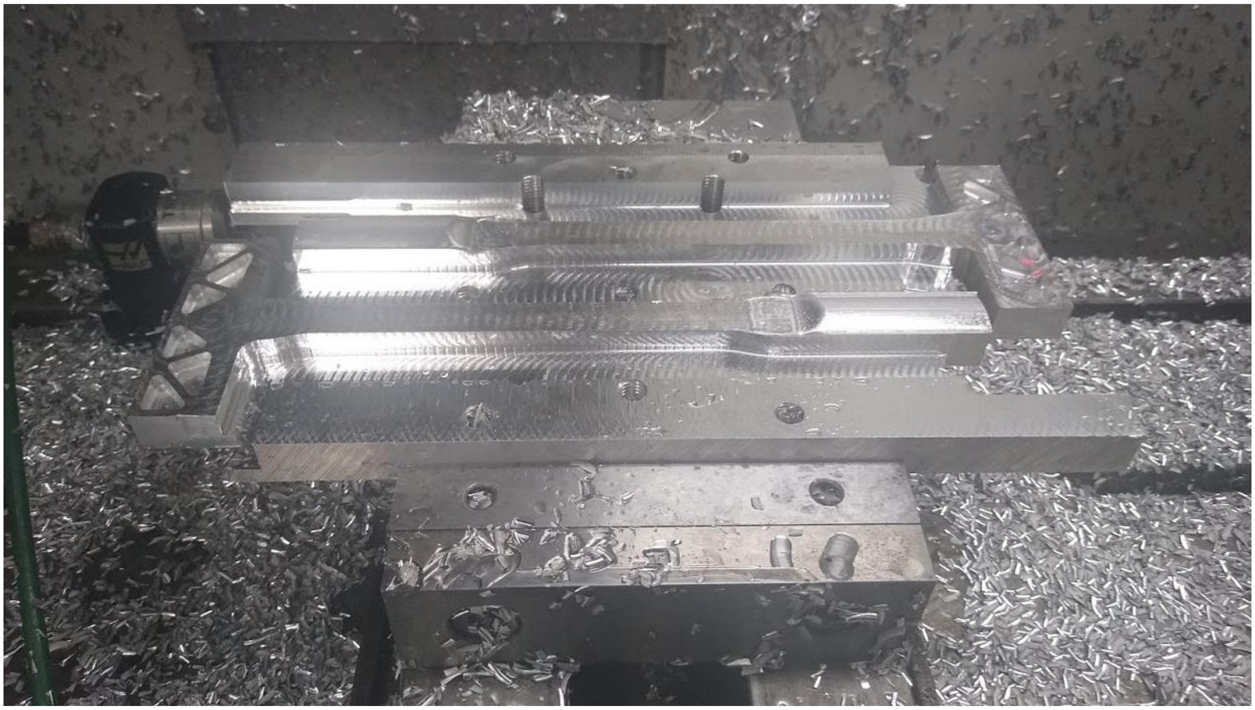


Figure 5-38 Spine milling in progress on WPI's HAAS MiniMill. The curved profile at the front of the spine is formed using a ½" ball end mill

Minor difficulties involved in the manufacturing of ebay components included challenges in establishing adequate fixturing for later-stage mill operations on the spine, which would not induce excessive chatter. The necked profile proved more difficult than anticipated to clamp to, eventually requiring an elaborate V-block based setup. The resultant finish, while imperfect, is adequate for the functionality of the part.

Figure 5-39 Mill marks on the final lightened spine. The chambfers on the upper surface help align it vertically during rotation.

Overall, the spine design was a great success. Electronic bay assembly which took multiple hours on last year's rocket, can be completed in approximately 20 seconds on the current assembled EBay.

5.3.1.7 Electronics Integration

The electronics bay components described above are housed together on a large 3d printed assembly referred to as the sled, which provides integrated mounting features which conform to the individual components, ensuring robust mounting. 3d printing was chosen as a manufacturing technique as it enabled us to add numerous complex features to the print, such as curved wireways, non-planar holes, and integrated zip tie mount points, without increasing time or cost of manufacture.

After the CDR submission, which featured a unibody printed sled, we elected to change the design to employ a two-piece clamshell sled construction, which would be printed in two parts, and clamp around the spine, rather than the original design which would require the spine be threaded up a square hole through the base. The main reason for this change was to enable the cutout in the sled to conform to the new lightened, hourglass shaped spine. Additionally, splitting the sled this way dramatically reduced print time and requirement for support material, and enabled improvements to wire passageways around the antenna. It also allowed us to streamline mounting of the sled by depending on the clamping force about the spine to constrain it in place axially.

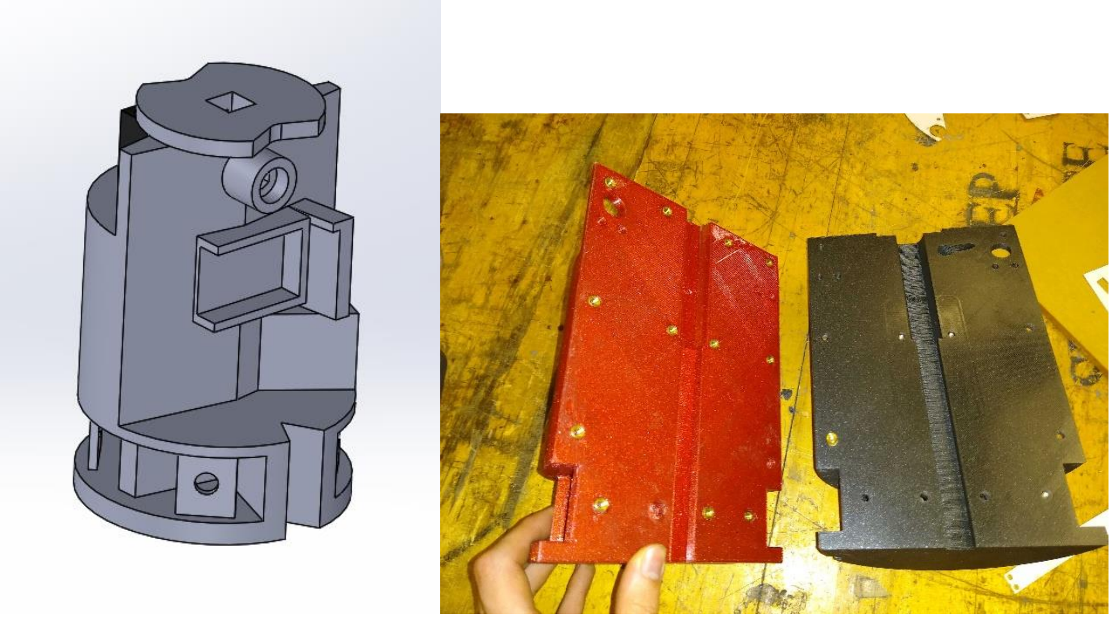


Figure 5-40 Left: CDR unibody sled design, with the spine installed from below. Right: First generation clamshell sled design

The details of the sled’s design was directly influenced by the subscale sled design, which went through three complete print iterations to dial in mounting features and other smaller elements. Many dimensions, such as the pocket which houses the telemetry package, and the captive hexagonal mount which secures the main telemetry antenna in place, were directly adapted from this design. Also like the subscale design, the overall layout is split across two sides of the sled, with telemetry components on one side, altimeters and power on the other.

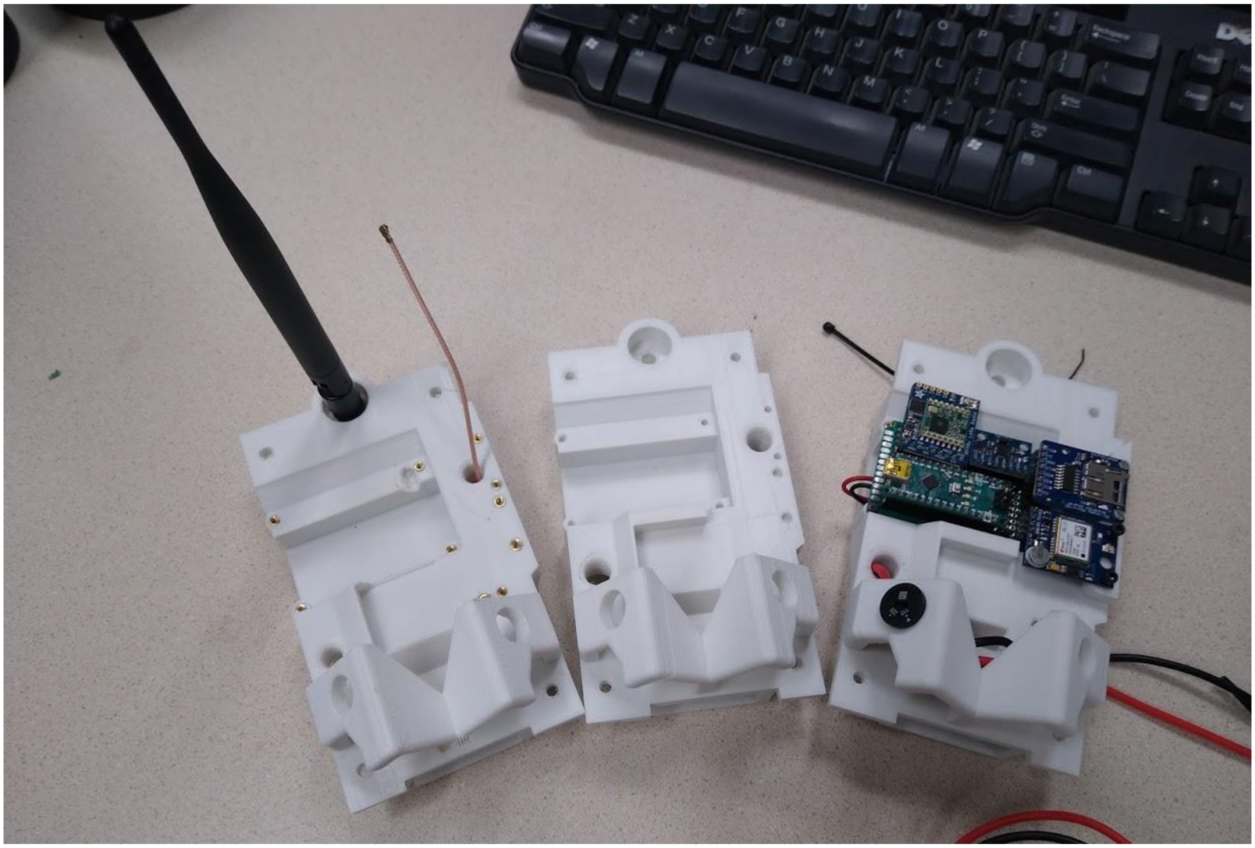


Figure 5-41 Subscale sled iteration, which directly influenced full scale design

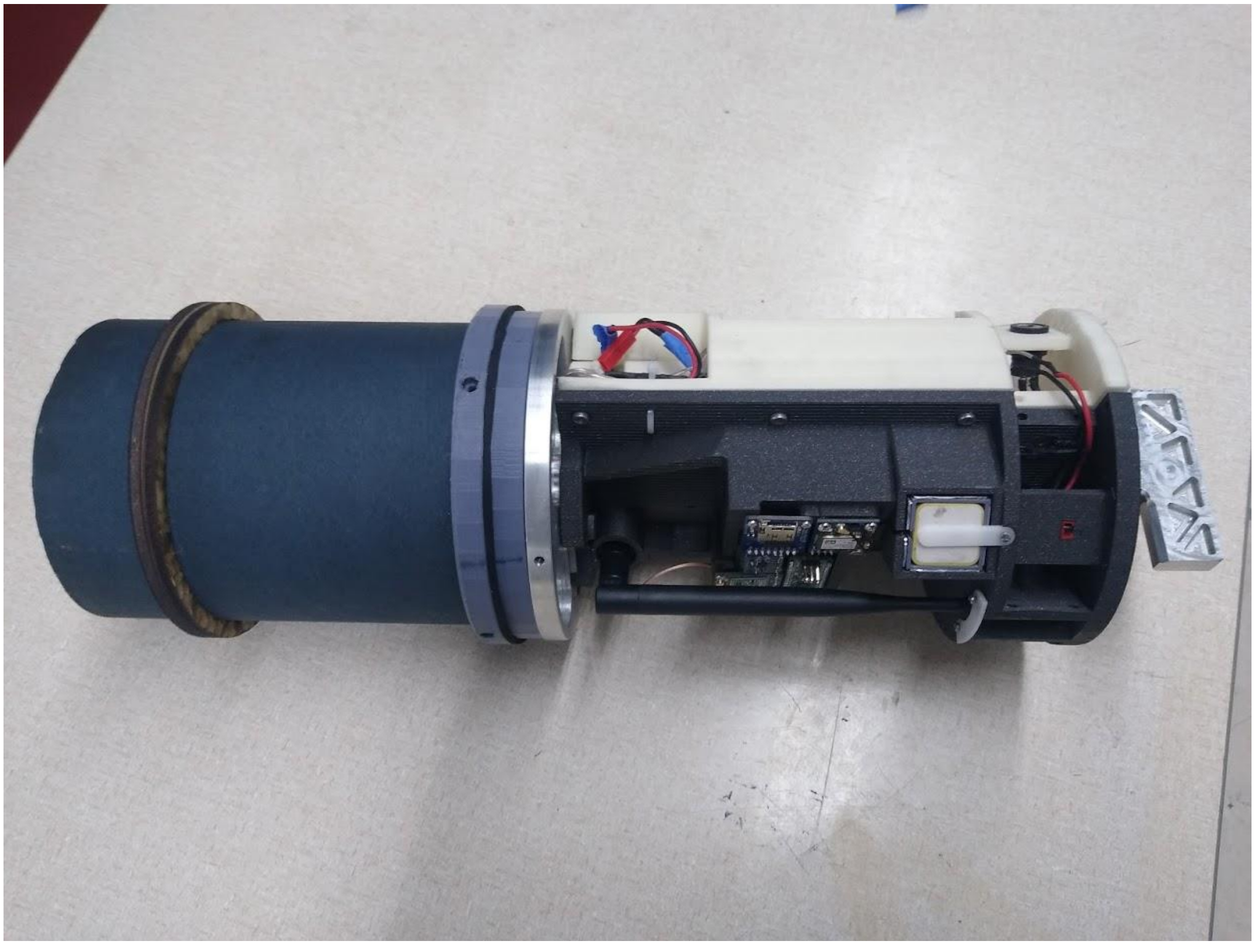


Figure 5-42 Final split sled design. Telemetry is on the black printed half, altimeters and batteries on the white.

Most components mount to the surface of the print using brass heat-set threaded inserts, using either M2 or 4-40 screws. Telemetry components are directly mounted to the surface, while the Strattologgers have a ¼” gap provided by male-female standoffs, to ensure that there is adequate clearance underneath the boards for the barometric sensors to operate.

Adequate fastening of potentially volatile lithium polymer batteries is also of great importance. The 3d printed sled allows us to surround the batteries with the structure of our electronics sled on five sides, lined in fire retardant neoprene rubber foam. The batteries are fastened in this cradle via a cap with loosely slides in place via a series of exposed steel dowel pins and a piloting feature on the sled print, for rapid installation/removal on launch day. When the ebay is fully constrained within the coupler tube of the rocket, this cap is held in place, preventing the batteries from moving.

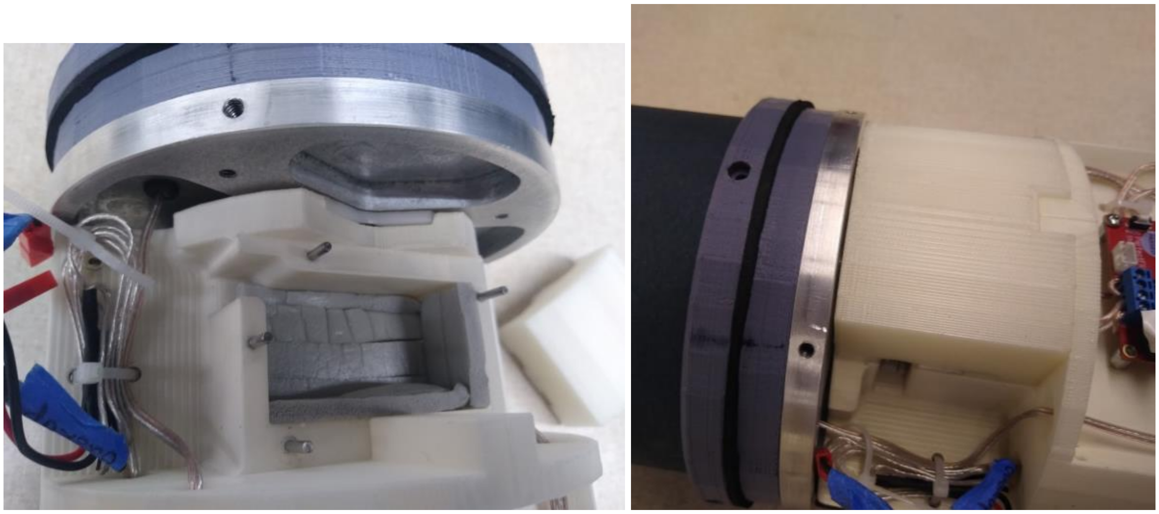


Figure 5-43 Battery cradle and wireway (left), and with cap installed (right). The curved top constrains the cap in place when the sled is installed in the coupler tube

A notable consideration for the full scale Ebay is electromagnetic and RF interference shielding. This was not considered on the subscale design, as the lack of competition environment would have few external sources of potential interference, and testing showed interference from our own antennas to be an unlikely problem. But for full scale, a properly shielded design was required. This necessitated building a cavity in which the Strattologgers could be mounted, which would be sealed on all sides running all the way up to the outer airframe. All interior surfaces of this cavity are lined in 1/32" thick aluminum plate which provides electromagnetic isolation between transmitting antenna and critical flight avionic electrical traces. This design which spans the entire coupler radially also allows the sled to self-center as it is being installed in the rocket. The GPS antenna is also shielded from the primary antenna, being mounted within a small aluminum "cup" feature.

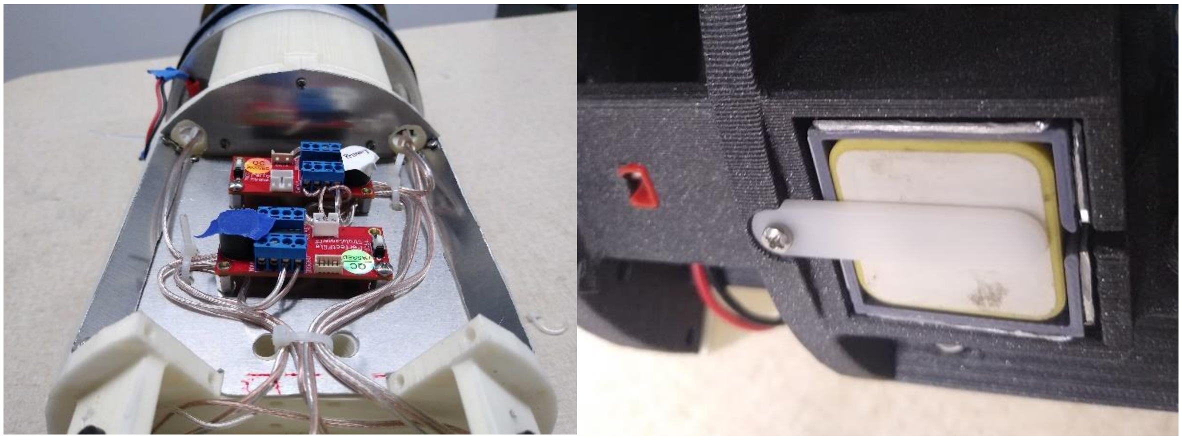


Figure 5-44 Left: aluminum lining of the Strattologger compartment providing electromagnetic shielding. Right: Aluminum shielding cup protecting the GPS antenna from external interference

Capturing the barometric Strattologgers in this way necessitates careful consideration be given to the pathway through which air flows from the pressure sampling holes to the Strattologgers. Four vent holes are used, corresponding to and aligning with the four devices which require external access: Primary switch, backup switch, keylock ground test switch, and ground test port. These four devices are mounted at the same level, within a band that is sealed against the coupler from above and below, and which steps down at the interface between the two sled halves to allow uninterrupted airflow all the way around the sampling region. Vent holes are sized to 0.3”, assuming that the circular profile of certain sled regions does not form a complete seal, and that the entire coupler must be pressurized, according to the Strattologger user’s guide.

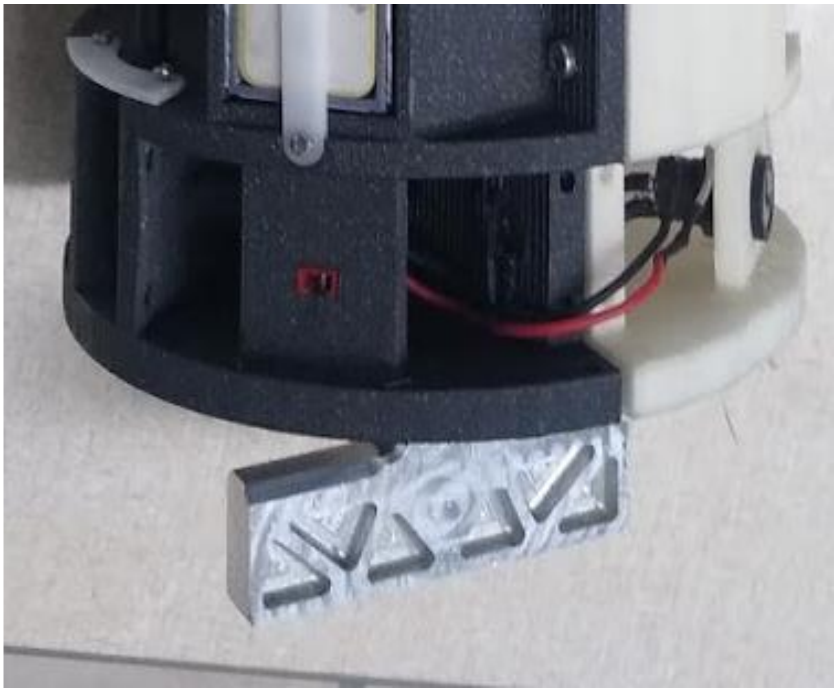


Figure 5-45 Band on which all externally accessed devices are mounted, to allow airflow up to Strattologgers

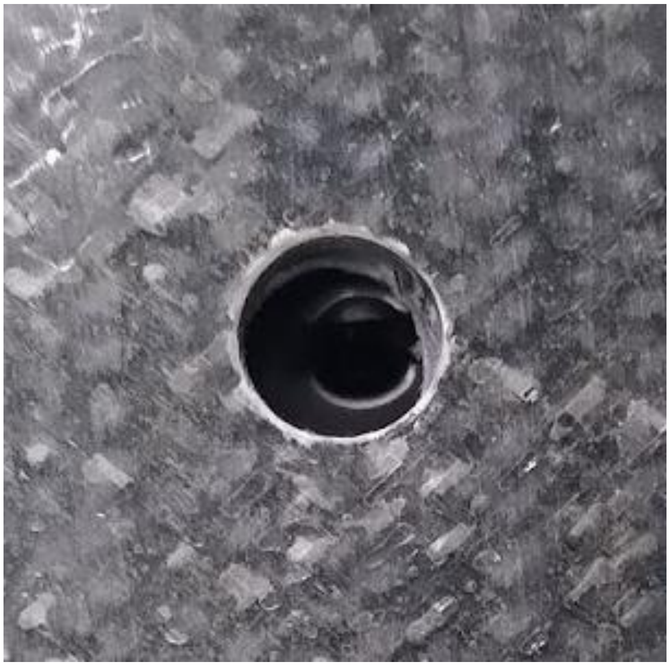


Figure 5-46 Alignment with key lock switch on fully assembled and installed sled with pressure sampling hole through airframe/coupler

The sled design went through two unique iterations during construction, with numerous small tweaks made based on feedback from the attempt at assembling the first generation design, including improved wireways, better fit of components such as the solidly mounted JST connector, localized print reinforcement around high-stress components such as the battery box dowel pins, and piloting features which lock the sled rotationally to lighting elements on the forward bulkhead.

The final ebay also features an additional printed component referred to as the ballast flange mounted to the forward bulkhead, which serves several functions. Its primary job is to retain the core tube used in the ballast system design, but it also enhances the ebay's functionality in several ways. It serves as the mounting point for the aluminum ejection wells and terminal blocks. It contains sealing grommets at all wire passageways. It also contains a lip, which traps a thin neoprene washer against the forward lip of the coupler tube. This washer and grommets seal the forward bulkhead from the interior of the electronics bay, preventing hot ejection gasses from entering the interior and damaging electrical components.

Figure 5-47 Ballast adapter print with ballast core tube removed, showing location of terminal blocks and ejection wells. The neoprene seal (black) is visible above the coupler tube

5.4 RETENTION ELECTRONICS BAY

The design for the payload rotation mechanism also houses the secondary electronics bay. This separately contains the electronics and batteries needed for tender descender deployment operations, discussed in section 5.6. The only effect this has on the primary E-Bay is that the Strattologger main ports will be left unwired. The electrical components hosted in this bay include a LiPo battery, Strattologger, continuous rotation servo, BEC for servo power regulation, rotary switch, Arduino Nano, LoRa transceiver, GPS, and transceiver dipole ¼ wave antenna.

The primary function of the retention bay is performed using a dedicated circuit connected only to the Strattologger and its arming switch, to meet recovery requirement 3.8, ensuring reliable operation. The Strattologger is connected in much the same way as the backup Strattologger in the primary electronics bay, being armed with a locking rotary switch. The Tender Descender output is wired to the main output, which is programmed to trigger at 700 feet. To ensure correct operation of the Strattologger, Vent holes placed at 90 degrees apart perpendicular to the servo orientation allow for air flow to the Strattologger compartment within the retention bay.

The secondary circuit, powered off its own separate battery, performs GPS tracking functionality for this independent section of the rocket, using the same components as used in the primary electronics bay. The transceiver in the retention bay, however, serves a different purpose. It is used to wirelessly communicate signals to other payload electrical components, which cannot be hard-wired to a single master controller due to the rotation the payload assembly undergoes during orientation operations. The transceiver antenna is physically isolated from the other components by a piece of 1/32-inch sheet metal to avoid radio wave interference. To allow vent access to the isolated section of the recovery E-Bay without leaking radio waves, a metal 1/8-inch diameter tube runs from the vent hole to the Strattologger.

The structure of the retention bay consists of a “core” design, printed in a single piece of PETG, which straddles the servo housed in the bay. This core mount is then surrounded by a 3d printed sleeve made of NylonX filament, which spans the gap between a carbon fiber bulkhead which make up part of the payload retention driver assembly, and the aluminum forward bulkhead and recovery harness. This sleeve provides the main structural link between the payload assembly and the surrounding airframe. The sleeve constrains the outer perimeter of the core print, and closes the surrounding volume off into a number of discrete compartments. As mentioned, one of these is electromagnetically isolated using an aluminum barrier.

The compact footprint available around the perimeter of the core print made wiring the electronics a challenge. Two iterations of the retention bay core were printed, with the second featuring improved wire passageways through the print, which enable wires to be routed between compartments, while also guiding the wires on gentle curvatures which do not place excessive load on soldered connections.

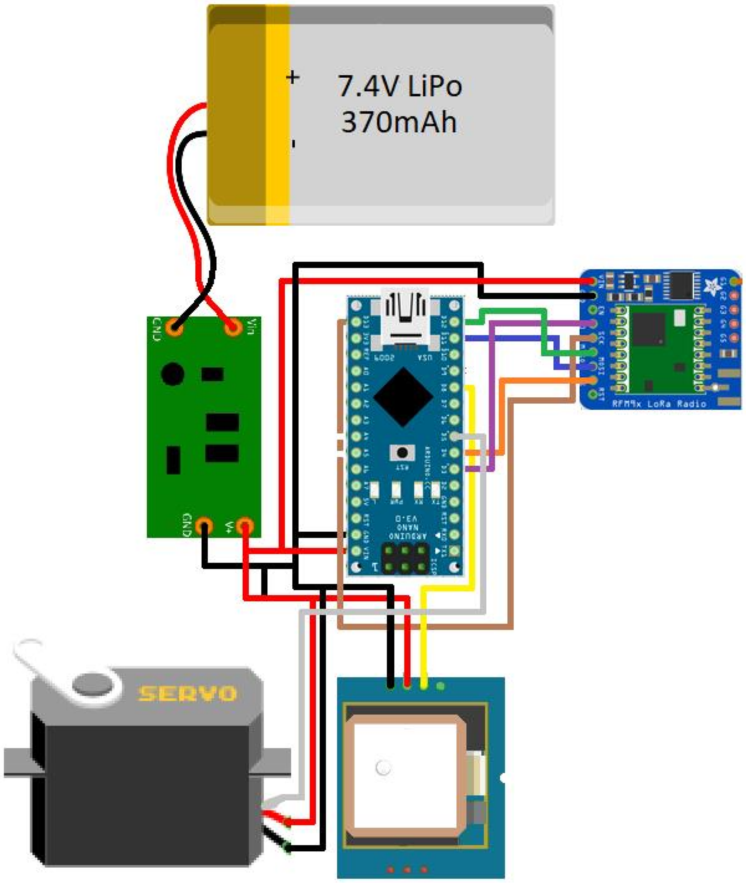


Figure 5-48 Retention bay arduino wiring diagram. The Strattologger and deployment electronics are powered via their own dedicated circuit

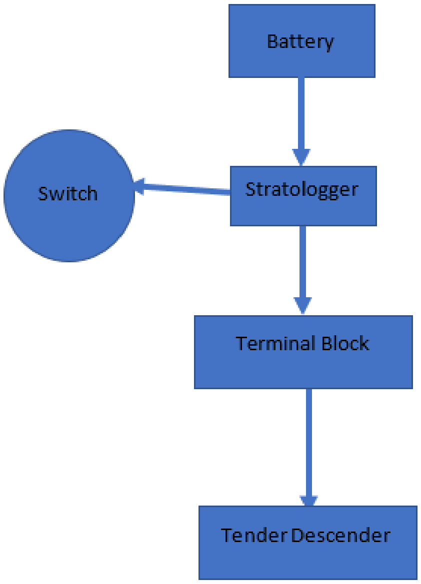


Figure 5-49 Tender Descender connection flow chart, equivalent to the backup Strattologger circuit.

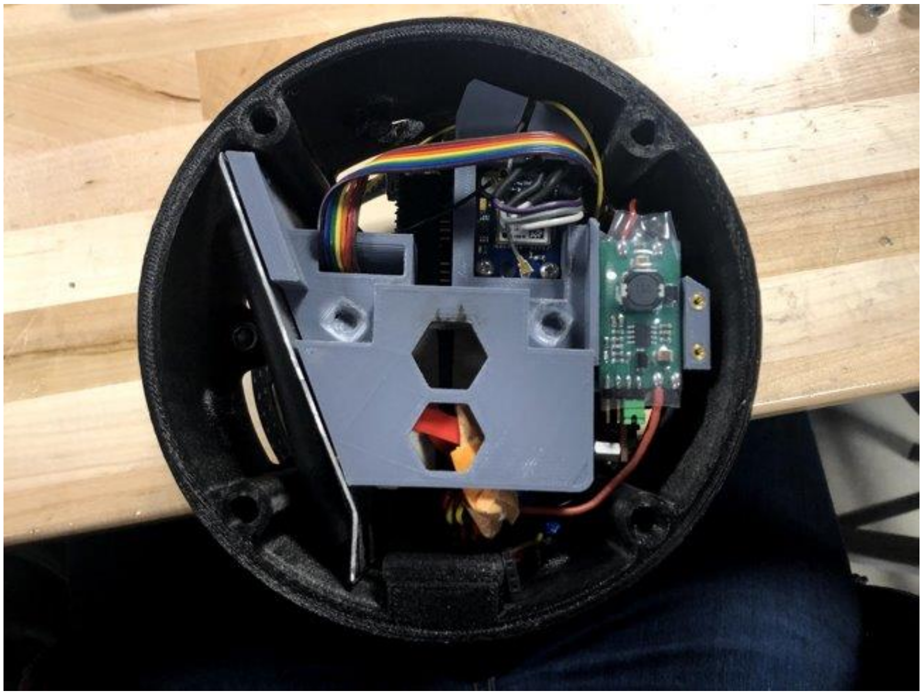


Figure 5-50 Retention Electronics Bay

5.5 BALLAST SYSTEM

The addition of a ballast system does not impact the stability of the launch vehicle, but it does affect the apogee of the launch vehicle by adding or removing weight. The ballast system is incorporated into the electronics bay build and is located 6in above the electronics bay at the center of mass of the launch vehicle, as seen in Figure 5-51. In order to help the launch vehicle, reach an apogee as close as possible to the target apogee, the amount of ballast must be adjustable. The ballast system is designed to hold 0.125in steel rings, as seen in Figure 5-52, in a cylindrical region that is 1.625in tall, which allows a maximum ballast weight of 2 lbs. When the full 2 lbs of ballast is not necessary, the region will remain filled by using foam rings in place of steel so that nothing moves during flight. The ballast will be located at the rocket's center of gravity and the steel rings will be added from the center outwards such that the rockets center of gravity is not affected by the addition of weight.

Figure 5-51 Ballast system with delrin rings.

Figure 5-52 Ballast system with delrin and steel rings

The amount of weight required to achieve the target apogee was determined to be zero. There was no ballast used during the test full scale flight due to additional weight in the nosecone and upper airframe due to payload in order to remain safe. Figure 5-53depicts the state of the ballast inner tube on the right with no ballast rings, as it was during Full scale flight.

Figure 5-53 Ballast system attached to electronics bay.

5.6 RECOVERY SYSTEM

The recovery system for our rocket consists of three parachutes that act to slow down the launch vehicle on descent. The design calls from a drogue parachute and two main parachutes. Since all parachutes are stored in the middle airframe, when the drogue parachute deploys at apogee, the two main parachutes remain closed outside of their respective airframes using a Jolly Logic Chute Release when ejection occurs. At 700 feet a Tinder Rocketry Tender Descender L2 will deploy and detach the upper body from the lower body, at 600 feet the Chute Releases will release the main parachutes so they may begin to open. This is timed so that at approximately 550 feet, the main parachute for the upper airframe and lower airframe will be fully deployed. The purpose of the drogue parachute is to slow the descent rate of the launch vehicle so that when the main parachutes are deployed, they do not experience a high impulse. The predicted ground hit velocity for the lower section is 15.28ft/s, and 15.27 ft/s for the upper section.

The drogue parachute is 36 inches, the upper main is 120 inches, and the lower main is 132 inches, all produced by Spherachutes, chosen due to their robust construction and customization options. The canopy is made from ripstop nylon (67 g/m 2). All shock cord connections are steel quick links and eye bolts. The shock cord connections are organized to prevent any parachutes from overlapping while fully laid out, as well as to prevent any interference between bodies when suspended from any of the three parachutes. The two bodies of the rocket are connected via 610 inches of shock cord, with a Tender Descender on the bulkhead of upper airframe. Measured from the upper airframe, the drogue parachute is at 205 in and the lower main is at 426 in, the another 184 in to the lower bulkhead. The upper main is on a second length of shock cord, not connected to the Tender Descender, tied to the upper airframe bulkhead measuring 10 in. The shock cord will be 1-inch tubular nylon shock cord.

Figure 5-54 Tender Descender Release

Figure 5-55 Jolly Logic Chute Release

Figure 5-56 Jolly Logic Chute Release (side view). Jolly logics are connected in series for redundancy, such that only one needs to function correctly to release the parachute.

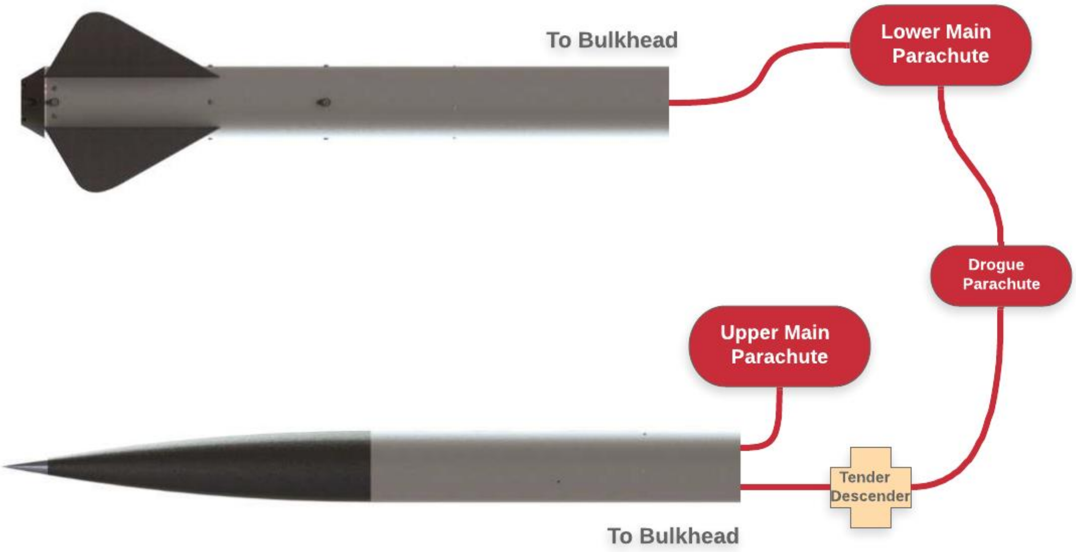


Figure 5-57 Recovery Assembly Overview

Component	Mass (lb)
Nose Cone	1.75
Payload	9.92
Upper Airframe	2.34
Upper Coupler	.613

Upper Main Parachute	1.28
Middle Airframe	2.97
Primary Electronics Bay	4.92
Recovery Harness	2.51
Drogue Parachute	.104
Lower Main Parachute	1.28
Lower Airframe	2.56
Fins	1.17
Fin Can	3.53
Motor	7.6
Total	42.5

Table 5.3 Mass Statement

5.6.1 Recovery Electronics

Electrical elements include a total of three altimeters. There are two located in the E-bay which are the main and backup altimeters. The third is located in the retention bay and is responsible for sending a signal to the Tender Descender at 700 feet. Each altimeter has its own switch and the switches for payload are in development. There are three battery connectors, one for each altimeter plus one for each of the four Arduinos making a total of seven connectors. The rocket has two transmitters, which are located in the upper airframe retention bay and in the lower airframe E-bay. The current LOS (line of sight) range is 2 km with a power of 100 mW (20 dBm).

The recovery system has no observed issues during operation alongside devices that generate electromagnetic fields such as the transmitters, there are also aluminum shielding plates surrounding the antenna for additional protection.

5.6.2 Redundancy Features

The recovery system contains multiple redundancies to ensure a safe descent and recovery of the launch vehicle and the included subsystems. There is a backup Strattologger with its own separate power source to ensure redundancy in the ejection and separation charges. Following the nominal flight profile of the vehicle, the first flight-redundancy involves the apogee deployment charge. The primary Strattologger altimeter sends a deployment charge signal to the deployment charges upon reaching apogee. The backup Strattologger sets off a second deployment charge at apogee plus one second. The next redundancy is to ensure separation of the upper and lower airframes with the use of a Tinder Rocketry Tender Descender L2 (Figure 5-54**Error! Reference source not found.**). The physical design of the Tender Descender ensures that even if there is a failure to detach from one airframe, the other airframe will detach from the Tender Descender, separating the airframes. Identical to the main ejection charge redundancy, the primary Strattologger sends a deployment charge signal to the Tender Descender at 600 ft AGL. The secondary Strattologger sends a deployment charge signal to the Tender Descender one second after sensing the launch vehicle has reached 600 ft AGL. Main parachute deployments are independent of all other electronics, minimizing points of failure. Deployment altitude is set on Jolly Logic Chute Releases that are configured together in a way (Figure 5-56) such that either of the main parachutes may experience a failure in one of their two Jolly Logic Chute Releases and the parachute will deploy nominally.

5.6.3 Recovery Diagram

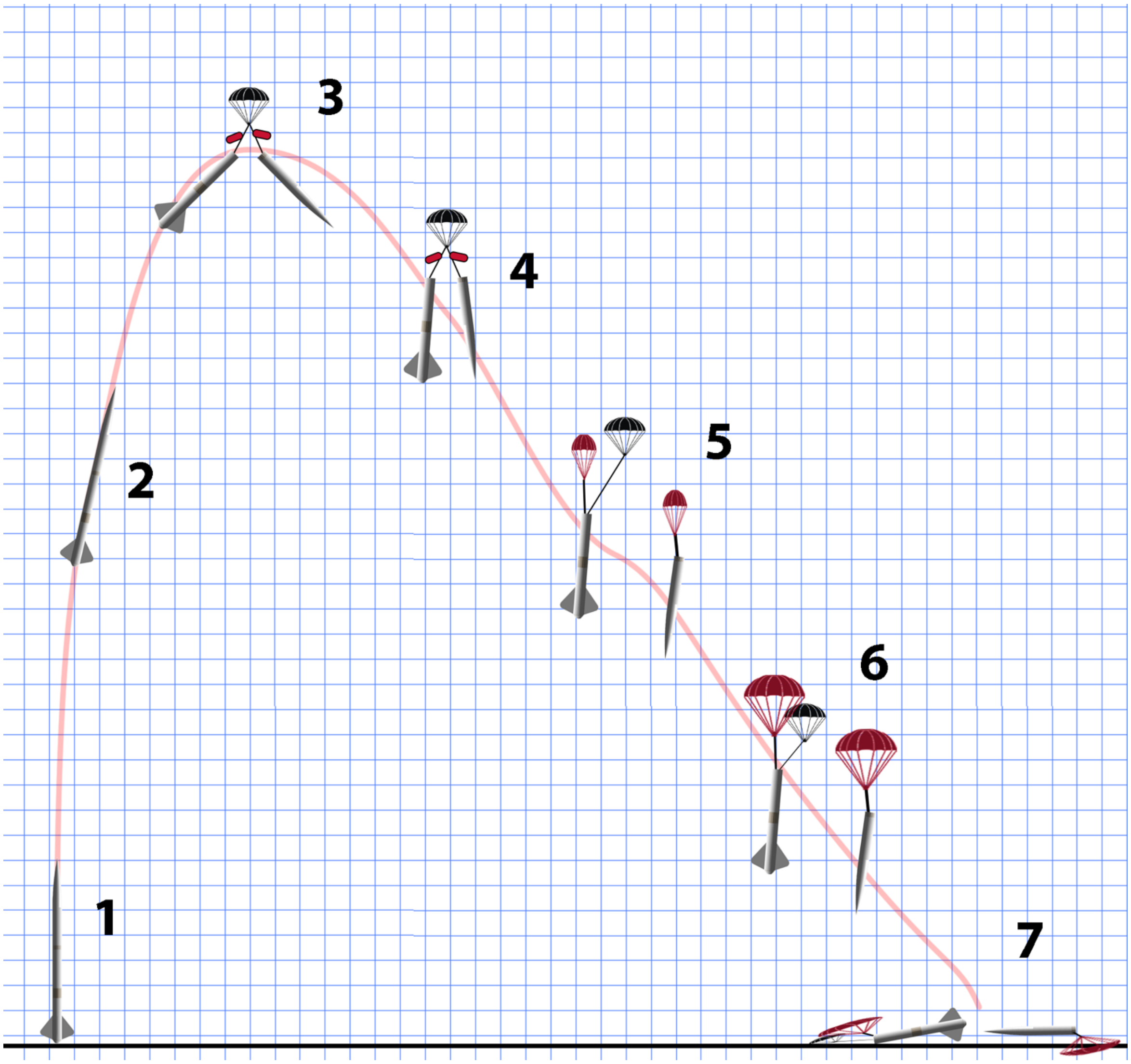


Figure 5-58: Recovery Diagram

Figure 5-59 From left to right, Stage 1/2, Stage 3, and Stage 4.

Figure 5-60 From left to right, Stage 5, Stage 6, Stage 7.

Number	Stage	Description
1	Rail	Rocket is secured to the rail mount until launch.
2	Launch	The engine ignites and the rocket ascends towards apogee.
3	Apogee, drogue, body separation	Upon reaching apogee, a black powder charge will separate the upper and lower airframes but keep them attached via shock-cord. This separation allows the drogue chute to deploy.
4	Drogue descent	The rocket's descent is slowed to maintain a safe velocity proceeding main parachute deployment.
5	Airframe separation and main parachute deployment	The Tinder Rocketry Tender Descender L3 detaches the upper and lower airframes from one another and the Jolly Logic's release, beginning main parachute opening.
6	Main parachute descent	Both upper and lower main parachutes open fully, allowing a safe downward velocity for both body segments to land.
7	Land	The rocket airframes complete their descent, landing separately.

Table 5.4 Recovery Stage Table

5.6.4 Parachute Calculations

Though there are many resources online to calculate the radius necessary for a parachute, it is important to understand the process. The University of Idaho walks through the process of calculating this in their "Sizing a Parachute" article online. When the launch vehicle starts from rest at apogee, it will accelerate until terminal velocity at which point it will have no acceleration, therefore a net force of zero. At that point, the weight (W) will be equal to the drag force (D).

$$W = D\ [1]$$

The equation for weight, in general form, is mass (m) multiplied by acceleration (a). In this case, we know the acceleration is just the force of gravity on the system.

$$W = ma = mg \; [2]$$

The drag force is calculated using the coefficient of drag (C_d) of the parachute, the area of the parachute (A_p), density of the fluid (ρ), in this case air, and relative velocity of the fluid (v).

$$D = \frac{1}{2} C_d A_p \rho V^2 \; [3]$$

Knowing the equation for area of a circle, we can equate the equations for weight (2) and drag (3) and solve for the radius of the parachute.

$$r = \sqrt{\left(\frac{2mg}{\pi C_d A_p \rho V^2}\right)} \; [4]$$

5.7 MISSION PERFORMANCE PREDICTIONS

5.7.1 Motor Selection

The vehicles launch day motor is the L1050-BS. It is a 45.6%L motor, 19.13” in length and 2.95” in diameter, and is manufactured by Cesaroni Technologies Incorporated. Its specifications can be seen in Table 5.5, and its thrust curve can be seen in Figure 5-61.

Motor Specifications	L1050
Average Thrust	235.2 lb
Class	45.6% L
Delays	Plugged
Designation	3727 L1050-P
Diameter	2.95 in
Length	19.13 in
Letter	L
Manufacturer	CTI
Name	L1050

Peak Thrust	271.7 lb
Propellant	APCP
Propellant Weight	1774 g
Thrust Duration	3.56 s
Total Impulse	837.9 lbf-s
Total Weight	3447.7 g
Type	Reloadable

Table 5.5: CTI L1050 Motor Specifications

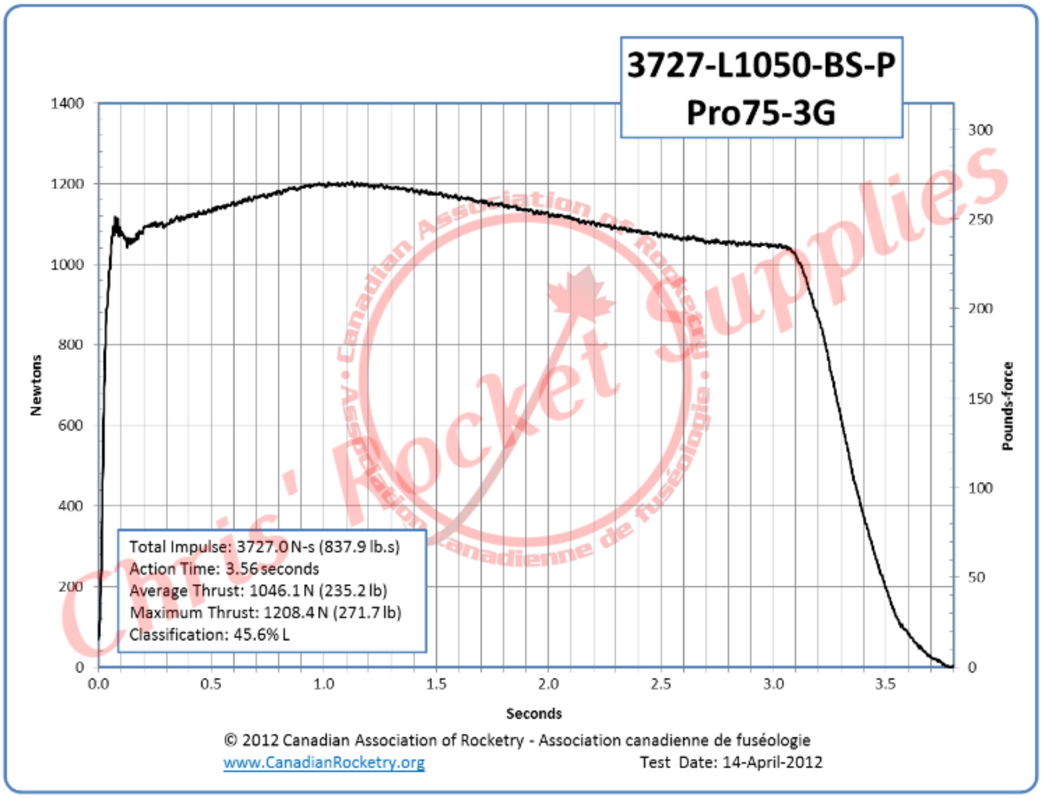
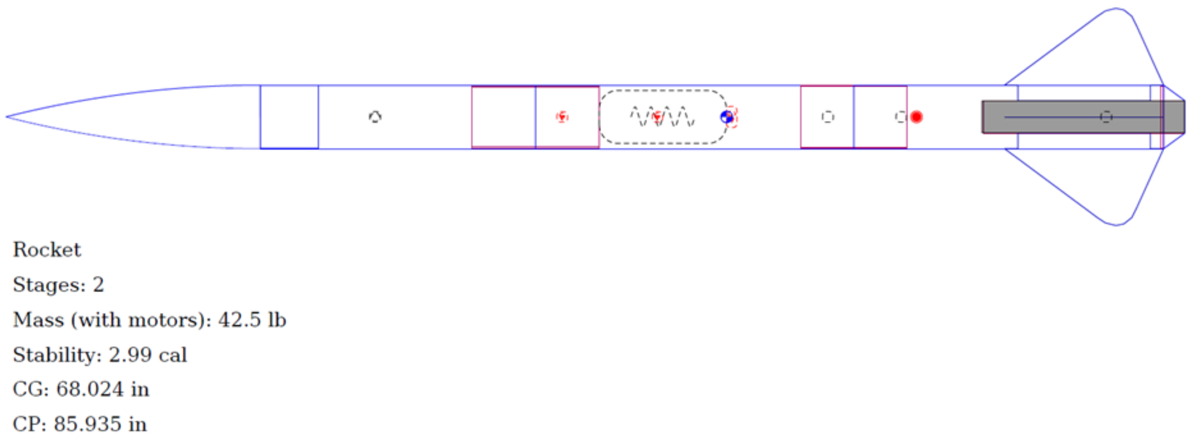


Figure 5-61: L1050-BS Thrust Curve

5.7.2 Design and Flight Profile

The launch vehicle is simulated in OpenRocket 15.03 to determine altitude and flight profile. The simulations were performed with zero ballast and flying on a CTI L1050. Simulation locates CG at 68.024 in from the nosecone tip, with the CP 85.935 in from the nosecone tip, as shown in Figure 5-62: Open Rocket Design Summary, the total length of the launch vehicle is 111 in. Also shown, is the launch vehicle mass at 42.5lb, with the Upper Airframe and Nosecone section weighing 15.7 lb, and the lower airframe weighing 19 lb without motors.



Rocket

Stages: 2

Mass (with motors): 42.5 lb

Stability: 2.99 cal

CG: 68.024 in

CP: 85.935 in

Figure 5-62: Open Rocket Design Summary

Figure 5-63 shows the predicted altitude, vertical velocity, and vertical acceleration throughout flight. Key flight parameters are shown in Table 5.6.

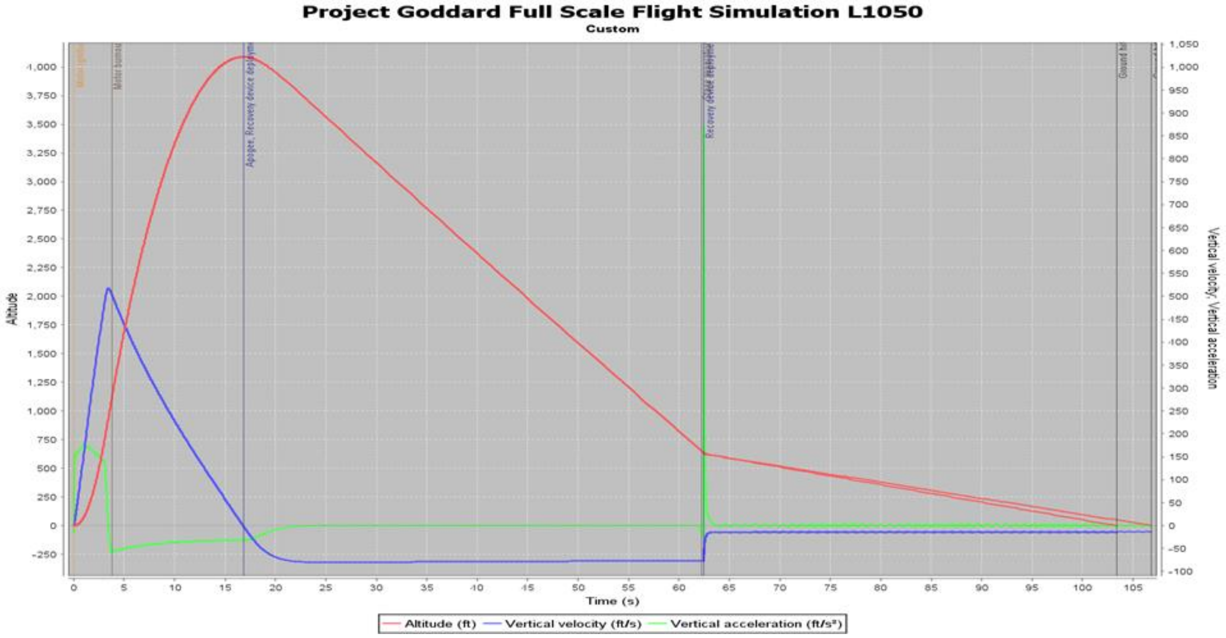


Figure 5-63: Full Scale Flight Simulation with L1050

Motor	L1050
Apogee	4088 ft
Maximum Velocity	517 ft/s
Maximum Acceleration	177 ft/s^2
Time to Apogee	16.8 s
Flight Time	107 s
Rail Exit Velocity	56.3 ft/s
Stability at Rail Exit	2.60 cal
TWR at Rail Exit	6.0:1

Table 5.6: Key Predicted Flight Parameters

Figure 5-64 details the launch vehicle's stability during the flight from rail exit to apogee.

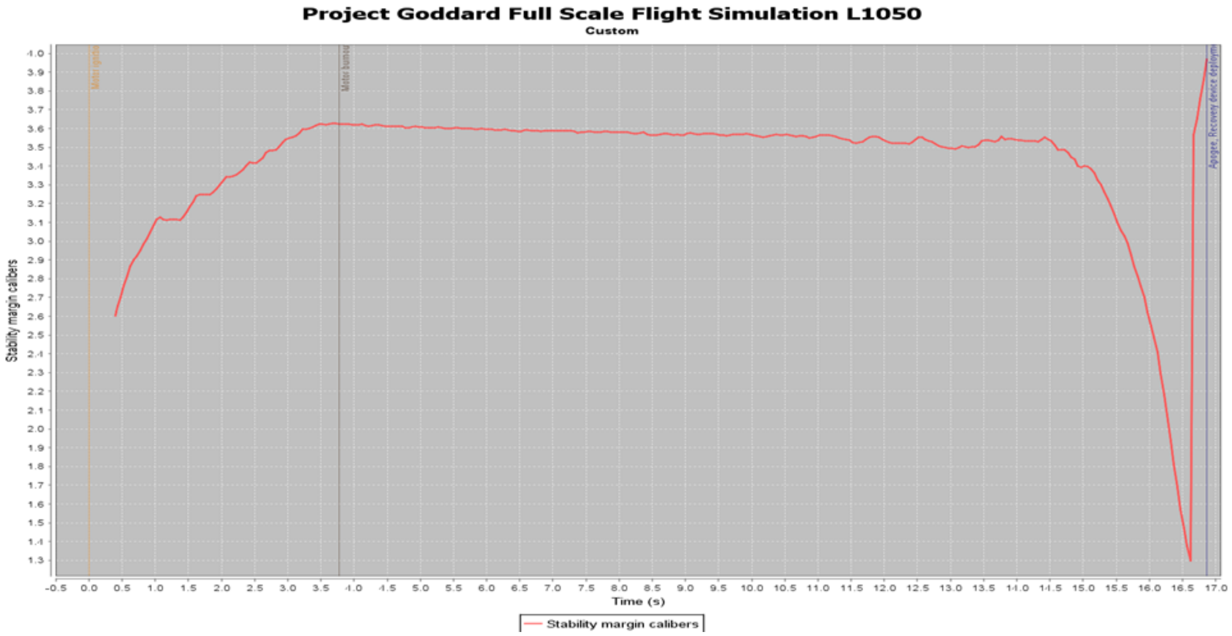


Figure 5-64: Full Scale Flight Stability with L1050

5.7.3 Descent Predictions

Descent predictions were made using both simulations in OpenRocket 15.03 and using a custom MATLAB program. The function and operation of this custom program is more thoroughly described in the CDR.

The descent predictions from Open Rocket are shown in Table 5.7.

Descent Time (Lower Section)	89.7 s
Descent Time (Upper Section	86.2 s
Kinetic Energy on Landing (Lower Section)	73.0 ft-lbs
Kinetic Energy on Landing (Upper Section)	54.1 ft-lbs

Table 5.7: Open Rocket Descent Predictions

The descent predictions from the algebraic solver in our custom MATLAB program are shown in Table 5.8. In addition, drift estimations are shown in Figure 5-65 and Table 5.9. To remain within the specified 2500ft drift on launch day, the wind must not exceed 19.5 mph.

Descent Time (Lower Section)	87.4 s
Descent Time (Upper Section	87.4 s
Kinetic Energy on Landing (Lower Section)	69.0 ft-lbs
Kinetic Energy on Landing (Upper Section)	57.0 ft-lbs

Table 5.8: Algebraic Descent Predictions

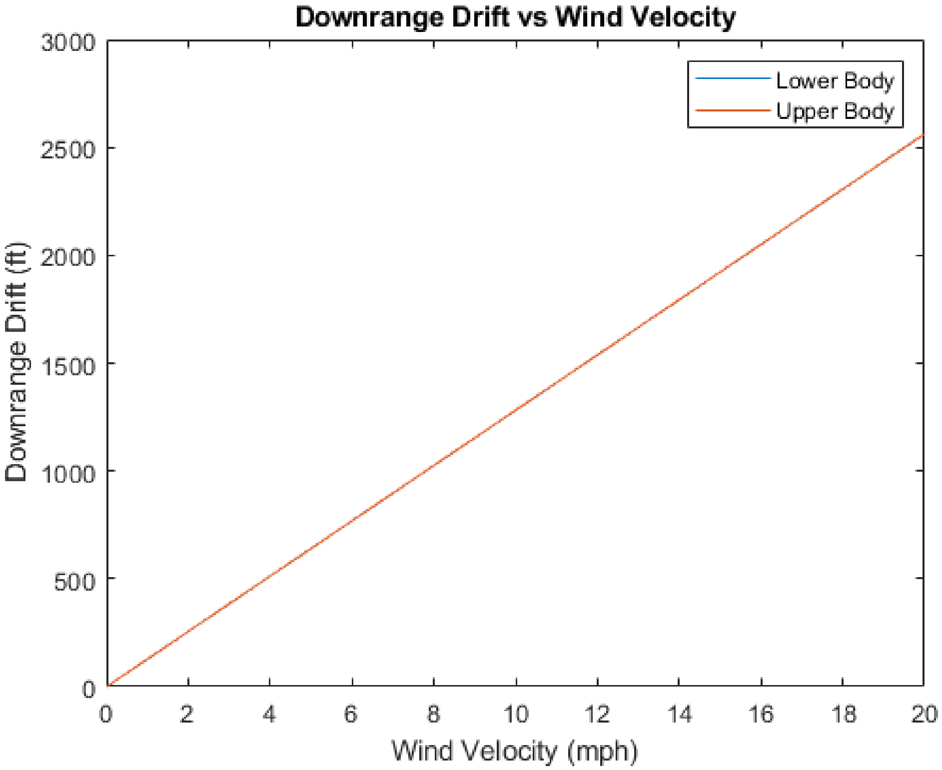


Figure 5-65: Downrange Drift vs Wind Velocity

Lower Body Drift (20 mph)	2563 ft
Upper Body Drift (20 mph)	2563 ft

Table 5.9: Drift Predictions at 20 mph wind

The descent predictions from the differential solver in our custom MATLAB program are shown in Table 5.10. In addition, plots of position, velocity, and acceleration during descent can be seen in Figure 5-66, Figure 5-67, and Figure 5-68.

Descent Time (Lower Section)	89.2 s
Descent Time (Upper Section	88.9 s
Kinetic Energy on Landing (Lower Section)	68.9 ft-lbs
Kinetic Energy on Landing (Upper Section)	56.9 ft-lbs

Table 5.10: Differential Descent Predictions

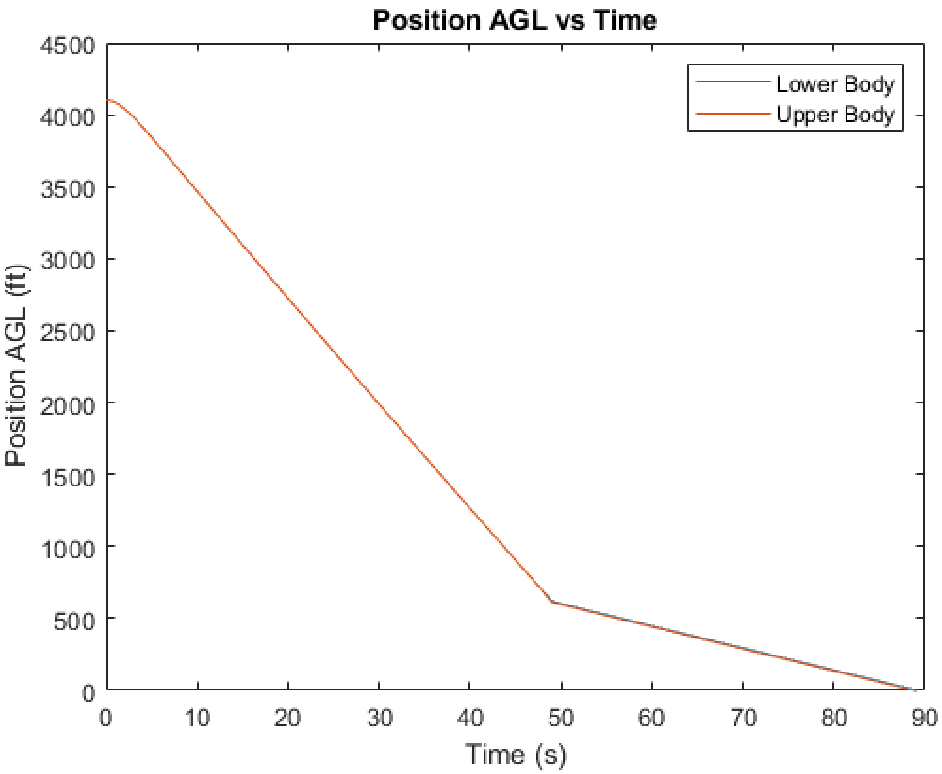


Figure 5-66: Descent Position AGL vs Time

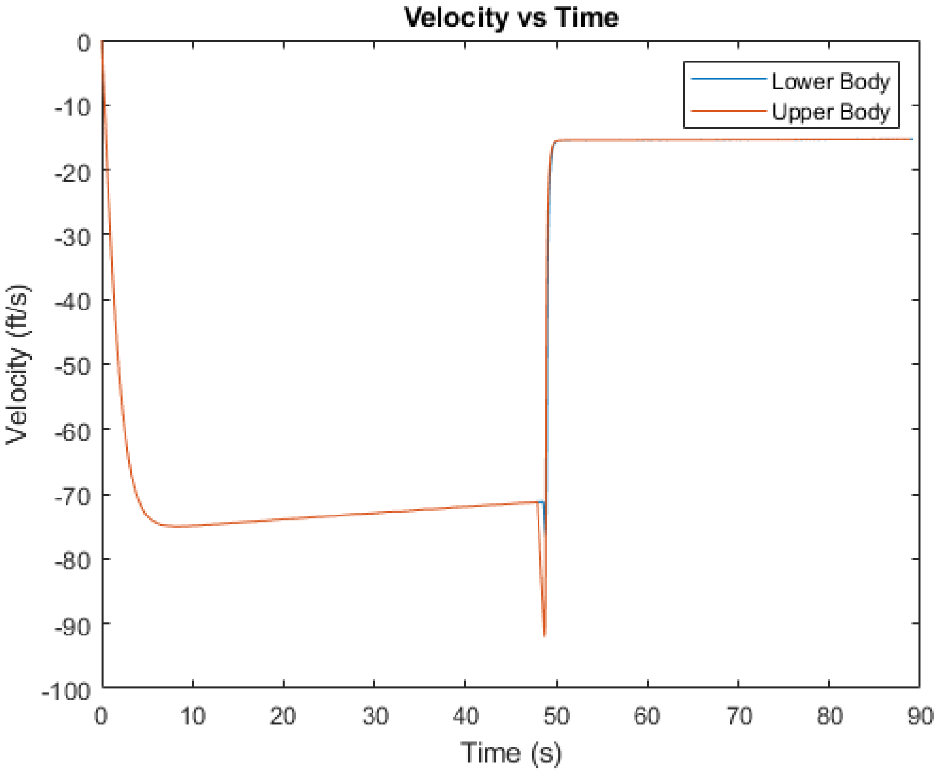


Figure 5-67: Descent Velocity vs Time

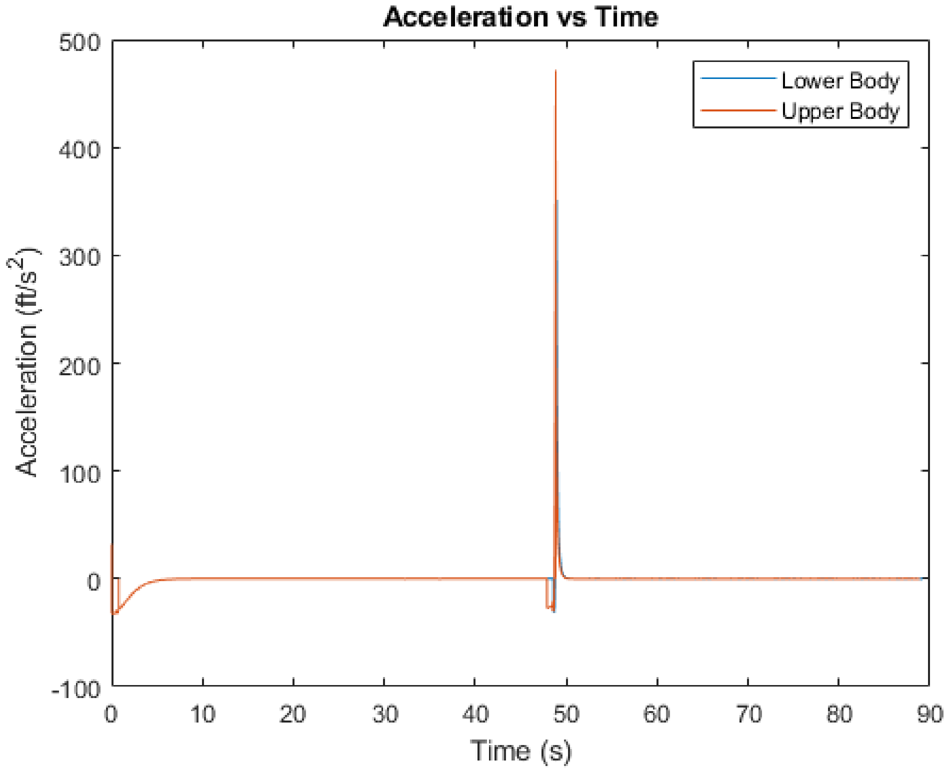


Figure 5-68 Descent Acceleration vs Time

Minimal variations are noticed from each of the descent calculation methods, though the MATLAB differential method has proven to produce the most accurate results in the past, and those will be the official predictions listed.

6 PAYLOAD CRITERIA

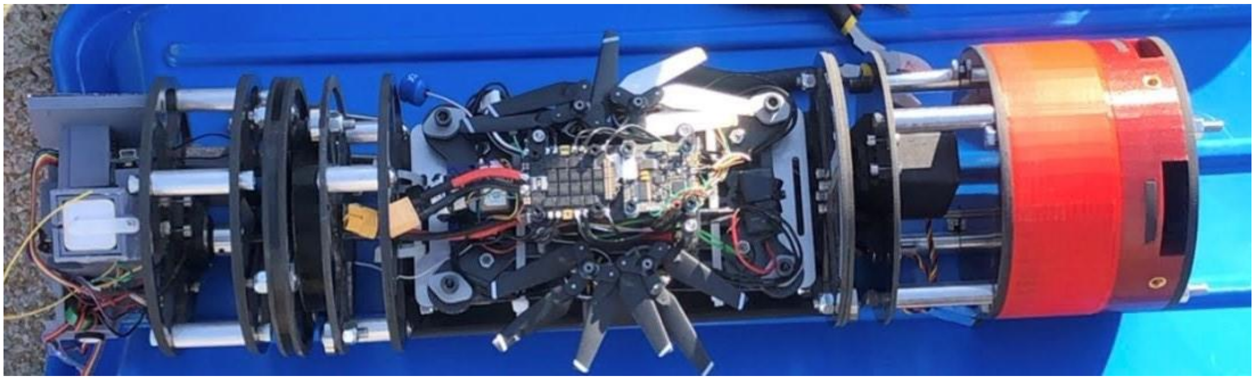


Figure 6-1 Assembled payload at fullscale test launch.

6.1 DEPLOYMENT

The payload deploys in 4 stages consisting of Driving, Stabilizing, Rotating, and Lifting (DSRL). Driving consists of the leadscrew driving the sled and nosecone assembly out of the nosecone. During Stabilization the stabilizing fins extend from the nosecone and prevent any rotation of the nosecone. The sled is then rotated to the upward orientation in the rotating phase. Finally, during the lifting phase, the scissor lift is engaged, and the UAV is deployed.

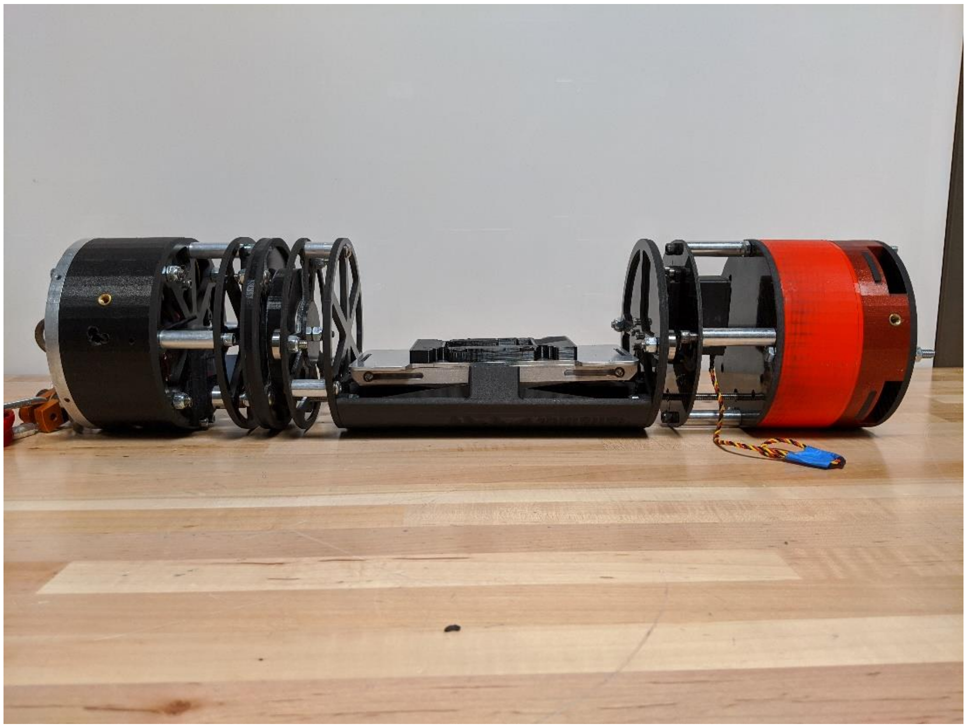


Figure 6-2 Deployment Stage 1. Undeployed.

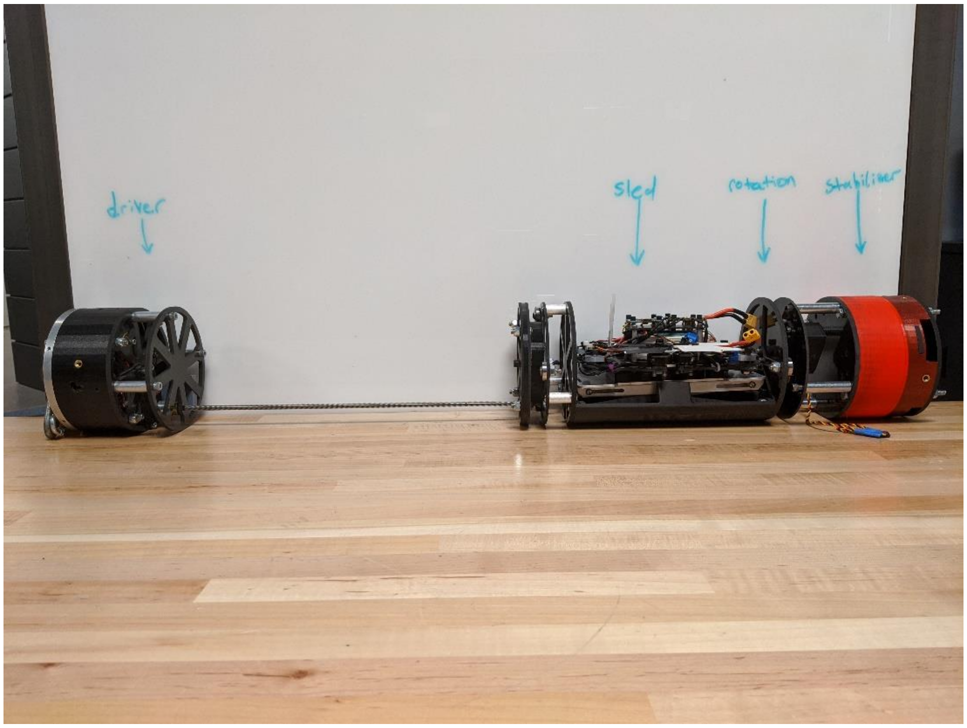


Figure 6-3 Deployment Stage 2. Lead screw extended.

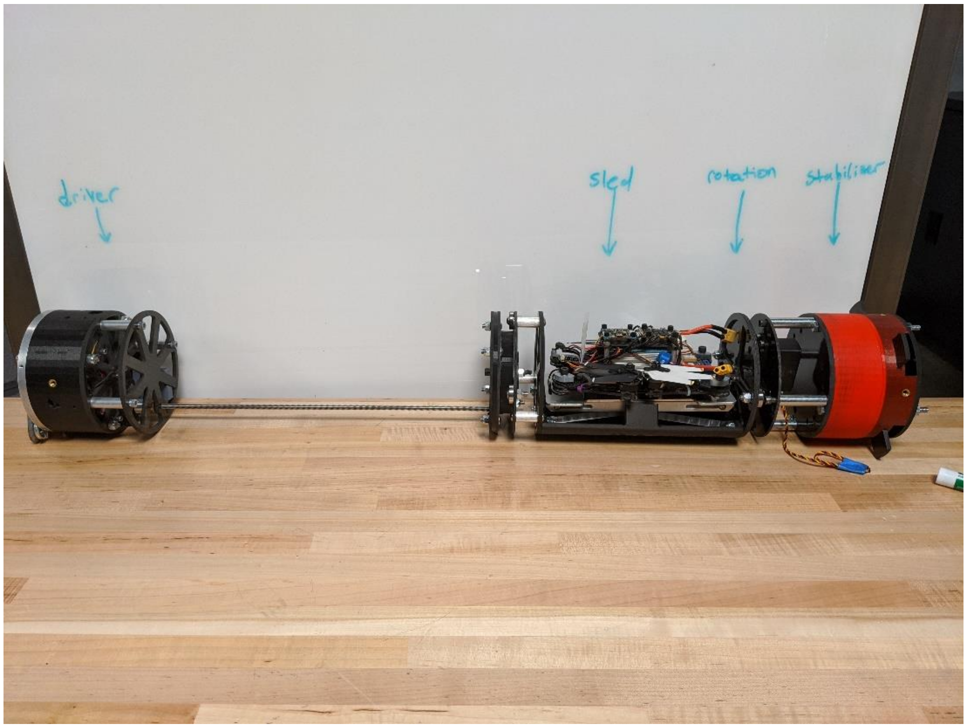


Figure 6-4 Deployment Stage 3. Flaps extended.

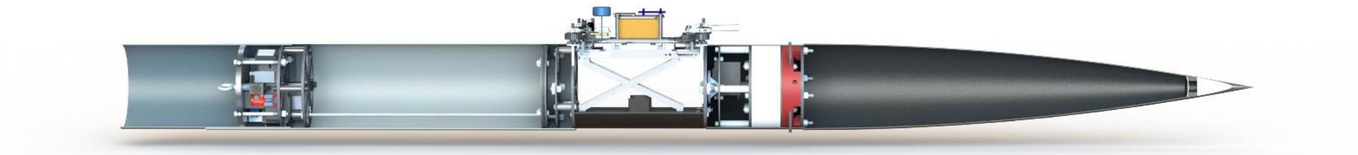


Figure 6-5 Deployment Stage 4. Scissor lift extended.

6.2 RETENTION

6.2.1 Lead Screw Driver

The payload retention driver is based around a Hitec HS-785HB continuous rotation servo and a ¼”-20 Acme threaded lead screw. The leadscrew translates the payload sled out of the airframe, when driven by the servo, so that it can be rotated into the correct orientation for the UAV to lift off. In the rear of the retention section is a 0.25” 6061-T6 aluminum bulkhead which allows for the shock cord to be secured through two eye bolts for redundancy. Attached to the bulkhead via four ¼”-20 bolts is a 3d-printed interstage with threaded inserts to secure it to the airframe. The interstage also has four holes which allows for airflow, as it houses electronics such as an altimeter which needs accurate pressure readings. These electronics are detailed in Payload Electronics. On the other side of the interstage, there are two 0.197” carbon fiber plates which allow for the servo to be mounted securely.

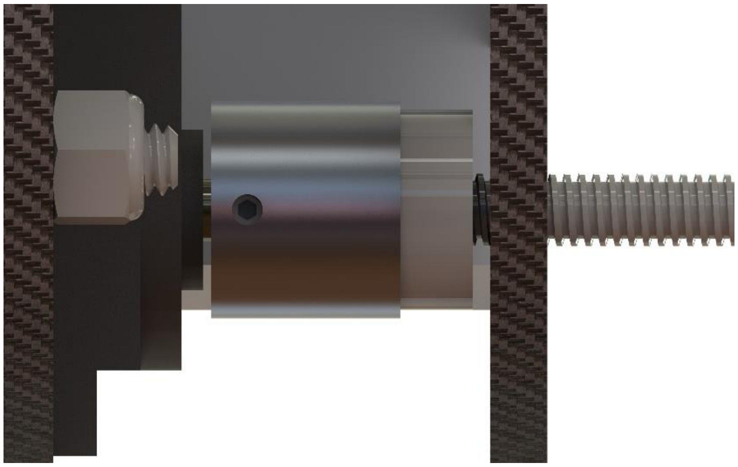


Figure 6-6 Leadscrew adapter side view

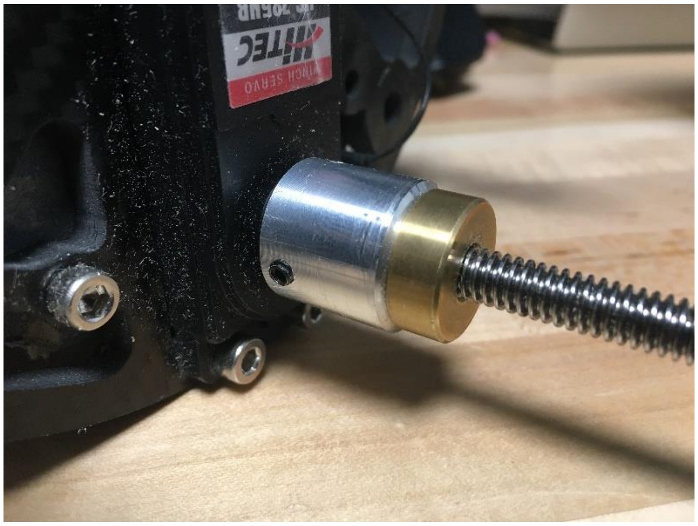


Figure 6-7 Leadscrew adapter

To attach the servo to the lead screw, there is a custom-designed part which allows a pre-made part (which adapts the ¼"-20 lead screw to a 9/16”-18 external thread) to be adapted to the 24-tooth spline on the servo. Originally, a HSA5MM Servo to Shaft Coupler was used in place of the custom part. However, the HSA5MM relied on a singular set screw and friction to hold the leadscrew in place which did not provide adequate grip strength to secure the leadscrew in place.

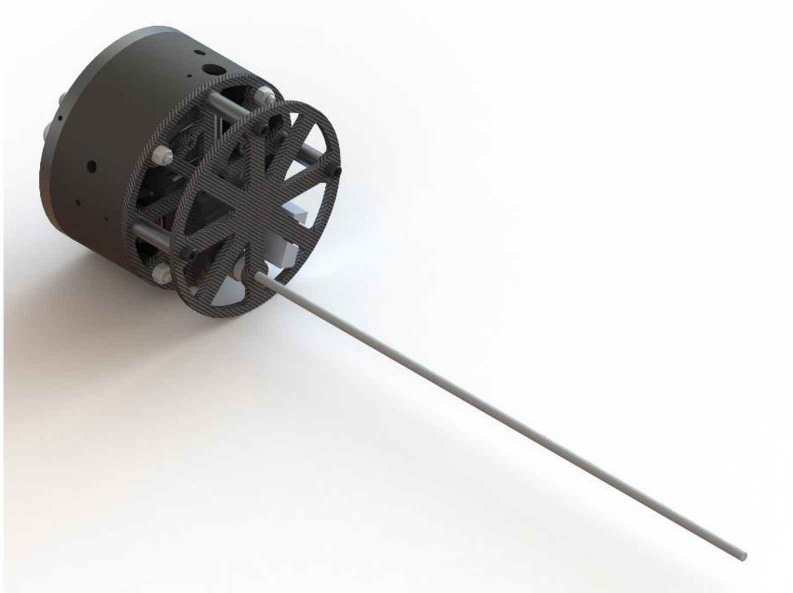


Figure 6-8 Payload retention driver isometric view

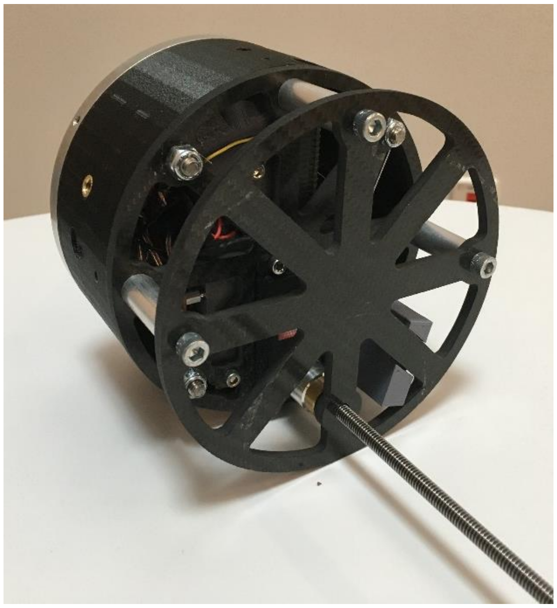


Figure 6-9 Payload retention driver assembled

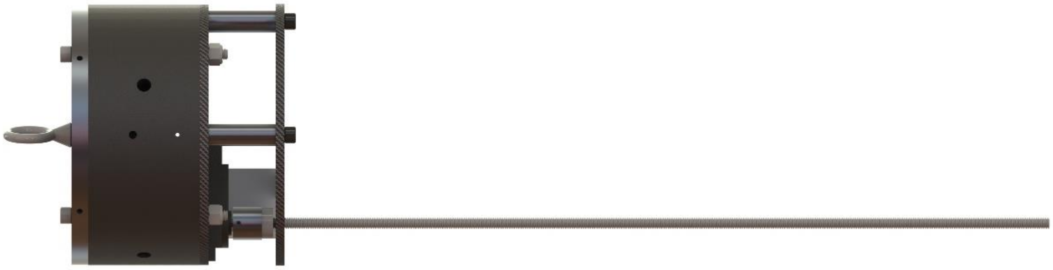


Figure 6-10 Payload retention driver side view

Figure 6-11 Payload retention driver assembled side view

Figure 6-12 Payload retention bulkhead rear view

6.2.2 Rotation System

From CDR the design of the Retention rotation system hasn't changed. The design for the payload rotation mechanism consists of one 5mm and two 3mm circular carbon-fiber plates in series, mounted to the interior of the nosecone. The aft plate provides structural support and serves as a mounting location for the rotation system's electronics and battery. The mid plate mounts the rotation mechanism, a HITEC HS-785HB Servo with a circular horn hub. This servo was chosen due to its output power and torque, and due to its use in the payload retention system's lead screw. 2" aluminum standoffs connect the aft and mid plates. The fore plate is the rotation plate, mating the servo horns to the payload sled. Bearings mounted around the perimeter of this plate allow for smooth rotation within the nosecone. Carbon fiber was chosen for the plates due to its strength and weight, as the assembly must be able to endure flight and impact forces but not significantly weigh down the nose of the rocket.

Testing of the mechanism has shown the servo is perfectly capable of rotating the whole assembly without problem and with tuning of the control loop can quickly orient the system upright.

6.2.3 Stabilization System

From CDR the retention stabilizer underwent a large change after problems occurred during testing. The first major change was replacing the mounting of the aft bulkhead inside of the nosecone from epoxy to bolts as concerns over the quality of the bond we raised. The new system bolts through the nosecone shoulder and as such small slots were cut in the upper airframe to allow the bolts to slide cleanly in and out of the airframe for deployment

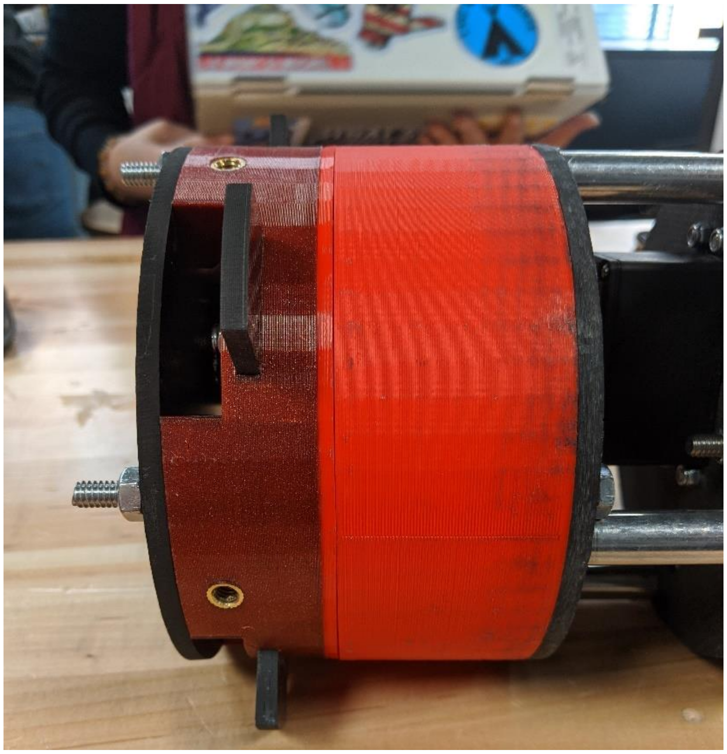


Figure 6-13 Assembled stabilization system.

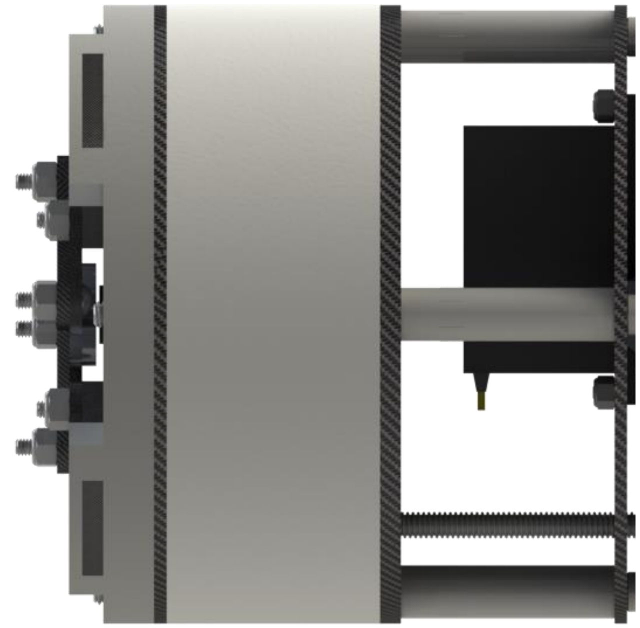
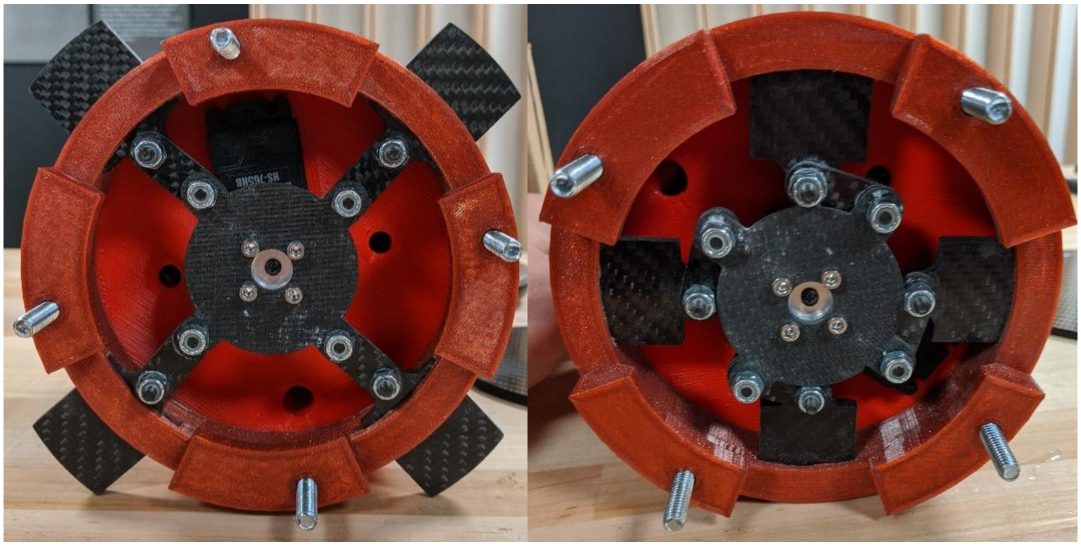


Figure 6-14 Side view of stabilization system

The second major change involved the slider crank linkage driving the stabilizer. The old linkage was difficult to actuate by the servo and concerts over sticking in the linkage lead to a switch to a new slider crank mechanism with better motor transmissions angles.



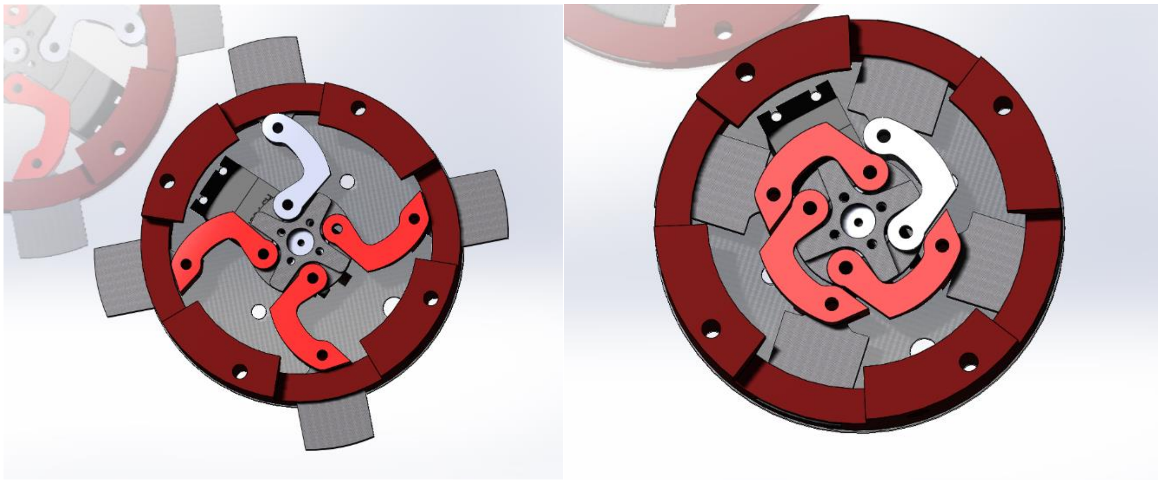


Figure 6-15 Interior of current stabilization system (Top) and interior of revised stabilization system (Bottom)

6.2.4 Payload Sled

Before the first test launch, a design error was found in the scissor lift. Originally, the lift was designed as a two-degree-of-freedom kinematic chain powered by two linear actuators. A decision was made to remove a linear actuator due to its questionable reliability, which then necessitated a change to the scissor lift's design. Due to kinematics oversight and an errant mate in our Solidworks model, this problem went undiscovered until about a week before the team's first test launch. The old design had too many degrees of freedom to act as a scissor lift, and a change in design based around already-fabricated parts was required.

First, the supporting elements must be changed to produce the proper movement. Whereas the old design had four brackets with pin connections for the scissor lift and actuator, the new design has two brackets with pin connections and two brackets with slot connections. A similar change had to be made to the scissor lift rails, which had already been machined by a sponsor. To change the rails, two holes were drilled and tapped on either end of one slot. These holes are used to attach a 3-D printed part that turns that slot into a pin.

Next, the moving parts must be changed to make the assembly fit in. In the old design, the linear actuator was supposed to rotate as the lift extended. In the new design, the actuator is fixed in a horizontal position. The linear actuator is attached to a custom 3dprinted clevis, which in turn drives a link in the scissor. The links also had to be redesigned and lightened for the linkage to fold flat. The moving links changed from a straight design to a Z-shaped one. Lightening patterns were also added to the links to help offset the weight accrued during the scissor lift redesign.

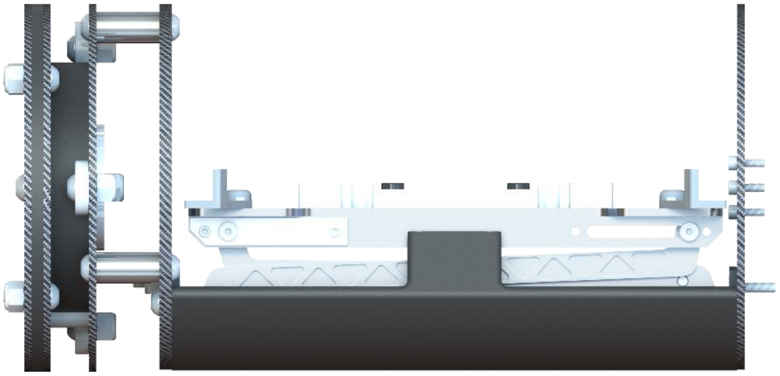


Figure 6-16 Retracted retention sled.

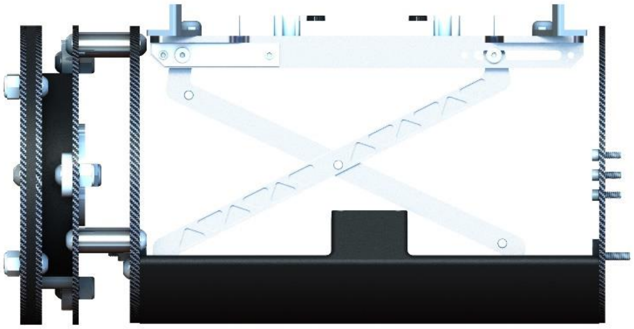


Figure 6-17 Extended retention sled.

6.2.5 Electronics

The payload retention electronics bay acts as a secondary electronics bay by housing the Arduino Nano, LoRa transceiver, GPS board, LiPo battery, Strattologger, continuous rotation servo, BEC servo power regulator, rotary switch, and transceiver dipole ¼ wave antenna. The Arduino Nano, LoRa transceiver, and GPS board broadcast data and listen to ensure the landing is confirmed before activating the lead screw motor and deploying the UAV. This system utilizes the same two cell LiPo battery that also powers the electronics bay. A change made from the CDR is the use of a BEC to regulate power to the servo motor rather than the original buck-boost converters. This change was made due to previously experienced malfunctions with the converters and the more adequate use of a BEC to drive an indictive load such as a motor. The only difference between the payload retention electronics bay and the orientational system bay is the replacement of the GPS with a gyroscope. This component senses the orientation of the retention system in order to properly command its servo motor to adjust the UAV sled for deployment.

The primary electrical components are mounted to a 3D-printed framework except for the transceiver antenna. To avoid radio wave interference, the transceiver antenna is separated from the other electrical components by a 1/32-inch thick piece of sheet metal.

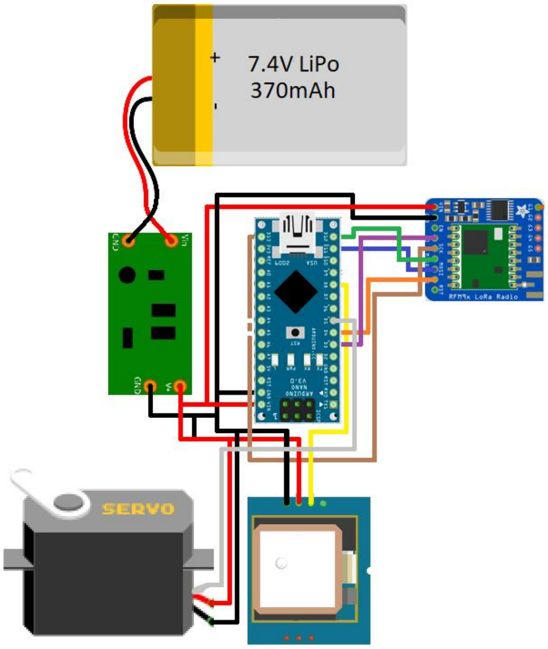


Figure 6-18 Retention Bay wiring schematic: including Arduino, GPS, LoRa, Continuous Rotation Servo

6.3 UAV

6.3.1 Structure

Figure 6-19 UAV Flight Test

6.3.1.1 Main Body:

The main body of the UAV is comprised of 2mm and 3mm thick carbon fiber plate because of its high strength and stiffness to weight ratios and our ability to waterjet parts from it without doing composite lay up for each part. A few defects occurred during the waterjetting process, but we are still confident in the performance of the parts. The defects encountered were delamination of the carbon sheets. There was also some partial cuts where the waterjet started making an incorrect cut but was stopped before it could slice through the entire sheet. Because of the size of the electronics, the central portion of the fuselage was able to be trimmed down to an “I” shape, saving space and weight. This saved space allows the propeller arms to fold alongside the body without adding additional width, something to avoid with a fixed rocket body diameter.

6.3.1.2 Arm Deployment:

The propeller arms will be held in place by mechanisms discussed in the retention system section. This mechanism holds the arms in place during flight as well as unfolds them upon landing. Upon reaching the appropriate opening angle, locking pins slide from above into holes in the arms under spring force and prevent rotational motion of the arm. The UAV arms are lubricated against the UAV body with a Teflon dry lubricant to reduce the necessary spring force.

6.3.1.3 Landing Legs:

The landing legs have been modified from the previous design of base mounted standoffs to posts mounted on the UAV’s folding arms. Mounting the landing posts to the UAV’s arms serves to not only expand our landing footprint for better stability but also to retain the arms while inside the rocket. Mounting the landing legs onto the UAV arms also mitigates interference with the electronics or retention system, a possibility with body-mounting landing legs.

6.3.2 Propulsion

To complete the mission, the need to create a compact and efficient power package for our quadcopter led us to use folding propellers in our design. Based loosely from the propeller designs of the DJI Spark, we have designed and 3D-printed a larger reinforced central hub through which the propellers attach. The propellers use a press-fit pin which allows free rotation of the blades between their folded and fully extended positions. Super glue is used to ensure the pins don’t slip out if the press-fit isn’t secure enough. The blades automatically fold to their extended position when rotated through wingtip vorticity forces.

We were forced to construct our own propeller central hubs because most folding propellers are designed for smaller UAVs which have a smaller diameter output shaft from their electric motors. Through testing of both a bi-prop and tri-prop design, we have concluded that the tri-props are a much better choice due to their ability to be easily balanced as well as provide more thrust. Below shows a graph of thrust vs throttle percentage of our propeller design. We also completed some destructive testing with the prop-centers. Our original tri-prop design self-destructed at 80% throttle. After observing the points where the part fractured, we decided to print the prop centers out of NylonX filament rather than PLA. This increased the structural strength of the prop centers. We also thickened the top layer of the centers such that the part was symmetrically strong. After these improvements, the prop-centers were able to throttle to 100%. The Props were also exposed to multiple instantaneous and sudden spin tests so we could be certain of their ability to endure impacts. With finalized prop-centers, we were able to verify thrust to weight ratio. A high thrust to weight ratio is necessary for the quadcopter’s maneuverability. From the graphs below, we have determined that there is no need to upgrade our batteries, motors, or propeller sizes. This was confirmed in a test flight where the quadcopter remained hovering airborne for 6 minutes.

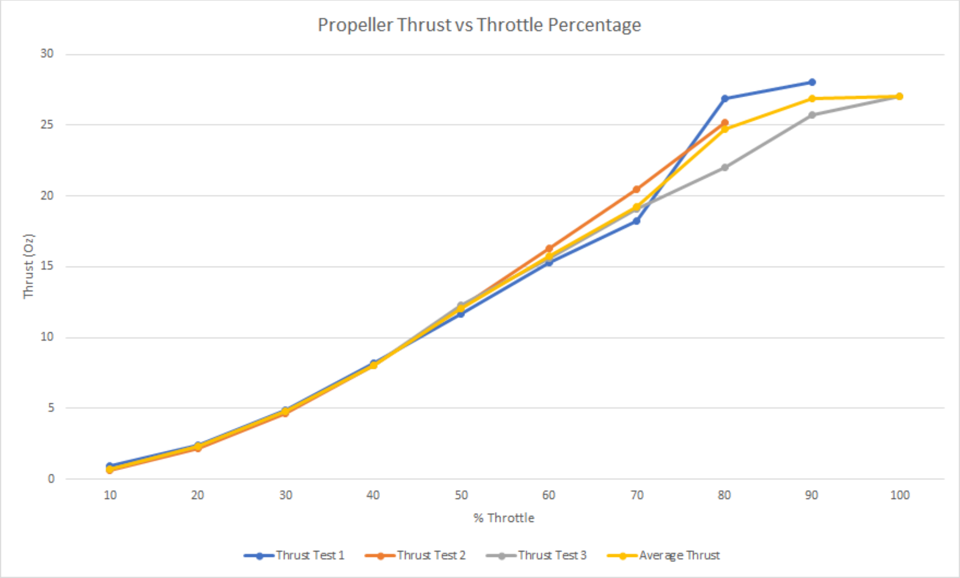


Figure 6-20 Propeller thrust to throttle percentage.

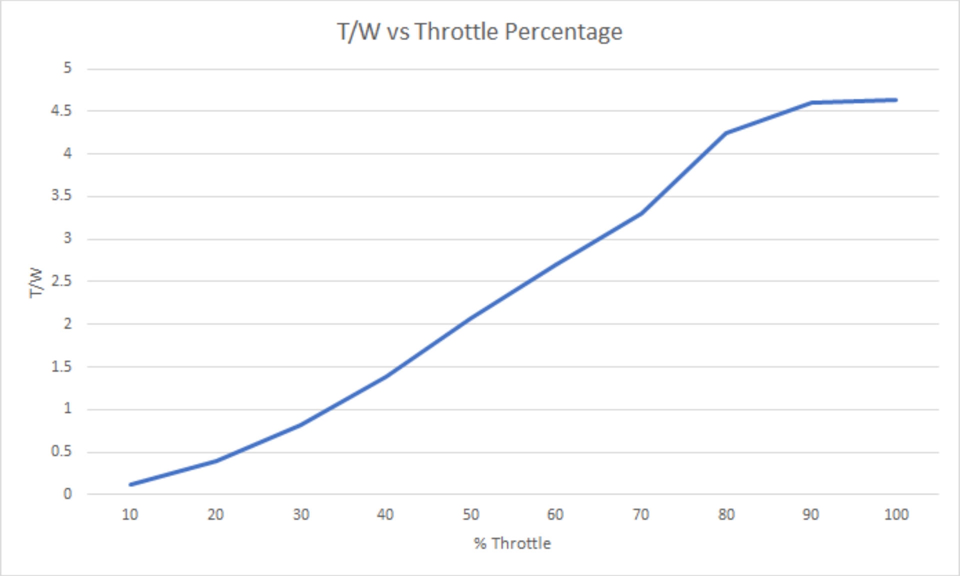


Figure 6-21 Thrust to weight over throttle percentage.

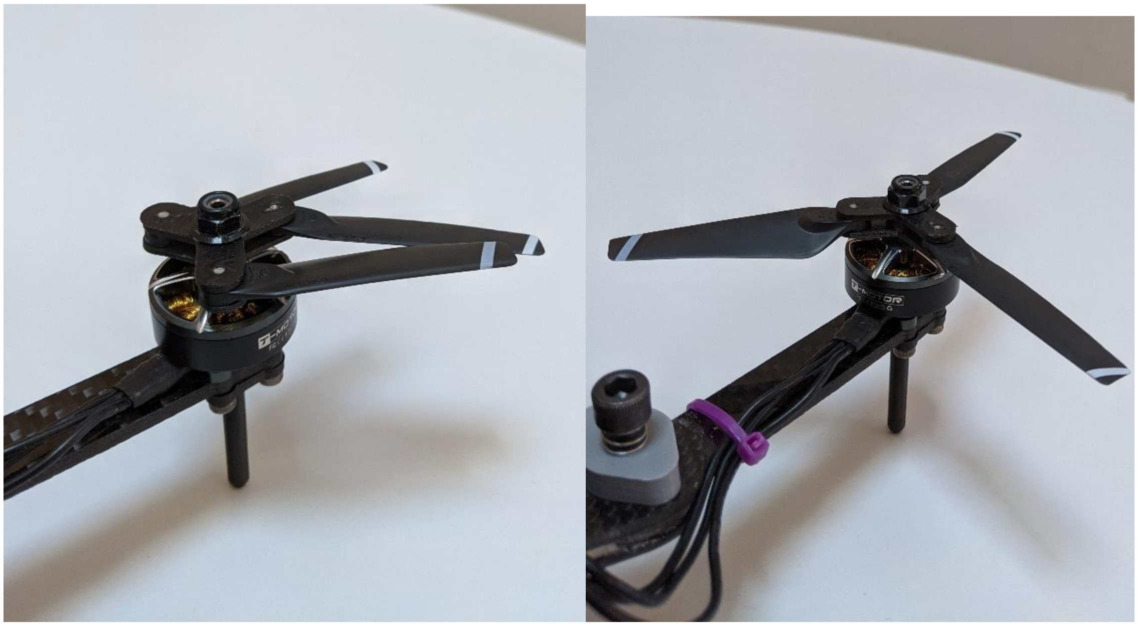


Figure 6-22 From left to right, the propellers in retained configuration and in flight configuration.

6.3.3 Electronics

6.3.3.1 Payload Control and Movement

Our UAV's electronics package consists of Diatone Mamba F722S Stack-506 50A Dshot1200 6S ESC as our flight computer. It is running BetaFlight software for programming, controls, and telemetry. The flight computer is used to control the UAV and perform the auxiliary function of as soil-sampling. The flight computer is be controlled through a FrSky X4R-SB - 3/16 Channel Receiver w/ SBUS connected to a FrSky Taranis X9 Lite RC Transmitter used by the pilot. We have changed to a new receiver on the UAV due to the need for an auxiliary SBUS channel which was missing from our previous receiver. Powering the quadcopter is a Pyro Drone 1500 Mah 4S Lipo battery. This powers all the electronics on the UAV as well as the four T-Motor F40 Pro III 2400Kv Racing Motors which are used to lift the UAV. Our thrust tests mentioned in the UAV Propulsion document illustrates that our current electronics package is capable of flying the mission.

6.3.3.2 Pilot Assistance Information

The Matek SAM-M8Q GPS Module is able to provide location telemetry throughout the mission to our ground station. We have implemented a First-Person View or FPV camera system into our UAV. This provides the pilot with an increased level of control and perspective of the UAVs operation. We are using the RunCam Micro Eagle - Lumenier Edition as our camera. The TBS Unify Pro32 HV 5.8GHz Video Transmitter (MMCX) and XILO AXII MMCX 5.8GHz Antenna (RHCP) are used to process and transmit the video captured by the camera back to the UAV's operator.

6.3.3.3 Programming

All essential programming of the quadcopter has been finished and the UAV now has flight and soil sampling capabilities. Pre-arming and Arming safety switches as previously mentioned in CDR are fully finished and the auxiliary motor for the soil-sampling mechanism is programmed onto the transmitter for the pilot's control.

Figure 6-23 UAV Electronics

Sources (Left to Right, Top to Bottom):

T-Motor F40, Diatone Mamba, SAM-M8Q U-blox, FrSky

FrSky, RunCam, TBS Unify, XILO

Figure 6-24 UAV during flight test.

7 DEMONSTRATION FLIGHT

On February 22nd, the WPI USLI team conducted the first test launch of their full-scale launch vehicle at the Lake Winnipesaukee High Powered Rocketry Launch Site, with an elevation of 600ft. This test launch was conducted to fulfil the requirements for the Vehicle Demonstration Flight. The temperature at the launch site was 25 degrees Fahrenheit, and winds were steady around 10 mph, with gusts of up to 15 mph.

The vehicle was flown on a motor consisting of one grain from a CTI L1050-BS, and two grains from a CTI L851. This motor configuration is discussed in Section 7.1. No ballast was flown on the launch vehicle, and the final payload was not flown. In its place, an unfinished payload consisting of all major components was assembled into the upper airframe and nosecone sections. Our team’s official target altitude is 4750 ft.

Figure 7-1: Launch Vehicle just after ignition

The launch vehicle flew to an apogee of approximately 2600 ft, compared to an expected apogee of 4161 ft. At apogee, the rocket separated as planned, however the Tender Descender also separated, allowing the nosecone and upper airframe to fall without drogue to 650ft, when the main chute deployed. The lower section of the rocket was recovered as expected, falling under drogue to 650ft, when the main parachute opened.

7.1 MOTOR AND FLIGHT OBSERVATIONS

The first observation to note arrives from the assembly of the motor. The CTI L1050-BS is a 3 grain Blue Streak motor. During assembly it was noted that only one grain was blue, however this was not expected to be an issue at the time, as all packaging had indicated the motor was an L1050-BS.

Figure 7-2: Motor Assembly and Grains

The motor was assembled under the supervisor of Jason Nadeau, our team mentor and the president of the Lake Winnipesaukee High Powered Rocketry Club. Jason previously worked for Animal Motor Works (AMW), the company the motor was purchased from, and due to his supervision, we have determined it to be unlikely that an assembly error caused the underperformance of our launch vehicle.

During the flight itself, the most obvious inconsistently arrives from the color of the motor. As can be seen in Figure 7-1 and Figure 7-3, the motor burnt with an orange/white color, rather than the expected bright blue.

Figure 7-3: Launch Vehicle just after lift-off

From further video analysis after the launch, the motor was noted to burn for close to 4.2s. An L1050 has an expected burn time of 3.56s, while an L851, which is also a white motor has an expected burn time of 4.3s.

The launch vehicle itself was noted by experienced members in attendance to have an unexpectedly low acceleration. Just after exiting the launch rod, the vehicle turned into the wind to an unknown angle. As discussed later, this complicated data analysis, but is notable as a likely result of the slower launch.

7.2 FLIGHT DATA

7.2.1 Predicted Flight Profile

Simulating the rocket on a L1050 using measured weights and launch day conditions results in an expected apogee of 4161ft.

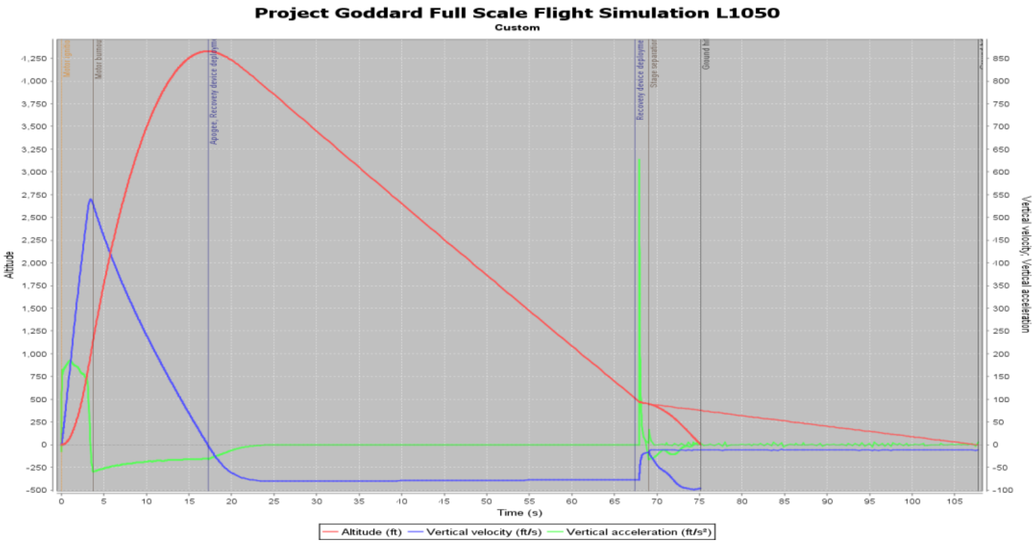


Figure 7-4: L1050 Full Scale Flight Simulation

Looking at the data for the initial stage of flight, the position, velocity and acceleration of the rocket can be plotted as follows:

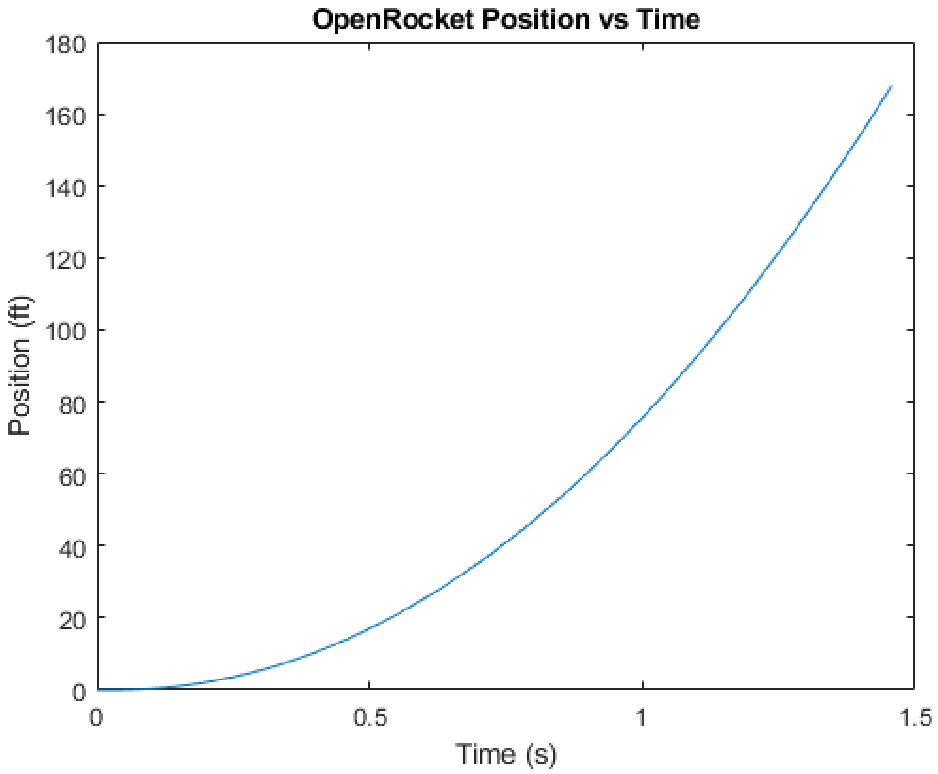


Figure 7-5: OpenRocket Position vs Time

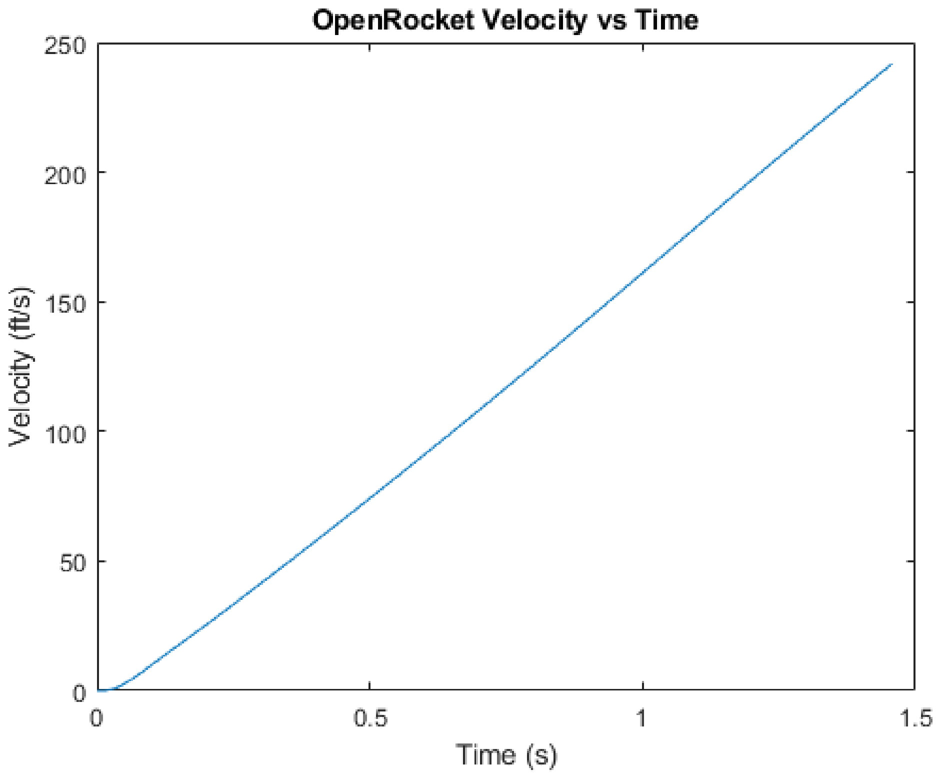


Figure 7-6: OpenRocket Velocity vs Time

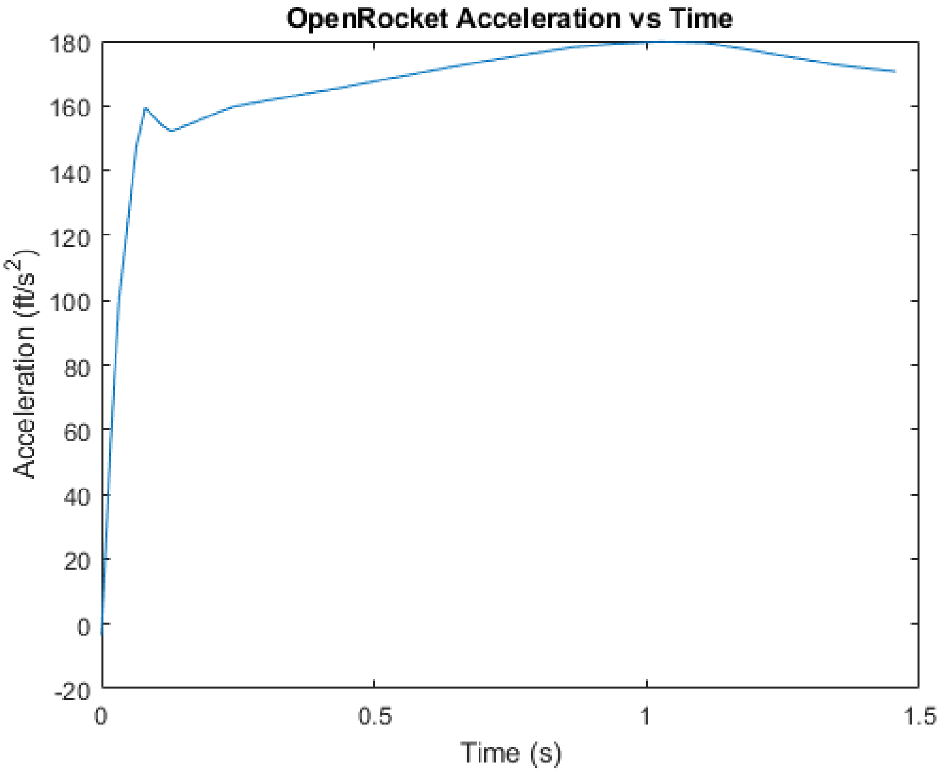


Figure 7-7: OpenRocket Acceleration vs Time

7.2.2 Altimeter Data

Flight data was primarily collected from two redundant StrattologgerCF Altimeters located in the electronics bay of the launch vehicle. Each Strattologger was tested in a vacuum chamber prior to flight to verify functionality, and both had previously flown successfully on our subscale vehicle. The Strattologgers output the following apogees:

	Apogee (ft)
Primary Strattologger	2586
Backup Strattologger	2590

Table 7.1: Reported Apogees

The altimeter data was then smoothed using MATLAB and plotted to determine position, vertical velocity and vertical acceleration throughout the flight.

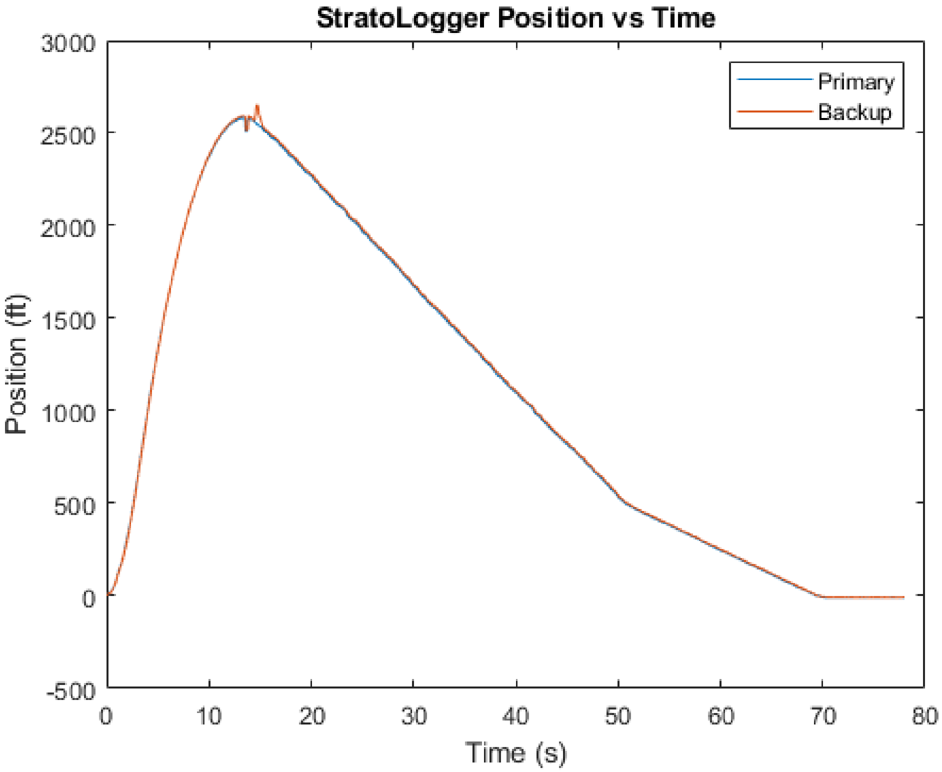


Figure 7-8: Strattologger Position vs Time

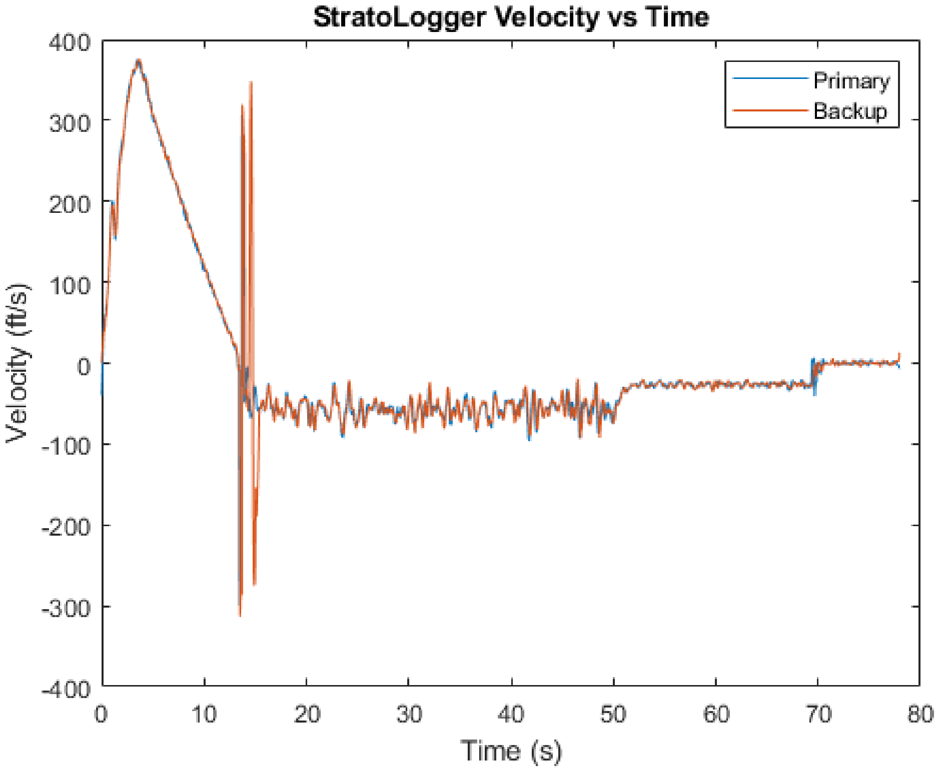


Figure 7-9: Strattologger Velocity vs Time

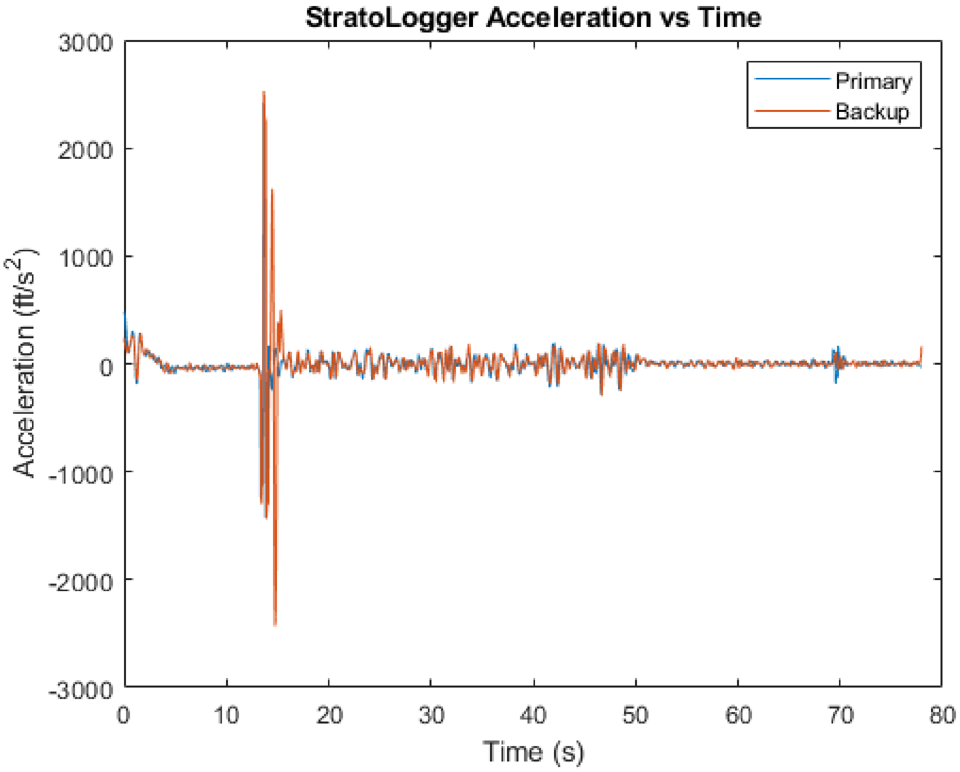


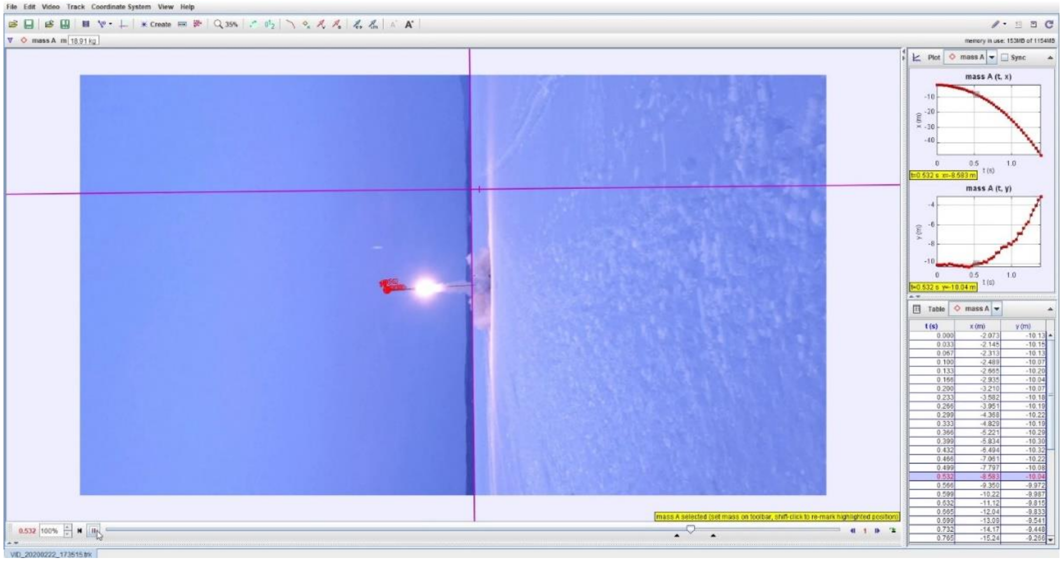
Figure 7-10: Strattologger Acceleration vs Time

The data from each Strattologger largely matches, suggesting reliable data collection. However, as the Strattologger measures only altitude data, the velocity and accelerations listed only apply to the vertical components of each. The launch vehicle turned to an unknown angle just after takeoff, and without knowing this angle it is impossible to determine total velocity and acceleration.

For this reason. velocity and acceleration data are only accurate for the first phase of flight, before the turn. Due to variability in launch detection, and the relatively small displacements experienced by the rocket in this time, it is necessary to supplement the Strattologger data.

7.3 TRACKER DATA

As a supplement, a video of the initial stage of the launch was analyzed in Tracker, an open source video analysis and modeling tool.



t (s)	x (m)	y (m)
0.000	-2.073	-10.13
0.033	-2.145	-10.15
0.067	-2.313	-10.13
0.100	-2.489	-10.07
0.133	-2.665	-10.20
0.166	-2.935	-10.04
0.200	-3.210	-10.07
0.233	-3.582	-10.18
0.266	-3.951	-10.19
0.299	-4.368	-10.22
0.333	-4.829	-10.19
0.366	-5.221	-10.29
0.399	-5.834	-10.30
0.432	-6.494	-10.32
0.466	-7.061	-10.22
0.499	-7.797	-10.08
0.532	-8.583	-10.04
0.566	-9.350	-9.972
0.599	-10.22	-9.987
0.632	-11.12	-9.815
0.665	-12.04	-9.833
0.699	-13.09	-9.541
0.732	-14.17	-9.448
0.765	-15.24	-9.266

mass A selected (set mass on toolbar, shift-click to re-mark highlighted position)

Figure 7-11: Tracker Video Analysis

To estimate position during the initial stage of flight first a coordinate system was defined based on the "horizon" of the lake in each frame of the video. Similarly, a scale was set in each frame defined by the length of the rocket itself. The rocket's position was tracked only along the x-axis shown in Figure 7-11, as during the first stage of flight it's position only changes vertically.

Having set a scale and coordinate system, the tip of the rocket was marked at each frame, and a position vs. time graph was generated. This data was again smoothed in MATLAB and differentiated to determine velocity and acceleration.

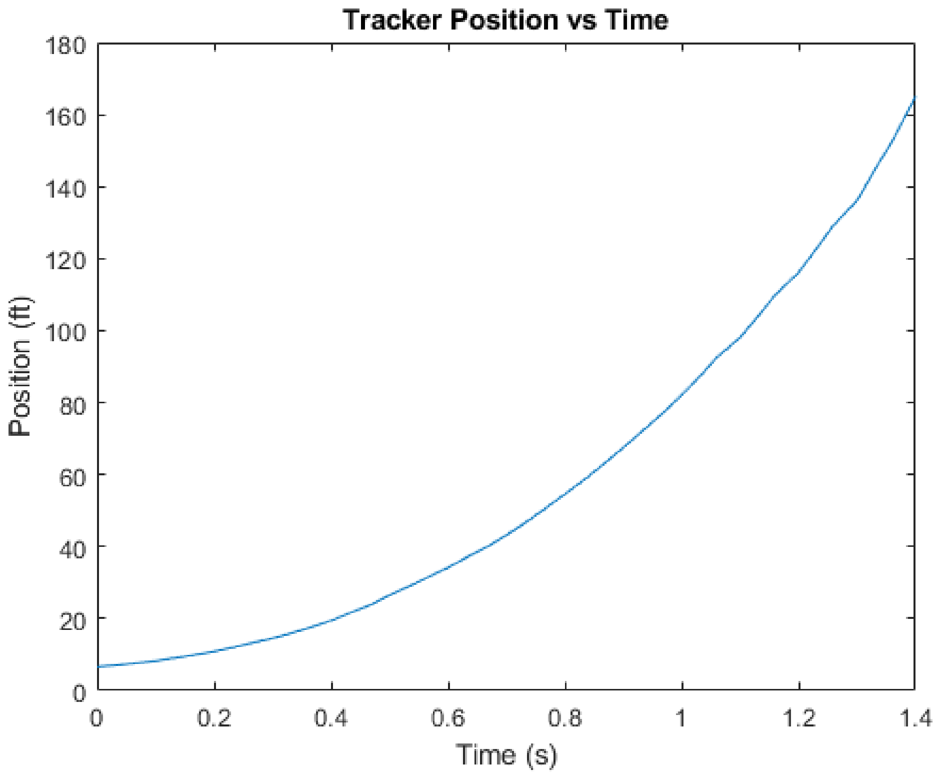


Figure 7-12: Tracker Position vs Time

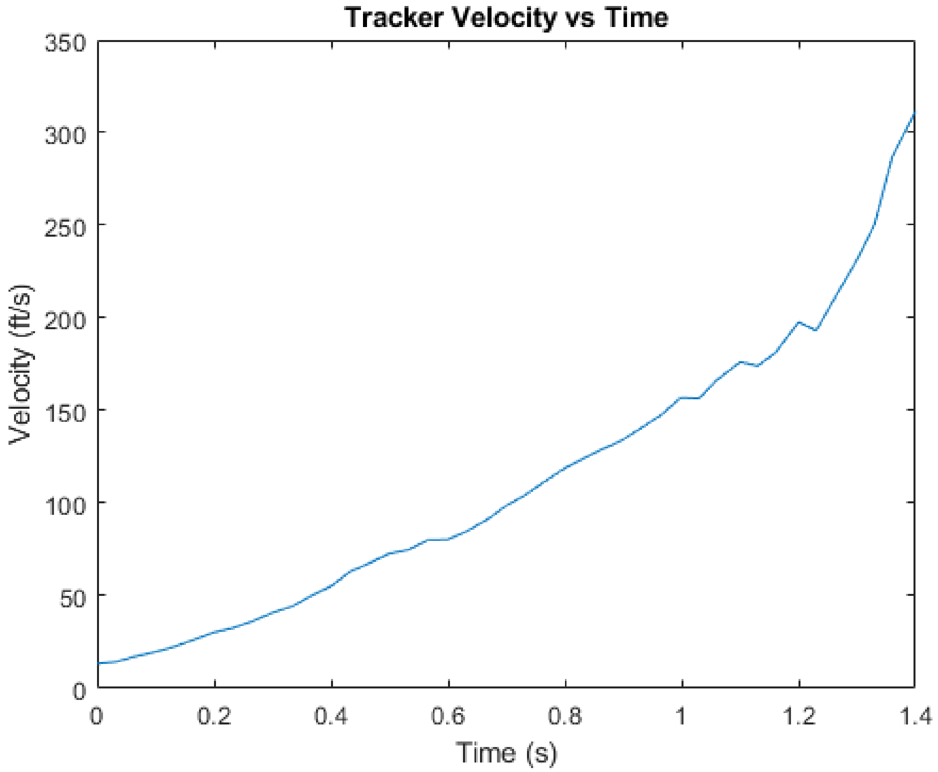


Figure 7-13: Tracker Velocity vs Time

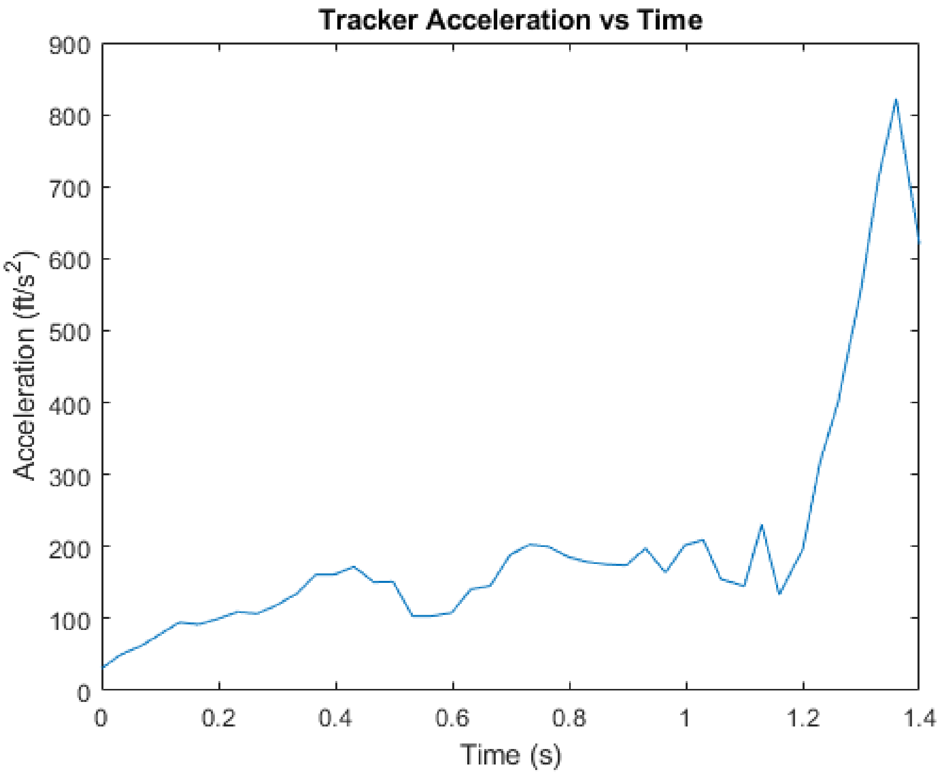


Figure 7-14: Tracker Acceleration vs Time

7.4 DATA ANALYSIS

Comparing all the data discussed above for the initial phase of flight results in the following graphs:

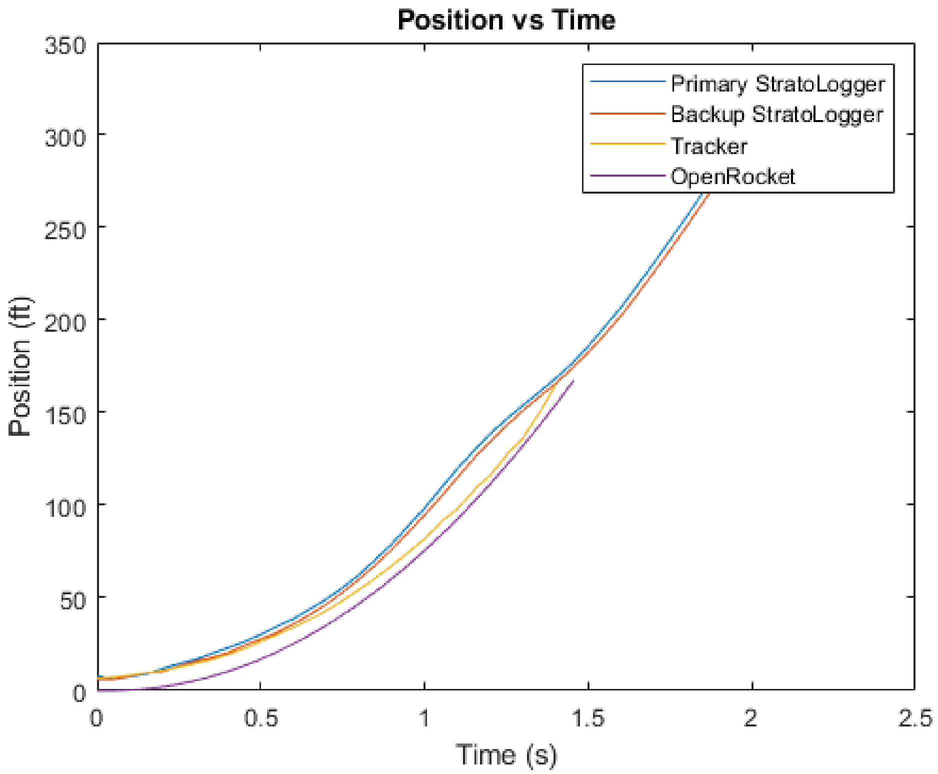


Figure 7-15: Initial Phase Comparison Position vs Time

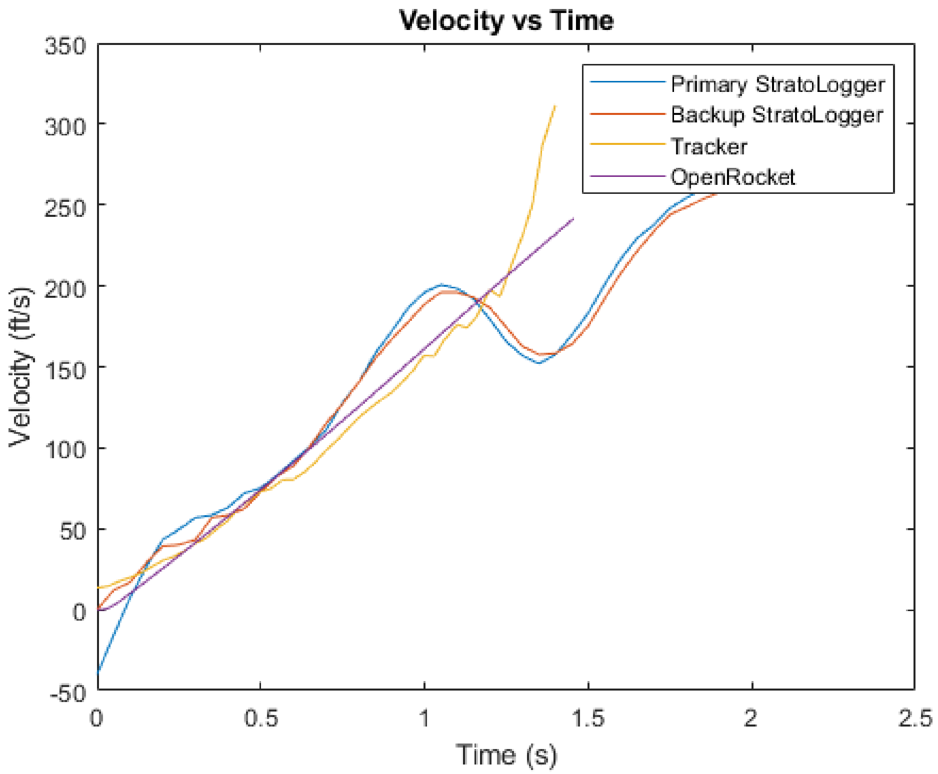


Figure 7-16: Initial Phase Comparison Velocity vs Time

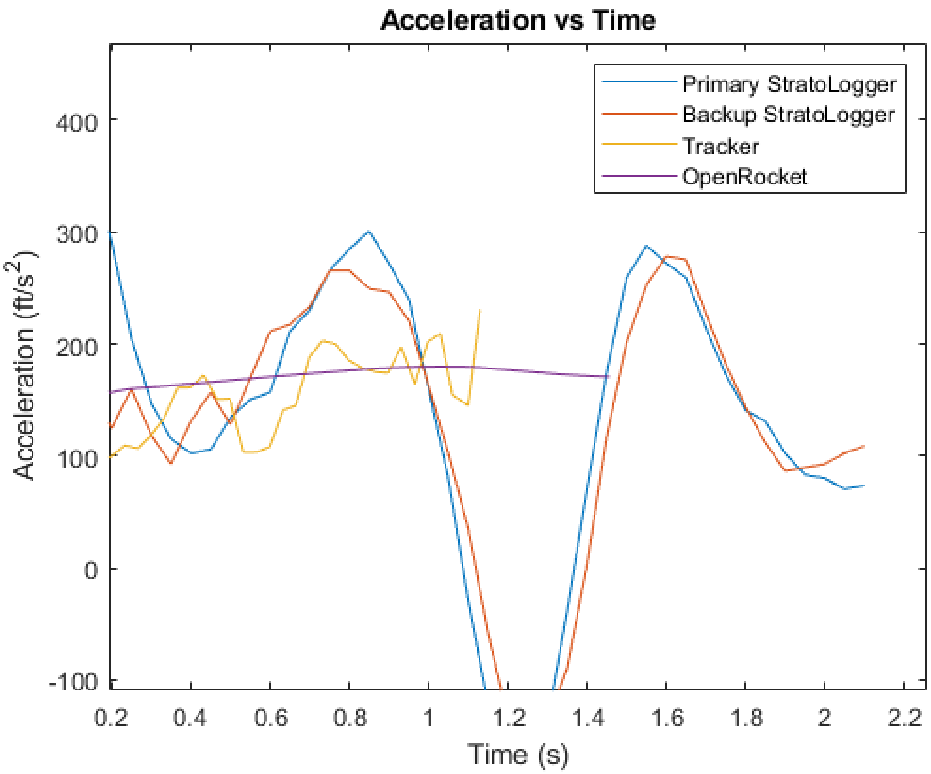


Figure 7-17: Initial Phase Comparison Acceleration vs Time

Looking at the acceleration graph in Figure 7-17, the Strattologger and Tracker data show similar results over the first .6 seconds or so, then diverge. The Strattologger data here likely diverged due to changes in air pressure caused by the abrupt turn made by the vehicle; A negative acceleration is extremely unlikely in the period where the motor is burning. As such, the Tracker data appears to be the most reliable estimate of acceleration.

Looking at the Tracker data then, the initial acceleration appears to be in the range of roughly 125-150 ft/s^2, compared to the estimate from OpenRocket at roughly 180 ft/s^2. After 0.6 seconds into flight, the accelerations converge to similar magnitudes.

Analyzing the full flight data recorded from the Strattologgers compared to the Open Rocket simulation results in the following graphs:

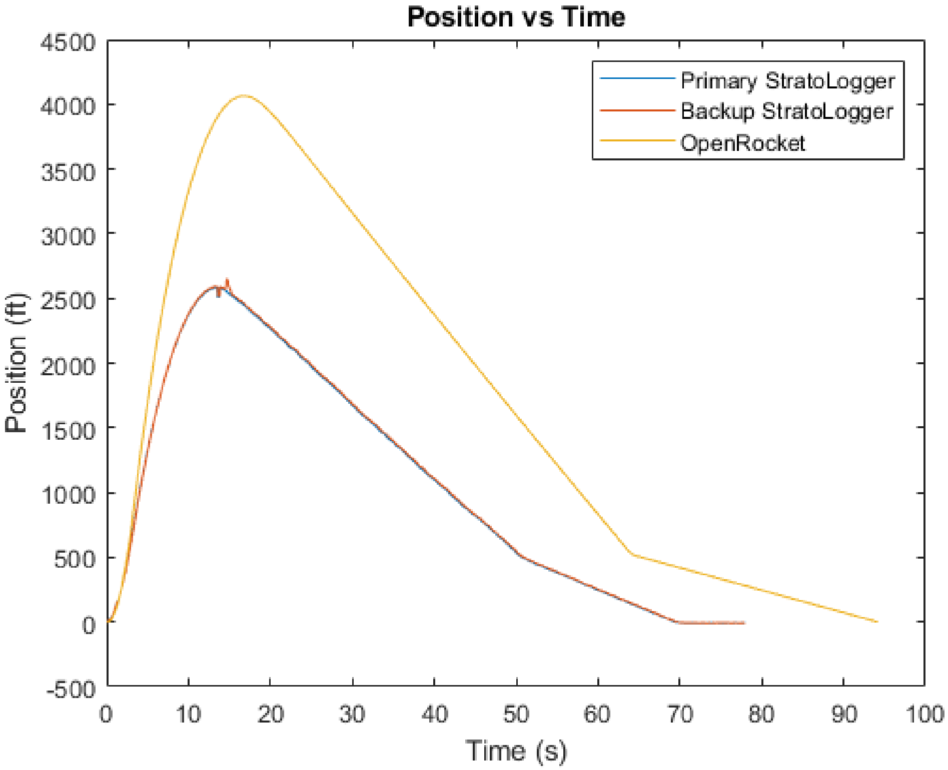


Figure 7-18: Full Flight Comparison Position vs Time

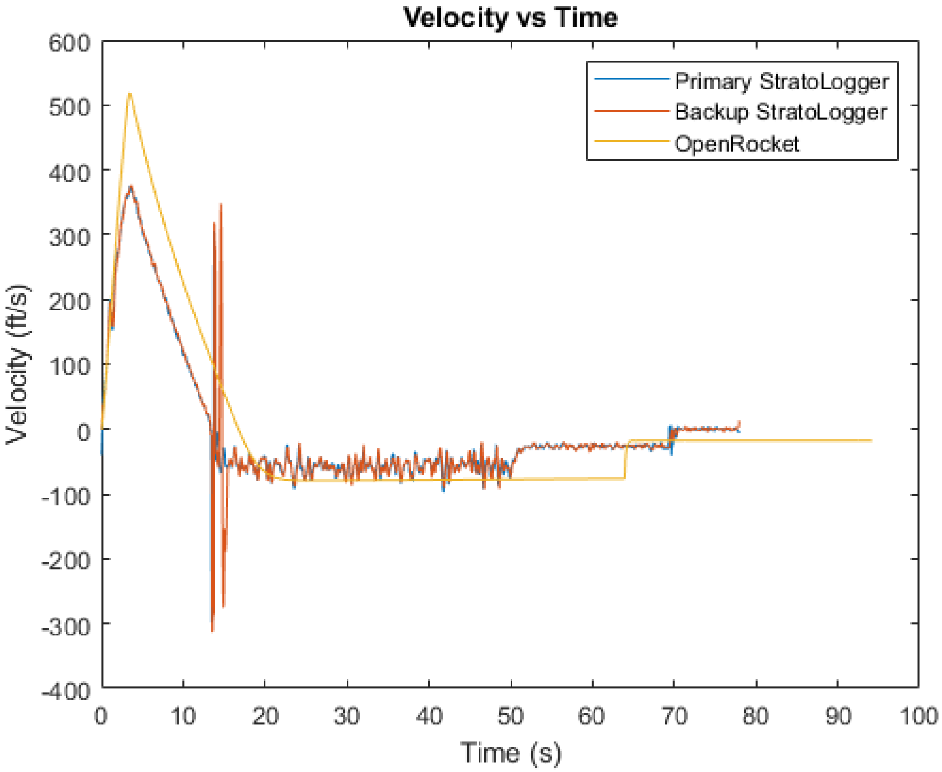


Figure 7-19: Full Flight Comparison Velocity vs Time

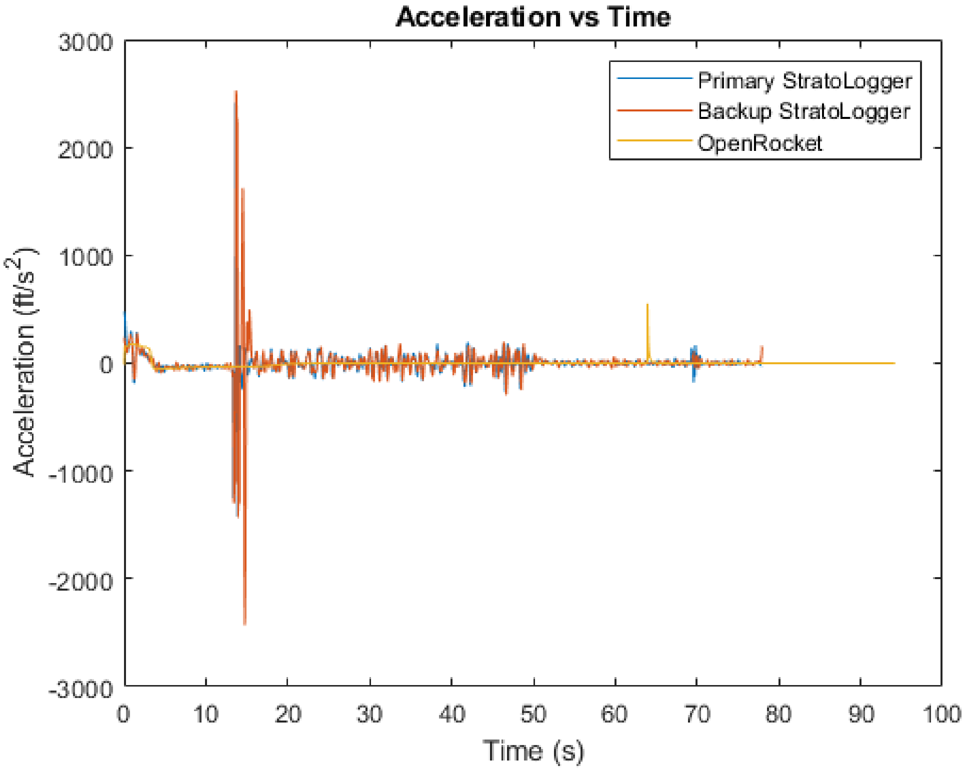


Figure 7-20: Full Flight Comparison Acceleration vs Time

The launch vehicle clearly failed to reach its expected apogee, as a result of the incorrect motor. In addition, the velocity of the lower section during its drogue descent phase was less than expected, as the simulation assumes the lower and upper sections remain attached.

7.5 DRAG COEFFICIENT ESTIMATION

To determine the drag coefficient, it is necessary to estimate the angle at which the vehicle flew. Since no data could be recovered from the onboard telemetry, this angle must be estimated using simulation. Using OpenRocket, the launch vehicle was simulated on a CTI L995, the best motor option available to approximate the thrust and weight of the combination motor. Various launch rod angles were simulated until a similar launch profile to that of the actual flight data was reached.

At a launch rod angle of 29 degrees, the simulated vehicle flew to an apogee of 2615 ft, with a maximum vertical velocity of 374 ft/s, similar results to the actual flight data. From this, the acceleration on the vehicle due to drag is determined by subtracting the measured vertical acceleration from the acceleration due to gravity and dividing of the cosine of the angle of flight. Thus, the equation for the drag coefficient becomes:

$$C_d = \frac{2m\left(\frac{a_v - a_g}{\cos\theta}\right)}{A\rho v^2}$$

Equation 1: Drag Coefficient

Using the data from flight as follows

m	Rocket mass	37.9 lb
a_v	Vertical Acceleration	-42 ft/s^2
a_g	Gravitational Acceleration	-32.2 ft/s^2
θ	Angle of Flight	30 deg
A	Reference Area	.1944 ft^2
ρ	Air Density	0.0758 lb/ft^3
v	Total Velocity	353.34 ft/s

Figure 7-21 Flight Data at t = 5

The estimated drag coefficient for the launch vehicle is 0.47. This estimate is supported by the open rocket estimate of .48, however data such as the angle of flight and air density are only estimates, so this number has some variability.

7.6 RECOVERY SYSTEM ANALYSIS

As discussed, during the flight, the Tender Descender deployed at apogee rather than at 700ft, allowing the upper and lower rocket sections to separate. Post flight inspection determined that this was due to the ejection charge for the Tender Descender being incorrectly wired to the drogue channel on the Strattologger, rather than the main channel.

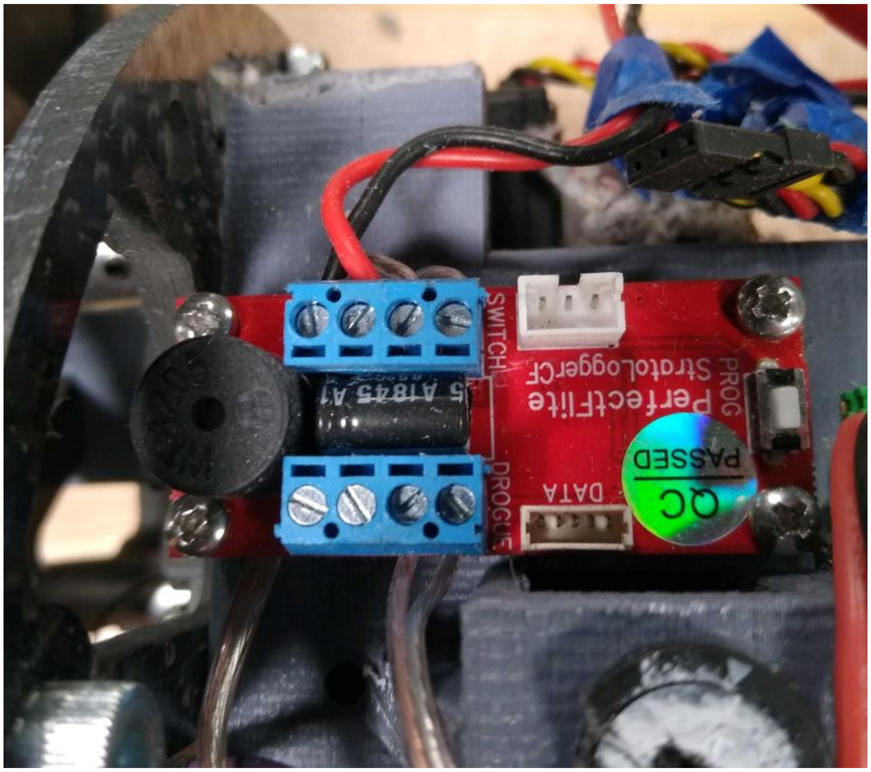


Figure 7-22 Retention Electronics Bay Strattologger Wiring

This error caused the upper section to fall ballistically to 650 ft, when the main parachute opened. This opening at around 100 ft/s caused the coupler section between the middle and upper airframes to zipper at its end, requiring replacement.

In addition, at some point during the flight of the upper section, the aluminum nosecone tip pulled its bulkhead out through the top of the nosecone. It is assumed that this was the result of a tip down landing into hard ice, though such a landing would not normally cause such a failure. It is possible that the bulkhead was damaged somehow during last year's competition, where our nosecone fell ballistically from 800ft after a motor failure and subsequent loss of vehicle. The metal tip will be replaced with a 3D printed one, which will fail before the nosecone's structure in the event of an abnormal landing.

Figure 7-23 Upper Airframe Coupler Zippering

Figure 7-24 Nose Cone Tip Damage

7.7 CONCLUSIONS

Based on the difference between actual and expected accelerations in the initial phase of flight, the most likely conclusion is that the two grey motor grains were from a L851, whereas the single blue grain was from an L1050. The 125-150 ft/s^2 acceleration range matches the initial performance of an L851 according to OpenRocket Simulations. Further supporting the claim, the extended burn time is more expected of the L851 grains, and the orange/white colored flame would only be present on an L851, or a motor consisting primarily of L851 grains.

The motor was assembled with the single blue (L1050) grain on the bottom of the stack. When lit from the top, the initial acceleration comes entirely from the L851 grains. The rocket likely left the rail with only the top two grains burning fully. At this point, due to its lower off-rail velocity that what was designed, the rocket turned dramatically into the wind, and by the time the L1050 grain ignited to make up for some of the lost thrust, the vehicle was flying at an angle that significantly reduced apogee from what was expected.

At this point, it is unknown if the error occurred at CTI or at the dealer. Regardless, in the future, the team will more closely inspect the received grains using the knowledge gained from this launch to ensure a correct order was fulfilled.

In the future, the recovery bay will be more closely inspected prior to launch, and a checklist item has been added to review the wiring of the ejection charges.

8 SAFETY AND PROCEDURES

8.1 PROJECT RISK OVERVIEW

Project Risk Overview analyzes the risks that could affect the overall project. The risks are ranked based on their probability and on their effect on timing, budget and design. For each risk there are mitigation methods that we will use to lower the chance of the risk occurring.

Project Risk Probability Definitions	
Rating	Description
A	The risk is expected to have negative effects if it is not mitigated.
B	The risk is likely have negative effects if it is not mitigated
C	The risk may have negative effects if it is not mitigated.
D	The risk is possible but unlikely to have negative effects.

Table 8.1 Project Risk Probability Definitions

Project Risk Severity Definitions	
Rating	Description
I	Irrecoverable failure.
II	Significant loss of money, time, or major design overhaul.
III	Minor loss of money, time, or minor design overhaul.
IV	Negligible effect to design, timeline, and budget.

Table 8.2 Table of Project Risk Severity Definitions

Project Risks Overview					
Risk	Probability/ Severity	Schedule Impact	Budget Impact	Design Impact	Mitigation
Destruction of Full Scale	AI	Disqualification from the competition. The team will have to reorganize the schedule to compensate to build a new full-	The budget would have to be increased to compensate for the construction of a new launch vehicle.	The design would need to be altered to prevent another full-scale destruction	Test all aspects of the full-scale launch vehicle to ensure they work correctly. Analyze and test all electronics within the launch vehicle. Do not expose the launch vehicle to any hazardous environments

		scale launch vehicle	The team may not be able to afford to construct a new launch vehicle		
Full Scale launch fail	AII	If no damage was done to the launch vehicle, minor time delays to reschedule the launch. Two-three-week delays to reorder parts and rebuild the launch vehicle. Additional time to edit the design.	The budget could be affected significantly (up to 2000$), depending on the number of repairs that need to be done	The design will be altered to avoid future launch fail	Analyze results of a subscale launch and simulations to ensure that the launch vehicle will not fail at launch. Follow all the instructions given by the RSO (Range Safety Officer) and all NAR regulations
Destruction of payload in testing.	AII	Two-three-week delays to reorder parts and rebuild the payload	The budget could be affected significantly (up to 500$), depending on the number of repairs that need to be done	Significant design changes will be made to ensure that the payload does not fail again	Use of simulations and separate testing of the UAV and the retention system before test launches
Damage to construction material	AIII	Small to hefty schedule impact depending on damaged material	Little impact on budget due to the use of school owned tools May need to buy more of the material	May need to use different methods or materials for construction	Use construction material carefully and sparingly
Sub-scale launch fail	BII	The sub-scale launch will have to be rescheduled, causing minor delays. One-two-week delays to reorder parts	The budget will be affected in a minor to significant way (up to 1500$), depending on the damage	The design will be altered to avoid future launch fail	Use simulations to ensure that the sub-scale launch vehicle will not fail at launch. Follow all the instructions given by the RSO and all NAR regulations

		and rebuild the sub-scale. Additional time to edit the design.			
Unexpected expenses (higher than expected shipping, parts, travelling costs	BII	Little schedule impact unless a shortage of funds results in an incomplete order of needed parts	Budget may have to be supplemented and more money would have to be raised to offset any additional costs	May impact supplies able to order due to looking for cheaper options to offset the more expensive ones	Keep a detailed budget and account for shipping when budgeting
Parts lost in shipment to the competition	DI	-Limited to unrecoverable schedule impact	-May need to use extra funds from budget to pay for parts lost	-May need to use different parts to replace those lost	-Use a more reliable shipping company
Damaged or delayed during shipping	DII	Limited to unrecoverable schedule impact	May need to use extra funds from budget to pay for parts damaged	May need to use different parts to replace those lost	Pack the launch vehicle and payload very carefully
Injury	CIII	Delays may occur due to ensuring the injured member's safety and determining the cause of the injure and ways of mitigating it	No impact	No impact	The team will follow all safety procedures, consult the Material Safety Data Sheets (MSDS) and follow the NAR requirements
Launch Cancellation	DIV	The launch may be rescheduled to a rain date NASA has scheduled	No impact	No impact	There is no mitigation due to this decision being up to NASA. Completion of design and construction will ensure the team is prepared for any potential launch date

Table 8.3 Table of Project Risk Overview

8.2 PERSONNEL HAZARD ANALYSIS

Personnel Hazard Analysis focuses on finding possible hazards that can occur, hazards analyzed in the Personnel Hazard Analysis may cause harm to team members and bystanders. The risks are ranked by their probability and severity. The purpose of the Personnel Hazard Analysis is to identify causes of each hazard and develop ways of mitigation and control to ensure everybody is safe.

Personnel Hazard Probability Definitions	
Rating	Description
A	The hazard expected to occur if it is not mitigated.
B	The hazard is likely occur if it is not mitigated
C	The hazard may occur if it is not mitigated.
D	The hazard is possible but unlikely to occur.

Table 8.4 Table of Personnel Hazard Probability

Personnel Hazard Severity Definitions	
Rating	Description
I	Significant chance of death or permanent injury.
II	Possibility of major injuries requiring hospitalization or permanent minor disability.
III	Chance of injury requiring hospitalization or period of minor disability.
IV	May cause minor injury which may require first aid.

Table 8.5 Table of Personnel Hazard Severity Definitions

Personnel Hazard Analysis						
Section	Hazard	Cause	Effect	Probability/ Severity	Mitigation & Controls	Verification
Machining/ building	Power Tool Injury	Improper training or human error during the	Injuries include, but are not limited to cuts,	CII	Members will receive proper training and will have	Safety officer or a lab monitor was present during all

		use of power tools	scrapes, amputation		access to instructions on how to operate each tool and will wear proper PPE specific to each tool. If an injury does appear a member will be given proper medical help.	machining using power tools along with the use of proper PPE specific for each tool.
	Tool Injury	Improper training or human error during the use of tools	Injuries include, but are not limited to cuts, scrapes, amputation, crush injury	CII		First aid kit was present in all labs where machining occurred.
	Caught in a machine	Loose items of clothing/jewelry/hair/gloves getting pulled into a machine	Partial or complete destruction of an item pulled in; injuries as severe as amputation	CII	Members will not be allowed to use machines while wearing loose items of clothing/jewelry/gloves or having long hair that are not contained.	Safety Officer or a member of the safety team ensured no one had loose clothing or jewelry that was able to get caught in machinery.
	Fire	Human error, short circuit or any other	Burns, inhalation of toxic fumes death	DI	Members will only work in facilities	Safety officer or member of the safety

		event that causes a fire to start			with proper fire safety systems installed.	team was present to ensure machines were used properly and inspected the areas for clear indications of emergency exits.
	Electric Shock	Coming in contact with an exposed wire	Burns, death from electrocution	DII	Members will inspect all wires before working with them.	Analysis of wires happened before any power was given.
	Debris from machine	Improper securing of the material/object that is being machined	Injuries include, but are not limited to eye injuries, cuts, crush injuries	CIV	Members will be properly trained to use the machines and will wear proper PPE specific to each machine.	Safety officer or a member of the safety team was present during machining and ensured the proper usage and PPE.
	Use of damaged or uncertified building equipment	User negligence or improper training	Injuries including lacerations, burns, broken bones etc.	DIII	All equipment will be inspected by trained individuals before members use, all members	Safety officer or a member of the safety team ensured all machines were in good conditions and

					will be trained.	operated as expected. WPI also has lab monitors that are responsible for keeping machines in working condition
Chemical	Exposure to epoxy	Improper PPE worn during construction	Eye and skin irritation; prolonged and reputative skin contact can cause chemical burns	AIII	During work with epoxy members will wear proper PPE including safety goggles, gloves, clothes that protect the skin from coming in contact with the material	MSDS sheet for epoxy was consulted and safety officer made sure masks, gloves and long clothing were worn for proper PPE.
	Exposure to carbon fiber/ fiberglass dust and debris	Sanding, using a Dremel tool, machining carbon fiber/ fiberglass	Eye, skin and respiratory tract irritation	BIII	During work with carbon fiber/ fiberglass members will wear proper PPE including safety goggles, gloves, long pants and long sleeve shirt.	MSDS sheet for each material was consulted. Safety Officer made sure everyone wore gloves, masks, long pants and long sleeves while working with potentially dangerous materials

	Exposure to black powder	Loading charges for stage separations or any other contact with black powder	Serious eye irritation, an allergic skin reaction; can cause damage to organs through prolonged and repetitive exposure	BIII	Only people who are trained in working with black powder will be allowed to handle it. They will wear proper PPE. Clothing that has black powder on it will be washed in special conditions.	Safety officer ensured that unauthorized members did not work with black powder. MSDS sheet for black powder was consulted and safety officer made sure all members wore proper PPE: gloves, googles and protective clothing
	Fire	Chemical reaction, explosion or any other event in which a chemical catches fire	Burns, inhalation of toxic fumes, death	DI	Members will only work in facilities with proper fire safety systems installed.	Safety officer or member of the safety team was present to ensure proper use of chemicals and inspected the area for clear indications of emergency exits. Chemicals that were used were written down to

						inform firefighters in case of an emergency about materials that may be present.
	Exposure to LiPo	LiPo battery leakage	Chemical burns if contacts skin or eyes	DIII	The battery will not be dismantled and will be checked for leaking before use.	Analysis of the battery was made to ensure it was not leaking.
	Exposure to APCP	Motor damage	Eye irritation, skin irritation	DIII	Members will wear proper PPE while handling the motor	MSDS sheet for APCP was consulted to make sure members wore proper PPE
Launch	Injuries due to recovery system failure	Parachute or altimeter failure	The launch vehicle/ parts of the launch vehicle go in freefall and injure personnel and spectators in the area causing bruising and possible death	BI	Parachutes will be properly packed, the altimeter will be calibrated correctly, the amount of black powder in separation chares will be weighted on an electronic scale	Wind speed was checked before launches and safety officer made sure everyone was 300 feet away before launch.
	Injuries due to the motor ejection	Motor installed and secured improperly	Motor and other parts of the launch	CI	The motor will be installed by	Safety officer ensured before

	from launch vehicle		vehicle go in freefall and injure personnel and spectators in the area causing burns and possible death		a certified mentor	launch that the motor is installed by a certified mentor, the motor wasn't tempered with before launch and was stored in the container it was sold in, prior to the launch the launch vehicle was inspected following the safety checklist
	Injuries from premature ignition of separation charges	Improper installation of igniters, stray voltage	Severe burns	CI	The battery will be switched off during installation of the igniters, black powder in separation charges will be weighted on an electronic scale	Safety officer ensured that all safety procedures listed in the safety checklists were followed during the installation of the charges
	Injuries due to a premature motor ignition	Improper storage of the motor, damage of the motor	Severe burns	DI	Motor and igniters will be bought from official suppliers, properly	Safety officer ensured that installation of the motor

		or early ignition			installed by a certified mentor and ignited by the RSO	was correct, and ignition is done by certified personnel
	Injuries due to unpredictable flight path	Wind, instability in thrust	The launch vehicle goes in unexpected areas and could injure personnel or spectators	DI	The launch vehicle will not be launched during strong winds, the launch vehicle design will be tested through simulations to make sure that it is stable during flight	Weather conditions were assessed, the launch vehicle was launched, because weather conditions met NAR standards. Multiple simulations were ran ensuring that the launch vehicle was stable
	Failure to provide a countdown to launch vehicle launch	Human negligence	The launch vehicle may descend ballistically and either injure or kill someone	DI	The safety officer will be required to ensure that the launch site has a proper speaker system to inform spectators of the launch	The speaker system was verified to work before launch, the safety officer was present at launch.
	Injury due to natural obstacles on the launch site	Improperly groomed field, trees, human structures	Members may become injured trying to	DIV	The members will be required to stay within a	The safety officer surveyed the launch site before

			traverse hazardous conditions		certain area and not traverse the launch site to unauthorized locations	going to retrieve the launch vehicle once it landed
	Injury due to approaching the launch vehicle after a misfire	Not waiting at least, a minute before approaching the launch vehicle after the misfire	Members may become injured if the launch vehicle misfires again when they approach it	CIII	The members will be required to wait at least a minute to approach the launch vehicle after a misfire	We didn't encounter a misfire, but in case of a misfire the team will follow the misfire safety checklists and obey all instructions given by the RSO

Table 8.6 Table of Personnel Hazard Analysis

8.3 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

The FMEA ranks failure modes based on probability and severity for the hardware components of the launch vehicle and the payload. Their possible causes and effects have been considered, as well as methods of mitigation and verification of the systems to avoid these failure modes.

We were able to avoid many of the following failures due to the safety checklists in Section 8.5.

FMEA Probability Definitions	
Rating	Description
A	The failure is expected to occur if it is not mitigated.
B	The failure is likely occur if it is not mitigated
C	The failure may occur if it is not mitigated.
D	The failure is possible but unlikely to occur.

Table 8.7 FMEA Probability Definitions

FMEA Severity Definitions	
Rating	Description
I	Complete loss of the item or system.

II	Significant damage to the item or system. Item requires major repairs or replacement before it can be used again.
III	Damage to the item or system which requires minor repairs or replacement before it can be used again.
IV	Damage is negligible.

Table 8.8 FMEA Severity Definitions

Launch Vehicle FMEA					
Hazard	Cause	Effect	Probability/Severity	Mitigation & Controls	Verification
Drogue parachute does not deploy	The parachute may not be packed properly, or it might be too tight of a fit in the airframe.	The launch vehicle would descend at a dangerous free fall velocity. If the main parachute deploys at this speed, the airframe will most likely be severely damaged.	BI	The drogue parachute will be properly sized and also have multiple systems to deploy it.	Drogue parachute was successfully deployed at full scale test launch on 2/22/20
Parachute detaches from launch vehicle	Improper installation of the recovery system	This would result in the complete destruction of the launch vehicle and payload upon ground impact. It could also injure personnel on the ground	BI	Proper installation of the recovery system and select correct sizes of hardware to handle ejection forces.	All parachutes remained secured to the launch vehicle during descent at the fullscale test launch on 2/22/20

		due to debris upon impact.			
Main parachute does not deploy	The parachute may not be packed properly, or it might be too tight of a fit in the airframe.	If the drogue parachute deploys, then the launch vehicle would still fall at a high speed, leading to minor damage. If the drogue parachute also does not deploy, then the entire launch vehicle would be destroyed upon impact of the ground.	BII	The main parachute will be properly sized and also have multiple systems to deploy it.	The main parachutes successfully deployed at the fullscale test launch allowing the body sections to slowly descend and suffer no damage upon landing
Melted or damaged parachute	The parachute bay is not properly sealed, or the parachutes aren't packed correctly.	This could prevent the parachutes from slowing the launch vehicle's descent rate, resulting in the possible loss of the launch vehicle and payload.	BII	Proper protection and packing of the parachutes.	Parachutes sustained no damage upon inspection after full scale test launch
Shock cord tangles	Parachutes are not packed properly	Could decrease the parachutes' effectiveness,	BII	Properly pack the parachutes	Minor tangling occurred in the shock

		resulting in the loss of the launch vehicle and payload upon ground impact.			cord during the fullscale test launch, but didn't affect the release of the parachutes on 2/22/20
Electronics bay is not secured properly	Electronic bay does not fit tightly into the airframe	Potential electronics and recovery failure	BII	Manufacture the electronics bay to fit accurately in the airframe	The electronics bay remained securely in place during and after the fullscale test launch, this was due to the use of a T-bar
Motor ejected from launch vehicle	The motor is secured improperly.	The motor could possibly go into freefall during flight. If it is still ignited, it may harm personnel in the vicinity or destroy the launch vehicle. It could also create free falling debris that could cause harm.	CI	The motor will be installed by a certified mentor. The motor retention system will also be inspected prior to launching the launch vehicle.	The motor was installed by our certified mentor and remained secured in the lower airframe throughout the duration of the fullscale test flight due to the use of a flange that is bolted below the aft closure of the motor casing

Fins break off during ascent	Large aerodynamic forces or poor fin design	Launch vehicle cannot be relaunched	CI	Mount fins properly onto the airframe	The fins remained securely attached to the airframe during the fullscale test launch
Airframe separates during ascent	Improper connection of airframe sections; large aerodynamic forces cause the airframe to separate	Launch vehicle cannot be relaunched	CI	Couplers are tight enough within the airframe to keep the airframe sections attached during ascent	The upper and lower main body sections remained attached until separated by a black powder charge at apogee during the fullscale test launch
Altimeter failure	Loss of power, low battery, disconnected wires, destruction by black powder charge, or burnt by charge detonation	Incorrect altitude readings and altitude deployment; can result in potential loss of launch vehicle and payload	CI	There will be a backup altimeter with a second power source in case the main altimeter fails. There will also be a set of backup black powder charges connected to the backup altimeter. Both	The altimeter successfully recorded and transmitted data during the fullscale test launch on 2/22/20

				altimeters will also be tested before launch.	
Altimeter switch failure	Switch comes loose during launch or component failure	Incorrect altitude readings and altitude deployment; can result in potential loss of launch vehicle and payload	CI	Test switches before launch	The altimeter performed correctly and remained powered throughout the fullscale test launch
Electronics bay failure	Loss of power, disconnected wires, destruction by black powder charge, or burnt by charge detonation	Altimeter or recovery system failure	CII	Test the electronic bay and altimeter before launch	The electronics bay performed correctly, remained powered, and did not sustain any damage during the fullscale test launch
Descent too fast	Parachute is too small	Potential damage or loss of launch vehicle and payload	CII	Properly size parachute; test recovery system before launch	The drogue and main parachutes deployed successfully due to a tender descender malfunction, they didn't deploy at right altitude however,

					they were still able to slow the vehicle sections to safe descent velocities
Motor Misfire	Damaged motor or damage to ignitor prior to launch.	Significant to unrepairable damage to the launch vehicle and possibility of harm to personnel	DI	The motor is only handled by a certified team mentor. If there is a misfire, the team will wait at least 60 seconds before approaching the launch vehicle and will follow the instructions of the RSO.	The motor was handled by a certified mentor and did not experience a misfire during the fullscale test launch. A misfire safety checklist was made in case a misfire occurs during later launches
Premature motor ignition	Damaged motor or accidental early ignition.	Possibility to harm personnel in vicinity during ignition.	DI	The motor will be replaced. It will be properly installed by a certified mentor and inspected by the RSO.	The motor was installed by a certified mentor and did not ignite prematurely during the fullscale test launch
Shock cord is severed	Faulty shock cord, weak cord from repeated testing, destruction	The parachutes would detach from the launch vehicle,	DI	The shock cord will be properly sized to handle ejection	The shock cord withstood the forces exerted during launch

	by black powder charge, or burnt by charge detonation	leading to the loss of the launch vehicle and payload.		loads. It will also be inspected before the parachutes are packed. A Nomex blanket will protect the shock cord from fire damage and the black powder charges will be measured carefully.	and recovery events and was found to be totally intact following the fullscale test launch
Fins do not keep the launch vehicle stable	Damaged fins	Predicted apogee from simulation is 4486 ft.	DI	Use OpenRocket vehicle simulations to make sure the fin design will keep the launch vehicle stable	Simulationsin OpenRocket showed that our stability at all points is above 2.0. The fins were inspected before the launch and the launch vehicle successfully achieved stable flight during ascent at the fullscale test launch.
Fins break off during landing	High impact during landing; point	Launch vehicle cannot be relaunched	CIII	Avoid fin designs with weak points and test fins	The fins were intact and remained attached to

	stresses on fins			with forces of final descent velocity	the launch vehicle upon inspection following the fullscale test launch
Descent too slow	Parachute is too large	Landing outside of max drift zone	CIII	Properly size parachute; test recovery system before launch	The launch vehicle descended at a safe rate that was not too slow, no excessive drift occurred during descent and recovery at the fullscale test launch and the vehicle landed within the 2500 ft radius of the launch rail
Pressure not equalized inside airframe	Vent holes are too small	Altimeters do not register accurate altitude	CIII	The vent holes will be drilled accurately	Our launch vehicle suffered no damage from unequalised pressure, which means that we have proper ventilation

Table 8.9 Launch Vehicle FMEA

Payload and retention system FMEA						
Function	**Hazard**	**Cause**	**Effect**	**Probability/ severity**	**Mitigation & Controls**	**Verification**

Payload Retention	Retention system becomes insecure	Retention system is loose and is unable to stay secure within the airframe.	Retention system damages the inside of the launch vehicle body and the payload if left insecure. Retention system falls from launch vehicle during flight. Retention system is damaged and rendered unusable	BII	Design the system in a way that ensures that it is secure inside the airframe. Install the system carefully.	Follow a safety checklist during installing the retention system. The safety checklist goes through the installation process and checks that need to be done before the flight
	Retention system fails to release payload	Incorrectly estimated payload weight. Improper retention system installation. Payload retention design flaw	Retention system fails to release payload and fails the mission.	BIII	Take extra measures during the design process to ensure that the retention system is fit for the UAV. Ensure that electronics telling the retention system to release the payload are in working condition.	Test electronics (servo that rotates the lead screw and linear actuator), the stabilizer and lead screw rotation
Payload Ejection	Payload becomes	Wrong amount of	The payload is ejected	BI	The black powder	Follow the ejection test

	damaged during ejection process	black powder in the ejection charge, electrical failure	forcibly and is destroyed		charges will be measured carefully using a scale, all electronics will be tested before flight	checklist to make sure the right amount of black powder for each charge is used, test the retention system before flight (see step above)
	Retention system is improperly oriented after landing preventing ejection	Payload retention design flaw	The payload is ejected while still inside the launch vehicle body, damaging the launch vehicle and payload, payload isn't ejected and fails the competition	BII	The design will account for any orientation of the retention system upon landing	We designed a system that after landing stabilizes and then rotates the retention sled to ensure that payload is facing upwards, test the ejection before launch day to ensure it works properly from each orientation
	Payload Ejection failure	False ejection signal, faulty assembly of retention system,	The payload isn't ejected and fails the competition	CIV	The retention system will be designed in a way that will ensure payload ejection,	Our design ensures that the payload can leave the body of the launch vehicle from each

		payload retention design flaw, electrical failure			electronics will be tested before flight	orientation by first rotating it into proper orientation (see step above), then using the lead screw moving the retention sled out of the launch vehicle body and using a scissor lift lifting the UAV to a position from which it can take off, electronics and retention will be tested before flight
UAV flight	UAV propellers damaged while inside the launch vehicle	Propellers get damaged while being inside the launch vehicle due to not being secured	The drone is destroyed and unable to complete its mission	CI	The UAV will be secured with clips within the body of the launch vehicle	Full scale testing of the launch vehicle with the UAV inside
	UAV propellers fail during flight (mechanically)	Propellers get damaged during flight upon collision with an object (a tree, a part of a launch	Depending on the altitude of flight UAV can be damaged severely due to the fall	CII	The UAV will be flown by a person with experience, a checklist will be followed before the launch to	Tests of propellers have been done to ensure they mechanically withstand the needed thrust and further

		vehicle etc.) or due to entanglement (loose wire)			make sure all parts are secure	testing will occur during payload demonstration flight. Safety checklist procedure will ensure that the UAV suffers no damage while being implemented and ejected from the launch vehicle
	UAV propellers fail during flight (electronically)	A faulty servo, shortcut or a loose wire	Depending on the altitude of flight UAV can be damaged severely due to the fall	CII	Electronics will be tested before flight; a safety checklist will be made to check the wiring before flight	Electronics were tested to make sure the propellers function correctly; a checklist will be followed to make sure the wiring is intact before flight, further testing will occur during payload demonstration flight
	Loss of communication between UAV and remote control	Loss of connection with radio signal from remote control,	The UAV falls and is severely damaged	CII	Ensure the radio signal of the remote is able to reach the UAV at any distance	The remote control was tested on the propellers to ensure that it can regulate

		faulty electronics, UAV is out of bounds that a signal can reach			within competition boundaries and knowing the limitations of the device	their rotation. On field testing will occur during payload demonstration flight
	Unstable takeoff conditions	High winds or hazardous weather conditions	The UAV is severely damaged or destroyed	DI	The UAV will not be launched during high winds, rain, snow	Check the weather forecast before going to the launch site and at the launch site
	Loss of battery	Faulty battery, battery wasn't charged, the UAV was in air for a longer period of time than anticipated	The UAV doesn't take off and fails the competition, UAV is damaged from the fall	DII	Choose a battery that has a long life and is not likely to be faulty	The battery will be tested and a person from the payload subteam will be assigned to be responsible for charging the battery, the battery charge will be checked prior to launch
	UAV is not able to handle environmental conditions	Flaw in the design of the UAV	The UAV can't fly in conditions at the launch sight	DII	Make sure that the UAV is designed and built to be able to withstand the most extreme allowed conditions	Possible testing in extreme conditions

Faulty/low battery	Battery dies while UAV is midair	Faulty battery, the battery wasn't fully charged, the battery was switched on too soon	The UAV falls midflight and is damaged or broken	CII	The battery will be able to hold charge for at least 2 hours and will be switched on right before launch	Testing the battery life, the battery charge will be checked before launch
	Battery dies before UAV takeoff		The UAV is unable to takeoff and complete its mission	CIV		
	Battery dies while soil sample is being collected		The UAV is unable to collect the sample and leave the sample collection area	CIV		
	Battery is not charged before launch	Purchase of a faulty battery, the battery is drained before competition	The UAV falls midflight and is damaged or broken, the UAV falls midflight and harms someone in the process, the UAV falls midflight and damages the environment	DIV	A member of the payload subteam will be responsible for making sure that the battery was charged prior to launch	The aforementioned member will sign the checklist when the task of charging batteries is completed
Electronics catch fire	A shortcut in electronics causes ignition	Overloading the system	The launch vehicle and payload are destroyed, if in air may	DI	The limitations of each device will be	Electronics were tested separately, for pre-launch tests

			cause the launch vehicle to become ballistic		accounted for while designing and using all electronics	we will create closed circuits around elements that need to be checked
	Improper wiring causes ignition	Incorrect wiring		DI	Wire the UAV in such a way that is least likely to cause a fire, the wiring will be done carefully, and the wires will be tested before launch	At least 2 people, who worked on the wiring will visually inspect wires to make sure there are no mistakes
	Overheating causes ignition	Overheating of the internals of the payload during launch or outside temperature		DI	We will design the retention system and UAV to be properly ventilated to prevent overheating, the UAV should be far enough from the motor, that its heat doesn't affect it	Full scale testing and testing in warm weather
Soil Collection device	Soil collector becomes damaged during flight	UAV became unsecured inside the launch vehicle body	Soil collector becomes stuck within the retention	CII	We will design the soil collection device, so it is properly	Follow the safety checklist and make sure that the clips,

			system and prevents ejection		contained within the launch vehicle	that hold the UAV inside the launch vehicle, are secure
	Soil collector becomes damaged during use	Faulty design of the soil collector or the soil collection assembly	Soil collector is unable to complete its task and fails the mission	DII	We will design the soil collector compatible with the soil sample and check the assembly of the soil collector prior to launch	Test the soil collector before launch, make sure all electronics work correctly, follow a safety checklist prior to launch
	Soil collector becomes stuck	Faulty design of soil collection	Soil collector is unable to complete its task and fails the mission, soil collector prevents the UAV from properly taking off	DIV	We will design the soil collector compatible with the soil sample	Test the soil collector on multiple soil samples before launch
	Soil container is unable to contain soil	The soil collection container becomes broken during launch, the collector is broken inside the retention system, faulty	The soil container is unable to properly hold soil and fails the mission, soil container is unable to open and release sample	DIV	We will design the container so it closes completely and cannot get stuck	We will test the container to make sure it works before launch day and use several different soil types to test on container

		assembly of the container to the UAV, faulty design of the container				

Table 8.10 Payload and Retention System FMEA

8.4 ENVIRONMENTAL CONCERNS

Environmental Concerns table is focused on negative effects natural conditions can have on the launch vehicle and vice versa. Each concern is assigned a rank based on its probability and severity, and for each concern we listed a way of mitigating it to minimize the risk.

Environmental Conditions Probability Definitions	
Rating	Description
A	Negative effects due to the condition are expected
B	Negative effects due to the condition are likely
C	Negative effects due to the condition may occur
D	Negative effects due to the condition are possible but unlikely

Table 8.11 Environmental Concerns Probability Definitions

Environmental Conditions Severity Definitions	
Rating	Description
I	The condition may cause death or permanent disability to personnel or loss of the system
II	The condition may cause major injuries or significant damage to the system
III	The condition may cause injury or minor damage to the system
IV	The condition may cause minor injury or negligible damage to the system

Table 8.12 Environmental Concerns Severity Definitions

Environmental Concerns Affecting the Launch Vehicle					
Phase	Environmental Condition	Effect	Probability/ Severity	Mitigation	Verification
Launch	Inclement Weather	Unsafe alterations to launch vehicle's	AI	The team will not launch in inclement weather.	Weather at our fullscale launch site was checked

		trajectory and launch vehicle itself.			prior to launch, we were able to launch since there wasn’t precipitation and the wind wasn’t strong enough for our launch vehicle to drift out of bounds
	Water/Rain	If the launch vehicle lands in water or gets significantly wet in any way, it could cause the electronics to fail.	All	The launch vehicle will not be launched near a significantly large unfrozen body of water, nor in severe or prolonged rain.	The launch vehicle was launched on a frozen lake, and it was not raining at the time of the launch. There was no water damage to the launch vehicle. For extra protection from water damage our launch vehicle is coated in fiberglass
	High Temperature	Overheated motors or energetics could start a fire and light any flammable objects in the area. This could also be a danger to circuits	CI	The electronics will be inspected and tested to prevent shorts and anything else that could cause overheating. Motors will be safely installed and arranged in a way to prevent them from stalling or being affected by	The electronics were inspected following a safety checklist, the motor was installed by our certified mentor

				other things that may overheat them.	
	Trees	Due to winds or an unpredicted flight path, the launch vehicle or payload could end up hitting or landing in a tree.	CII	The launch vehicle will be aimed in a direction with wind in mind and far from any trees to ensure the best chance of avoiding trees.	Our launch occurred on a frozen lake which minimized our risk of hitting a tree during flight or upon landing. The RSO aimed the launch rail away from the nearest island
	Birds	If the launch vehicle hits a bird, it could damage the launch vehicle and alter its trajectory depending on the size of the bird.	DII	The launch vehicle will not be launched while there are birds too close to it.	We launched on a clear day so it was easy to verify that there are no birds that could get harmed during our launch
	Strong Winds	Unsafe alterations to launch vehicle's trajectory.	BIV	Alter course and adjust trajectory to prevent launch vehicle's landing from leaving the exclusion zone. If the RSO deems the winds to be too high, the team will wait for the winds to die down.	We were able to launch since the wind at the launch site was on average 8.3 mph
	Sand	If the launch vehicle lands in sand or has	DIII	The launch vehicle will not be launched	The launch vehicle was launched on a

		sand blown into it, it could disrupt or get stuck in small components.		near a significantly sandy area.	frozen lake to avoid any sand damage.
Payload Retention System	Obstruction	A plant, rock, or other object could get in the way of the retention system deploying and get damaged or prevent the system from functioning.	DIV	The retention system will be designed to deploy slowly in order to minimize potential damage to it and to any surroundings.	The area of the launch had minimal abstractions. The retention system will be deployed slowly in order to minimize damage to it and to any surroundings.

Table 8.13 Environmental Concerns Affecting the Launch Vehicle

Environmental Concerns Affecting the Payload and Retention System					
Event	**Cause**	**Effect**	**Probability/ Severity**	**Mitigation**	**Verification**
Surrounding area catches fire during ignition	Poor condition of the launch site (small vegetation, debris etc.)	Fire can deal significant damage to the surrounding plants and animals	DI	The vehicle will be launched on a launch rail with a blast deflector. The area will be cleared of flammable materials.	The vehicle was launched on a launch rail with a blast deflector. The launch occurred on a frozen lake, which prevented the risk of any flammable materials being present in the area. The motor casing and motor tube protect the fin can from heat and motor retention parts are

					made from aluminum, so they won’t catch fire
Launch vehicle hits a bird during flight	Inattentiveness during launch or birds entering the area above the launch field after the launch vehicle is launched	Significant damage to the bird that can lead to death	DI	We will not launch the lunch vehicle if there are birds insight	We launched on a clear day so it was easy to verify that there are no birds that could get harmed during our launch
Launch vehicle lands out of bounds and is not recovered	Inclement Weather, proximity of the launch pad to field boundaries	The mission is failed, the decaying vehicle may be hazardous to the wildlife in the area	DII	The team will not launch during high winds or close to the boundaries of the launch site	With the current stability rate, our launch vehicle will not drift out of bounds during winds up to #
Chemical leakage	Battery leakage	Release of a toxic substance into the ground	DII	The battery will be checked before launch to make sure it is intact	Safety checklists are followed during launch day preparation, as part of them we inspected all the batteries prior to launching
UAV loses control during flight	Faulty electronics, UAV flying out of reach for the controller	Losing control of the UAV could result in it damaging plants and possibly any animals in the area.	CIII	A proper connection will be ensured prior to activating the UAV and there will be a failsafe in the case of a	We will ensure that we have good connection before activating the UAV (following a safety

				dropped connection or loss of control.	checklist) and there will be a failsafe in the case of a dropped connection or loss of control
Launch vehicle lands in a body of water	There are strong winds in the area or the launch vehicle is launched too close to an unfrozen body of water	It may cause disturbances to local plants and animals	DIII	The launch vehicle will not be launched during strong winds or near a significantly large unfrozen body of water	The launch vehicle was launched on a frozen lake, and it was not raining at the time of the launch. There was no water damage to the launch vehicle. For extra protection from water damage our launch vehicle is coated in fiberglass
A part of the rocket is left on the field	A part of the rocket is not found after landing	A part becomes trash	CIV	Pre-launch checklists will ensure that all parts are securely attached to each other and to the parachutes; post-launch checklist will ensure that all parts are accounted for to minimize the risk of leaving something behind	During the full scale testing all parts of the rocket were recovered and accounted for in the post-launch inspection checklist. Our team also ensured that we leave no waste at the launch site.

Table 8.14 Environmental Concerns Affecting the Payload and Retention System

8.5 FINAL ASSEMBLY AND LAUNCH PROCEDURES

Final assembly and launch procedures are vital for our team's success in completing the mission. They list all the steps that need to be completed prior to each launch and after each launch. Some important steps require a specific officer to complete or verify, such steps have the officers position listed next to them. Our team understands the importance of following these checklists. First, they ensure that all parts of the launch vehicle, eBay and payload are accounted for. Secondly, it helps with preparing our launch vehicle, eBay and payload, since it shows all the steps that need to be done. That way we eliminate the risk of forgetting to do something. If a step were to be missed, the safety of the entire mission could be compromised. This misstep could also lead us to fail during the competition, so it is vital to follow each of the steps on the checklists diligently. Checklists also help us ensure the safety of team members and bystanders. All steps that require PPE show the PPE required and strictly following checklists ensures there are no loose parts that could harm bystanders.

8.5.1 Launch Vehicle Checklist

Launch Vehicle Checklist	
Task	Verified by (position listed if necessary)
Motor tube and fin can assembly	
Take the motor tube with the attached motor retention sleeve. Slide the trust plate onto the motor tube from a side opposite from the retention sleeve	
Slide the lower fin bracket on top of the thrust plate	
From the retention sleeve side, slide on the tail cone	
Make sure the slots on the tail cone align with the holes on the retention sleeve	
Align the bolt holes in the tail cone with those in the lower fin bracket	
Bolt the tail cone with the lower fin bracket using 4 ¼-20 button head bolts	
Slide the fins into the lower fin bracket. Bolt the fins using 8 ¼-20 socket head bolts	
Slide upper fin bracket on to the fins and bolt the fins using 8 ¼-20 socket head bolts	
Bolt the assembled fin can into the lower airframe using 11 ¼-20 x 0.5 bolts.	
Insert motor into motor tube according to motor checklist.	Mentor

Bolt the motor retention flange with 4 8-32 x 0.5 bolts below the aft closure	
Aft bulkhead and coupler assembly	
The aft bulkhead components are placed together in this order: The upper aft bulkhead, aft bulkhead print, Delrin bowtie, neoprene bowtie, and then lower aft bulkhead.	
Bolt the bulkhead together using 10 10-32 bolts.	
Align electronics bay coupler over aft bulkhead, aligning the coupler so that it is flush with the lower aft bulkhead and aligned with the radial holes.	
Using hot glue temporarily connect bulkhead to coupler.	
Insert aft bulkhead and coupler into the top of the lower airframe, arrow on the coupler lines up with the arrow on the tube and secure using 8 ¼-20 x 0.5 in bolts.	
Complete eBay checklist up until the “After the vehicle is placed on the pad” section	Safety Officer:
Sled assembly	
Remove key from ground test switch (if not already removed)	
Loosen the ballast flange mount bolts by 4 revelations	
Pull on the ballast flange to make sure that is pulled towards bolt heads on all sides	
Make sure the T-bar is secure by simultaneously twisting on the U-bolt and the T-bar	
Insert sled assembly into the coupler, T-bar side first, white side to the “white” mark, black side to the “black” mark on the blue tube. Visually make sure the T-bar lines up with the sled retention slot. (Will know it is correctly inserted when forward bulkhead is recessed ½ inch)	
Rotate the sled assembly 90 deg clockwise until it stops moving.	
Pull on U-bolt to validate that it is secure and aligned.	
Visually confirm that radial hole in forward bulkhead align with holes in coupler.	

Visually confirm that switches and ground test plug align with vent holes.	
Temporarily secure forward bulkhead with 2 of 4 8-32 bolts. These should be 180 deg opposite each other.	
Tighten the bolts on the ballast flange to eBay forward bulkhead	
Visually inspect that rubber gasket forms a seal around the coupler without significantly protruding from the radius of the ballast adapter flange	
Visually inspect seal on bulkhead around ejection wires.	

Installing the ejection charges

Mentor will pack ejection charges into ejection caps. Extra volume will be packed using cellulose insulation. (Amount of black powder needed will be estimated using a MATLAB script and refined in ejection test. The amount will be weighed out on a scale. MATLAB estimate is 3.9g for main and 4.3g for backup charges.)	Mentor:
Verify that both altimeters are powered off, by actuating each power switch in both directions, listening for the position which does not produce any audible beep tones	
Install ground test key and rotate to TEST position to isolate charge from altimeter	
Probe the terminals of each ejection terminal block with a multimeter and verify that there is no voltage running across the terminal blocks	Safety officer:
Insert and tighten ejection wires into terminal block.	
Secure ejection charges into ejection caps using at least three wraps of electrical tape	
Provide strain relief to the e-match wires by taping them to the bulkhead in front of the terminal block	

Ballast *Only if ballast is used

Slide ballast core into circular slot in ballast flange.	
Place required ballast around core. Loading weight outward from the CG. *	

Initially secure ballast rings in place using VHB tape. To prevent rings from moving while the launch vehicle is being assembled *	
Install upper ballast bulkhead into middle airframe using 3 ¼-20 3/8 long bolts at the marked locations	
Install an airfoiled rail button into the 4th radial hole using ¼-20 flat head bolt	

Installation of middle airframe onto the eBay

Remove the 2 8-32 bolts that were temporarily securing the eBay into the lower airframe coupler	
Install the middle airframe over the eBay coupler verifying that the rail buttons are in alignment with each other	
Verify that the ballast upper bulkhead aligns with the ballast core tube and adjust if needed	
Verify that the middle airframe can be installed snug over the lower airframe	
Verify that the bolt holes on the middle airframe align with the radial bolt holes on the upper bulkhead	
Reinsert bolts 8-32 bolts	

Packing parachutes and shock chord

Pack recovery system (shock cord and parachutes). Triangle fold parachutes, then fold them into squares and wrap shroud lines around them.	
Pass side of shock cord that connects to electronics bay bulkhead through the middle airframe and link it to the U-bolt.	
Wrap Nomex blankets around parachutes pack with cellulose insulation	
Spiral feed shock cord into middle airframe and pack with more cellulose insulation	
Put shock cord with lower main and drogue chutes into middle airframe. Leave out one end to connect it to the upper airframe bulkhead.	
Connect upper airframe to the tender descender then to shock cord from the lower main	
Wrap Nomex blankets around upper main parachute	
Pack the upper main parachute into the upper airframe and pack with cellulose insulation	

Do the Retention eBay Checklist	Safety Officer:
Connect the shock cord with drogue and lower main parachute to the upper airframe bulkhead.	
Connect the shock cord with the upper main parachute to the upper airframe bulkhead.	
Connect the upper and middle airframe with nylon screws. (amount and type determined by ejection test)	

Table 8.15 Launch Vehicle Checklist

8.5.2 Electronics Bay **Checklist**

Electronics Bay Checklist	
Task	**Verified by (position listed if necessary)**
Tug on wire connectors to ensure they are all firmly connected.	
Shake electronics-bay unit, pull on bulkhead to ensure nothing is loose.	
Check integrity of screw/standoff/3D printed mounts for avionic components (Strattologgers, rotary switches, wire terminal blocks, batteries, tracker unit and antennas)	
Ensure both batteries are fully charged, use LiPo battery tester/monitor	
Switch ground test port into flight mode	
Plug each altimeter into a computer and verify that each is programmed for power mode 3 and for dual deployment at apogee and 700ft. Backup Strattologger has an apogee delay set for 1.5 s	
Check that electronics-bay bulkhead unit is wired properly, that all wire terminal connections are electrically corrected and secure to their corresponding channels on the altimeters (all tasks above are complete)	Safety Officer:
Install 2 7.4V LiPo batteries into the battery section with wires facing out	
Plug one battery into each of the male power connectors	
Apply electrical tape at connectors	

Use the zip tie to connect all wires to the sled, make sure none of them stick past the radius of the bulkhead	
Power on each altimeter and check for beep codes: Program mode 3 Make sure that main skips the backup code Backup gives the read out for 1.5 s Battery voltage is at least 8 V	
Create a closed circuit across the forward bulkhead terminal blocks and make sure each Strattologger gives continuity beeps	
Confirm that a proper telemetry signal can be received on powerup	
Inspect battery cover, make sure the pin holes are unobstructed, proper padding is present.	
Slide it over the batteries using the guide mounts and make sure the top is within the radius of bulkhead	
After the vehicle is placed on the pad	
Arm avionics, power on primary and backup flight systems with the two switches and the Tender Descender. Use a small flathead screwdriver, insert it in the two radial pressure holes facing away from the guide rail. Primary switch is on the left and backup is on the right	
One at a time listen to the Strattologger beeping code to verify that they are programed to fire their drogue and main charges at 700 ft, table guide will be pictured/linked	Launch Vehicle lead:
Connect to the tracker system with the ground station unit to verify that the primary altimeter and sensors are functioning properly.	

Table 8.16 Electronics Bay Checklist

8.5.3 Retention Electronics Bay Checklist

Retention Electronics Bay Checklist	
Task	Verified by (position listed if necessary)
Tug on wire connectors to ensure they are all firmly connected.	
Shake electronics-bay unit, pull on bulkhead to ensure nothing is loose.	
Check integrity of screw/standoff/3D printed mounts for avionic components (Strattologgers,	

rotary switches, wire terminal blocks, batteries, tracker unit and antennas)	
Ensure both batteries are fully charged, use LiPo battery tester/monitor	
Insert 2 LiPo batteries into the box above the servo motor Ensure wires are directed to the right	
Plug the LiPo batteries into the two connecters above the power switch, plug one of the batteries into the Strattologger power port, and the other to the BEC power plug	
Put electrical tape onto the power connectors	
Do a power on check by screwing the switch, and ensuring the Arduino switches on	
Confirm that a proper telemetry signal can be received on powerup	
Verify that the Strattologger beep codes indicate: Mode 3 Main set to 700 ft Battery voltage is at least 8 V	
Create a closed circuit across the tender descender output leads and make sure the Strattologger gives 2 continuity beeps	
Visually inspect wiring to make sure it is done correctly. Inspection must be done but at least 2 people	
Install the sleeve and align the large hole with Arduino USB port. Make sure no wires are pinched during installation process	
Install payload bulkhead over retention eBay using 4 ¼-20 bolts	
Install wires from Strattologger into bulkhead terminal block	

Table 8.17 Retention Electronics Bay Checklist

8.5.4 Ejection Test

Ejection Test	
Task	Verified by (position listed if necessary)
Complete the electronics bay and sled assembly checklists as normal, with the exception that no batteries be installed in the electronics bay	

Complete the ejection charge assembly checklist, following the differences noted for ground test operations. Note the quantity of black powder installed. Start with 3.5 grams, or last successful test quantity	
Complete the ballast, middle airframe, retention bay, and payload assembly checklists	
Install shear pins into upper coupler holes	
Place rocket on ground test stands, with the rail buttons facing upwards, such that the middle of the upper airframe is centered on one stand, and the transition between lower and middle airframe is centered on the other	
Ensure that no people are standing directly in front of or behind the rocket, within 75’	Safety Officer:
Cover the leads of the ground test jumper cable in electrical tape to insulate them from any electrostatic charge	
Plug the ground test jumper cable into the red JST connector within the upper-left vent hole on the airframe	
Verify that there is no voltage across the ground test power supply alligator clips using a multimeter	
One at a time, remove the electrical tape from the jumper cable leads, and clip it to one of the alligator clips of the ground test power supply	
Standing to the side of the rocket, rotate the ground test key to the TEST position	
Spool the ground test power supply out to a safe distance (>30ft) from the rocket, perpendicular to the direction the rocket is facing	
Ensure that all personnel are at least 30 feet from the rocket in all directions, and at least 75 feet from the front or back of the rocket	
Audibly brief all personnel present on misfire procedure – if the charge does not ignite, the rocket may not be approached for at least 60 seconds due to the potential that smoldering ematch remains may ignite the charge without warning	Safety Officer:
Give an audible countdown “Five…Four…Three…Two…One…Start”	
On “Start,” connect the ignitor wire to the ground test power supply.	

In the case of a misfire, failure to ignite, failure to separate, or other anomalous condition: Wait 60 seconds and instruct others to do so	
As soon as it is safe to do so, and all parts of the rocket have stopped moving, safe the eBay by rotating the key switch back to the FLIGHT position, and remove the jumper cable from the rocket	
Measure the separation achieved between the sections. NO-GO if under 10’	
Verify that all three parachutes are not constrained within any airframe or coupler. NO-GO if chutes remain constrained	
Inspect the parachutes and shock cords for excessive burns. NO-GO if chutes are visibly damaged	
Remove the middle airframe from the rocket, by unscrewing the four 8-32 bolts which connect it to the coupler, and pulling upwards.	
Inspect the ballast adapter piece. NO-GO if the print is excessively damaged or melted	
Inspect the charge and ematch remnants. NO-GO if unburnt powder remains	
If none of the NO-GO conditions are met, test can be considered successful. If a NO-GO condition occurred, perform adjustments to powder quantity (in 0.25g increments), shear pin distribution, charge packing strategy, recovery frame protection, or other elements in accordance with the failure mode.	

Table 8.18 Ejection Test Checklist

8.5.5 Payload Checklist

Payload Checklist	
Task	**Verified by (position listed if necessary)**
Charge payload, 2 transmitter and 2 retention batteries	
Check the voltages on the batteries with the voltmeter. Payload battery 14.8 V 2 receiver batteries 3.7 V E-bay/Retention system battery 7.4 V	

Full UAV check	
Manually check that when the lead screw is fully extended the sled can rotate. Turn off the power while doing this step	
Check that the scissor lift is operational	
Check that all arms fully unfold and that all locks have been deployed	
Check that the UAV boots up. To do that plug in the UAV battery.	
Check that the propellers spin using the controller	
Installing the Payload into the upper airframe	
Fold arms in	
Make sure all propellers are folded correctly	
Place the UAV on the scissor lift platform	
Clamp the UAV to the platform	
Actuate it down, by activating the scissor lift servo from a computer	
Activate the lead screw mechanism, that will pull the entire assembly inside the retention system	
4 #8-32 ¼ inch button head bolts are installed through the upper airframe and coupler into the bulkhead	
Check the assembly of the upper airframe by lifting it by the nose cone and shaking it	

Table 8.19 Payload Checklist

8.5.6 Payload Retention System Electronics Checklist

Payload Retention System Electronics Checklist	
Task	Verified by (position listed if necessary)

Ensure that the retention system is wired correctly and that all components are secure	Payload lead:
Tug on wires, shake unit and pull on the bulkhead to ensure nothing is loose.	
Ensure the battery is fully charged.	
Powering on the system	
Plug in the battery, verify status with power lights on components	
Test connection with ground station unit	

Table 8.20 Payload Retention System Electronics Checklist

Motor Checklist PPE required: Safety glasses	
Task	Verified by (position listed if necessary)
Ensure all metal components are in working condition and that the motor has not been removed from its package or tampered with in any way.	Mentor
Remove the motor from its packaging and assemble following the manufacturer instructions.	Mentor
Mount the motor on the launch vehicle, such that the aft closure of the motor casing rests against the underside of the internal ring on the sleeve	Mentor

Table 8.21 Motor Checklist

8.5.7 Structural Checklist

Structural Checklist	
Task	Verified by (position listed if necessary)
Visually inspect the airframe to ensure that it is in working condition with no dents or fractures.	Launch Vehicle Lead
Visually inspect the fins to ensure that they are in working condition with no bending or fractures.	Launch Vehicle Lead

Visually inspect the nose cone to ensure that it is in working condition with no dents or fractures.	Launch Vehicle Lead

Table 8.22 Structural Checklist

8.5.8 Launch Checklist

Launch Checklist		
Task	**Required Personnel**	**Initials**
Check the weather and wind speed at the launch site to ensure that the vehicle is safe to launch	Logistics Officer	Logistics Officer Log the conditions:
If the vehicle has been flown before, ensure that the Post-Flight Inspection Checklist has been completed. ⚠ Operation Hazard: If the vehicle has failed the inspection, it may only be flown after the failure mode has been determined and a mitigation plan has been written, implemented, and verified.	Safety Officer	Safety Officer
Do the ejection test following the Ejection Test checklist	Launch Vehicle Lead	Launch Vehicle Lead
Complete Launch Vehicle Checklist.	Launch Vehicle Lead	Launch Vehicle Lead
Complete EBay Checklist except the “After the vehicle is placed on the pad” section.	Launch Vehicle Lead	Launch Vehicle Lead

Complete Retention eBay Checklist	Launch Vehicle Lead	Launch Vehicle Lead
Complete Payload Checklist.	Payload Lead	Payload Lead
Complete Payload Retention System Electronics Checklist	Payload Lead	Payload Lead
Complete Motor Checklist	Mentor	Mentor
Complete Structural Checklist.	Launch Vehicle Lead	Launch Vehicle Lead
Conduct final visual inspection to ensure launch vehicle is completely assembled. The motor retention screws must be fully tightened, shear pins must be inserted properly, and the eBay must be secured with screws to the upper airframe.	Launch Vehicle Lead Payload Lead Team Captain Safety Officer	Team Captain
Verify with RSO that vehicle is safe to launch. ⚠Operation Hazard: The RSO has the final say on the safety of the vehicle.	RSO	Team Captain
Mount launch vehicle on the 1515 launch rail designated by the RSO. If there are high winds, the launch		Team Captain

angle may be moved up to 20° from the vertical to compensate. ⚠Setup Hazard: Mounting the vehicle on the launch rail should only occur after the range has been cleared. ⚠Operation Hazard: The launch angle should never be more than 20° from the vertical. Doing so violates the NAR High Power Rocket Safety Code and risks the vehicle colliding with personnel or objects on the field.		
Arm launch vehicle.	Team Captain	Team Captain
Complete the "After the vehicle is placed on the pad" section in the EBay Checklist.		Team Captain
Secure new ignitor in motor. ⚠Setup Hazard: To avoid premature ignition, do not connect the ignitor to the launch wire in this step.		Team Captain
Check that the launch wire is not live before connecting the ignitor to the launch wire. Check for igniter continuity. ⚠Setup Hazard: Ensure the ignitor wire is not live before connecting the ignitor to avoid premature ignition.		Team Captain

Table 8.23 Launch Checklist

8.5.9 Troubleshooting Checklist

Troubleshooting Checklist

Task	Verified by (position listed if necessary)
Inform the RSO of the issue and follow all instructions given by the RSO	Team Captain
Remove the launcher's safety interlock	Team Captain
Wait 60 seconds after the launch attempt before approaching the launch vehicle (as regulated by the NAR High Power Rocketry Safety Code)	Team Captain
Walk to the launchpad and disarm all electronics	Team Captain
Remove the launch vehicle from the launch rail	Team Captain
Reinstall the igniter	Team Captain
Mount launch vehicle on the launch rail	Team Captain
Re-arm electronics (see "After the vehicle is placed on the pad" section in the EBay Checklist) and the e-match igniter	Team Captain
Retry launching the launch vehicle	Team Captain

Table 8.24 Troubleshooting checklist

8.5.10 Post-Flight Inspection Checklist

Post-Flight Inspection Checklist		
Task	**Required Personnel**	**Initials**
Ensure all components are accounted for. This includes the lower airframe, middle airframe, upper airframe, eBay, retention eBay, nose cone, drogue parachute, 2 main parachutes, Nomex blankets, payload retention and the payload		Safety Officer

Visually inspect the airframe and fins for damage such as dents, zippering, holes, cracks, and anything that would prevent the vehicle from being flown again. This includes checking internal components such as u-bolts and bulkheads.		Safety Officer
Check that all components are attached appropriately. The nose cone should still be secured to its parachute by shock cord. The upper airframe should be secured to the nose cone by the retention system. The middle and lower airframes should still be secured to the eBay by four bolts on each end. The eBay should be secured to the lower main and drogue parachutes via shock cord. The boat tail should still be attached to the thrustplate by four bolts and the internal motor retention ring should still be secured by four bolts. All four fins should be secured in their slots and should not be able to wiggle.		Safety Officer
Check that the motor and the motor casing are still secured inside of the motor tube and that all ejection charges have been detonated. Properly dispose of the spent motor and ignitors.		Safety Officer
Check that there are no holes or burns in any of the parachutes and that none of the parachute's chords have broken.		Safety Officer
Open the eBay and ensure that all components are still secured within it. Visually inspect all electrical components for damage.		Safety Officer
Download flight data from both altimeters.		Safety Officer
If it was flown on the launch vehicle, visually inspect the UAV for damage such as dents, holes, cracks, and		Payload Lead

anything that would prevent the vehicle from being flown again.		
Verify that all payload electrical components are functional.		Payload Lead

Table 8.25 Post-Flight Inspection Checklist

9 PROJECT PLAN

9.1 TESTING

9.1.1 Shear Pin Testing

Objective: To validate the ability of the shear pins to hold the vehicle together until ejection.

Motivation: To ensure the vehicle does not prematurely separate and deploy parachutes.

Items Tested:

- Shear Pins

Success Criteria:

Success: The lower and upper vehicle sections do not separate under their own weight

Failure: The lower and upper vehicle sections separate under their own weight

9.1.1.1 Testing Procedures

Equipment:

- Full-scale launch vehicle

Setup:

The full-scale vehicle will be assembled with the desired number of shear pins securing the upper and lower sections. The vehicle will be suspended from the upper section and agitated to ensure the shear pins do not break until ejection.

Procedure:

1. The vehicle will be assembled in flight configuration
2. A designated team member will lift the vehicle by the upper section, and agitate it to ensure the full weight of the lower section is suspended by the shear pins
3. If the vehicle separates, more shear pins will be added, and the test will be performed again.

9.1.2 Ejection Charge Testing

Objective: To validate the ability of the ejection charge to separate the vehicle.

Motivation: To ensure the ejection charges will be capable of separating the launch vehicle in flight and release the parachutes.

Items Tested:

- Ejection charges
- Ejection charge wiring

Success Criteria:

Success: The ejection charges fire, separating the upper and lower sections of the vehicle cleanly, exposing the recovery bay

Failure: The ejection charges do not fire, not separating the upper and lower sections of the vehicle cleanly or exposing the recovery bay

9.1.3 Testing Procedures

Equipment:

- Full-scale launch vehicle
- Horizontal vehicle stands

Setup:

The full-scale vehicle will be assembled with the desired amount of black powder for ejection placed and wired into the recovery bay. Team members will clear the area and remotely detonate the black powder, then check for proper separation.

Procedure:

1. The vehicle will be assembled in flight configuration
2. A designated team member will transport the vehicle onto its test stands and connect the black powder ignitors to an unpowered detonator.
3. The team safety officer will clear the test area.
4. Once cleared, the ejection charges will be fired
5. If the charges do not ignite, the detonator will be disconnected, and team members will remain clear of the vehicle for at least 1 minute
6. After successful ejection, the vehicle will be checked for damage.

9.2 FULL SCALE PRE-FLIGHT TESTING RESULTS

9.2.1 Shear Pin Test

Once the launch vehicle was completely assembled for the ground ejection test, it was stood up vertically. Four shear pin holes were drilled at 90° intervals around the body, and nylon shear pins were inserted. The rocket was lifted by the upper airframe (above the shear pins). Upon verifying that the shear pins did not break under the static weight of the lower airframe. The upper airframe was shaken up and down to induce greater stress on the shear pins. Since the shear pins still did not break, we proceeded to ground eject testing to verify that not too many shear pins were used.

9.2.2 Ground Eject Test

The main charge was packed by our mentor using the tips of latex gloves to contain the black powder. This method was used over the use of charge caps due to them being untested. The circuit connections were tested for unwanted voltage. The upper and lower airframes separated completely, and the parachutes were ejected from the airframe onto the ground. The Nomex blanket properly shielded the parachute components from the detonation. The rocket successfully passed a ground ejection test, and the structural integrity of the rocket was not compromised by the charge.

9.2.3 Full Scale Test Launch 1 Successes

The rocket properly separated at apogee as predicted by the ground ejection test. The drogue and main parachutes deployed and opened as expected. The upper and lower airframes landed properly under their respective main parachutes with minimal damage.

9.2.4 Full Scale Test Launch 1 Failures

Though the separation of the airframe occurred properly at apogee, the tender descender detached prematurely at apogee as well. We suspect that the tender descender was wired erroneously. After apogee, the drogue parachute deployed properly which slowed the descent of the lower airframe. Unfortunately, the upper airframe and nosecone experienced freefall until the deployment of its main parachute at 600ft and it fully opening at 550ft. Due to the additional freefall velocity, a coupler in the upper airframe experienced tearing. The tender descender was incorrectly tethered to the shock cord instead of the bulkhead in the upper airframe, which caused a degree of tangling of the shock cord near the lower airframe.

9.3 REQUIREMENTS COMPLIANCE

In order to ensure the team's work is completed to the standards that are expected, the status of all requirements given in the handbook are tracked. The team is on track to meet all NASA Requirements by the competition as well as all team derived requirements aside from LV.3 (see Table 9.6) and PP.1 (see Table 9.10). More details about why LV.3 will not be met can be seen in Section 5.1.2. PP.1 was not met as the subscale construction was not completely done before the start of Winter Break. One of the team's General Members became a certified Lab Monitor for Washburn Machine Shop giving him the training and permission to safely open Washburn Machine Shop for use allowing us to work there will still following WPI's lab protocol.

9.3.1 General Requirements

1. General Requirements			
Ref	**Description**	**Verification Method**	**Status**
1.1	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams will submit new work. Excessive use of past work will merit penalties.	The team will demonstrate minimal use of past work in documentation and will not allow adult mentors to contribute beyond general advising.	IN PROGRESS

1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	The team will demonstrate a maintained project plan by including it in documentation and reviewing it at every officer meeting.	IN PROGRESS
1.3	Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.	The team will demonstrate this by notifying NASA of foreign nationals.	VERIFIED
1.4	The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include: 1.4.1. Students actively engaged in the project throughout the entire year. 1.4.2. One mentor (see requirement 1.13). 1.4.3. No more than two adult educators.	The team will demonstrate this by maintaining a list of active members and submitting a list of those who choose to attend the competition to NASA.	VERIFIED
1.5	The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the STEM Engagement Activity Report, by FRR. To satisfy this requirement, all events must occur between project acceptance and the FRR due date and the STEM Engagement Activity Report must be submitted via email within two weeks of the completion of the event. A sample of the STEM Engagement Activity Report is on page 35.	The team will demonstrate this taking attendance at events and submitting STEM Engagement Activity Reports on time.	VERIFIED
1.6	The team will establish a social media presence to inform the public about team activities.	The team will demonstrate this by consistently posting content on social media.	VERIFIED

1.7	Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient.	The team will demonstrate this by submitting documentation on time.	IN PROGRESS
1.8	All deliverables must be in PDF format.	The team will demonstrate this by ensuring all deliverables are PDFs and end in a .pdf file extension.	IN PROGRESS
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	The team will demonstrate this by utilizing Microsoft Word's automatic table of contents feature.	IN PROGRESS
1.10	In every report, the team will include the page number at the bottom of the page.	The team will demonstrate this by utilizing Microsoft Word's automatic page numbering feature.	IN PROGRESS
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	The team will inspect audio and visual equipment prior to presentations to ensure they are in working order.	VERIFIED
1.12	All teams will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted on the launch field. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on launch day. The exact cant will depend on launch day wind conditions.	The team will demonstrate this by designing and constructing the launch vehicle using 1515 rail buttons.	VERIFIED

1.13	Each team must identify a “mentor.” A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the NAR or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend launch week in April.	The team will demonstrate this by including the information of its mentor in documentation.	VERIFIED

Table 9.1 General Requirements

9.3.2 Vehicle Requirements

2. Vehicle Requirements			
Ref	**Description**	**Verification Method**	**Status**
2.1	Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team’s altitude score during Launch Week.	The team will demonstrate this by declaring a target altitude in the PDR.	VERIFIED
2.2	The vehicle will deliver the payload to an apogee altitude between 3,500 and 5,500 feet AGL. Teams flying below 3,000 feet or above 6,000 feet on Launch Day will be disqualified and receive zero altitude points towards their overall project score.	The team will perform an analysis of the launch vehicle to ensure that its apogee is within the specified range. This will also be demonstrated in the full-scale launch.	IN PROGRESS

2.3	The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner. The Altitude Award will be given to the team with the smallest difference between their measured apogee and their official target altitude on launch day. This altimeter may also be used for deployment purposes (see Requirement 3.4)	The team will demonstrate this by utilizing a Strattologger in all flights of the vehicle.	IN PROGRESS
2.4	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	After test flights, a post launch inspection will be conducted by the Safety Officer to determine if the vehicle could be relaunched.	VERIFIED
2.5	The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute. 2.5.1. Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length. 2.5.2. Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	The team will demonstrate this by including dimensions for shoulders in documents and listing all independent sections.	VERIFIED

2.6	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	The team will create a pit crew consisting of members from both the rocket and payload divisions. Prior to the competition, the pit crew will be tested to ensure that its members can prepare the vehicle for launch within a maximum of 2 hours and a goal of less than 30 minutes.	VERIFIED
2.7	The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.	An analysis of the electronics will be performed to ensure that the batteries are enough to stay active for a minimum of 2 hours with a goal of 3 hours.	VERIFIED
2.8	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.	The team will utilize only commercially available APCP solid motors and will demonstrate this capability at test launches.	VERIFIED
2.9	The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	The launch vehicle will never be connected to anything other than a 12-volt direct current firing system during test launches to demonstrate its independence of external ground support equipment.	VERIFIED

2.10	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR). 2.10.1. Final motor choices will be declared by the Critical Design Review (CDR) milestone. 2.10.2. Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing the safety margin. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.	The team will demonstrate this by declaring the final motor in the CDR and only purchasing that motor from a licensed vendor.	VERIFIED
2.11	The launch vehicle will be limited to a single stage.	The team will demonstrate this by including only one motor in all designs as specified in documentation.	VERIFIED
2.12	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class). The total impulse provided by a High School or Middle School launch vehicle will not exceed 2,560 Newton-seconds (K-class).	The motor declared in the CDR will not by greater than an L class motor.	VERIFIED

2.13	Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria: 2.13.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews. 2.13.2. Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank. 2.13.3. The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	The team will demonstrate compliance with this requirement by never including pressure vessels in designs or on the launch vehicle.	VERIFIED
2.14	The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	An analysis of the rocket will be performed using an OpenRocket simulation to ensure its static stability margin is greater than 2.0. Before being launched, center of gravity will be determined experimentally to verify the result from the analysis.	VERIFIED
2.15	Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	The team will demonstrate this by detailing any structural protuberances in the documentation.	VERIFIED

2.16	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	An analysis of the vehicle will be performed using an OpenRocket simulation to ensure it exits the rail at 52 fps.	VERIFIED
2.17	All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets. 2.17.1. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model. 2.17.2. The subscale model will carry an altimeter capable of recording the model's apogee altitude. 2.17.3. The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project. 2.17.4. Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.	The team will demonstrate this by including the design of the subscale in documentation along with submitting telemetry gathered by the vehicles electronics in the CDR.	VERIFIED

2.18.1	Vehicle Demonstration Flight - All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown must be the same rocket to be flown on launch day. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight: 2.18.1.1. The vehicle and recovery system will have functioned as designed. 2.18.1.2. The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project. 2.18.1.3. The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply: 2.18.1.3.1. If the payload is not flown, mass simulators will be used to simulate the payload mass. 2.18.1.3.2. The mass simulators will be located in the same approximate location on the rocket as the missing payload mass. 2.18.1.4. If the payload changes the external surfaces of the rocket (such as with camera hous- ings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.	The team shall demonstrate compliance with this requirement by including flight telemetry and photos of the vehicle, before and after, of all flights in documentation. Flight videos will be posted to the team's social media.	VERIFIED

	2.18.1.5. Teams shall fly the launch day motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the launch day motor or in other extenuating circumstances (such as weather). 2.18.1.6. The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle. 2.18.1.7. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO). 2.18.1.8. Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement. 2.18.1.9. Vehicle Demonstration flights must be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight must submit an FRR Addendum by the FRR Addendum deadline.		IN PROGRESS

2.18.2	Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown must be the same rocket to be flown on launch day. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria must be met during the Payload Demonstration Flight: 2.18.2.1. The payload must be fully retained until the intended point of deployment (if applicable), all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair. 2.18.2.2. The payload flown must be the final, active version.2.18.2.3. If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required. 2.18.2.4. Payload Demonstration Flights must be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.	The team will demonstrate this by including photographs of the mission in documentation, posting video on social media. An inspection of the payload will be preformed to determine if it sustained any damage during flight.	NOT VERIFIED

2.22	Vehicle Prohibitions 2.22.1. The launch vehicle will not utilize forward canards. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability. 2.22.2. The launch vehicle will not utilize forward firing motors. 2.22.3. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.) 2.22.4. The launch vehicle will not utilize hybrid motors. 2.22.5. The launch vehicle will not utilize a cluster of motors. 2.22.6. The launch vehicle will not utilize friction fitting for motors. 2.22.7. The launch vehicle will not exceed Mach 1 at any point during flight. 2.22.8. Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast). 2.22.9. Transmissions from onboard transmitters will not exceed 250 mW of power (per transmitter). 2.22.10 Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams. 2.22.11. Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of light- weight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	The team will demonstrate this by not utilizing any of these prohibited items and by not including any of them in documentation.	VERIFIED

Table 9.2 Vehicle Requirements

9.3.3 Recovery Requirements

3. Recovery Requirements			
Ref	**Description**	**Verification Method**	**Status**

3.1	The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO. 3.1.1. The main parachute shall be deployed no lower than 500 feet. 3.1.2. The apogee event may contain a delay of no more than 2 seconds. 3.1.3. Motor ejection is not a permissible form of primary or secondary deployment.	The team will demonstrate this requirement at launch by utilizing the drogue parachute and main parachute correctly.	IN PROGRESS
3.2	Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.	The team will conduct the necessary ejection tests.	VERIFIED
3.3	Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	The team will verify using MATLAB and will also use the Strattologger velocity to verify kinetic energy.	IN PROGRESS
3.4	The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	The team will demonstrate this requirement at launch by including two Strattologgers in the design.	VERIFIED
3.5	Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.	The team will demonstrate this by using two cell LiPo battery to power each altimeter	VERIFIED
3.6	Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	The team will demonstrate this requirement by including two rotary switches in the design.	VERIFIED

3.7	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	The team will demonstrate this at launch by using rotary switches, which cannot switch off due to flight forces.	VERIFIED
3.8	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	The team will demonstrate this by including design plans in documentation to show that the payload and recovery systems are completely independent.	VERIFIED
3.9	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	The team will demonstrate this at launch by using removable shear pins for the singular parachute compartment.	VERIFIED
3.10	The recovery area will be limited to a 2,500 ft. radius from the launch pads.	The team will analyze this using MATLAB.	VERIFIED
3.11	Descent time will be limited to 90 seconds (apogee to touch down).	The team will analyze this using OpenRocket	VERIFIED
3.12	3.12. An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver. 3.12.1. Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device. 3.12.2. The electronic tracking device(s) will be fully functional during the official flight on launch day.	The team will demonstrate this by including a GPS in every independent section.	VERIFIED

3.13	3.13. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing). 3.13.1. The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device. 3.13.2. The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics. 3.13.3. The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system. 3.13.4. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The team will demonstrate the electronics bay design on the subscale flight to ensure electronics do not experience interference and will demonstrate this at future launches of the full scale.	VERIFIED

Table 9.3 Recovery Requirements

9.3.4 Payload Requirements

4. Payload Requirements			
Ref	**Description**	**Verification Method**	**Status**

4.2	Teams will design a system capable of being launched in a high-power rocket, landing safely, and recovering simulated lunar ice from one of several locations on the surface of the launch field. The method(s)/design(s) utilized will be at the teams' discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring. If the team chooses to fly an additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.	The team will design a payload and retention system, then iterate on the design with data gathered from freestanding and onboard testing. After test launches, it will be inspected to ensure that	VERIFIED
4.3.3	The recovered ice sample will be a minimum of 10 milliliters (mL).	The team will design a sample recovery mechanism capable of shifting 10 mL of coarse grain material. The team will demonstrate its ability in a test prior to its integration with the launch vehicle.	VERIFIED
4.3.4	Once the sample is recovered, it must be stored and transported at least 10 linear feet from the recovery area.	The distance from the recovery area that the UAV travels will be measured using a measuring tape.	IN PROGRESS
4.3.5	Teams must abide by all FAA and NAR rules and regulations.	Operation of the UAV will be overseen by either the Safety Officer of Payload Lead to ensure rules and regulations are followed.	IN PROGRESS

4.3.6	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Any ground deployments must utilize mechanical systems.	The team will demonstrate this by only utilizing electrically powered systems in the payload and retention mechanisms.	VERIFIED
4.3.7	Any part of the payload or vehicle that is designed to be deployed, whether on the ground or in the air, must be fully retained until it is deployed as designed.	The team will design a mechanism that retains the payload on a sled in the upper airframe that can only be actuated by a lead screw, which will not be activated until cleared for deployment.	IN PROGRESS
4.3.7.1	A mechanical retention system will be designed to prohibit premature deployment.	The team will design a mechanical retention system consisting of a sled, lead screw, rotating mechanism, and corresponding servos that will be housed entirely within the upper airframe.	VERIFIED
4.3.7.2	The retention system will be robust enough to successfully endure flight forces experienced during both typical and atypical flights.	The team will conduct shake tests and drop tests of the payload and retention system. The payload and retention system will also be flown on a flight test.	IN PROGRESS
4.3.7.3	The designed system will be fail-safe.	The team will conduct tests of the payload and retention system mechanisms in a controlled environment to determine failure conditions.	IN PROGRESS

4.3.7.4	Exclusive use of shear pins will not meet this requirement.	The team will demonstrate this by not utilizing shear pins in the design of the payload retention system.	VERIFIED
4.4.1	Any experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event.	The team will demonstrate this by remotely controlling the payload retention system.	IN PROGRESS
4.4.2	Unmanned aerial vehicle (UAV) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAV.	The team will not design the payload to be deployed during descent as detailed in documentation.	VERIFIED
4.4.3	Teams flying UAVs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see https://www.faa.gov/uas/faqs).	Operation of the UAV will be overseen by either the Safety Officer of Payload Lead to ensure rules and regulations are followed.	IN PROGRESS
4.4.4	Any UAV weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.	The team will mark the number using a printed label.	NOT VERIFIED

Table 9.4 Payload Requirements

9.3.5 Safety Requirements

5. Safety Requirements			
Ref	**Description**	**Verification Method**	**Status**
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	The team will demonstrate that by including the checklists in the FRR reports	VERIFIED

5.2	Each team must identify a student safety officer who will be responsible for all items in sections 5.3. - 5.6.	The team demonstrated in the proposal that the safety officer, Veronika Karshina, has been chosen to be responsible for items in sections 5.3. - 5.6.	VERIFIED
5.3.1.	The role and responsibilities of the safety officer will include but are not limited to: Monitor team activities with an emphasis on safety during: 5.3.1. Design of vehicle and payload 5.3.2. Construction of vehicle and payload components 5.3.3. Assembly of vehicle and payload 5.3.4. Ground testing of vehicle and payload 5.3.5. Subscale launch test(s) 5.3.6. Full-scale launch test(s) 5.3.7. Launch day 5.3.8. Recovery activities 5.3.9. STEM Engagement Activities	Safety officer will demonstrate compliance with this rule by being present at all events listed in section 5.3. and emphasizing safety during these events	IN PROGRESS
5.3.2.	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The safety officer will demonstrate that by using checklists and signing off steps after verifying their completion during completing construction, assembly, launch, and recovery activities	IN PROGRESS
5.3.3.	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	The safety officer will demonstrate that by providing hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data in proposal, PDR, CDR or the FRR	VERIFIED

5.3.4.	Assist in the writing and development of the team’s hazard analyses, failure modes analyses, and procedures	The team will demonstrate that by leaving the safety officer responsible for writing and developing the hazard analyses, failure modes analyses, and procedures	VERIFIED
5.4.	During test flights, our team will abide by the rules and guidance of the local rocketry club’s RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club’s President or Prefect and RSO before attending any NAR or TRA launch.	The team will demonstrate that by creating and following a checklist that will include abiding to rules and guidance of the RSO	VERIFIED
5.5.	Teams will abide by all rules set forth by the FAA.	The team will inspect the design and the rocket/payload to ensure that FAA regulation are met. The team will follow a checklist before launch to ensure that all rules set forth by the FAA are met	IN PROGRESS

Table 9.5 Safety Requirements

9.3.6 Team Derived Launch Vehicle Requirements

Team Derived Launch Vehicle Requirements

Ref	Requirement	Justification	Verification Method	Status
LV.1	The vehicle must have a ballast system.	The rocket will weigh more than in simulations, so it must weigh more than in simulations in order to reach its target apogee.	The team will test this in test launches.	VERIFIED

LV.2	The vehicle's fin can must be assembled using bolts rather than epoxy.	Will reduce shipping prices via flat-packing and will increase ease of maintenance.	The team will confirm this by checking quotes from shipping companies.	VERIFIED
LV.3	The vehicle must reuse last year's nose cone	Reduction of costs to fit within budget.	The team will demonstrate this by including it in documentation and construction	NOT VERIFIED
LV.4	The vehicle must use a two-cell battery	Dimension (smaller more compact and significantly less in diameter), doesn't need as much voltage (doesn't need more than 7.2 v), relatively low C rating (maximum continues discharge rate) Straloggers say it gets damaged more than 5A	The team will demonstrate this by including it in documentation and construction	VERIFIED
LV.5	The airframe must have a 6 inch diameter	In order to reuse the nose cone the team already has, the diameter of this year's rocket must match that of last year.	The team will demonstrate this by including it in documentation and construction	VERIFIED
LV.6	Rocket must have waterproof finish	There is a high probability of the rocket landing in snow.	The team will test this by placing Blue Tube in crushed ice for at least 10 minutes without delaminating.	VERIFIED
LV.7	Material and components must be accounted for before leaving for any launch	All parts, both primary and secondary, as well as tools, must be present for each launch	A launch vehicle checklist will be utilized to ensure required components are accounted for.	IN PROGRESS

LV.8	The separated airframe will not come into excessive contact while during descent	Avoiding excessive contact will minimize potential damage to airframe components	Shock cord will be measured to a total length of three times the length of the entire launch vehicle, then signed on the construction checklist	VERIFIED
LV.9	All deployable recovery components will be correctly packed	Proper packing of parachutes, Nomex blankets and shock cord will ensure a safe deployment and prevent damage to the materials	Parachutes will be packed so that they may be easily deployed, and paired with appropriate Nomex blankets and shock cord	IN PROGRESS
LV.10	Altimeters must be programmed for parachute deployment at apogee and 650ft	Proper deployment of parachutes will result in recovery of the launch vehicle and payload	A primary and redundant secondary altimeter will be used to fire ejection charges	VERIFIED
LV.11	All data-collecting devices will be powered on and transmitting	Failure to power-on pertinent electronics will result in not collecting necessary flight metrics or mission goals	A electronics checklist will be utilized for power on status, and a computer will be set to receive transmissions from any wireless devices onboard the launch vehicle	IN PROGRESS
LV.12	Launch vehicle will be set up on the launchpad	Only licensed persons shall be allowed to configure the rocket on the launch rail	A level II high powered rocketry certified (NAR or Tripoli) individual will attend all launch events	IN PROGRESS

Table 9.6 Team Derived Launch Vehicle Requirements

9.3.7 Team Derived Recovery Requirements

Team Derived Recovery Requirements				
Ref	**Requirement**	**Justification**	**Verification Method**	**Status**

RC.1	The recovery system must utilize a Tender Descender.	This needs to be used in order to allow the upper and lower bodies of the launch vehicle to descend separately while having all parachutes stored in the same cavity.	Will be included in design documentation and demonstrated on the subscale flight.	VERIFIED
RC.2	The recovery system must utilize four Jolly Logic Chute Releases.	This is required so that the parachutes will not deploy on drogue deployment as all parachutes are stored in the same cavity.	Will be included in design documentation and demonstrated on the subscale flight.	VERIFIED

Table 9.7 Team Derived Recovery Requirements

9.3.8 Team Derived Payload Requirements

Team Derived Payload Requirements				
Ref	**Requirement**	**Justification**	**Verification Method**	**Status**
PL.1	The payload and retention system must weigh less than 7 pounds.	In order to keep the upper body below the 75 lbf*ft maximum kinetic energy on landing to comply with requirement 3.3.	Calculate total weight of payload and retention system in solid works assembly.	VERIFIED
PL.2	The UAV must have a flight time of at least 4 minutes	In order to ensure completion of the mission increased flight time is required to account for any possible pilot error.	A test flight will be conducted to determine its maximum flight time	VERIFIED
PL.3	The retention system must fit inside of a 26 in long 6 in diameter section of blue tube.	To comply with derived requirement LV.5.	The design of the system will be detailed in documentation. It will be test fit to ensure sizing.	VERIFIED
PL.4	The retention system must autonomously orient and translate the UAV into deployment position	In order to ensure clean and precise release of UAV and ensure mission success	The system will be tested at least 4 different orientations that are at least 30 degrees apart.	IN PROGRESS

PL.5	The UAV must be able to unfold to a larger size	In order to increase stability of the UAV	The design of the system will be detailed in documentation.	VERIFIED
PL.6	The payload must be deployed post landing	In order ensure the safety of the UAV and retention system upon landing	The design of the system will be detailed in documentation.	VERIFIED
PL.7	The UAV propellers must fold	In order to ensure packing proper packing inside of the rocket frame	The system will be tested to ensure that the propellers correctly unfold on activation.	VERIFIED
PL.8	The soil sampling mechanism must be able to hold at least 20mL of unknown sample	In order to ensure we account for possible losses in transit or during the soil sampling process	The volume of the system will be calculated to ensure it is at least 20mL	VERIFIED

Table 9.8 Team Derived Payload Requirements

9.3.9 Team Derived Safety Requirements

Team Derived Safety Requirements				
Ref	**Requirement**	**Justification**	**Verification Method**	**Status**
SF.1	Solder joints must not be cold solder joints.	Cold solder joints are significantly weaker than a proper joint. This could cause breaks in the joint, creating discontinuities that prevent the electronics from functioning and possibly preventing deployment.	Solder joints on each electrical system will be visually inspected at construction and must be signed off on construction checklists.	VERIFIED

SF.2	Components used, created, and constructed will adhere to all on-campus lab and workshop requirements and regulations.	Regulations enforced by the institution that is allowing us to use their facilities should be adhered to in order to best protect students and help further safety practices.	Team members will be strongly encouraged to become basic users in facilities used in the construction of the launch vehicle and payload. Regulations of these facilities will be strictly abided by.	VERIFIED
SF.3	Prior to travel, any member traveling will need to fill out a travel waiver form.	This is required by WPI to ensure the safety of students on trips.	Prior to travel, members will be checked to ensure they submitted a waiver.	VERIFIED

Table 9.9 Team Derived Safety Requirements

9.3.10 Team Derived Project Plan Requirements

Team Derived Project Plan Requirements				
Ref	**Requirement**	**Justification**	**Verification Method**	**Status**
PP.1	All construction must occur outside of WPI vacations.	During vacation, most members are not available. Machine shops and labs are closed as lab monitors also leave for vacation.	The team will log construction events and ensure they do not occur during vacation.	NOT VERIFIED
PP.2	Money raised from corporate philanthropy will be used to subsidize flights as much as possible.	SGA is able to pay for all travel costs except for airfare. Only out of pocket or donated money can be used for flights.	The team will track sponsorship funds in the budget and ensure they are not used for other expenses.	VERIFIED
PP.3	The team will elect an interim Payload Lead and Rocket Lead between the dates of 1/9/20 and 3/1/20.	Both the Rocket Lead and Payload Lead are unable to attend the competition.	The interim executives will be reported to NASA.	VERIFIED

Table 9.10 Team Derived Project Plan Requirements

9.4 BUDGETING

9.4.1 Launch Vehicle Budget

Full Scale							
Component	**Specific Item**	**Quantity**	**Price**	**Total**	**Vendor**	**Comments**	**Purchased/ Have**
Nose Cone	6” Fiberglass Nose Cone	0	$139.00	$0.00	AMW Pro-X	Already Owned	Yes
Nose Cone Tip	Metal Tip for DX3 Massive	1	$20.00	$20.00	MadCow Rocketry		Yes
Parachute Deployment	Tender Descender	1	$129.00	$129.00	Tinder Rocketry		Yes
Parachute Deployment	Chute Release	4	$129.95	$519.80	Jolly Logic		Yes
Main Tube	Blue Tube 2.0 6”x0.074”x48”	2	$66.95	$133.90	Always Ready Rocketry	Airframe	Yes
Fin Core	Foam - .125" x 24" x 48" 6PCF Polyurethane Foam	1	$24.00	$24.00	ACP Sales		Yes
Fin Exterior	Carbon Fiber - 5.7 oz. 2x2 Twill Weave Carbon Fiber Fabric 50"	3	$39.00	$117.00	ACP Sales		Yes
Motor Tube	75mm Blue Tube	1	$32.05	$32.05	Apogee		Yes
Inner Tube	Blue Tube 2.0 6’x0.077”x48”	1	$66.95	$66.95	Always Ready Rocketry		Yes
Motor Case	Cesaroni 75mm 3-Grain Hardware Set	1	$388.42	$388.42	Apogee		No
Flight Computer	Strattologger CF	3	$48.89	$146.7	Perfect Flite		Yes
Arming Switch	Mini On/Off Push-Button Switch	4	$.95	$3.80	Adafruit		Yes
Wiring	Wiring	0	$5.00	$0.00	WPI	Already Owned	Yes
Main Engine	Cesaroni L1050 C-Star Rocket Motor	1	$279.00	$279.00	AMW		Yes
Separation Charges	Black Powder Charges	0	$0.00	$0.00	WPI	Already Owned	Yes
Shear Pins	2-56x1/2” Nylon Screws	0	$10.64	$0.00	McMaster-Carr	Already have	Yes

Rail Buttons	Large Airfoiled Rail Buttons (fits 1.5” rail – 1515)	2	$11.17	$22.34	Apogee Rockets		Yes
Nomex Blankets	Sunward 18in Nomex Blanket	2	$10.91	$21.82	Apogee Rockets	Already Owned	Yes
Igniter	Full Scale Igniter	0	$0.00	$0.00	WPI	Already Owned	Yes
Parachutes	36” Drogue	1	$33.00	$33.00	Spherachutes	Drogue	Yes
Parachutes	108” Upper	1	$176.00	$176.00	Spherachutes	Main	Yes
Parachutes	96” Lower	1	$136.00	$136.00	Spherachutes	Main	Yes
Shock Cord	BlueWater 1" Climb-Spec Tubular Webbing - 30 ft.	2	$13.50	$27.00	REI		Yes
U-Bolt	U-Bolts	0	$0.00	$0.00	WPI	Already Owned	Yes
Drop Cover	10 ft. x 25 ft. Clear 3.5 mil Plastic Sheeting (2-Pack)	1	$17.98	$17.98	Home Deopt		No
Quick Links	316 Stainless Steel Quick Link	0	$5.08	$0.00	McMaster-Carr	Already Owned	Yes
Swivel Mounts	Swivel 12/0 1500 lb	0	$4.00	$0.00	AMW ProX	Already Owned	Yes
Nuts/Bolts/ Washers	Assorted	0	$15.00	$0.00	McMaster-Carr	Already Owned	Yes
Blue Painters Tape	ScotchBlue 1.88”x60yds	0	$6.58	$0.00	Home Depot	Already Owned	Yes
Gorilla Tape	Gorilla 1-7/8x35yds	0	$8.98	$0.00	Home Depot	Already Owned	Yes
Organizer	15-Compartment Interlocking Small Parts Organizer in Black	1	$11.97	$12.72	Home Depot	2 pack	No
Thrust Plate	Aluminum Plate - Multipurpose 6061 Aluminum	1	$12.53	$12.53	McMaster		Yes
Sleeve and Collar	Aluminum Cylinder - Multipurpose 6061 Aluminum 3-1/8" Diameter	1	$34.85	$34.85	McMaster		Yes

Ballast Core Tube	5.5" x .077 wall x 16" Bluetube Coupler	1	$25.95	$25.95	Always Ready Rocketry		Yes
Aft Bulkhead Forward Retention Plate	9 ply birch aircraft plywood, 1/2"x12"x24"	1	$12.82	$12.82	National Balsa		Yes
Aft Bulkhead Rear Plate	5 ply birch aircraft plywood, 1/2"x12"x24"	2	$9.15	$18.30	National Balsa		Yes
Key switch for ground testing	DPDT Keylock switch	1	$16.18	$16.18	Digikey		Yes
Ebay aft bulkhead assembly	Alloy Steel BHCS, 2.25" long, 10-32 thread, 50-pack	1	$13.15	$13.15	McMaster		Yes
Ebay forward bulkhead recovery harness	5/16 - 18 U-bolt, 1.75" ID	1	$1.36	$1.36	McMaster		Yes
Various ebay electronics mounts	M2x6mm bolts, 100-pack	1	$6.53	$6.53	McMaster		Yes
Various ebay electronics mounts	4-40x1/4" bolts, 100-pack	1	$3.39	$3.39	McMaster		Yes
Bulkhead/motor retention	1x 6.25in OD x 10" round bar	1	$87.19	$87.19	Midwest Steel Supply		Yes
Bulkhead/motor retention	1x 4in OD x 6" round bar	1	$28.69	$28.69	Midwest Steel Supply		Yes
Ebay tension spine	0.75"x6"x12" 6061-T6 Aluminum bar stock	1	$23.37	$23.37	Midwest Steel Supply		Yes
Ballast Steel Rings	12"x48" 0.135" Mild Steel Hot Roll Sheet	1	$53.86	$53.86	Online Metals		Yes
Filler ballast rings	Acetal/Delrin Sheet, 1/8"x12"x48"	1	$48.90	$48.90	McMaster		Yes
RF Shielding for ebay	.032" Aluminum sheet, 12"x36"	1	$13.91	$13.91	Online Metals		Yes
Fiberglassing	6 Ft of Fiberglass 6.0 Light Natural 7.6 inch dia (12in flat Clear) Treated Shrink Tubing	2	$80.12	$160.24	Soller Composites		Yes

Fiberglassing	6 Ft of Fiberglass 6.0 Light Natural	1	$19.54	$19.54	Soller Composites		Yes
3D Printing	NylonX Carbon Fiber Filament - 1.75mm (0.5kg)	1	$61.63	$61.63	MatterHackers		Yes
Brass Heat-Set Inserts for Plastic	1/4"-20 Thread Size, 0.312" Installed Length	1	$14.82	$14.82	McMaster		Yes
Brass Heat-Set Inserts for Plastic	1/4"-20 Thread Size, 3/8" Installed Length	1	$8.14	$8.14	McMaster		Yes
Black-Oxide Alloy Steel Flanged Button Head Screw	1/4"-20 Thread, 2" Long	1	$8.46	$8.46	McMaster		Yes
SBR Rubber Grommet	for 1/4" Hole Diameter and 3/32" Material Thickness, 1/8" ID	1	$2.03	$2.03	McMaster		Yes
White Delrin® Acetal Resin Sheet	1/16" Thick, 12" x 12"	1	$9.36	$9.36	McMaster		Yes
Multipurpose Neoprene Foam Strip	Medium, 12" Wide, 1/8" Thick, 12" Long	1	$6.96	$6.96	McMaster		Yes
18-8 Stainless Steel Socket Head Screw	1/4"-20 Thread Size, 3-3/4" Long	1	$1.00	$1.00	McMaster		Yes
Corrosion-Resistant 3003 Aluminum Tube	Telescoping, 0.014" Wall Thickness, 1/8" OD, 1 Foot Long	1	$2.21	$2.21	McMaster		Yes
Male-Female Threaded Hex Standoff	Aluminum, 3/16" Hex Size, 1/4" Long, 4-40 Thread Size	16	$.36	$5.76	McMaster		Yes
Potential Additional Fiberglass	6 Ft of Fiberglass 6.0 Light Natural	1	$19.56	$19.56	Soller Composites		No
Potential Additional Upper Airframe	6" x .074 wall x 48" Airfraime/MMT	1	$66.95	$66.95	Always Ready Rocketry		No
Additional Coupler	6" x .077 wall x 48" Full Length Bluetube Coupler	1	$66.95	$66.95	Always Ready Rocketry		No
Parachute	144” Spherachute	1	$244.00	$244.00	Spherachutes		No
Nose Cone	Fiberglass Nose Cone 6”	1	$104.99	$104.99	PublicMissles		No

Subscale							
Main Tube	4”x0.062”x48”	2	$38.95	$77.90	Always Ready Rocketry		Yes
Nose Cone	Fiberglass 4" Filament Wound 5:1 Ogive	1	$79.95	$79.95	Madcow Rocketry		Yes
Motor Tube	2.15”x.062”x24”	1	$23.95	$23.95	Always Ready Rocketry		Yes
Inner Tube	4”x0.062”x8”	2	$10.95	$21.9	Always Ready Rocketry		Yes
Wiring	Wiring	0	$0.00	$0.00	WPI	Already Owned	Yes
Parachutes	18” Spherachute	1	$15.00	$15.00	Spherachutes	Drogue	Yes
Parachutes	24” Spherachute	1	$19.00	$19.00	Spherachutes	Upper Main	Yes
Parachutes	30” Spherachute	1	$27.00	$27.00	Spherachutes	Lower Main	Yes
Separation Charges	Black Powder Charges	0	$0.00	$0.00	WPI	Already Owned	Yes
Overhead	Miscellaneous Bits and Shipping	1	$100.00	$100.00	Various		
	316 Stainless Steel Washer for Number 8 Screw Size, 0.174" ID, 0.375" OD	1	$3.45	$3.45	McMaster		Yes
	Low-Strength Steel Hex Nut Zinc-Plated, 8-32 Thread Size	1	1.65	1.65	McMaster		Yes
	Button Head Hex Drive Screw Black-Oxide Alloy Steel, 8-32 Thread, 1-1/8" Long	2	10.82	21.64	McMaster		Yes
	Button Head Hex Drive Screw Black-Oxide Alloy Steel, 8-32 Thread, 1/4" Long	1	11.34	11.34	McMaster		Yes
	Button Head Hex Drive Screw Black-Oxide Alloy Steel, 8-32 Thread, 3/8" Long	1	14.05	14.05	McMaster		Yes
	Pull- Out Resistant Screw-to-	1	6.71	6.71	McMaster		Yes

	Expand Inserts for Plastic, 8-32 Thread Size, 1 Fin						
Motor Casing	CESARONI 54MM 3-GRAIN CASE	1	86.87	86.87	Apogee Components		Yes
Aft Closure	CESARONI 54MM STANDARD REAR CLOSURE	1	53.52	53.52	Apogee Components		Yes
Motor	CESARONI - P54-3G CLASSIC (J295)	1	115.14	115.14	Apogee Components		Yes
Rail Buttons	STANDARD AIRFOILED RAIL BUTTONS (FITS 1" RAIL - 1010)	2	7.83	15.66	Apogee Components		Yes
3D Printing	OVERTURE PETG Filament 1.75mm with 3D Build Surface 200 x 200 mm 3D Printer	1	19.89	19.89	Amazon		Yes
Fiberglassing	19.56 6 Ft of Fiberglass 6.0 Light Natural and 1 51 7.6 inch dia (12in flat Clear) Treated Shrink Tubing	1	80.12	80.12	SollerComposites		Yes

Table 9.11 Launch Vehicle Budget

9.4.2 Payload Budget

Payload							
Component	**Specific Item**	**Quantity**	**Price**	**Total**	**Vendor**	**Comments**	**Purchased/ Have**
UAV Motor	T-MOTOR F40 PRO III MOTOR - 2400KV	4	$26.9	$107.6	Pyrodrone		Yes
High Gauge Wire	22AWG colored wire	1	$15.99	$15.99	Amazon		No
Transceiver	NRF24L01	4	$5.00	$20.00	Amazon		No
FPV Camera	FX798T micro FPV camera	1	$30.00	$30.00	GetFPV	Possible option	Yes
FPV Monitor	4.3” LM403 LCD FPV Monitor	1	$70.00	$70.00	GetFPV	Possible option	No
Controller & Receiver	Flysky FS-i6X	1	$54.00	$54.00	Amazon	Possible option	Yes
3D Printer Filament	Nylon X	1	$70.00	$70.00	-		No
3D Printer Filament	PLA	2	$30.00	$60.00	-		No

Propellers	DJI - Quick-release Folding Propellers for DJI Spark Quadcopter (Pair) - Gray	2	$12.99	$25.98	Best Buy		Yes
	1018 Carbon Steel Precision Acme Lead Screw	1	$23.40	$23.40	McMaster		Yes
	Oil-Embedded Flanged Sleeve Bearing	6	$.81	$4.86	McMaster		Yes
	1/4"-20 Thread Size Flange Nut for Ultra-Precision Lead Screw	1	$17.45	$17.45	McMaster		Yes
	Stainless Steel Ball Bearing	10	$6.61	$66.10	McMaster		Yes
Flight Computer	Diatone Mamba F722S Stack - 506 50A Dshot1200 6S ESC	2	$79.99	$159.98	GetFPV		Yes
3D Printer Bit	All Metal Hotend Kit for Creality CR-10 / CR10S / CR20 / Ender 2, 3, 5 Printers	1	$63.50	$63.50	MicroSwiss		Yes
UAV Chassis	Lumenier 3K Carbon Fiber Sheet - 2mm Thick (200x300mm)	1	$34.99	$34.99	GetFPV		Yes
UAV Chassis	Lumenier 3K Carbon Fiber Sheet - 3mm Thick (200x300mm)	1	$44.99	$44.99	GetFPV		Yes
UAV Battery	INFINITY 2200MAH 4S 85C GRAPHENE TECH LIPO BATTERY	1	$27.99	$27.99	PyroDrone		Yes
UAV Receiver	FRSKY R-XSR S.BUS/CPPM 8/16 CHANNEL MICRO RECEIVER	1	$19.99	$19.99	PyroDrone		Yes
UAV Transmitter	FRSKY TARANIS X9 LITE RC TRANSMITTER - Black	1	$69.99	$69.99	PyroDrone		Yes
UAV FPV Camera	RunCam Micro Eagle - Lumenier Edition (White)	1	$46.99	$46.99	GetFPV		Yes
UAV FPV Transmitter	TBS Unify Pro32 HV 5.8GHz Video Transmitter (MMCX)	1	$49.95	$49.95	GetFPV		Yes

UAV FPV Antenna	XILO AXII Straight MMCX 5.8GHz Antenna (RHCP)	1	$9.99	$9.99	GetFPV		Yes
UAV GPS	Matek M8Q-5883 GPS Module	1	$28.99	$28.99	GetFPV		Yes
Sample Drive Motor	Pololu 1000:1 Micro Metal Gearmotor HPCB 12V	1	$24.95	$24.95	Pololu		Yes
E-bay/ retention system battery	Turnigy nano-tech 370mah 2S 25~40C Lipo Pack	4	$4.25	$17.00	HobbyKing		Yes
Connector wires for the batteries	Male JST Battery Pigtail 12cm Length	1	$2.19	$2.19	HobbyKing		Yes
Wiring the pyro leads from the e-bay	Terminal block	4	$3.55	$14.2	Apogee Components		Yes
Switching e-bay on/off when in rocket	Electronics rotary switch	2	$10.33	$20.66	Apogee Components		Yes
Mounting the altimeters to the e-bay sled	Altimeter mounting posts	3	$3.83	$11.49	Apogee Components		Yes
Interfacing with Strattologgers	DT4U USB Data Transfer Kit	2	$22.46	$44.92	PerfectFlite Direct		Yes
Tracking the location of the rocket	DIYmall 6M GPS Module	2	$17.00	$34.00	Amazon		Yes
Sensing orientation/accel of the rocket	MPU-6050 gyroscope/accelerometer	1	$8.99	$8.99	Amazon		Yes
Wireless comms from the e-bay	900Mhz Antenna Kit and connector	1	$13.50	$13.50	Adafruit		Yes
High frequency data logging	FRAM Breakout board	2	$9.95	$19.90	Adafruit		Yes
Retention system lead screw	Rotary encoders	1	$8.54	$8.54	Amazon		Yes
Payload Retention Motors	HS-785HB Servo	2	$49.99	$99.98	ServoCity		Yes
	4mm 24 Tooth Spline Servo to Shaft Couplers	1	$12.99	$12.99	ServoCity		Yes

	Female Threaded Round Standoff, Aluminum, 1/2" OD, 2" Long, 1/4"-20 Thread Size	3	$2.88	$8.64	McMaster		Yes
	Female Threaded Round Standoff, Aluminum, 1/2" OD, 1" Long, 1/4"-20 Thread Size	2	$1.10	$2.20	McMaster		Yes
	Steel Eyebolt with Shoulder - for Lifting, 1/4"-20 Thread Size, 1" Thread Length	1	$3.21	$3.21	McMaster		Yes
	Aluminum Screw-to-Expand Insert for Plastic, 8-32 Thread Size, 1/4" Installed Length	1	$6.10	$6.10	McMaster		Yes
	Female Threaded Round Standoff, Aluminum, 1/2" OD, 1-1/2" Long, 1/4"-20 Thread Size	4	$2.71	$10.84	McMaster		Yes
	2 pack ultrafire 18 650 battery 2600mAh 3.7V Li-ion	1	$15.99	$15.99	Amazon		Yes
BEC servo power regulator	HENGE UBEC 6V 6A 2-6S Lipo NiMh Battery Switch Mode BEC	6	$7.41	$44.46	Banggood		Yes
Embedded micro processor	Arduino Nano	1	$19.88	$19.88	Amazon		Yes
Radio Transceiver	RFM95W LoRa Radio Transceiver Breakout	1	$19.04	$19.04	Amazon		Yes
Arduino mounting bolt	Black-Oxide Alloy Steel Socket Head Screw	5	$5.03	$25.15	McMaster		Yes
Arduino mounting nut	18-8 Stainless Steel Narrow Hex Nut	1	$5.34	$5.34	McMaster		Yes
Solder Wick	NTE Electronics SW02-10 No-Clean Solder	1	$6.48	$6.48	Amazon		Yes

	Wick, 4 Blue.098" Width, 10' Length						
E-bay/retention system battery	Turnigy nano-tech 370mah 2S 25~40C Lipo Pack	2	$4.25	$8.50	Hobbyking		Yes
Machining	2mm Carbon Sheet - 200 x 300 mm	1	$25.23	$25.23	Hobbyking		Yes
Machining	3mm Carbon Sheet - 12" x 24"	1	$213.30	$213.30	DragonPlate		Yes
Machining	5mm Carbon Sheet - 400 x 500 mm	1	$159.14	$159.14	RockWest		Yes
	HS-765HB Servo	1	$39.99	$39.99	Servocity		Yes
	0.500" x 1.00" Servo Shafts	1	$7.99	$7.99	Servocity		Yes
	Actobotics Standard Hub Horns	2	$5.99	$11.98	Servocity		Yes
	HS-785HB Servo	1	$49.99	$49.99	Servocity		Yes
Precision Acme Externally Threaded Nut	Right Hand, 360 Brass, 1/4"-20 Thread Size	1	$23.66	$23.66	McMaster		Yes
Economy Carbon Steel Tap	Taper Chamfer, 9/16"-18 Thread Size, 1-21/32" Thread Length	1	$8.54	$8.54	McMaster		Yes
	Oversized Multipurpose 6061 Aluminum Sheet 3/8" Thick	1	$33.01	$33.01	McMaster		Yes
Brass Heat-Set Inserts for Plastic	Flanged, 8-32 Thread Size, 0.185" Installed Length	1	$11.24	$11.24	McMaster		Yes
	M1.6 X 5mm Slotted Countersunk Screws (DIN 963) - A2 Stainless Steel	1	$18.52	$18.52	ACCU		Yes
Additional Motor	T-Motor F40 Pro III 2400Kv Racing Motor	1	$26.90	$26.90	Pyrodrone		No

Motor	1000:1 Micro Metal Gearmotor HPCB 12V	1	$24.95	$24.95	Pololu		No
	The FrSky X4R-SB - 3/16 Channel Receiver w/ SBUS	1	$24.99	$24.99	Get FPV		No

Table 9.12 Payload Budget

Budget	
Total Allotted	**$4,124.84**
Sponsors and Fundraisers	**$1,466.05**
Total Remaining	**$0.00**

Table 9.13 Total Budget

9.4.3 Additional Funding

Our total remaining for both the components budget, in the table above, and the logistics budget, not depicted, is zero. This is the total spent from our original budget given to us through Worcester Polytechnic Institute's (WPI) Student Government Association (SGA). A more substantial budget is given to WPI's American Institute of Aeronautics and Astronautics (AIAA) Chapter, of which our USLI team is a subcommittee of. Our team is then given a portion of the overall AIAA budget, $4124.84 for components and $4033.44 for logistics. Our logistics budget may be used for hotels, buses, and shipping expenses. It may also be used for any component purchasing, but no amount of the component budget may be used for logistics. Neither allocation of funds can be used for the payment of flights.

We plan to subsidize the cost of flights and polos for students with the use of our sponsorship and fundraising money, which is non-restricted. In lieu of adding the sponsorship and fundraising money to our components or logistics budget, we have opted to complete funding requests (FR). This is a way of asking SGA for more funds to purchase specific items that we detail and present to them. This has worked in the past, as we have had some FR's approved throughout the year, including a substantial one for logistics. We believe that since our budget is near zero and we will only need to purchase a couple more items, that SGA will approve additional funds. If not, we are prepared to use sponsorship and fundraising money for essential component purchasing.

9.5 TIMELINE

The team's schedule is organized in the following Gantt Chart

	ⓘ	Name	Duration	Start	Finish
1		Recruiting	10 days	8/22/19 8:00 AM	8/31/19 5:00 PM
2	▦	Orientation	5 days	8/30/19 8:00 AM	9/3/19 5:00 PM
3		**Proposal**	**14 days?**	**9/4/19 8:00 AM**	**9/17/19 5:00 PM**
4		Brainstorming	3 days	9/4/19 8:00 AM	9/6/19 5:00 PM
5	▦	Concept Selections	1 day	9/7/19 8:00 AM	9/7/19 5:00 PM
6		Outline	3 days	9/8/19 8:00 AM	9/10/19 5:00 PM
7		Proposal Writing	5 days?	9/11/19 8:00 AM	9/15/19 5:00 PM
8		Revision	2 days?	9/16/19 8:00 AM	9/17/19 5:00 PM
9		Workshops	16 days?	9/18/19 8:00 AM	10/3/19 5:00 PM
10		Team Social Events	16 days?	9/18/19 8:00 AM	10/3/19 5:00 PM
11	▦	**PDR**	**28 days?**	**10/3/19 8:00 AM**	**10/30/19 5:00 PM**
12		Rocket Design	14 days?	10/3/19 8:00 AM	10/16/19 5:00 PM
13		Payload Design	14 days?	10/3/19 8:00 AM	10/16/19 5:00 PM
14	▦	Safety Documentation	18 days?	10/8/19 8:00 AM	10/25/19 5:00 PM
15	▦	Project Planning	10 days?	10/10/19 8:00 AM	10/19/19 5:00 PM
16		Outline	5 days?	10/17/19 8:00 AM	10/21/19 5:00 PM
17		PDR Writing	7 days?	10/22/19 8:00 AM	10/28/19 5:00 PM
18		Revision	2 days?	10/29/19 8:00 AM	10/30/19 5:00 PM
19	▦	**CDR**	**70.875 day...**	**11/1/19 9:00 AM**	**1/10/20 5:00 PM**
20		Rocket Design	19.875 days?	11/1/19 9:00 AM	11/20/19 5:00 PM
21		Payload Design	19.875 days?	11/1/19 9:00 AM	11/20/19 5:00 PM
22		Safety Analysis	7 days	11/21/19 8:00 AM	11/27/19 5:00 PM
23	▦	Write Procedures and Requi...	6.875 days?	11/21/19 9:00 AM	11/27/19 5:00 PM
24		Verification	20 days	11/28/19 8:00 AM	12/17/19 5:00 PM
25		Outline	6 days?	11/28/19 8:00 AM	12/3/19 5:00 PM
26		CDR Writing	23 days?	12/4/19 8:00 AM	12/26/19 5:00 PM
27		Revision	15 days	12/27/19 8:00 AM	1/10/20 5:00 PM
28	▦	Subscale Construction	8.875 days?	11/9/19 9:00 AM	11/17/19 5:00 PM
29		Subscale Launch Prep	6 days?	11/18/19 8:00 AM	11/23/19 5:00 PM
30		Subscale Analysis	3 days	11/24/19 8:00 AM	11/26/19 5:00 PM
31	▦	Winter Break	31.875 days?	12/14/19 10:00 AM	1/15/20 9:00 AM
32	▦	**FRR**	**69.875 day...**	**1/14/20 9:00 AM**	**3/23/20 5:00 PM**
33		Rocket Revisions	13 days	1/14/20 9:00 AM	1/27/20 9:00 AM
34		Payload Revisions	13 days	1/14/20 9:00 AM	1/27/20 9:00 AM
35	▦	Parts Ordering	15.875 days?	1/17/20 9:00 AM	2/1/20 5:00 PM
36	▦	Requirements Verification	30 days	1/29/20 9:00 AM	2/28/20 9:00 AM
37		Rocket Construction	24.875 days	1/27/20 9:00 AM	2/20/20 5:00 PM
38		Payload Construction	24.875 days	1/27/20 9:00 AM	2/20/20 5:00 PM
39	▦	Full-Scale Launch	1 day	2/22/20 9:00 AM	2/23/20 9:00 AM
40		Final Design Revision	26.875 days	2/23/20 9:00 AM	3/20/20 5:00 PM
41	▦	Full-Scale Launch	1 day?	3/21/20 8:00 AM	3/21/20 5:00 PM
42		Outline	3 days	1/14/20 9:00 AM	1/17/20 9:00 AM
43	▦	FRR Writing	5.875 days	2/24/20 9:00 AM	2/29/20 5:00 PM
44		Revision	1 day?	3/1/20 8:00 AM	3/1/20 5:00 PM
45	▦	FRR Adendum	2 days?	3/22/20 8:00 AM	3/23/20 5:00 PM
46	▦	Competition	4.875 days?	4/1/20 9:00 AM	4/5/20 5:00 PM
47		**PLAR**	**22 days?**	**4/6/20 8:00 AM**	**4/27/20 5:00 PM**
48		Analysis of Competition Pref...	10 days?	4/6/20 8:00 AM	4/15/20 5:00 PM
49		Lessons Learned	3 days	4/16/20 8:00 AM	4/18/20 5:00 PM
50		Outline	3 days	4/19/20 8:00 AM	4/21/20 5:00 PM
51		PLAR Writing	5 days	4/22/20 8:00 AM	4/26/20 5:00 PM
52		Revision	1 day	4/27/20 8:00 AM	4/27/20 5:00 PM

USLI - page1

Predecessors	Resource Names
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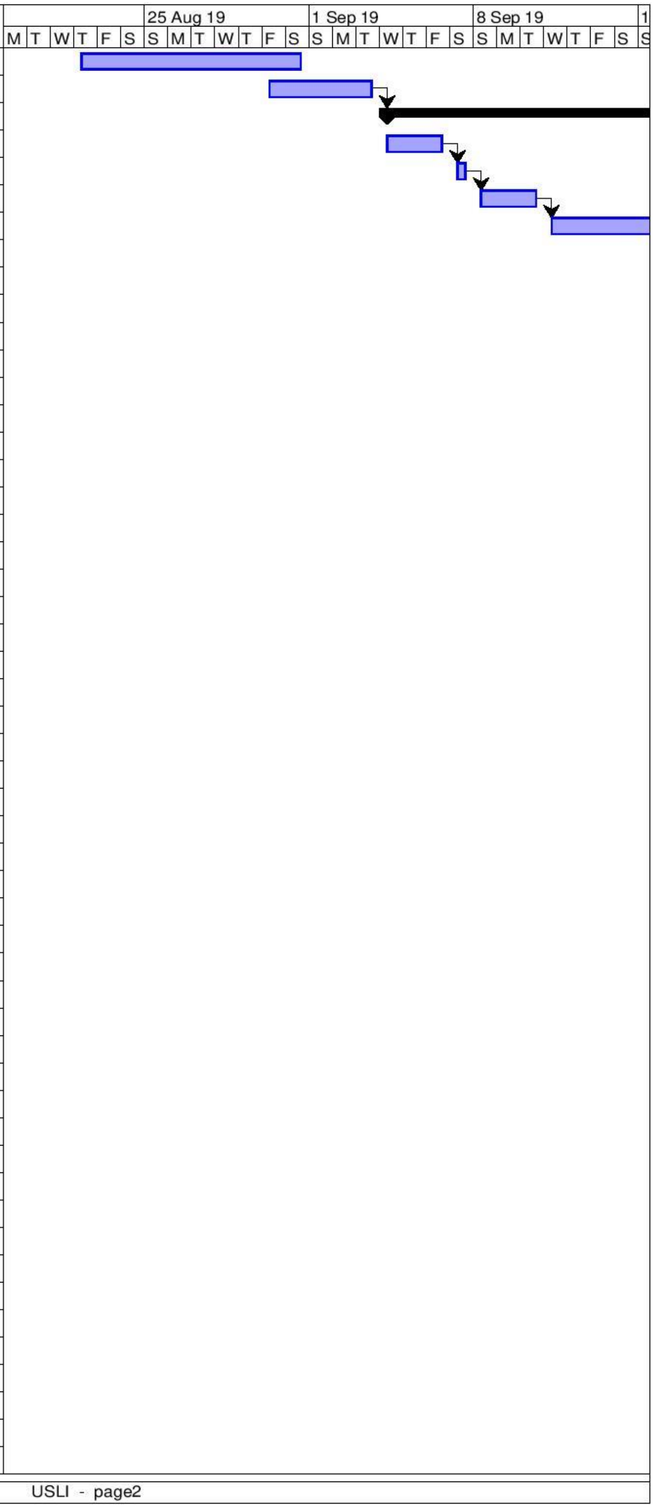

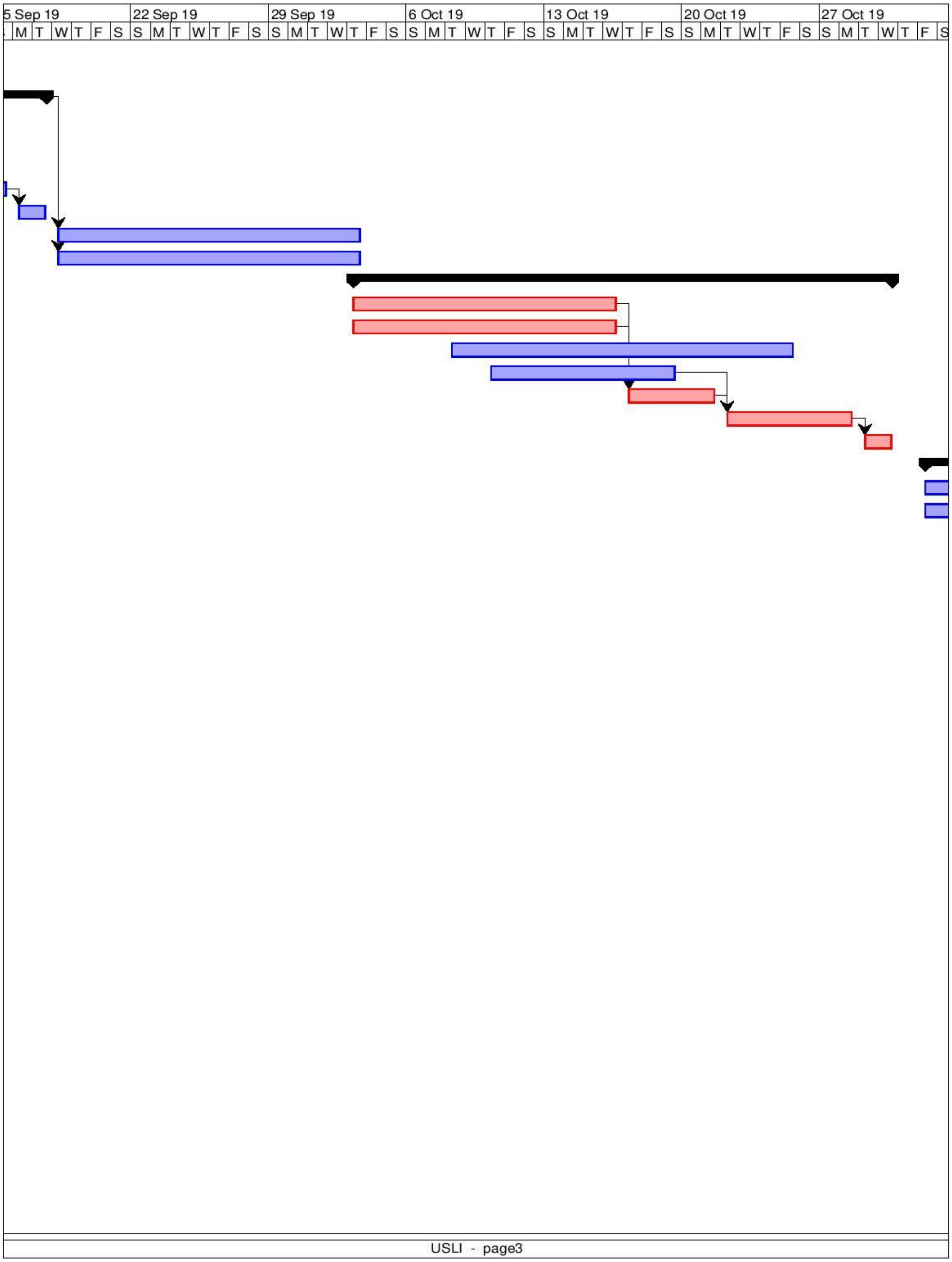
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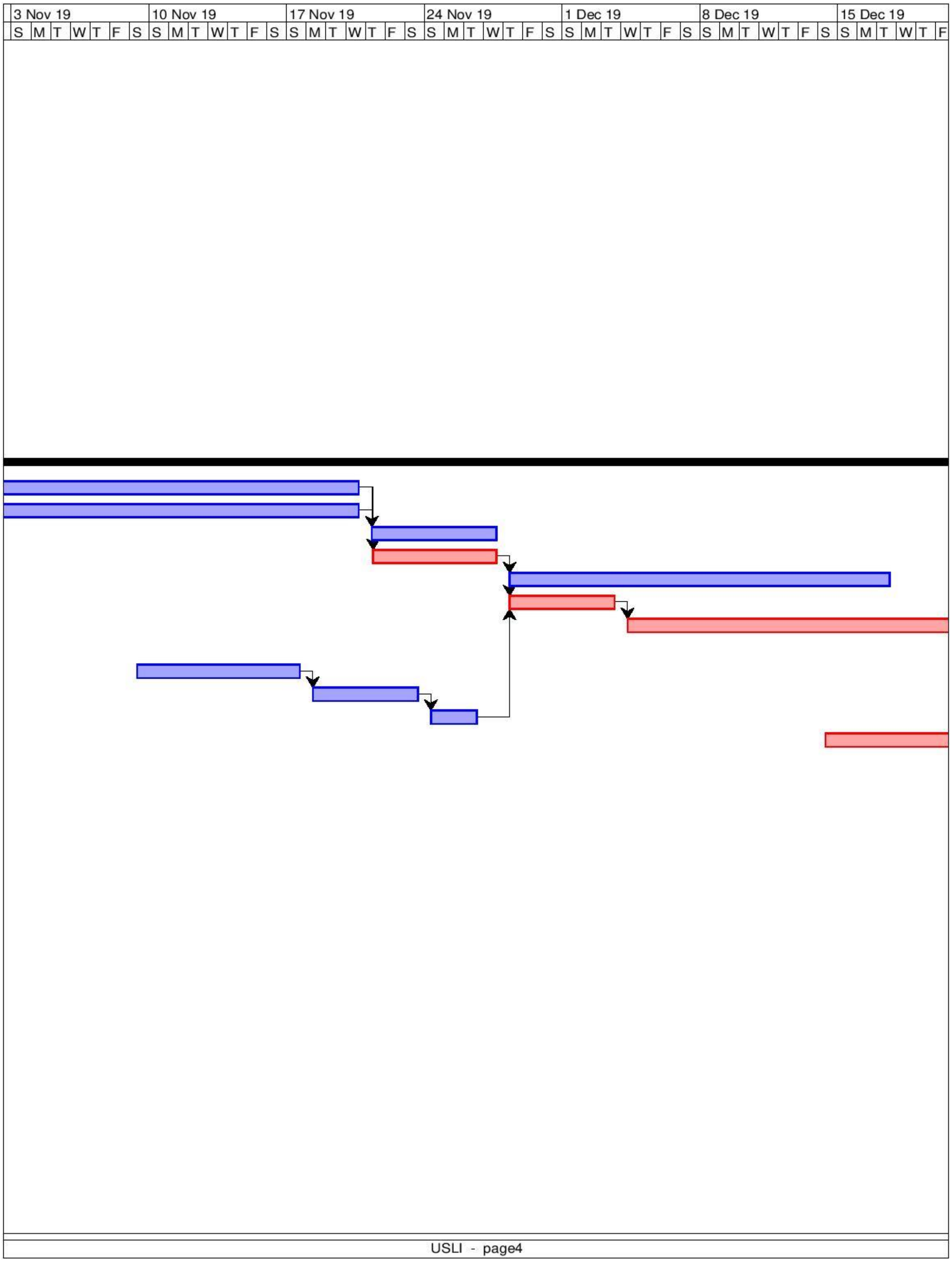
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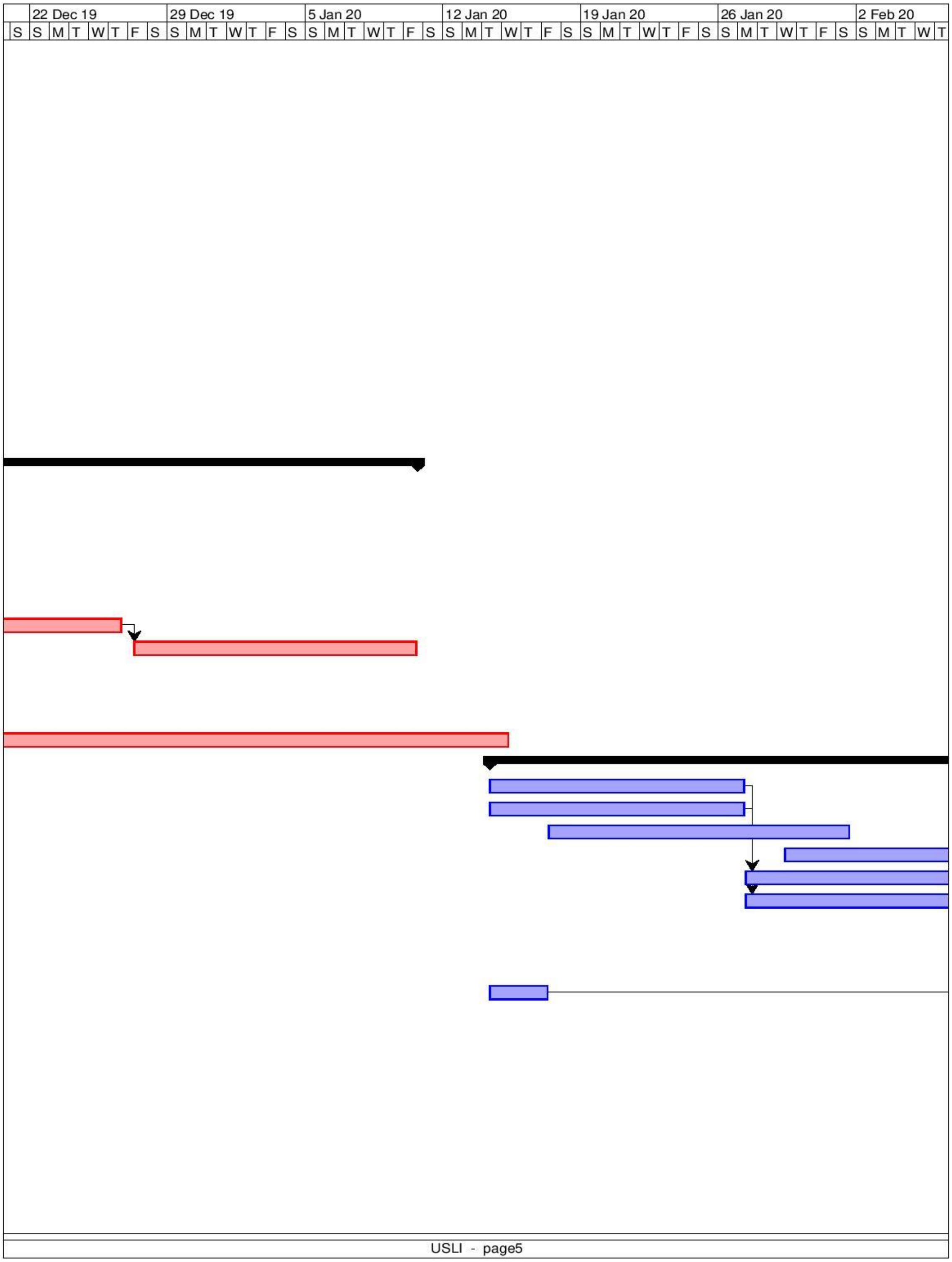
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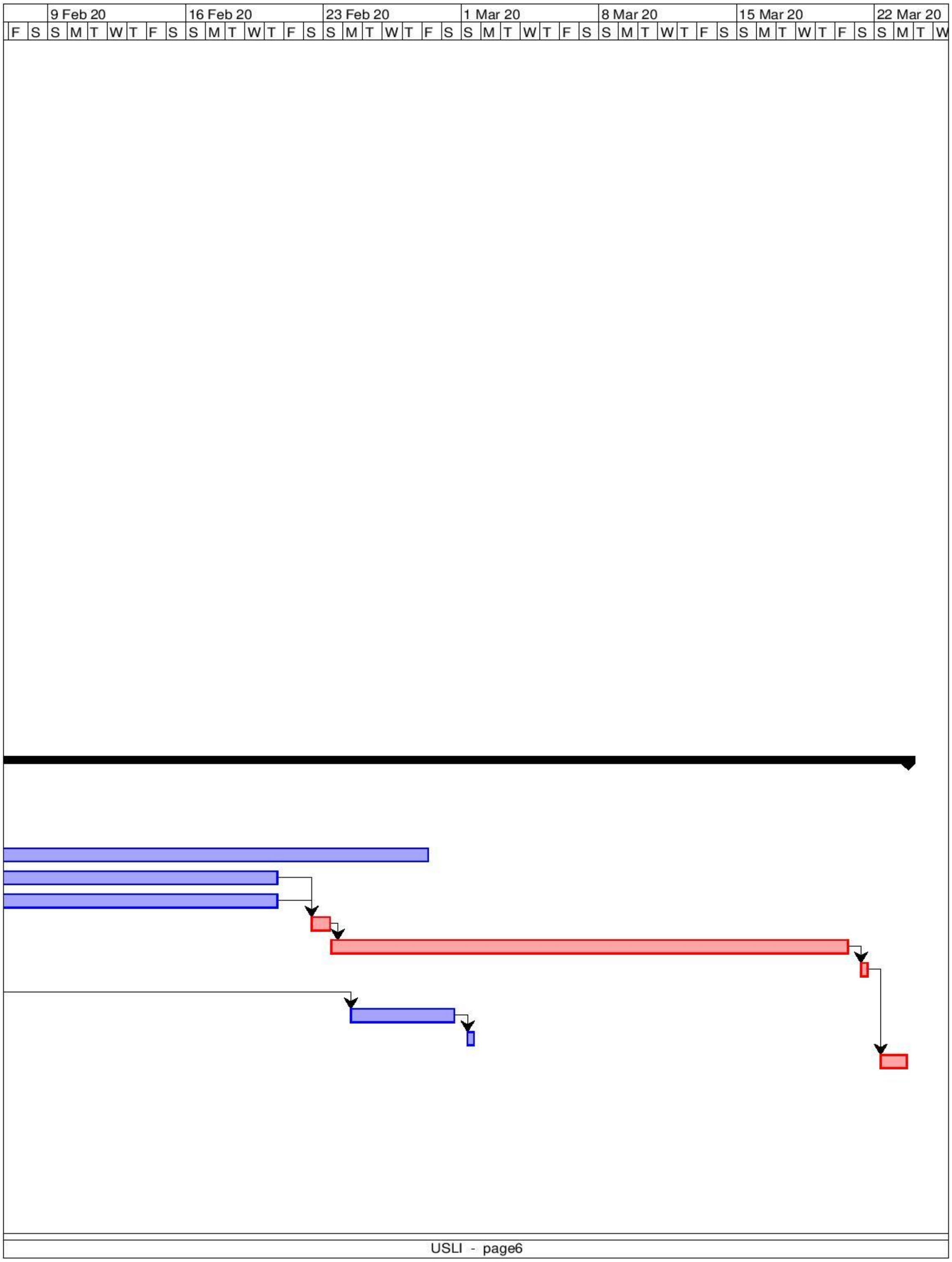
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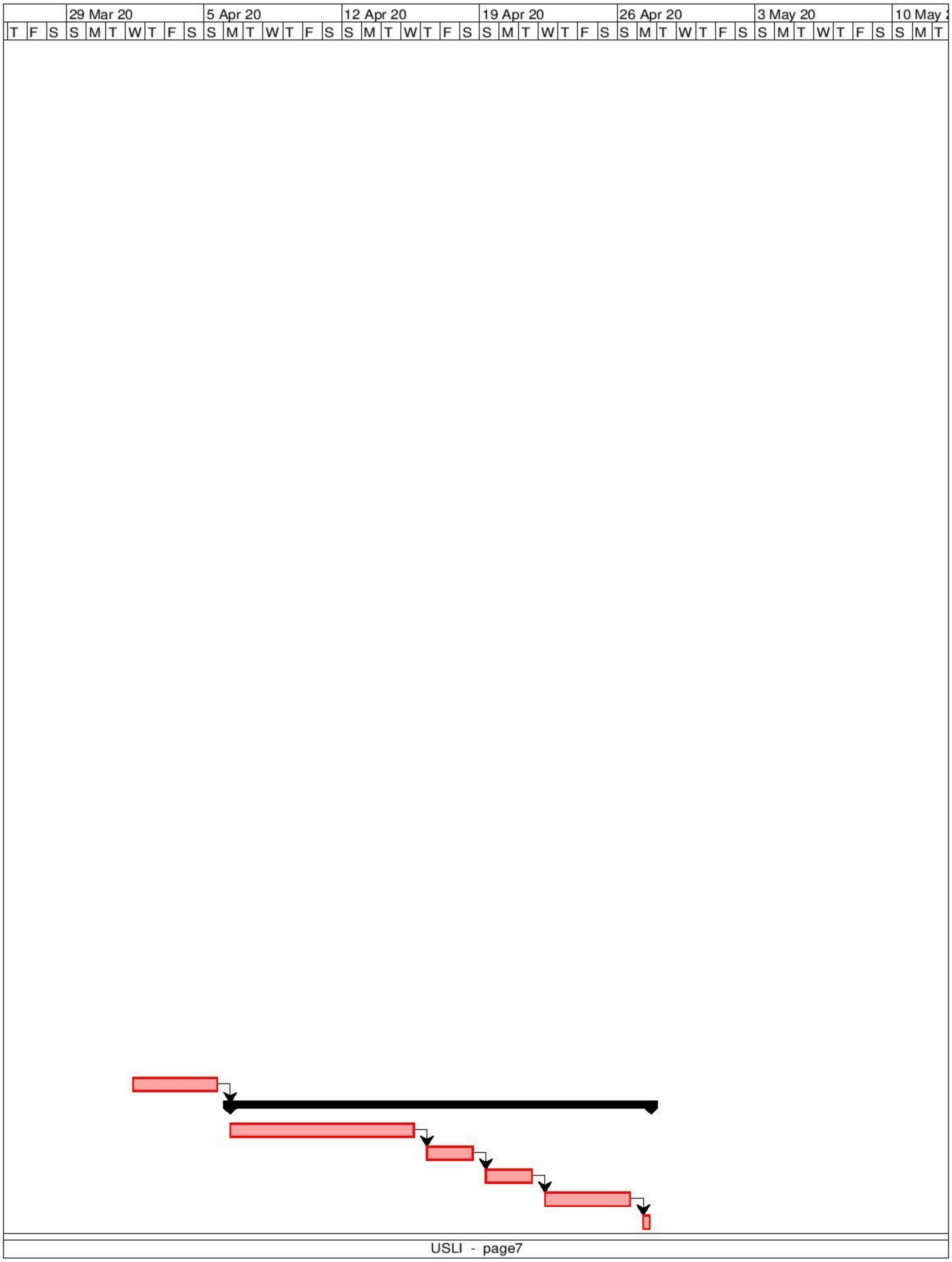
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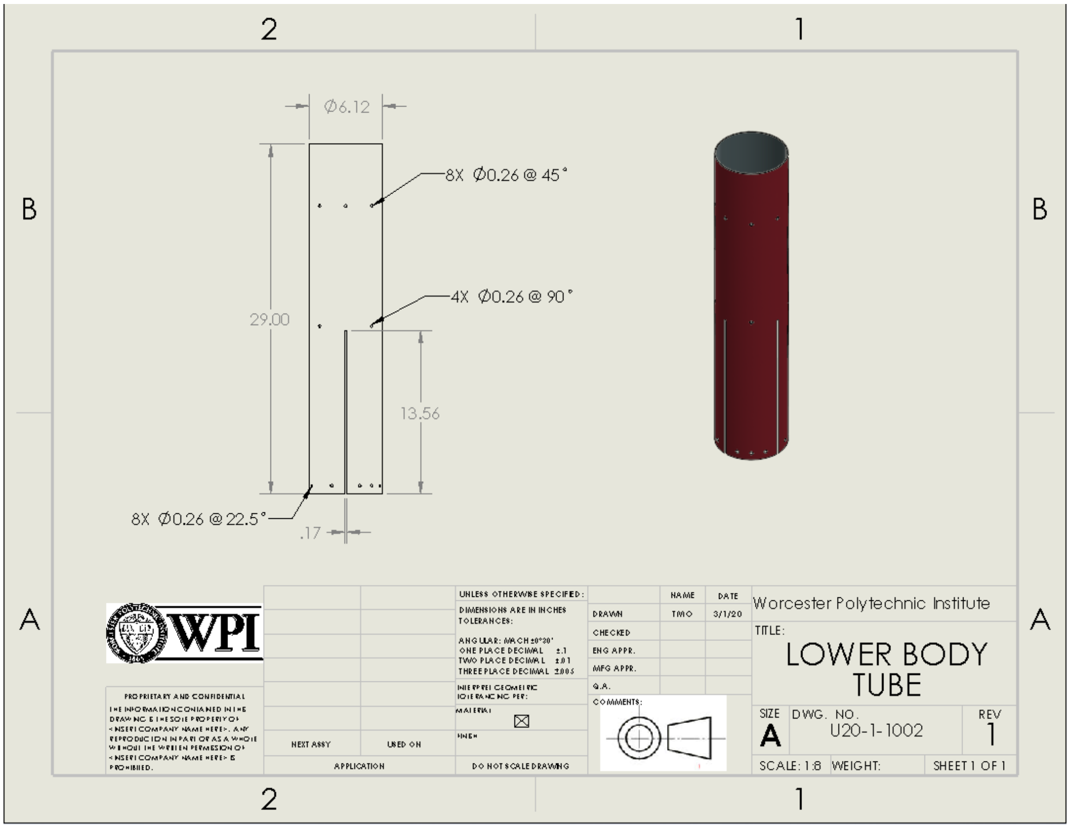
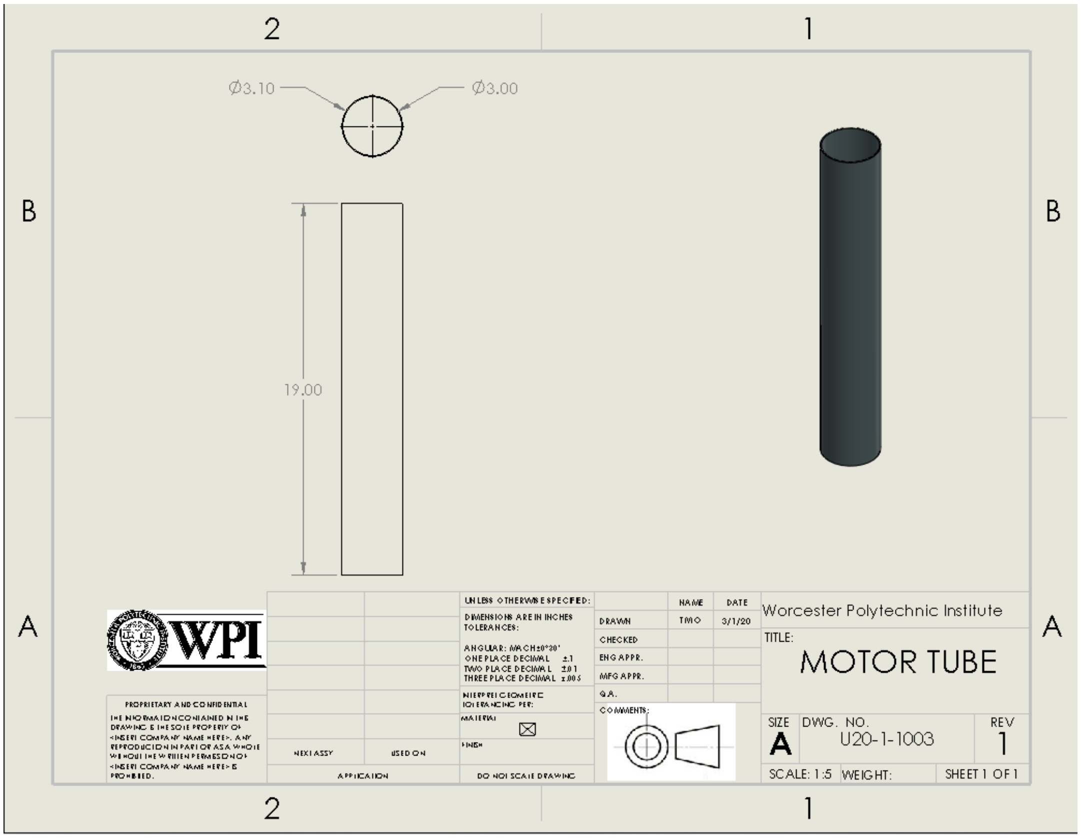
USLI - page7

10 APPENDIX

10.1 AS-BUILT SCHEMATICS

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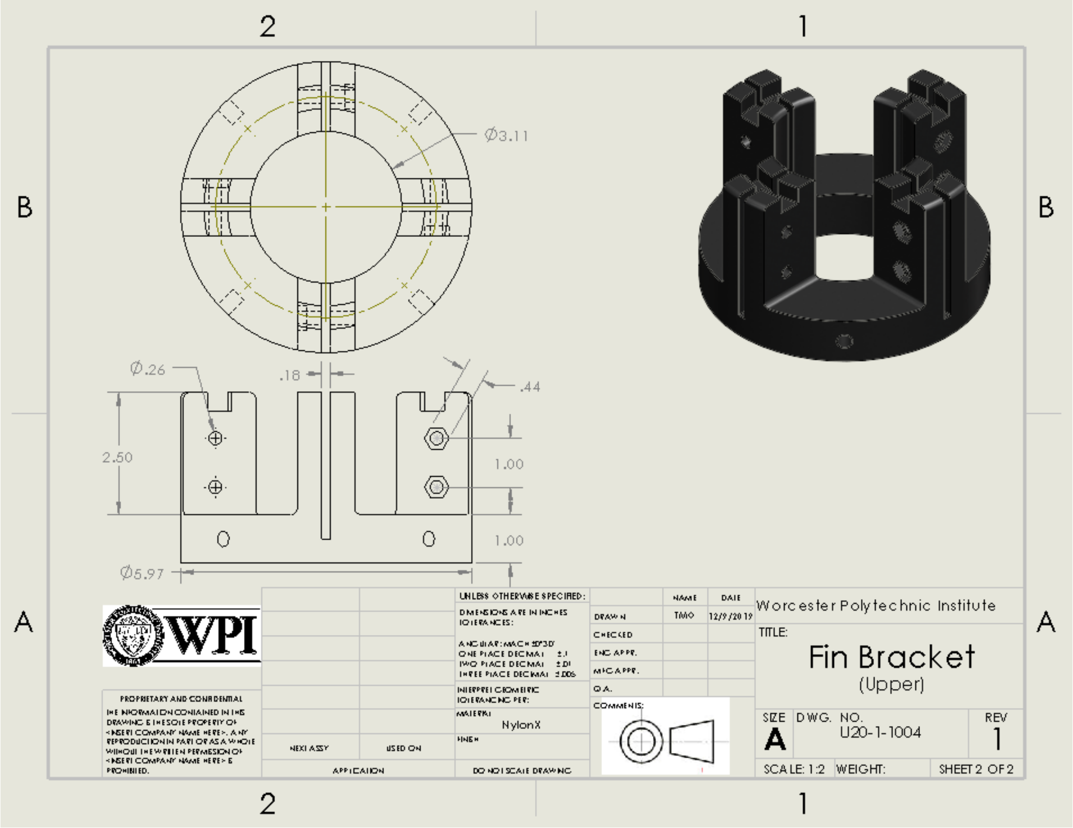
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MFG APPR.
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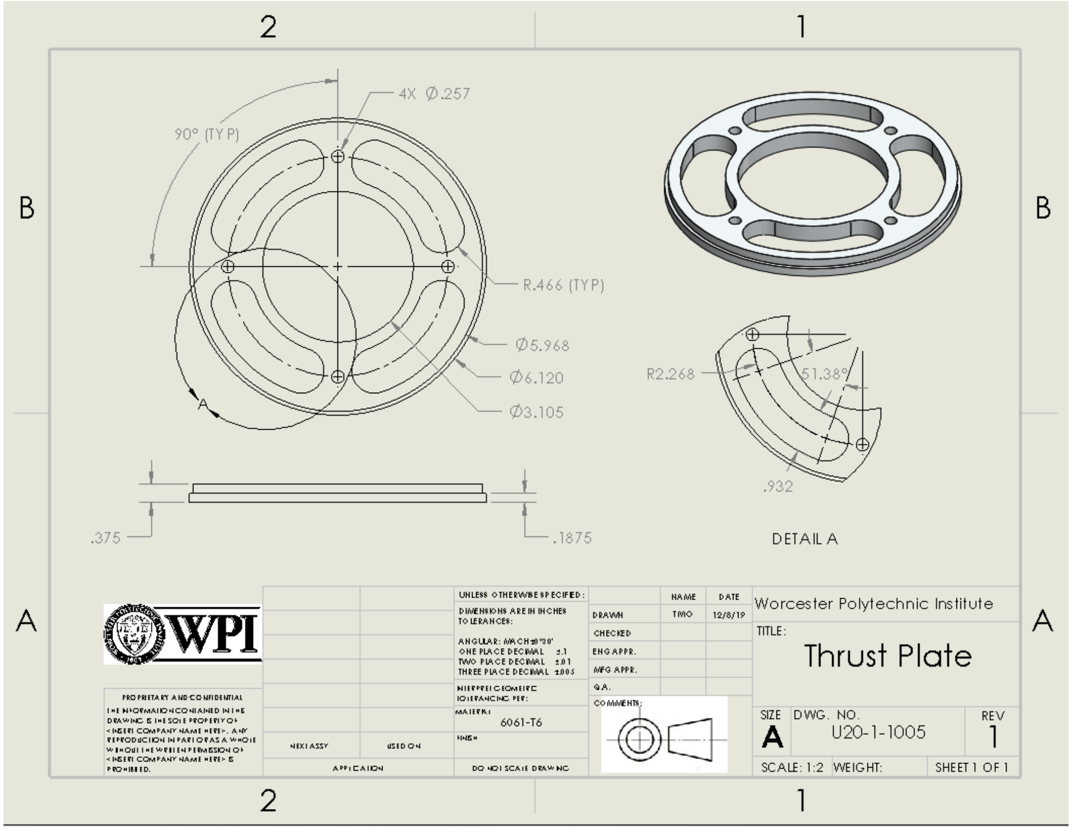
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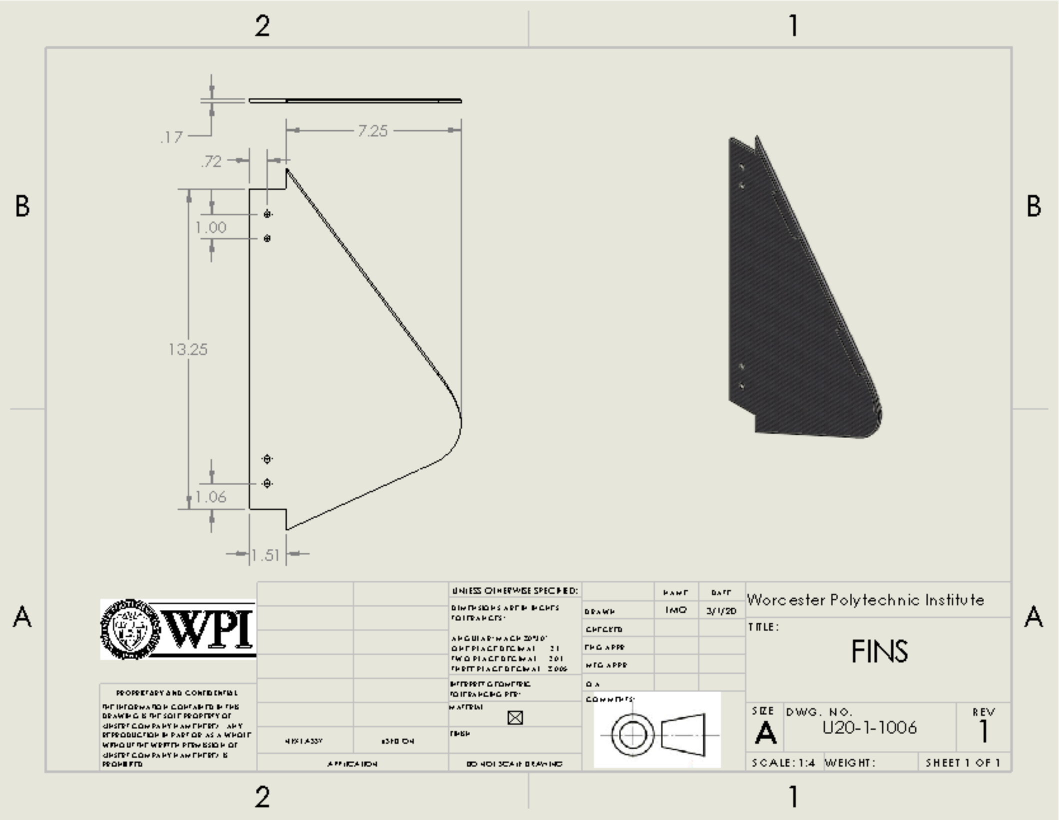
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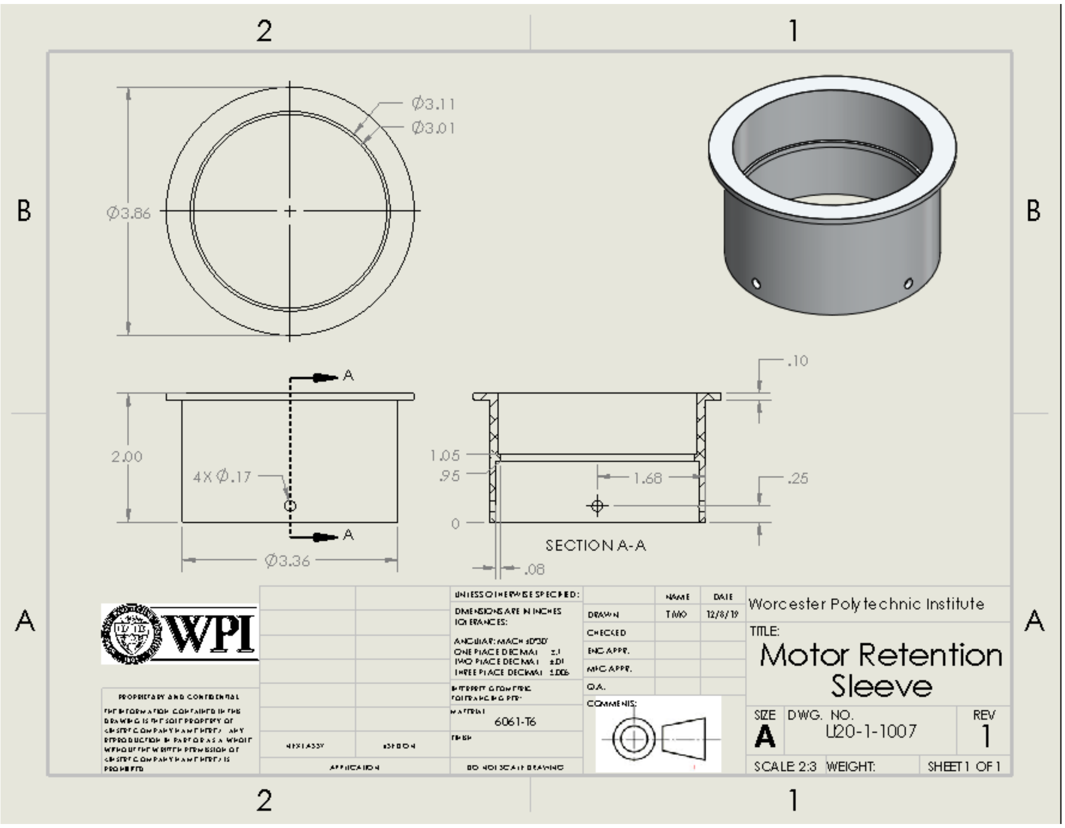
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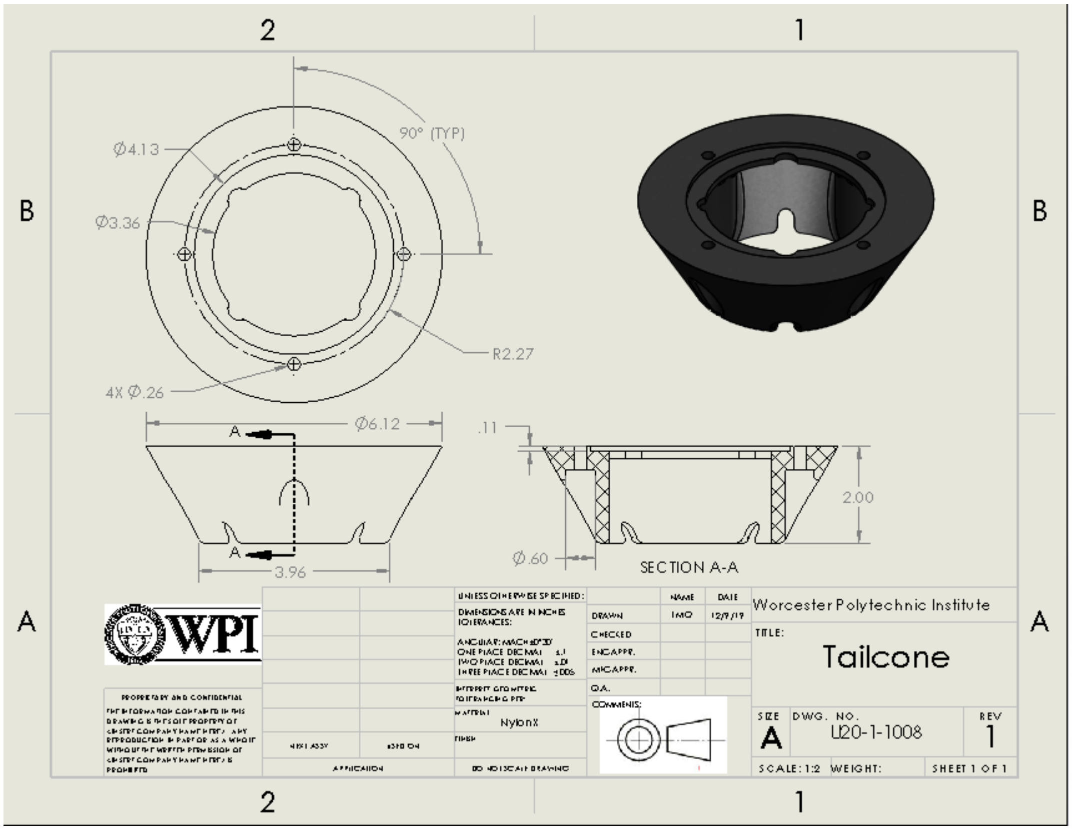
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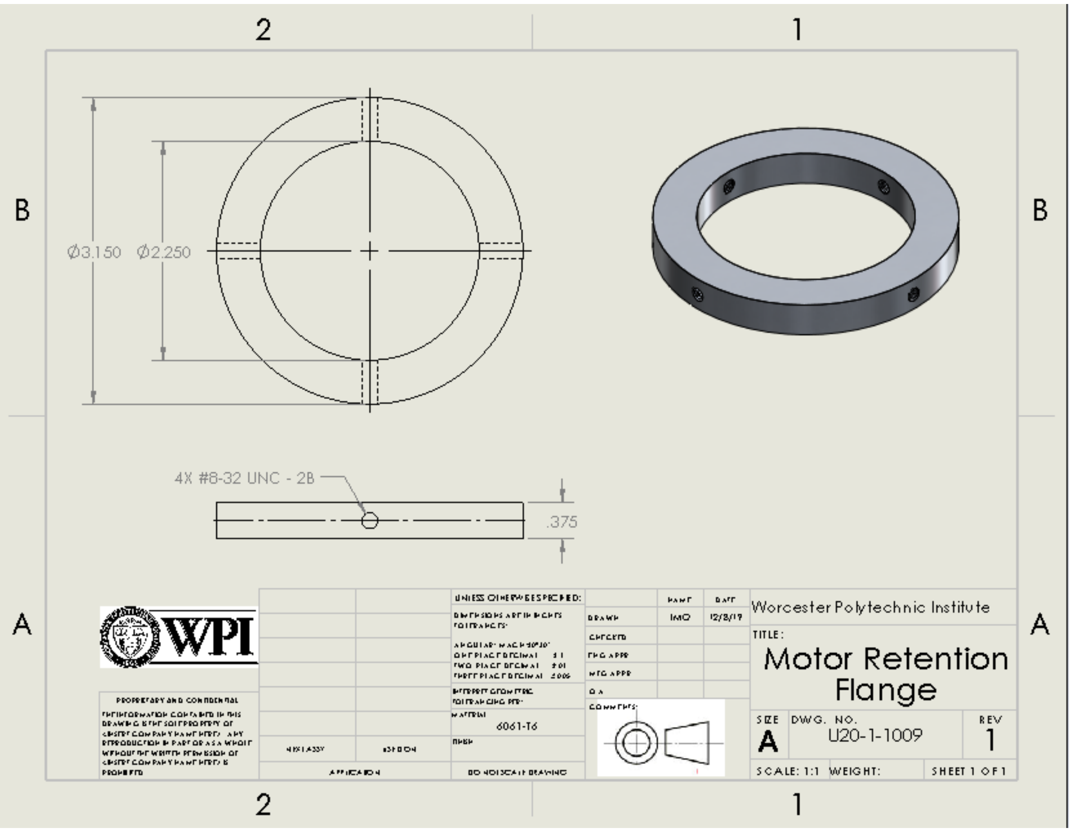
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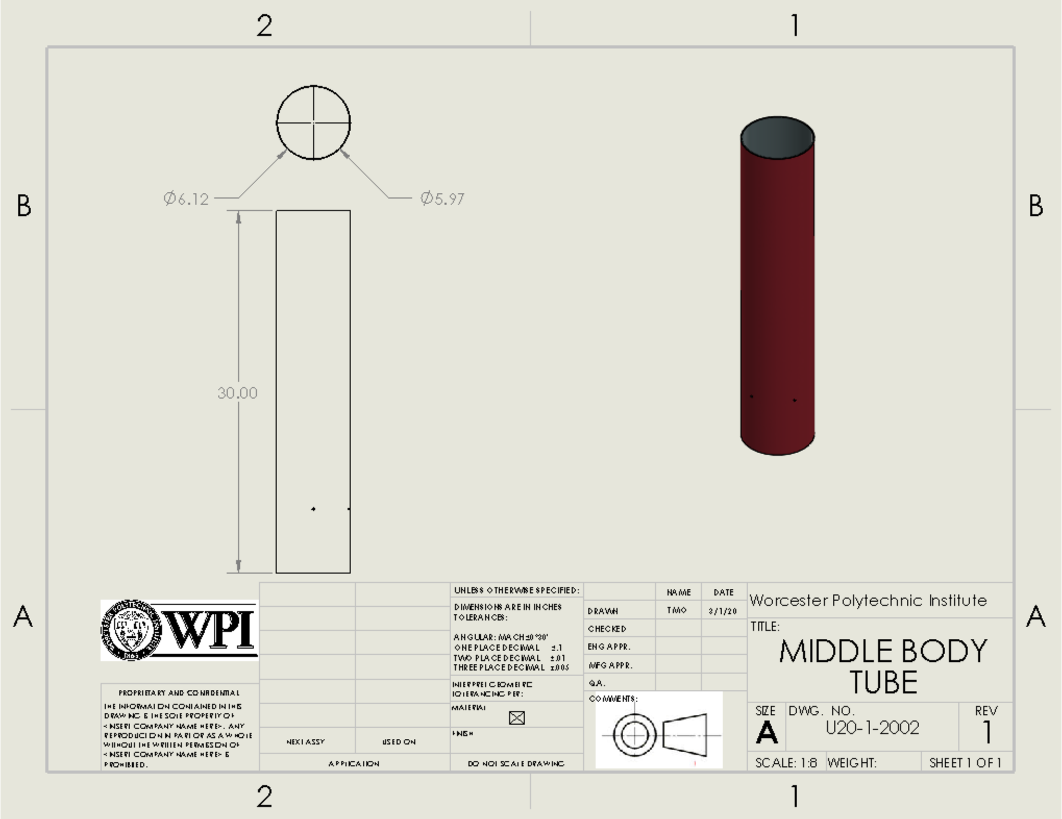
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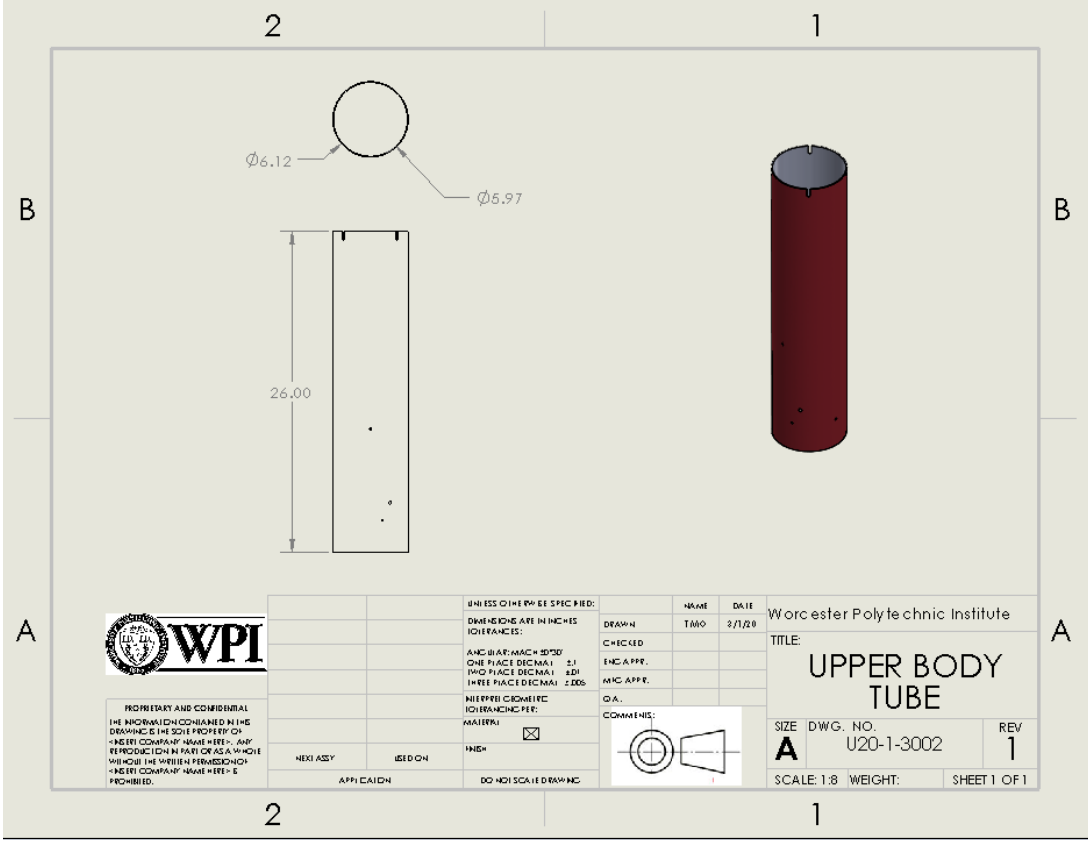

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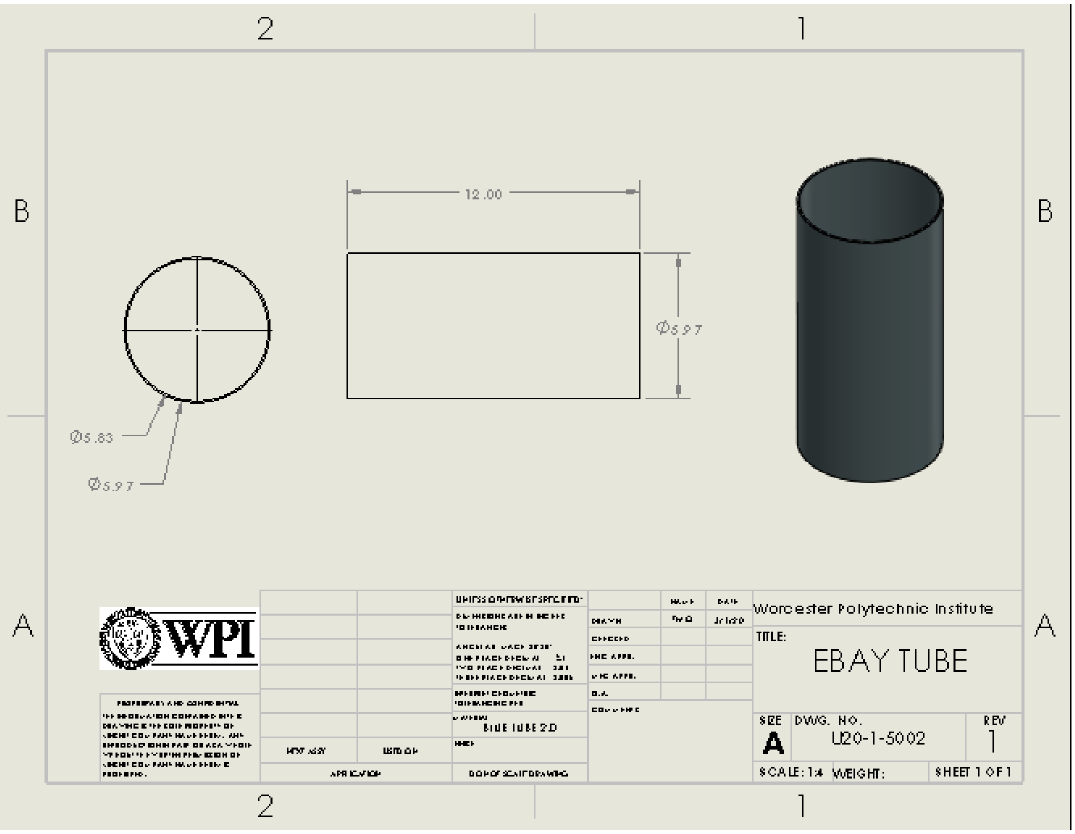

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COMMENTS:
Worcester Polytechnic Institute
TITLE:
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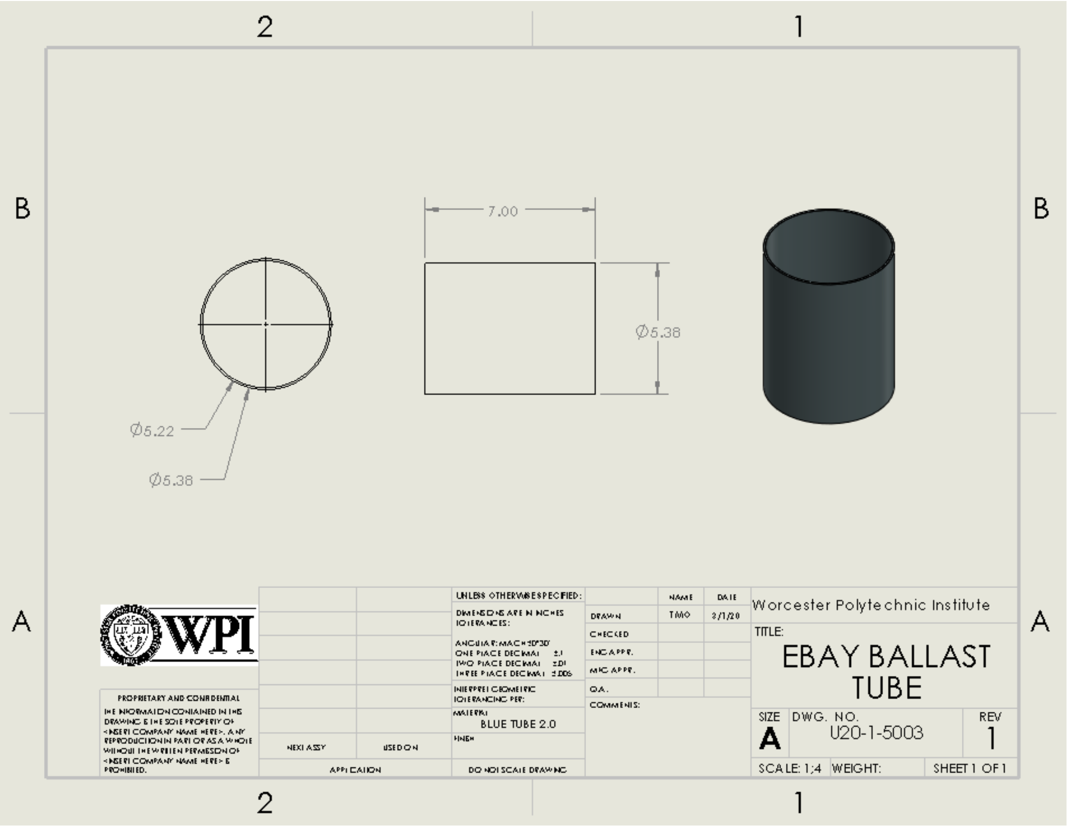
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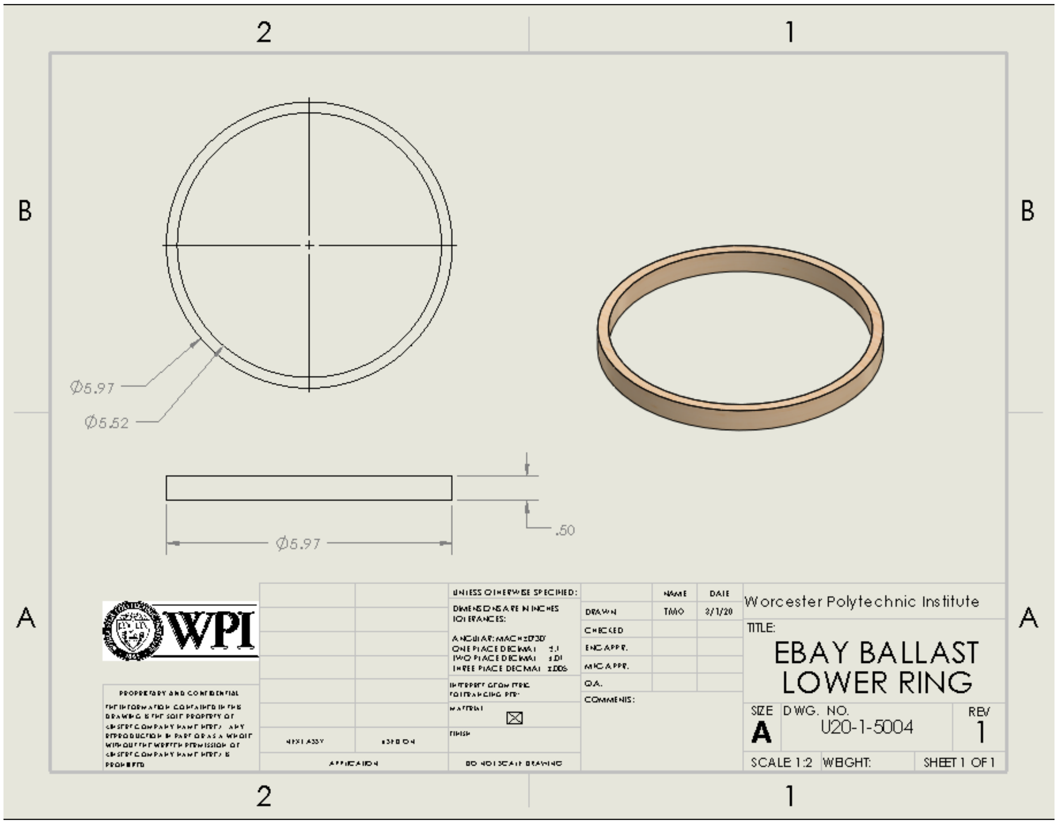
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COMMENTS:
Worcester Polytechnic Institute
TITLE:
EBAY BALLAST LOWER RING
SIZE
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U20-1-5004
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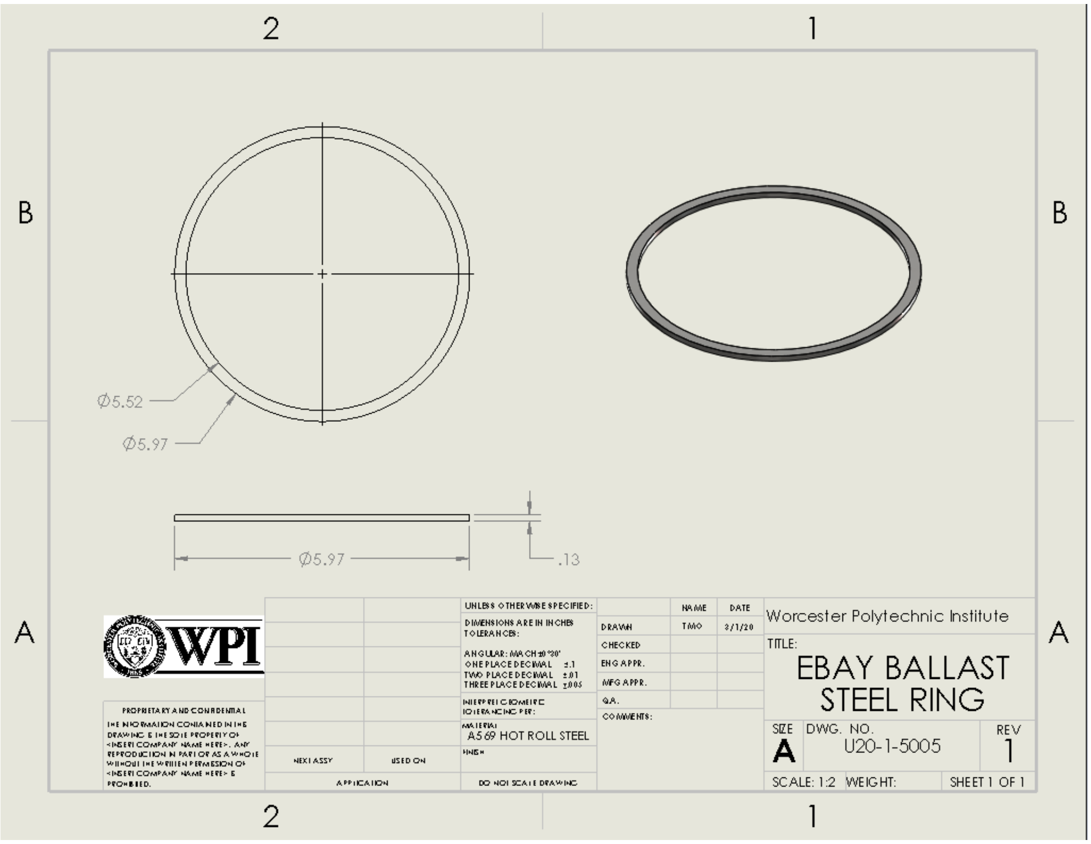
SHEET 1 OF 1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THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
A569 HOT ROLL STEEL
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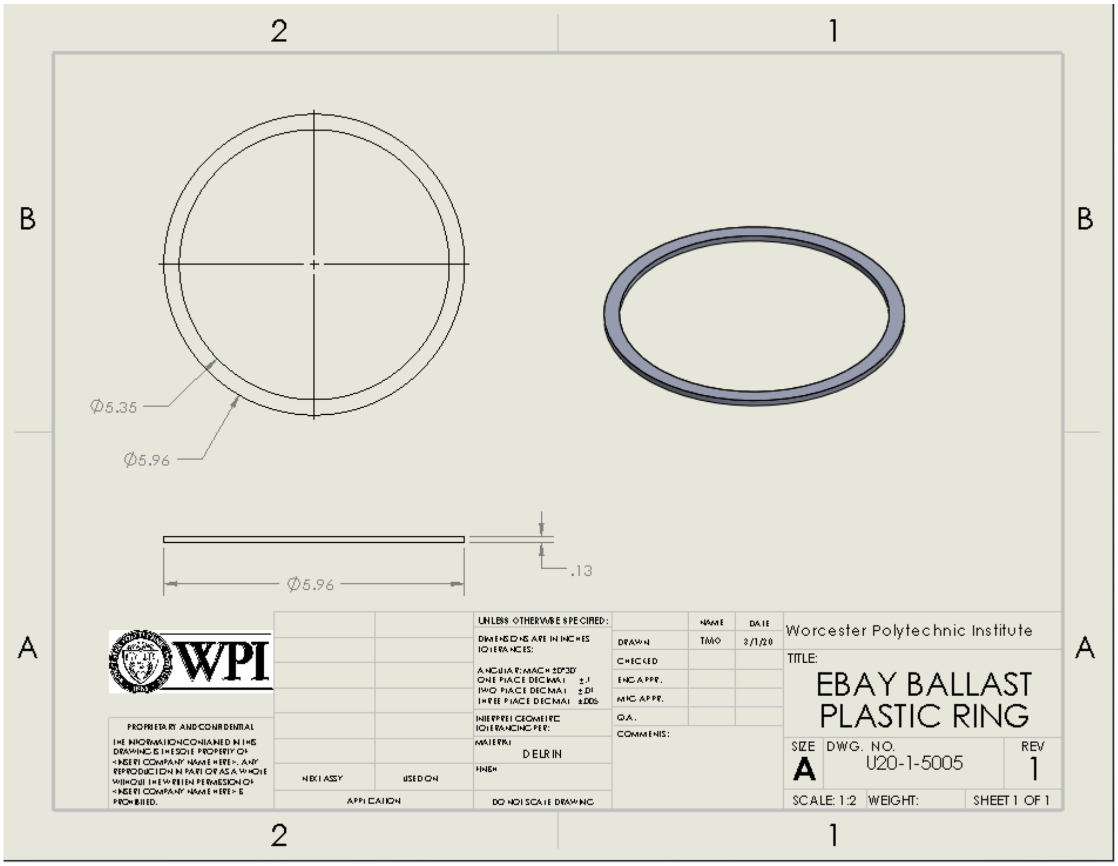
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COMMENTS:
Worcester Polytechnic Institute
TITLE:
EBAY BALLAST PLASTIC RING
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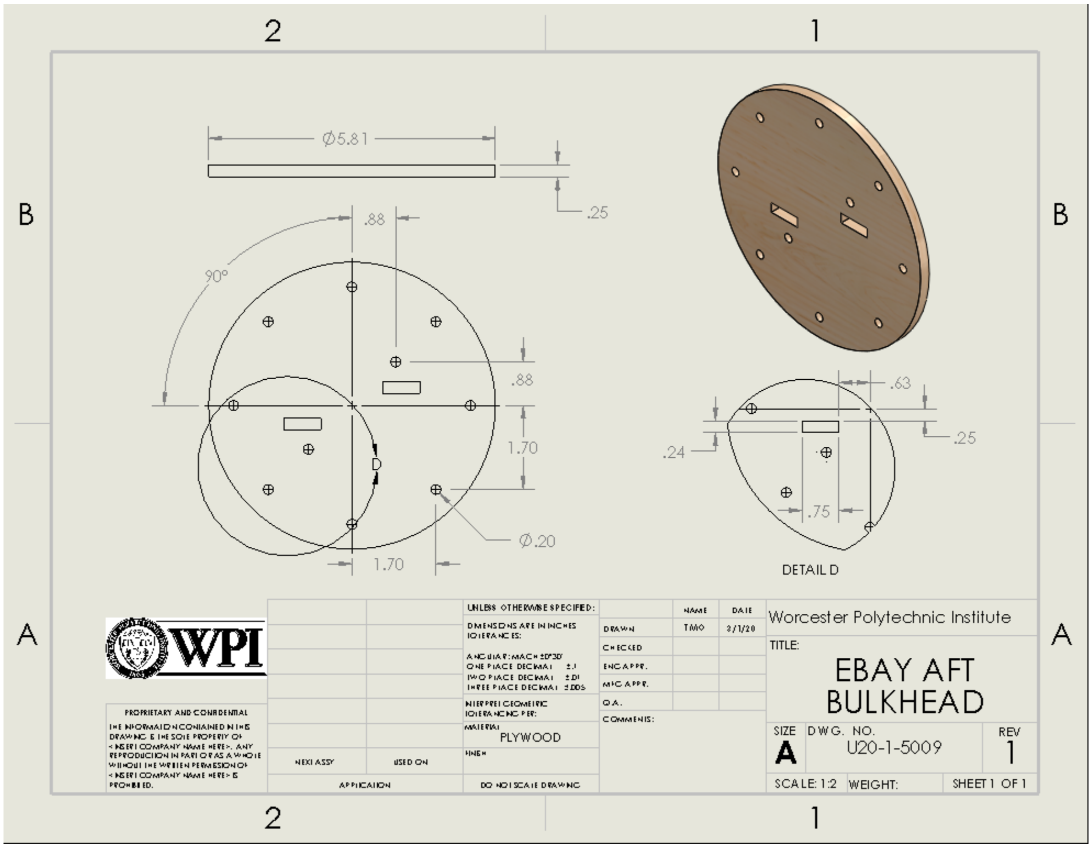

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INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL: PLYWOOD
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COMMENTS:

Worcester Polytechnic Institute

TITLE: EBAY AFT BULKHEAD

SIZE A DWG. NO. U20-1-5009 REV 1

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

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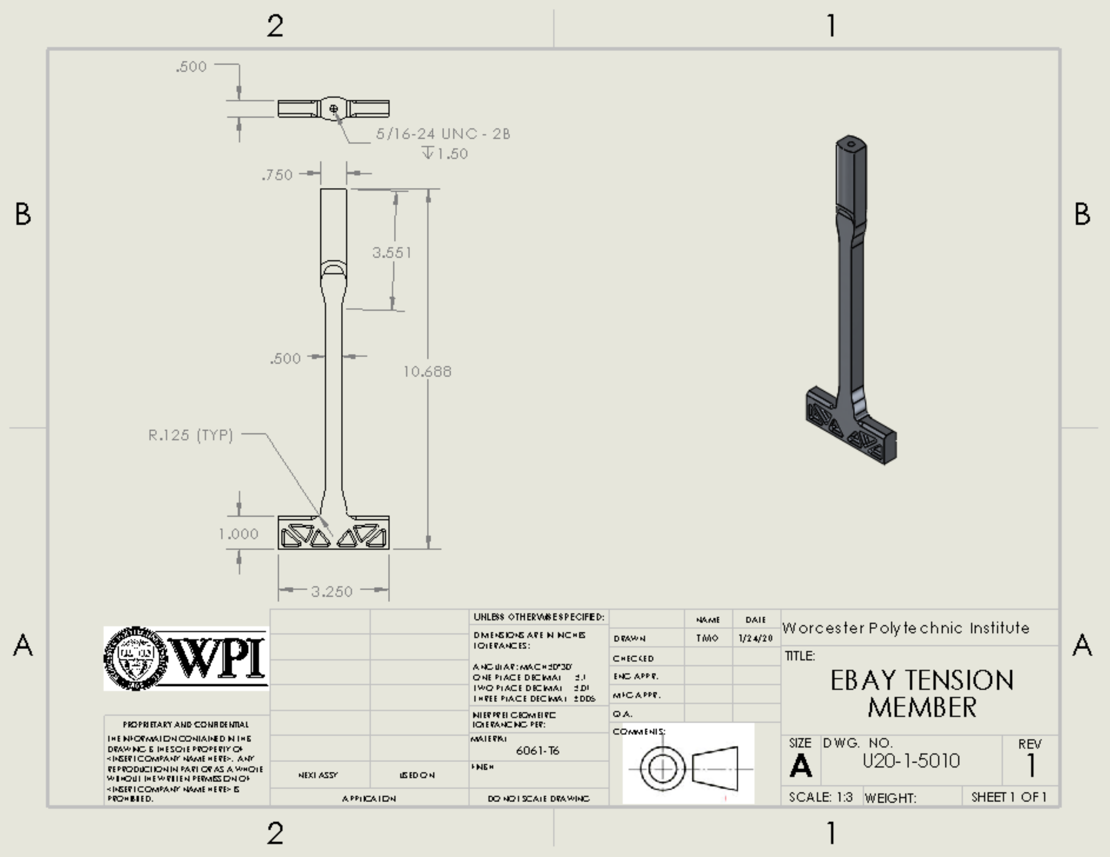

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INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL: 6061-T6
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COMMENTS:

Worcester Polytechnic Institute

TITLE: EBAY TENSION MEMBER

SIZE A DWG. NO. U20-1-5010 REV 1

SCALE: 1:3 WEIGHT: SHEET 1 OF 1

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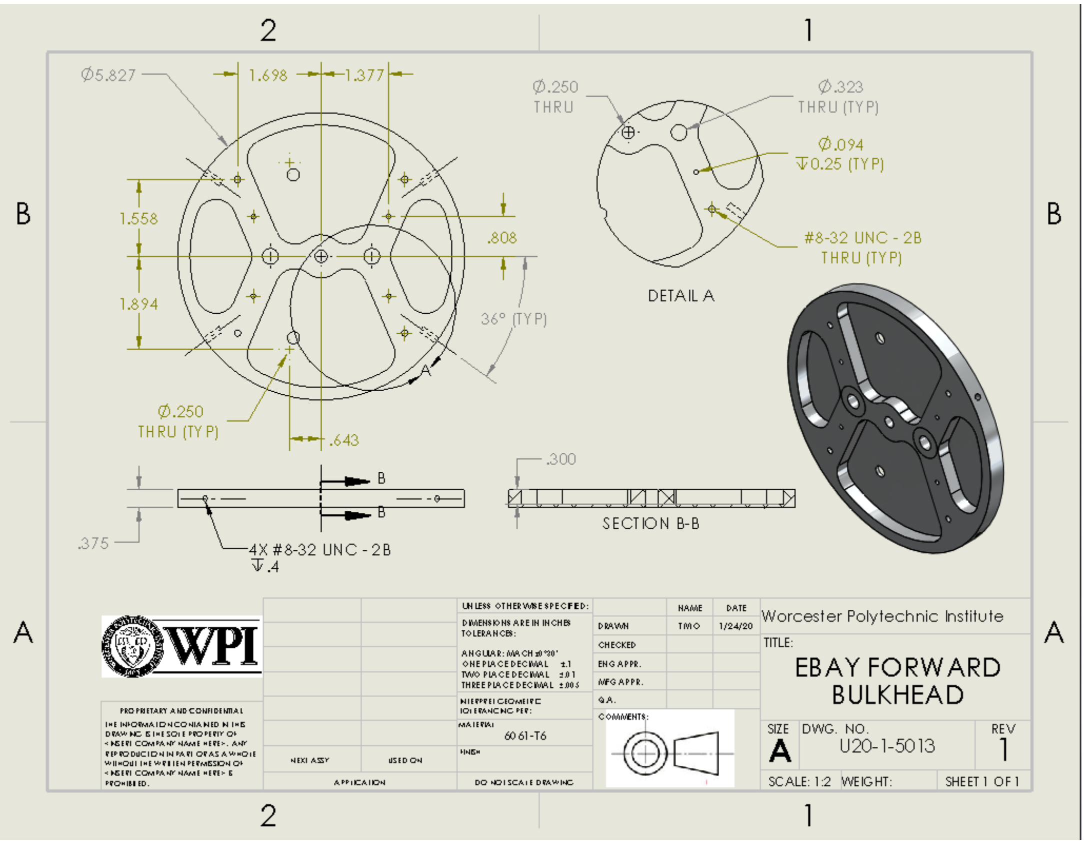

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COMMENTS:

Worcester Polytechnic Institute
TITLE:
EBAY FORWARD BULKHEAD
SIZE A
DWG. NO. U20-1-5013
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SCALE: 1:2
WEIGHT:
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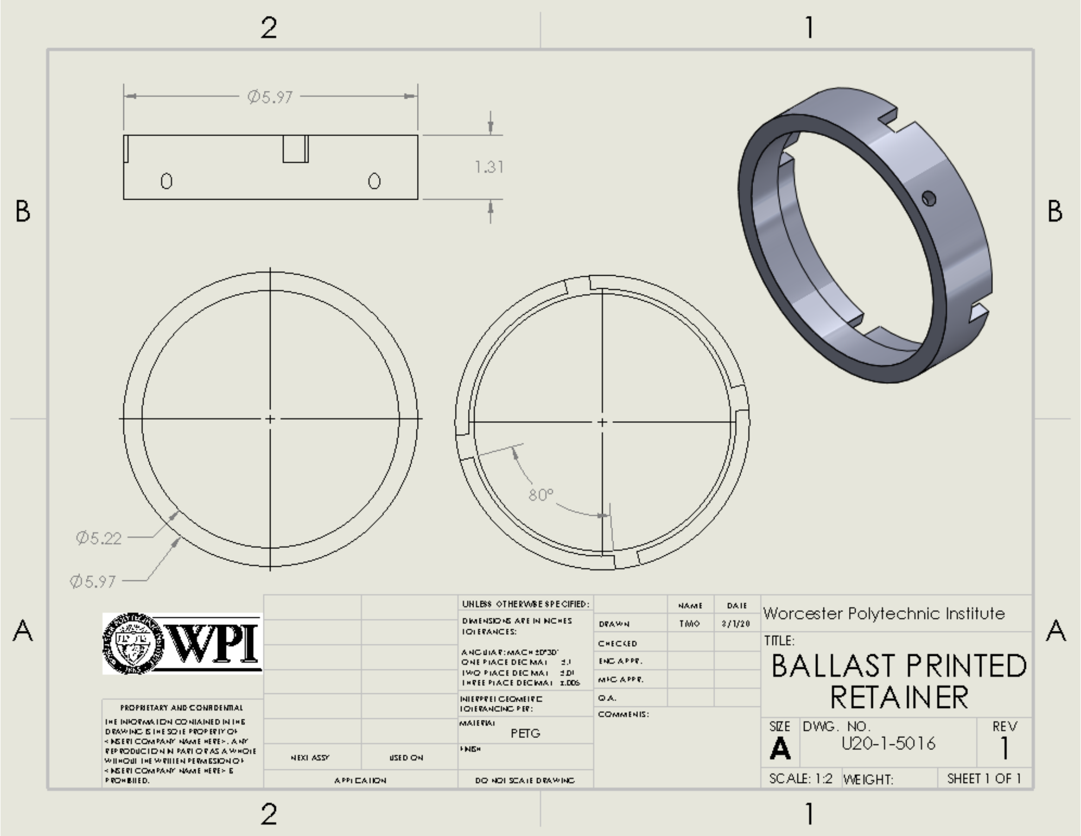

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COMMENTS:

Worcester Polytechnic Institute
TITLE:
BALLAST PRINTED RETAINER
SIZE A
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REV 1
SCALE: 1:2
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10.2 MATLAB SCRIPT

WPI USLI Comprehensive Calculator

```
clear variables; close all; clc
```

Constants

```
g = 9.8; % Gravitational Acceleration (m/s^2)

R_Combustion = 119.2; % Combustion Gas Constant (J/kg*K)
T_Combustion = 1837.2; % Combustion Gas Temperature (K)

p0 = 101325; % Atmospheric Pressure at Sea Level (Pa)
R = 8.31446; % Universal Gas Constant (J/mol*K)
R_Specific = 287.058; % Specific Gas Constant for Air (J/kg*K)
L = 0.00976; % Temperature Lapse Rate for Air (K/m)
M = 0.02896968; % Molar Mass for Air (kg/mol)

Shear_Pin_Strength = 169.03; % Breaking Strength of #4 Shear Pins (N)
```

Input Parameters

Vehicle Parameters

```
Airframe_Diameter = 6; % Airframe Diameter (in)

Recovery_Bay_Length = 30; % Recovery Bay Length (in)
Coupler_Length = 6; % Length of Recovery Bay Coupler (in)
Shock_Cord_Length = 400; % Length of Shock Cord (in)

Lower_Mass = 19; % Lower Section Mass (lb)
Upper_Mass = 15.7; % Upper Section Mass (lb)

Drogue_Diameter = 36; % Drogue Chute Diameter (in)
Packed_Drogue_Diameter = 2.85; % Packed Drogue Chute Diameter (in)
Drogue_n = 2.5; % Drogue Chute Canopy Fill Constant (see Parachute Recovery Systems Design Manu
Lower_Main_Diameter = 132; % Lower Main Chute Diameter (in)
Packed_Lower_Main_Diameter = 4; % Packed Lower Main Chute Diameter (in)
Lower_Main_n = 2.5; % Lower Main Chute Canopy Fill Constant (see Parachute Recovery Systems Des
Upper_Main_Diameter = 120; % Upper Main Chute Diameter (in)
Packed_Upper_Main_Diameter = 4; % Packed Upper Main Chute Diameter (in)
Upper_Main_n = 2.5; % Upper Main Chute Canopy Fill Constant (see Parachute Recovery Systems Des


Fin_Area = 5.11; % Frontal Area of Fins (in^2)

Parachute_Cd = 0.75; % Parachute Coefficient of Drag
Lower_Cd = 0.32; % Lower Section Coefficient of Drag (from OpenRocket)
Fin_Cd = 0.09; % Fin Coefficient of Drag (from Open Rocket)
Upper_Cd = 0.11; % Upper Section Coefficient of Drag (from OpenRocket)
```

Flight Parameters

```
Burnout_AGL = 1477; % Predicted Burnount AGL (ft)
Apogee_AGL = 4099; % Predicted Apogee AGL (ft)
Main_AGL = 650; % Main Parachute Deployment Altitude AGL (ft)

Maximum_Velocity = 58; % Maximum Velocity during flight (ft/s)

Maximum_Drift = 2500; % Maximum Allowable Drift (ft)
```

Launch Site Parameters

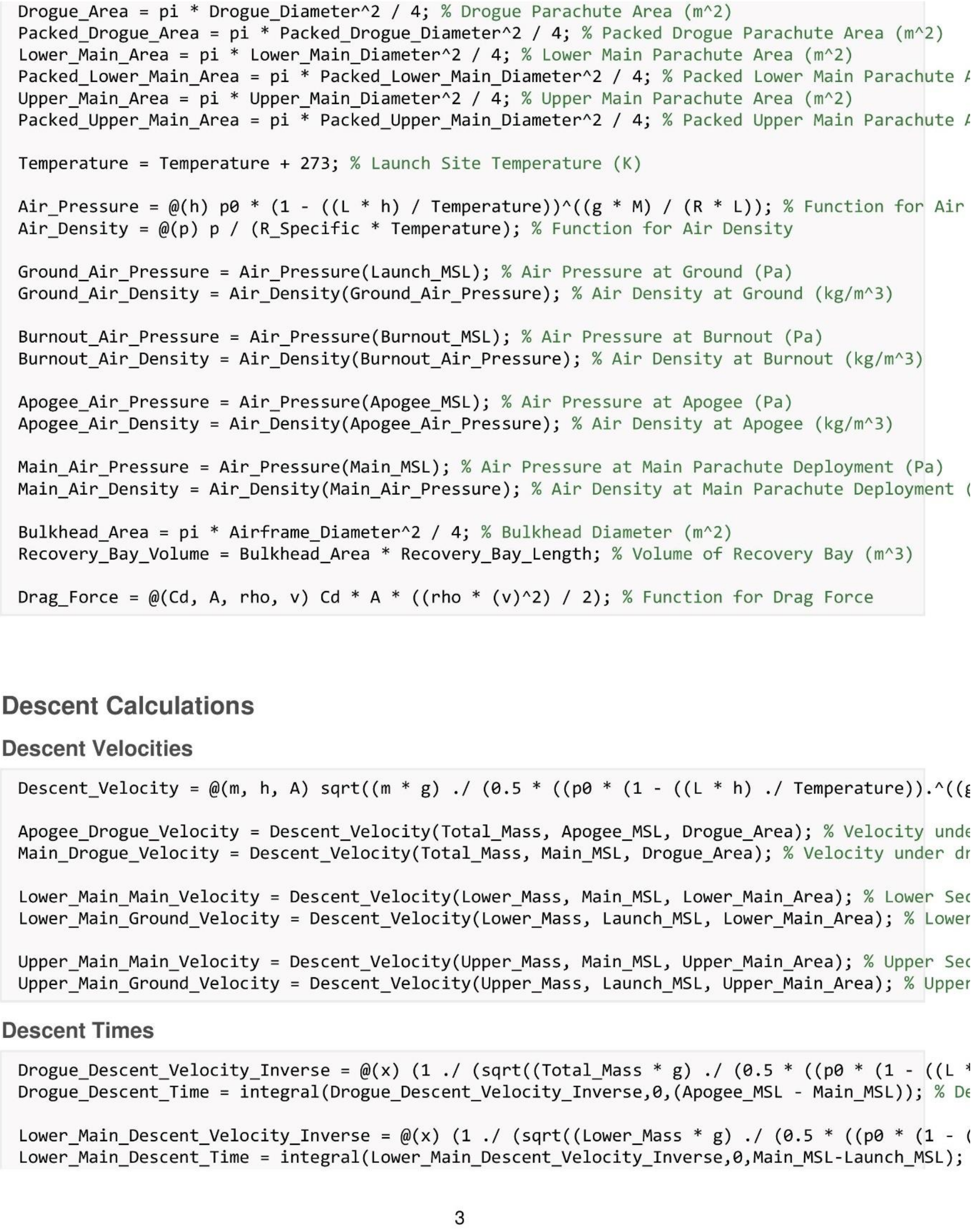
```
Launch_MSL = 600; % Launch Site Elevation (ft)
Temperature = 70; % Launch Site Temperature (°F)
Maximum_Launch_Wind_Velocity = 20; % Maximum Allowable Wind Velocity for Launch (mph)
```

Unit Conversions

```
Airframe_Diameter = Airframe_Diameter / 39.37; % in to m
Recovery_Bay_Length = Recovery_Bay_Length / 39.37; % in to m
Coupler_Length = Coupler_Length / 39.37; % in to m
Shock_Cord_Length = Shock_Cord_Length / 39.37; % in to m

Lower_Mass = Lower_Mass / 2.205; % lb to kg
Upper_Mass = Upper_Mass / 2.205; % lb to kg

Drogue_Diameter = Drogue_Diameter / 39.37; % in to m
Packed_Drogue_Diameter = Packed_Drogue_Diameter / 39.37; % in to m
Lower_Main_Diameter = Lower_Main_Diameter / 39.37; % in to m
Packed_Lower_Main_Diameter = Packed_Lower_Main_Diameter / 39.37; % in to m
Upper_Main_Diameter = Upper_Main_Diameter / 39.37; % in to m
Packed_Upper_Main_Diameter = Packed_Upper_Main_Diameter / 39.37; % in to m

Fin_Area = Fin_Area / 1550; % in^2 to m^2

Burnout_AGL = Burnout_AGL / 3.281; % ft to m
Apogee_AGL = Apogee_AGL / 3.281; % ft to m
Main_AGL = Main_AGL / 3.281; % ft to m

Maximum_Velocity = Maximum_Velocity / 3.281; % ft/s to m/s

Maximum_Drift = Maximum_Drift / 3.281; % ft to m

Launch_MSL = Launch_MSL / 3.281; % ft to m
Temperature = (Temperature - 32) * (5/9); % °F to °C
Maximum_Launch_Wind_Velocity = Maximum_Launch_Wind_Velocity / 2.237; % mph to m/s
```

Derived Parameters

```
Total_Mass = Lower_Mass + Upper_Mass; % Total Vehicle Mass (kg)

Burnout_MSL = Launch_MSL + Burnout_AGL; % Predicted Burnount MSL (m)
Apogee_MSL = Launch_MSL + Apogee_AGL; % Predicted Apogee MSL (m)
Main_MSL = Launch_MSL + Main_AGL; % Main Parachute Deployment Altitude MSL (m)
```



```
Drogue_Area = pi * Drogue_Diameter^2 / 4; % Drogue Parachute Area (m^2)
Packed_Drogue_Area = pi * Packed_Drogue_Diameter^2 / 4; % Packed Drogue Parachute Area (m^2)
Lower_Main_Area = pi * Lower_Main_Diameter^2 / 4; % Lower Main Parachute Area (m^2)
Packed_Lower_Main_Area = pi * Packed_Lower_Main_Diameter^2 / 4; % Packed Lower Main Parachute
Upper_Main_Area = pi * Upper_Main_Diameter^2 / 4; % Upper Main Parachute Area (m^2)
Packed_Upper_Main_Area = pi * Packed_Upper_Main_Diameter^2 / 4; % Packed Upper Main Parachute

Temperature = Temperature + 273; % Launch Site Temperature (K)

Air_Pressure = @(h) p0 * (1 - ((L * h) / Temperature))^((g * M) / (R * L)); % Function for Air
Air_Density = @(p) p / (R_Specific * Temperature); % Function for Air Density

Ground_Air_Pressure = Air_Pressure(Launch_MSL); % Air Pressure at Ground (Pa)
Ground_Air_Density = Air_Density(Ground_Air_Pressure); % Air Density at Ground (kg/m^3)

Burnout_Air_Pressure = Air_Pressure(Burnout_MSL); % Air Pressure at Burnout (Pa)
Burnout_Air_Density = Air_Density(Burnout_Air_Pressure); % Air Density at Burnout (kg/m^3)

Apogee_Air_Pressure = Air_Pressure(Apogee_MSL); % Air Pressure at Apogee (Pa)
Apogee_Air_Density = Air_Density(Apogee_Air_Pressure); % Air Density at Apogee (kg/m^3)

Main_Air_Pressure = Air_Pressure(Main_MSL); % Air Pressure at Main Parachute Deployment (Pa)
Main_Air_Density = Air_Density(Main_Air_Pressure); % Air Density at Main Parachute Deployment

Bulkhead_Area = pi * Airframe_Diameter^2 / 4; % Bulkhead Diameter (m^2)
Recovery_Bay_Volume = Bulkhead_Area * Recovery_Bay_Length; % Volume of Recovery Bay (m^3)

Drag_Force = @(Cd, A, rho, v) Cd * A * ((rho * (v)^2) / 2); % Function for Drag Force
```

Descent Calculations

Descent Velocities

```
Descent_Velocity = @(m, h, A) sqrt((m * g) ./ (0.5 * ((p0 * (1 - ((L * h) ./ Temperature)).^((

Apogee_Drogue_Velocity = Descent_Velocity(Total_Mass, Apogee_MSL, Drogue_Area); % Velocity unde
Main_Drogue_Velocity = Descent_Velocity(Total_Mass, Main_MSL, Drogue_Area); % Velocity under dr

Lower_Main_Main_Velocity = Descent_Velocity(Lower_Mass, Main_MSL, Lower_Main_Area); % Lower Sec
Lower_Main_Ground_Velocity = Descent_Velocity(Lower_Mass, Launch_MSL, Lower_Main_Area); % Lower

Upper_Main_Main_Velocity = Descent_Velocity(Upper_Mass, Main_MSL, Upper_Main_Area); % Upper Sec
Upper_Main_Ground_Velocity = Descent_Velocity(Upper_Mass, Launch_MSL, Upper_Main_Area); % Upper
```

Descent Times

```
Drogue_Descent_Velocity_Inverse = @(x) (1 ./ (sqrt((Total_Mass * g) ./ (0.5 * ((p0 * (1 - ((L
Drogue_Descent_Time = integral(Drogue_Descent_Velocity_Inverse,0,(Apogee_MSL - Main_MSL)); % De

Lower_Main_Descent_Velocity_Inverse = @(x) (1 ./ (sqrt((Lower_Mass * g) ./ (0.5 * ((p0 * (1 -
Lower_Main_Descent_Time = integral(Lower_Main_Descent_Velocity_Inverse,0,Main_MSL-Launch_MSL);
```

```
Upper_Main_Descent_Velocity_Inverse = @(x) (1 ./ (sqrt((Upper_Mass * g) ./ (0.5 * ((p0 * (1 - (
Upper_Main_Descent_Time = integral(Upper_Main_Descent_Velocity_Inverse,0,Main_MSL-Launch_MSL);

Lower_Descent_Time = Drogue_Descent_Time + Lower_Main_Descent_Time; % Descent Time for Lower Se
Upper_Descent_Time = Drogue_Descent_Time + Upper_Main_Descent_Time; % Descent Time for Upper Se

fprintf('Descent time for Lower Body: %0.1f sec',Lower_Descent_Time)
```

```
Descent time for Lower Body: 87.4 sec
```

```
fprintf('Descent time for Upper Body: %0.1f sec',Upper_Descent_Time)
```

```
Descent time for Upper Body: 87.4 sec
```

Landing Kinetic Energies

```
Lower_KE = .5 * Lower_Mass * Lower_Main_Ground_Velocity^2; % Kinetic Energy of Lower Section at
Upper_KE = .5 * Upper_Mass * Upper_Main_Ground_Velocity^2; % Kinetic Energy of Lower Section at

Lower_KE = Lower_KE / 1.356; % J to ft-lbf
Upper_KE = Upper_KE / 1.356; % J to ft-lbf

fprintf('Impact energy for Lower Body: %0.1f ft-lbf',Lower_KE)
```

```
Impact energy for Lower Body: 69.0 ft-lbf
```

```
fprintf('Impact energy for Upper Body: %0.1f ft-lbf',Upper_KE)
```

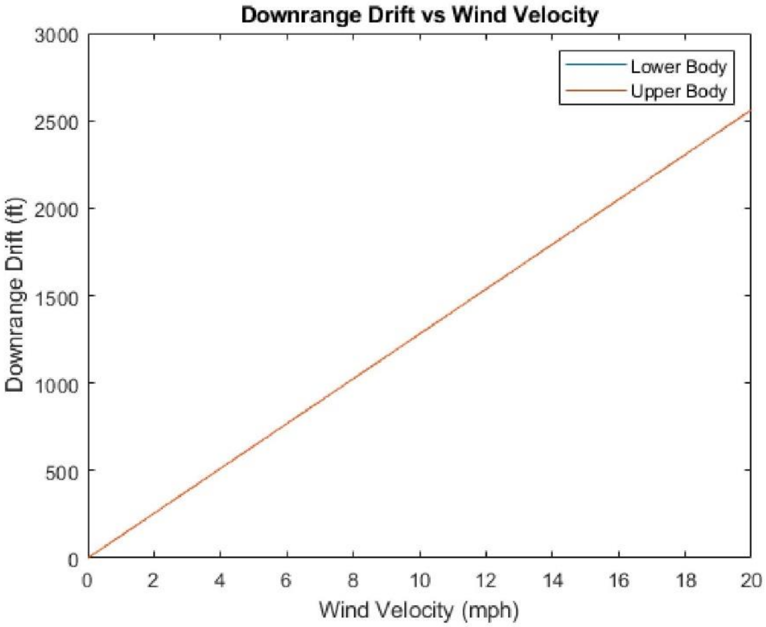
```
Impact energy for Upper Body: 57.0 ft-lbf
```

Downrange Drift

```
Wind_Velocities = 0:Maximum_Launch_Wind_Velocity;
Wind_Velocities = [Wind_Velocities Maximum_Launch_Wind_Velocity];
Lower_Drift = Wind_Velocities .* Lower_Descent_Time;
Upper_Drift = Wind_Velocities .* Upper_Descent_Time;

Maximum_Wind_Velocity = Maximum_Drift / max(Lower_Descent_Time, Upper_Descent_Time); % Maximum

Wind_Velocities = Wind_Velocities .* 2.237; % m/s to mph
Lower_Drift = Lower_Drift .* 3.281; % m to ft
Upper_Drift = Upper_Drift .* 3.281; % m to ft
Maximum_Wind_Velocity = Maximum_Wind_Velocity * 2.237; % m/s to mph
Maximum_Launch_Wind_Velocity = Maximum_Launch_Wind_Velocity * 2.237; % m/s to mph

fprintf('Maximum wind velocity at launch is limited by drift to %0.1f mph',Maximum_Wind_Velocit
```

```
Maximum wind velocity at launch is limited by drift to 19.5 mph
```

```

plot(Wind_Velocities, Lower_Drift, Wind_Velocities, Upper_Drift)
title('Downrange Drift vs Wind Velocity')
xlabel('Wind Velocity (mph)')
ylabel('Downrange Drift (ft)')
legend('Lower Body','Upper Body')
```



Ejection Calculations

Pre Separation

Separation Forces

```
Pressure_Separation_Force = (Ground_Air_Pressure - Apogee_Air_Pressure) * Bulkhead_Area; % Sepa
Drag_Separation_Force = (Drag_Force(Lower_Cd, Bulkhead_Area, Burnout_Air_Density, Maximum_Veloc

Total_Separation_Force = Pressure_Separation_Force + Drag_Separation_Force; % Total separation
```

Shear Pins

```
Required_Shear_Pins = ceil((Total_Separation_Force * 1.25) / Shear_Pin_Strength); % Required nu
Shear_Pin_Breaking_Force = Required_Shear_Pins * Shear_Pin_Strength; % Maximum Shear Pin Force
```

Post Separation

Ejection Charges

```
Ejection_Force = 1.5 * Shear_Pin_Breaking_Force; % Required Ejection Force with a 1.5x safety f

Ejection_Pressure = (Ejection_Force / Bulkhead_Area); % Required Ejection Pressure (Pa)
Black_Powder_Mass = (Ejection_Pressure * Recovery_Bay_Volume)/(R_Combustion * T_Combustion); %

% Ejection Charge calculations taking into account air pressure differences between apogee and
% Minimum_Ejection_Pressure = (Ejection_Force / Bulkhead_Area) - (Ground_Air_Pressure - Apogee_
% Minimum_Black_Powder_Mass = (Minimum_Ejection_Pressure * Recovery_Bay_Volume)/(R_Combustion *
```

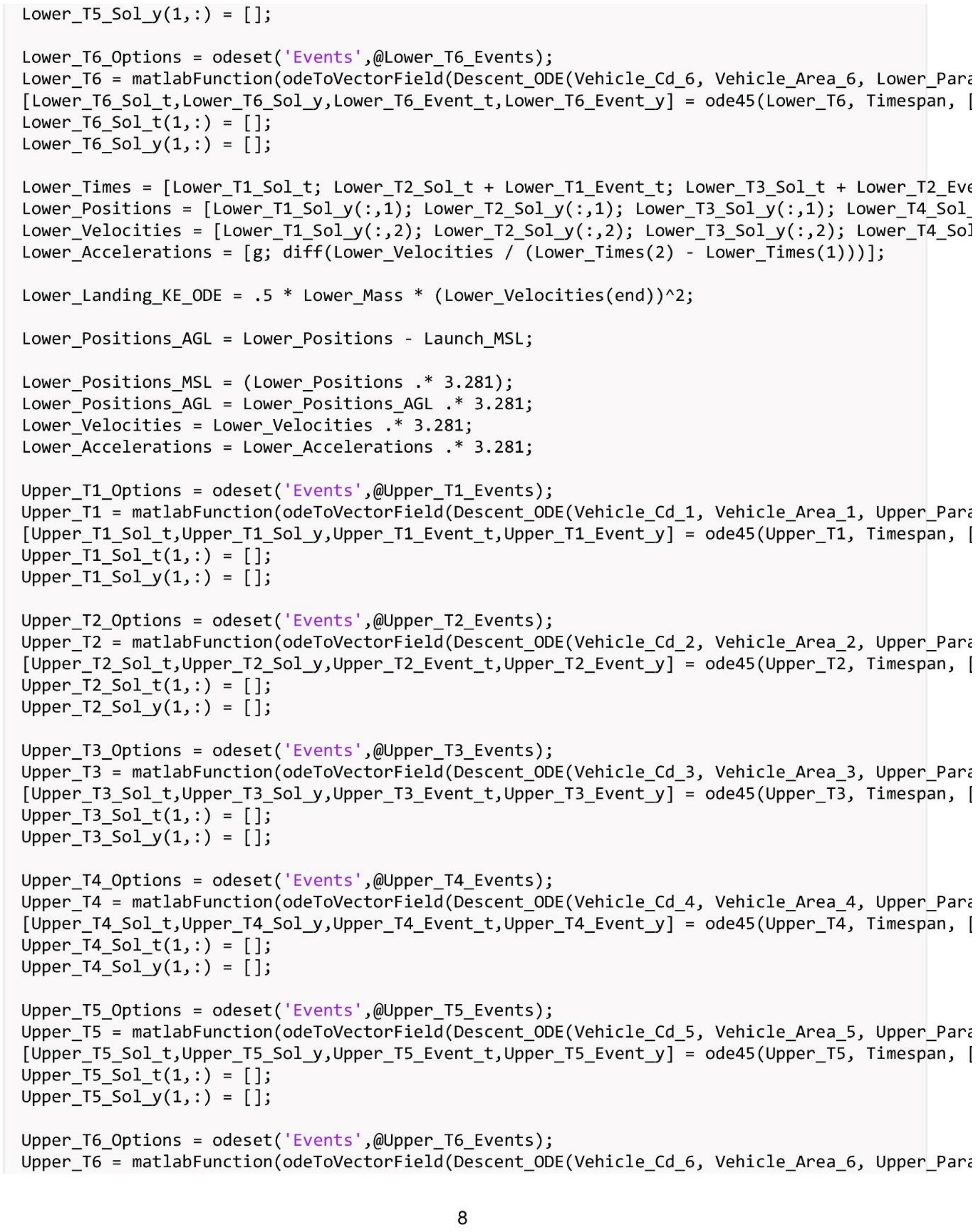
Ejection Velocities

```
syms Lower_Ejection_Velocity Upper_Ejection_Velocity
Force_Eq = @(x) (Black_Powder_Mass * R_Combustion * T_Combustion) ./ (Recovery_Bay_Length + x);
Work_Integral_Equation = integral(Force_Eq,0,Coupler_Length / 2); % Ejection Work based on tota
Work_Equation = (1/2) * Lower_Mass * (Lower_Ejection_Velocity)^2 + (1/2) * Upper_Mass * (Upper_
Moment_Equation = Lower_Mass * (Lower_Ejection_Velocity) == Upper_Mass * (Upper_Ejection_Veloci
Ejection_Velocities = solve([Work_Equation, Moment_Equation], [Lower_Ejection_Velocity, Upper_E
Lower_Ejection_Velocity = double(Ejection_Velocities.Lower_Ejection_Velocity);
Lower_Ejection_Velocity = Lower_Ejection_Velocity (Lower_Ejection_Velocity > 0);
Upper_Ejection_Velocity = double(Ejection_Velocities.Upper_Ejection_Velocity);
Upper_Ejection_Velocity = Upper_Ejection_Velocity (Upper_Ejection_Velocity > 0);
```

Parachute Deployment Forces

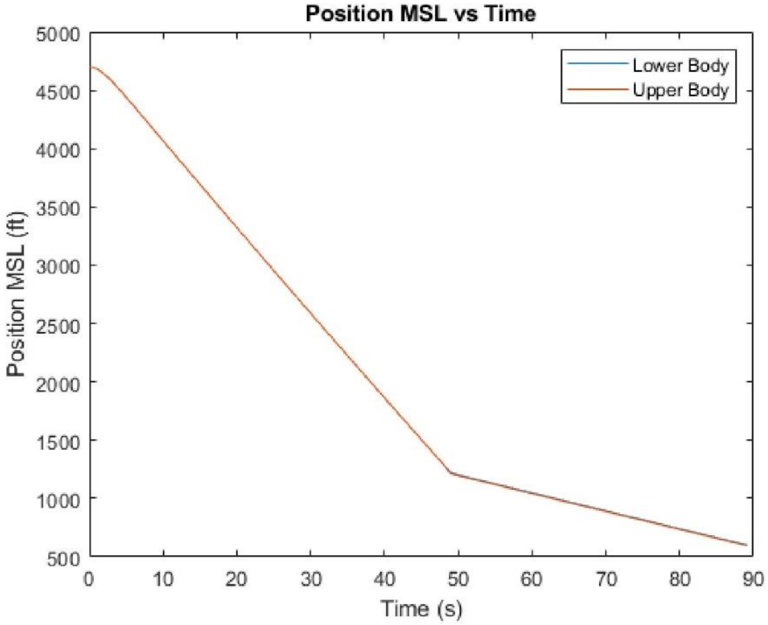
```
Inflation_Time = @(n, D, v) (n * D) / v;
Drogue_Inflation_Time = Inflation_Time(Drogue_n, Drogue_Diameter, 8);
Lower_Main_Inflation_Time = Inflation_Time(Lower_Main_n, Lower_Main_Diameter, Main_Drogue_Veloc
Upper_Main_Inflation_Time = Inflation_Time(Upper_Main_n, Upper_Main_Diameter, Main_Drogue_Veloc

Chute_Area = @(A, Ap, t, tf) A * ((1 - (Ap / A)) * (t / tf)^3 + (Ap / A))^2;
Drogue_Inflation_Area = @(t) Chute_Area(Drogue_Area, Packed_Drogue_Area, t, Drogue_Inflation_Ti
Lower_Main_Inflation_Area = @(t) Chute_Area(Lower_Main_Area, Packed_Lower_Main_Area, t, Lower_M
Upper_Main_Inflation_Area = @(t) Chute_Area(Upper_Main_Area, Packed_Upper_Main_Area, t, Upper_M

% For t0 < t < t1
Vehicle_Cd_1 = 0.4;
Vehicle_Area_1 = .2;
Lower_Parachute_Cd_1 = Parachute_Cd;
Lower_Parachute_Area_1 = Packed_Drogue_Area;
Upper_Parachute_Cd_1 = Parachute_Cd;
Upper_Parachute_Area_1 = Packed_Drogue_Area;

% For t1 < t < t2
Vehicle_Cd_2 = 0.4;
Vehicle_Area_2 = .2;
Lower_Parachute_Cd_2 = Parachute_Cd;
Lower_Parachute_Area_2 = @(t) Drogue_Inflation_Area(t);
Upper_Parachute_Cd_2 = Parachute_Cd;
Upper_Parachute_Area_2 = @(t) Drogue_Inflation_Area(t);

% For t2 < t < t3
Vehicle_Cd_3 = 0.4;
Vehicle_Area_3 = .2;
Lower_Parachute_Cd_3 = Parachute_Cd;
Lower_Parachute_Area_3 = Drogue_Area;
Upper_Parachute_Cd_3 = Parachute_Cd;
Upper_Parachute_Area_3 = Drogue_Area;

% For t3 < t < t4
Vehicle_Cd_4 = 0.4;
Vehicle_Area_4 = .2;
Lower_Parachute_Cd_4 = Parachute_Cd;
Lower_Parachute_Area_4 = Drogue_Area;
```

```
Upper_Parachute_Cd_4 = Parachute_Cd;
Upper_Parachute_Area_4 = Packed_Upper_Main_Area;


% For t4 < t < t5
Vehicle_Cd_5 = 0.6;
Vehicle_Area_5 = Bulkhead_Area;
Lower_Parachute_Cd_5 = Parachute_Cd;
Lower_Parachute_Area_5 = @(t) Lower_Main_Inflation_Area(t);
Upper_Parachute_Cd_5 = Parachute_Cd;
Upper_Parachute_Area_5 = @(t) Upper_Main_Inflation_Area(t);

% For t5 < t < t6
Vehicle_Cd_6 = 0.6;
Vehicle_Area_6 = Bulkhead_Area;
Lower_Parachute_Cd_6 = Parachute_Cd;
Lower_Parachute_Area_6 = Lower_Main_Area;
Upper_Parachute_Cd_6 = Parachute_Cd;
Upper_Parachute_Area_6 = Upper_Main_Area;

% Differential Equations
syms x(t)
Descent_ODE = @(Cdv, Av, Ap, Cdp, m) diff(x, 2) == ((.5 * ((p0 * (1 - ((L * x) / Temperature))

Timespan = 0:.0001:100;

Lower_T1_Options = odeset('Events',@Lower_T1_Events);
Lower_T1 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_1, Vehicle_Area_1, Lower_Para
[Lower_T1_Sol_t,Lower_T1_Sol_y,Lower_T1_Event_t,Lower_T1_Event_y] = ode45(Lower_T1, Timespan, [
Lower_T1_Sol_t(1,:) = [];
Lower_T1_Sol_y(1,:) = [];

Lower_T2_Options = odeset('Events',@Lower_T2_Events);
Lower_T2 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_2, Vehicle_Area_2, Lower_Para
[Lower_T2_Sol_t,Lower_T2_Sol_y,Lower_T2_Event_t,Lower_T2_Event_y] = ode45(Lower_T2, Timespan, [
Lower_T2_Sol_t(1,:) = [];
Lower_T2_Sol_y(1,:) = [];

Lower_T3_Options = odeset('Events',@Lower_T3_Events);
Lower_T3 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_3, Vehicle_Area_3, Lower_Para
[Lower_T3_Sol_t,Lower_T3_Sol_y,Lower_T3_Event_t,Lower_T3_Event_y] = ode45(Lower_T3, Timespan, [
Lower_T3_Sol_t(1,:) = [];
Lower_T3_Sol_y(1,:) = [];

Lower_T4_Options = odeset('Events',@Lower_T4_Events);
Lower_T4 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_4, Vehicle_Area_4, Lower_Para
[Lower_T4_Sol_t,Lower_T4_Sol_y,Lower_T4_Event_t,Lower_T4_Event_y] = ode45(Lower_T4, Timespan, [
Lower_T4_Sol_t(1,:) = [];
Lower_T4_Sol_y(1,:) = [];

Lower_T5_Options = odeset('Events',@Lower_T5_Events);
Lower_T5 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_5, Vehicle_Area_5, Lower_Para
[Lower_T5_Sol_t,Lower_T5_Sol_y,Lower_T5_Event_t,Lower_T5_Event_y] = ode45(Lower_T5, Timespan, [
Lower_T5_Sol_t(1,:) = [];
```



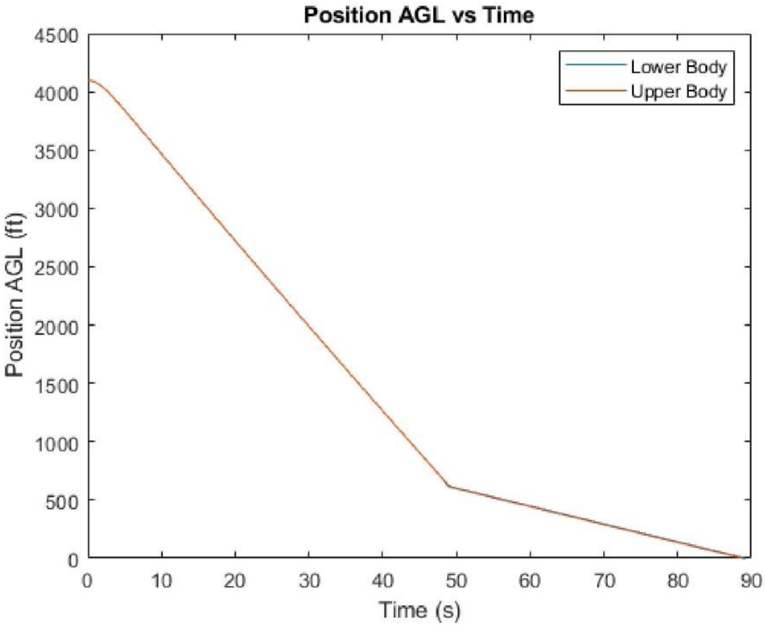
```
Lower_T5_Sol_y(1,:) = [];

Lower_T6_Options = odeset('Events',@Lower_T6_Events);
Lower_T6 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_6, Vehicle_Area_6, Lower_Para
[Lower_T6_Sol_t,Lower_T6_Sol_y,Lower_T6_Event_t,Lower_T6_Event_y] = ode45(Lower_T6, Timespan, [
Lower_T6_Sol_t(1,:) = [];
Lower_T6_Sol_y(1,:) = [];

Lower_Times = [Lower_T1_Sol_t; Lower_T2_Sol_t + Lower_T1_Event_t; Lower_T3_Sol_t + Lower_T2_Eve
Lower_Positions = [Lower_T1_Sol_y(:,1); Lower_T2_Sol_y(:,1); Lower_T3_Sol_y(:,1); Lower_T4_Sol_
Lower_Velocities = [Lower_T1_Sol_y(:,2); Lower_T2_Sol_y(:,2); Lower_T3_Sol_y(:,2); Lower_T4_Sol
Lower_Accelerations = [g; diff(Lower_Velocities / (Lower_Times(2) - Lower_Times(1)))];

Lower_Landing_KE_ODE = .5 * Lower_Mass * (Lower_Velocities(end))^2;

Lower_Positions_AGL = Lower_Positions - Launch_MSL;

Lower_Positions_MSL = (Lower_Positions .* 3.281);
Lower_Positions_AGL = Lower_Positions_AGL .* 3.281;
Lower_Velocities = Lower_Velocities .* 3.281;
Lower_Accelerations = Lower_Accelerations .* 3.281;

Upper_T1_Options = odeset('Events',@Upper_T1_Events);
Upper_T1 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_1, Vehicle_Area_1, Upper_Para
[Upper_T1_Sol_t,Upper_T1_Sol_y,Upper_T1_Event_t,Upper_T1_Event_y] = ode45(Upper_T1, Timespan, [
Upper_T1_Sol_t(1,:) = [];
Upper_T1_Sol_y(1,:) = [];

Upper_T2_Options = odeset('Events',@Upper_T2_Events);
Upper_T2 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_2, Vehicle_Area_2, Upper_Para
[Upper_T2_Sol_t,Upper_T2_Sol_y,Upper_T2_Event_t,Upper_T2_Event_y] = ode45(Upper_T2, Timespan, [
Upper_T2_Sol_t(1,:) = [];
Upper_T2_Sol_y(1,:) = [];

Upper_T3_Options = odeset('Events',@Upper_T3_Events);
Upper_T3 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_3, Vehicle_Area_3, Upper_Para
[Upper_T3_Sol_t,Upper_T3_Sol_y,Upper_T3_Event_t,Upper_T3_Event_y] = ode45(Upper_T3, Timespan, [
Upper_T3_Sol_t(1,:) = [];
Upper_T3_Sol_y(1,:) = [];

Upper_T4_Options = odeset('Events',@Upper_T4_Events);
Upper_T4 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_4, Vehicle_Area_4, Upper_Para
[Upper_T4_Sol_t,Upper_T4_Sol_y,Upper_T4_Event_t,Upper_T4_Event_y] = ode45(Upper_T4, Timespan, [
Upper_T4_Sol_t(1,:) = [];
Upper_T4_Sol_y(1,:) = [];

Upper_T5_Options = odeset('Events',@Upper_T5_Events);
Upper_T5 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_5, Vehicle_Area_5, Upper_Para
[Upper_T5_Sol_t,Upper_T5_Sol_y,Upper_T5_Event_t,Upper_T5_Event_y] = ode45(Upper_T5, Timespan, [
Upper_T5_Sol_t(1,:) = [];
Upper_T5_Sol_y(1,:) = [];

Upper_T6_Options = odeset('Events',@Upper_T6_Events);
Upper_T6 = matlabFunction(odeToVectorField(Descent_ODE(Vehicle_Cd_6, Vehicle_Area_6, Upper_Para
```

```
[Upper_T6_Sol_t,Upper_T6_Sol_y,Upper_T6_Event_t,Upper_T6_Event_y] = ode45(Upper_T6, Timespan, [
Upper_T6_Sol_t(1,:) = [];
Upper_T6_Sol_y(1,:) = [];

Upper_Times = [Upper_T1_Sol_t; Upper_T2_Sol_t + Upper_T1_Event_t; Upper_T3_Sol_t + Upper_T2_Eve
Upper_Positions = [Upper_T1_Sol_y(:,1); Upper_T2_Sol_y(:,1); Upper_T3_Sol_y(:,1); Upper_T4_Sol_
Upper_Velocities = [Upper_T1_Sol_y(:,2); Upper_T2_Sol_y(:,2); Upper_T3_Sol_y(:,2); Upper_T4_Sol
Upper_Accelerations = [g; diff(Upper_Velocities / (Upper_Times(2) - Upper_Times(1)))];

Upper_Positions_AGL = Upper_Positions - Launch_MSL;

Upper_Positions_MSL = (Upper_Positions .* 3.281);
Upper_Positions_AGL = Upper_Positions_AGL .* 3.281;
Upper_Velocities = Upper_Velocities .* 3.281;
Upper_Accelerations = Upper_Accelerations .* 3.281;

ODE_Lower_KE = (0.5 * Lower_Mass * (Lower_Velocities(end) / 3.281)^2) / 1.356;
ODE_Upper_KE = (0.5 * Upper_Mass * (Upper_Velocities(end) / 3.281)^2) / 1.356;

plot(Lower_Times,Lower_Positions_MSL,Upper_Times,Upper_Positions_MSL)
title('Position MSL vs Time')
xlabel('Time (s)')
ylabel('Position MSL (ft)')
legend('Lower Body','Upper Body')
```

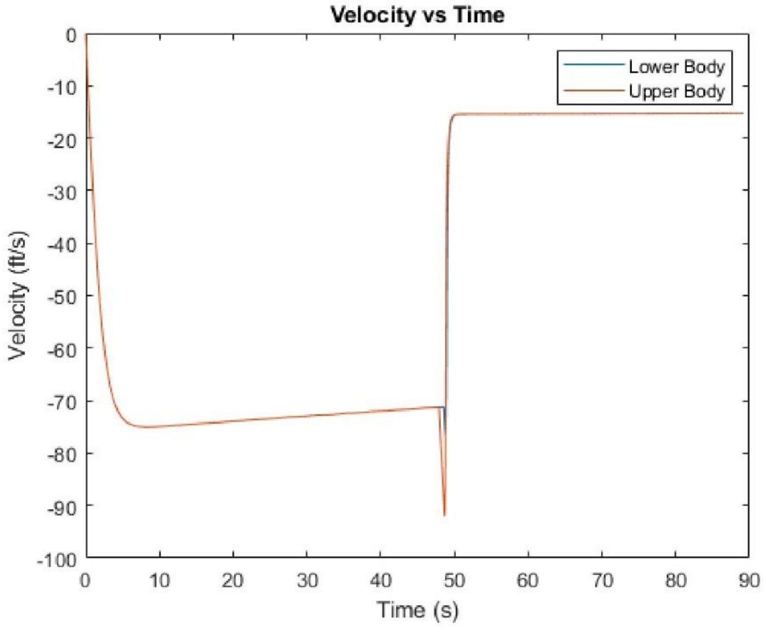


```
plot(Lower_Times,Lower_Positions_AGL,Upper_Times,Upper_Positions_AGL)
title('Position AGL vs Time')
xlabel('Time (s)')
```

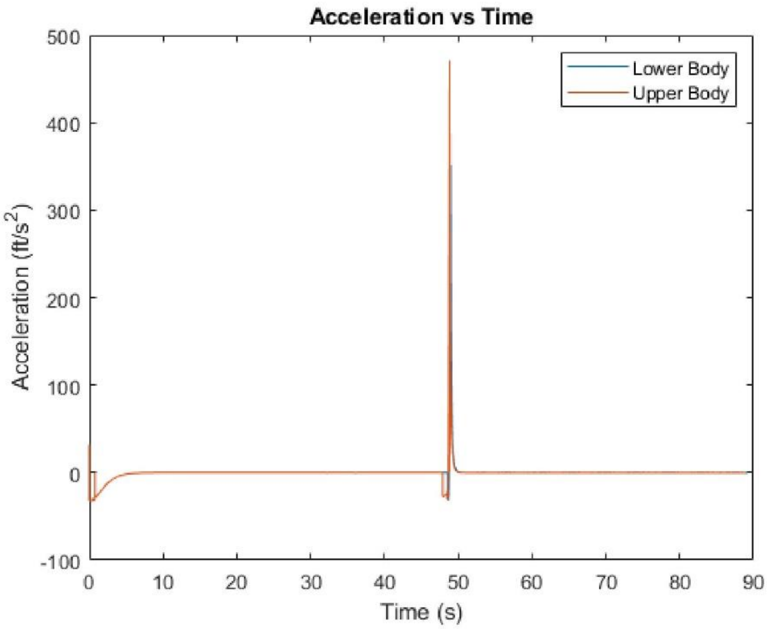
```
ylabel('Position AGL (ft)')
legend('Lower Body','Upper Body')
```



```
plot(Lower_Times,Lower_Velocities,Upper_Times,Upper_Velocities)
title('Velocity vs Time')
xlabel('Time (s)')
ylabel('Velocity (ft/s)')
legend('Lower Body','Upper Body')
```



```
plot(Lower_Times,Lower_Accelerations,Upper_Times,Upper_Accelerations)
title('Acceleration vs Time')
xlabel('Time (s)')
ylabel('Acceleration (ft/s^2)')
legend('Lower Body','Upper Body')
```



```
fprintf('Maximum Acceleration of Lower Body during Descent: %0.1f ft/s^2',max(Lower_Acceleratio
```

```
Maximum Acceleration of Lower Body during Descent: 351.2 ft/s^2
```

```
fprintf('Maximum Acceleration of Upper Body during Descent: %0.1f ft/s^2',max(Upper_Acceleratio
```

```
Maximum Acceleration of Upper Body during Descent: 471.3 ft/s^2
```

```
fprintf('Descent Time of Lower Body: %0.1f sec',Lower_Times(end))
```

```
Descent Time of Lower Body: 89.2 sec
```

```
fprintf('Descent Time of Upper Body: %0.1f sec',Upper_Times(end))
```

```
Descent Time of Upper Body: 88.9 sec
```

```
fprintf('Impact energy for Lower Body: %0.1f ft-lbf',ODE_Lower_KE)
```

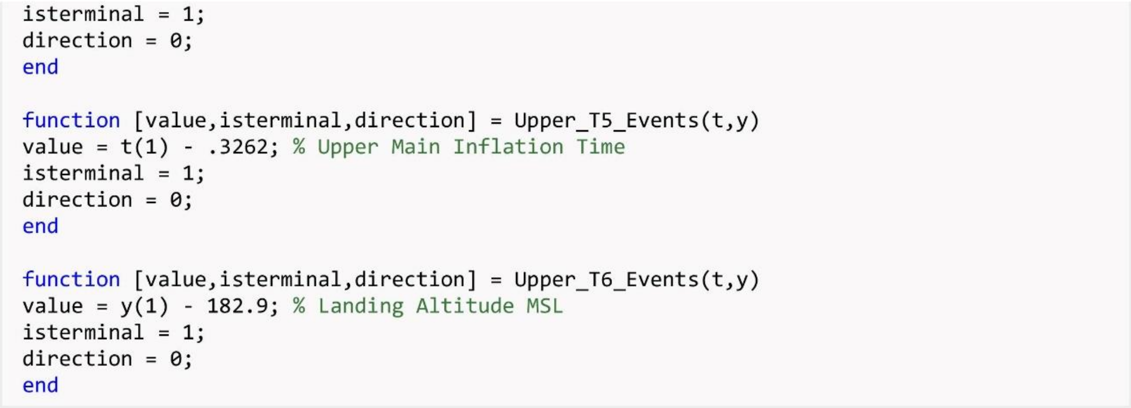
```
Impact energy for Lower Body: 68.9 ft-lbf
```

```
fprintf('Impact energy for Upper Body: %0.1f ft-lbf',ODE_Upper_KE)
```

```
Impact energy for Upper Body: 56.9 ft-lbf
```

```
function [value,isterminal,direction] = Lower_T1_Events(t,y)
value = y(1) - 1431; % Apogee_Altitude minus Shock Cord Fall Distance
```

```
isterminal = 1;
direction = 0;
end

function [value,isterminal,direction] = Lower_T2_Events(t,y)
value = t(1) - .2858; % Drogue Inflation Time
isterminal = 1;
direction = 0;
end

function [value,isterminal,direction] = Lower_T3_Events(t,y)
value = y(1) - 396; % Drogue Sep Altitude MSL
isterminal = 1;
direction = 0;
end

function [value,isterminal,direction] = Lower_T4_Events(t,y)
value = y(1) - 381; % Main Deployment Altitude MSL
isterminal = 1;
direction = 0;
end

function [value,isterminal,direction] = Lower_T5_Events(t,y)
value = t(1) - .3585; % Lower Main Inflation Time
isterminal = 1;
direction = 0;
end

function [value,isterminal,direction] = Lower_T6_Events(t,y)
value = y(1) - 182.9; % Landing Altitude MSL
isterminal = 1;
direction = 0;
end

function [value,isterminal,direction] = Upper_T1_Events(t,y)
value = y(1) - 1431; % Apogee_Altitude minus Shock Cord Fall Distance
isterminal = 1;
direction = 0;
end

function [value,isterminal,direction] = Upper_T2_Events(t,y)
value = t(1) - .2858; % Drogue Inflation Time
isterminal = 1;
direction = 0;
end

function [value,isterminal,direction] = Upper_T3_Events(t,y)
value = y(1) - 396; % Drogue Sep Altitude MSL
isterminal = 1;
direction = 0;
end

function [value,isterminal,direction] = Upper_T4_Events(t,y)
value = y(1) - 381; % Main Deployment Altitude MSL
```



```
isterminal = 1;
direction = 0;
end

function [value,isterminal,direction] = Upper_T5_Events(t,y)
value = t(1) - .3262; % Upper Main Inflation Time
isterminal = 1;
direction = 0;
end

function [value,isterminal,direction] = Upper_T6_Events(t,y)
value = y(1) - 182.9; % Landing Altitude MSL
isterminal = 1;
direction = 0;
end
```