By:

The Georgia Institute of Technology Launch Initiative Team

(GIT LIT)

NASA Student Launch

2017-2018 Flight Readiness Review

March 5th, 2018

Georgia Institute of Technology
School of Aerospace Engineering
270 Ferst Drive, Atlanta GA 30332-0150

1. Summary of FRR Report

1.1. Team Summary

Team Name: Georgia Institute of Technology Launch Initiative Team (GIT LIT)

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1.2. Launch Vehicle Summary

Table 1.2.1 Launch Vehicle Summary

Vehicle Feature	**Value**
Vehicle Length/Diameter	108 in. / 5.562 in.
Mass	39.374 lbm
Motor	Aerotech L1390G
Drogue Parachute Model/Diameter	Apogee 29095 / 36 in.
Main Parachute Model/Diameter	Fruity Chutes IFC-96 / 96 in.
Rail Size	1515 / 144 in.

1.3. Payload Summary

Our selected payload is the Deployable Rover. Our rover system consists of a four-wheeled, battery powered rover, which is mounted in a lead-screw separation deployment system. Once the rocket has landed, the team will trigger the separation of the body tube using an RC transmitter, and the rover will then autonomously drive out, perpendicular to the body tube. Once moving at least five feet away from the launch vehicle, the rover will deploy servo-mounted, foldable solar panels. This rover system will not be active for the competition flight, due to a lack of full assembly and testing prior to the FRR test flight.

2. Changes made since CDR

2.1. Changes to Vehicle Criteria

The telemetry and battery voltage monitoring systems have been removed from the rocket. Development on these systems will continue but they will not be implemented this season. The apogee targeting will no longer be utilizing airspeed sensor data. Consequently, no pitot tube will be present on the exterior of the rocket. The rover will now be controlled by an Arduino Nano microcontroller as opposed to an ATmega328 chip paired with a custom printed circuit board. Due to complications with the rover deployment system, the original PVC pipe design for the GPS bay has been abandoned in favor of a flat-plate design that can be easily mounted to the back of the pusher plate.

2.2. Changes to Payload Criteria

Due to severe unforeseen delays in the delivery of flight critical components, the team had to shift focus to the manufacturing, assembly, and testing of these components once they arrived. This shift in focus helped maintain the teams slot in the competition. Maintaining the competition slot came at the cost of vehicle payload performance. Therefore, the competition flight will see the payload systems fly fully assembled and mounted as inactive mass simulators only.

2.3. Changes to Project Plan

The major change to the project plan is the shift of the payload testing schedule. As the payloads will not be flown in an active configuration for competition, a majority of the payload tests have been scheduled for the future, to allot more time for flight critical tests.

3. Vehicle Criteria

3.1. Design and Construction of Launch Vehicle

The airframe of the launch vehicle is primarily constructed from G10 and G12 filament wound fiberglass and aluminum 6061 alloy while the other subsystems - Rover and Rover Deployment System, Apogee Target System (ATS), and Recovery Subsystem - utilize PLA plastic 3D printed parts extensively. In the CDR, the launch vehicle was designed such that, with the minimal mass to maintain strength, it will reach the target apogee of 5,280 ft with the drag induced by the ATS. However, due to additional masses of GPS, epoxy and hardwares, the launch vehicle's total mass increased from that in the CDR, forcing the team to abandon the target apogee of 5,280 ft. Nevertheless, the team is determined to participate in the competition with this functional and safe launch vehicle. The figure immediately below depicts the five sections of the launch vehicle: Nose Cone section, Rover Housing section, Avionics Bay, ATS Housing section, and Booster section. The actual image of the fully constructed launch vehicle as well as the table summarizing the overall specification of the as built launch vehicle and the mass and length of each section follow this figure.

Figure 3.1.1: Sections of Full Scale Launch Vehicle

Figure 3.1.2: Fully Constructed Full Scale Launch Vehicle

Table 3.1.1: Overall specification of the as built launch vehicle

Property	Value
Overall length	108 in
Launch vehicle diameter	5.562 in
Overall mass with motor loaded	39.734 lb_m
Center of gravity (measured from nose cone)	71.926 in
Center of pressure (measured from nose cone)	83.764 in

Table 3.1.2: Mass and Length for each section

Section	Mass (lb_m)	Length (in)
Nose Cone	1.050	21.75
Rover Housing	8.880	33.875
Avionics Bay	4.830	12
ATS Housing	3.650	22.75
Booster	21.324	28.875
Total	39.734	108

3.1.1. Changes from CDR

Due to the additional mass, the manufacturing processes and the full-scale launch vehicle test results, full-scale launch vehicle design changes were made to ensure the success of the mission.

Table 3.1.3 Items changed from GPS

Changed item	Description
Overall vehicle length increased from 107 in to 108 in	Cutting the fin slots for booster body tube was consigned to the machine shop on campus, yet the body tube was returned to the team few days before the full scale launch. Rather than spending a day to cut the body tube to the length stated in CDR, the team cherished the time for curing the epoxy used to assemble the booster section. The fact that the stability of the launch vehicle increases with the additional length also supported the decision making
Overall mass of the vehicle increased from 37.38 lb_m to 39.734 lb_m	Mass assumption for the subsystems were underestimated and masses of hardwares such as quicklinks, eye-bolts, and U-bolts were not considered in the mass estimation in the CDR.
Key switch hole was drilled to ATS Housing tube	In order to allow the access to the key switch on the ATS electronics bay from outside of the launch vehicle, a hole was drilled to the ATS housing tube.
On board camera was removed	On board camera will require an additional hole to be drilled on the booster section and will add mass to the booster section. These will affect the drag and stability of the launch vehicle negatively, hence the on board camera was not installed to the full scale launch vehicle.
Shock cord length was increased from 20 ft to 24 ft for drogue parachute and from 20 ft to 30 ft for main parachute	Length of the shock cords were increased in order to increase the shock cords' abilities to absorb the kinetic energy at parachute deployments.
Monitoring system removed	The telemetry and battery voltage monitoring systems were removed from the rocket. Additionally, the apogee targeting will no longer be utilizing airspeed data. Development on these systems will continue, however they will not be implemented in the rocket this season.

Pitot tube removed	Due to the changes in monitoring systems, the pitot tube present on the exterior of the rocket was removed.
GPS bay design changed	The original PVC pipe design was abandoned in favor of a flat-plate design easily mountable onto the back of the pusher plate due to complications with the rover deployment system.
ATS avionics bay design change	The Avionics for the ATS did not have any major changes since the CDR aside from small adjustments to nut housings on the ATS Avionics housing to ensure that the components do not come loose. Most nut housings were made smaller by 1/64th of an inch. The bay housing was also 3d printed in 2 parts and connected to ensure that all the dimensions that were expected were represented in the product.

3.1.2. Overall Assembly

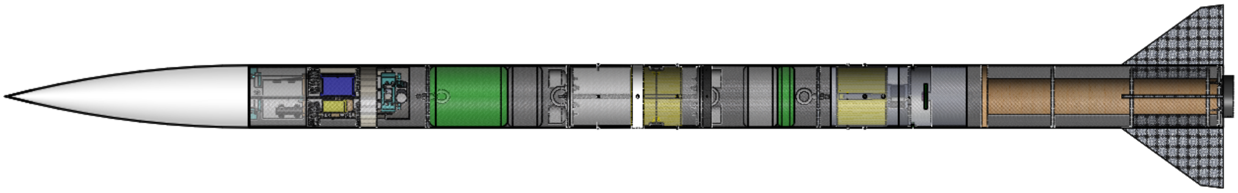


Figure 3.1.3: Launch Vehicle Layout CAD

From left to right of the figure above, the launch vehicle consists of five sections: Nose Cone, Rover Housing, Avionics Bay, ATS Housing, and Booster. During the flight of the vehicle, the Nose Cone and Rover Housing, as well as the ATS Housing and Booster will not separate, following the requirement of the maximum of four independent sections. The linkage mode between each section as well as the separation mechanism and event are summarized in the table below. The numbering of the separation points can be seen from the figure below.

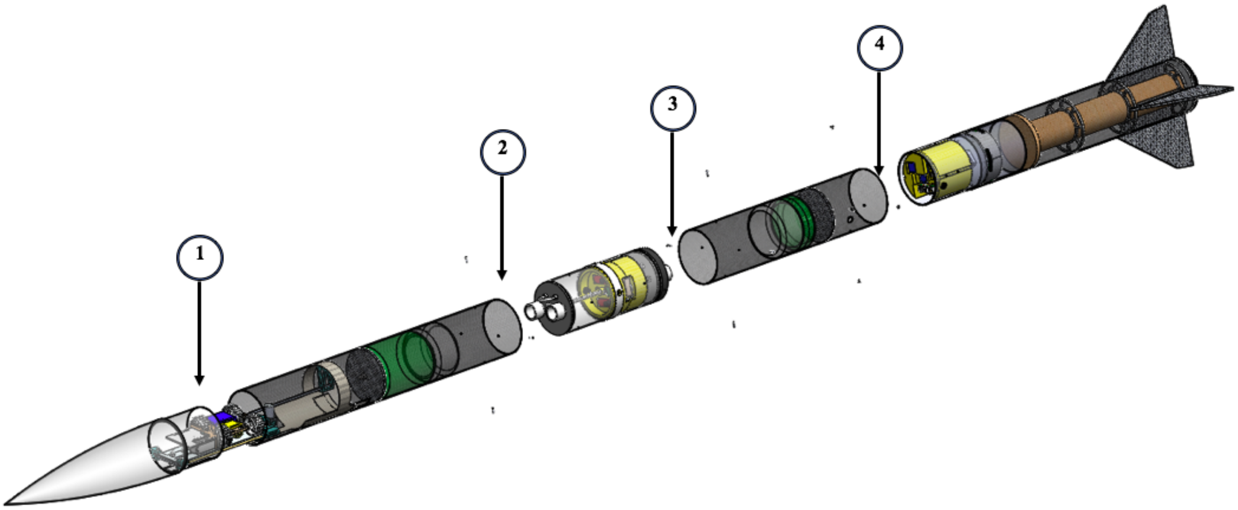


Figure 3.1.4: Exploded View of the Full Scale Assembly

Table 3.1.4 Linkage method, separation mechanism and timing for each separation points

No.	Linkage mode	Separation Mechanism	Separation Event
1	Bracket from rover deployment system	Rover deployment system pushing the nose cone out of the rover housing	Post-landing (Rover deployment)
2	2-56 nylon shear pins	Pressure produced by ejection charge breaking the shear pins	Main parachute deployment
3	2-56 nylon shear pins	Pressure produced by ejection charge breaking the shear pins	Drogue parachute deployment
4	Removable plastic rivets	N/A	N/A

Nose cone - Rover Housing

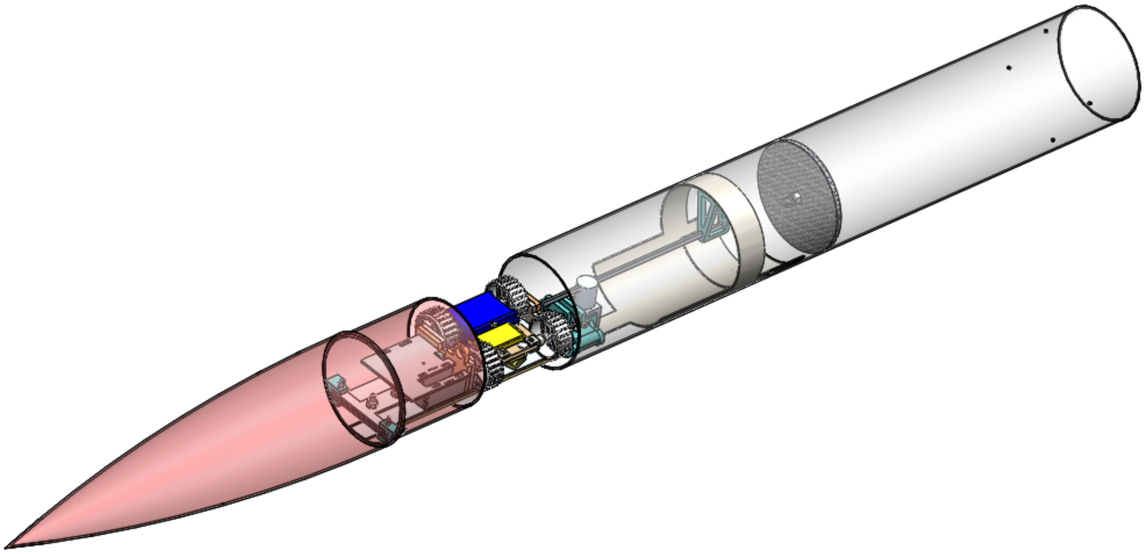


Figure 3.1.5: Nose Cone and Rover Housing Section

The figure above is a close up view of the Nose Cone and Rover Housing section at a configuration to deploy the rover. The nose cone houses the GPS for locating the rocket after landing. The rover, rover deployment system, main parachute and shock cord are included in the Rover Housing section. The specifications of the rover and the rover deployment system will be discussed in detail in the Payload section. The beams of the rover deployment system have brackets on their ends which will be epoxied to the inside of the nose cone. Accompanied with a fairly high friction between the nose cone and the body tube, the brackets locks the nose cone onto the Rover Housing section in place during the flight of the launch vehicle. After landing, when the receiver on the rover deployment system receives a radio signal, the system pushes the nose cone out, allowing the rover to move out of the launch vehicle.

Rover Housing - Avionics Bay - ATS Housing

Figure 3.1.6: Rover Housing, Avionics Bay, and ATS Housing

Four equally spaced 2-56 nylon shear pins are used as the linkage mode between the Rover Housing section and Avionics Bay and between the Avionics Bay and the ATS Housing section. A close view of the separation points between the Rover Housing, Avionics Bay, and the ATS Housing Sections can be seen in the figure above. The Avionics Bay houses the electronics for the recovery subsystem, having a hole that allows the access to the key switch from outside launch vehicle. The ATS Housing Section contains the drogue parachute and shock cord. Copper wire tape runs through this section so that power is supplied from the Avionics bay to the ATS electronics bay in the Booster section. The coupler tube used for the Avionics Bay is sandwiched by two bulkheads, each having two ejection caps mounted on them for redundant ejection charges, and these bulkheads are secured to the coupler tube and centralized via 3/8 inches thread rod. Once the launch vehicle reaches apogee, the recovery subsystem ignites the main ejection charge on the ATS Housing side. The pressure increase of the ATS Housing section caused by the ejection charge breaks the four shear pins connecting the Avionics Bay and the ATS Housing section, deploying the drogue parachute. At the altitude of 750 ft, the main ejection charge on the Rover Housing side is ignited, and the same mechanism is used to break the shear pins and deploy the main parachute. The Avionics Bay is tethered to the Rover Housing and ATS Housing sections via 30 ft and 24 ft tubular nylon shock cords respectively, and the parachutes are tied to these shock cords via quicklinks.

ATS Housing - Booster

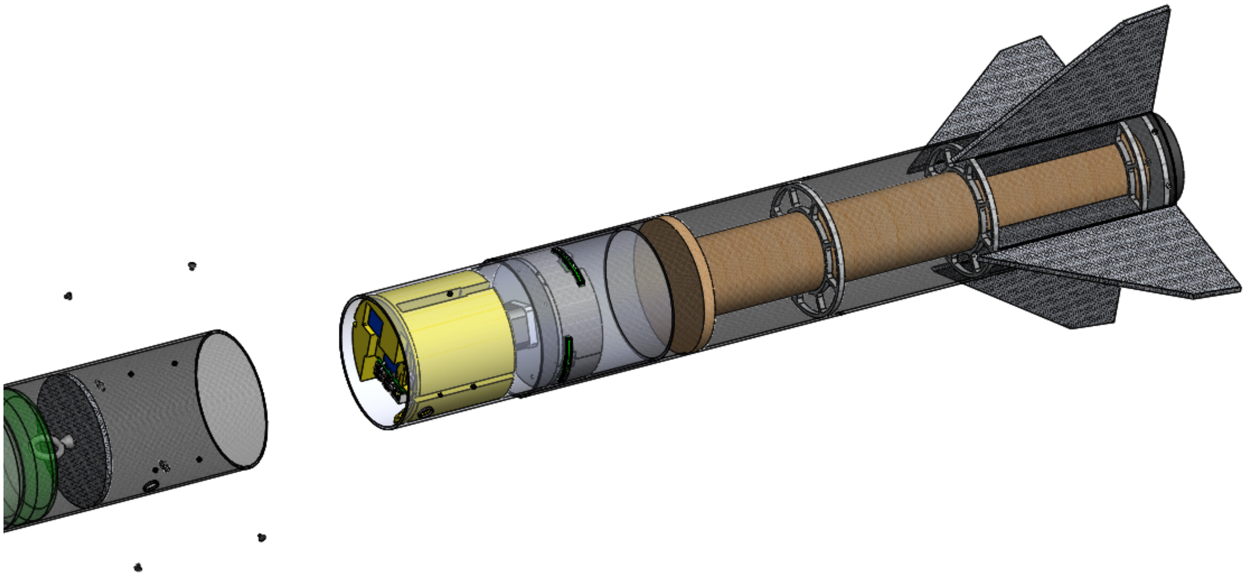


Figure 3.1.7: ATS Housing and Booster

The figure above shows the interface between the ATS Housing and Booster sections. The ATS Housing and Booster sections are “permanently” secured via removable four equally located plastic rivets, that is, the two sections never separate during any time of the entire mission of the vehicle. In order to allow the insertion and retrieval of the ATS electronics bay and the ATS mechanisms for malfunction fixture, the rivets are removable are used rather than using epoxy to secure the two sections together. The coupler tube placed between the two sections has half of its length epoxied to the booster section.

3.1.3. Airframe Structural Elements

Nose cone

To be consistent with the diameter of the body tube, the nose cone has a diameter of 5.5 inches with a 4:1 length to diameter ratio. With its high strength and melting point the structural integrity could be maintained, hence G10 fiberglass was chosen as the material of the nose cone. The material ensures that the nose cone would be able to withstand impacts reliably during the course of the flight of the rocket, without the compromise of adding too much mass to the vehicle as a whole. The two images below are the CAD and actual images of nose cone, followed by a table summarizing the main properties of the nose cone.

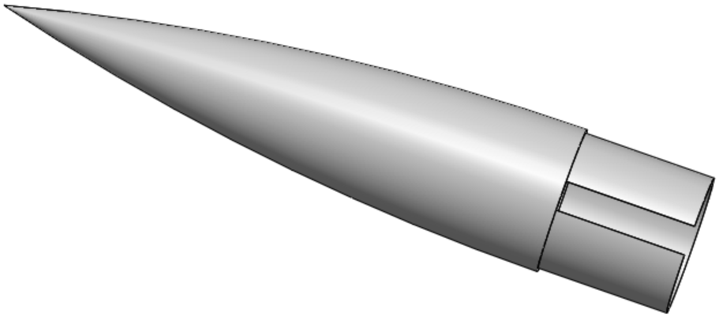


Figure 3.1.8: Nose Cone CAD

Figure 3.1.9: Actual image of the Nose Cone

Table 3.1.5 Nose Cone Specifications

Properties	Values
Material	G10 Fiberglass
Mass	1.05 lb_m
Nose Length	21.75 in
Shoulder Length	5.25 in
Outside Diameter	5.50 in
Should Diameter	5.28 in

Bulkheads

The bulkheads were constructed from G10 filament wound fiberglass. The material choice was made based on the material's strength to withstand the impulse caused by the ejection charge to deploy the parachutes. The high strength allowed the bulkheads to be thinner, benefiting the overall launch vehicle by minimizing necessary body tube lengths and reducing the mass.

Finite Element Analysis (FEA) was conducted to minimize the thickness of the bulkhead while maintaining the strength to withstand a 235 pound force generated by the ignition of main parachute backup ejection charge. The thickness of the bulkhead as 1/4 inches is kept from the CDR as a result of the analysis. There are three different types of bulkheads produced: bulkhead with an Eye-bolt hole, Avionics Bay body tube bulkhead, and Avionics Bay coupler tube bulkhead. The bulkhead with an Eye-bolt hole are epoxied in the Rover Housing and ATS Housing section. One of the ends of each shock cord are tied to the Eye-bolt on these bulkhead, tethering the two sections to the Avionics bay. The Avionics Bay body tube and coupler tube bulkheads are used to seal the Avionics Bay from both sides, having the ejection caps and U-bolts attached to them. The bulkheads with the Eye-bolt and the Avionics Bay body tube bulkheads were cut to have a 5.376 inch diameter as to fit within the inner diameter of the body tube while the Avionics Bay coupler tube bulkheads were cut to 5.169 inch diameter as to fit within the inner diameter of the Avionics Bay coupler tube. The actual images as well as the stress plot of the FEA on each bulkhead are shown below.

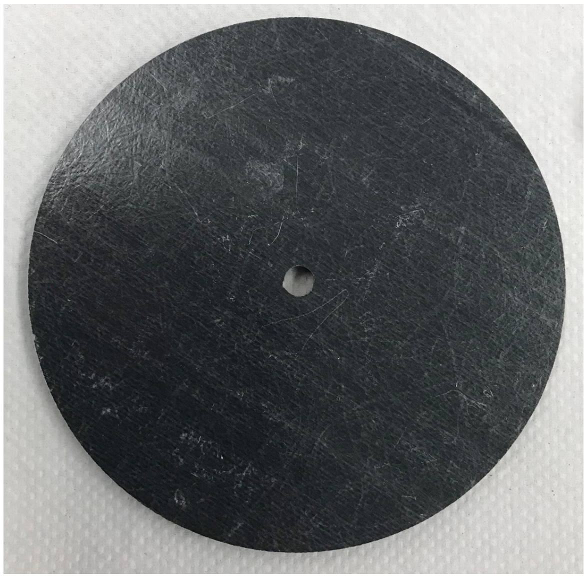


Figure 3.1.10: Bulkhead with Eye-bolt hole

Figure 3.1.11: Actual image of Avionics Bay bulkhead

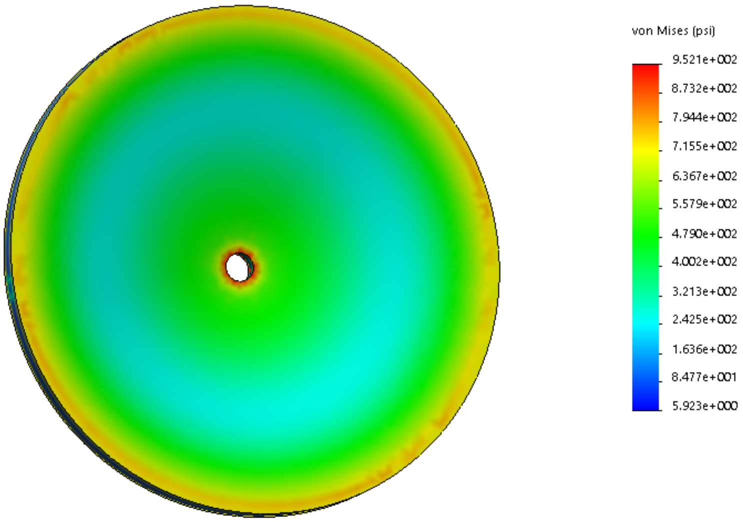


Figure 3.1.12 FEA for bulkhead with eye-bolt hole

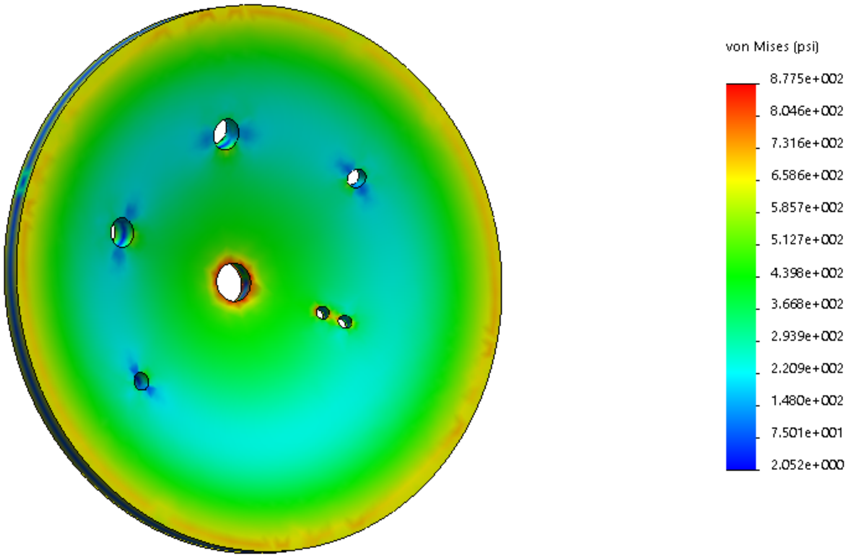


Figure 3.1.13 FEA of Avionics Bay coupler tube bulkhead

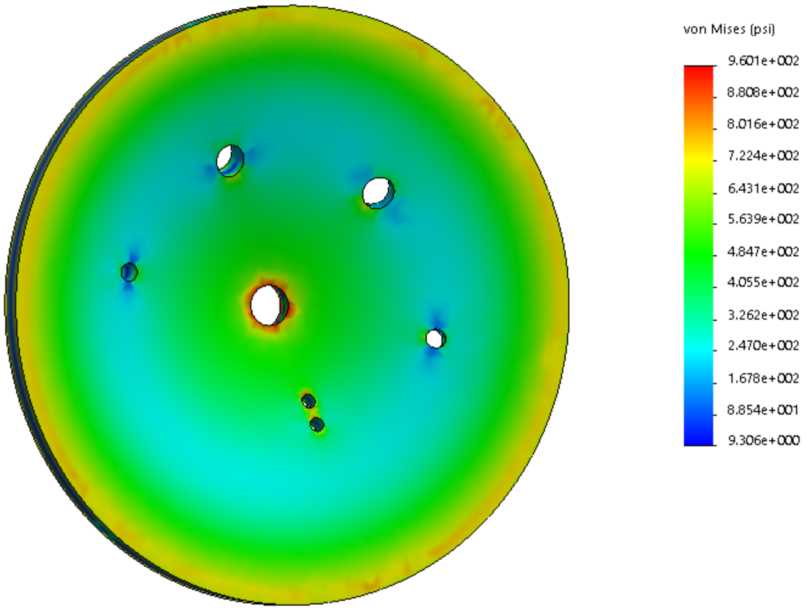


Figure 3.1.14 FEA of Avionics Bay body tube bulkhead

Booster Section

Motor mount tube

The motor mount tube functions as the housing of the motor casing and the motor. It will be manufactured by cutting a 75mm brown kraft paper (LOC) tube into 20.65 inches, the length of the motor. Brown kraft paper rather than fiberglass was adapted as the material of the tube since brown kraft paper has light density and is strong enough to resist deformation by the impact of landing. The motor mount tube with the centering rings will assure the motor to be aligned properly with the entire launch vehicle.

Figure 3.1.15 Motor mount tube

Fin design

Although additional weight is added, the launch vehicle utilizes four fins in order to meet the minimum static stability margin requirement as well as to be consistent with ATS system. Since the ATS system employs four flaps, the number of fins must be identically four in order to prevent any airflow from changing the direction or stability of rocket during the actuation of the ATS. The fins were machined from G10 fiberglass using Maxiem Waterjet. The figures below illustrates the detailed drawing of the fin and the actual image of the manufactured fin.

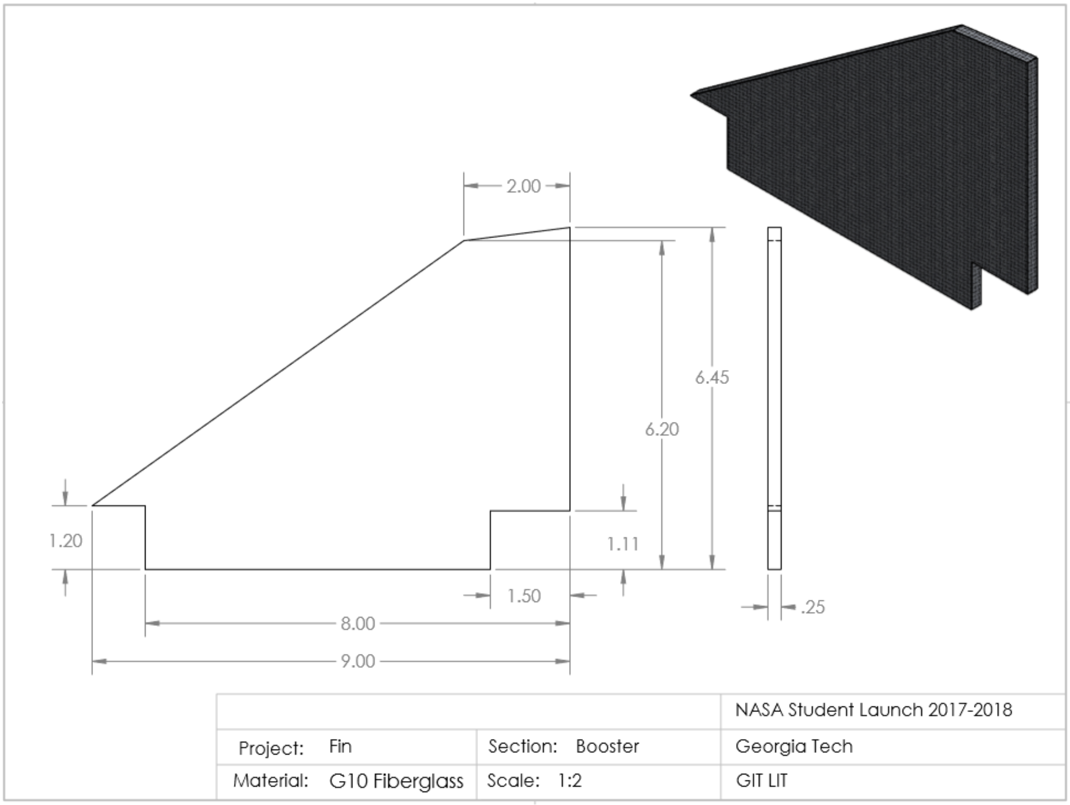


Figure 3.1.16 Fin part drawing

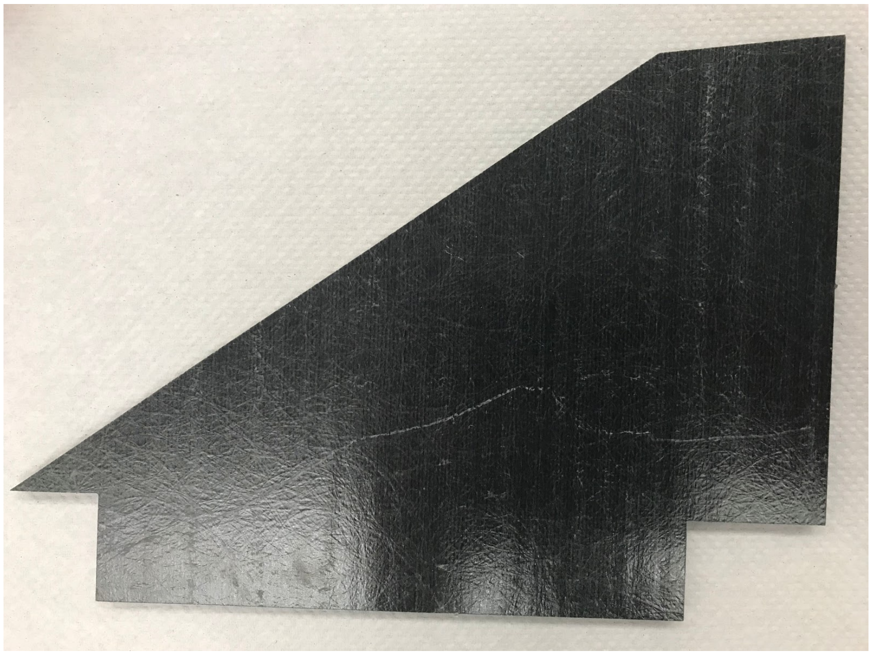


Figure 3.1.17 Actual image of the fin

The material used for the fins is G10 fiberglass, due to its high strength to withstand the force applied at landing. The thickness of the fins is 1/4 inch, which is not too low to break at ground contact and not too high to increase the mass of the booster section unnecessarily and reduce stability. The general design of the fin was chosen by iterative alternation of the design until the stability margin of the launch vehicle became above 2.0 at rail exit as required. The design with some portion of the fins going below the bottom of the rocket was avoided since there was a possibility that such portion may chip off with some landing orientations.

Thrust plate:

The main two roles of the thrust plate are to prevent the motor from ejecting through the launch vehicle and to protect the ATS payload from the hot air ejected from the motor. The thrust plate was manufactured by epoxying two thrust plates made out of 1/4 in plywood together, having an overall 1/2 inch thickness. The plates were manufactured using the Trotec laser cutter available on campus. The thrust plate has a diameter of 5.367 inches. Below, there is a Finite Element analysis for the thrust plate, which was generated by applying a force equivalent to the maximum thrust of the motor, as well as an image of the thrust plate before its installation in the rocket:

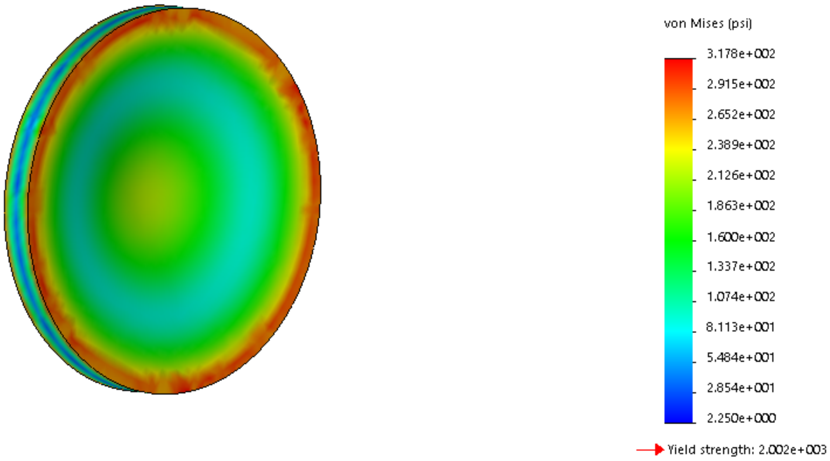


Figure 3.1.18 FEA Stress plot for thrust plate

Figure 3.1.19 Thrust plate

Centering rings:

The centering rings were constructed from 6061-aluminum using the Maxiem Waterjet. The material used provided us with an acceptable compromise between weight, ease of manufacture and strength of the centering rings. In order to ensure a stable alignment of the motor, there were three centering rings used in the booster section. All the centering rings have a circular hole in the middle through which the motor mount tube goes through. The centering rings were also made mostly hollow, to reduce the overall weight of the ring itself, allowing the total mass of the rocket to be reduced further. The detailed drawing with essential dimensions of the centering rings is shown below:

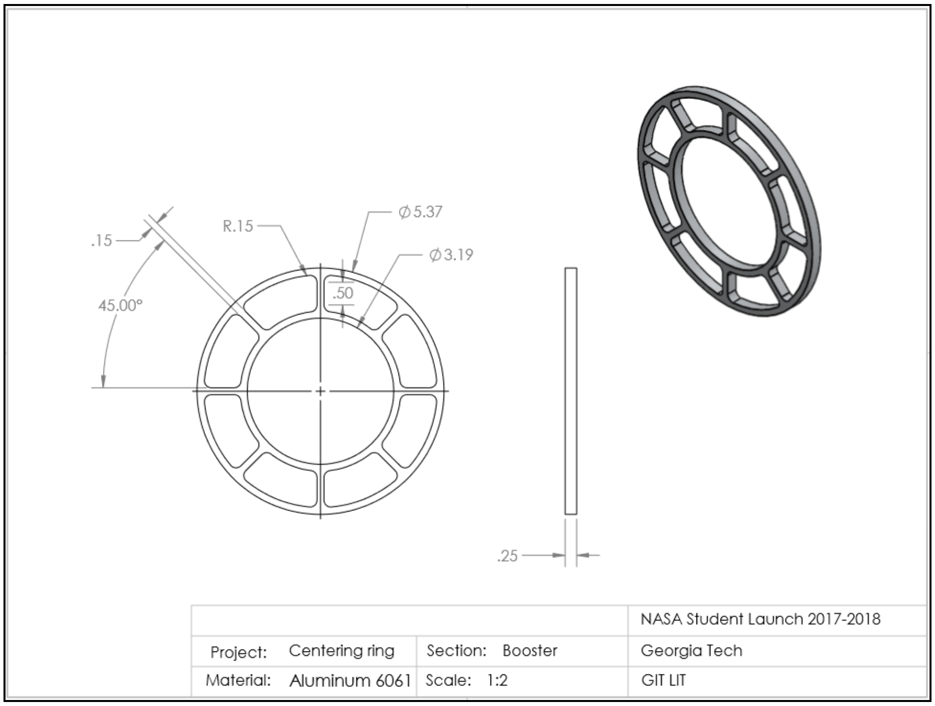


Figure 3.1.20 Detailed drawing of the centering ring

Since the centering ring is also subjected to high stresses and strains during the launch, an FEA plot was made for the centering ring as well, and the results of the analysis can be found below:

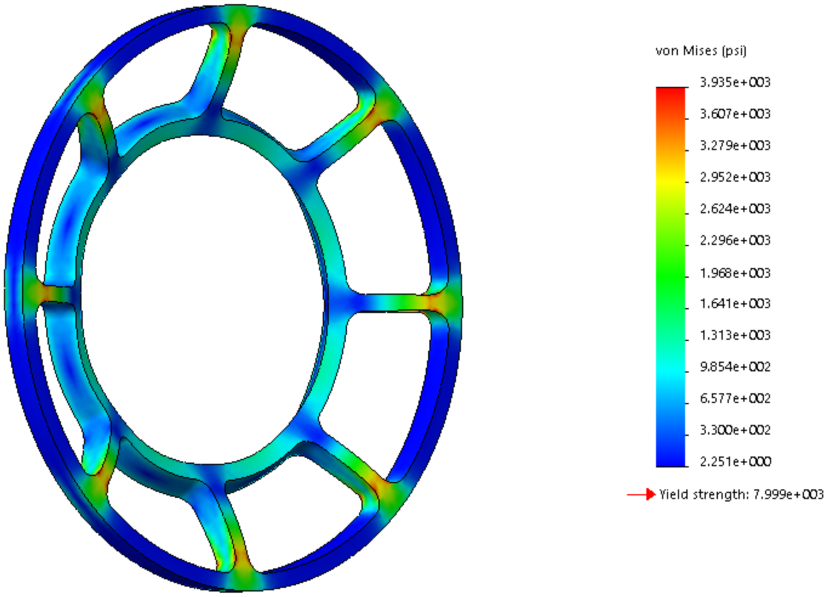


Figure 3.1.21 FEA Stress plot for centering ring

Retention ring:

The retention ring ensures that the motor remains in its proper location within the launch vehicle throughout its mission. Identical to the centering rings, the retention ring was machined from 6061-aluminum using Maxiem Waterjet. The retention ring was attached to the booster body tube by eight 4-40 screws from the sides as well as epoxy at the contacting surface of the retention ring and the booster body tube. On the surface of the retention ring are four holes which are used to screw on a threaded motor retention cap which holds the motor in place during the flight. These screws are thread locked, preventing any situation in which the motor falls from the launch vehicle during the entire flight. The figures below are detailed drawing of the retention ring and an image showing the retention ring installed in the booster section. Since the retention ring also experiences a significant force when the main parachute deploys, FEA was performed, to ensure that it will not fail during the launch phase.

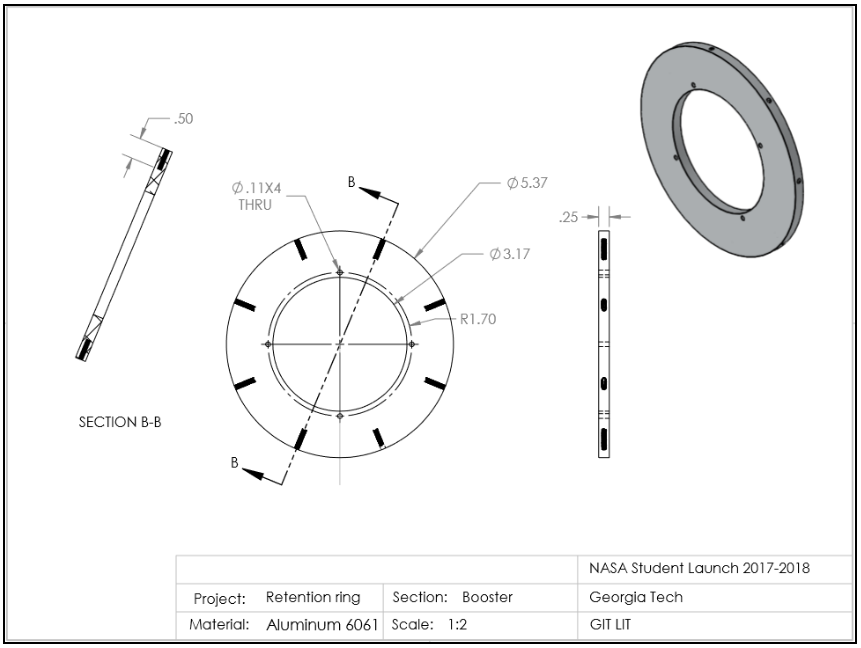


Figure 3.1.22 CAD drawing of the retention ring

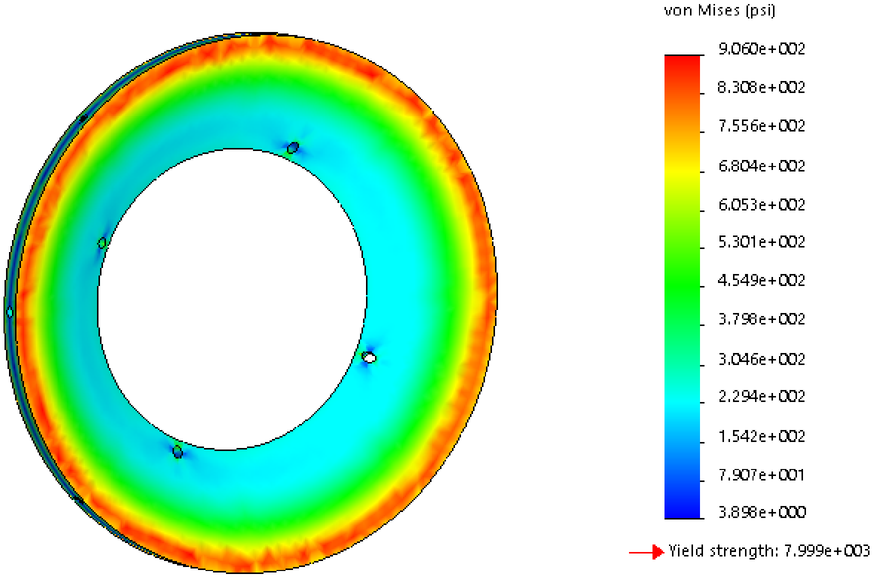


Figure 3.1.23 FEA stress plot of the retention ring

Figure 3.1.24 Retention Ring installed to the Booster section

As already discussed in the previous sections, FEA was conducted for the bulkheads, thrust plate, centering ring and the retention ring in order to ensure that these components will not fail during any time of the flight. The 235 lb_f applied force on the bulkheads is equivalent to the pressure force generated by the backup ejection charge of the main parachute since the most amount of ejection charge is used among the four ejection charges. The thrust plate FEA utilized the maximum thrust of the motor as the applied force. In order to consider the situation in which one of the centering rings fails, a force tantamount to half of the maximum thrust of the motor was applied for the centering ring FEA. Based on the acceleration experienced by the vehicle at main parachute deployment, the maximum force on the retention ring during the flight was calculated and applied for the FEA. The table below summarizes the applied force as well as the minimum safety factor for each component FEA. All the safety factor was above 2, meeting the team derived requirement related to structural safety.

Table 3.1.6 Structural Component FEA Summary

Component	Applied force (lb_f)	Safety factor
Bulkhead with eye-bolt	235	39.9
Avionics Bay coupler bulkhead	235	43.3
Avionics Bay body tube bulkhead	235	39.6
Thrust plate	371	6.30
Centering ring	186	2.03
Retention ring	387	8.83

Rail Button

The rail button used for the launch vehicle is compatible to the 1515 launch rail. In order to maximize the stability margin of the launch vehicle at rail exit, the longer the launch rod is needed. For the competition, 1515 launch rail will have a length of 12 ft, hence the team decided on using this rail button size. The following is the photo of the rail button installed to the Booster section.

Figure 3.1.25 Rail Button on Booster section

3.1.4. Airframe Component Attachment Materials

In order to assure that the structural integrity of the launch vehicle is maintain throughout the flight of the launch vehicle, adhesives and methods of attachment were carefully determined. Where the attachment of a component to another was permanent and did not require removal, epoxy with a ratio of 4:1 of resin and hardener was used. Since it takes 24 hours to cure the epoxy, no component was attached using the epoxy the day before the full scale launch.

The retention ring and ATS mechanism are attached to the Booster section by 0.5 inch long 4-40 screws. The screw size was determined based on the thickness of the aluminum plate used for the retention ring and ATS mechanism, which was a 1/4 in. 4-40 screw was the maximum size that could be drilled into this thickness while maintained high strength to retain. 8 and 4 of these screws are used to attach the retention ring and the ATS mechanism to the booster body tube, respectively.

Four 2-56 nylon shear pins are used to attach the Rover Housing section to the Avionics Bay and the ATS Housing section to the Avionics bay. The shear pins are strong enough to retain the full assembly configuration of launch vehicle during the ascent. The black powder of the ejection charges are calculated such that they will provide enough pressure to break these shear pins at parachute deployment.

The ATS Housing section and Booster section are attached to each other via four equally spaced removable plastic rivets. The rivets will not be removed nor broken throughout the flight of the launch vehicle, assuring the two sections are firmly connected. On the ground, the team could remove the rivets to take out the ATS electronics bay and mechanism. The following is a table summarizing the attachment methods used in the launch vehicle along with their usage locations.

Table 3.1.7 Attachment methods and locations

Attachment method	Location (Quantity)
Epoxy (4:1 resin vs hardener)	Bulkheads with eye-bolts - Body tube Centering rings - Motor mount tube Fins - Motor mount tube Retention ring - Body tube Thrust plate - Body tube
Mixture of epoxy and fiberglass	Fillets between fins - Booster body tube
0.5 in 4-40 screws	Retention ring - Booster body tube (x8) ATS mechanism - Booster body tube (x4)
2-56 nylon shear pins	Rover Housing - Avionics Bay (x4) Avionics Bay - ATS Housing (x4)
Removable plastic rivets	ATS Housing - Booster (x4)

3.1.5. Airframe Electrical Elements

Recovery Electrical Elements:

To create two breakout boards, protoboards were cut and sized to fit the avionics bay. A Molex female eight-pin connector was mounted to one board and a Molex female ten-pin connector was mounted to the other. The altimeters were then connected to the mounted protoboards. Solder bridges were used to connect the altimeter wires to the Molex female connectors on each protoboard. Electrical components were soldered and heat-shrink wrapped to maintain connection integrity. All components were then assembled into the bulkheads and avionics bay. A set of six pogo connectors were mounted to a 3D printed circular ring, which was used to facilitate connection between a Molex ten-pin male connector and strips of copper tape running down the length of the tube. The pogo connectors were set in the ring using a cyanoacrylate glue. To accelerate the glue drying reaction, sodium bicarbonate was applied to the glue. The amount of copper tape required was underestimated, so 22 gauge solid core wire was soldered to the copper tape and used to complete the connections through the bulkhead to the ATS bay.

Figure 3.1.26 Bulkhead with connector joined to terminal blocks

3.1.6. Flight Reliability

Due to several reasons, the launch will not meet several of the mission success criteria. Firstly, the apogee of the rocket will be much lower than the expected 5,280 ft failing to achieve the success criteria of an apogee altitude within 50 ft of one mile. During the full scale launch, the vehicle reached an an apogee of 4734 feet which differs from the 5,280 ft by 546 ft. With the consideration of additional mass during manufacturing, the OpenRocket flight simulations for the rocket placed the apogee below the target by 199 ft as well. Additional differences between the simulation and the actual performance of the rocket can be accounted for by changes to the rocket profile that likely created extra drag. There were holes in the rocket cut for the ATS flaps, the ATS avionics bay, and the main avionics bay. These may have created some turbulence in the rocket itself, inducing an expected drag on the rocket. Additionally, damage to the rocket during the manufacturing process such as chipping of the nose cone and imperfect joining of the rocket sections would have created additional drag. These differences between the simulation and real life could account for the differences. Regardless of the actual cause of the difference, the rocket will not meet the apogee mission criteria.

All aspects of rover deployment mission criteria will not be fulfilled because the system was not completed in time for a full-scale test launch. However, all recovery and flight critical aspects of the mission will be accomplished.

The launch vehicle ascended with an vertical trajectory during the full scale launch. Despite the strong wind speed of nearly 15 mph at the launch site, the ascent of the launch vehicle was very straight. The result of the full scale launch will be discussed further in detail in the later sections, but the data showed that the launch vehicle had a steady rise, indicating that the rocket stayed it's vertical course. If it was blown off course or did not ascend straight, there would be a change in the rate of vertical ascent. The main deployed at 4734 ft and the drogue deployed at 750 ft. This is within a reasonable tolerance to the programmed values of parachute deployment. The motor was retained throughout the entirety of the full scale launch, and there were no signs of damage to the motor retention system such as separation of epoxy of bending of screws after the full scale launch. This indicates the motor retention system should be sufficient to retain the motor for the entirety of flight. The velocity at landing was 15.4 ft/s and the heaviest tethered section of the launch vehicle, the combined section of the ATS Housing and Booster sections, had a maximum kinetic energy of the rocket was 73.25 lb-ft which is below the required kinetic energy of 75 lb-ft.

3.1.7. Component Manufacturing

The following table summarizes the procedures taken to manufacture the structural elements of the launch vehicle. The manufacturing process of the components for rover, rover deployment system, Avionics bay, ATS electronics bay, and ATS will be discussed in their designated sections. The figures below the table show the water jet cutter and laser cutter used for some of the components.

Table 3.1.8 Manufacturing procedure for each structural element

Component	Manufacturing Procedure
Nose cone	1. Guidelines for cutting a vertical slot were drawn using a ruler 2. Following the guidelines from the previous step, dremel was used to cut out the slot from the shoulder of the nose cone
Body tubes	1. Desired length of the body tube were marked onto the G12 filament wound fiberglass tube 2. Bandsaw and dremel were used to cut the tubes at the markings Booster section: 3. Cutting the vertical slots for the fins on the booster body tube was consigned to the Aerospace Engineering Machine Shop on campus 4. Masking tape was wrapped around the body tube to mark the locations of the horizontal slots for the flaps of the ATS to come out 5. Using the guidelines, dremel was used to cut the slots out of the body tube 6. Hand drill was used to drill the eight holes for the screws to secure the retention ring onto the booster body tube and the four holes for the screws to lock the ATS mechanism in place ATS Housing section: 7. Masking tape was wrapped around to mark the positions of the holes for the shear pins, rivets, and screws (preventing the ATS electronics bay from rotating) onto the body tubes 8. Hand drill was used to drill the holes 9. To drill the key switch hole for the ATS electronics bay, hand drill was used to initially make small hole on the body tube 10. Using the dremel, the hole was widen to the desired diameter

	Rover Housing section 11. Masking tape was wrapped around to mark the positions of the shear pin holes 12. Hand drill was used to drill the holes
Coupler tube	Coupler tube for Avionics Bay*[1]: 1. Desired length of the body tube was marked onto the G12 filament wound fiberglass tube 2. Following the guidelines from the previous step, dremel was used to cut the coupler tube to the desired length 3. Hand drill was used to drill the holes for the screws that prevent Avionics bay electronics housing from rotating inside the bay Coupler tube between Booster and ATS Housing 4. Masking tape was wrapped around the coupler tube to mark the horizontal slots for the ATS flaps to come out 5. With the guidelines, the horizontal slots were cut using dremel 6. Hand drill was used to drill the holes for the screws that prevent ATS electronics bay from rotating inside the coupler tube 7. To drill the hole for accessing the key switch of ATS electronics bay from outside, hand drill was used to initially drill a small hole 8. Dremel was used to widen the hole to the desired diameter
GPS Mount	1. 2D part drawings of the components were exported to a dxf file 2. With the dxf file, the components were cut from ⅛” plywood via Trotec Speedy 400 laser cutter
Bulkheads Fins	1. 2D part drawings of the components were exported to a dxf file 2. With the dxf file, the components were cut from the G10 filament wound fiberglass plate via Maxiem 1515 waterjet
Centering rings Retention ring	1. 2D part drawings of the components were exported to a dxf file 2. With the dxf file, the components were cut out from the Aluminum 6061 alloy plate via Maxiem 1515 waterjet Retention ring: 3. Markings of the hole locations were made using 90 degrees ruler 4. Metal drill press was used to drill the holes for the screws securing the retention cap and for the screws securing the retention ring to the booster body tube 5. The holes for securing the retention ring to the booster body tube were threaded using a taper
Thrust plate	1. 2D part drawing of the thrust plate was exported to a dxf file 2. With the dxf file, the thrust plate was cut out from the 1/4 inch plywood plate via Trotec Speedy 400 laser cutter

*1: The Avionics Bay from last year was reused

Figure 3.1.27 Maxiem 1515 Waterjet cutter

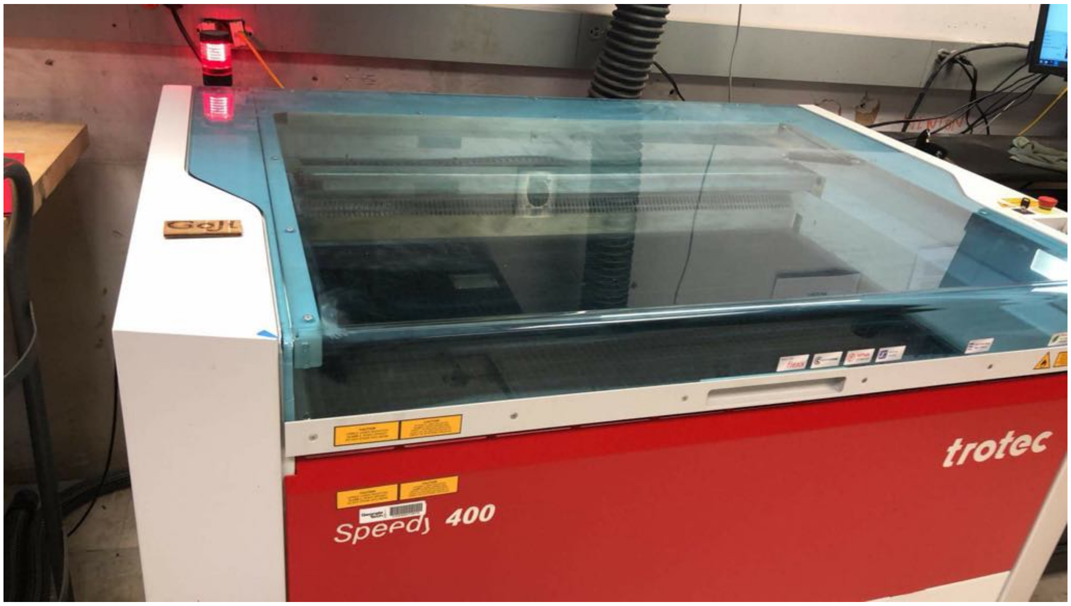


Figure 3.1.28 Trotec Speedy 400 Laser cutter

3.1.8. Vehicle Assembly

Nose Cone Section Assembly

The brackets on the supporting beam of the rover deployment system will be epoxied to the inside of the nose cone. The following figure shows the configuration of the rover deployment housing and nose cone in which the rover is deployed from the launch vehicle.

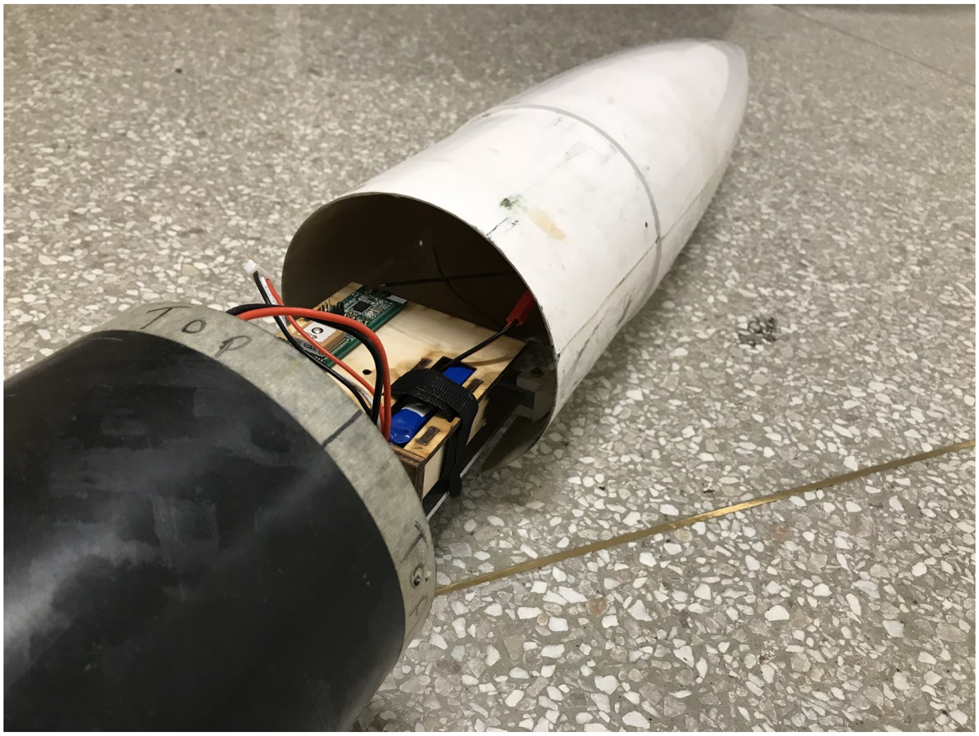


Figure 3.1.29 Configuration for deploying the rover

Rover Housing Section Assembly

Four equally space out copper wire tapes, which supply power from the Avionics Bay to the rover system, was ran from one edge to the other edge of the body tube. Then, the rover deployment system was assembled and installed onto the rover housing body tube via epoxy. (The assembly procedures of the deployment system as well as the rover are discussed in detail under the payload section.) Sealing with a lock nut, the eye bolt was attached to the bulkhead and the bulkhead was epoxied at the determined location within the body tube. The following figure shows the actual image of the Rover Housing Section.

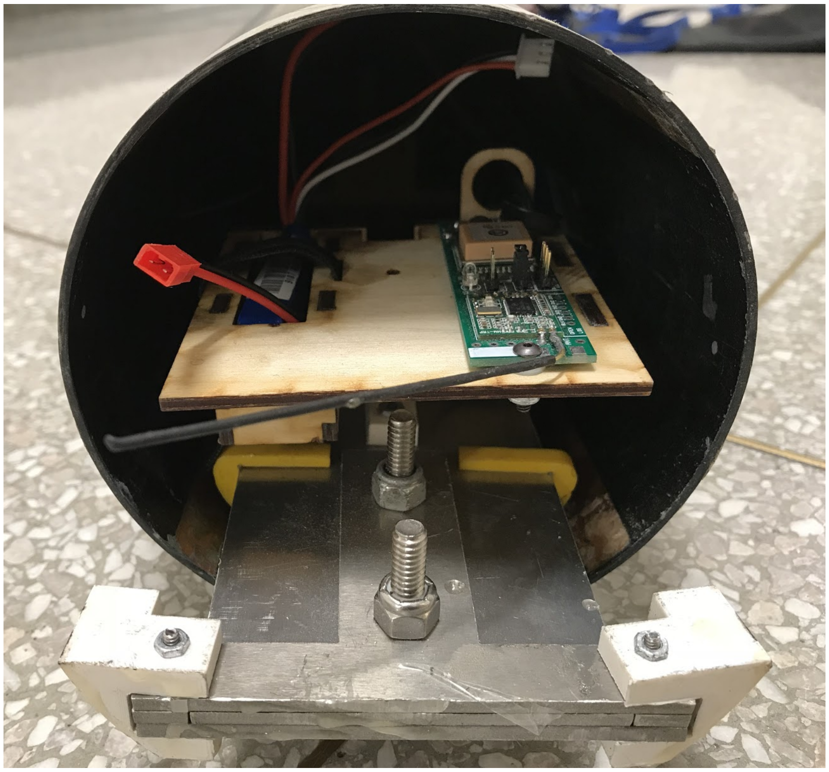
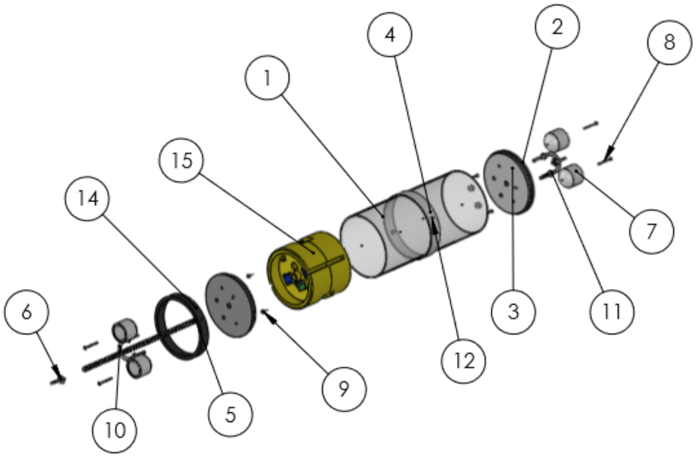


Figure 3.1.30 Actual image of the Rover Housing Section

Avionics Bay Assembly

The 4-40 screws were installed through the holes on the coupler tube which were drilled during the manufacturing stage and from inside the coupler tube, nuts were attached to the screws, securing them tight to the coupler tube. The Avionics Bay electronics housing was slid into the coupler tube, using the screws from the side to prevent itself from rotation within the coupler tube. The ejection caps and u-bolts were screwed onto the bulkheads and the wires that connect the electronics housing and the ejection ignitors were run through the designated holes on the bulkheads. Onto the bulkhead facing the ATS housing section, a ring with pogo connectors was attached by hot glue. The wires connecting the pogo connectors and the electronics housing were run through their designated holes as well. The 3/8 inch threaded rod was then installed through the center of the electronics housing, attaching the bulkheads on both of its side. Wing nuts were used to lock the bulkheads onto the coupler tube. The figures below show the exploded view of the Avionics Bay as well as the actual image of the Avionics Bay.



ITEM NO.	PART NUMBER	QTY.
1	AvionicsBayCoupler	1
2	Body tube bulkhead for abay	2
3	Coupler tube bulkhead for abay	2
4	A-bay strip tube	1
5	98790A059	1
6	92001A339	2
7	Ejection cap	4
8	91772A156	4
9	90866A007	4
10	8896T94	2
11	94804A029	8
12	91255A110	2
13	91841A005	2
14	6_pin_pogo_contact_assem	1
15	avionics_A_Bay	1

				NASA Student Launch 2017-2018
Project:	Avionics Bay Assy	Section:	Avionics Bay	Georgia Tech
Material:	N/A	Scale:	1:10	GIT LIT

Figure 3.1.31 Exploded view of the Avionics Bay

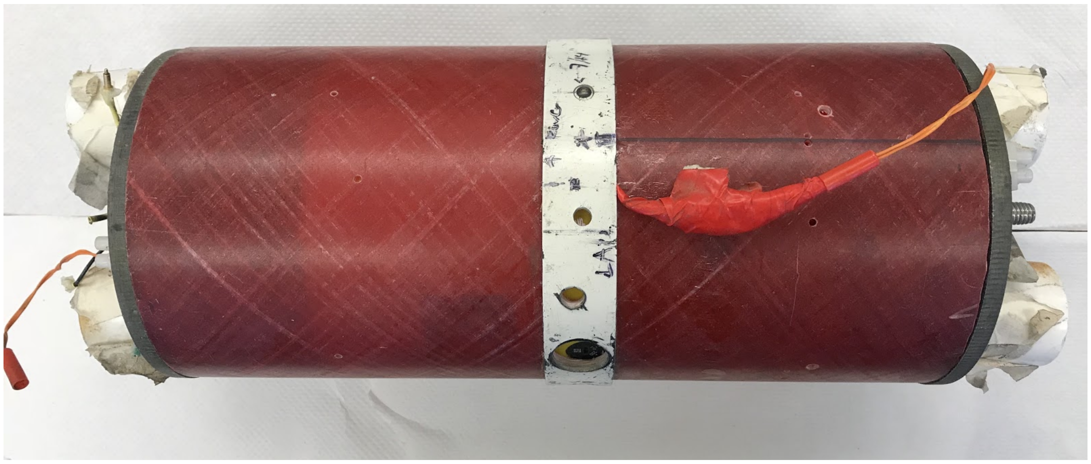


Figure 3.1.32 Actual image of the Avionics Bay

ATS Housing Section Assembly

Six, equally spaced, copper wire tapes were ran through the ATS body tube to allow the Avionics Bay to provide power to the ATS electronics bay. Then the bulkhead, with the eye bolt installed, was epoxied to the determined location within the body tube. The figure below shows the actual appearance of the ATS Housing Section.

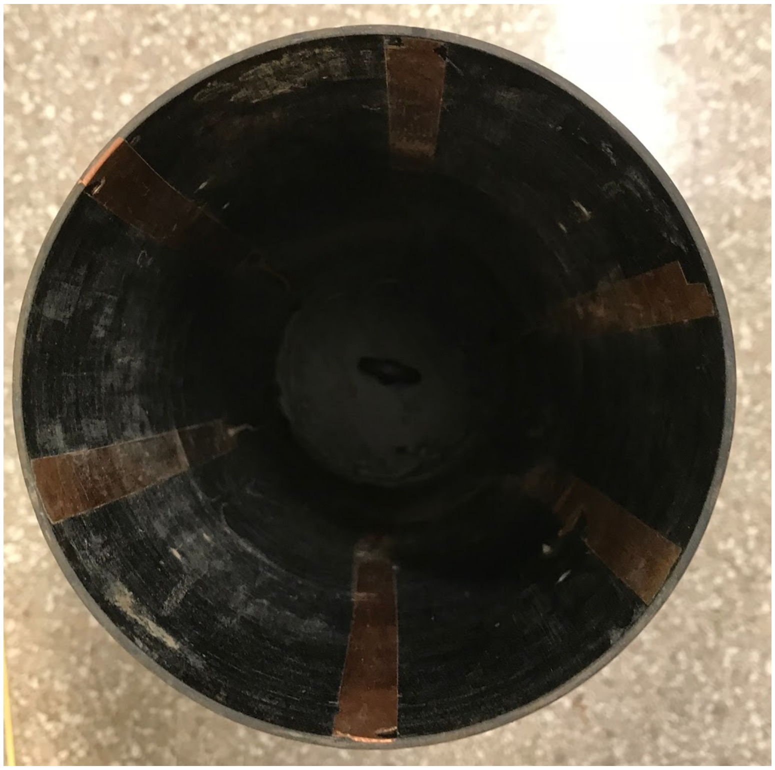
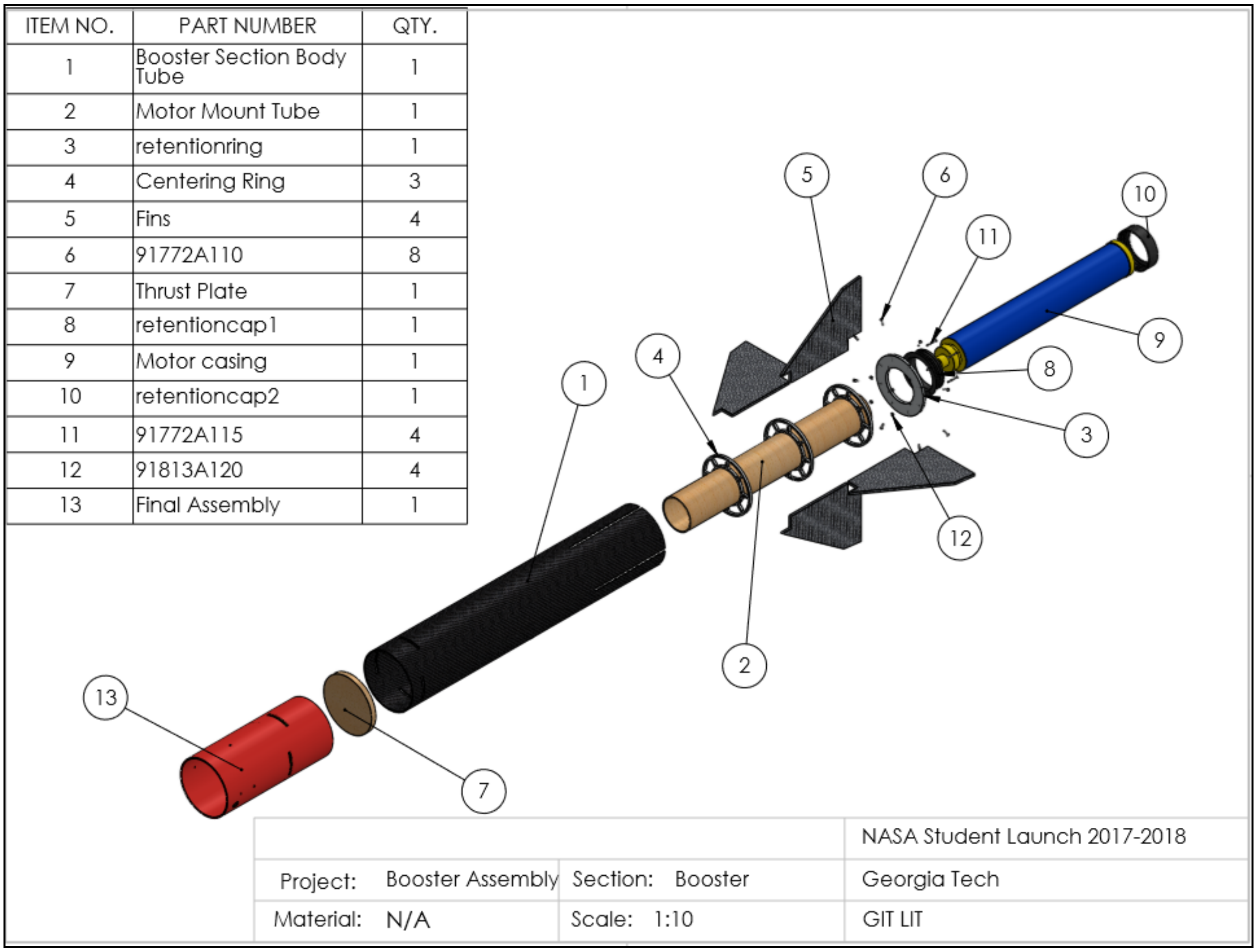


Figure 3.1.33 Actual image of the ATS Housing Section

Booster Section Assembly

With the marking of the locations of the centering rings made onto the motor mount tube by using a ruler, the centering rings were epoxied to the motor mount tube. Using the vertical fin slots on the body tube as a guide, the fins were carefully aligned and epoxied onto the motor mount tube. After the epoxy cured, the assembly was then slid into the body tube and a mixture of epoxy and fiberglass was used to create fillets at the contact points of the fins and the body tube. The thrust plate was then placed on top of the motor mount tube, having its edges epoxied to the body tube. The coupler tube was then epoxied to the body tube while assuring that the horizontal slots for the ATS flaps of the coupler tube and the body tube were aligned with each other. The retention cap was screwed onto the retention ring, using threadlocker to ensure that the screw will be tight throughout the flight. Then the retention ring was screwed from its sides onto the body tube and epoxied at its edge to have it firmly placed within the body tube. The figures below are the exploded view of the Booster Section and the actual image of the Booster section.



ITEM NO.	PART NUMBER	QTY.
1	Booster Section Body Tube	1
2	Motor Mount Tube	1
3	retentionring	1
4	Centering Ring	3
5	Fins	4
6	91772A110	8
7	Thrust Plate	1
8	retentioncap1	1
9	Motor casing	1
10	retentioncap2	1
11	91772A115	4
12	91813A120	4
13	Final Assembly	1

			NASA Student Launch 2017-2018
Project:	Booster Assembly	Section: Booster	Georgia Tech
Material:	N/A	Scale: 1:10	GIT LIT

Figure 3.1.34 Exploded view of the Booster Section

Figure 3.1.35 Actual image of the Booster Section

Overall Vehicle Assembly

Knots were created on both edges of each shock cord to attach the quicklinks to the shock cords. At the position one third of the length of the shock cords, another knot was created for the quicklinks attached to the parachutes to be connected to the shock cords. The shock cord for the main parachute had its shorter side attached to the eye bolt on the bulkhead inside Rover Housing section and its longer side to the U bolt on the bulkhead of Avionics Bay. The shock cord for the drogue parachute had its shorter side attached to the U bolt of the Avionics Bay and its long end to the eye bolt on the bulkhead inside the ATS Housing section. The parachutes were fold and the shock cords with the parachutes were put into the Rover Housing and ATS Housing sections. The eight shear pins were put into their holes, locking the Rover Housing and ATS Housing sections onto the Avionics Bay. The ATS mechanism was slid into the coupler tube of the Booster section, having its sides screwed from outside the body tube by 4-40 screws. Then the ATS electronics bay was slid into the coupler tube while ensuring the keyhole of the ATS body tube match the key switch of the ATS electronics bay. The ATS body tube was then attached to the Booster section, having the four rivets securing the attachment of the two sections. Lastly, the motor case with propellants loaded was slid into the motor mount tube and the retention cap was sealed to prevent the motor from falling out from the launch vehicle during the flight. The following image is the completed assembly of the actual launch vehicle.

Figure 3.1.36 Full assembly of the launch vehicle

3.1.9. Differences from older models

The main difference between older models and the current model of the rocket is the activity of the systems on the rocket. The rover deployment system will not be active on this rocket, so the nose cone will no longer be held in by the rover deployment mechanism but instead by two screws with bolts securing them on the other side of the body tube. Additionally, the ATS system will not be active on the rocket, but the mechanism for retention of ATS will remain the same.

Another key difference between earlier models and the current model is the length of the booster body tube section. In previous models, the booster body tube was increased from 27.4” to 28.7” The body tube length was increased due to manufacturing and time constraints. The tube was sent to a machining mall to create the fin slots. However, it was not returned until 2/13 which was several days before the first targeted launch date. The tube was returned 1” longer than expected. It was decided to keep the body tube at the same length, because the body tubes of the other sections became shorter while sanding the edges to make them straight. Because it is difficult to get the space to cut fiberglass, cutting the body tube would have pushed back the manufacturing timeline by at least a day. To allow sufficient time for epoxy to cure and ensure a careful and safe assembly of the booster section, the longer booster section body tube was applied.

Finally, the mass of the rocket was much heavier than expected. In previous models, masses of hardware such as i-bolts and u-bolts were not taken into account. Additionally, the mass estimations for each of the subsystems such as the ATS system were far too optimistic. These were not major changes to the rocket itself, but just oversight during the design process.

3.2. Recovery Subsystem

3.2.1. Structural Elements

Shock Cord:

The shock cord used for the launch vehicle is made out of Tubular Nylon 9/16" and its minimum breaking strength is 1500 lbs. The shock cord length for the drogue parachute is 24 ft and for the main parachute is 30 ft. In order to have a higher marginal safety, the shock cord lengths were increased from CDR. The parachutes are attached to the shock cords by using quicklinks and the ends of the shock cords are attached to the bolts on the bulkheads of Rover Housing, Avionics Bay, and ATS Housing via quicklink. The main parachute is attached to the shock cord at a point whose distance from the Rover Housing section is equivalent to 1/3 of the length the shock cord. Likewise, the drogue parachute is attached to the shock cord at a point whose distance from the Avionics Bay is equivalent to 1/3 of the length of the shock cord.

U-Bolts and Eye-bolts:

Two types of bolts were used in the construction of the Rocket: 5/16 inch eye bolts and 1/4 inch U-bolts. The eye bolts fabricated from steel with a -18 thread type, are attached to the bulkheads inside the Rover Housing and ATS Housing sections. The U-bolts, on the other hand, are made from 304 Stainless steel with a -20 thread size and are attached to the Avionics Bay bulkheads. From the previous years' experience, it is proven that these bolts are capable of handling the pressure force generated by the ejection charges. The following are engineering drawings and the images of the bolts.

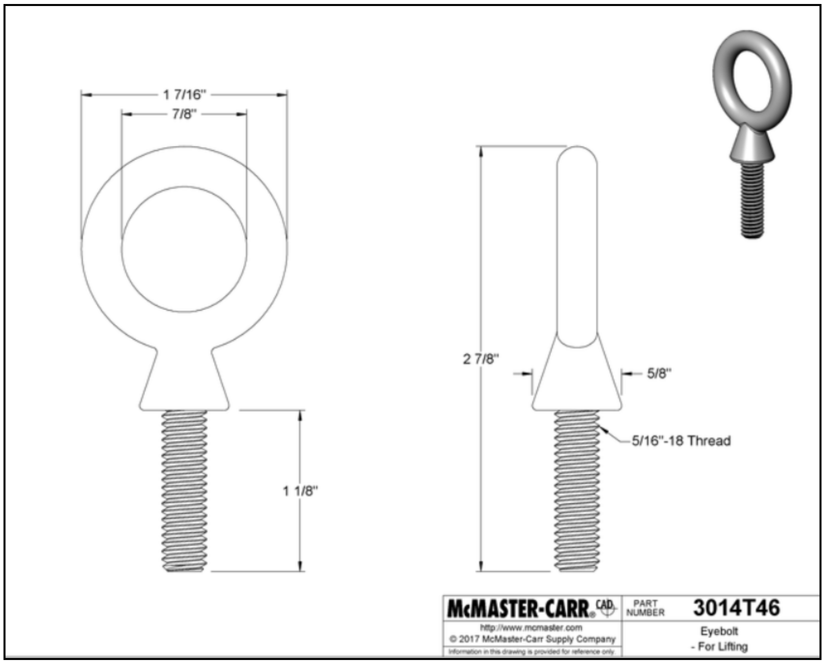


Figure 3.2.1 detailed drawing of the Eye bolt from McMaster Carr

Figure 3.2.2 Eye bolt used on the rocket

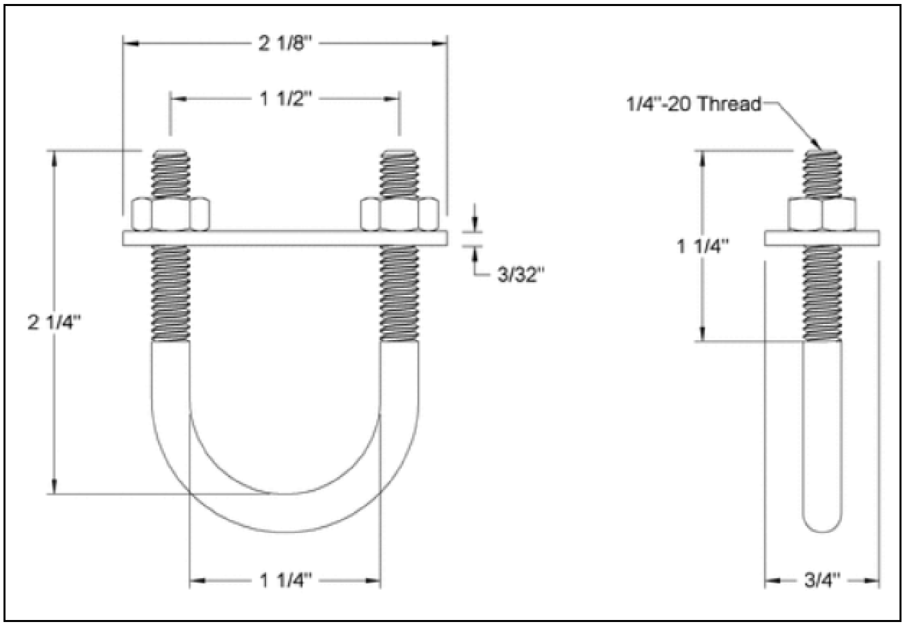


Figure 3.2.3 Detailed drawing of U-bolts from McMaster Carr

Figure 3.2.4 Image of U-bolt used on the rocket

Ejection Charges:

As written in the previous sections, four shear pins will hold together the Rover Housing section to the Avionics Bay and the ATS Housing section to the Avionics Bay during the ascent of the launch vehicle. At apogee, the drogue parachute and at 750 ft AGL, the main parachute deploy. The black powder housed inside the ejection caps on the Avionics bay bulkheads will be ignited at these determined altitudes, increasing the pressure of the chamber and breaking shear pins. In order to counteract the case in which the main ejection charge does not break the shear pins, the backup ejection charges have 0.2 g more black powder than the main ejection charges. The drogue parachute backup ejection charge is ignited with 1 sec delay of the main ejection charge and the main parachute backup ejection charge is ignited at 700 ft. The mass of the ejection charges were calculated based on the total force needed to break five shear pins instead of four for safety. The table below summarizes the mass of the black powder used for each ejection charges.

Table 3.2.1 Mass of black powder for each ejection charges

Ejection charge	Mass of black powder (g)
Main parachute main ejection charge	1.3
Main parachute back up ejection charge	1.5
Drogue parachute main ejection charge	1.0
Drogue parachute back up ejection charge	1.2

Avionics Housing:

There are eight primary components housed within the Avionics section: two rotary switches, two battery voltage monitors, two nine volt batteries, and two altimeters. There is ample space within the avionics section to mount these components. Additionally, as the section is well forward of the center of gravity, low mass is not as critical for the Avionics bay housing. However, The threaded rods needed to hold a tray within the section would add an unacceptable amount of weight aft of the center of gravity, and mounting all components within a single tray would result in a very tight packaging, making it challenging to assemble and access them as well as make the required electrical connections. Alternatively, it was decided that a housing would be 3D printed from either ABS or PLA plastic. This decision was made to streamline the design and manufacture of the avionics structures. The initial design for the avionics section housing, with the components mounted, is shown below. Two views are shown to display all the components.

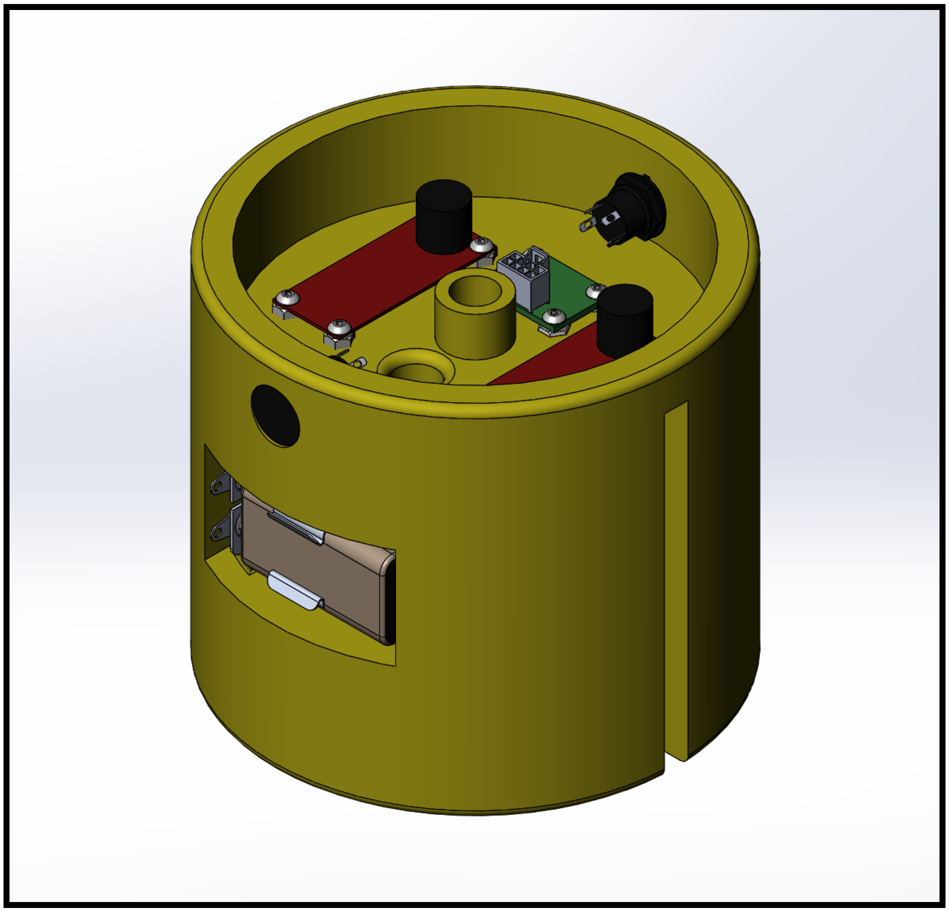


Figure 3.2.5 Avionics Section Avionics Assembly Isometric Top View

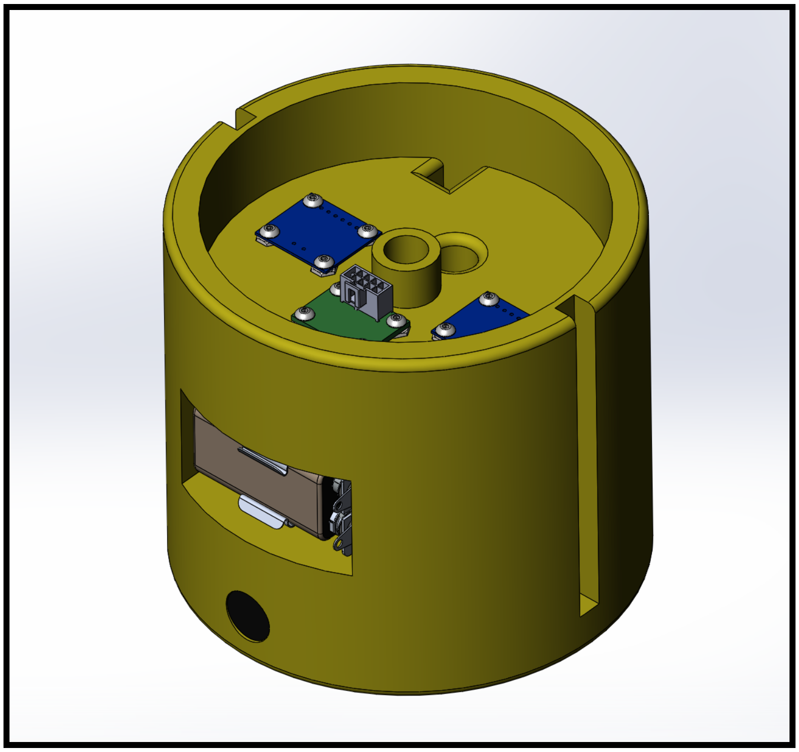


Figure 3.2.6 Avionics Section Avionics Assembly Isometric Bottom View

The voltage sensors, battery holders, and breakout boards would be screwed into locknuts which would be epoxied into hexagonal holes made in the housing. The Stratologger CF would be similarly mounted except that they would be screwed into 4-40 standoffs instead of lock nuts because the spacing between the edge of the stratologger and the breakout board was not enough to fit a 4-40 lock nut. There would be slits created from a corner of the location of the batteries to the bottom section to allow connections between the battery and the voltage monitors. Two holes on the top section of the housing would be made to fit the rotary switches. A single ⅜ inch threaded rod would run through the central hole of the housing, anchoring the bulkheads at either end of the 13 inch long Avionics bay section. A hole through the entire housing (next to the hole for the threaded rod) would enable connections between the components mounted on the two sides of the housing. The avionics section housing would sit in the center of the Avionics section. It would be prevented from rotating by two 4-40 screws driven through the body tube on each side of the rocket. Four 4-40 lock nuts would be used to secure the screws on the inside of the body tube. These nuts interface with the rails the channels cut from each side of the housing, preventing rotation. A drawing of housing is shown below.

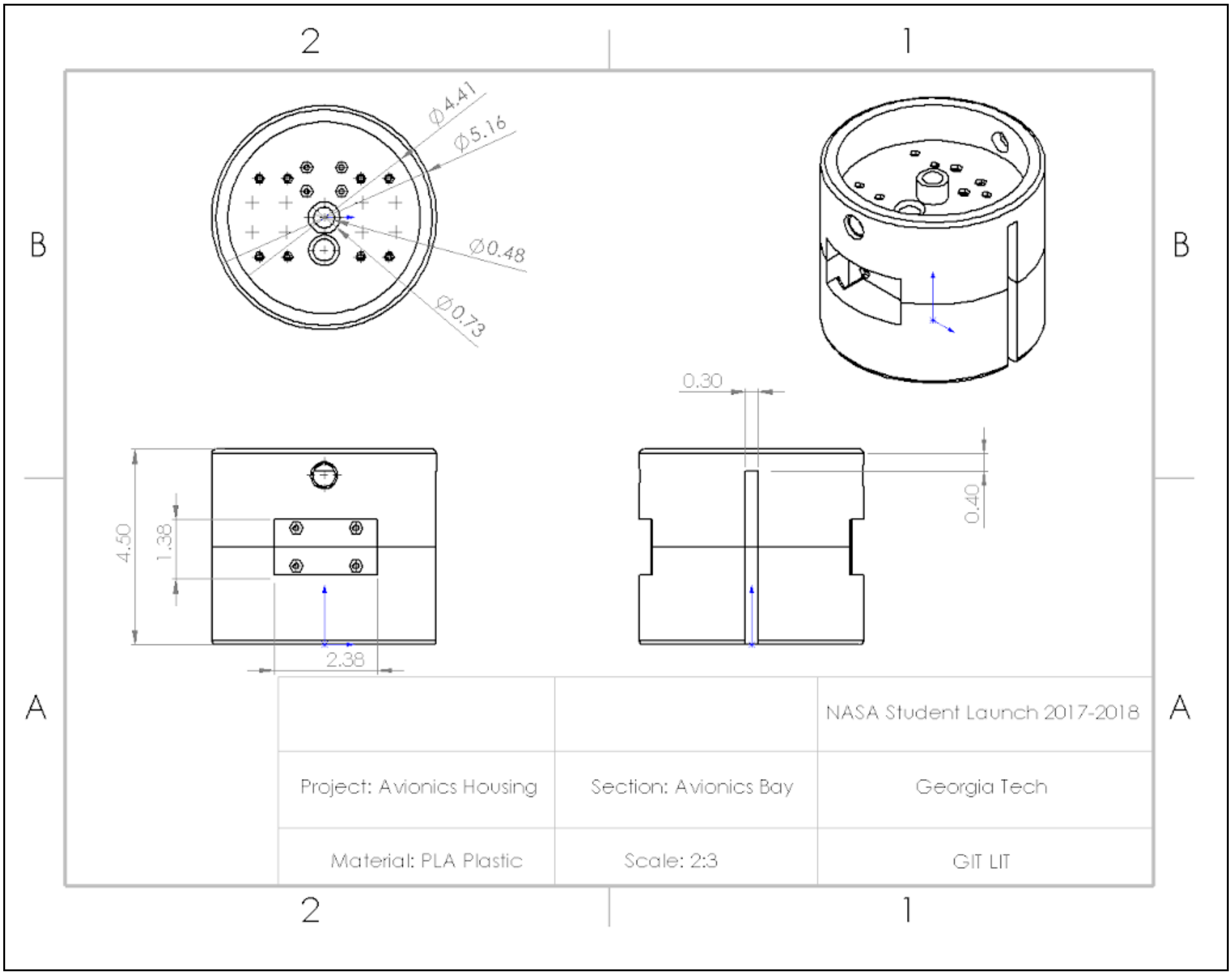


Figure 3.2.7 Avionics Section Avionics Housing Drawing

Manufacturing, Construction, and Design Modifications:

The housing was 3D printed from PLA. However the geometry of the original design of the Avionics bay housing did not allow for the desired tolerance for the 4-40 lock nuts' holes placed on the rear end of the housing. These holes are for the mounting of the voltage sensors and breakout board (with the 10 pin connector mounted on it). Therefore, it was decided that the Avionics Bay housing will be split into two halves and those halves will be 3D printed individually. This solved the issue of incorrect tolerances and ensured a tight fit of all the electrical components into the housing. The two halves were then epoxied together for structural integrity of the Avionics bay. Then, the 4-40 lock nuts and standoffs were epoxied into the holes designed for their placement. 2 screws were placed into the airframe and tightened with 4-40 nuts for the Avionics bay to slide through into the airframe. This ensured no rotation of the Avionics housing during flight. The fully constructed Avionics Bay with the electrical elements mounted is shown below.

Figure 3.2.8 Avionics Section Avionics Housing

GPS Mount:

Due to the configuration of the rover deployment system within the nose cone, the original PVC tube design for the GPS bay (which required inserting a bulkhead into the nose cone shoulder) was abandoned in favor of a flat-plate design that can be attached to the back of the pusher plate. The final GPS mount has a slot and tab interlocking design and consists of five parts. To simplify the design and reduce the size of the assembly, the pusher plate was modified to include a hole to house a rotary switch. When assembled, the largest dimensions are 3.50” by 3.50” by 1.13”.

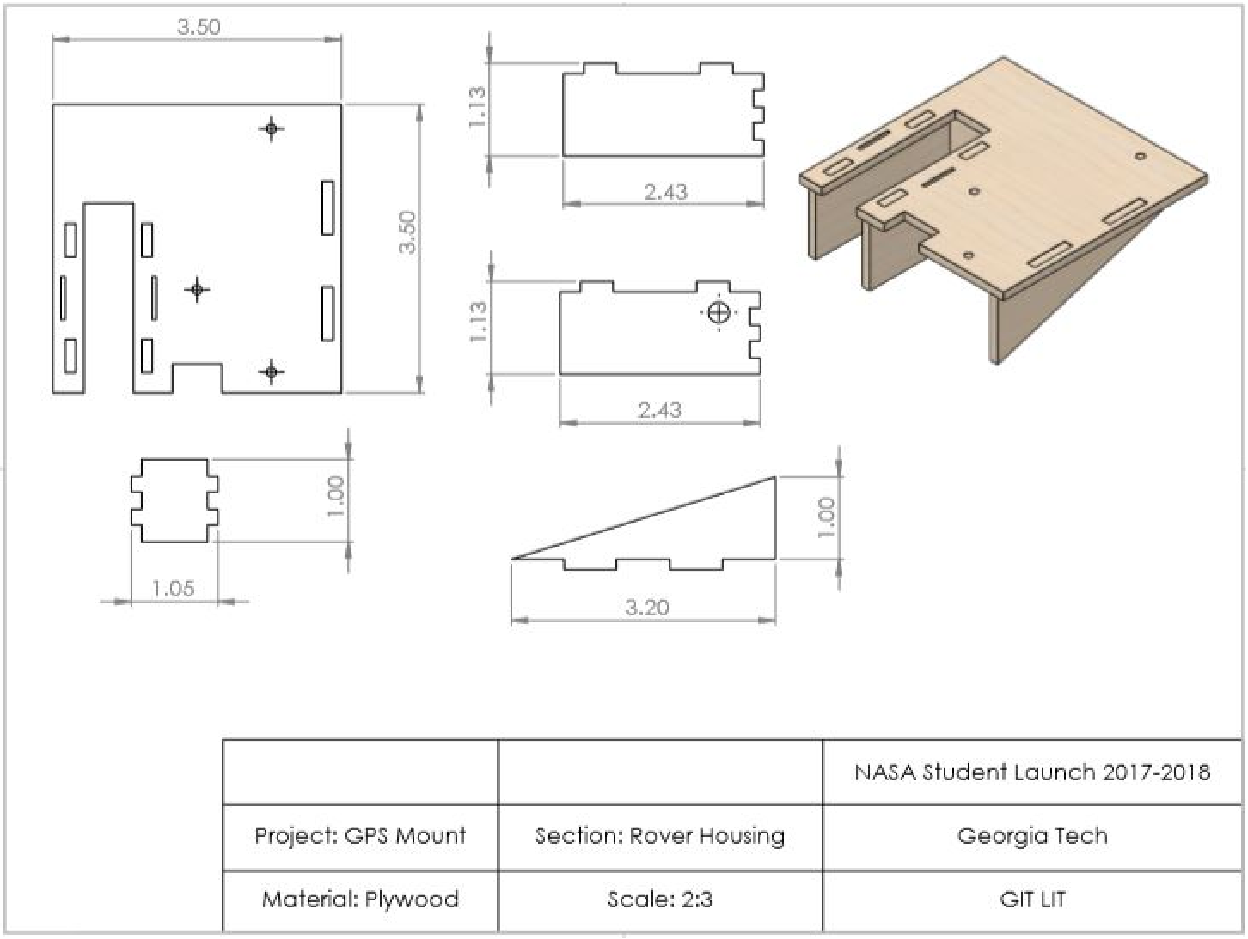


Figure 3.2.9 GPS Mount

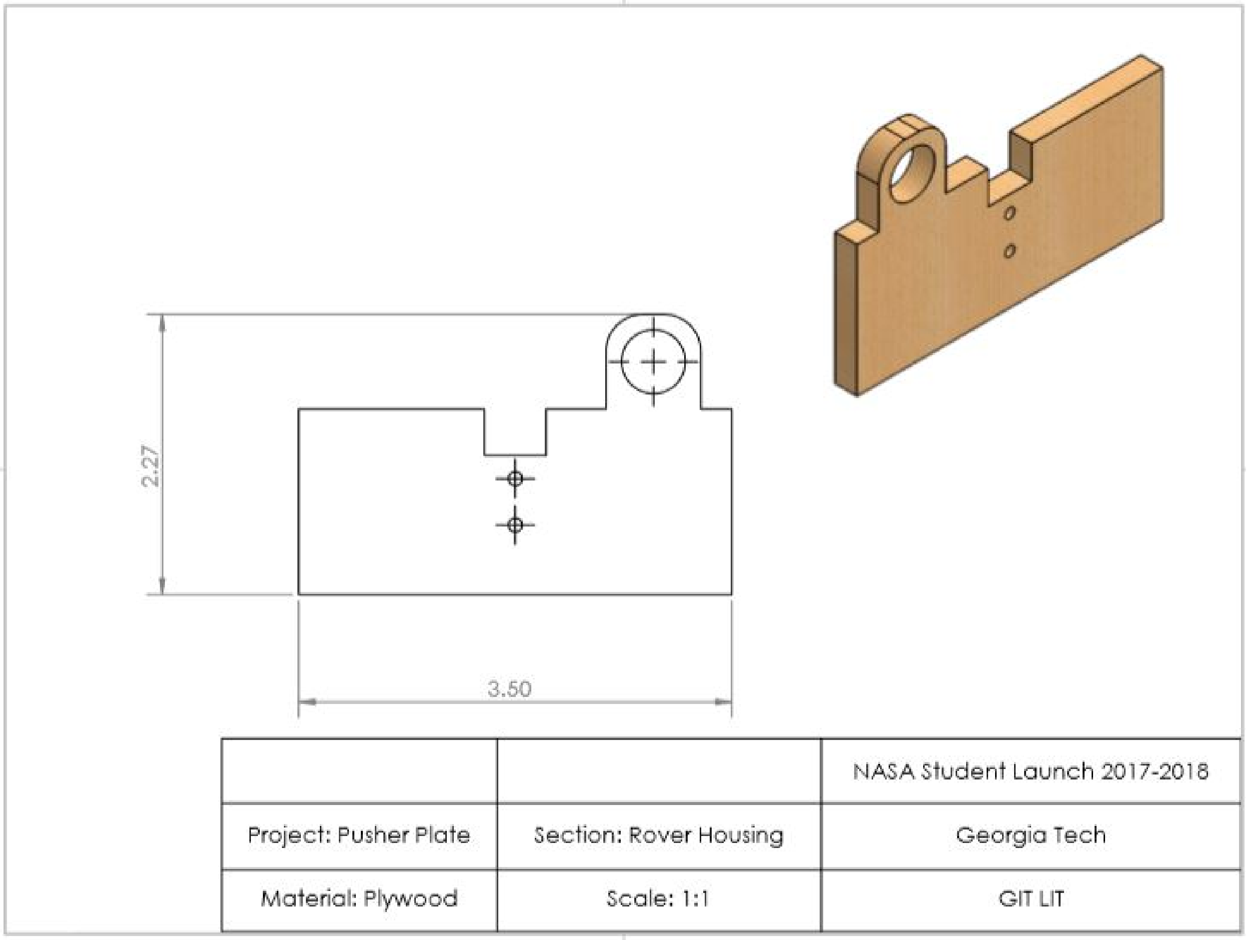


Figure 3.2.10 Modified Pusher Plate

The GPS mount is constructed from five ⅛” plywood parts. After generating a 3D model of the assembly in SolidWorks, the 2D part drawings were exported to DXF files for laser cutting. The parts are assembled with wood glue, and the complete assembly is epoxied to the pusher plate in the rover housing section. A 4-40 standoff runs through the the top plate to center the mount and provide additional structural support.

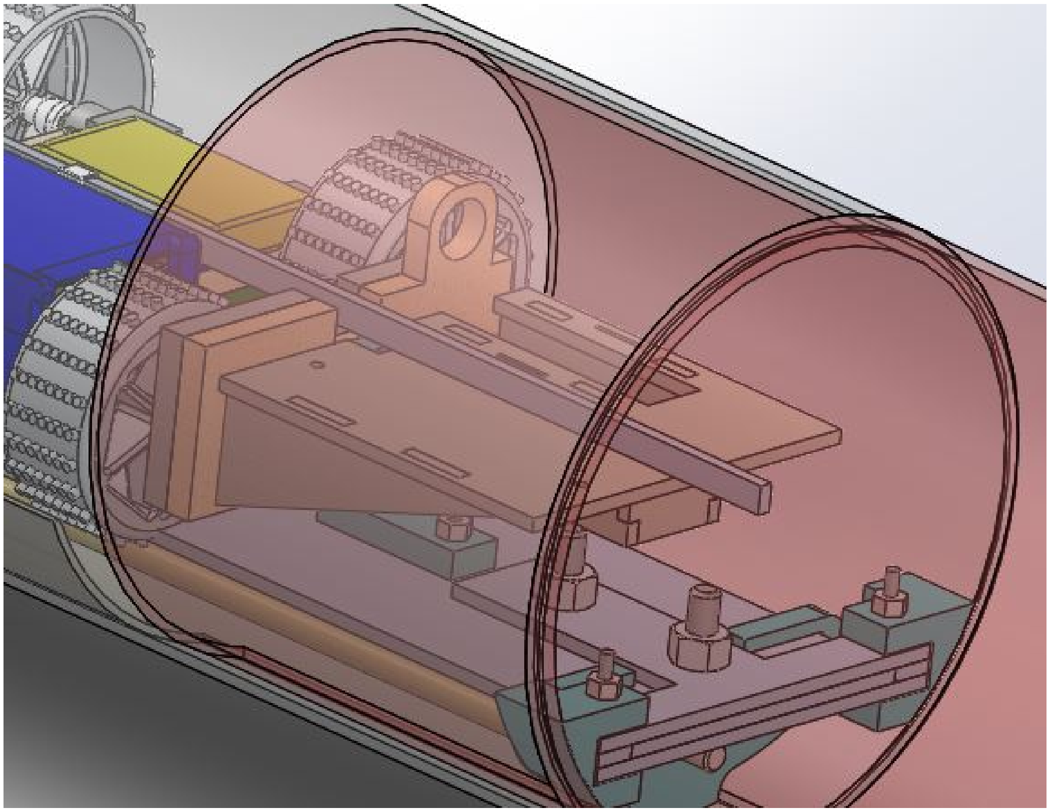


Figure 3.2.11 GPS Mount Assembly within Rover Housing Section

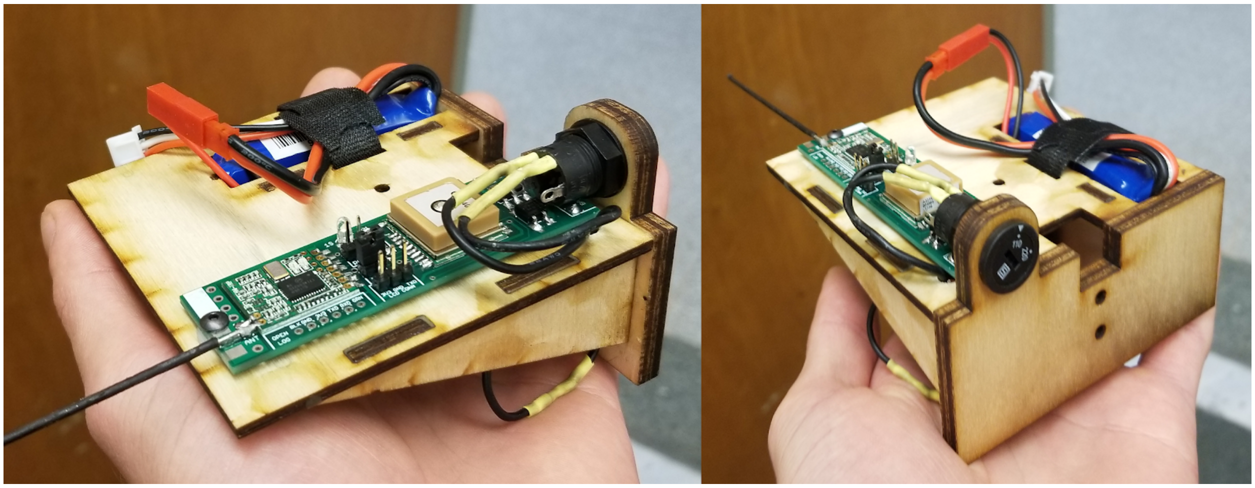


Figure 3.2.12 Assembled GPS Mount

3.2.2. Electrical Elements

Altimeters:

StratoLogger CF altimeters, pictured below, will be used to implement dual deployment recovery of the launch vehicle.

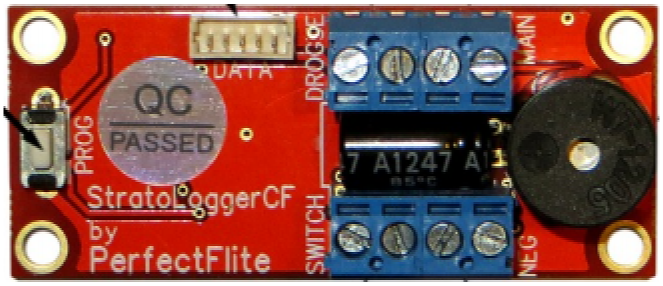


Figure 3.2.13 StratoLogger CF Altimeter

These altimeters record altitude data at a rate of 20 samples per second for up to 18 minutes. The altimeter reports the rocket's peak altitude and maximum velocity after flight via a sequence of beeps. Detailed flight data can be retrieved via an FTDI programming cable. The StratoLogger CF altimeter draws a continuous current of 1.5 mA and can output up to 5 A for up to 1 second to the pyrotechnic channels, provided the battery is capable of supplying this current. The StratoLogger CF power requirements and precision are listed below.

Table 3.2.2 Altimeter Specifications

Component	Voltage Rating	Current Consumption	Precision
StratoLoggerCF altimeter	4V-16V	1.5mA	< 38,000 ft MSL (±1 ft.) Additional for calibration (±0.05%)

The altimeter has two pyro outputs: one for deploying a small drogue chute at apogee to minimize drift and another for deploying a larger chute closer to the ground to further reduce the velocity prior to impact. Main chute deployment altitude is adjustable between 100 feet and 9,999 feet. The deployment of the drogue chute can also be delayed for up to 5 seconds after apogee. The altimeter also includes a Data I/O connection which allows real-time altimeter data to be sent via serial connection to the onboard Raspberry Pi 3. The table below lists the different ports of StratoLogger CF and briefly describes the functionality of each. A schematic showing the location of these ports is also pictured.

Table 3.2.3 StratoLogger CF Port Description

Port	*Name*	*Description*
+ -	Power input and output	Connects to 9V Battery
S1,S2	Port to Key Switch	Connects to Key Switch, which turns on the altimeter
M1,M2	Main Ejection Output	Connects to main chute ejection charges
D1,D2	Drogue Ejection Output	Connects to drogue chute ejection charges
GND	Ground	Connects to the GND port on the Raspberry Pi 3
TX	Transmitting Signal	Sends live data to the Raspberry Pi 3
RX	Receiving Signal	Not used. Purpose is to receive commands/signals from a microcontroller
3.3V	High Voltage Port	Not used.
N/C	N/C	Not used.

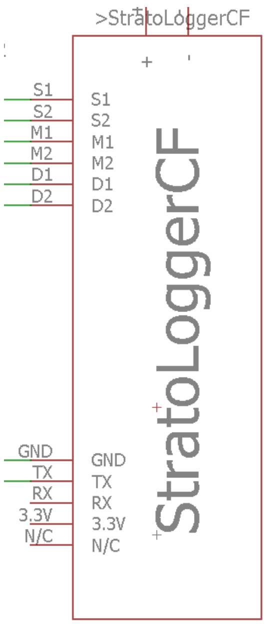


Figure 3.2.14 StratoLogger CF Schematic

GPS:

The Eggfinder GPS Tracking system, produced by Eggtimer Rocketry, is used to help track the launch vehicle during descent and locate the vehicle after landing. The transmitter module transmits in the 900 MHz license-free ISM band at 100mW. Data is formatted according to NMEA(National Marine Electronics Association) protocol and sent in packets at 9600 baud, with 8 bits, and no parity. The Eggfinder GPS Tracking System comes as kit that includes a RX(receiver) and TX(transmitter) module. Both modules had to be assembled before use. The GPS module weighs approximately 20 grams and draws 70-100 mA while operating and 10-20 mA while on standby. The transmitter module is powered by a 2 cell, 7.4 volt, 500 miliamp-hour lithium polymer battery. The receiver module is connected to a laptop computer which powers the module and displays the received GPS data. An image of an assembled GPS and receiver Eggfinder module is shown in the figure below.

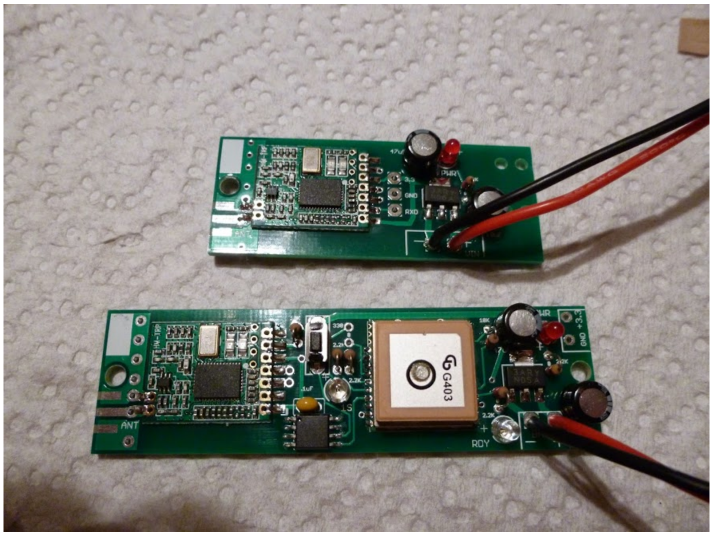


Figure 3.2.15 Assembled Eggfinder GPS Tracking System

The Eggfinder GPS system is advertised to have a line-of-sight range of 8000 feet using the stock antennas. Unfortunately, this has not been replicated using the modules currently in use. During testing, the system was only able to maintain connection at a distance of approximately 1000 feet. Likely causes for this unexpectedly short range include mounting too close to metal components within the rocket, interference, and faulty assembly. A new kit will be ordered and assembled to ensure that the GPS system can achieve the expected range before competition in April.

Other Components:

Molex eight-pin connectors were utilized to easily connect and disconnect the altimeters from the ejection charge wiring. A breakout board comprised of a Molex 8-pin female connector and a protoboard was created to connect the Stratologger CF pyro channels to the drogue ejection charges. The terminal blocks are wired to a Molex 8-pin male connector, which provides a quick, reliable method of connection/disconnection between the avionics bay and the bulkhead. The terminal block provides connection between the male connector wires and electric matches used to ignite ejection charges. This setup is used to release the drogue chute at apogee. The primary altimeter is programmed to ignite these charges at apogee and the backup is set to ignite one second later.

A similar setup is in use for the main chute. A ten-pin breakout board female connector is wired to the altimeters. Four connections on the board are used to ignite ejection charges for the main chute; the primary altimeter was set to deploy at 750 feet and the backup was set at 700 feet.

Another two connections from the breakout board are used to feed the altitude data stream to the Raspberry Pi 3 as serial connections. The final four of these connections were intended for I2C voltage monitoring. These connections were ultimately not used, as the voltage monitoring system will not be flown in competition.

Each altimeter has a two-position rotary switches used for arming. Each switch is wired in line between the negative lead of a 9V battery and the ground of an altimeter.

3.2.3. Redundancy Features

To ensure the reliability of the recovery system, a backup recovery system was installed in the Avionics bay in case the main system fails to deploy the parachutes. This system is a duplicate copy of the main recovery system with a second 9V battery powering a second Stratologger CF. This altimeter is connected to a duplicate electric matches for both the main and drogue ejection charges. The backup recovery system has its own arming switch and is entirely isolated from the primary recovery system. A wiring schematic of the backup recovery system is shown in the figure below.

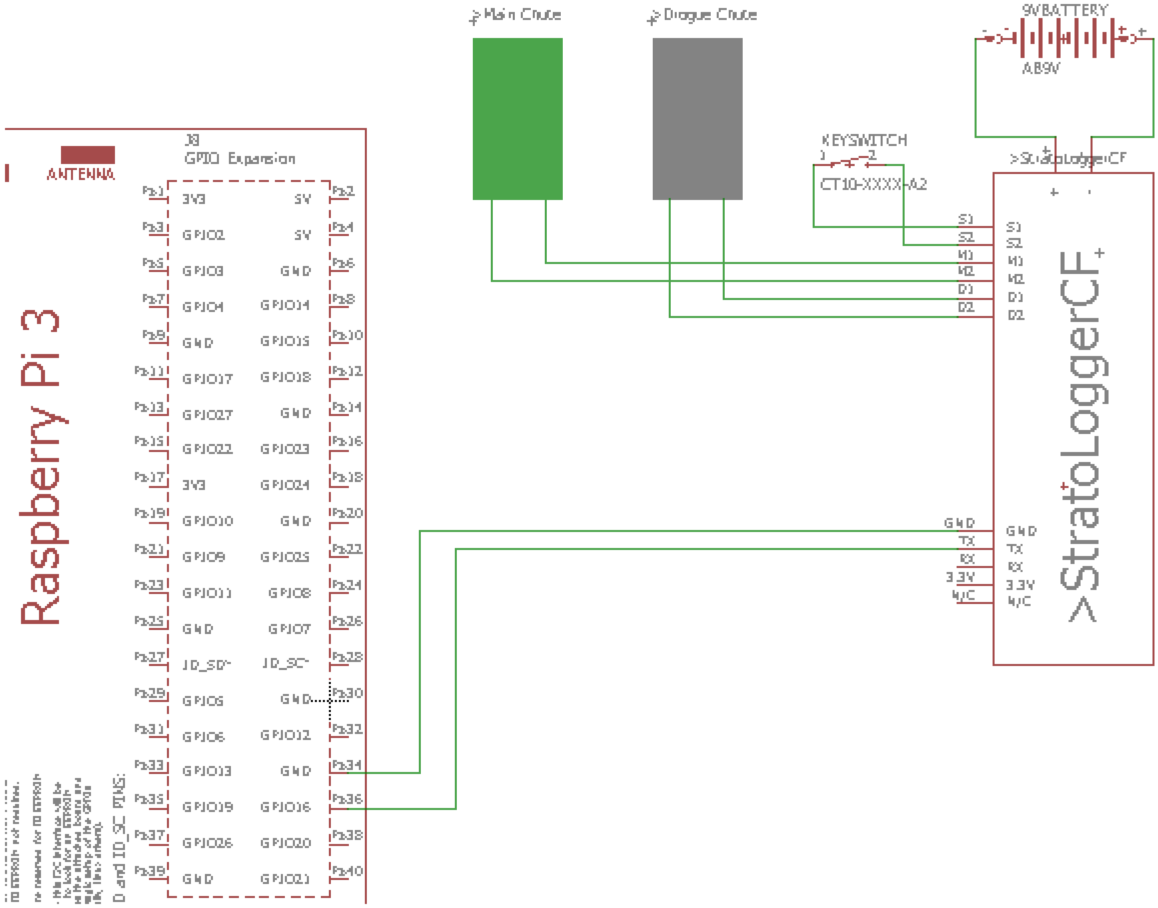


Figure 3.2.16 Recovery System Wiring

3.2.4. Parachute Specifications

Main parachute

The main parachute used in the rocket is a 96-inch Iris Ultra Compact Parachute. It is an ultra-compact toroidal or an annular parachute and is made primarily of nylon. It weighs 1.32 lbs. The shroud lines are made out of flat nylon, capable of withstanding a force of 400 lb. It has a drag coefficient of 2.2 and has a rating of 50 lbs. at 20 fps, meaning that it can descend with a load of 50 lbs at 20 feet per second. With the high drag coefficient, the parachute was applied to the launch vehicle in order to save the packing space while minimizing the kinetic energy at landing, despite its high cost. The main parachute is linked to the shock cord connecting the

Rover Housing section and Avionic Bay via a quicklink. The figure below is the actual image of the parachute and the table following is the specification of the main parachute.

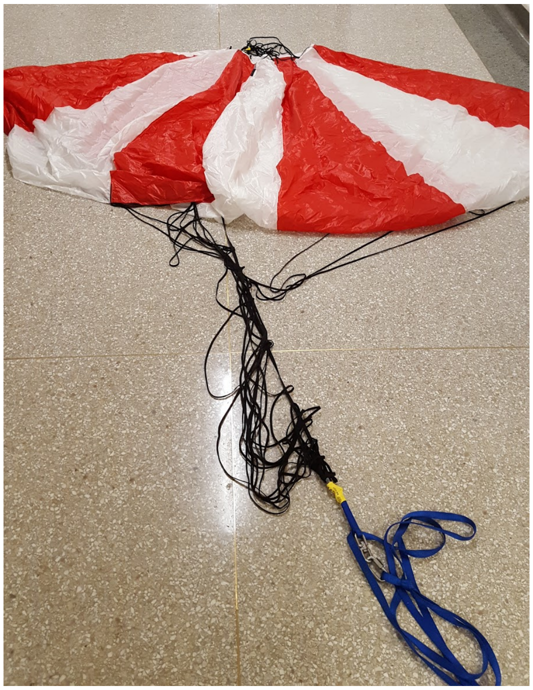


Figure 3.2.17 Actual image of the main parachute fully extended

Table 3.2.4 Main Parachute Specifications

Parachute Description	Specification
Diameter	96 in
Material	Nylon
Shape	Torodial
Mass	1.32 lbs
Decent Rate	50 lbs @ 20 fps
C_D	2.2
Packing Volume	4.9 x 4.8 : 90.5 in^3

Drogue parachute

As the drogue parachute, the launch vehicle utilizes the 36” printed nylon parachute manufactured by Apogee Rockets. In order to minimize With an octagonal shape, it is primarily made up from ripstop nylon. The drogue parachute has a coefficient of drag of 0.75. In order to minimize the drift time of the main parachute, the diameter of the parachute was determined. Similarly to the main parachute, the drogue parachute is connected to the shock cord tethering the Avionics Bay and the ATS Housing section via a quicklink. The figure below shows the actual image of the drogue parachute. The table following the image is the specifications of the drogue parachute.

Figure 3.2.18 Actual image of the drogue parachute fully extended

Table 3.2.5 Drogue Parachute Specifications

Parachute Description	Specification
Diameter	36 in
Shape	Octagonal
Weight	0.12 lbs
C_D	0.75

3.2.5. As-Built Schematics

The recovery subsystem consists of the Rover Housing, Avionics Bay, and ATS Housing. As mentioned in Table 3.1.3, the Rover Housing and Avionics Bay are linked via 2-56 nylon shear pins. These are then separated by pressure produced by an ejection charge, which breaks the shear pins and deploys the main parachute. The figure below is the schematics of the recovery subsystem.

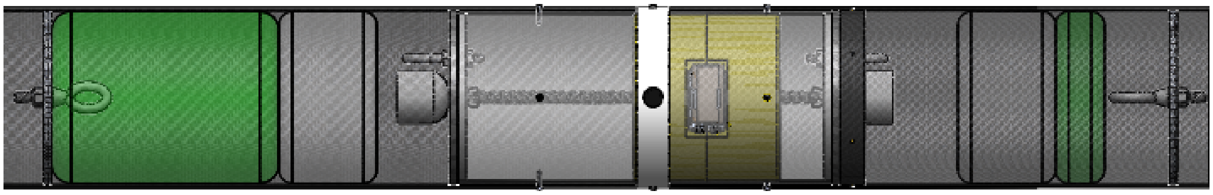


Figure 3.2.19 Drogue Parachute Packed Schematics

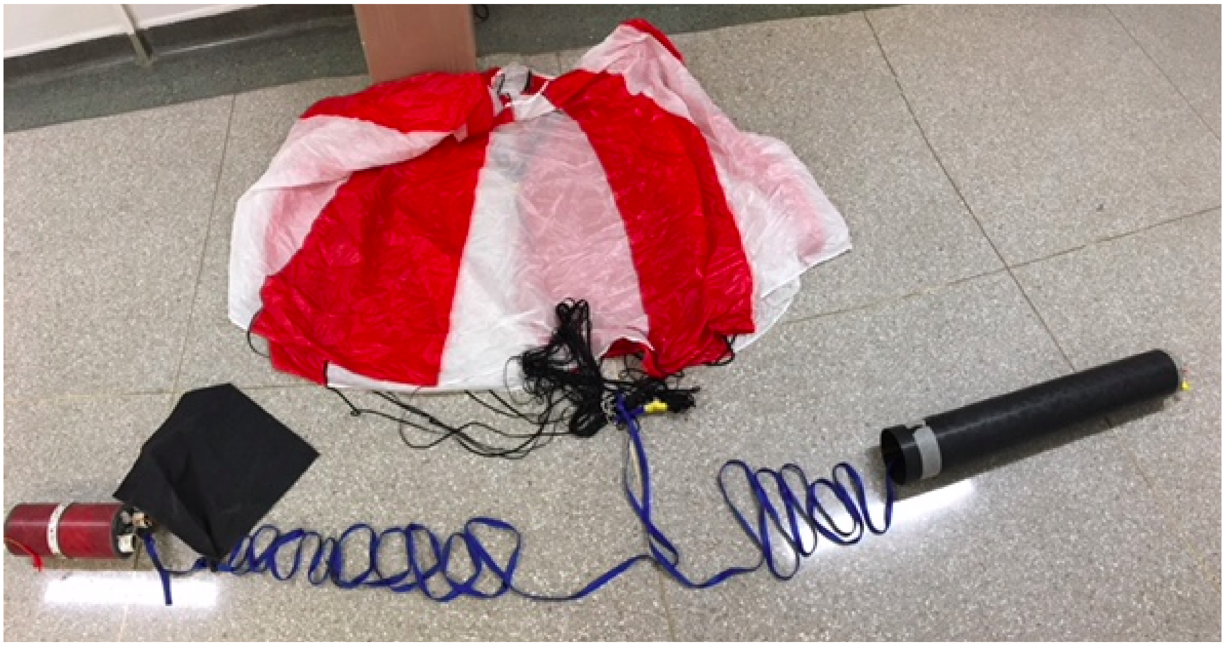


Figure 3.2.20 Main Parachute Schematics

The figure above depicts how the main parachute is attached to both of the stages. Attached to two ripcords with a quicklink, the shock cords attach to their respective stages with an eye bolt and U-bolt after being wrapped in a “figure 8” motion to prevent tangling. The main parachute canopy is folded lengthwise in thirds, and then folded once more to the center. Then, the suspension lines are stowed along the folded canopy – with at least 2 inches remaining outside of it – and the parachute is rolled along the suspension lines to minimize the volume it will take in its housing. Furthermore, a flame resistant tarp attached to the shock cord is placed and folded to be within the same housing tube to keep the parachute from the avionics. This is so that the the ejection charge will not ignite or damage the parachute and put the rocket at risk of failure during deployment.

Figure 3.2.21 Quicklink

Figure 3.2.22 Shock Cord Folding

Figure 3.2.23 Parachute Folding

Figure 3.2.24 Packed Parachute

The Avionics Bay and ATS Housing are also connected by 2-56 nylon shear pins and are separated by pressure produced by an additional ejection charge. The resulting separation event is the deployment of the drogue parachute.

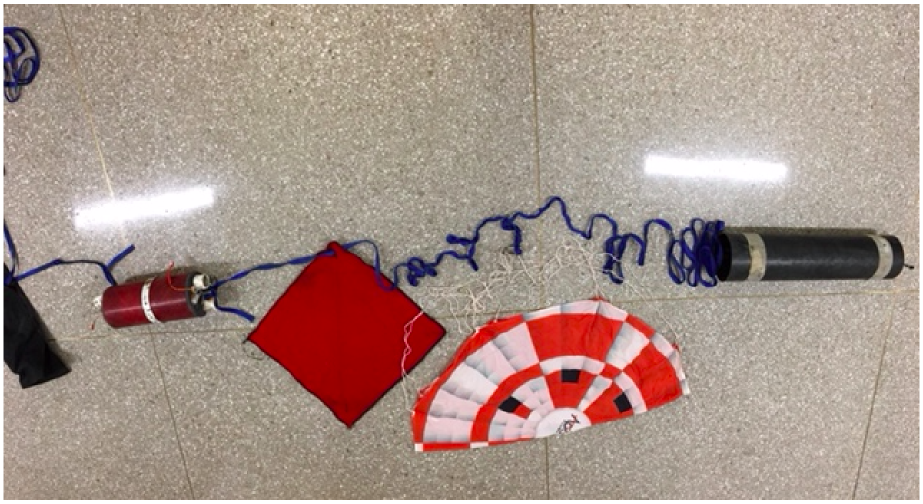


Figure 3.2.25 Drogue Parachute Layout

As the figure above shows, the location and attachment of the drogue parachute mimics that of the main parachute. A quicklink attaches the parachute to the shock cord, and each end of the shock attaches to a different stage: one end is attached to the ATS housing by connecting a quick link to an eye bolt, and the other attaches to the Avionics Bay by connecting a quick link to a U-bolt. The drogue parachute is folded in the same way as the main parachute, and a flame resistant tarp separates the drogue from the ejection charges on the avionics bay in the same way, as well.

Figure 3.2.26 Packed Drogue Parachute

3.2.6. System Sensitivity

One concern relating to the safety of the rocket's recovery system is the effect of electromagnetic(EM) radiation. If large electric or magnetic fields are experienced by the electrical components of the recovery system it could cause them to malfunction. Large electromagnetic fields could also produced induced currents in wiring throughout the rocket. This is particularly dangerous if these induced currents occur in the leads of the electric matches or the wires running from the altimeters to the terminal blocks. Such an event could cause unexpected ignition of the ejection charges, damaging the rocket and injuring bystanders.

The only significant source of EM radiation onboard the rocket is the GPS locator. This transmitter is not regarded as a hazard to the recovery system as it operates at only 100 mW and is located far from the avionics bay. To reduce the risk of induced currents in the recovery components the GPS locator has been mounted a large distance of 23 inches from the nearest recovery component, the electric matches for the drogue ejection charges. To further reduce the risk of induced currents in the electric matches, the leads to the electric matches are twisted before installation.

3.3. Mission Performance Predictions

3.3.1. Mission Statement/Success Criteria

The missions of the launch vehicle are to deliver a payload to 5,280 ft above ground, to recover safely onto the ground, and to deploy the rover. The success of the mission will be determined based on the following criteria:

1. The launch vehicle ascents with a vertical trajectory
2. The launch vehicle with the payload reaches an apogee of 5,280 ± 50 ft
3. The drogue and main parachutes deploy at the programmed altitude
4. The launch vehicle safely recovers to ground, each section satisfying the kinetic energy requirements
5. The motor is retained throughout the flight
6. The rover is deployed from the launch vehicle with remote control
7. The rover autonomously drives away from the vehicle for more than 5 feet
8. The rover deploys its solar panel

3.3.2. Flight Profile Predictions

In order to predict the flight profile of the launch vehicle, OpenRocket software was used as a simulation tool. The final OpenRocket model for the full scale launch vehicle was generated based on the actual mass of the components while the previous documentations used mass estimation via material density. The final model is displayed in figure below. The overall layout of the launch vehicle did not change from the CDR, yet the overall mass of the vehicle increased significantly, implying that the mass estimations were inaccurate as well as some masses such as epoxy which were thought to be fairly small were actually significant.

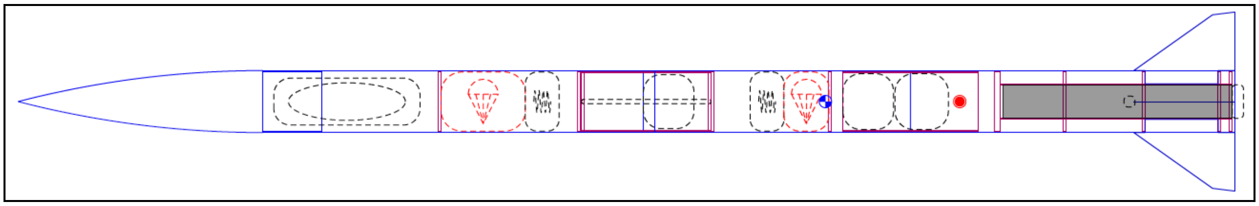


Figure 3.3.1 OpenRocket Model of Full-Scale Assembly

Table 3.3.1 OpenRocket Simulation of Flight Profile Characteristics

Flight Profile Behavior	Projected Values
Apogee	5081 ft
Rail Exit Velocity	73.8 ft/s
Maximum Velocity	628 ft/s
Maximum Acceleration	275 ft/s^2
Velocity at Main Parachute Deployment	75.5 ft/s
Ground Hit Velocity	15.4 ft/s
Thrust-to-Weight Ratio	7.78 : 1

The projected values of the the full-scale vehicle's flight path are summarized in the table above. As seen in this table, the apogee is predicted to be 5081 ft. The team's initial plan was to activate the ATS that will induce drag and allow the launch vehicle to approach the target of 5280 ft. However, the final, manufactured version of the rocket contained much more mass than initially presumed, leading to an apogee below the target. Due to the fact that the ATS could not function during the full scale launch as well as the lower predicted apogee without ATS activation led to the team's decision on not activating the ATS during the competition. However, other than the apogee altitude prediction, the launch vehicle's key flight profile characteristics will comply to the competition requirements.

Using the OpenRocket software simulation, the below figures, illustrating the flight profile path and behaviors of the full-scale assembly during the launch, were created. The first figure shows the variance in altitude, vertical velocity, and vertical acceleration with time. The value of acceleration at main parachute deployment, indicated as the spike in the figure, was used for calculating the force applied in the FEA of the retention ring. The second figure showing the vertical velocity until motor burnout proves that the vehicle will have sufficient velocity at launch exit, meeting the minimum requirement of 52 fps. The third figure, converting the vertical velocity into mach numbers, also proves that the launch vehicle will not exceed mach 1 at any point in time of the launch.

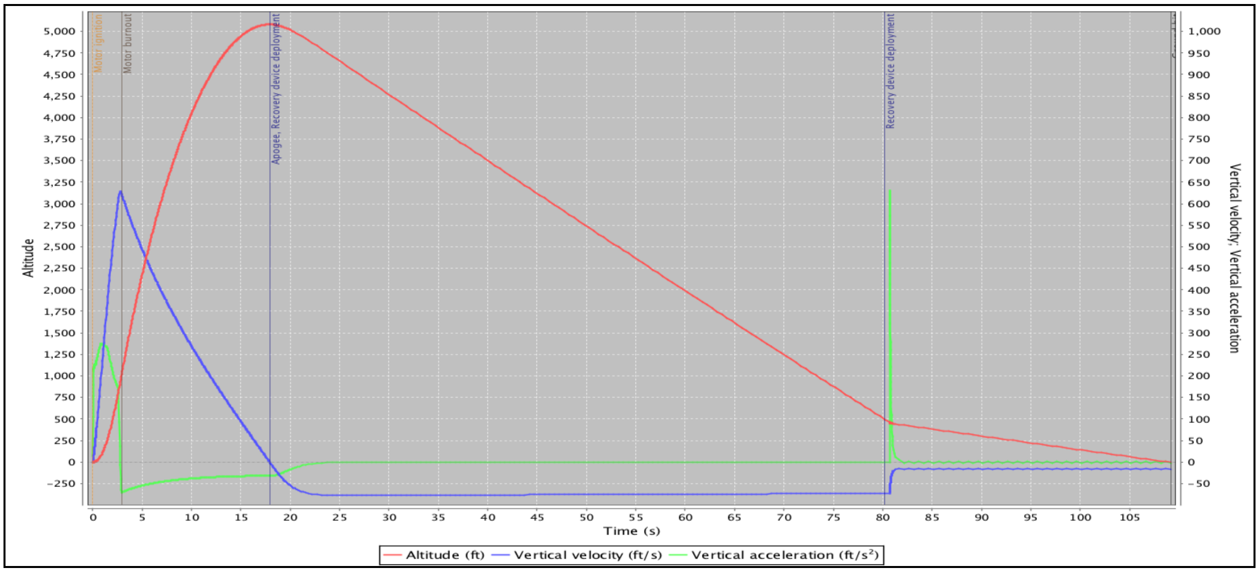


Figure 3.3.2 Full-Scale Flight Simulation

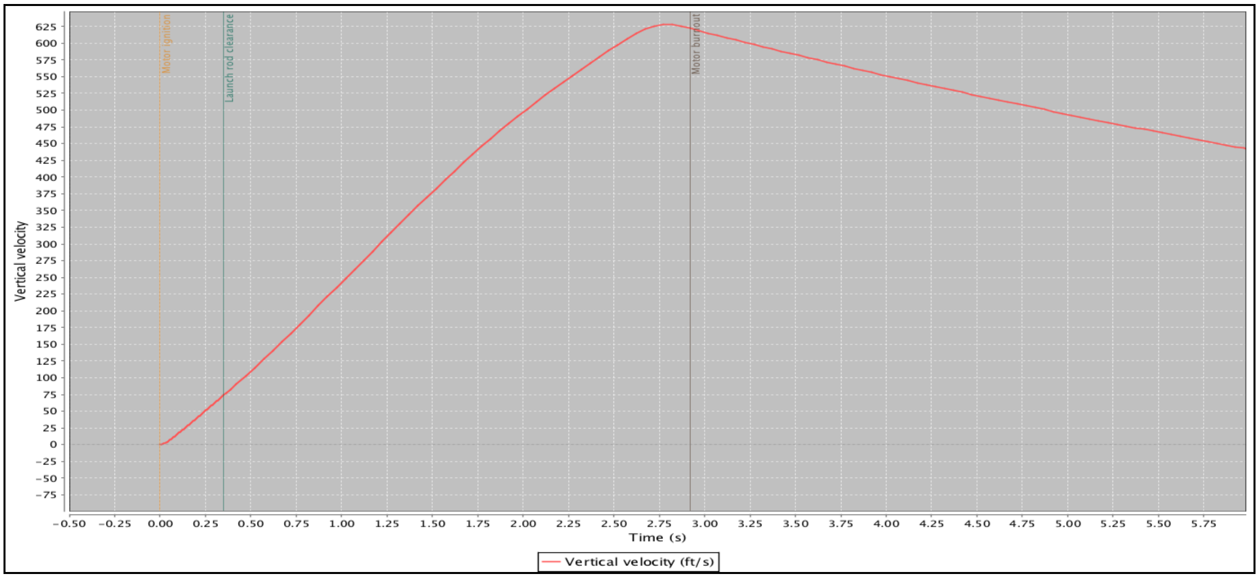


Figure 3.3.3 Full-Scale Flight Simulation - Time vs. Vertical Velocity

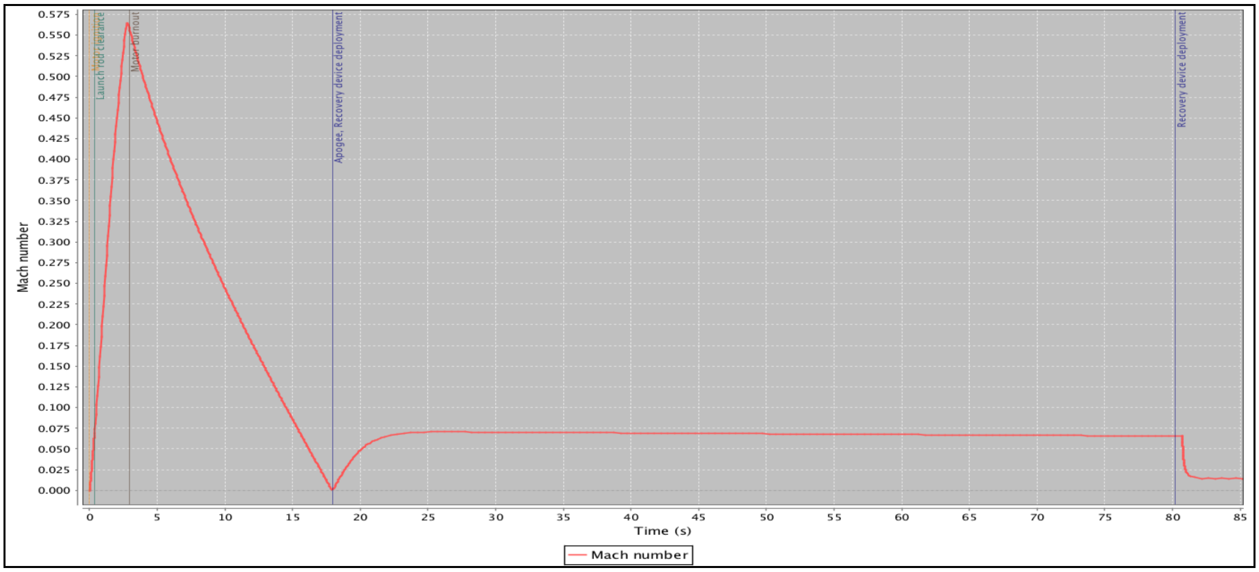


Figure 3.3.4 Full-Scale Flight Simulation - Time vs. Mach Number

3.3.3. Component weights

In order to accurately predict the flight performance of the rocket using OpenRocket simulation, it is imperative to know the mass of each section of the launch vehicle. The actual mass of each component in the launch vehicle was measured using a scale. The mass distribution of the launch vehicle among the sections are summarized in the figure below.

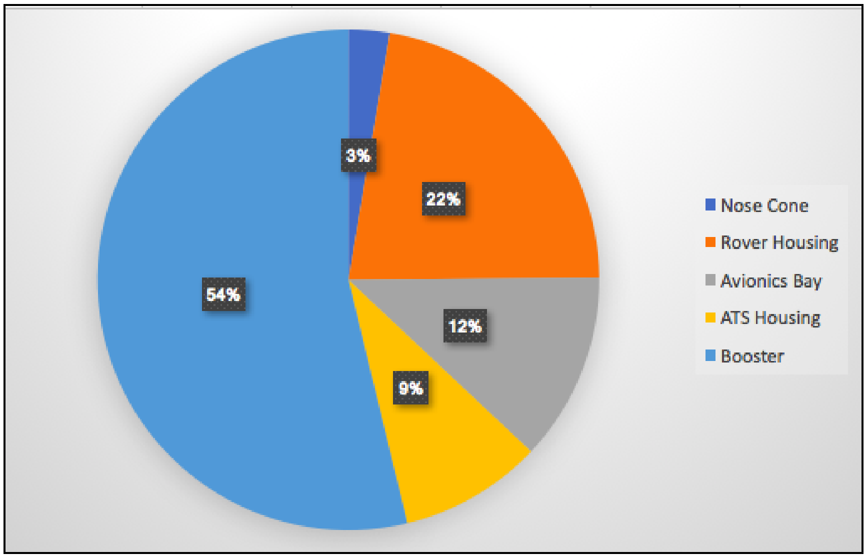


Figure 3.3.5 Mass distribution of the launch vehicle by sections

The following tables summarize the material and mass of the components and subsystems housed in each section of launch vehicle. The materials used to construct the subsystems in each section will be summarized in the designated sections of this document.

Table 3.3.2 Nose Cone section mass breakdown

Component/Subsystem	Material	Mass (lb_m)
Nose cone	G10 fiberglass	1.05

Table 3.3.3 Rover Housing section mass breakdown

Component/Subsystem	Material	Mass (lb_m)
Body tube	G12 fiberglass	3.39
Rover, Rover Deployment System, GPS	N/A	2.75
Bulkhead (with Eye-bolt)	G10 fiberglass	0.49
Main parachute	Kevlar	1.32
Shock cord (with 3 quicklinks and chute protector)	Tubular nylon	0.83
Epoxy	Epoxy	0.10
Total		8.88

Table 3.3.4 Avionics Bay mass breakdown

Component/Subsystem	Material	Mass (lb_m)
Coupler tube (with strip)	G12 fiberglass	1.42
Body tube bulkhead (x2) (with ejection caps, U-bolt, wirings)	G10 fiberglass	0.74
Coupler tube bulkhead (x2)	G10 fiberglass	0.33
Central threaded rod	Steel	0.39
Avionics Bay electronics	N/A	0.88
Total		4.83

Table 3.3.5 ATS Housing section mass breakdown

Component/Subsystem	Material	Mass (lb_m)
Body tube	G12 fiberglass	2.16
Drogue parachute	Ripstop nylon	0.12
Shock cord (with 3 quicklinks and chute protector)	Tubular nylon	0.78
Bulkhead (with Eye-bolt)	G10 fiberglass	0.49
Epoxy	Epoxy	0.10
Total		3.65

Table 3.3.6 Booster section mass breakdown

Component/Subsystem	Material	Mass (lb_m)
Coupler tube	G12 fiberglass	1.30
Body tube (with rail button)	G12 Fiberglass	2.89
Thrust plate	Plywood	0.28
Motor mount tube	White kraft paper	0.50
Centering ring (x3)	6061-aluminum	0.13
Fin (x4)	G10 Fiberglass	0.58
Retention ring	6061-aluminum	0.36
Retention cap	N/A	0.26
Motor casing	N/A	4.35
Motor propellant	N/A	4.20
ATS mechanism	N/A	2.51
ATS electronics bay	N/A	1.38
Epoxy	Epoxy	0.58
Total		21.32

3.3.4. Motor

Due to additional masses, the motor selected by the team in the previous documents, the AeroTech L1390 will be insufficient to reach the target apogee of 5,280 ft according to OpenRocket simulation. Nevertheless, the team will continue on using this motor since the motor casing is already available and the team's focus is to create a functional rocket. The FEA conducted for the components to retain the motor - thrust plate, centering rings, and motor retention ring - were based on the maximum thrust provided by AeroTech L1390 motor, demonstrating that the retention system will be robust enough to withstand the acceleration generated by this motor. The thrust curve and the specifications of the AeroTech L1390 motor can be seen in the figure and table below, respectively.

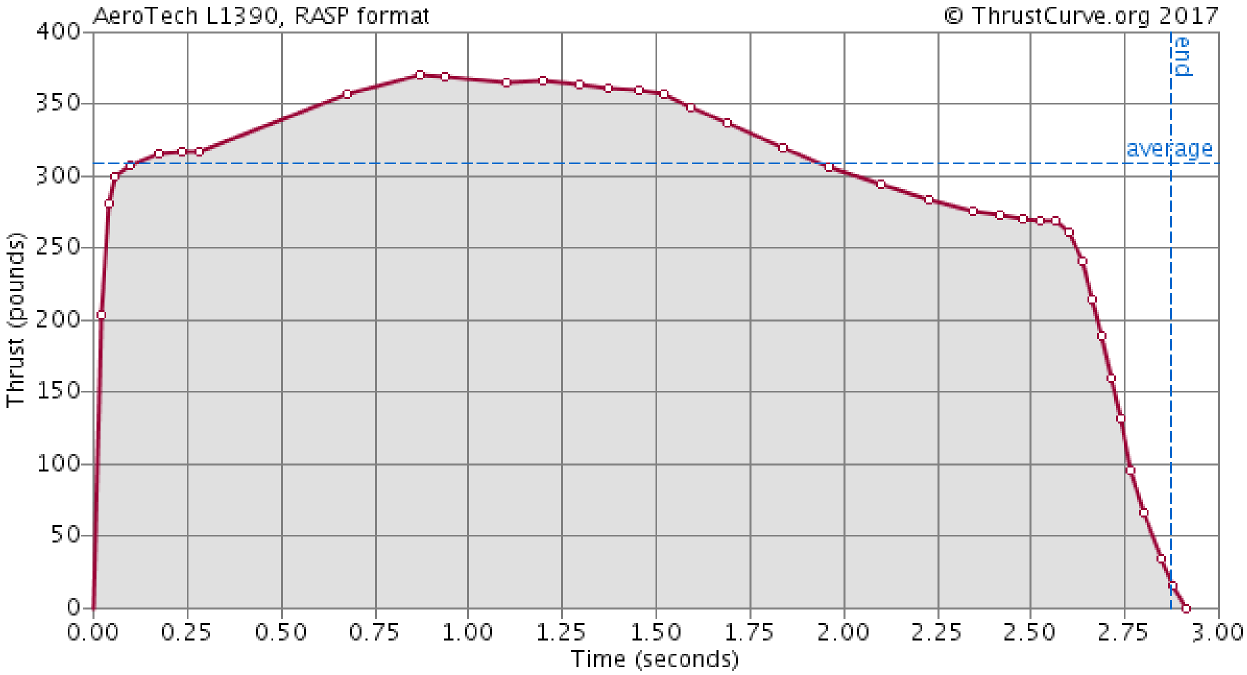


Figure 3.3.6 Thrust curve for AeroTech L1390 motor

Table 3.3.7 AeroTech L1390 G-P specifications

Property	Value
Diameter (in)	2.95
Length (in)	20.87
Total mass (lb_m)	8.54
Propellant mass (lb_m)	4.35
Average Thrust (lb_f)	305.63
Maximum Thrust (lb_f)	370.90
Total Impulse (lbf·s)	887
Burn time (s)	2.91

3.3.5. Stability, Center of Pressure and Center of Gravity

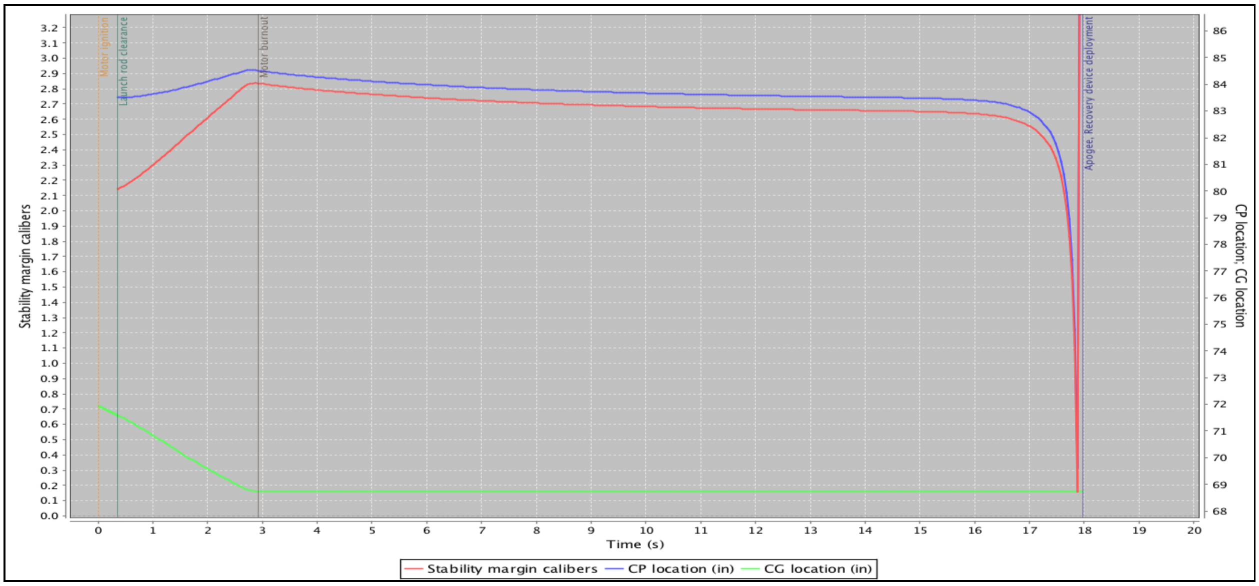


Figure 3.3.7 Time vs Stability Margin, Center of Pressure, and Center of Gravity

The figure above, generated by OpenRocket simulation, shows the change in the launch vehicle's stability margin and locations of the center of pressure (CP) and the center of gravity (CG) over time. The value of the distances for CP and CG are measured relative to the tip of the nose cone. The stability margin measures how "stable" the launch vehicle is and is equivalent to the ratio of the distance between CG and CP to the diameter of the launch vehicle. For the team's vehicle, the stability margin is 2.14 at rail exit, reaching the maximum value of 2.84 around motor burn out and keeping an average of 2.65 throughout the ascent of the launch vehicle. Thus, the minimum requirement of 2.0 will be maintained throughout the flight, proving that the vehicle will be stable during its ascent. The following table summarizes the values of stability margin at specific instances and of the locations of CP and CG at mach 0.3.

Table 3.3.8 Stability Margins

Property	Value
Center of Pressure (measured from nose cone)	83.764 in
Center of Gravity (measured from nose cone)	71.926 in
Stability margin at rail exit	2.13
Max static margin caliber	2.84
Average static margin caliber	2.65

3.3.6. Kinetic Energy at Landing

After the flight simulation of the launch vehicle was conducted via OpenRocket, the maximum kinetic energies of the launch vehicle's individual, tethered sections were calculated. Using ground-hit velocity of 15.4 ft/s extracted from the OpenRocket simulation, the kinetic energy equation was applied to compute these values. The following table summarizes the kinetic energy at landing of the three tethered stages.

Table 3.3.9 Maximum Projected Kinetic Energies of Full-Scale Sections

Tethered Stages	Mass (slugs)	Ground-Hit Kinetic Energy (ft-lbf)
Nose Cone + Rover Housing	0.3061	36.30
Avionics Bay	0.1501	17.80
ATS Housing + Booster	0.6177	73.25

The mass values in the table were recorded by measuring the individual sections using a scale. With the ground hit velocity of 15.4 ft/s, the stage combining the ATS Housing and Booster sections, which is the heaviest individual section, has a kinetic energy of 73.25 ft-lb_f.

The greatest kinetic energy a section may have at landing is defined to be 75 ft-lbf by the competition criteria and the table shows that all of the individual sections meet this criteria. The success in meeting the criteria proves that the specifications of the main and drogue parachutes were applicable to the launch vehicle and will recover the launch vehicle safely onto ground.

3.3.7. Drift Calculations

In order to examine the drift of the launch vehicle from the launch pad for different wind speeds, a simple hand calculation was done along with OpenRocket simulation to confirm the results. The following is a list of assumptions made for the calculation:

1. The launch vehicle ascents vertically without any wind
2. The launch vehicle experiences a constant wind from the apogee
3. The launch vehicle drifts at the same velocity as the wind
4. The terminal velocity is reached instantaneously after the deployment of each parachute

With these assumptions, the drift of the launch vehicle will be the product of the wind speed and the time difference between landing and apogee, since the launch vehicle does not experience acceleration in both vertical and horizontal direction during the recovery. Based on this simple math, the drift distance due to 0, 5, 10, 15, and 20 mph were calculated, and the results are summarized below.

Table 3.3.9 Drift distance of the launch vehicle due to different wind speeds

Wind speed (mph)	Drift time (s)	Drift distance (ft)
0	91.1	0
5	91.1	668
10	90.1	1321
15	90.1	1960
20	89.2	2617

To verify that the hand calculations are accurate, OpenRocket simulations with the various wind speeds were conducted. The following five figures depict the lateral displacement of the launch vehicle with the different wind speeds calculated by the OpenRocket software.

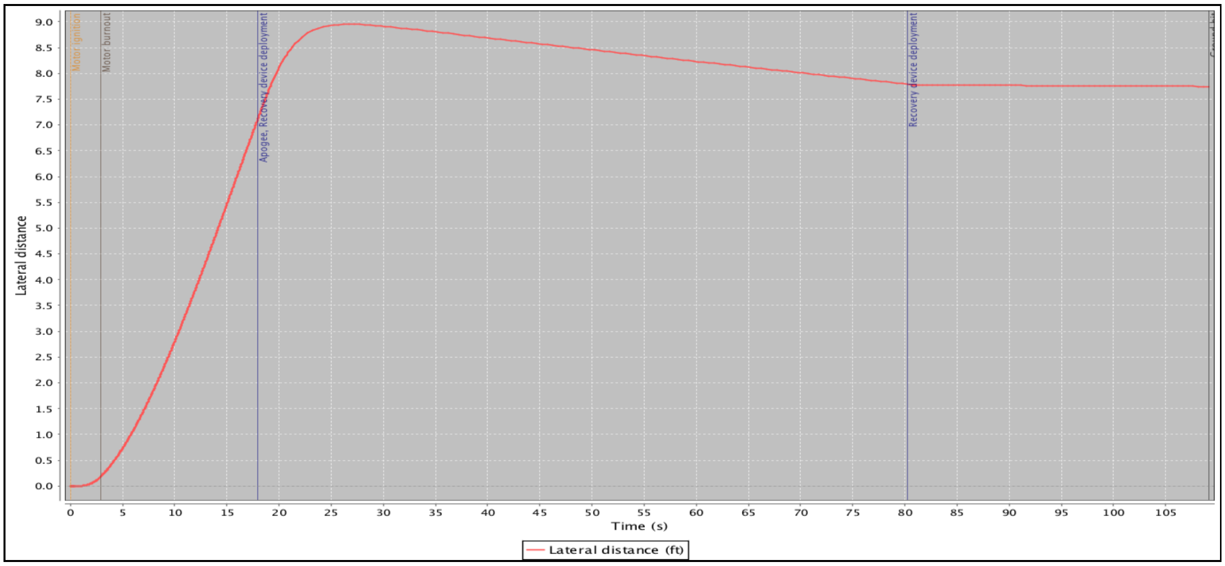


Figure 3.3.8 Drift due to 0 mph wind

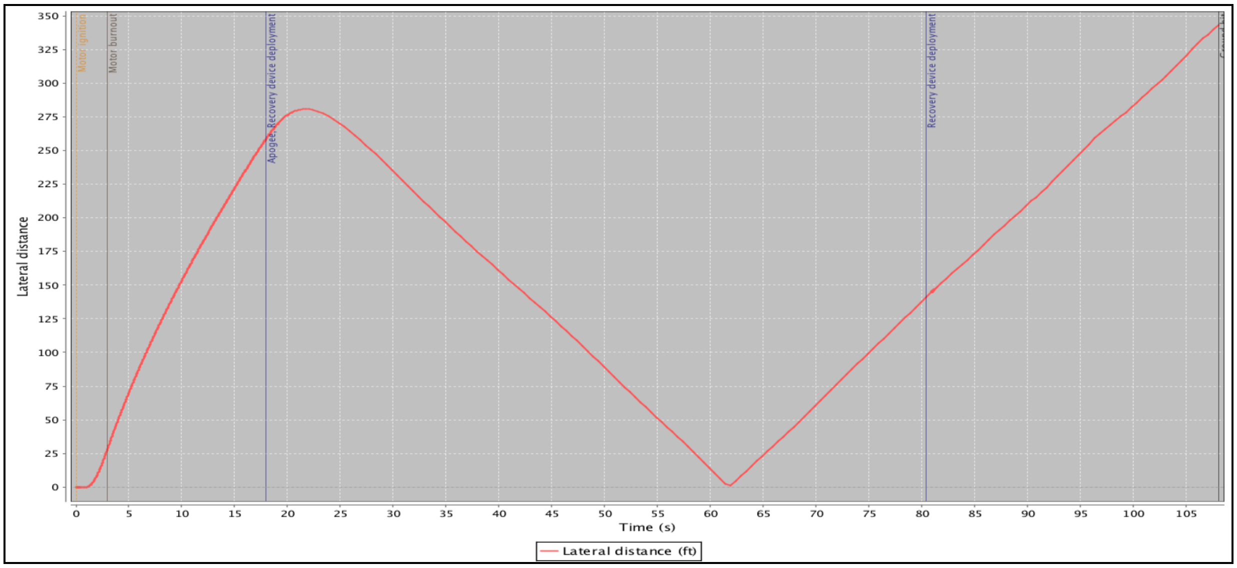


Figure 3.3.9 Drift due to 5 mph wind

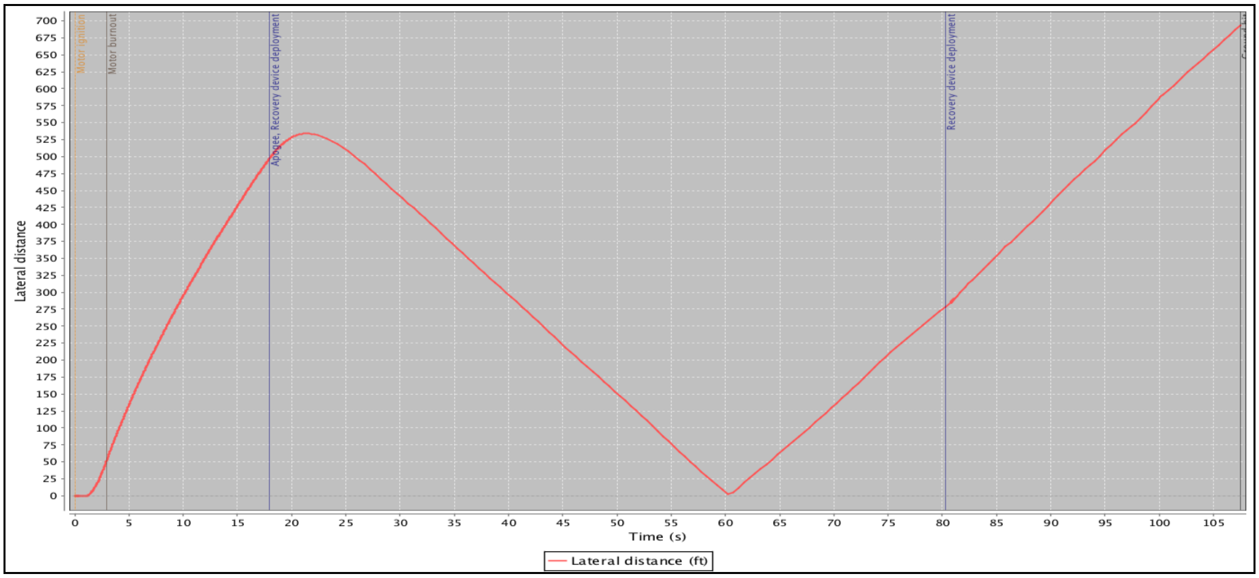


Figure 3.3.10 Drift due to 10 mph wind

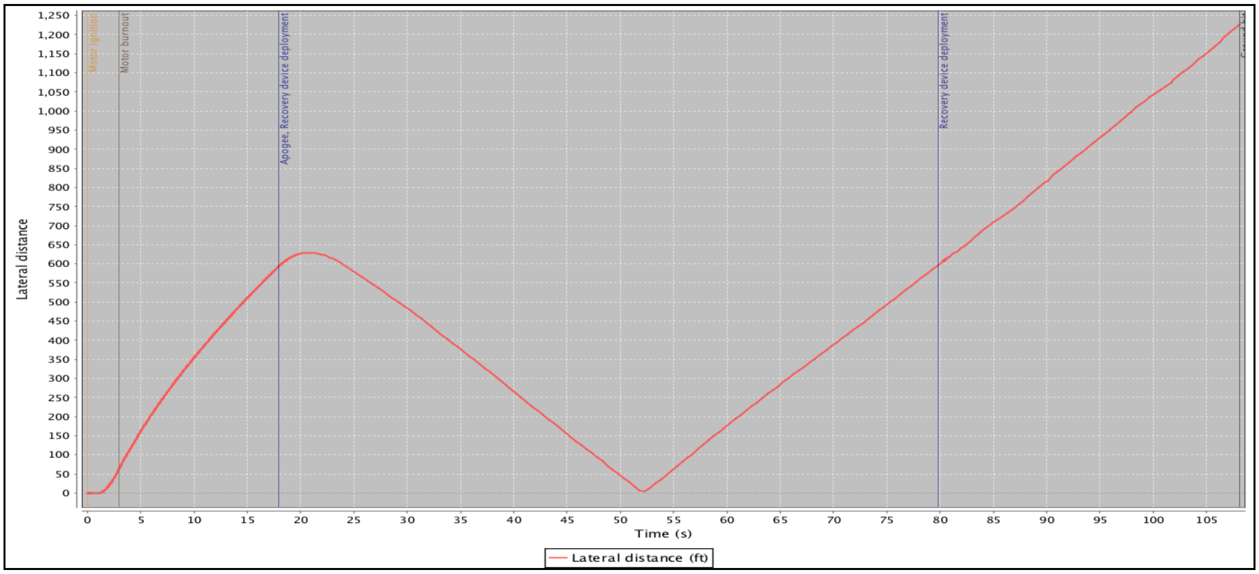


Figure 3.3.11 Drift due to 15 mph wind

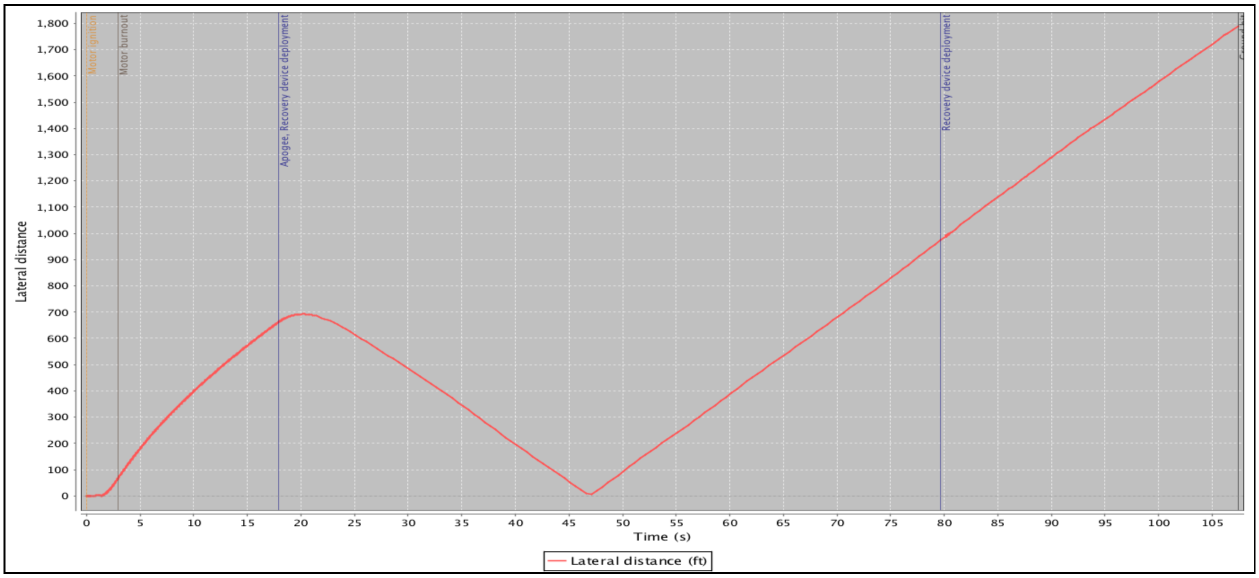


Figure 3.3.12 Drift due to 20 mph wind

Table 3.3.10 Drift distance prediction by hand calculation and OpenRocket simulation

Wind condition (mph)	Hand calculation predicted drift distance (ft)	OpenRocket predicted drift distance (ft)
0	0	8
5	668	343
10	1321	693
15	1960	1227
20	2617	1789

The values obtained from hand calculation and the OpenRocket simulation were quite different as demonstrated in the table above. While the hand calculation suggested that the launch vehicle will recover within the required recovery area of 2,500 ft radius up until 19 mph, the OpenRocket simulation suggested that the launch vehicle can be recovered up until wind velocity close to 25 mph. The difference may have emerged due to the fact that the OpenRocket simulation considers the effect of the wind onto the launch vehicle during the ascent as well.

Table 3.3.11 Effect of Wind Speed on Apogee Altitude

Wind speed (mph)	Apogee altitude (ft)
0	5081
5	5073
10	5043
15	5028
20	4999

Additional to the simulation on the effect of wind speed on the drift distance, the effect of wind speed on the predicted apogee was examined using OpenRocket. The divergence in the apogee altitude at different wind speed could be seen in the table above. The table shows that the higher the wind speed is, the lower the apogee altitude is. This fact is intuitive since with the wind, the launch vehicle will not ascent perfectly vertical, utilizing some portion of its thrust on horizontal acceleration rather than vertical. The difference in the apogee altitude between 0 mph and 20 mph wind is roughly 80 ft, which suggests that one of the reasons why the launch vehicle did not achieve the predicted apogee by the OpenRocket simulation during the full scale launch was the high wind speed at the launch site.

3.4. Full Scale Flight

3.4.1. Launch Day Conditions and Simulations

The full scale launch of the vehicle was conducted near Samson, Alabama. At the time of launch, approximately 3:30 PM CST on February 24th 2018, the temperature was 62 °F, average wind speed was 7.8 mph in the southwest direction, with 60% humidity and an atmospheric pressure of 1018 mbar. Using these weather conditions, OpenRocket simulation was run to predict the flight performance of the launch vehicle. The summary of the result is shown in the table below and the predicted flight profile of the launch vehicle follows the table.

Table 3.4.1 Flight Performance Prediction under Full Scale Launch Weather

Flight performance characteristics	Predicted Value
Apogee altitude	5060 ft
Maximum velocity	627 ft/s
Maximum acceleration	275 ft/s^2
Flight time	107 s

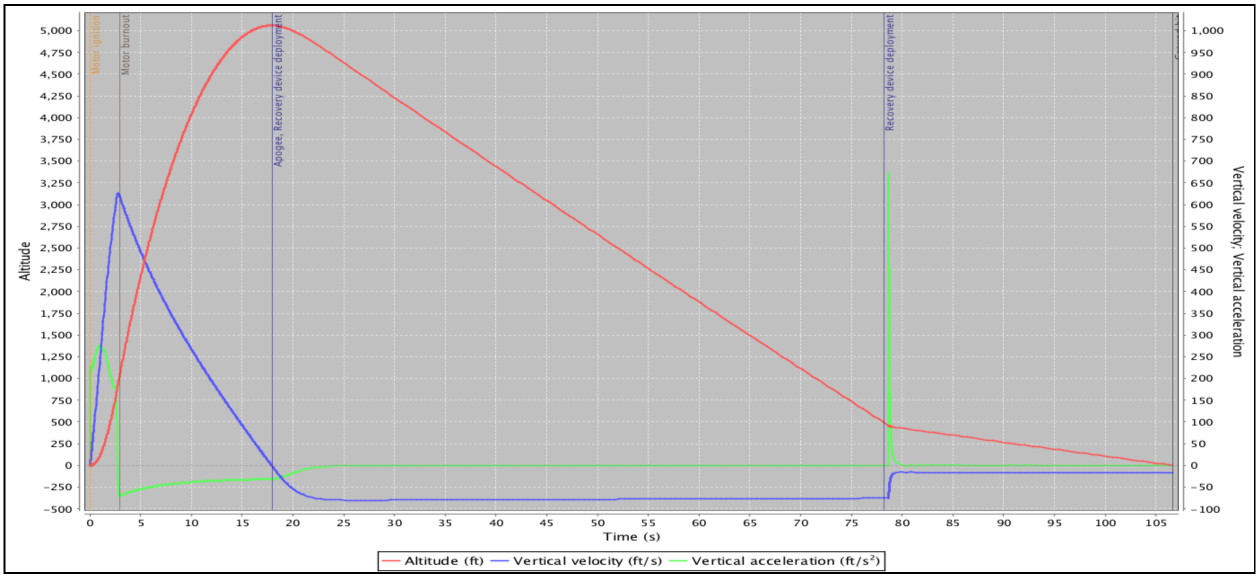


Figure 3.4.1 Full Scale Flight Simulation

3.4.2. Full Scale Flight Analysis

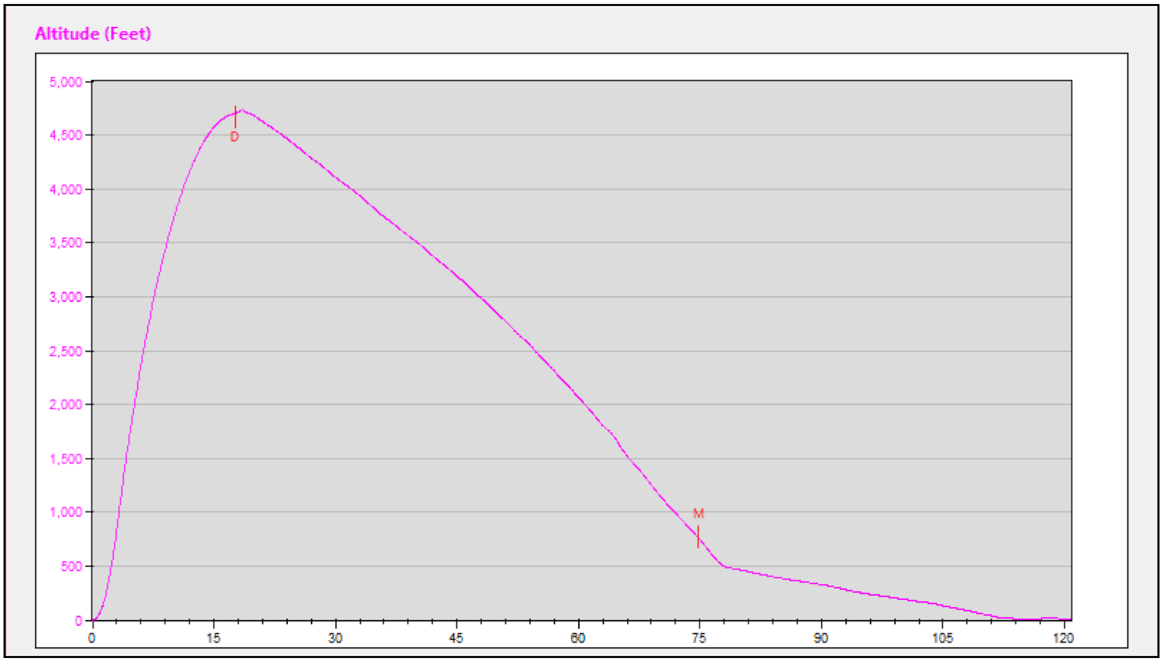


Figure 3.4.2 Full Scale Flight Altitude Data

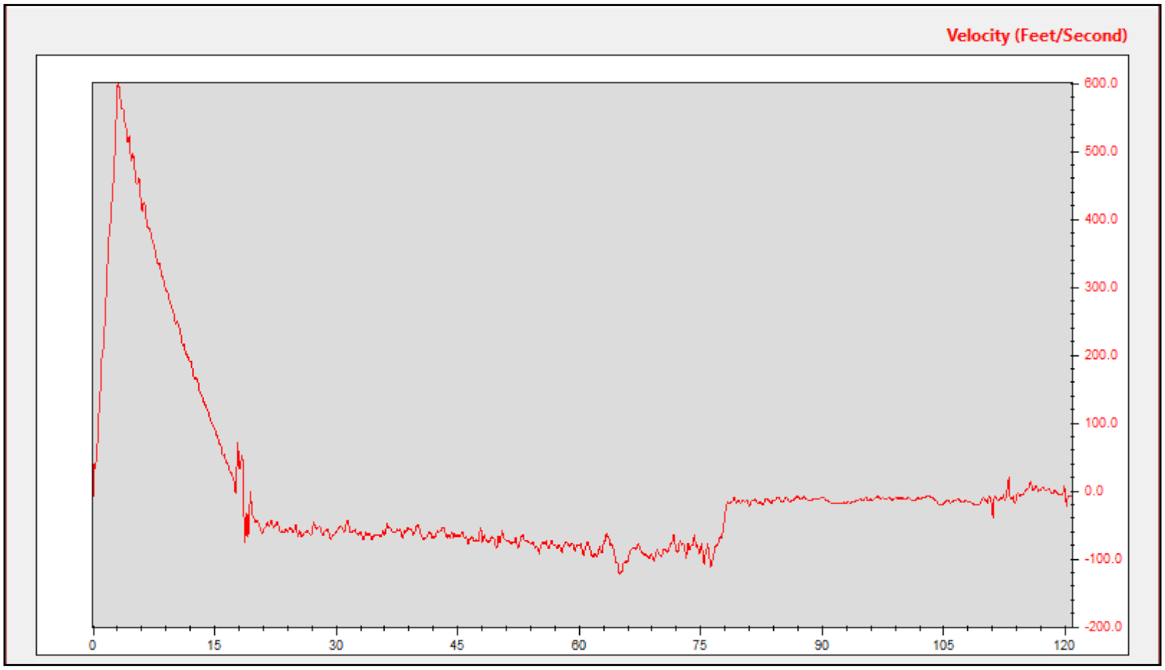


Figure 3.4.3 Full Scale Velocity Data

The above two figures display the altitude and vertical velocity data recorded by the stratologgers in the Avionics Bay. Based on the graph reading, it is found that the apogee was reached at 4734 feet AGL, with a maximum velocity of approximately 600 ft/s.

Table 3.4.2 Predicted vs Recorded Data

	Predicted	Recorded	Difference
Apogee	5060 ft	4734 ft	6.44 %
Max Velocity	627 ft/s	600 ft/s	4.31 %

The table above compares the flight performance data that was predicted by the OpenRocket software using the weather condition at launch site and that was actually recorded by the launch vehicle. While absolute difference between the predicted and recorded apogee altitude differed by more than 300 ft, the percent difference was 6.44 %. The predicted and recorder value of the maximum velocity was even closer, shown by the percent difference of 4.31 %.

There are several potential factors that could have caused the difference between the actual and predict values. One of the them is the effect of gust wind. While wind condition used for the simulation was the average wind speed of the day, which was 7.8 mph, the gust speed on the launch day reached up to 33 mph, and the team faced a very high wind speed at the moment of the launch. The fact that the launch vehicle was moved a significant distance after landing on the ground also suggests the high wind speed condition that was not considered in the average wind speed. It is possible that a rogue gust of wind or unsimulated wind current caught the rocket in a particular way and changed the trajectory during the ascent, causing the thrust to gain a lateral angle and, therefore, the launch vehicle to fail in reaching the predicted apogee obtained under the assumption that wind was uniformly and constantly flowing at the average velocity.

There are several geometric features that the OpenRocket cannot simulate, and this fact may have been another factor of the difference in the predicted and actual values. There are two key switch holes, one for Avionics Bay electronics and one for ATS electronics housing, running from the outer surface of the launch vehicle to inside of the launch vehicle. Moreover, four horizontal slots were cut into the Booster body tube to allow the ATS flaps to come out and induce drag. These holes could have caused turbulence in the air flowing along the launch vehicle, causing additional drag that is not included in the OpenRocket simulation.

It is also probable that the imperfection of the manufacturing and assembling of the launch vehicle caused the discrepancy between the actual and predicted values. During the manufacturing phase, the nose cone was accidentally dropped, having its tip chipped off by a small amount. Epoxy mixed with fiberglass was applied to fix this, yet this may have caused a nonuniform flow of the air along the launch vehicle. The edges of the body tubes are not perfect, meaning that when the rocket is assembled completely the surface is not uniform, again possibly causing random airflow along the rocket. These imperfections may have contributed to additional drag and driven the apogee to a much lower altitude.

Another possibility for the difference in the actual and predicted values is the difference in the actual and ideal thrust of the launch vehicle. Though the propellant was carefully installed to the motor casing, it could have not burned in a uniform way, providing less thrust than it is supposed to. The lower value of the thrust would translate into lower apogee altitude and maximum velocity and this is consistent with the observation made for the actual data.

With the combination of all of these factors, the actual performance data of the full scale launch vehicle may have differed from the predicted data based on OpenRocket simulation. Nevertheless, as been highlighted throughout this document, the launch vehicle will not be able to reach the target apogee of 5,280 ft even without the activation of ATS.

3.4.3. Subscale vs Full scale

The subscale and full scale launch vehicles had different objectives. Due to the space constraint of the body tube, the subscale launch vehicle aimed to only test the flight critical systems such as the recovery subsystem and to actuate the ATS to collect data. Due to software related issues, the ATS did not activate during the flight though the ground test of the rover deployment system was successful. The objectives of full scale launch vehicle was to prove the robustness of the recovery subsystem, activate the ATS, and actuate the rover deployment system. This time, the ATS did not actuate due to the friction between the flaps and the housing, and the rover deployment system was not finished until the launch, making it impossible to test at the launch.

Table 3.4.3 Sub-scale vs Full scale Flight performance

	Subscale	Full Scale
Apogee	3147 ft	4734 ft
Maximum velocity	678 ft/s	600 ft/s
Ground Hit Velocity	25 ft/s	15.4 ft/s
Time in Flight	110 s	100 s

The table above compares the flight data collected from the subscale launch, conducted on November 18th, 2017 with that from the full scale launch, conducted on February 24th, 2018. The maximum velocity and the ground hit velocity of the subscale launch vehicle was higher than that of the full scale. With the consideration of the lack of space for the rover deployment system, the team decided to not include the rover deployment system after the final design of the subscale vehicle was made. Since the motor was selected based on the vehicle mass with the deployment system, the loss of weight contributed significantly on the increase in maximum velocity and apogee altitude. Due to the fact that the subscale launch vehicle had lighter weight for each individual tethered section, the ground hit velocity was able to be higher than that of the full scale launch vehicle.

4. Payload Criteria - Rover

4.1. Changes since CDR

4.1.1. Payload

The Payload has undergone a few minor developments since CDR. Unfortunately, due to repeated delays in receiving materials the system development was sidelined in order to ensure that the rocket would be ready for flight. The push towards flight readiness was an attempt to ensure that the team will be able to continue to compete. Due to the aforementioned emphasis the competition continues but, the Payload will be in an inactive configuration.

4.1.2. Rover System

The Rover has maintained all key features displayed in CDR. Only two minor changes have occurred. The filleted edges on the rover wheels were removed to simplify their manufacturing. Additionally, the number and placement of splines on the rover wheels were decreased and the placements were adjusted to improve traction developed across the terrain. The rover control board will now utilize an arduino nano as the microcontroller driving solar panel deployment and rover motion, though this change will not change the system functionally in any way and the components used on the control board will also remain unchanged. The CDR also neglected to mention modifications taken to change 180 degree servos to continuous rotation servos. These modifications were taken and tested successfully prior to any construction of rover.

4.1.3. Deployment System

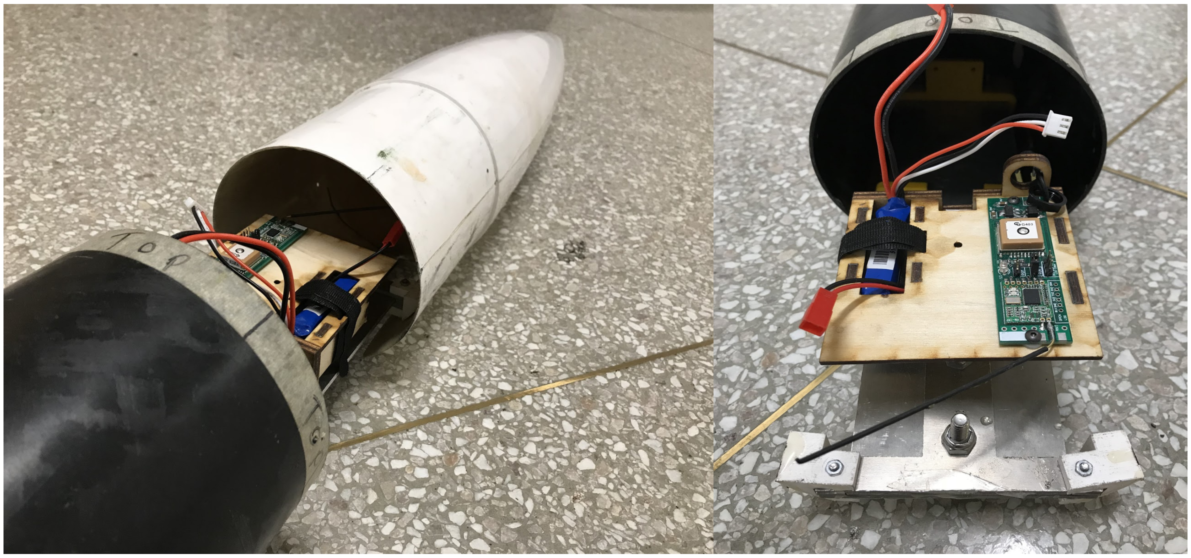


Figure 4.1.1: Rover Deployment Section

The only significant part change since CDR was the removal of the cardboard coupler tray. The deployment section was thereby affixed to the inside of the fiberglass airframe with the use of epoxy. This change was due to the indefinite delivery date provided by the shipper after our delayed order was finally submitted and the desire to demonstrate an active and successful rover retention during the test flight on February 24th. Due to electrical failures however, the retention system flew in an inactive configuration and will not be utilized in our competition flight. The electronics that drive the deployment system required two major changes from CDR: the addition of a second battery for driving the motor in reverse and a change to 11.1V batteries to drive the system. These features were tested successfully outside of the rocket tube, but failed inside of the tube, likely due to underestimates in the battery capacity required to drive the deployment system for a prolonged amount of time. In the future, batteries with a capacity greater than 1000 mAh will be used.

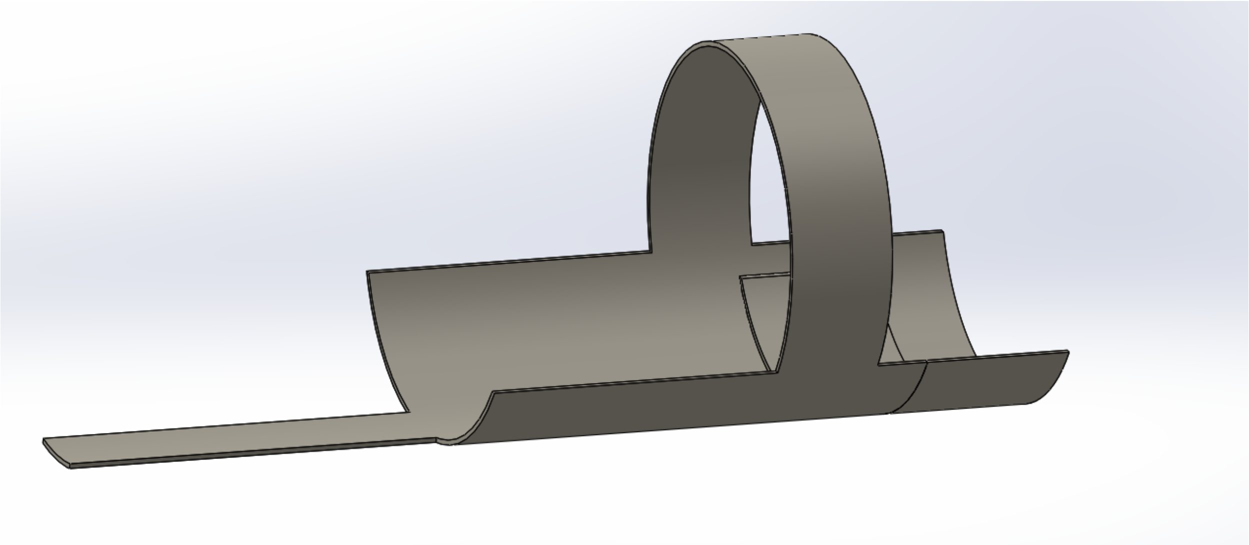


Figure 4.1.2: Tray from Deployment Section

4.2. Rover Construction

4.2.1. Material Choices

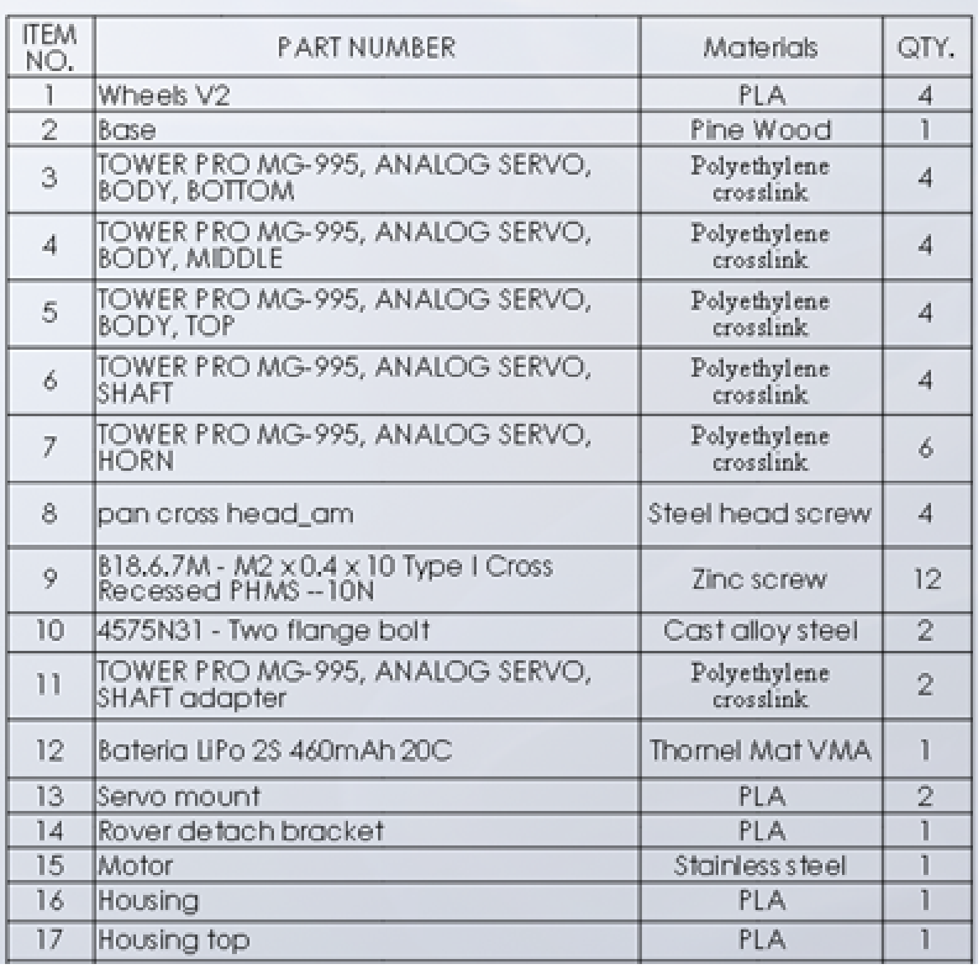
PLA plastic was an appropriate choice of material, given its general rigidity and strength to assist in sustaining forces and torsions during flight. It is also creep resistant, thus preventing deformations and alterations to its shape and proportions, and has dimensional stability even during high temperatures, which is necessary given the high potential temperature of a rocket during flight. Because the rover, theoretically, would run after the rocket's landing, its functionality and mechanical properties must be maintained. Thus, its shock resistant character is also vital to the rover's ultimate material choice.

Most parts are manufactured using 3D printing, predominantly with materials as PLA plastic and polyethylene crosslink via resin print. The wheels are specifically made using ABS plastic, because the polybutadiene rubber property of the material, along with the extruded dimples of the part will allow for more movement when the rover is faced with a rough and nonuniform terrain. The base is constructed using pine wood because of its lightweight and sturdy nature, which would allow for more degrees of freedom for the rover, since the weight of the supporting base will be trivial. Because the main purpose of the base is to hold and serve as an attaching hub for other vital parts of the rover, the weightless attribute is necessary. It is also somewhat malleable and flexible in its structure. As a result, this would be ideal for instigating interference fit, if necessary, to be better connected to the bearings. The tower pro MG-995 analog servo parts, consisting of the body (bottom, middle, and top), shaft, horn, and shaft adapter, are made from polyethylene crosslink, which provides high tensile strength. Thus, it would not be easily deformed when succumbed to the pressure during the flight. Its crosslinking makes for a more robust material ideal for compression under flight forces.

Two of the screws used for the rover assembly are the B18.6.7M - M2 x 0.4 x 10 Type I Cross Recessed PHMS--10N flathead machine screw, which is made from zinc coated steel, and the pan cross head screw, which is made from carbon steel. These fasteners are useful in assembly, as they can be easily screwed in and out during the assembly. Their metallic nature, however, could potentially invoke more vibration in the system compared to nonmetallic and plastic materials. To account for this fact, thread-locking fluid was added to the threads, in order to prevent the screws from becoming unfastened during the flight.

The two-flange bolt ball bearings are crucial in joining together the wheels to the base of the rover assembly. Thus, cast alloy steel was used to withstand high tensile in the rocket, as it is necessary in binding and holding together the assembly. The Bateria lithium polymer battery is used to power the rover, and offers a higher energy-source compared to other lithium battery packs. It is more lightweight and contains a rigid metal case that can prevent the battery itself from getting deformed from the pressure in flight.

Table 4.2.1 Bill of Materials of the Rover Assembly



ITEM NO.	PART NUMBER	Materials	QTY.
1	Wheels V2	PLA	4
2	Base	Pine Wood	1
3	TOWER PRO MG-995, ANALOG SERVO, BODY, BOTTOM	Polyethylene crosslink	4
4	TOWER PRO MG-995, ANALOG SERVO, BODY, MIDDLE	Polyethylene crosslink	4
5	TOWER PRO MG-995, ANALOG SERVO, BODY, TOP	Polyethylene crosslink	4
6	TOWER PRO MG-995, ANALOG SERVO, SHAFT	Polyethylene crosslink	4
7	TOWER PRO MG-995, ANALOG SERVO, HORN	Polyethylene crosslink	6
8	pan cross head_am	Steel head screw	4
9	B18.6.7M - M2 x 0.4 x 10 Type I Cross Recessed PHMS --10N	Zinc screw	12
10	4575N31 - Two flange bolt	Cast alloy steel	2
11	TOWER PRO MG-995, ANALOG SERVO, SHAFT adapter	Polyethylene crosslink	2
12	Bateria LiPo 2S 460mAh 20C	Thornel Mat VMA	1
13	Servo mount	PLA	2
14	Rover detach bracket	PLA	1
15	Motor	Stainless steel	1
16	Housing	PLA	1
17	Housing top	PLA	1

4.2.2. Manufacturing Process

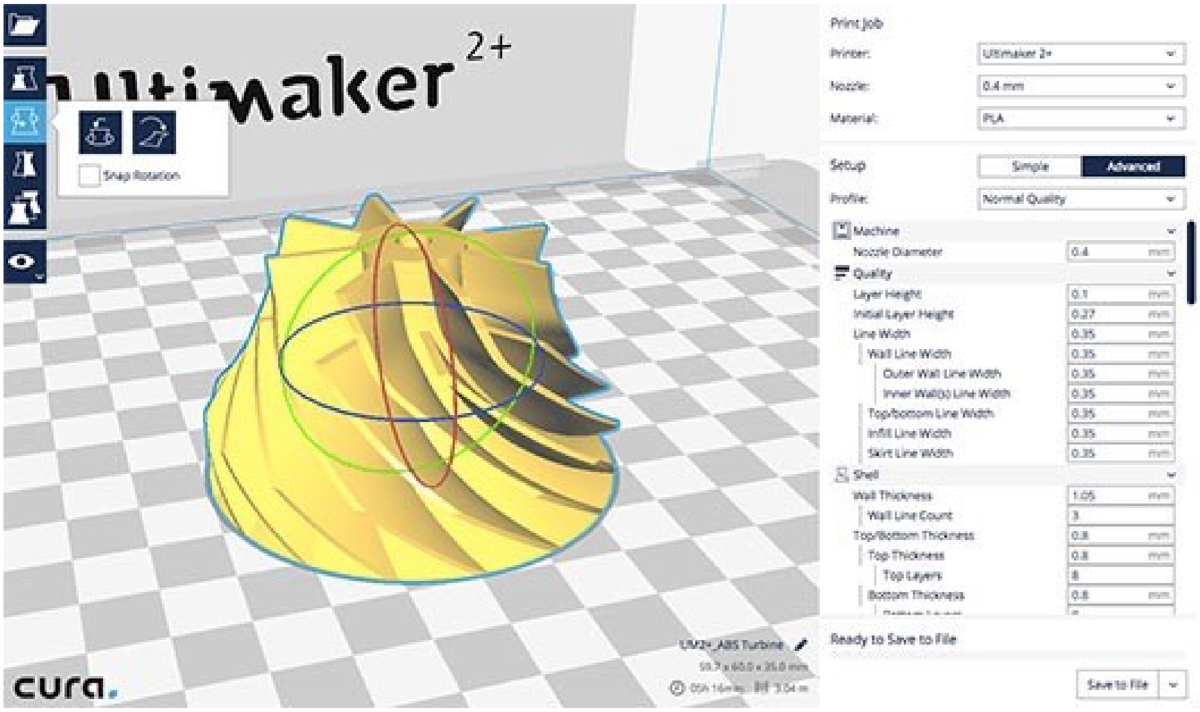
Since most of the parts for the rover were 3D printed, the rover was mainly manufactured at the Invention Studio (a makerspace under the department of Mechanical Engineering). Since

ABS had a tendency to warp during a print if the heat is not properly maintained the decision was made to use Polylactic acid (PLA). PLA is a biodegradable filament that is more brittle and less heat resistant than ABS. Although ABS seems like the best choice in terms of material selection the consistency of PLA prints outweighed the worse material properties. The 3D printer used to print the parts were Ultimaker 2+, which is known for its reliability and ease of use interface. An Ultimaker 2+ uses fused deposition modeling (FDM) to manufacture a part. This process is done by heating a heating block while filament is extruded through a nozzle and then deposited onto a build plate. The heat that is transferred to the nozzle as the printer is running helps the filament stay hot enough to fuse with the previous layer. In order to set up a print, the part was designed in Solidworks and converted to a stereolithography (STL) file. This file format is a conversion of a three dimensional part into a mesh of triangles with varying size and angles. The greater the number of triangles there are in the mesh the higher quality the print is.

Figure 4.2.1: Line of Ultimaker 2+ printers from the Invention Studio

The software that generates the machine code that dictates the movement of the nozzle in relation to the build plate (slicer) used was Cura. Cura reads the STL files and generates g code that the Ultimaker 2+ understands to produce the final manufactured part. The g code is read by the motherboard of the Ultimaker and signals are sent to the corresponding stepper motors that drive belts that the printer head is attached to. For a n Ultimaker 2+, the printer head moves about the x - and y - axes. The build plate is attached to a lead screw that rotates for z - axis motion.

Several aspects of the print were changed in Cura depending on the application the part. For a more a part with a tighter tolerance, lowering the print speed as well as decreasing the layer height help to achieve a much smoother part finish. The only downside is it significantly increased print time. In order to make a more durable part the diameter of the exit of the nozzle was increased so a thicker strand of filament is deposited.



Print Job
Printer: Ultimaker 2+
Nozzle: 0.4 mm
Material: PLA
Setup: Advanced
Profile: Normal Quality
Machine
Nozzle Diameter 0.4 mm
Quality
Layer Height 0.1 mm
Initial Layer Height 0.27 mm
Line Width 0.35 mm
Wall Line Width 0.35 mm
Outer Wall Line Width 0.35 mm
Inner Wall(s) Line Width 0.35 mm
Top/bottom Line Width 0.35 mm
Infill Line Width 0.35 mm
Skirt Line Width 0.35 mm
Shell
Wall Thickness 1.05 mm
Wall Line Count 3
Top/Bottom Thickness 0.8 mm
Top Thickness 0.8 mm
Top Layers 8
Bottom Thickness 0.8 mm
Ready to Save to File

Figure 4.2.2: Screenshot of Cura in use

For smaller parts that require precision and accuracy, Formlab Form 2 was used to manufacture them. Unlike Ultimaker 2+, Form 2 uses stereolithography (SLA) manufacturing to 3D print, where a laser shines onto and solidifies photosensitive liquid resin within each layer.

The process, like that of a FDM printer, utilizes STL files and g code is generated to determine the speed, angle and duration of the laser. SLA printers print upside down compared to FDM printers and thus burn in layers are required to ensure that the part does not fall in to the tray of resin as it prints. The main difficulty with SLA printers is figuring out the timing for the burn in layers. If the timing is off the print would fail before it actually started printing the part. If the part was successful in printing then the part would be removed from them build plate and is washed in 90% Isopropyl alcohol for five minutes then rinsed in water for another five minutes. After that, the part would be dried and fully cured under a UV lamp. This machine required that nitrile gloves are worn when handling the have resin on it since it carcinogenic.

Figure 4.2.3: Formlabs Form 2 print station

The last tool used for manufacturing the rover was the laser cutter. It was used to cut the base that would hold all the components of the rover. The software for the laser cutter reads Drawing Exchange Format (DXF) files. These files can be produced from a simple drawing of a two dimensional object or is extracted from one side of a three dimensional part. The third dimension of the part is determined by the thickness of the material that is cut. Engraving gives the ability of altering the dimension of the z-axis.

Figure 4.2.4: Preparation of the laser cutter

4.2.3. Procedures and Safety Concerns

Min Personnel Requirements: 2 people

Materials:

- PLA plastic wheels
- Pine wood support plate
- Tower Pro MG-995, Analog Servo (top, middle, bottom)
- Two-bolt flange mounted ball bearing
- Tower Pro MG-995, Analog Servo shaft
- Tower Pro MG-995, Analog Servo horn
- Bateria LiPo battery
- Servo mount (top,bottom)
- Rover detach brackets

- Motor
- Housing (bottom)
- Housing (top)
- Control board

Safety Equipment Required: N/A

Procedure:

1. Assembling the wheels system
    a. Take one two-bolt flange mounted ball bearing, and in the extruded, cylindrical portion, fit the tower Pro MG-995 Analog Servo shaft inside the hole.
    b. Attach the tower Pro MG-995 Analog Servo horn's wider opening to the exposed part of the Pro MG-995 Analog Servo shaft after its assembly
    c. Attach the thin, extruded part of the interior of the wheels to the horn
    d. Take the pine wood support plate and fit the bearing around the plate in such a way that the larger holes all align with each other
    e. Bolt the flange to the plate using pan-cross head screws
    f. Repeat steps a-d for the opposite side of the plate
    g. Repeat steps b-c for future steps

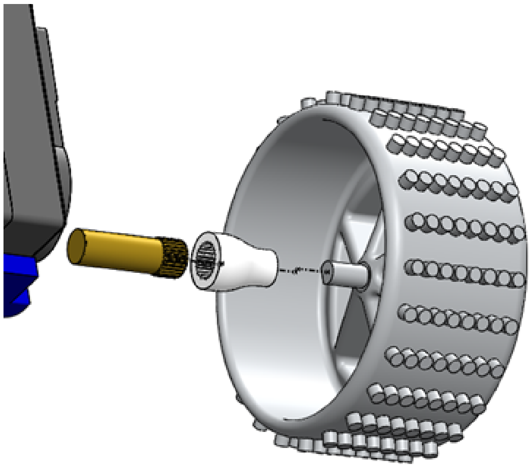


Figure 4.2.5: Exploded view of the construction of the wheels

2. Assembling the motor housing onto the plate
    a. Take the motor and fit it through the larger hole between the two bearings

    b. Attach this motor to the back lower housing, such that the shelled area should be facing away from the plate
    c. Attach the extruded portion of the top housing to the hole of the lower housing
3. Add the Bateria LiPo battery on the support plate, which should be opposite the side of the motor housings
4. On the same side of the motor housings, add the control board in such a way that each hole should align with those of the support plate
    a. Stabilize the assembly using B18.6.7M – M2x0.4x10 Type I Cross Recessed zinc screws
5. Take the bottom servo mount and align the holes to those of the support plate
    a. Stabilize the assembly using B18.6.7M – M2x0.4x10 Type I Cross Recessed zinc screws
6. Assembling the Tower Pro MG-995
    a. Take the tower Pro MG-995 Analog Servo top and take the assembly from Step 1 Part g and attach them together in a way that the shaft fits in the tower Pro MG-995 Analog Servo top
    b. Fit the tower Pro MG-995 Analog Servo top assembly to the edge of the bottom servo mount
    c. Attach the middle tower Pro MG-995 Analog Servo to the top
    d. Align the holes of the bottom tower Pro MG-995 Analog Servo to those in the middle tower Pro MG-995 Analog Servo and screw them together using B18.6.7M – M2x0.4x10 Type I Cross Recessed zinc screws
    e. Repeat steps a-d for the opposite and mirrored side of the rover
    f. Replace the top servo mount and attach it to the bottom servo mount
    g. Bolt together the two servo mounts to the plate (all holes should be aligned)
7. Attach the rover detach bracket in the center of the top servo mount, such that the two should be parallel to the servo mount and side of the LiPo battery

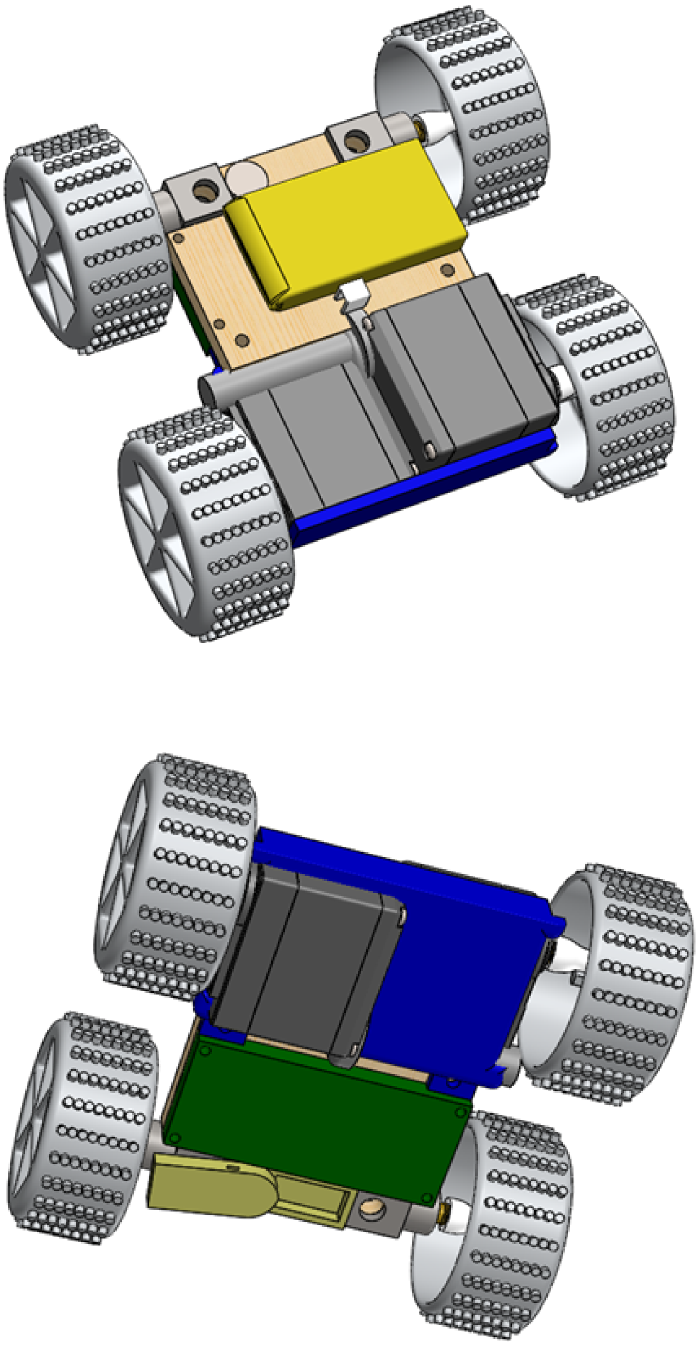


Figure 4.2.6: Final assemblies of the rover subsystem

4.2.4. Difficulties Faced

The biggest difficulty that was faced was printing in ABS. Since Ultimakers do not com with the enclosure needed to print in ABS, all prints came out warped. This lead to the decision to start printing in PLA instead. Some parts required a tight tolerance in order to function properly. In even the print speed was lowered and the layer height decreased some parts like then servo horns would not seat properly. In order to fix this the Form 2 was used for its better resolution. Although this finish quality allowed for the parts to fit the resin prints proved to be more fragile.

4.3. Rover Deployment Construction

4.3.1. Material Choices

The fasteners in the rover deployment assembly, which consists of the lead nut and lead screw, 0.25-20 screws, 0.25-20 nuts, standoffs, 2.5mm screw, 4-40 screw (0.75), 4-40 nut, 4-40 screw short, 4-40 screw (1.25), 2.5mm nut, and the uncoated Grade 8 steel nylon-insert locknut, are made predominantly of metal. As aforementioned in the section on the rover assembly's choice of materials, vibration can potentially lead to screws unfastening, though this was resolved through thread-locking fluids. Because the rover deployment assembly should be sturdy, as it is the main structure that holds the rover assembly in place, nuts were further used in order to make it more durable by binding the object between the head of the screw and the nut. This would ensure critical contraptions will not fall apart during flight, in which excessive forces will be applied to the parts. Extreme forces will, especially, be applied to the rover rail brackets, as indicated by the Finite Element Analysis (FEA) produced by SolidWorks, as it has a large surface area that can be impacted by torsion. Similarly, only one face is fixed, to the main rocket assembly, leading to a destabilized assembly, though this is remedied by the support plate. As a result of the forces, ABS plastic was used to produce the rover rail brackets, because ABS is generally a tough material that can withstand the pressure and forces acted on the part itself.

Another reason for the usage of ABS is due to its ability to bond when applying epoxy. ABS is an ideal material when used to link ABS objects and epoxy to other objects.

Corrugated paper is used to construct the tray, as it would provide more adhesion when bonding the rover rail brackets to the rocket. As the surface area connecting to the rocket assembly is miniscule, a more grainy and rough material should be used in order to provide more traction and friction in the system versus a smooth, somewhat-frictionless surface like steel, so the brackets will not become detached, which would prove detrimental to the rover's deployment, as it would render the rover rails inoperable. For the same reasons, the corrugated paper's large surface area would allow for more adhesion to the rocket itself, which would assist in the stability of the whole deployment system. Like the tray, the tray extension and tray patch utilize corrugated paper to increase traction in the system to greaten the resistance to the forces and torsion.

The two structures that help guide the rails of the system are the carriage and the worm motor brackets. Both are constructed with ABS plastic, which is necessary in ensuring a stable overall assembly, as the rover rails and guide rails deviate from this alignment. Its sturdy nature helps with the stabilizing aspect.

The threaded rods, cut to length from aluminum rods, are used to increase the rover deployment system's stability. We used threaded rods versus smooth rods to increase adhesive friction provided by the ridges and threads. Because the threaded rods give more stability to the support plate, and in connecting the worm gear motor to the carriage, the rods are crucial in maintaining the intended structure. In regard to the material of the rod, aluminum would be ideal as it is lightweight yet rigid and long-lasting. Though it is somewhat malleable and flexible, it runs parallel to the upwards direction of the flight, so the forces would have less impact on the small circular surface area of the rod. Similarly, the threads can assist in preventing extreme deformation. Despite this concern, a bent threaded rod would not severely limit the rover deployment assembly's capacity.

Given its light nature, aluminum was used to fabricate multiple parts of the assembly. The two guide rails are similarly made from quarter-inch aluminum rods to provide stability of the support plate, as well as for the connection between the worm motor bracket and the carriage.

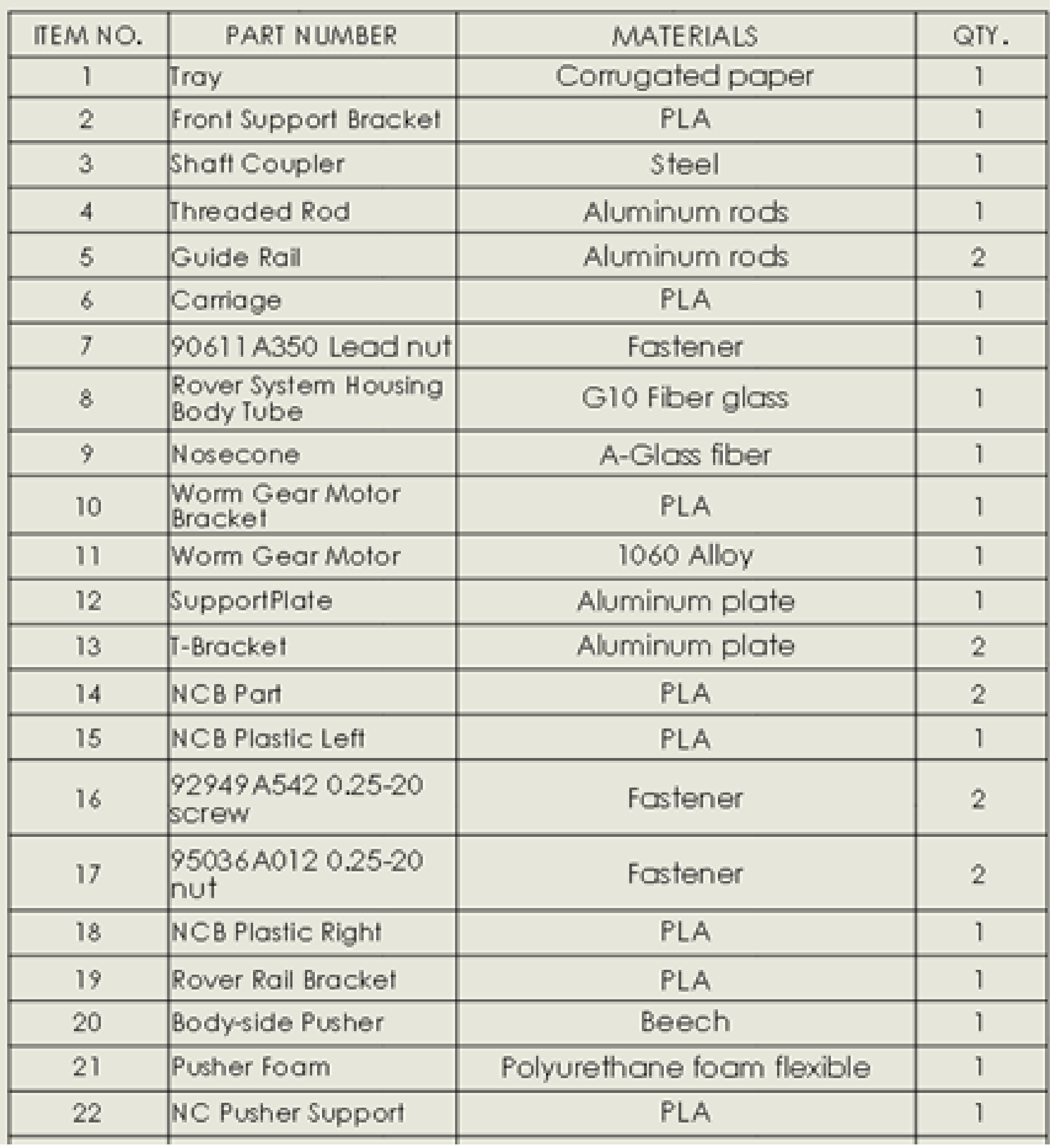
Similarly, the support plate and T-brackets are manufactured by using the waterjet on aluminum plates. Being a large structure that holds the assembly together, being lightweight and less bulky would be necessary to lessen the weight of the rocket. Because the plate's center of mass is located in the lower end of the rocket, when held horizontally, it would shift the weight drastically should it be an alternative material. Thus, aluminum was chosen for the support plate. The T-bracket is also made from the same material. The two T-brackets are placed in polarized sides from the support plate to add stability to the assembly. The aluminum lightweight properties don't add much weight in such a way that would distort the location of the center of mass.

As for the worm gear motor bracket, which holds another electronic bay for the rover, it is made from PLA plastic, which as mentioned before, is very sturdy and can withstand high pressure. Thus, in using PLA, it could house and protect another part of the system, the worm gear motor, which is made from 1060 aluminum alloy. The alloy is evidently more fragile compared to PLA and could sustain more deformities from forces, as it has relatively low strength compared to plastic and other materials used in the assembly.

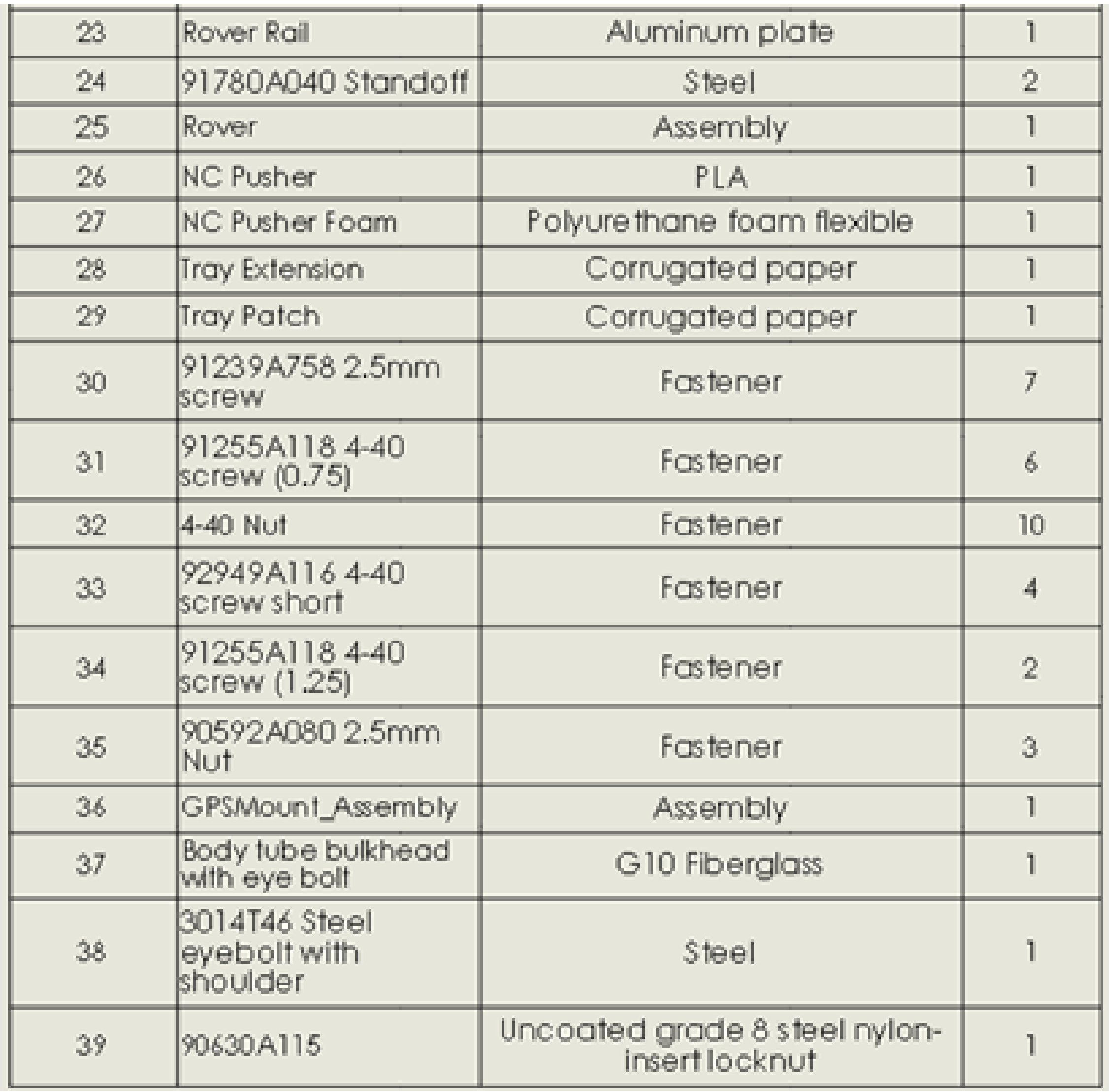
Supporting parts such as the front support bracket, nose cone brackets (NCB) parts, and both the nose cone (NC) pusher and support provides more stability, especially being that it is made from PLA plastic. As it is not as flexible, it would generate a more reliable method in maintaining the assembly's structure and firmness. The nose cone pushers in the rover deployment utilize a softer material. It is made from flexible polyurethane foam to provide a support against the pressure and force succumbed by the rover and rover deployment system during extreme stages of flight, such as the ignition and thrust phase, and during when the initial parachute is ejected. It cushions the assemblies from being forced into an otherwise rigid surface. The body side pusher uses beech wood, which is extremely hard and grainy. Though the surface is tough, it is shock and wear-resistant, which makes it ideal for providing support and lessening impact.

The rover housing body tube is made from G10 fiberglass. It is durable even during high temperatures and weather changes. Thus, it would be apt in preventing deformities and wear to the rover and rover deployment assemblies.

Table 4.3.1 Bill of Materials of the Rover Deployment Assembly



ITEM NO.	PART NUMBER	MATERIALS	QTY.
1	Tray	Corrugated paper	1
2	Front Support Bracket	PLA	1
3	Shaft Coupler	Steel	1
4	Threaded Rod	Aluminum rods	1
5	Guide Rail	Aluminum rods	2
6	Carriage	PLA	1
7	90611A350 Lead nut	Fastener	1
8	Rover System Housing Body Tube	G10 Fiber glass	1
9	Nosecone	A-Glass fiber	1
10	Worm Gear Motor Bracket	PLA	1
11	Worm Gear Motor	1060 Alloy	1
12	SupportPlate	Aluminum plate	1
13	T-Bracket	Aluminum plate	2
14	NCB Part	PLA	2
15	NCB Plastic Left	PLA	1
16	92949A542 0.25-20 screw	Fastener	2
17	95036A012 0.25-20 nut	Fastener	2
18	NCB Plastic Right	PLA	1
19	Rover Rail Bracket	PLA	1
20	Body-side Pusher	Beech	1
21	Pusher Foam	Polyurethane foam flexible	1
22	NC Pusher Support	PLA	1



23	Rover Rail	Aluminum plate	1
24	91780A040 Standoff	Steel	2
25	Rover	Assembly	1
26	NC Pusher	PLA	1
27	NC Pusher Foam	Polyurethane foam flexible	1
28	Tray Extension	Corrugated paper	1
29	Tray Patch	Corrugated paper	1
30	91239A758 2.5mm screw	Fastener	7
31	91255A118 4-40 screw (0.75)	Fastener	6
32	4-40 Nut	Fastener	10
33	92949A116 4-40 screw short	Fastener	4
34	91255A118 4-40 screw (1.25)	Fastener	2
35	90592A080 2.5mm Nut	Fastener	3
36	GPSMount_Assembly	Assembly	1
37	Body tube bulkhead with eye bolt	G10 Fiberglass	1
38	3014T46 Steel eyebolt with shoulder	Steel	1
39	90630A115	Uncoated grade 8 steel nylon-insert locknut	1

4.3.2. Manufacturing Process

All of the parts for the rover deployment were manufactured using either water jetting machines, laser cutting machines, or by 3D printing. In the figure below, all of the parts in *green*, such as the carriage, or the motor bracket, were manufactured using 3D printing.

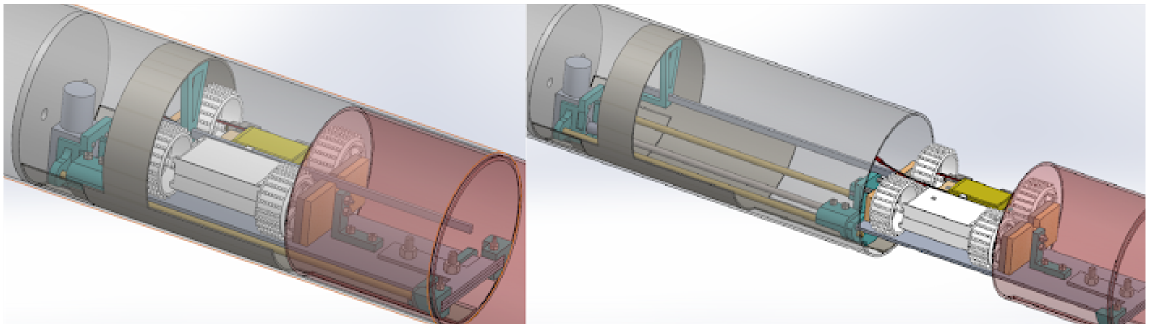


Figure 4.3.1: SolidWorks view of rover deployment system.

Additionally, the guide rails and threaded rod, along with the aluminum nose cone bracket (the T-plate on the bottom right of both pictures) and support plate were manufactured using water jetting. Lastly, the nose cone pusher and body pushers were manufactured with laser cutting, using quarter inch plywood.

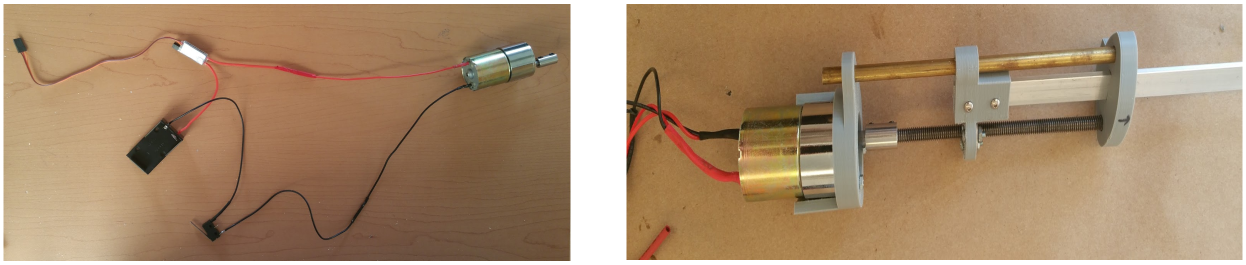


Figure 4.3.2: Motor construction and assembly.

The motor for the rover deployment system is shown above. This system consists of a motor connected to the motor bracket, which is subsequently connected to the threaded rod and one of the guide rails. Also shown in the right picture is the support plate, which freely slides through the front support bracket and carriage to let the rover deploy. For rover deployment, these manufactured parts were puth together with different sized nuts and bolts, and put inside the rover bay tube, as shown below. The only parts actually glued (epoxied) to the tube are the motor mount and the front support bracket. The whole point of the rover deployment system is to allow ease of motion to let the rover out, so having freely sliding parts, such as the guide rails and support plate are essential in this regard.

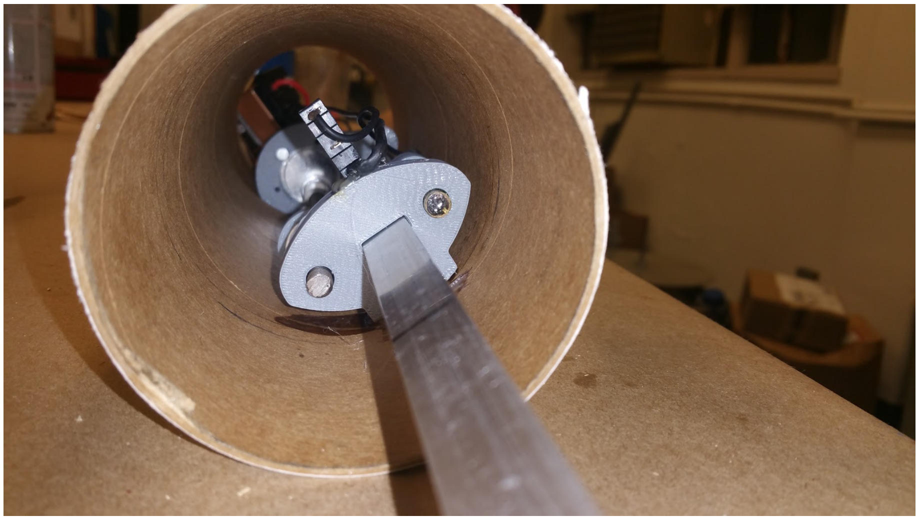


Figure 4.3.3 Inside view of rover deployment system.

4.3.3. Procedures and Safety Concerns

Minimum Personnel Requirement: 2

Materials:

- Rover Rail Bracket
- Rover Rail
- Threaded Rod
- NC Pusher
- Pusher Foam/Wood
- Rover Bay Tube
- Nose Cone Bracket
- Deployment Motor
- Motor Bracket
- Guide Rails
- Carriage
- Support Plate
- Front Support Bracket

Safety Equipment Required: N/A

Procedure:

1. Motor System
    a. Attach motor bracket to deployment motor
    b. Insert the two guide rails into the motor bracket holes
    c. Insert threaded rod into the middle hole of the motor system
    d. Attack rover rail bracket to motor bracket
    e. Slide in rover rail through the rover rail bracket, making sure that it extends through approximately the same length as the guide rails
2. Support Plate System
    a. Screw in nose cone bracket into support plate, from both sides, with screws going in bottom side up
    b. Screw in L-bracket into support plate from the bottom, and NC pusher foam and wood from the side
    c. Slide in front support bracket into roughly the middle of the support plate
    d. Screw in carriage in the front of the support plate, making sure that the rectangular part faces upward
    e. Connect pusher foam and wood to the carriage from the top
3. Combining Support Plate System with Motor System
    a. Slide guide rails through the carriage *and* the front support bracket
    b. Slide threaded rod through front support bracket
4. Connecting Rover Deployment to Rocket
    a. Epoxy both the front support bracket and the base of the motor mount to the rover bay tube such that the front support bracket is ¾ in. from the front of the tube.

4.3.4. Difficulties Faced

We faced a lot of difficulties trying to epoxy the motor system to the rover bay tube. The reason for this is that the tube is fairly small in diameter, and to successfully epoxy the motor system, we had to be absolutely sure that we didn't get any epoxy on the wires themselves, *only* the base of the motor. In addition, from the small diameter of the bay, it was extremely hard to even put your hands in there, and with gluing the basis of the whole motor deployment system, precision is needed. Another difficulty was trying to figure out the exact positioning of where to put the deployment system when epoxying to the tube. Since the guide rails can freely move once connected to the support plate system, we had to be sure that while they were epoxied, they would remain in place. Other than that, there were not really other problems faced in the rover deployment construction.

4.4. Rover Electronics

4.4.1. Rover Control System

The rover control system hardware provides a platform for control software to run on. The system must also interfaces the microprocessor that controls rover function with the servos that drive the rover and the stepper motor that deploys the solar panels. At the center of the system is the ATMEGA8 microprocessor unit. This unit is the same as the unit used in the arduino UNO, which was a large factor in the choice of the unit; its widespread use has given the avionics team an ample amount of resources to use while designing a board around the microprocessor. There are many components on the control board that are used only by the microprocessor to achieve normal function. A few of the key components in this area are the 16 MHz oscillator, the 5V regulator, and the reset circuit. The 16 MHz oscillator functions as a clock for the microprocessor, which is needed to function. The 5V regulator brings the 7.4V input voltage from the battery down to 5V, which is the value required by the ATMEGA8. The reset circuit allows for a hard reset of the microprocessor by the touch of a button. This will be important if anything malfunctions during testing of the rover control board.

Outside of the microprocessor, there are a few other components that interface the control board with rover hardware. First, the bootloading board attached to the top of the control board is used for programming the ATMEGA8 after it has been installed on the board. This programming is done through a simple serial connection. Second, there is a stepper motor driver attached to the top of the control board that will take signals from the microprocessor and drive the stepper motor to deploy the solar panels accordingly. The connection between the stepper driver and the stepper motor is facilitated through male headers on the control board. Third, there are two sets of three pin holes for connecting the female servo connection to the male pin headers that will be inserted in the board. The specific board layout and wire connections for all components are located in figure 4.4.1 and 4.4.2.

One additional provision that is worthy of note is the connection between the rover control subsystem and the rover deployment subsystem. In order to release the rover without hitting the rocket fuselage, it is vital that the rover receive a signal when it is clear of the fuselage. The solution to this problem is simple: there will be a single wire connected from GND to a digital port on the microprocessor. This wire will also be attached within the rover deployment system in such a way that the wire is pulled loose from the rover when it clears the fuselage. When the wire is pulled loose, the rover control board will receive that signal and a logic loop will alert the next step of the process: moving the rover forward.

Although it was originally planned to use the custom board for controlling the rover after deployment, it has since been decided that the use of an arduino nano board is more optimal for control of the rover. The primary reason for this change was difficulty in bootloading the ATMEGA8 chip, which requires a complicated setup and an AVR programmer which we do not have access to. To increase reliability, the pre-boot loaded arduino nano board will be attached to the same I/O devices originally planned for use in the rover control system. This microcontroller change will not change the function or layout of the rover control system, as the custom rover control board was essentially just an arduino nano with the board components explicitly defined. Although these planned changes will simplify the rover subsystem, they were never completed due to issues in the prerequisite rover deployment system. The team plans on implementing the changes to the rover control board after the competition launch; for experience in electronics implementation and design. However, we will not be launching or deploying the rover during competition flight, as we couldn’t prove that the system would function correctly during flight.

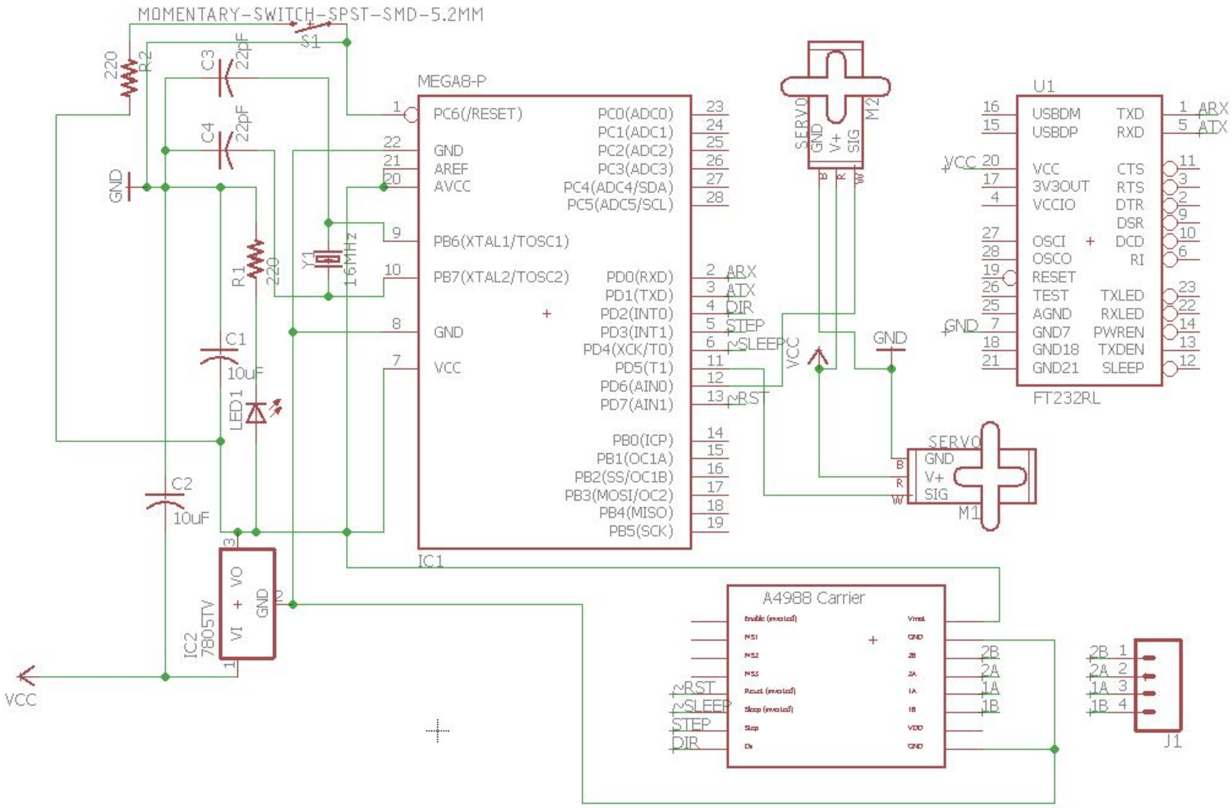


Figure 4.4.1 Rover Control Board Schematic

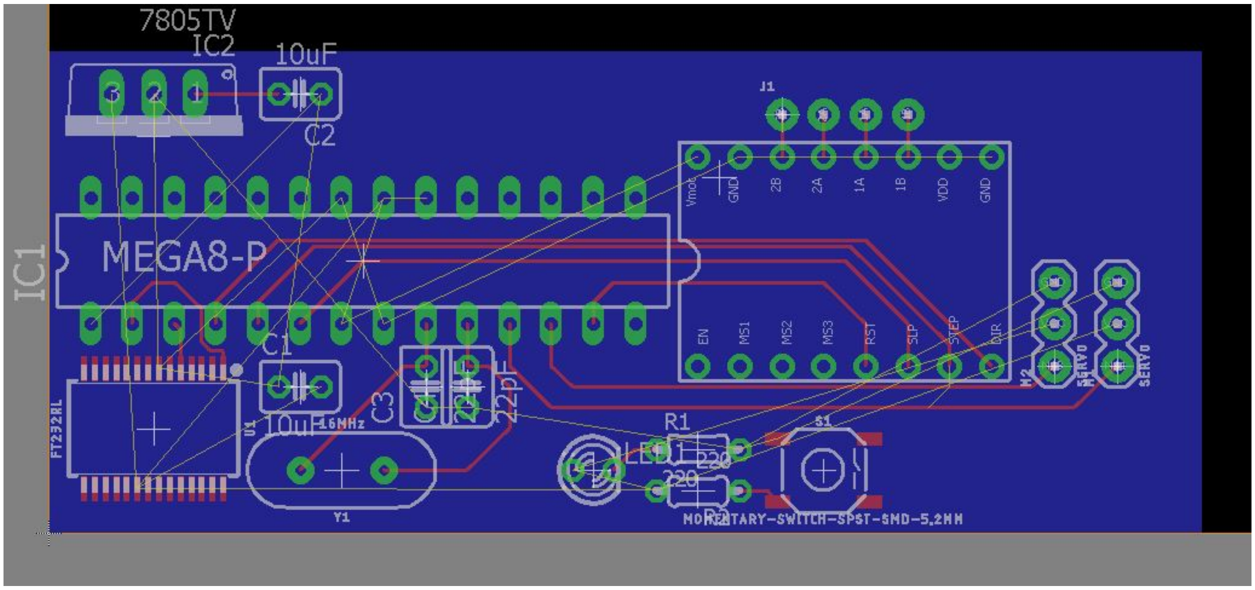


Figure 4.4.2 Rover Control Board Layout

There were a few key components in the Rover subsystem to consider when choosing the correct battery. Because the team chose servos for the drive system of the rover and a small stepper motor for the solar panel deployment, the spike in current draw while these systems are operating is not a major concern, given that all LiPo batteries in consideration by the team had greater than 30A peak current discharge rating. The main points of consideration for the battery, then, were capacity, voltage, and size. Given that both the servos and stepper motor run off of a 5V source, the team decided to go with a commonly available 7.4V battery (2 cells). A 5V regulator will be used to drop the voltage to 5V for all components on the rover. To determine minimum capacity requirements, it was necessary to find/calculate current draw for all rover components and estimate the total time that each component will be active for. These values can be found in the table below. The overall capacity required turned out to be relatively low at a value of 251 mAh, so a 430 mAh battery was chosen to add a safety threshold. The size constraint of the battery was determined by the rover cad, and the Venom Fly 30C 2S 430mAh 7.4V LiPo Battery fit this and all other constraints, and was therefore the best choice of battery.

Table 4.4.1 Capacity Draw Matrix

Component Name	Current Draw	Total Time Active	Capacity Draw
Left Drive Servo	500 mA	0.008 Hours	4 mAh
Right Drive Servo	500 mA	0.008 Hours	4 mAh
Rover Control Board	120 mA	2 Hours	240 mAh
Stepper Motor	1000 mA	.003 Hours	3 mAh
			Total: 251 mAh

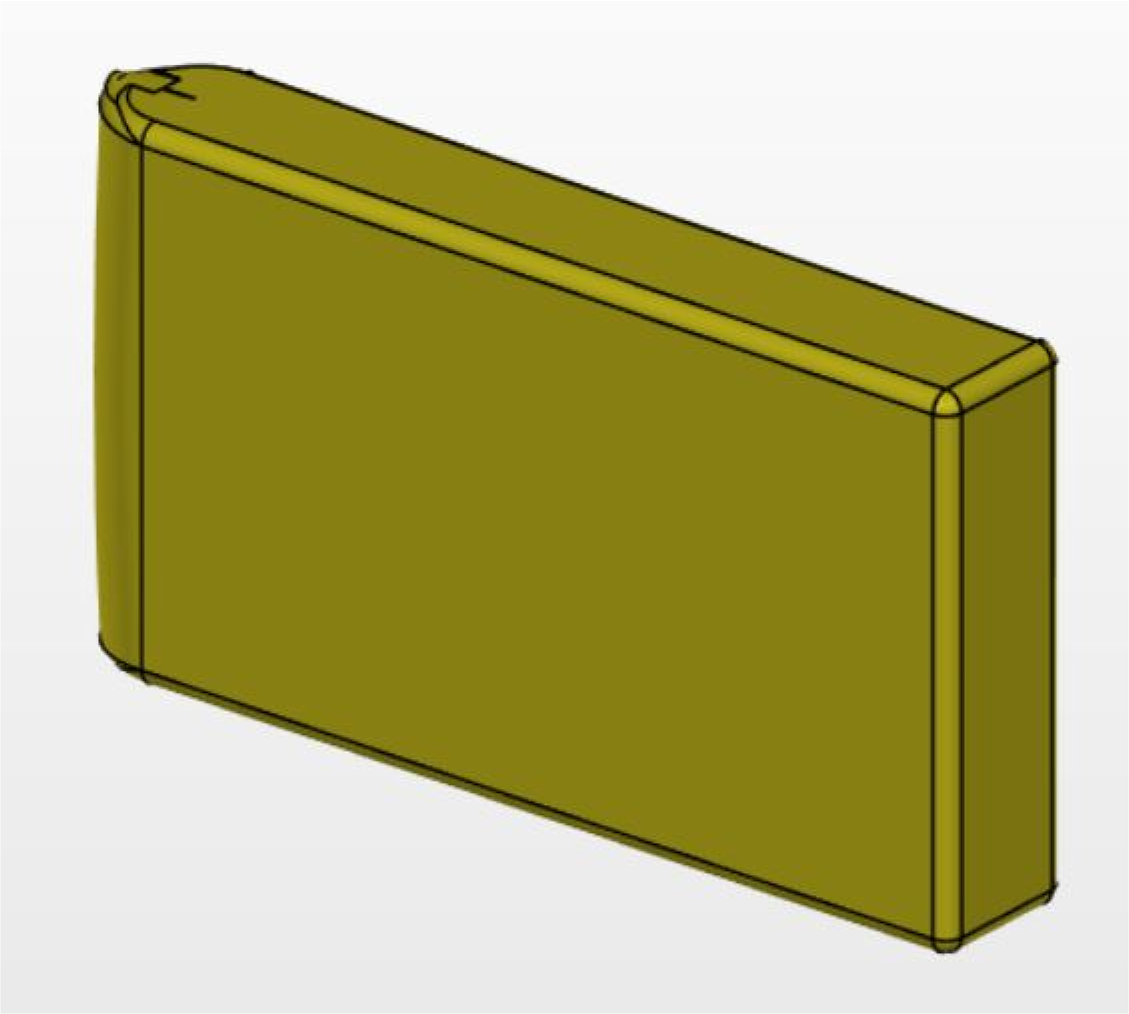


Figure 4.4.3. Battery CAD

4.4.2. Rover Deployment System

The rover deployment system has a primary purpose of moving the rover to a point where it can easily exit the rocket's fuselage. The specific details of the deployment system hardware are discussed in the hardware section of the rover subsystem description, but a brief overview of the system is necessary for a complete understanding of the electronics that drive the system. Essentially, the rover deployment system is just a motor that drives a lead screw. This lead screw pushes the nose cone off of the top of the rocket and moves the rover, which is attached to the lead screw, out of the rocket so that it can drive forward and complete its ultimate goal. The electronics that drive this system are relatively simple, and consist of a radio transmitter, receiver, battery, motor, 2 receiver-controlled-switches, and limit switch. A block diagram of the deployment system's function is outlined in 4.4.5 below. The battery is connected through the receiver controlled switch which is then connected through the motor, a limit switch and finally back to the battery. When a switch is flipped on the transmitter, the receiver controlled switch closes (by means of a signal from the receiver), thus allowing current to flow through the motor. This drives the lead screw. When the motor drives nose cone off of the rocket, the carriage that holds the rover makes contact with the limit switch, which opens the circuit. This stops current flow to the motor and prevents the motor from damaging rocket hardware. There is an additional mesh that consists of a second battery connected to a receiver controlled switch that then connects to the motor leads in an inverted manner. This circuit is not used in launch, and is merely to close the rover deployment system, as the motor is relatively inaccessible after installation in the rocket. A circuit diagram of the system can be found on Figure 4.4.4.

The avionics and rover subteams took precaution in selecting ideal components for each task necessary for successful deployment of the rover. The transmitter and receiver pair used for triggering the rover subsystem has multiple free channels, allowing multiple signals to be sent to the rover after landing. The avionics subteam discussed using a transistor to control current flow with the transmitter, but eventually chose the receiver controlled switch due to its ability to allow large amounts of current flow through the circuit. The receiver controlled switch is also less fragile than a transistor, as it is a system packaged onto a PCB. This type of robustness would have been difficult to achieve with a transistor; solder joints are liable to break, while the connections on a PCB are more permanent.

The motor was selected by the rover subteam, and met the necessary torque requirement to drive the rover and nose cone out of the rocket from a theoretical standpoint. In practice, this motor needed more current than originally expected and was not able to drive the nose cone out of the body tube using our original battery selection: a 9V battery. This issue warranted a battery change, to a 11.1V LiPo battery. Even with this battery, however, the system had great difficulty actuating, leading to our failed deployment during test flight, and our eventual elimination of the functional rover system from competition launch.

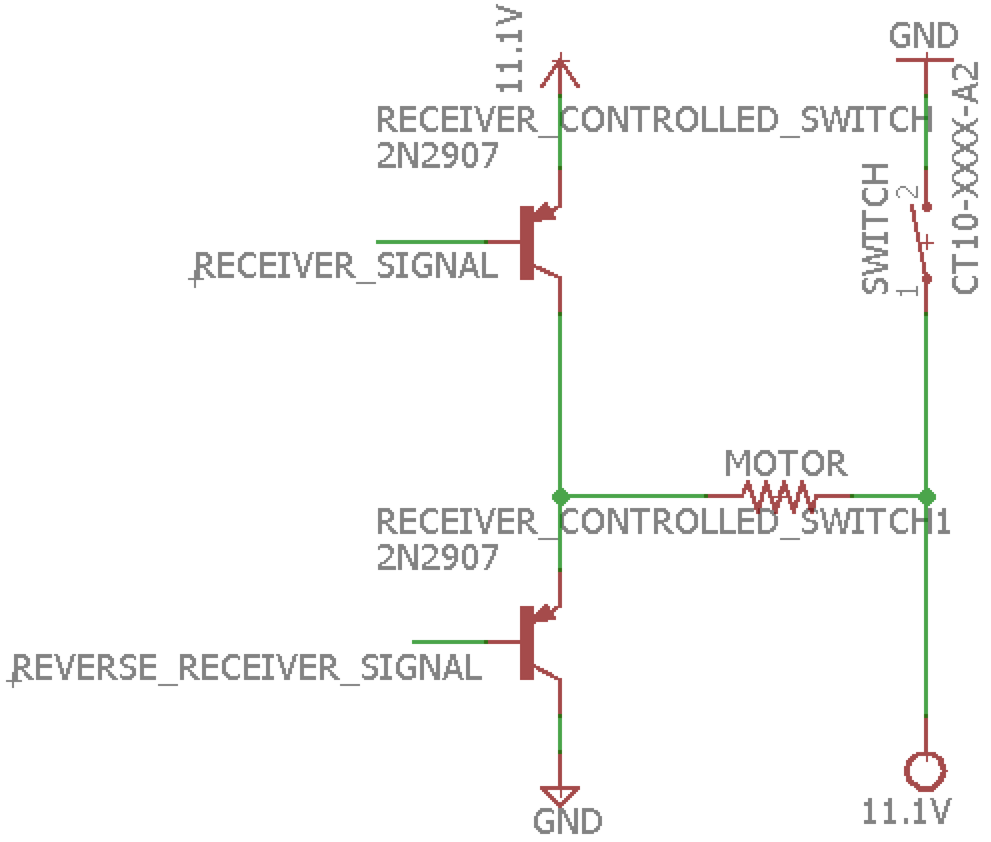


Figure 4.4.4 Rover Deployment Circuit Diagram

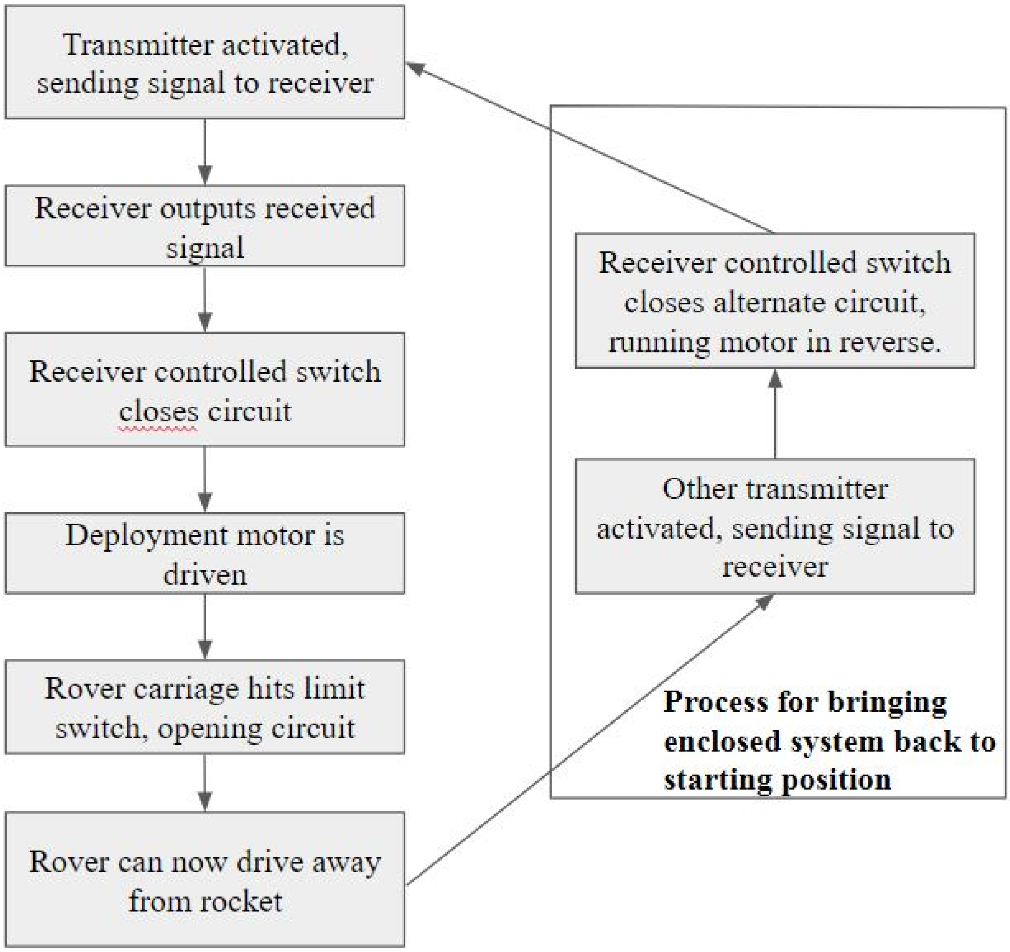


Figure 4.4.5. Rover Deployment Electronics Block Diagram

4.5. Rover Software

Because the rover control system consists of an ATMEGA8 microcontroller for processing data, the final choice of programming language was Arduino, which is built specifically to run on this microcontroller. The avionics team chose this language after discussing a few alternatives, namely, C++ and C. The choice became simple when we searched for libraries available for each of these languages. While libraries exist for C and C++, these languages are more commonly used in industrial settings. As a result, many of the libraries we might use are closed-source. Arduino is a language built on open-source principles, and is not widely used in industrial settings, so it was easy to find and implement libraries for servo control and ultrasonic sensor usage.

Given the small size of the avionics team, it was extremely important that we eliminate some of the low-level programming so that we could focus on the big picture: controlling the rover's function. The rover has the primary functions of driving forward at least 6 feet and subsequently deploying solar panels. The servos are controlled by a simple PWM square wave sent through a single signal wire. The ATMEGA8 is capable of sending this type of signal. The distance travelled is controlled by a stoppage of the drive servos after a given time threshold is reached. This duration of time is calculated based on preliminary testing of the rover. After the time threshold is reached, the stepper motor will begin turning, causing the solar panels to deploy. This turning motion will be a result of short digital pulses sent to the stepper motor driver from the ATMEGA8 microcontroller. On deployment, the solar panels will begin charging the battery that drives the rover.

Much of the source code is shown in snapshots below, and can also be found at the following GitHub link: https://github.com/atrimper/roverControl. Also shown below is a high-level overview of the flow of control of the rover code.

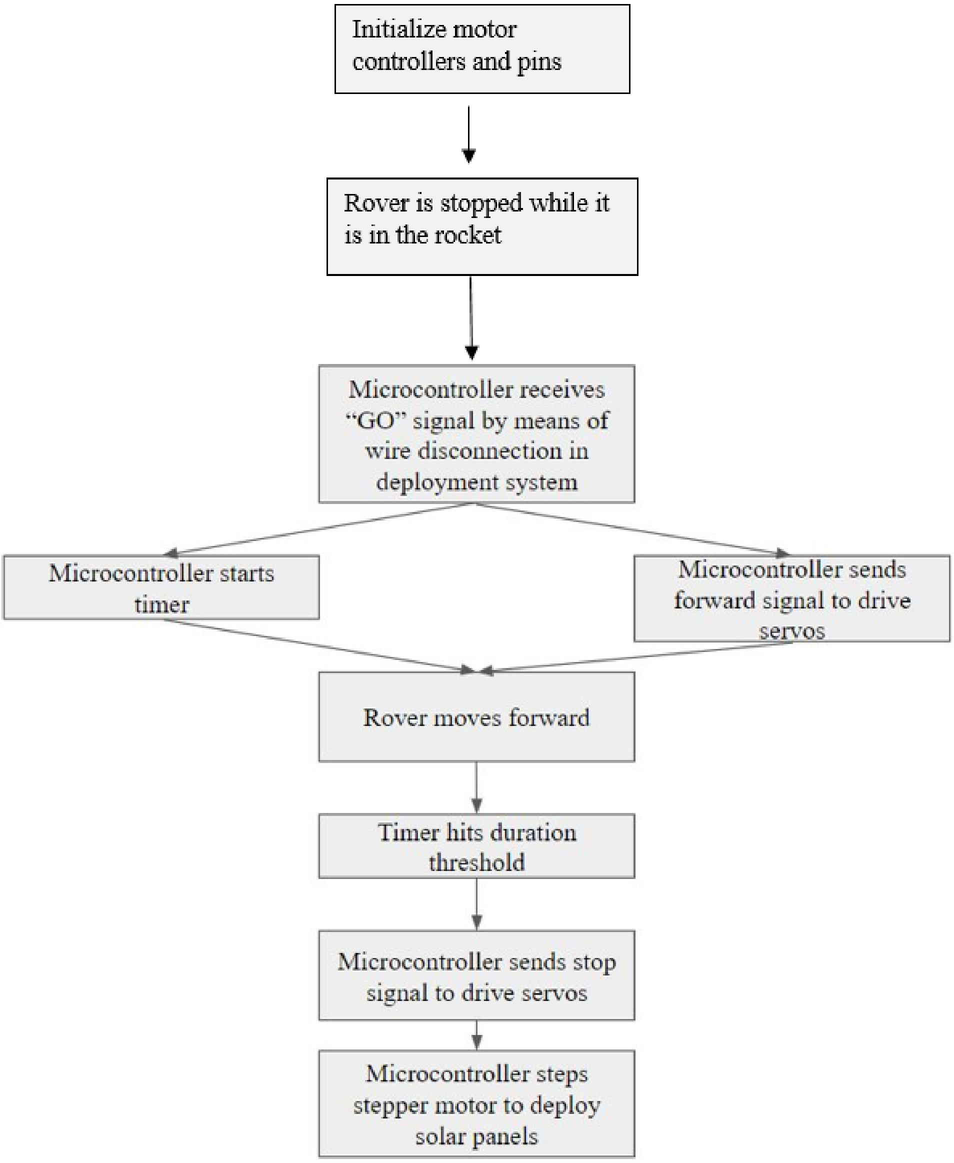
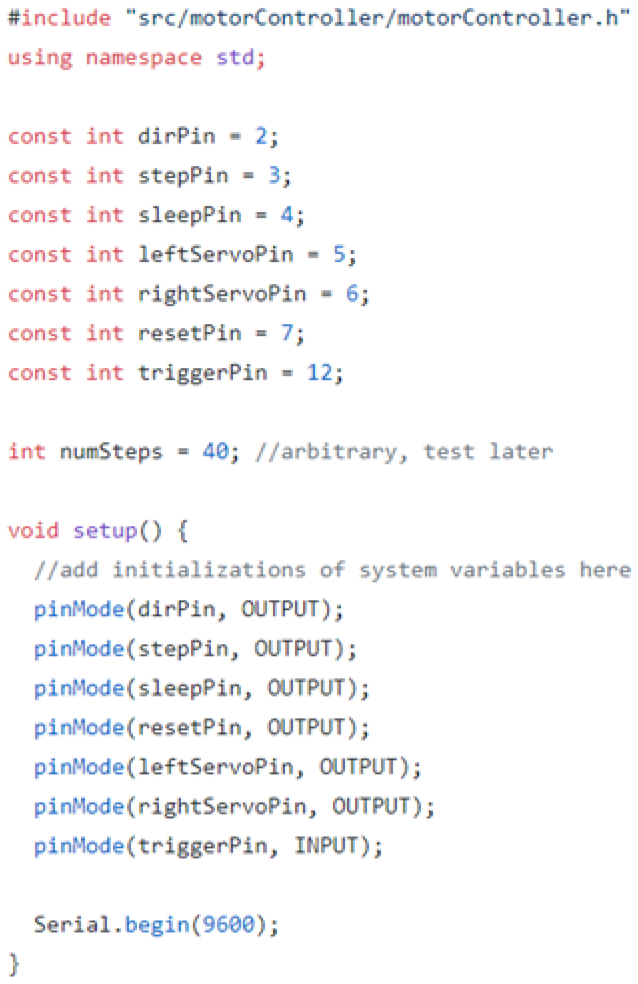


Figure 4.5.1. Flow of Control of Rover Code



```
#include "src/motorController/motorController.h"
using namespace std;

const int dirPin = 2;
const int stepPin = 3;
const int sleepPin = 4;
const int leftServoPin = 5;
const int rightServoPin = 6;
const int resetPin = 7;
const int triggerPin = 12;

int numSteps = 40; //arbitrary, test later

void setup() {
  //add initializations of system variables here
  pinMode(dirPin, OUTPUT);
  pinMode(stepPin, OUTPUT);
  pinMode(sleepPin, OUTPUT);
  pinMode(resetPin, OUTPUT);
  pinMode(leftServoPin, OUTPUT);
  pinMode(rightServoPin, OUTPUT);
  pinMode(triggerPin, INPUT);

  Serial.begin(9600);
}
```

```
void loop() {
  //most of the implementation for rover will be in libraries

  MotorController leftMotor(leftServoPin); //initialize left and right motor controller objects
  MotorController rightMotor(rightServoPin);

  while(1){
    leftMotor.drive(0.0); //stop the rover while it is in the rocket
    rightMotor.drive(0.0);
    if(digitalRead(triggerPin) == LOW){ //when the trigger wire is pulled away...
      break; //break out of the loop
    }
  }

  while(timer < driveTime){
    leftMotor.drive(1.0); //drive at full power while the timer has not expired
    rightMotor.drive(1.0);
  }

  leftMotor.drive(0.0); //stop the rover once the timer has expired
  rightMotor.drive(0.0);

  //extend solar panels
  for(int i = 0; i < numSteps; i++){
    digitalWrite(dirPin, HIGH);
    digitalWrite(sleepPin, HIGH);
    digitalWrite(resetPin, HIGH);
    if((i % 2) == 0){
      digitalWrite(stepPin, HIGH);
    } else {
      digitalWrite(stepPin, LOW);
    }
    delay(20);
  }
}
```

```
#ifndef ENCODER_H
#define ENCODER_H

#include "Arduino.h"
using namespace std;

class Encoder{
                private:
                        int currentTotalSteps;
                        int lastStepNum;
                        int currentStepNum
                        int port;
                        int getCurrentStepNum();
                public:
                        Encoder();
                        Encoder(int);
                        //implementations in Encoder.cpp
                        double getDistance(); //probably return in feet
                        double getRate(); //probably return something from -1 to 1
}

#endif
```

```
#include "MotorController.h"
#include "Arduino.h"
using namespace std;

//function implementations for MotorController go here
//single argument constructor will:
//create MotorController with a given signal port number
//driveMotor will:
//-Take in a speed from -1 to 1 and convert that into a PWM pulse
//-Send PWM pulse to motor controller to acheive desired speed

MotorController::MotorController(int signalPin) : port(signalPin) {  }

MotorController::drive(double driveVelocity){
        convertedVelocity = (driveVelocity + 1) * 127;
        analogWrite(port, convertedVelocity);
}
```

Figure 4.5.2. Snapshots of Rover Code

4.6. Rover Conclusion

Overall, although all individual components have been manufactured for both the rover and rover deployment, a lack of time prior to the full scale test launch prevented the team from fully assembling and testing these systems. Therefore, the rover and rover deployment system will both be placed in the rocket in an inactive configuration for the competition launch for mass purposes. As the system will not be active, and the mass will be in the correct location, the flight of the rocket will not be affected, as seen by the successful FRR test flight. However, the team still plans on finishing the assembly and testing of these systems for use in a competition-independent test launch.

5. Payload Criteria - ATS

5.1. Changes since CDR

The ATS system has undergone few changes since the CDR. One of the major change is the dimension of the flap. It had to be changed because the flap could not be fully retracted due to the screw on the side of the center rotary coupler. All the dimensions for flap except the length are the same; the length was reduced to 1.65 inches from 1.9 inches. One other change is the shape and size of nylon guide due to manufacturing complication. At the point of CDR, the method of manufacturing was not finalized; when the nylon glide was 3d printed, the surface of a nylon guide was not smooth enough that it could reduce the friction. So it was manufactured using waterjet. However, since the nylon plate, which was used to make nylon guides was flat, it was very hard to make the curved surface, therefore, the the shape of the guide was changed to rectangle. Also due to manufacturing tolerances, all the parts were sanded before assembly.

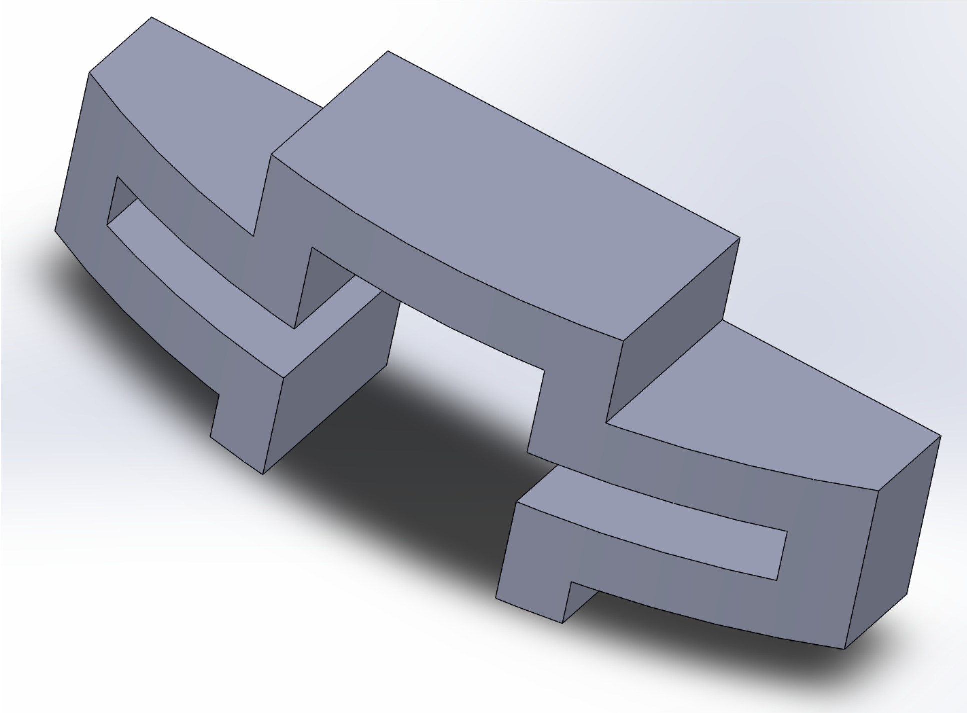


Figure 5.1.1 Design of Nylon Guide in CDR

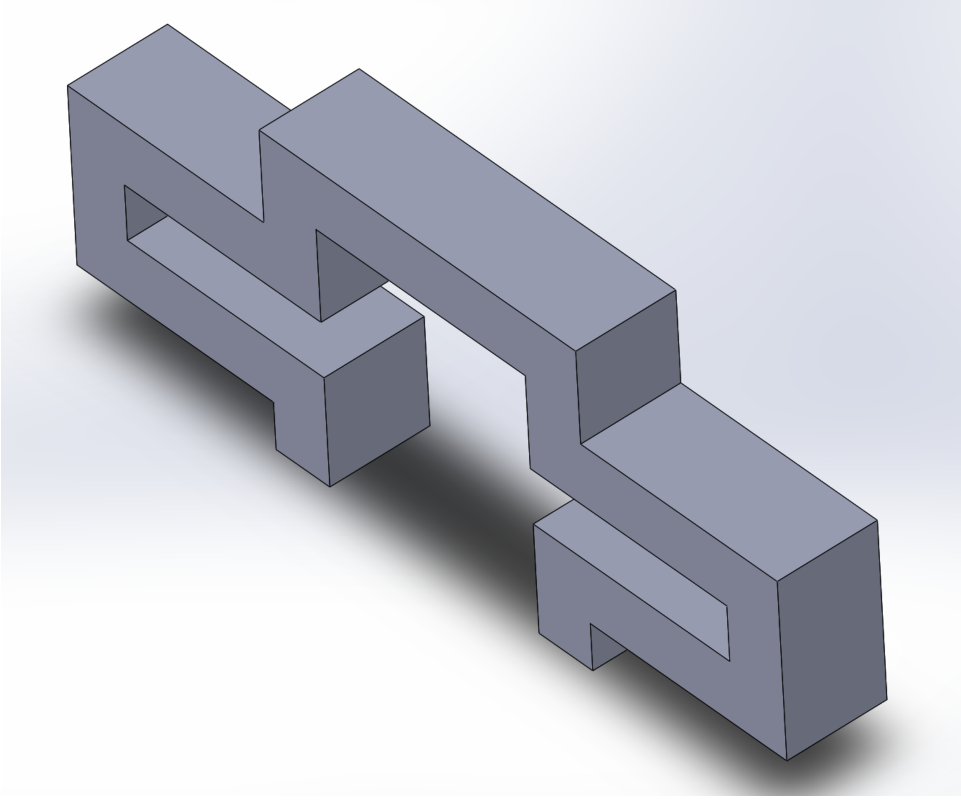


Figure 5.1.2 Final Design of Nylon Guide.

Although they are included in the sections below, the I2C devices (the voltage and airspeed sensors) were not ready for the test flight despite being tested separately on the ground; thus they will not be included in our final competition launch but are documented regardless.

Since the telemetry system was neither constructed nor tested and thus removed from the design, ATS components that would have transmitted data from the pi to the transmitter have been discarded.

5.2. Features of ATS

5.2.1. Mechanical Feature of ATS

There is no change in the mechanism of fully constructed ATS as there was no significant design change. The ATS system consists of a housing that contains a four-armed mechanism that uses a stepper-motor to shift four flaps between a fully retracted, halfway, and fully extended state. The three stages of deployment will be used to minimize or maximize drag in the first and final configuration, and the middle configuration will be used to create moderate drag to control the apogee of the rocket as it is being approached.

5.2.2. Electrical Feature of ATS

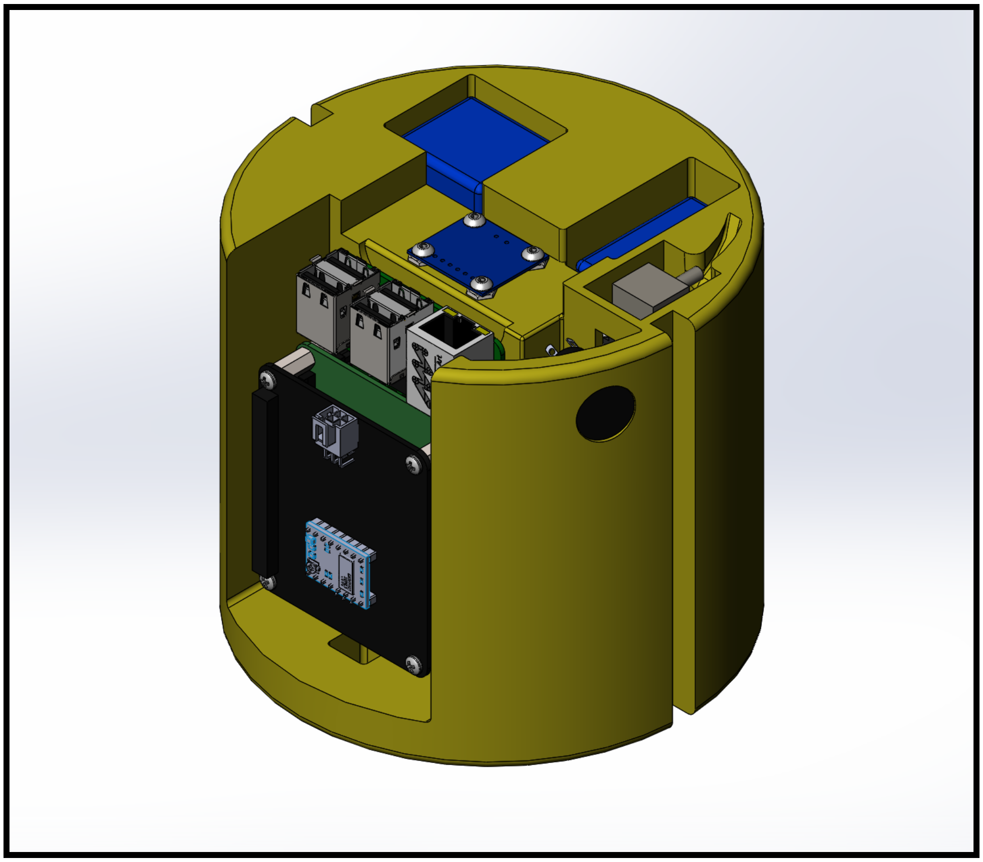


Figure 5.2.1 ATS Section Avionics Assembly Isometric View

There are ten primary components housed within the ATS section: one rotary switch, one UBEC power supply, one Raspberry Pi, one raspberry pi sensor hat, one radio transceiver, one airspeed sensor, one stepper motor driver, two lithium polymer batteries, and one battery voltage monitor. These components are all held within a 3d printed housing, in order to preserve the center of gravity of the rocket. A CAD assembly of the housing is shown above. The rails on the side of the housing will be used to prevent the assembly from rotating. The rails will interact with four 4-40 lock nuts to prevent rotation.

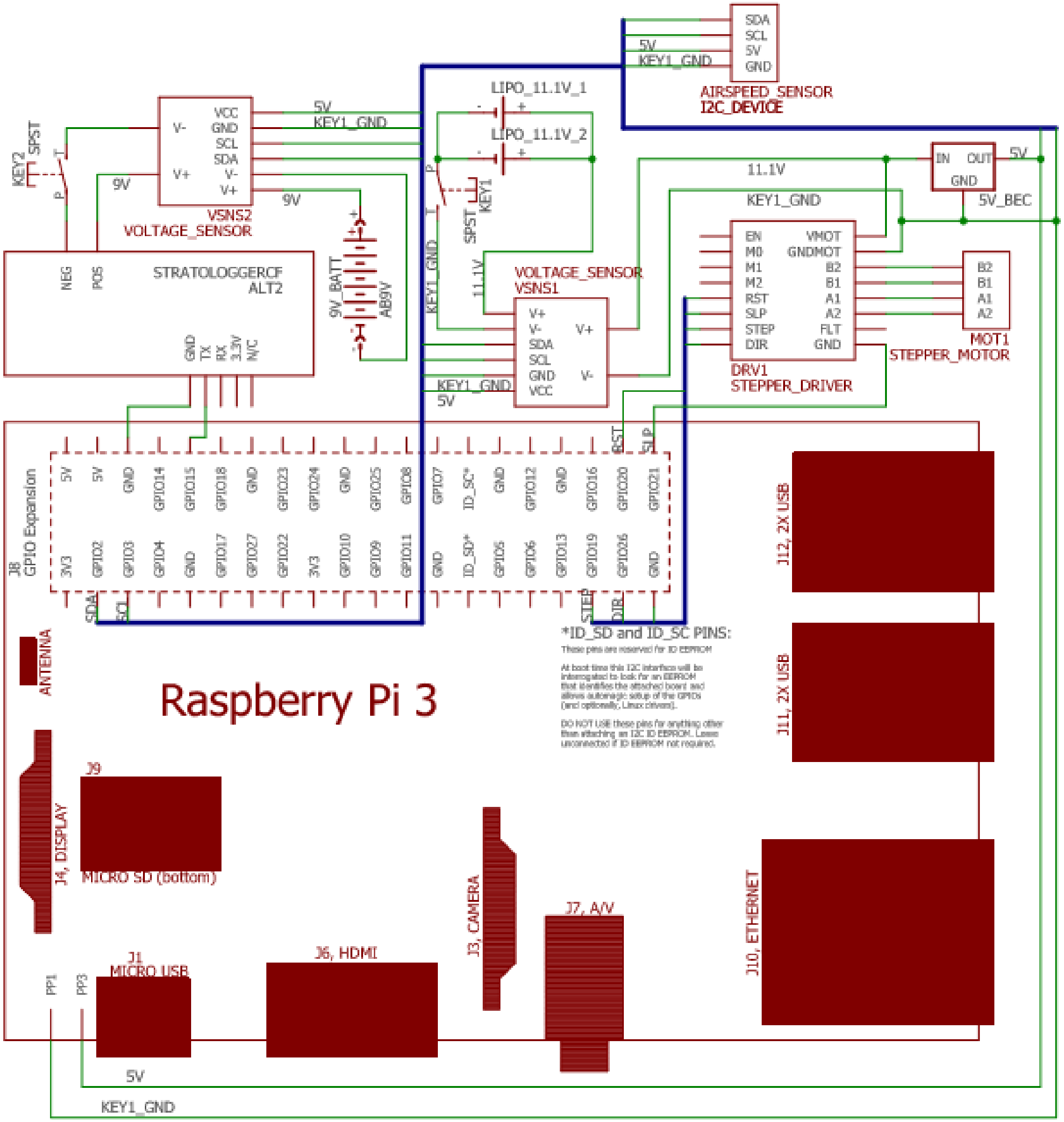


Figure. 5.2.2 ATS Circuit Schematic

ATS circuit was built based on this circuit schematic. This circuit allows Raspberry Pi to receive the data from air speed sensor to determine whether ATS needs to be actuated and send signals to the stepper motor driver. The final circuit is electrically equivalent. However, to increase the integrity of the circuit, protoboard is used.

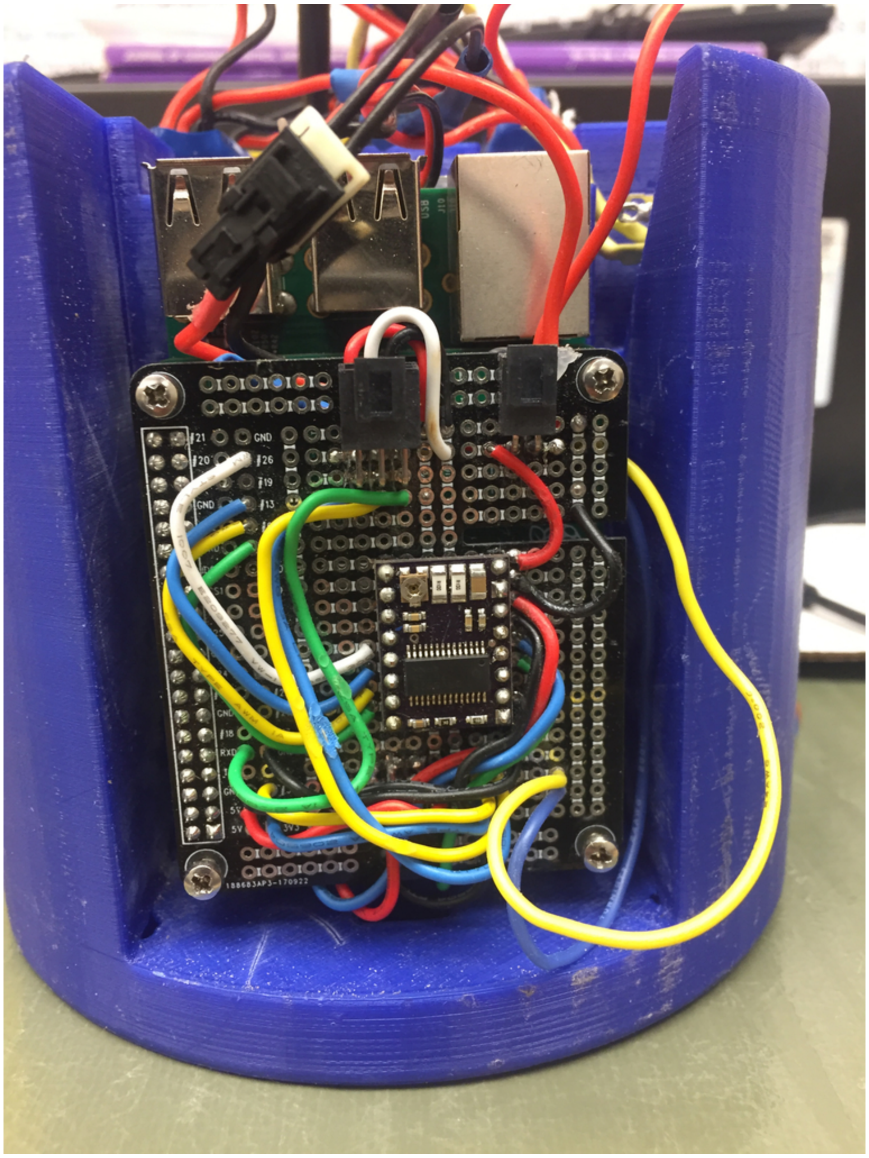
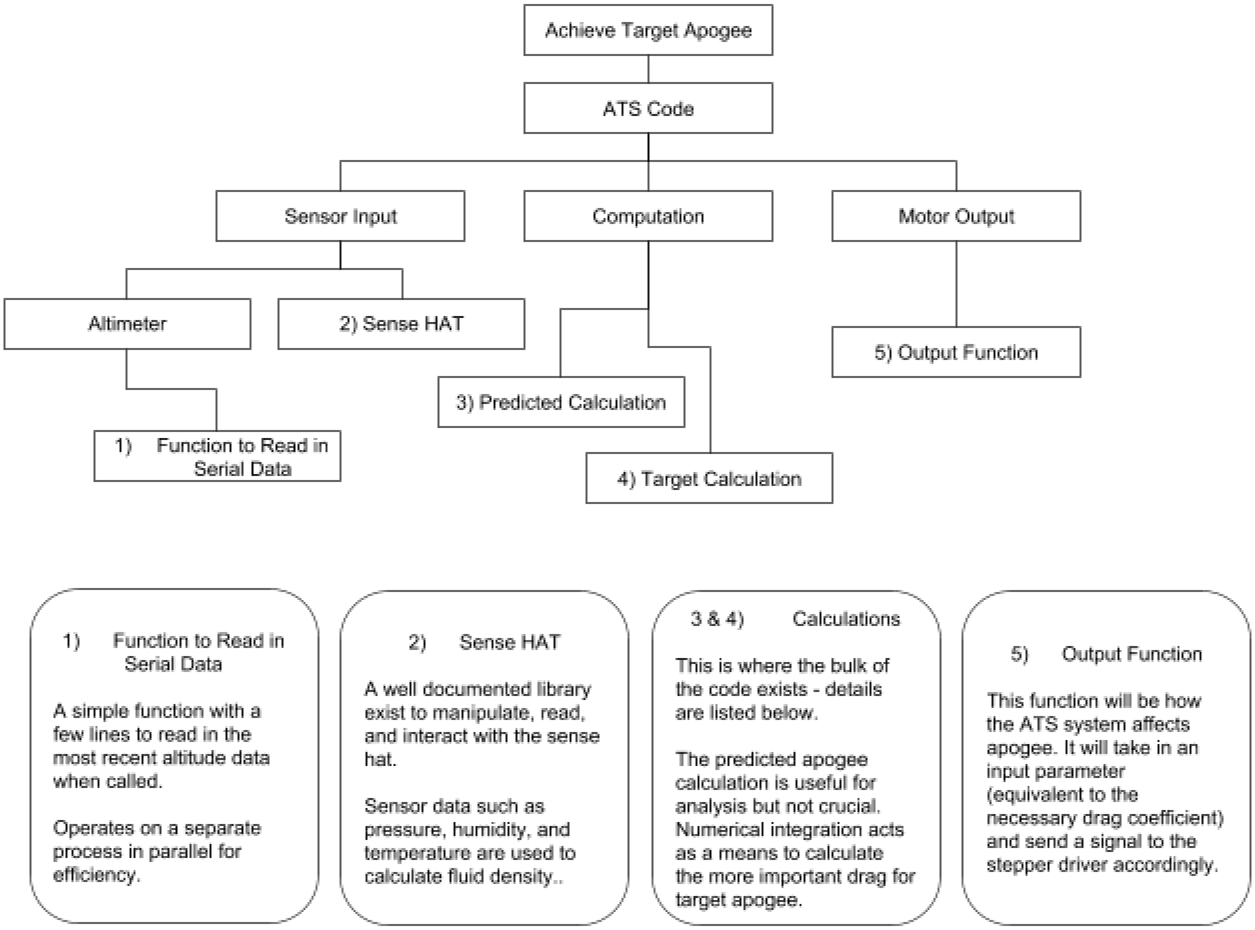


Figure 5.2.3 ATS Circuit for Full Scale Flight

5.2.3. Software Features of ATS

Few if any software changes were made to ATS between CDR and now. The plan to add another process in parallel dedicated to telemetry has been dismissed since telemetry is not included. Minor optimizations in the method for altitude and accelerometer checks for burnout detection were made, and the addition of a event log file outputted from the calculation process that records time of actuation and connections/shutdowns was included.



1) Function to Read in Serial Data

A simple function with a few lines to read in the most recent altitude data when called.

Operates on a separate process in parallel for efficiency.

2) Sense HAT

A well documented library exist to manipulate, read, and interact with the sense hat.

Sensor data such as pressure, humidity, and temperature are used to calculate fluid density..

3 & 4) Calculations

This is where the bulk of the code exists - details are listed below.

The predicted apogee calculation is useful for analysis but not crucial. Numerical integration acts as a means to calculate the more important drag for target apogee.

5) Output Function

This function will be how the ATS system affects apogee. It will take in an input parameter (equivalent to the necessary drag coefficient) and send a signal to the stepper driver accordingly.

Figure 5.2.4 ATS Software Function Tree

Sensory data will be sent to the microcontroller from the altimeter and Sense HAT. While the altimeter data is most important for apogee calculations, gyroscopic and accelerometer data from the Sense HAT will also be used to predict apogee, in addition to climate data used to determine air density. Altitude and accelerometer data are also used to detect burnout to ensure the ATS does not actuate while the motor is still active. All sensory data input will be logged during flight for post-flight analysis by the team. This will be done in parallel on the quad-core CPU on the Raspberry Pi 3 to prevent negative impact on the apogee calculations.

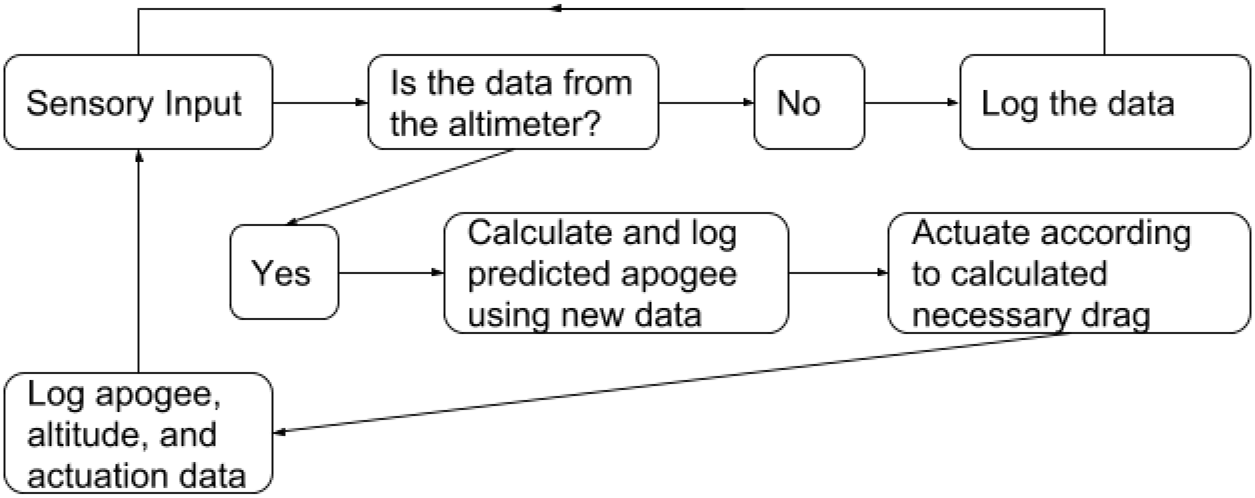
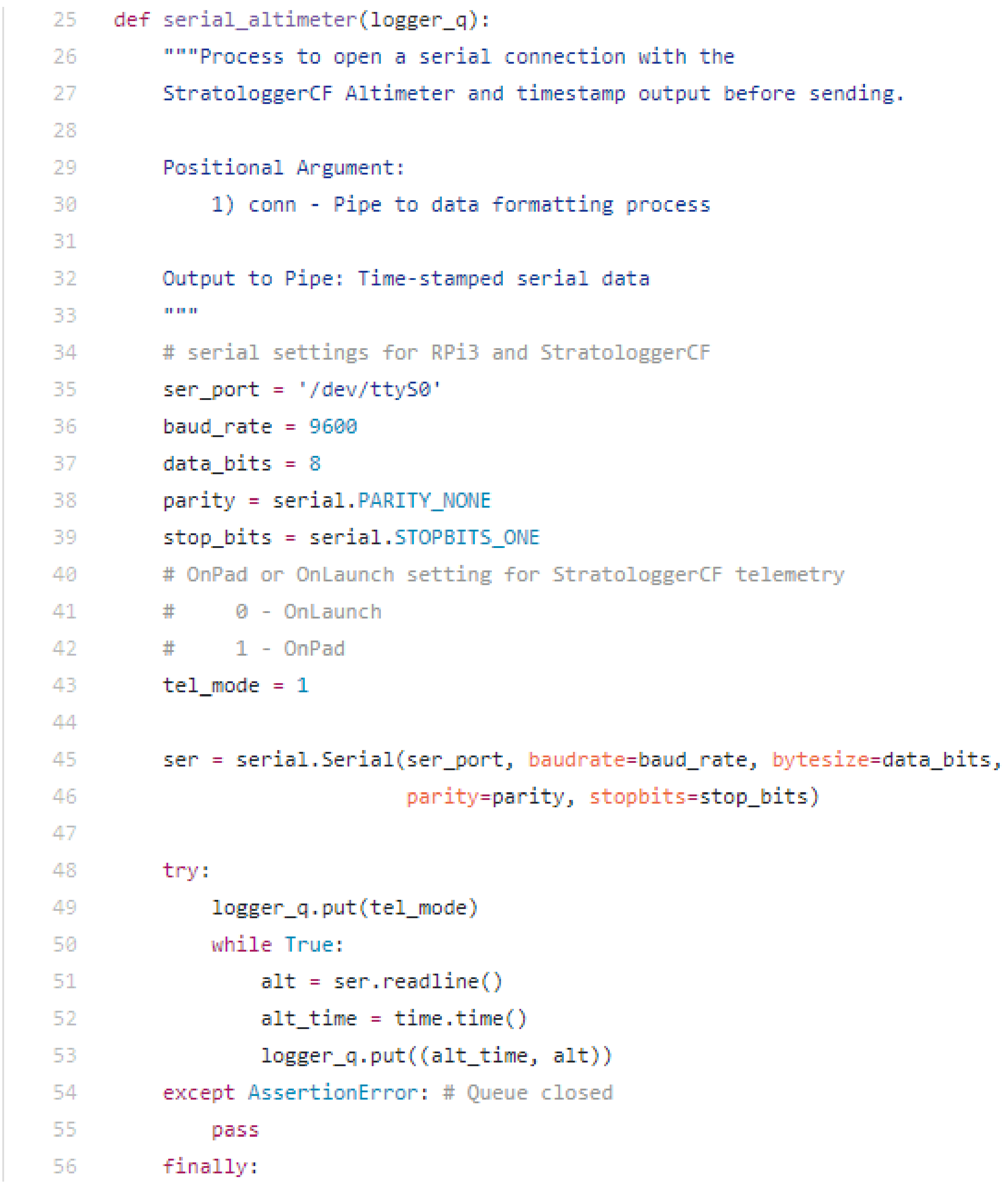


Figure 5.2.5 ATS Software Flowchart

The ATS software runs in a parallelized python script that makes full use of each of the four cores on the Raspberry Pi 3. The individual processes each perform a core task of the ATS. They are as follows: a process dedicated to receiving and time-stamping altimeter data 20 times a second before sending it to the logging process, a process solely focused on collecting and arranging data before it is logged and sent to other processes, and the core calculation and actuation process of the ATS.



```
def serial_altimeter(logger_q):
    """Process to open a serial connection with the
    StratologgerCF Altimeter and timestamp output before sending.

    Positional Argument:
        1) conn - Pipe to data formatting process

    Output to Pipe: Time-stamped serial data
    """
    # serial settings for RPi3 and StratologgerCF
    ser_port = '/dev/ttyS0'
    baud_rate = 9600
    data_bits = 8
    parity = serial.PARITY_NONE
    stop_bits = serial.STOPBITS_ONE
    # OnPad or OnLaunch setting for StratologgerCF telemetry
    #     0 - OnLaunch
    #     1 - OnPad
    tel_mode = 1

    ser = serial.Serial(ser_port, baudrate=baud_rate, bytesize=data_bits,
                        parity=parity, stopbits=stop_bits)

    try:
        logger_q.put(tel_mode)
        while True:
            alt = ser.readline()
            alt_time = time.time()
            logger_q.put((alt_time, alt))
    except AssertionError: # Queue closed
        pass
    finally:
```

Figure 5.2.6 ATS Serial Process Code

While recording data, the rest of the ATS software is directed at processing altimeter output to predict an apogee and actuate accordingly in a loop. The code will use a method of numerically solving a second order nonlinear differential equation (Euler's method) to iteratively calculate the altitude of the rocket based on the equation for acceleration. This can be done by solving for a the time derivative of altitude using the normal Euler's method and then numerically integrating to get height. Using Euler's method, the predictions will become increasingly accurate given smaller and smaller time steps between adjacent points. It is a goal to integrate the full altitude function of the rocket up to apogee in a time equivalent to one time step; thus if the software can iterate faster, smaller time steps can be used and the predictions will be more accurate. For this reason performance is vital to the ATS and the software needs to be aptly optimized to generate useful predictions. The quad-core CPU of the Pi is especially appealing for this reason as it is more than sufficient for this purpose.

Actuation will occur in an iterative manner based on the comparison between the predicted apogee and target apogee. This is necessary because we may not be directly calculating the drag coefficient needed to reach target apogee, and ideally this ideal drag coefficient will be reached after a few iterations. This problem is significant because there is no way to generate additional upwards force on the rocket since we do not have variable thrust; thus if the apogee is decreased too far below the target, nothing can be done to raise it. The flight time will also be short so there will be little time to correct these errors.

5.3. Construction of ATS

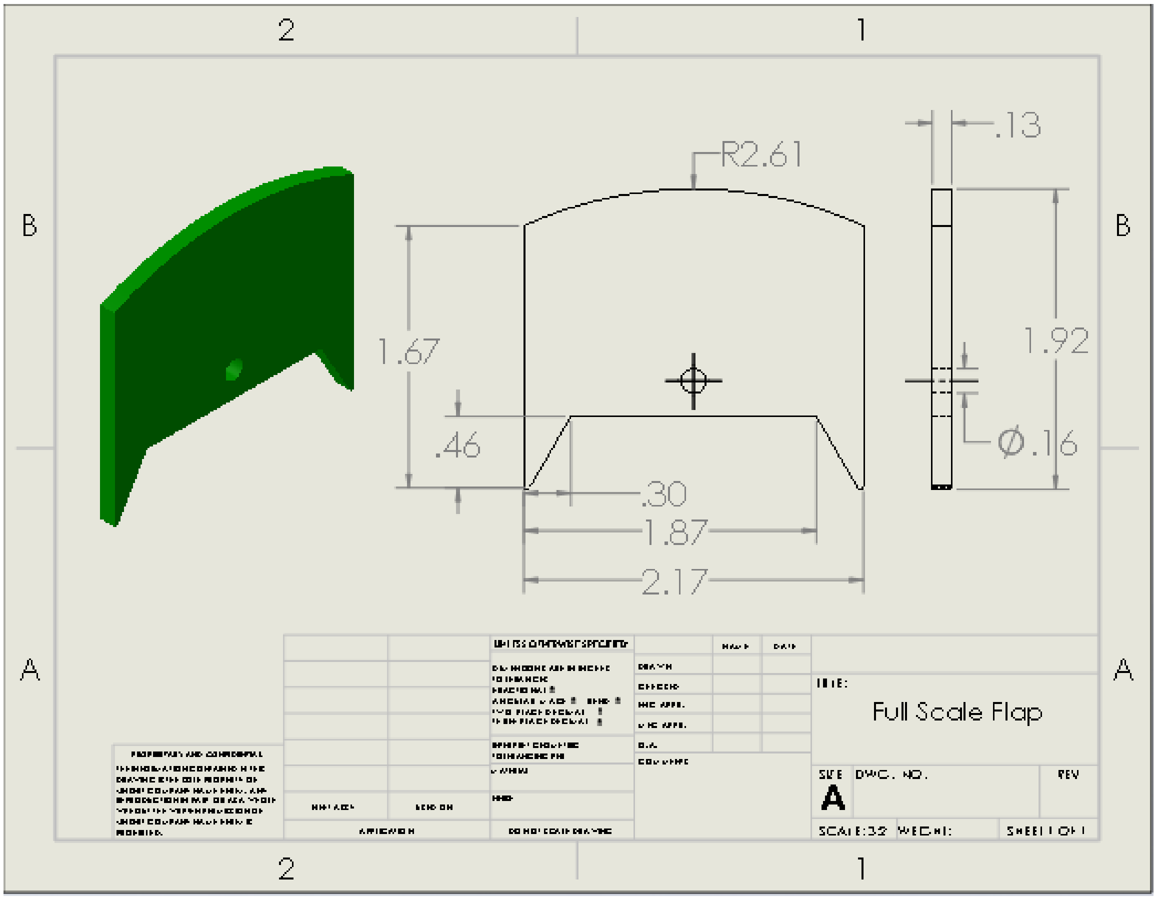


Figure 5.3.1 Drawing of Full Scale Flap.

Four flaps were manufactured using waterjet. For the manufactured part, the difference in the dimension was less than 0.01 inches.

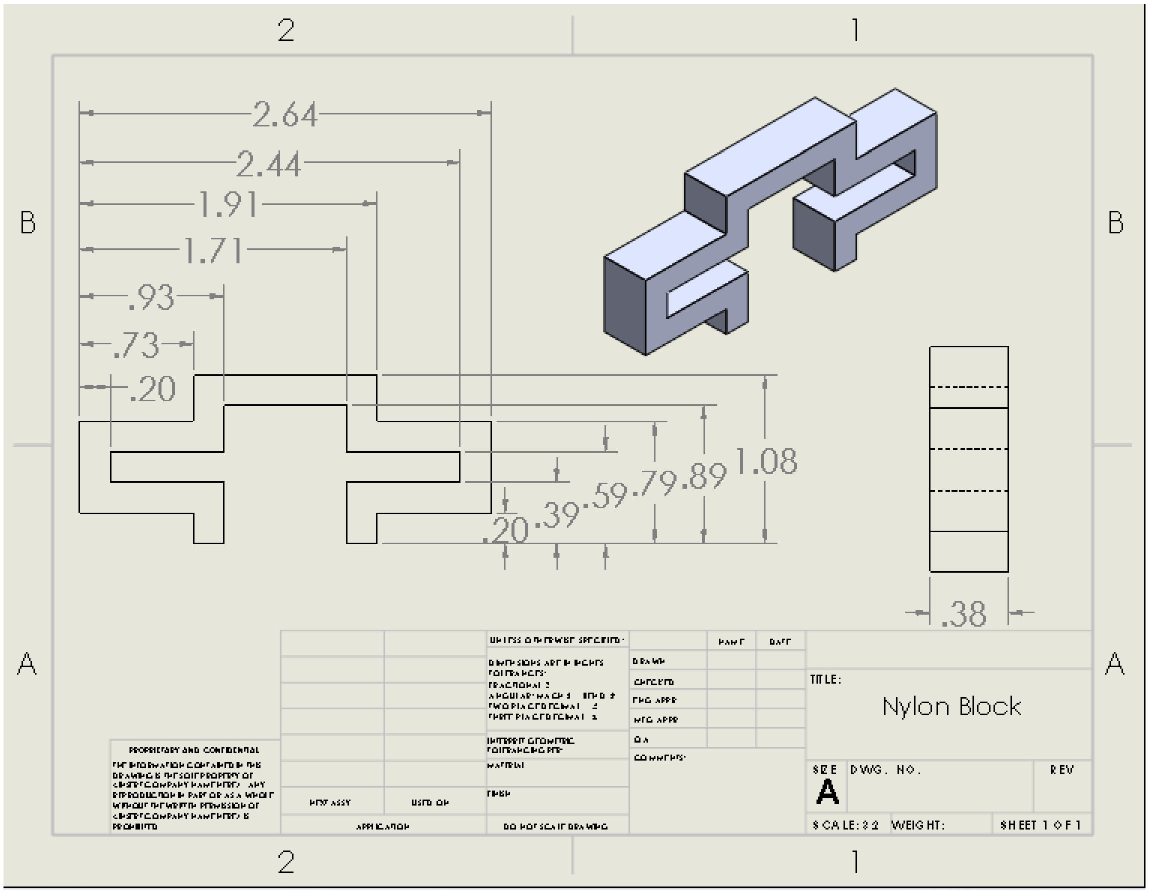


Figure 5.3.2 Drawing of Full Scale Nylon Guide.

The nylon guide was also manufactured using waterjet. However, due to the high temperature of the waterjet, some parts were severely warped, especially the slits. The height of the slit is supposed to be 0.2 inches. However, the narrowest height of the slit of the manufactured part was 0.17 inches. Since such tolerance was bigger than what was expected, the part had to be sanded.

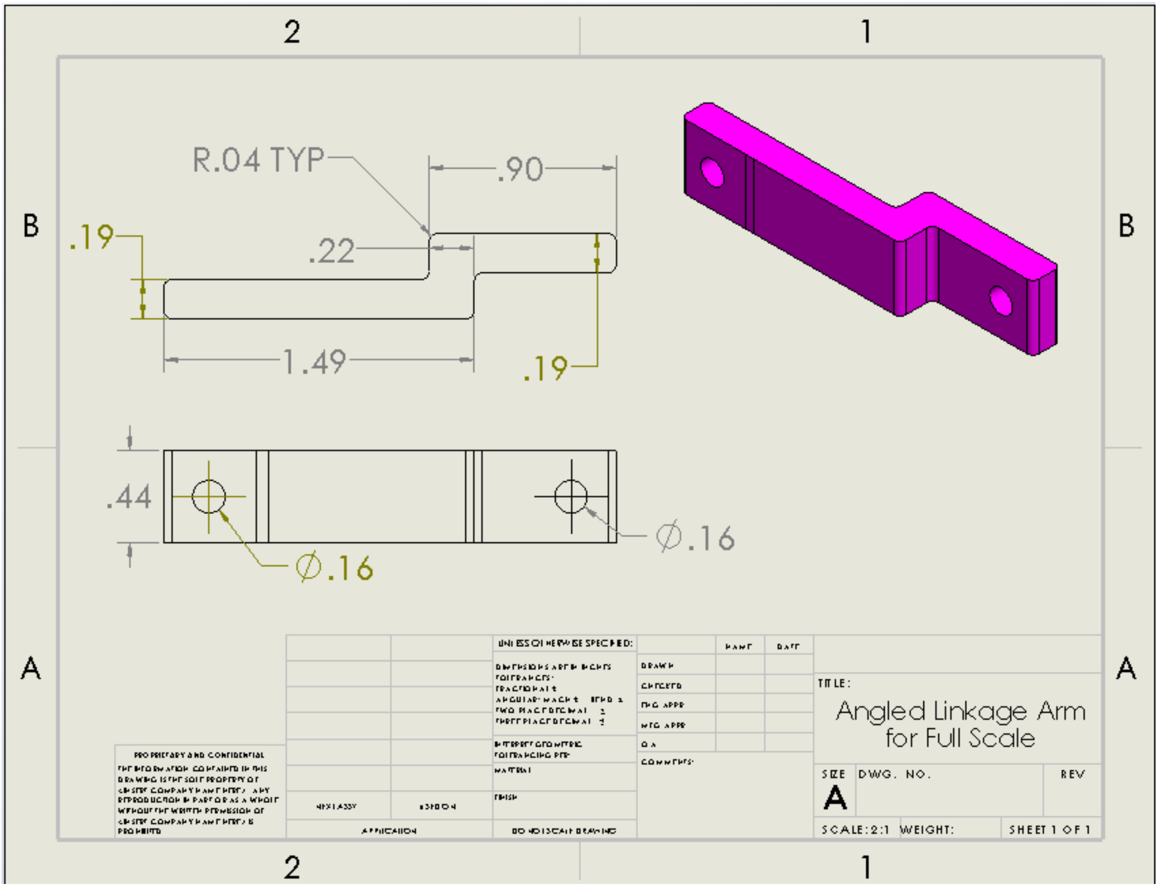


Figure 5.3.3 Drawing of Full Scale Linkage Arm.

The angled linkage arms are also manufactured with waterjet, so the difference dimensions are very small: ~0.01 inches. However, since the holes are drilled using drill press, the position of the holes are not located perfectly at the position indicated in the drawing, but they are also within small range which is about 0.05 inches.

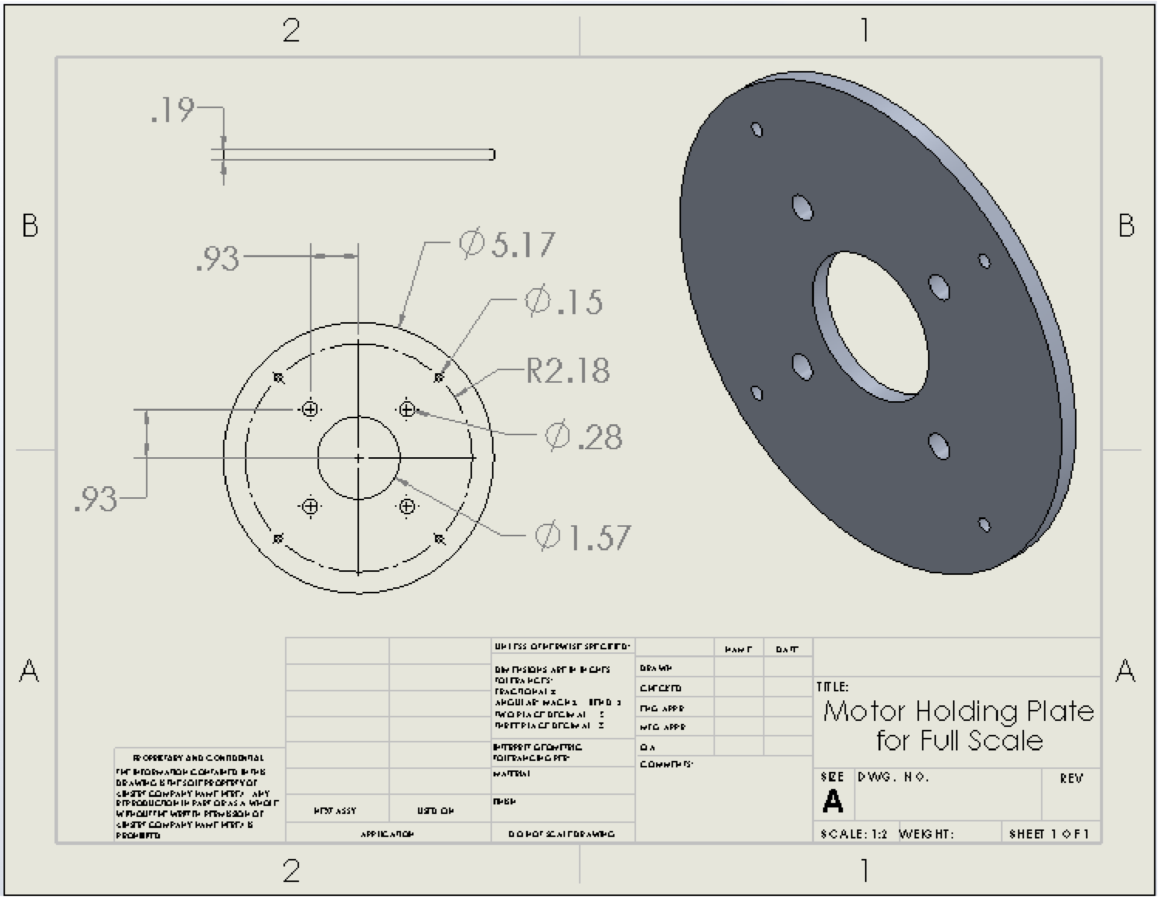


Figure 5.3.4 Drawing of Full Scale Motor Holding Plate

The motor holding plate was also manufactured using waterjet so all the dimensions are within expected tolerance which is about 0.01 inches.

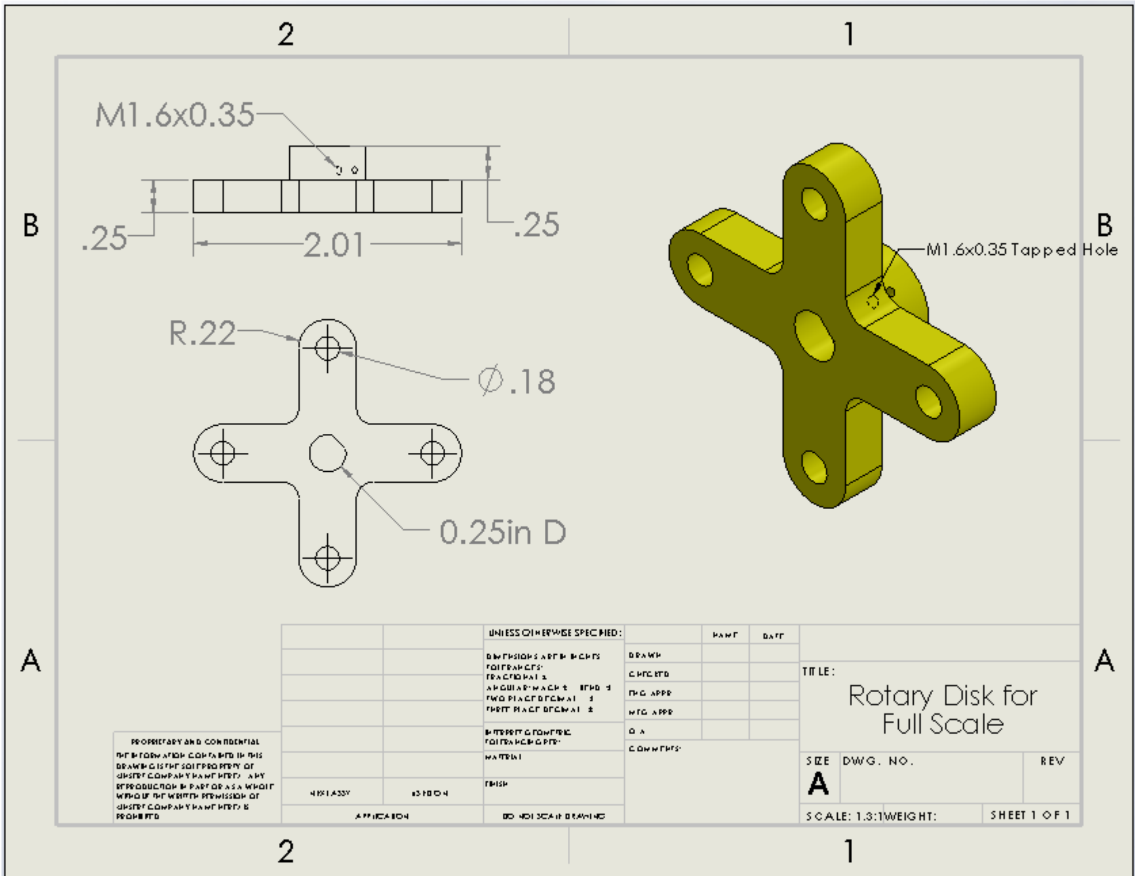


Figure 5.3.5 Drawing of Full Scale Center Rotary Coupler

The center rotary coupler was made using both waterjet and manual lathe. So the whole and the arms were made using waterjet but the central cylinder was made using manual lathe. So the tolerances are under control and was able to manufacture parts with dimension within 0.01 inches difference.

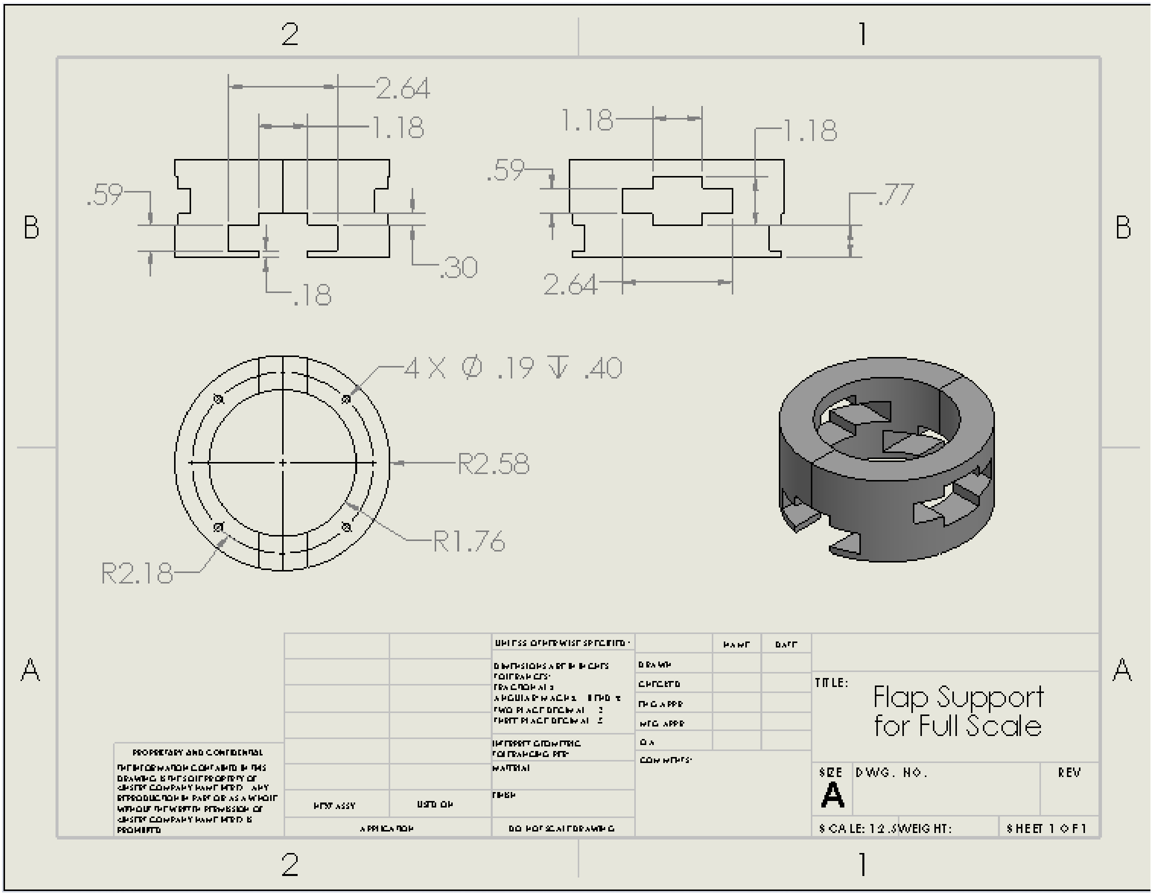


Figure 5.3.6 Drawing of Full Scale Flap Housing

Flap housing was 3d printed with PLA. However, due to the quality of the 3d printer, the parts were slightly warped; the part is not perfectly circular. Fortunately, it was not warped significantly that it had to be manufactured using different method or different material.

Once all parts are manufactured, they are assembled in the following order:

1. Insert press fit into the ATS housing
2. Attach motor to the motor holding plate

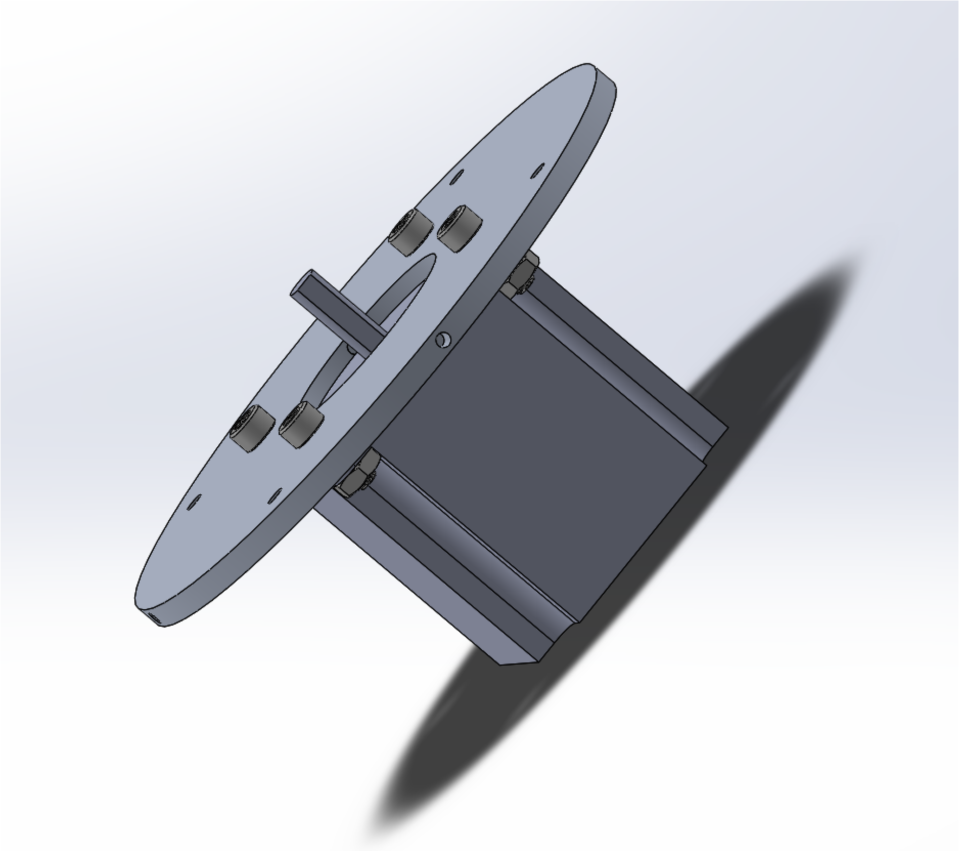


Figure 5.3.7 ATS assembly after step 2

3. Insert center rotary coupler into the shaft of the motor

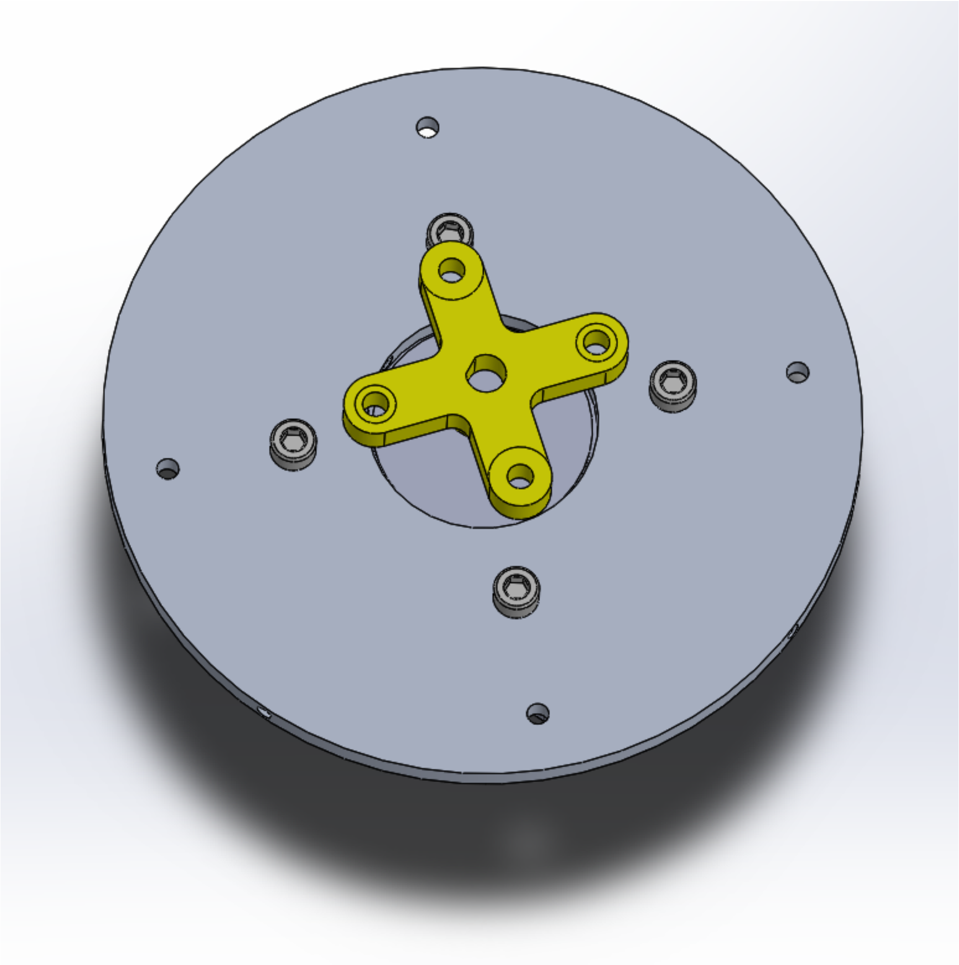


Figure 5.3.8 ATS assembly after step 3

4. Assemble angled linkage arm to the center rotary coupler; apply threadlocker to the screws

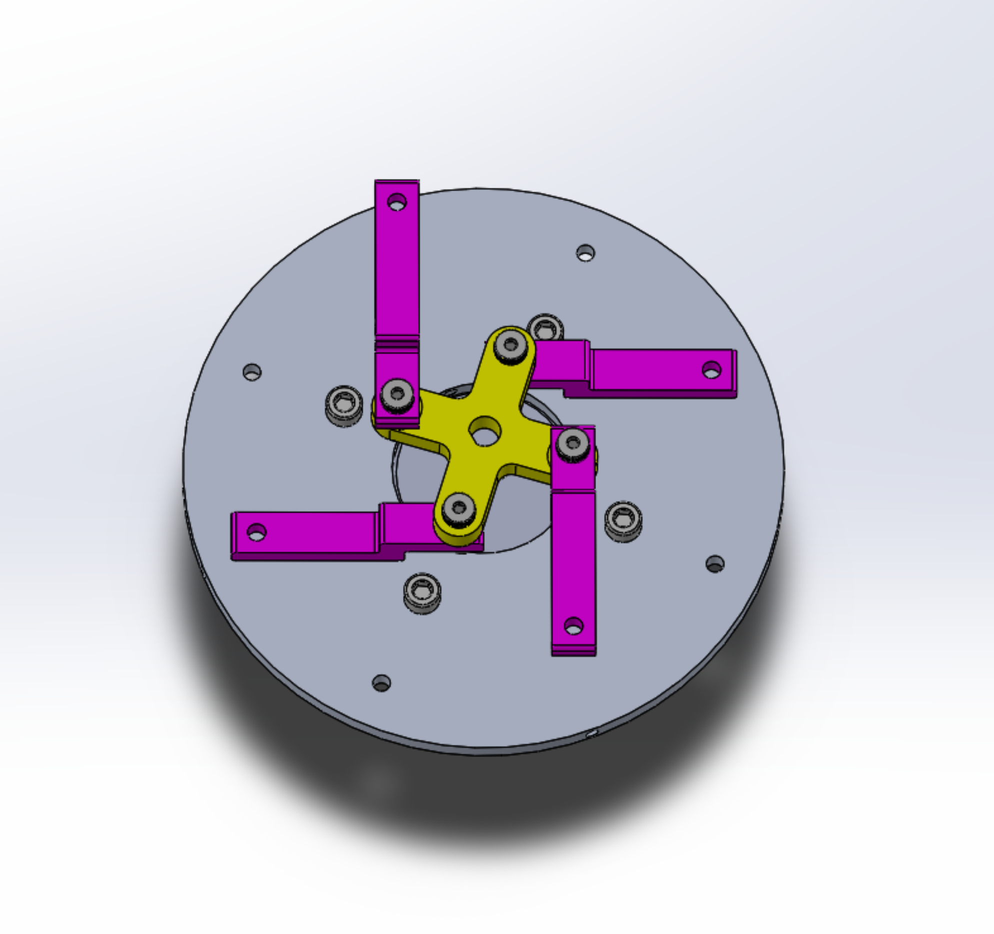


Figure 5.3.9 ATS assembly after step 4

5. Attach two adjacent flaps on the linkage arms; apply threadlocker to the screws

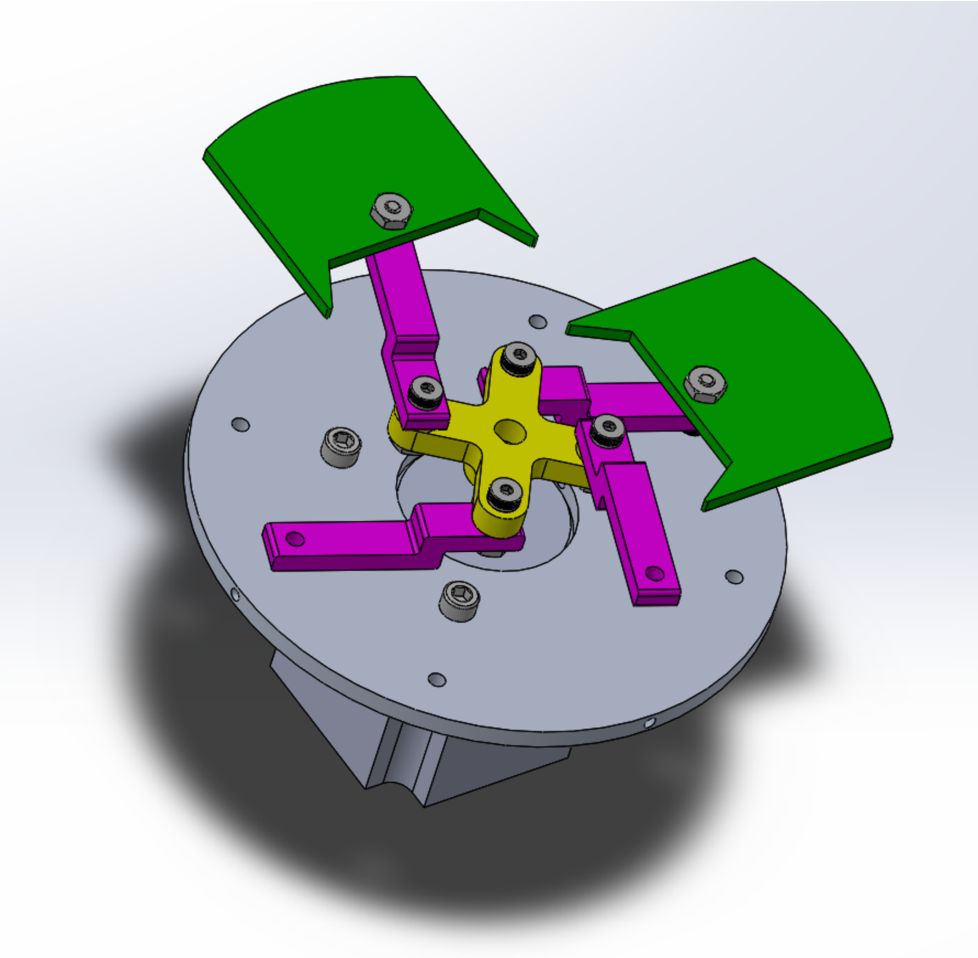


Figure 5.3.10 ATS assembly after step 5

6. Attach one piece of ATS housing to motor holding plate and insert nylon guides

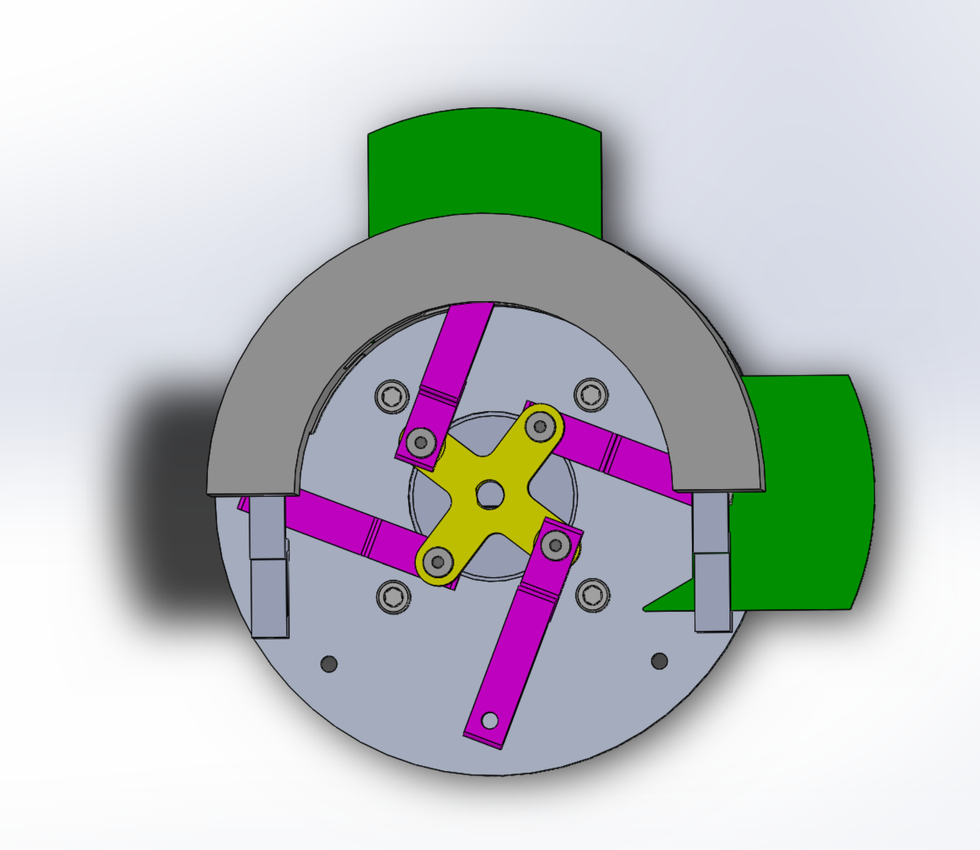


Figure 5.3.11 ATS assembly after step 6

7. Assemble rest of flaps on linkage arms; apply threadlocker to the screws

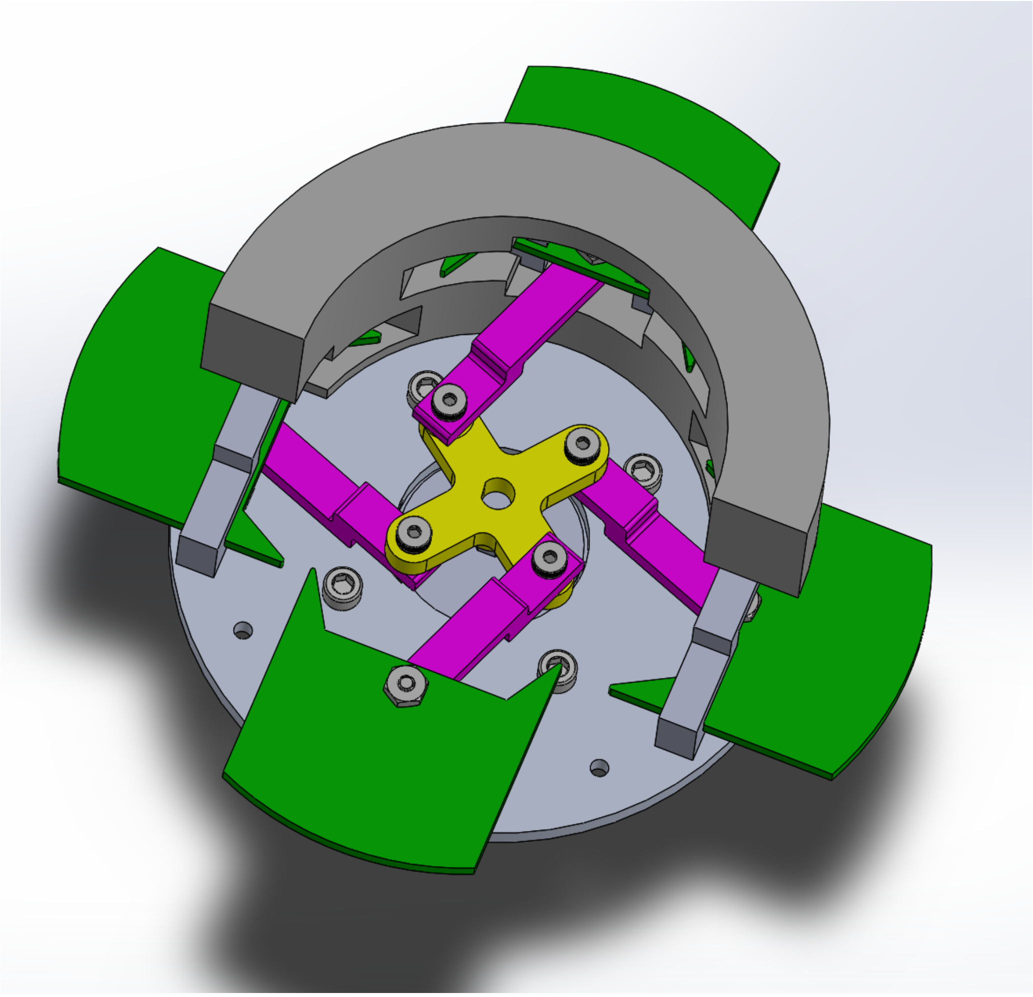


Figure 5.3.11 ATS assembly after step 7

8. Attach another piece of ATS housing to motor holding plate and insert last nylon glide

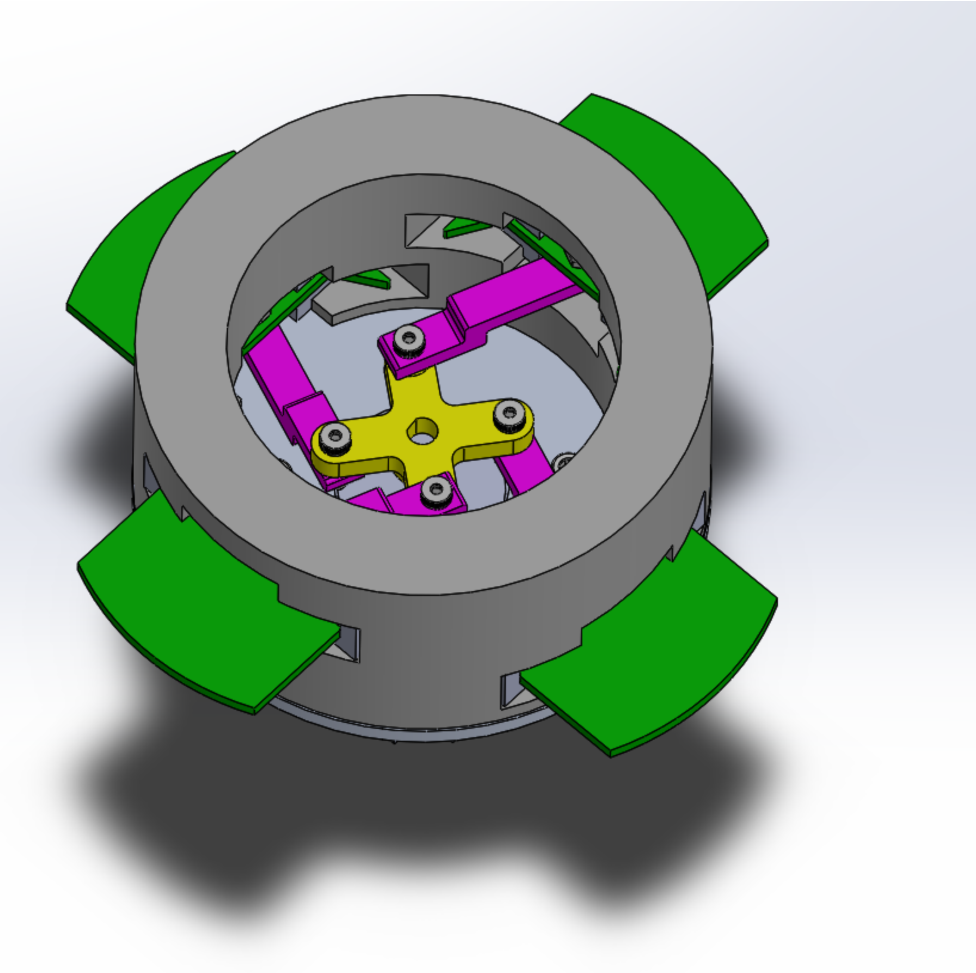


Figure 5.3.12 ATS assembly after step 8

9. Mount ATS to the coupler tube

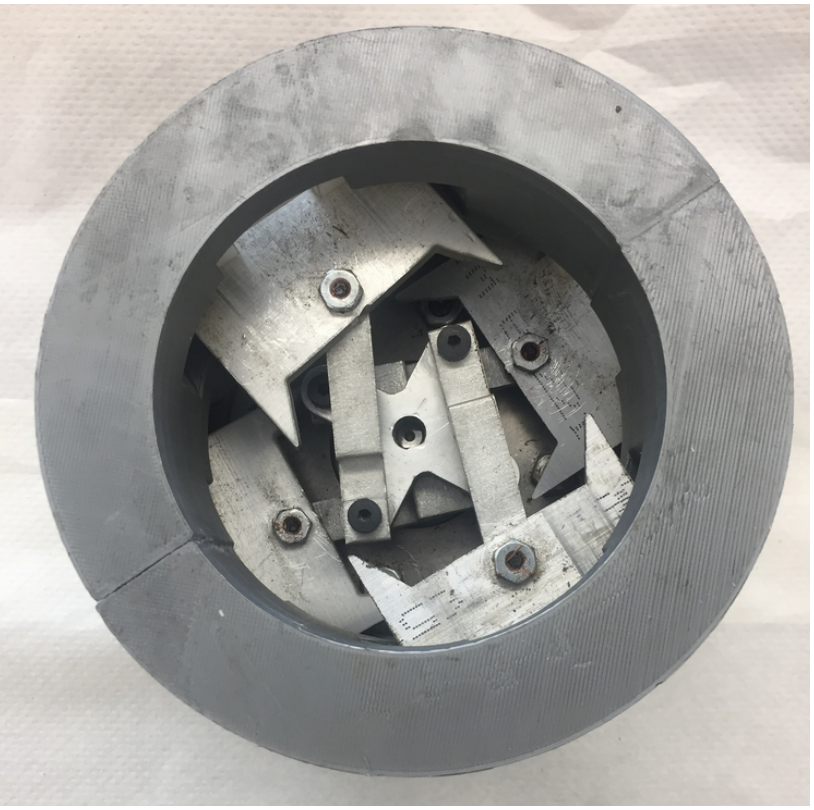


Figure 5.3.13 Fully Assembled ATS

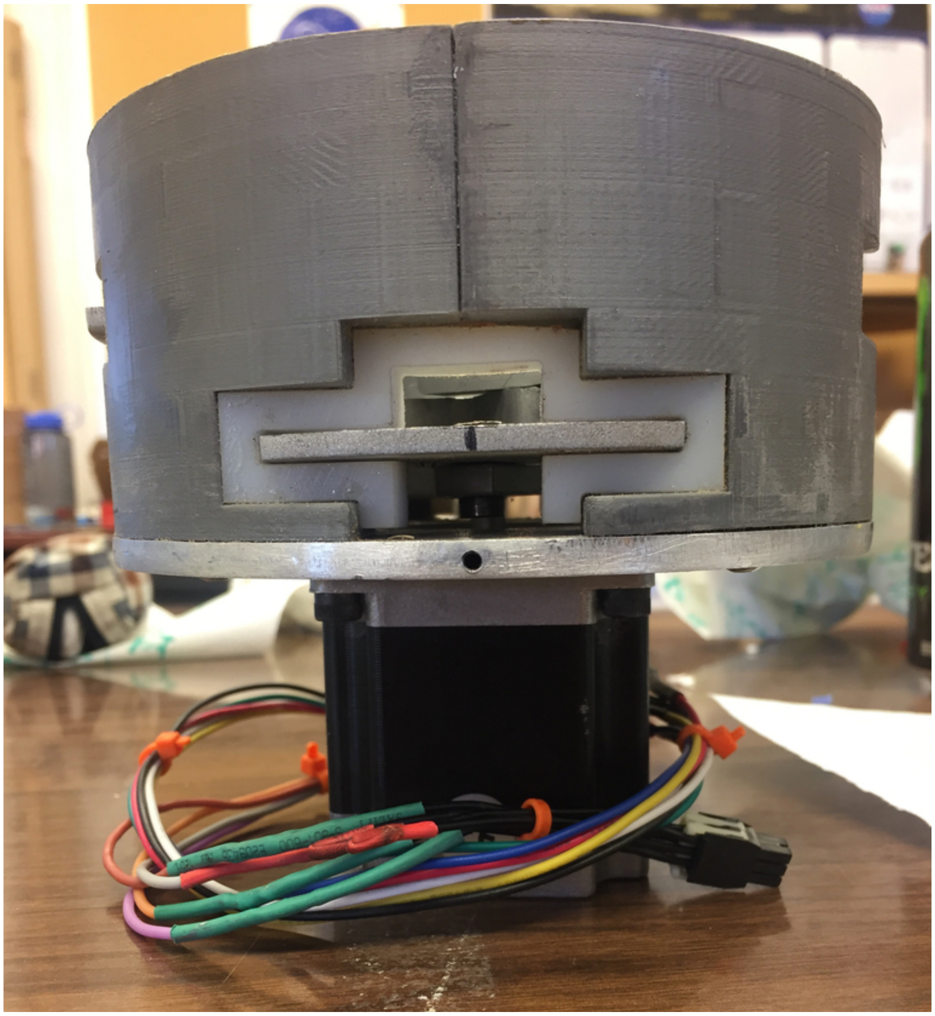


Figure 5.3.14 Fully Assembled ATS

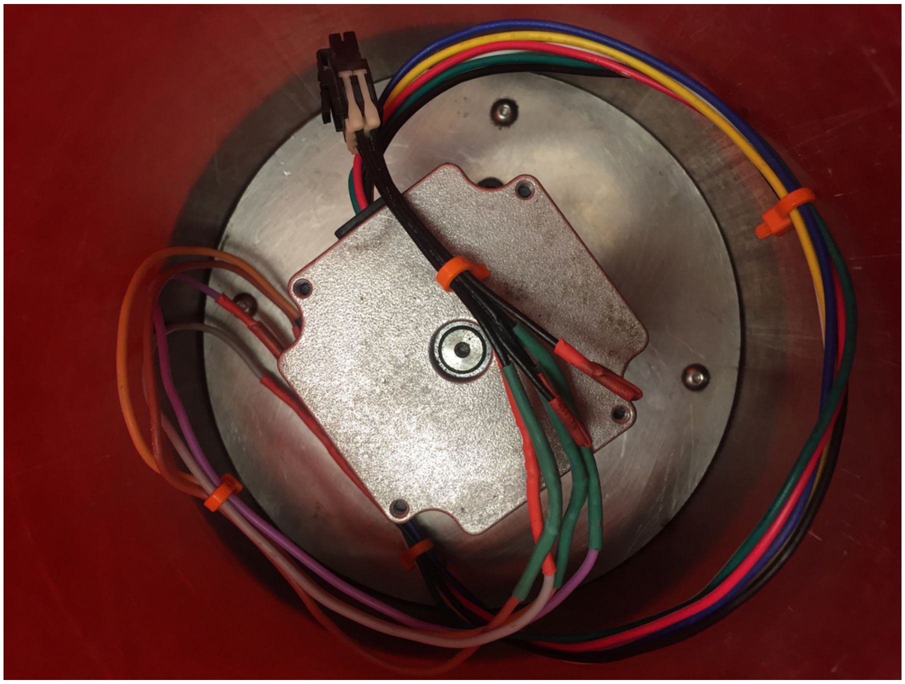


Figure 5.3.15 ATS mounted in the coupler tube

Figure 5.3.16 Fixing ATS to the body tube

5.4. Flight Reliability

Based on the updated data from OpenRocket simulation, the static simulations on SolidWorks were to ran to verify that the parts will not fail. The force applied is 12.02 ft-lbs, which is calculated as the highest possible force, if the flaps are extended and 100 percent of the surface area is exposed.

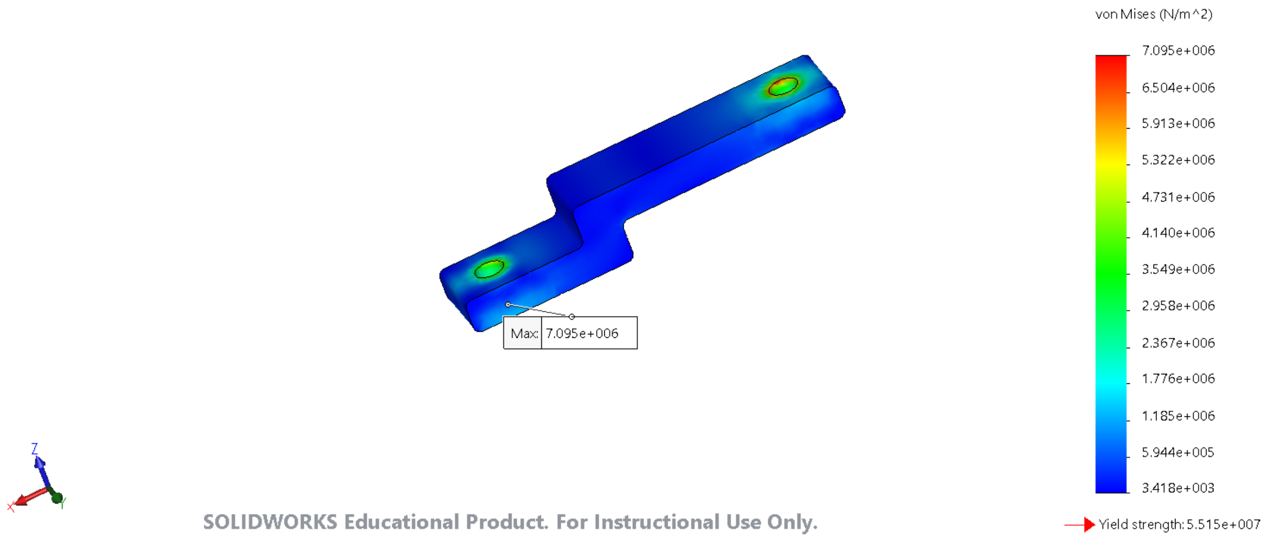


Figure 5.4.1 Stress Simulation of Linkage Arm

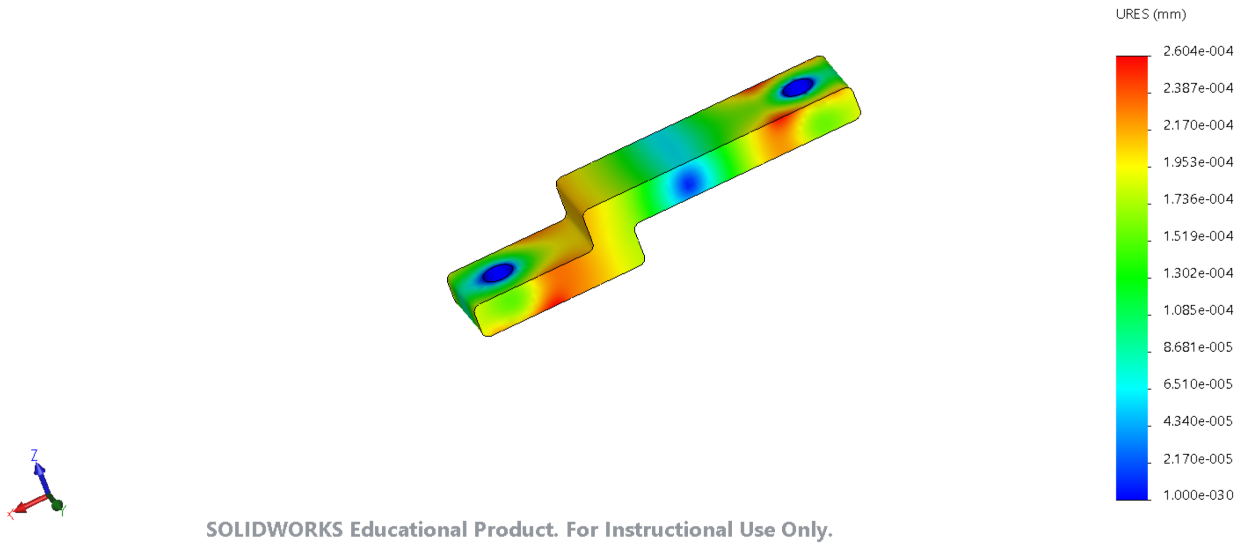


Figure 5.4.2 Displacement Simulation of Linkage Arm

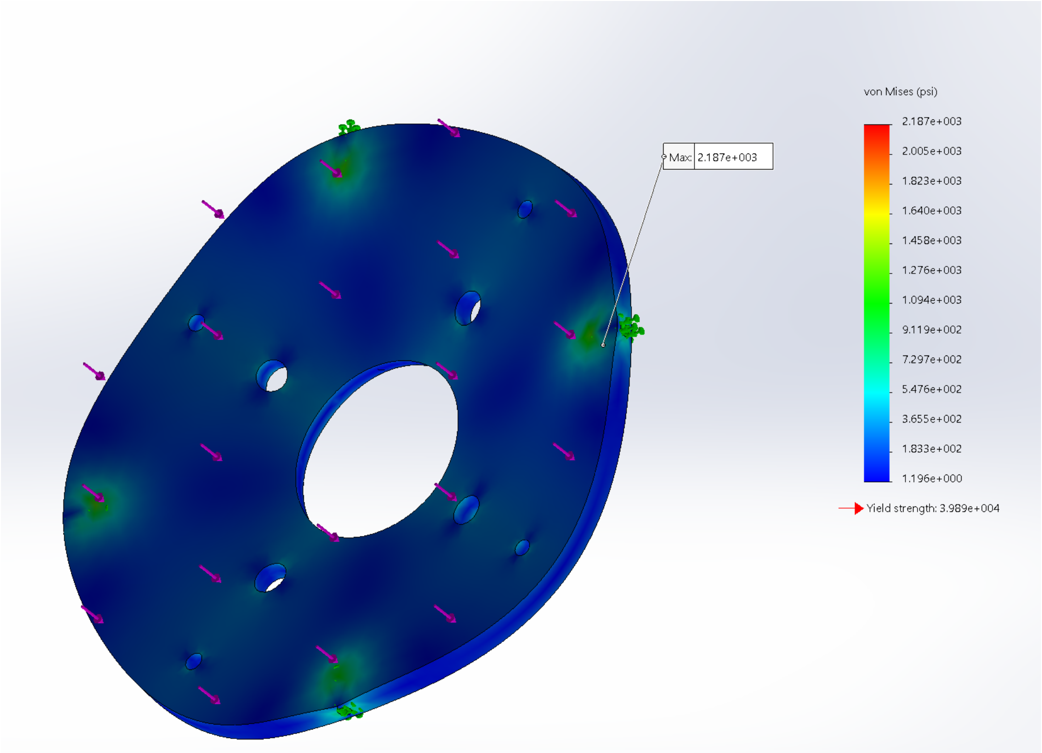


Figure 5.4.3 Stress Simulation of Motor Holding Plate

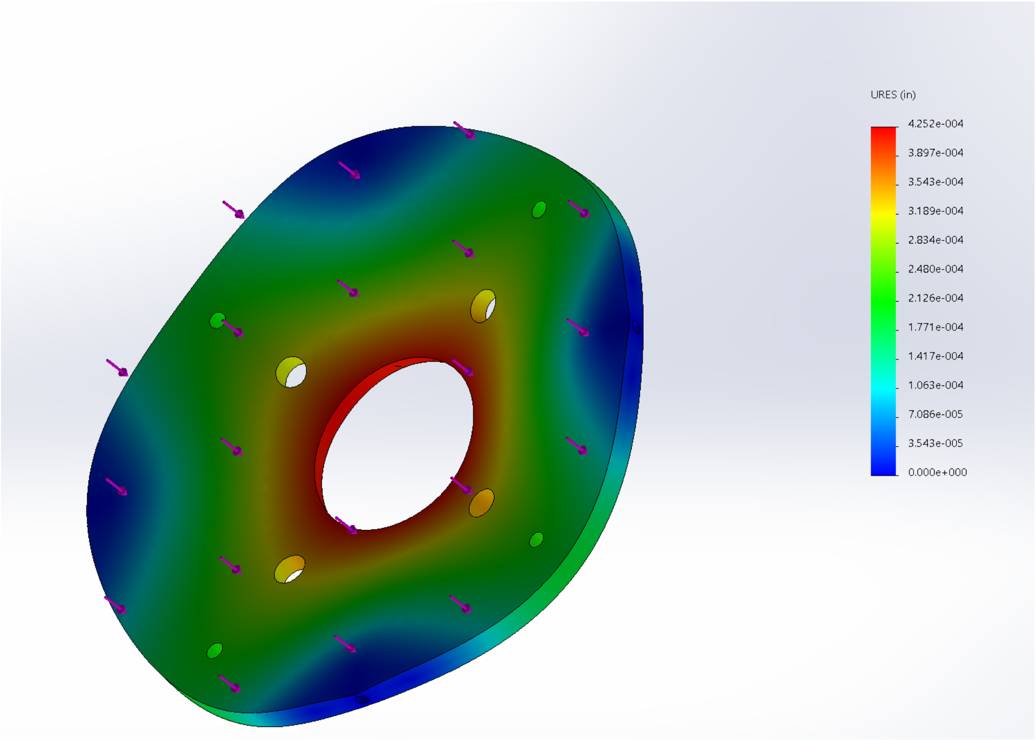


Figure 5.4.4 Displacement Simulation for Motor Holding Plate

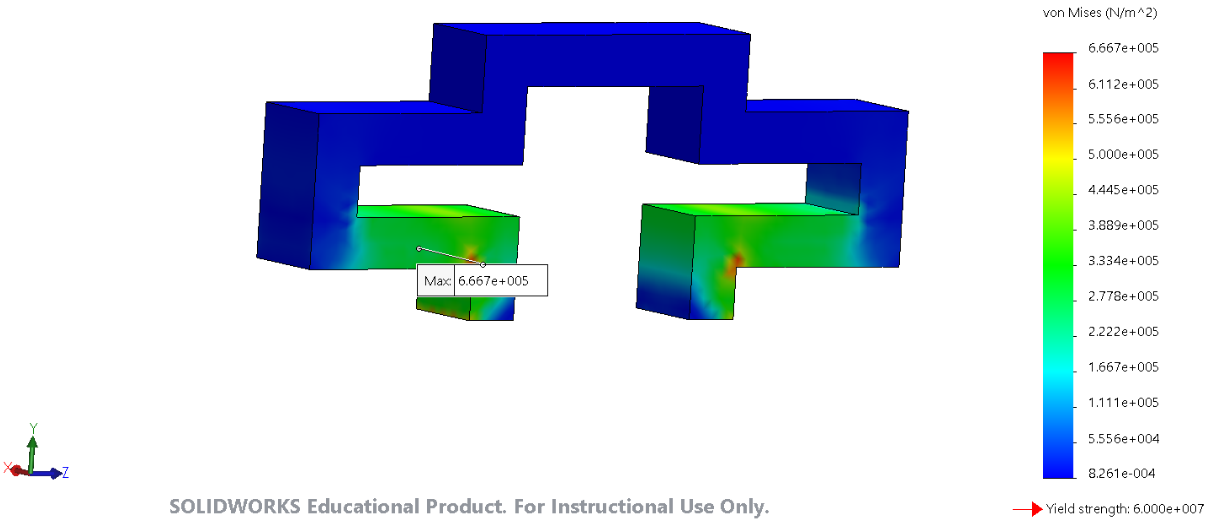


Figure 5.4.5 Stress Simuation of Nylon Guide

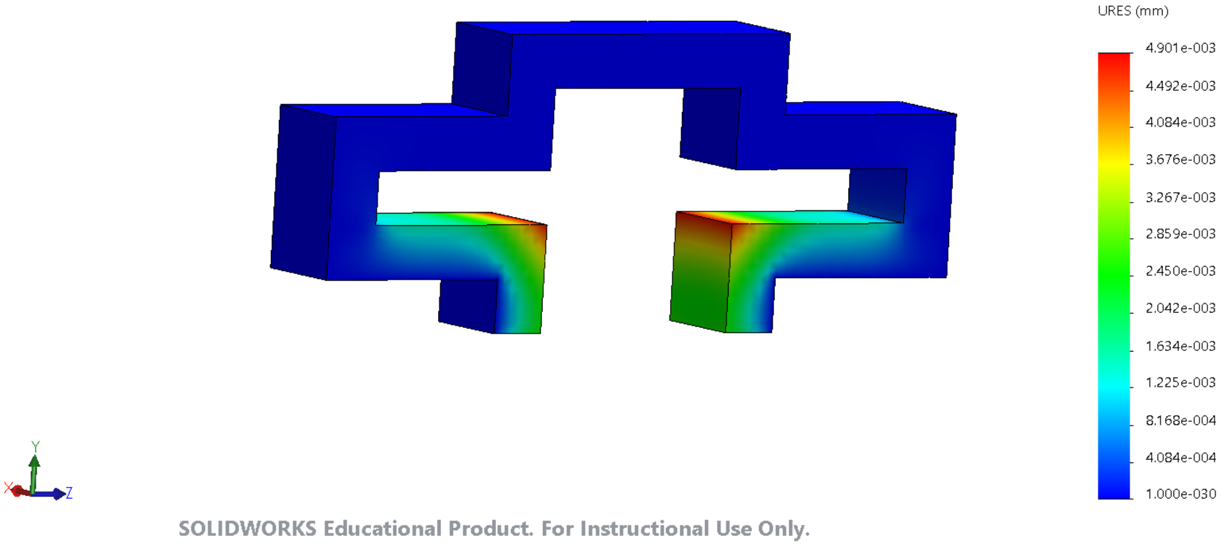


Figure 5.4.6 Displacement Simulation of Nylon Guide

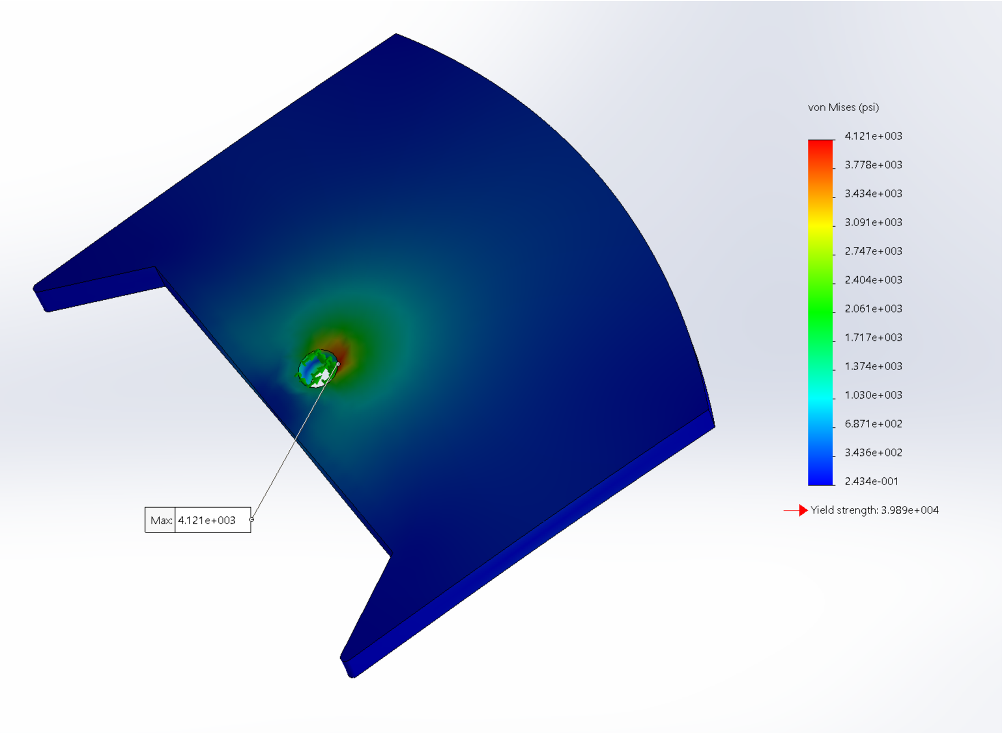


Figure 5.4.7 Stress Simulation of Flap

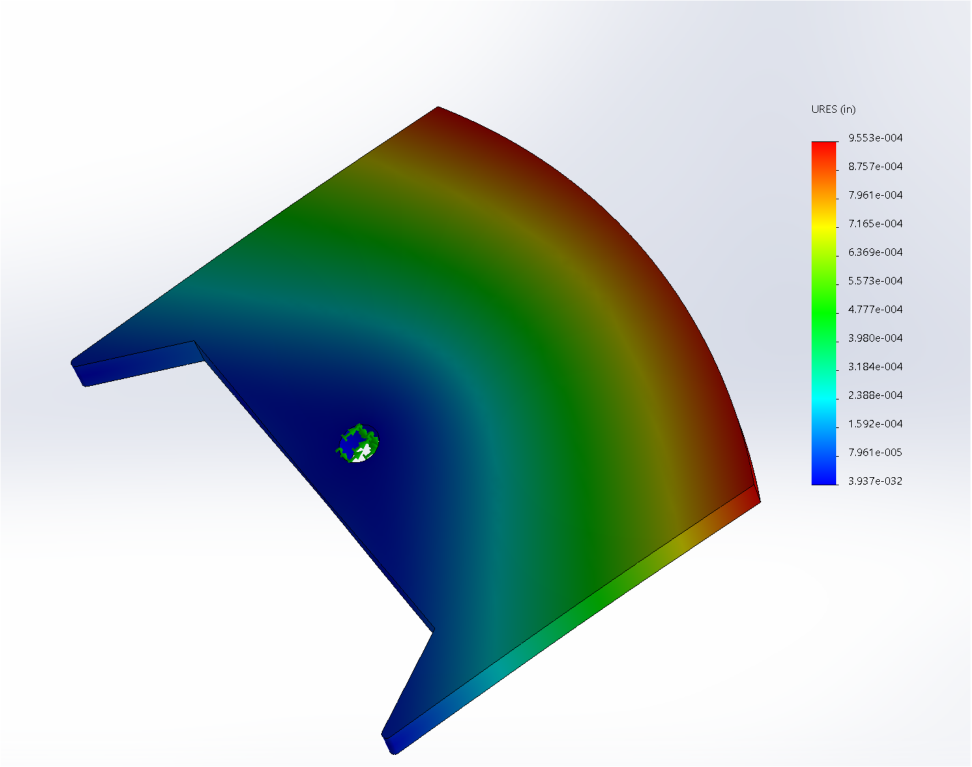


Figure 5.4.8 Displacement Simulation of Flap

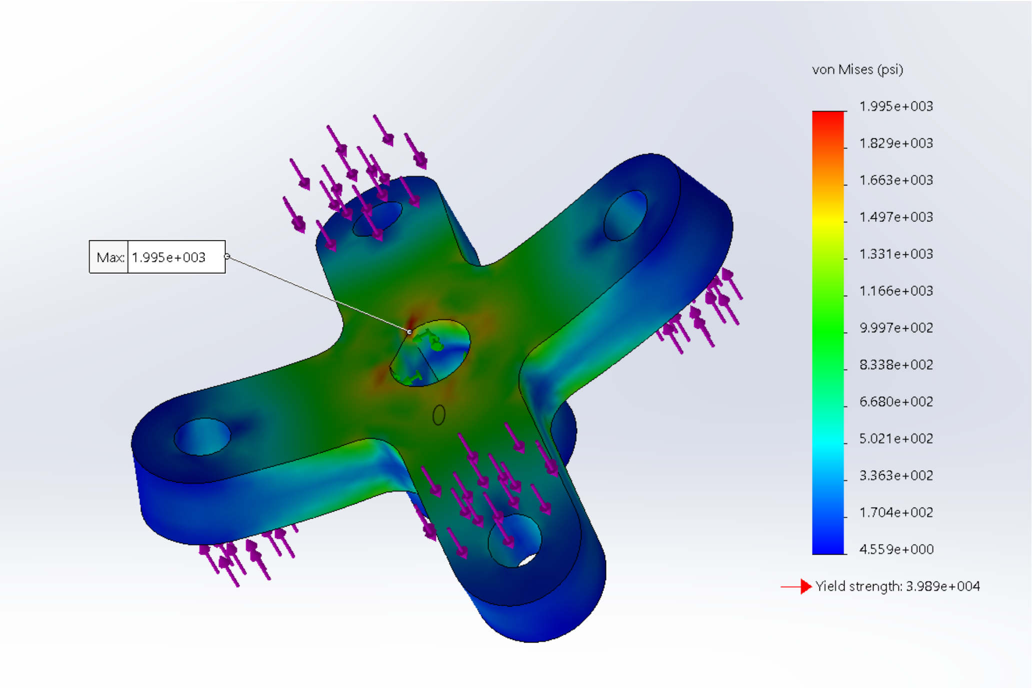


Figure 5.4.9 Stress Simulation of Center Rotary Coupler

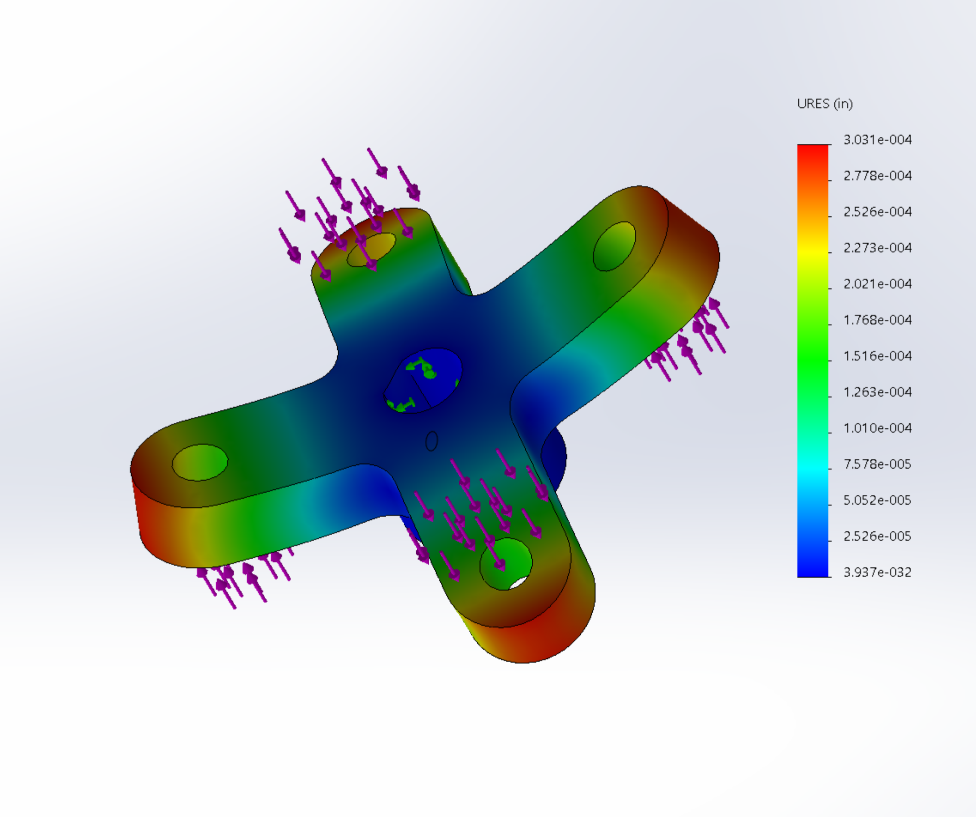


Figure 5.4.10 Displacement Simulation of Center Rotary Coupler

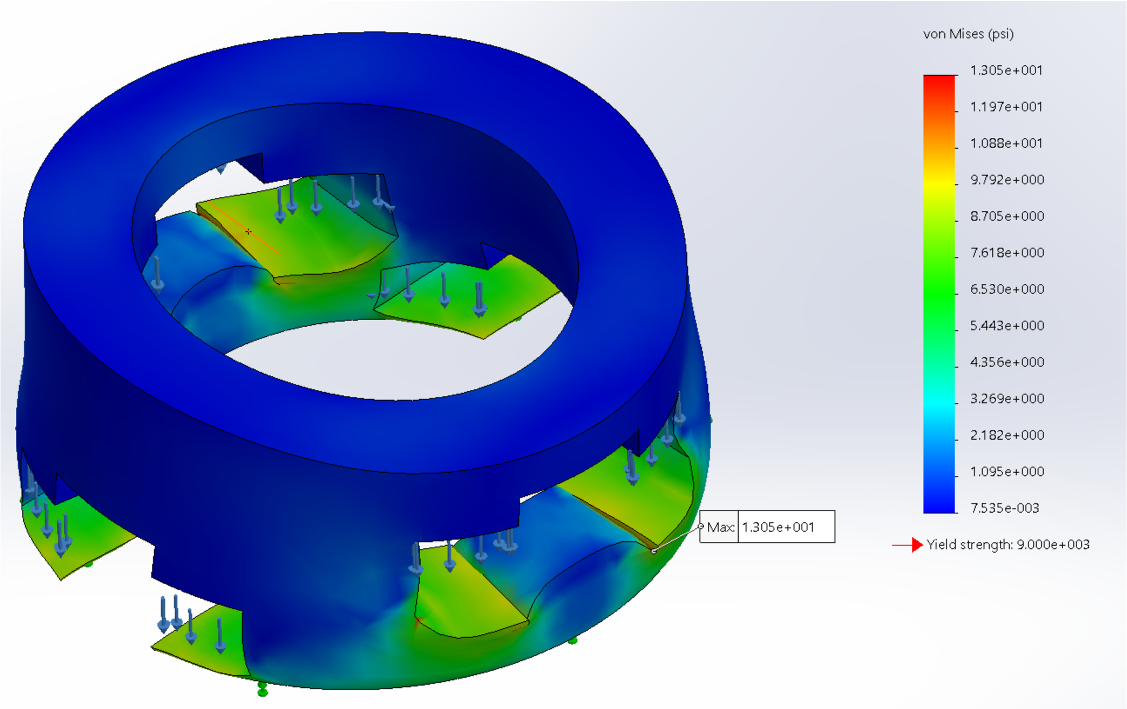


Figure 5.4.11 Stress Simulation of ATS housing

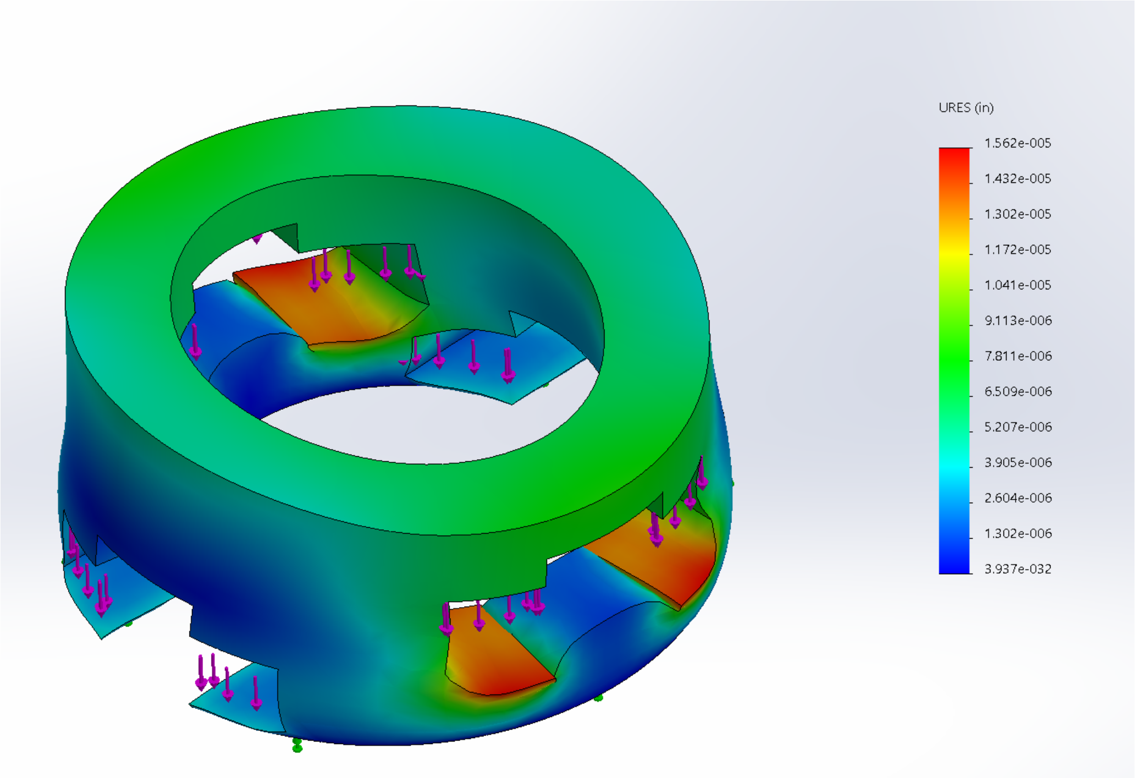


Figure 5.4.11 Displacement Simulation of ATS housing

The simulation revealed that the parts will not deform significantly and will have safety factor bigger than 2 under the maximum stress condition.

Once ATS was assembled and before it was mounted, it was tested by plugging it into the electrical systems. Also it was tested manually and inspected. When it was not mounted in the rocket, it was functional. However, when it was mounted on the rocket, it was not able to actuate its flaps. Since there was not enough time in between when the system was fully assembled and mounted into the rocket and the test launch of the rocket, the system couldn't be fixed. If there were more time, it could have been fixed because the problem had most likely be due the manufacturing tolerance.

6. Safety

6.1. FMEA/Personal Hazard/Environmental Concerns

6.1.1. FMEA Criteria

Table 6.1.1: FMEA Criteria

Probability	Severity			
	1 CATO	2 Critical	3 Marginal	4 Negligible
A - Frequent	1A	2A	3A	4A
B - Probable	1B	2B	3B	4B
C - Occasional	1C	2C	3C	4C
D - Remote	1D	2D	3D	4D
E - Improbable	1E	2E	3E	4E
Severity-Probability Correlation	**Acceptance Level / Approving Authority**			
High Risk	Unacceptable. Requires approval from Avionics and Vehicle			

	Leads, as well as Safety Officer. Must
Medium Risk	Undesirable. Documented approval from the facility/operation owner's Department/Laboratory/Office Manager or designee(s) or an equivalent level management committee.
Low Risk	Acceptable. Documented approval from the supervisor directly responsible for operating the facility or performing the operation.
Minimal Risk	Acceptable. Documented approval not required, but an informal review by the supervisor directly responsible for operation the facility or performing the operation is highly recommended. Use of a generic JHA posted on the SHE Web page is recommended, if a generic JHA has been developed.

Table 6.1.2: Airframe FMEA Chart

Hazard	Causes	Impacts	Risk	Mitigation Strategy
Structural cracks in the body airframe	heat from motor	rocket buckles mid-flight and make the rocket fail and not land safely	1C	insulate motor from airframe body
	impulses from parachute deployment			verify there are no cracks in body before launch
thrust plate structural integrity fails	material used to make the thrust plate was already compromised and wasn't checked before manufacturing	motor shoots through rocket, damaging all systems	1B	verify there are no cracks in thrust plate before it is inserted into body
	epoxy used to secure thrust plate failed			use enough epoxy to estabish acceptable factor of safety
motor explodes	motor manufacture error	rocket disintegrates or falls uncontrollably to the ground, most if not all sub-systems useless	1B	verify motor housing and mount are free of defects before insertion into the body
	inappropriate propellant was used			verify that the correct propelant was selected, order and used
motor does not ignite	ignition wire not connected properly to the motor	rocket does not fly and sub-systems do not get a chance to be used	2B	verify all wires are connected properly/ use a voltmeter to ensure charge is flowing
all centering rings break during flight	epoxy failed because it was not made properly	motor in the booster section tilts, forcing the rocket to arc; altimeter may deploy drogue chute early if it thinks the rocket reached apogee as the rocket arcs	1B	ensure enough epoxy is used to enable a proper factor of safety
	material used was not strong enough			ensure appropriate selection of centering ring material
	centering rings not aligned properly		2C	use measuring devices to verify centering rings are actually centered
fins separate from airframe during flight	epoxy failed because it was not made properly	rocket loses stability and arcs during flight, causing failures in altimeters and ATS system	1B	ensure enough epoxy is used to enable a proper factor of safety

fins do not direct the rocket perfectly up	fins not aligned properly during manufacturing	rocket loses stability and arcs during flight, causing failures in altimeters and ATS system	3C	use template for mounting the fins to the body correctly
Rover section separates during flight	someone sits on the receiver and prematurely separates the rover section	rover falls to the ground and is destroyed, so rover challenge cannot be completed	2B	store receiver somewhere it cannot be accidentally actuated
ATS flaps are not pushed out symmetrically	not enough lubricant for the flaps	rocket loses stability and arcs during flight, causing failures in altimeters and ATS system	1A	use enough lubricant to allow the flaps to push out correctly
couplers break during the flight	couplers cannot withstand the moments applied during flight	rocket comes apart mid-flight, causing all sub-systems to malfunction, rover falls to ground, ATS cannot be deployed, parachutes could get tangled or damaged, avionics bay wires get disconnected, motor falls away from booster section, causing what's left of the rocket to arc	1B	ensure correct material is selected for each of the couplers so that each connection has an appropriate factor of safety
shear pins and rivets break mid-flight prematurely	shear pins vibrate out during flight	rocket comes apart mid-flight, causing all sub-systems to malfunction, rover falls to ground, ATS cannot be deployed, parachutes could get tangled or damaged, avionics bay wires get disconnected, motor falls away from booster section, causing what's left of the rocket to arc	1A	verify that shear pins are mounted correctly
	cannot withstand external forces			ensure correct shear pins are purchased to allow for an appropriate factor of safety
Rivets do not come apart when needed	there is not enough force to break them	subsystems work, but ejection charges are not strong enough to break rivets, so parachutes do not deploy, the rocket crashes into the ground, and the rover challenge is not possible	1B	ensure both ejection charges and rivets are correctly selected given the amount of force in the separation
bulkheads and U-bolt (attached to shock cord) breaks during flight	epoxy was not properly made	parachutes do not deploy, the rocket crashes into the ground, and the rover challenge is not possible	1B	ensure enough epoxy is used to enable a proper factor of safety
	bulkhead structure is not strong enough			ensure both the U-Bolt and bulkhead are fastened properly

shock cords are damaged by the ejection charges	shock cords were not packed properly	subsystems work, but shock cords become tangled and hinder its performance or ejection charges damage the shock cords, so parachutes deploy damaged, causing the rocket to drift or crash into the ground, and the rover challenge is not possible	1B	verify that the shock cords and parachutes are packed correctly
	incorrect ejection charge was used			ensure the ejection charges are selected appropriately
Main parachute malfunctions during flight	altimeters fail, causing parachute to not deploy or deploy at the wrong time	subsystems work, but when main parachute doesn't deploy correctly, the rocket drifts and crashes into the ground, so the rover challenge is not possible	1B	verify that both the primary altimeter and secodary altimeters are functioning correctly before launch
	parachute wasn't packed properly			verify that the shock cords and parachutes are packed correctly
	ejection charges go off incorrectly and deploy damaged	subsystems work, but when main parachute is damaged when deployed: the rocket falls too fast, hits the ground hard, but rover subsystem survives (best case scenario) or the main parachute is completely destroyed and the rocket crashes into the ground, making the rover challenge impossible		ensure that the ejection charges are both correctly selected and correctly fastened to the body
drogue parachute malfunctions during flight	altimeters fail, causing parachute to not deploy or deploy at the wrong time	rocket falls too fast, which may cause the rocket to crash into the ground if the main parachute doesn't deploy correctly, which means the rover challenge is not possible	2B	verify that both the primary altimeter and secodary altimeters are functioning correctly before launch
	parachute wasn't packed properly	parachute cords become tangled and hinder its performance, causing the rocket to drift or crash into the ground, hinder the performance of the main parachute, and the rover challenge is not possible		verify that the shock cords and parachutes are packed correctly
a	ejection charges go off incorrectly and deploy damaged	rocket falls too fast, which may cause the rocket to crash into the ground if the main parachute doesn't deploy correctly, which means the rover challenge is not		ensure that the ejection charges are both correctly selected and correctly fastened to the body

		possible	🟥	
nose cone does not properly direct the rocket	incorrect nose cone selected	rocket loses stability and arcs during flight, causing failures in altimeters and ATS system	3E	verify that correct nose cone was selected, purchased, and installed
	nose cone improperly manufactured			verify that the nose cone is devoid of any manufacturing errors

Table 6.1.3: Recovery FMEA Chart

Hazard	Causes	Impacts	Risk	Mitigation Strategy
Unplanned ignition of electric match	Extreme levels of electromagnetic noise	Possible parachute ejection during boost resulting in destruction of rocket and injury to observers. Possible parachute ejection during setup resulting in injury to team members, observers, and/or range safety officers.	1D	No transmitting devices located within the avionics bay. Leads to electric matches are twisted to reduce the risk of induced current.
Ejection charge does not ignite	no signal from the avionics bay	The parachutes do not deploy and the rocket free falls to the ground	1B	ejection charge testing
	the powder is oxidized			
	the powder does not catch fire			
Ejection charge does not separate rocket	not enough black powder to provide sufficient pressure	The parachutes do not deploy and the rocket free falls to the ground	1B	ejection charge testing
	there is not sufficient space for the ejection charge to build pressure			black powder weight calculations
Bulkheads break	insufficient epoxy applied to bulkheads	The rocket is no longer tethered and part of the rocket will free fall potentially causing harm to observers	1C	visual inspection of epoxy during manufacturing
	i bolt breaks the bulkhead			FEA on the bulkheads will be performed

Main shock cord or drogue shock cord breaks	excess force is applied on the shock cord	The rocket is no longer tethered and part of the rocket will free fall potentially causing harm to observers	1C	Excess shock cord will be used to provide a factor of safety of 2 greater than manufacturer's specifications
	the manufacturer provides shock cords that can take force below the rated specifications			
ejection charge burns parachute	too much black powder is used	The parachute is damaged and the rocket will be more unstable when falling	3B	Safety officer will oversee the packing of the parachutes
	the parachute is not properly packed with the thermal barrier			ejection charge testing
main parachute does not come out of body tube	parachute chords snag on i-bolt	The rocket falls with only the drogue parachute slowing it down	1D	Safety officer will oversee the packing of parachutes
	parachute packed too tightly			will inspect the ability of parachutes to come out after packing
drogue parachute does not come out of body tube	parachute chords snag on i-bolt	The rocket falls with only the main parachute slowing it down	2D	Safety officer will oversee the packing of parachutes
	parachute packed too tightly			will inspect the ability of parachutes to come out after packing
main parachute does not unfold	parachute chords are extremely tangled	The rocket falls with only the drogue parachute slowing it down	1E	Safety officer will oversee the packing of parachutes
				The parachute chords will be carefully placed when packing
drogue parachute does not come out of body tube	parachute chords are extremely tangled	The rocket falls with only the main parachute slowing it down	2E	Safety officer will oversee the packing of parachutes
				The parachute chords will be carefully placed when packing

Molex connectors fail	Connection to altimeters fail	Ejection charges fail to ignite and rocket falls with one or both parachutes failing to deploy, potentially harming spectators	2B	Ejection charge testing to ensure cables are functional. Connectors should never be carried by wires.
	Connection to terminal block fails			
	Internal wire failure			
	Improper handling of connector wires			
Abay housing cracks where interfacing with 4-40 nuts/bolts	Gload during boost stresses component	Cables disconnect, ejection charges fail, and rocket falls without one or both parachutes	2D	Visually inspect Abay for cracks/fractures after test fligh.t
Solder smoke inhalation	Improper ventilation	Solder fume inhalation is detrimental to long-term lung health	3B	Only solder in well-ventilated area with air circulation. Wear a gas mask.
Solder joint failure	Improper handling of wires	Ejection charges fail to ignite and rocket falls with one or both parachutes failing to deploy	2B	Test wires for continuity after soldering. Use heat shrink over joints to prevent disconnection. Ejection charge testing to ensure wires are functional.
	Wires soldered improperly			

Table 6.1.4: Rover FMEA Chart

Hazard	Causes	Impacts	Risk	Mitigation Strategy
Rover deployment actuates during flight	Signal interference	Creates highly unstable flight leading to loss of vehicle, Challenge incomplete	1C	Rover deployment system does not actuate unless sensors indicate that the rocket has landed
	Coding error			
	Improper wiring			
	Component failure in a non safe mode			

Rover deployment mechanism structural failure	Pre-existing crack propagation	Slight imbalance affecting flight path, Premature rover deployment, Rover unable to deploy, Challenge incomplete	2D	Deployment mechanism components will undergo structural testing to ensure they can withstand all loads with a factor of safety of 2
	Delamination of printed material			
	Adhesive improperly mixed and set			
	Hard impact with ground			
Rover drivetrain unable to move	No signal reception	Rover unable to leave rocket navigate or avoid obstacles, Challenge incomplete	2C	Rover will use accelerometer data to adjust course if stuck
	Depletion of LiPo Battery			
	Component failure			
	Coding error			
Rover encounters obstacles	Unfavorable landing location	Rover unable to move, Battery depletion, Challenge incomplete	4B	Wheels will be large and have strong traction and high-torque motors, lead screw deployment mechanism is strong and can open despite obstacles
	Deployment system obstruction			
	Challenging terrain			
	Inadequate ground clearance			
Rover deployment does not activate	No signal reception	Solar panels unable to actuate, Rover drivetrain unable to move, Challenge incomplete	4C	System will be tested in advance, receiver will have a large antenna
	Depleted 9V battery			
	Component structural failure			
	Coding error			

Solar panels do not actuate	No signal reception	No power generation, LED not lit, Challenge incomplete	4D	System will be tested in advance, simple design with a high torque servo minimizes chance of failure due to obstruction or structural failure
	Physical obstruction			
	Structural failure			
	Coding error			

Table 6.1.5: Propulsion FMEA Chart

Hazard	Causes	Impacts	Risk	Mitigation Strategy
Improper assembly of motor	Incorrect spacing between propellant grains	Motor failure; unstable flight; target altitude not reached; damage or loss of rocket	1A	Ensure proper training and supervision by safety advisor for motor assembly by student safety officer
	Motor case improperly cleaned			
	End caps improperly secured			
Motor detachment from rocket body during flight	Lack of epoxy for connecting components to each other in the motor retention system	Loss of thrust; Uncontrolled flight; Target altitude not met; Main parachute may not deploy; Injury from being hit by the motor falling	1C	Finite element analysis of each component of the booster section as well as the assembly itself; Visual inspection of sufficient usage of epoxy; Ground static fire test of motor to ensure that the retention system withstands high stress
	Breakage of screws attaching the retention ring onto the body tube			
	Breakage of retention ring			
Premature propellant burnout	Improper motor assembly	Insufficient total impulse; Target altitude not reached; Main parachute may not deploy;	1C	Motor assembly by student safety officer which is overseen by safety advisor; Utilize motor from a reliable supplier;
	Insufficient propellant			

	Propellant became wet before motor assembly			
	Faulty propellant			
Centering ring failure	Centering ring's structure not durable to force	Unstable flight; Unexpected flight trajectory; Damage/loss of rocket;	2B	Usage of high yield strength material for the centering ring; Design that allows the centering ring to withstand force resulting from failure of another centering or retention ring; Visual inspection to ensure that sufficient epoxy is used in the assembly; Stress test on the centering ring
	Material used for centering ring has low yield strength			
	Insufficient epoxy used to attach the centering ring onto the body tube and motor mount tube			
Thrust plate failure	Propellant burning through motor casing	Unstable flight; Unexpected flight trajectory; Motor shoots through the rocket; Destruction of ATS system; Destruction of drogue parachute Damage/loss of rocket;	2B	Usage of high yield strength material for the thrust plate; Usage of thicker material; Visual inspection of sufficiency of the epoxy;
	Material used for thrust plate not capable to withstand the mechanical stress and thermal stress			
	Insufficient thickness			
	Insufficient epoxy used to attach the thrust plate to the body tube			
Propellant burns through casing	Improper motor assembly	Loss of thrust; Loss of stability; Destruction of ATS; Unexpected flight trajectory; Destruction of drogue parachute; Loss/catastrophic failure of rocket;	1D	Motor assembly by student safety officer which is overseen by safety advisor; Thermal/structural design analysis of thrust plate;
	Damage on motor casing during transportation			
	Damage/destruction of thrust plate			
	Faulty propellant			
Propellant explosion	Faulty propellant	Destruction of motor casing; Loss of rocket;	1D	Motor assembly by student safety officer which is overseen by safety advisor;
	Improper motor assembly			

Propellant ignition failure	Defective igniter	Rocket does not launch; Replacement required	3B	Inspection of the igniter before launch; Inspection of the connection between the igniter and the motor, and igniter with the power source;
	Loose connection of the igniter			
	Improper motor assembly			
	Faulty propellant			
Motor misalignment	Centering rings not equally sized	Unanticipated, arched flight trajectory; Unstable flight;	3B	Manufacturing of centering ring with careful consideration of tolerance; Assembly of fins and centering rings onto the motor mount tube using fin alignment jig
	Centering rings not aligned properly			
	Fins not attached to motor mount tube perpendicularly			

Table 6.1.6: ATS FMEA Chart

Hazard	Causes	Impacts	Risk	Mitigation Strategy
ATS disintegration	Mechanical failure of components	Creates moment, Insufficient Drag	1C	Accurate stress analysis
	Loose bolts			Thorough inspection after assembly
	Threadlocker disintegration			Application of threadlocker according to the manual
ATS deployed during burnout	Wrong Input sent from Raspberry Pi	creates moment	1D	Flight simulation before actual flight
				Thorough code Inspection
No response from ATS	Depleted LiPo battery	Insufficient or excessive drag	3C	Check battery status before flight
	Depleted 9V battery			
	No input from Raspberry Pi			Flight simulation before actual flight
				Thorough code Inspection
	Wrong data from altimeters			Test/inspection before assembly

	Severed connection between altimeter and Avionics bay			Shock/vibration proof connection
	Internal failure of Motor			Test/inspection before assembly

Table 6.1.7 : Raspberry Pi and Sense HAT Failure Chart

Hazard	Impact	Cause	Risk	Mitigation Strategy
Loss of power	Loss of actuation and failure to reach target altitude; Halt in data collection; Possible data corruption	Battery drain	2C	Ensure battery is fully charged before flight
		Improper battery voltage		Maintain good care of battery, care to prevent overuse
		UBEC failure		Test proper function before flight
		Wire failure (disconnection, short)		Ensure wired connection are secure and insulated
Total GPIO Failure	Loss of GPIO; Improper signal outputs and failure to reach target altitude; Possible backpowering of data connections	Short between GPIO pins	2E	Ensure care is taken when manually altering GPIO; Insulate GPIO connections
Output Failure	Loss of actuation and failure to reach target altitude	Faulty code (blocking, improper loop termination)	2D	Extensive software testing
		Output wire failure (disconnection, short)		Ensure stable, strong, insulated wire connections
Improper calculations	Failure to reach target altitude	Faulty code	2D	Extensive software testing

Table 6.1.8: ATS Avionics Housing

Hazard	Impact	Cause	Risk	Mitigation Strategy
Improper Deployment of ATS	Failure to Properly deploy ATS, overshoot or undershoot apogee	Insecure connections on ATS housing, Nut sockets that are loose.	3C	Double-check integrity of screws before assembly.
		Cable disconnect within housing		Properly and securely connect all cables, and check before flight.

Electric Shock	Injury to team member	Improper wiring within housing, cable fault	3B	Handle electronics with care, and properly connect all wires

Table 6.1.9: GPS

Hazard	Impact	Cause	Risk	Mitigation Strategy
Signal Failure	Unable to get GPS lock and locate the rocket.	Improper Soldering- Solder Bridges	2B	Check all the solder joints to ensure no faulty soldering
		Interference from Rover Electronics		Verify signal transfer before flight
Battery Failure	GPS Transmitter failure	Battery Drain	2D	Insert a new battery into the GPS to ensure a fully functional battery during launch
Disconnection from the Rover plate	Harm the Rover system and/or airframe due to collisions	Loose joint between the GPS mount and pusher plate or between GPS and GPS mount	2C	Test and ensure tight connections
Soldering Lead	Injury to team member	Improper soldering techniques used during Surface Mount soldering on a small circuit board	3B	Hand-solder the electronics with caution and check each connection before performing the next one

6.2. Design, Construction, and Assembly Safety

6.2.1. Machining Procedures

Title: Machining Metal Components

Min Personnel Requirements: 2 people

Materials (ref 6.3 Material Handling)

- Metal (conglomerates and particulates)

Safety Equipment Required

- Safety glasses
- Safety gloves

Material Preparation

- Ensure clean material surface
- If surface finish is important, can sandwich workpiece in between to piece of wood, or place tape over surface for finer cutting procedures
- Pre-measure and mark up surface of material to designate cutting lines
- Have a dimension drawing for the part readily available for reference

Workspace Preparation & Precautions

- N/A

Power Sawing

1. Ensure metal piece is not too thick. Most bandsaws do not support cutting pieces of aluminum over .25”, and that number is even lower for steels
2. While tool is off, clean the area and tool of any dust or left over metal shavings
3. Ensure correct blade is being used (metal not wood)
4. Lower blade guard so the the bottom of it is as close to the top surface of the metal as possible
5. Turn on
6. Set correct speed for material being cut (slower for metals)
7. Ensure another person is supervising
8. Hold the metal firmly with two hands
9. Ensure hands are not positioned in a way that could cause them to run into blade if metal suddenly gives
10. Begin cut, be patient and precise

Water-jetting

1. Ask PI for supervision or help setting up the waterjet
2. Ensure workpiece is flat
3. Clamp workpiece to constrain x and y axis movement. This step is critical as the waterjet creates large forces and vibrations that have high tendencies to shake parts loose and ruin the operation.
4. Ensure that position of jet cutter is centered above piece
5. Ensure path of jet never leaves the workpiece
6. Ensure "kerf", or jet diameter is on correct side of cutting line to achieve desired dimensions
7. Adjust offset height from workpiece
8. Raise water level between .25" and .5" above the workpiece
9. Make sure waterjet settings are set to cut the specific metal being used

Drilling

1. Measure location of hole
2. If needed, mark or create indentation at the center of the hole. An indentation will help prevent the bit from traveling. These are commonly done with a center punch
3. Align and clamp material in place to prevent workpiece from coming loose and spinning around drill bit during drilling
4. Find appropriate drill speed for type of metal being used
5. Avoid slow drilling speeds, as they tend to cause the drill bit to "bite" into the metal and create a screw-like effect
6. Blow off any metal shavings or dust as those can build up and not only damage the surface of the workpiece, but also cut flesh
7. Use a deburring tool to smooth the edges of the hole
8. To clean the inside walls of the hole, set the drill to a high speed and slowly move it through the center of the hole

Safety Officer Signature: ______________________________

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Title: Machining Wood Components

Min Personnel Requirements: 2 people

Materials (ref 6.3 Material Handling)
- Wood (conglomerates and particulates)

Safety Equipment Required
- Safety glasses
- Safety gloves

Material Preparation
- Ensure clean material surface
- If surface finish is important, can sandwich workpiece in between to piece of wood, or place tape over surface for finer cutting procedures
- Pre-measure and mark up surface of material to designate cutting lines
- Have a dimension drawing for the part readily available for reference

Workspace Preparation & Precautions
- N/A

Power Sawing
1. While tool is off, clean the area and tool of any dust or left over wood
2. Turn on ventilation system
3. Ensure correct blade is being used (wood not metal)
4. Lower blade guard so the the bottom of it is as close to the top surface of the wood as possible

5. Turn on
6. Set correct speed for material being cut
7. Ensure another person is supervising
8. Hold the wood firmly with two hands
9. Ensure hands are not positioned in a way that could cause them to run into blade if wood suddenly gives
10. Begin cut, be patient and precise

Water-jetting

1. Ask PI for supervision or help setting up the waterjet
2. Ensure workpiece is flat
3. Clamp workpiece to constrain x and y axis movement. This step is critical as the waterjet creates large forces and vibrations that have high tendencies to shake parts loose and ruin the operation.
4. Ensure that position of jet cutter is centered above piece
5. Ensure path of laser never leaves the workpiece
6. Ensure “kerf”, or jet diameter is on correct side of cutting line to achieve desired dimensions
7. Adjust offset height from workpiece
8. Ensure water level does not contact workpiece, or wood will become soggy and warp

Laser-cutting

1. Ask PI for supervision or help setting up the laser cutters
2. Ensure workpiece is flat
3. Place tape on surface of workpiece if surface finish is important
4. Ensure that position of laser cutter is centered above piece
5. Ensure path of laser never leaves the workpiece
6. Adjust laser offset height from workpiece to achieve optimal focal length

Drilling

1. Measure location of hole
2. If needed, mark or create indentation at the center of the hole. An indentation will help prevent the bit from traveling. These are commonly done with a center punch
3. Align and clamp material in place to prevent workpiece from coming loose and spinning around drill bit during drilling
4. Find appropriate drill speed for density of wood being used
5. Avoid slow drilling speeds, as they tend to cause the drill bit to “bite” into the wood and create a screw-like effect
6. Blow off any wood shavings or dust
7. Use a deburring tool to smooth the edges of the hole
8. To clean the inside walls of the hole, set the drill to a high speed and slowly move it through the center of the hole

Safety Officer Signature: ______________________________

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Title: Soldering

Min Personnel Requirements:1 person

Materials (ref 6.3 Material Handling)

- Unleaded Solder
- Soldering Iron
- Helping Hands

Safety Equipment Required

- Safety glasses
- Safety gloves

Material Preparation

- Inspect material for cracks or other structural defects
- Turn on the soldering iron and allow it to heat ensuring it kept in a safe orientation
- Tin the tip of the soldering iron with a small dot of solder
- Secure the workpiece in the helping hands soldering jig

Workspace Preparation & Precautions

- Ensure all flammable / combustible materials are clear of the soldering area
- Ensure solder tip is clean
- Make sure to wash your hands at the end of work

Soldering

1. Insert all electrical components to be connected into protoboard
2. Bend the ends of the components to ensure they do not move while soldering
3. Touch tip of soldering iron and solder to the component lead to be soldered from the back side of the board.
    a. Be careful to use only the amount of solder needed to secure the connection
4. Visually inspect your work to ensure the correct components are soldered together and no short circuits have been inadvertently created.

Safety Officer Signature: ______________________________

- -

Title: LiPO Charging

Min Personnel Requirements:1 person

Materials (ref 6.3 Material Handling)

- LiPO Battery

- Charging transformer

Safety Equipment Required

- Safety glasses
- Safety gloves

Material Preparation

- Inspect battery for bulges, punctures, and other forms of physical damage
- Take care to prevent the battery voltage from dropping below the allowable recharge threshold

Workspace Preparation & Precautions

- Ensure all flammable / combustible materials are clear of the charging area
- Ensure the charger is set to the correct recommended safe settings for the battery to be charged.

Charging

Special Care must be taken to ensure battery is never left unattended during a charge cycle, allowed to overheat, be punctured, or otherwise damaged else serious injury may occur.

1. Plug the charging transformer into the wall and double check the settings and the battery type to be charged.
2. Plug in the battery's charging lead to the appropriate receptacle on the charging transformer
3. Begin the charge cycle

Safety Officer Signature: ______________________________

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6.3. Material Handling

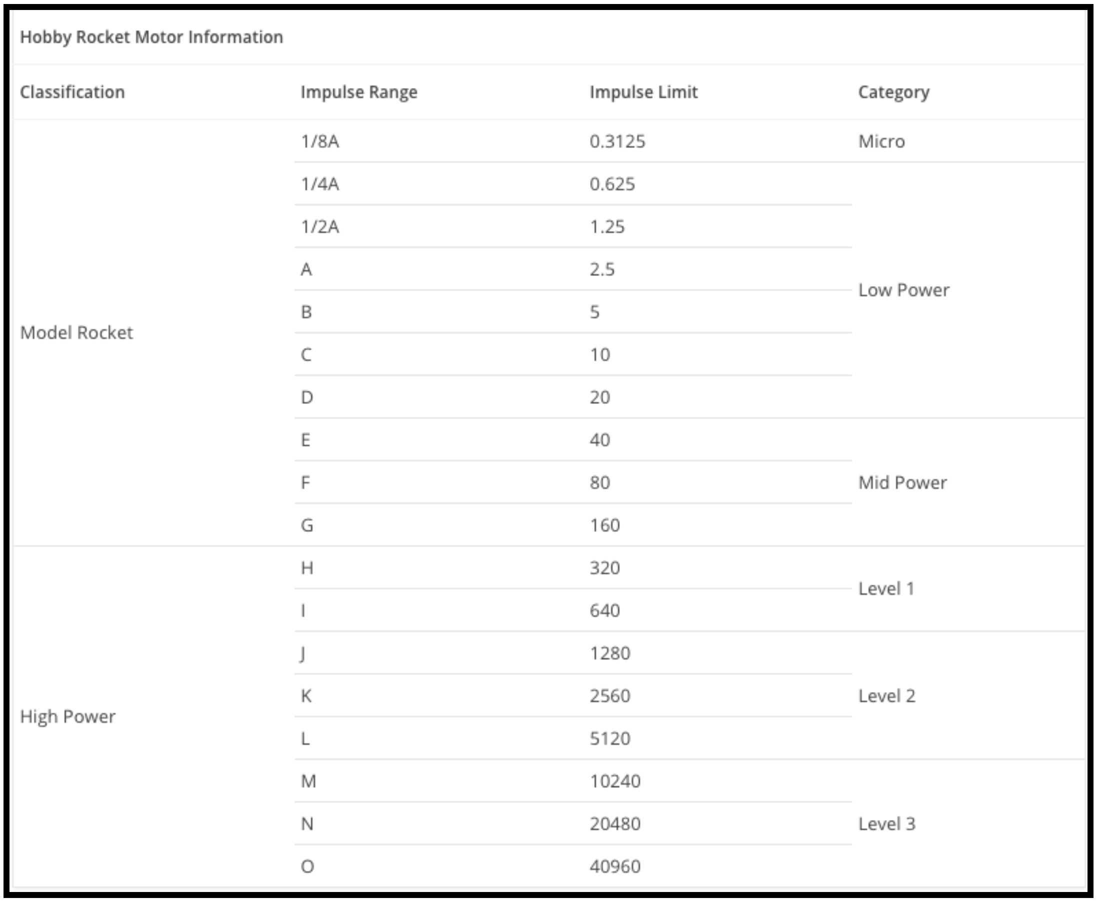
Table 6.3.1 Common Materials Used and their Properties

Material	Description	Density (kg/m^3)	Young's Modulus (GPa)	Shear Strength (MPa)	Compressive Strength (MPa)	Flammability
Balsa (longitudinal HD)	Tropical, light wood used in model building, packaging, and insulation	240 - 300	7.2 - 8.8	4.5 - 5.6	18 - 26	High
Balsa (transverse HD)	Tropical, light wood used in model building, packaging, and insulation	240 - 300	0.23 - 0.28	13.5 - 16.8	1 - 1.45	High
Balsa (longitudinal LD)	Tropical, light wood used in model building, packaging, and insulation	120 - 140	2.8 - 3.4	2.2 - 2.7	6.2 - 9.5	High
Balsa (transverse LD)	Tropical, light wood used in model building, packaging, and insulation	120 - 140	0.09 - 0.11	6.6 - 8.1	0.5 - 0.85	High
ABS	Thermoplastic commonly used in 3D printing/molding	1020 - 1080	2 - 2.9		35.9 - 69	High
ABS (15% carbon fiber)	Thermoplastic commonly used in 3D printing/molding	1100 - 1140	10.3	52 - 62.9	109 - 120	High
Basswood (longitudinal)	Hardwood	370 - 460	10 - 12.2	6.1 - 7.5	29.4 - 35.9	High
Basswood (transverse)	Hardwood	370 - 460	0.43 - 0.48	18.4 - 22.4	2.3 - 2.81	High
Carbon Fiber (PEEK)	Used as resin for aerospace app.	1420 - 1440	20.7 - 25		172 - 240	Self - Extinguishing
PC (30% glass fiber)		1400 - 1430	8.62	9.65	124 - 138	Self - Extinguishing
G12CR Fiberglass		1810	21 - 24	152	448	Low
G10/Fr-4 Fiberglass		1850	21 - 24	152	448	Flame - retardant
Polyurethane Foam	Used as impact pads, insulation, packaging	75 - 85	0.00033 - 0.0004	0.0125 - 0.015	0.025 - 0.03	Self - Extinguishing

Phenolic	Used in heat shields	62.7 - 65.3	0.000489 - 0.00123	1.05 - 1.16	3.87 - 4.27	Self - Extinguishing

6.4. Purchase, Shipping, and Transporting of Rocket Motors

Rocket motors are designated by their impulse limits, as shown below. Since we are using an L1390 motor, our motor is consider a Class 2 High Power Rocket Motor.



Hobby Rocket Motor Information

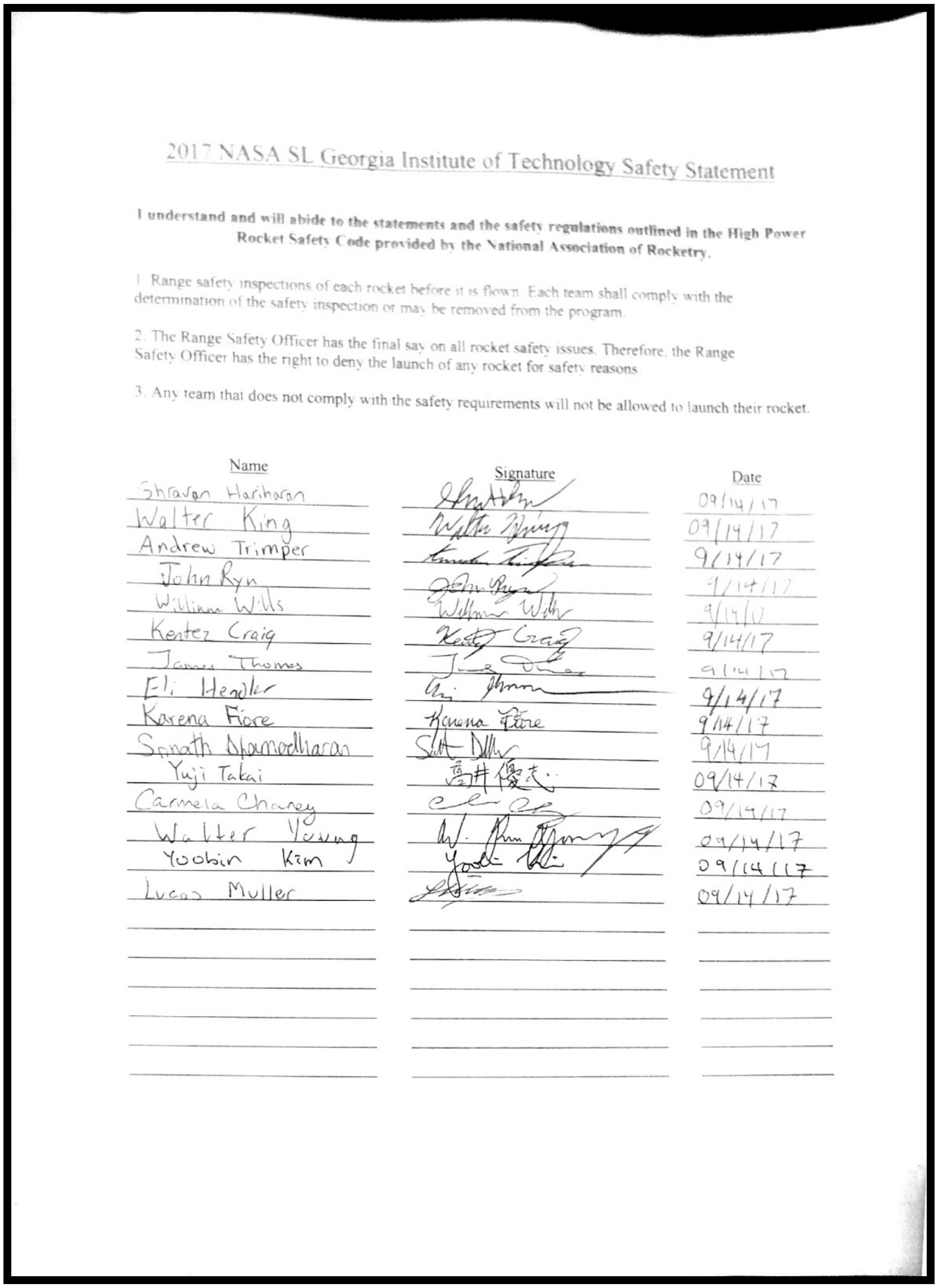
Classification	Impulse Range	Impulse Limit	Category
Model Rocket	1/8A	0.3125	Micro
	1/4A	0.625	Low Power
	1/2A	1.25	
	A	2.5	
	B	5	
	C	10	
	D	20	
	E	40	Mid Power
	F	80	
	G	160	
High Power	H	320	Level 1
	I	640	
	J	1280	Level 2
	K	2560	
	L	5120	
	M	10240	Level 3
	N	20480	
	O	40960	

Figure 6.4.1 Rocket Motor Classification (www.nar.org)

Our rocket motor will be purchased from an authorized, commercial retailer. Any motor purchases will be made by our Level 2 Certified mentor. Motors will not be tampered with in any way. Handling of these motors will be in compliance with Government regulation and NAR/Tripoli standards.

Rocket motors are composed of high-energy propellant and flammable materials, and are thus considered “hazardous materials”. Motors will be purchased in person from an authorized retailer, and transported back to the University in fire-resistant chests, well packed with dampening material to mitigate the possibilities of propellant damage. From there, motors will be unloaded and placed into fire-cabinets in a dry environment, where they will remain, untouched, until they are transported to the launch site in fire-resistant chests aboard our vehicles.

6.5. Team Safety Agreement



2017 NASA SL Georgia Institute of Technology Safety Statement

I understand and will abide to the statements and the safety regulations outlined in the High Power Rocket Safety Code provided by the National Association of Rocketry.

1. Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.

2. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.

3. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

Name	Signature	Date
Shravan Hariharan		09/14/17
Walter King	Walter King	09/14/17
Andrew Trimper		9/14/17
John Ryn		9/14/17
William Wills	William Wills	9/14/17
Kentez Craig	Kentez Craig	9/14/17
James Thomas		9/14/17
Eli Hendler		9/14/17
Karena Fiore	Karena Fiore	9/14/17
Sanath Damodharan		9/14/17
Yuji Takai	高井優志	09/14/17
Carmela Chaney		09/14/17
Walter Young		09/14/17
Yoobin Kim		09/14/17
Lucas Muller		09/14/17

Figure 6.5.1 Team Safety Agreement

7. Launch Operations Procedures

7.1. Recovery Preparation

Procedure Title: Folding and Packing Parachutes

Min Personnel Requirements: 2 people

Materials (ref 6.4 Material Handling)
- Nylon parachute
- Kevlar sheet
- Nylon shock cord

Safety Equipment Required
- N/A

Procedure
1. Folding Parachute
    a. "Fluff", or lay out, chute on a flat surface
    b. Straighten the lines so they come to a point away from the chute
        i. Untangle lines if tangled
    c. Grab all shroud lines and organize the panels of the chute
    d. Fold on the panel lines toward the center
    e. Continue folding until width is approx 2X length you desire it occupy in the rocket
    f. Bring shroud line bundle up through center, then fold over and pull back down so a small length lies outside the parachute
    g. Fold one more time, over the shroud lines

    - h. Wrap up the chute from the tip, tightly packing as you go

2. Attaching to Shock Cord
    - a. Tie a knot in the shock cord line, about ⅓ the length from the connection point to the above section
    - b. Use a quicklink to connect the knotted loop to the end of the shroud lines sticking out of the packed parachute
3. Assembling into Tube
    - a. Thread a kevlar parachute protector sheet over the shock cord until it reach the parachute (in its packed form still)
    - b. Have another person bundle up the shock cord to one side of the parachute in a figure 8 pattern
    - c. Push the bundled shock cord and packed parachute (now partially covered by the kevlar sheet) into the tube and push until it hits the bulkhead on the other end
    - d. Bundle the shock cord on the other end of the parachute in a similar way and shove into tube
    - e. Connect the two sections of the rocket to encapsulate the parachute+shock cord assembly in between the two sections of the rocket

Safety Officer Signature: ______________________________

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7.2. Motor Preparation

Procedure Title: Launch Motor Preparation

Min Personnel Requirements: 2 people

Materials (ref 6.4 Material Handling)
- Aluminum particles
- Ammonium perchlorate
- Iron oxide

Safety Equipment Required
- Safety glasses
- Latex/Nitrile gloves

Procedure
1. Delay Grain Assembly
    a. Without touching the ends of the delay grain, place the grey propellant cylinder into the delay insulator
    b. Slide this assembly into the delay spacer
    c. Grease the o-ring with synthetic teflon lube and place over exposed section of propellant grain
        - Be careful not to get any grease on the end of the propellant grain
2. Assembly of Delay Grain into FWD Closure
    a. Grease the inside of the fwd closure, make sure to clean the small hole if it become filled with grease in this step
    b. Place neoprene washer at the bottom on the well
    c. Press the delay grain assembly into the well, o-ring-side entering first

    d. Grease the main fwd o-ring, and place over the end of the fwd closure

3. Liner Insertion into Main Casing
    a. Slide liner into casing, check to ensure that it slides smoothly
        - If not, maybe have to sand down liner
    b. After ensuring fit, pull out liner, thoroughly grease the outsides, and push back in, wiping grease as it builds up around the edge. Leave .5” exposed
        - Do not grease if liner is black phenolic
    c. Place an insulator disk on top of the exposed liner, and push in until internal threads are exposed
    d. Screw on FWD closure assembly so that o-ring presses against the insulator disk
4. Grain Assembly into Casing
    a. Stand motor on FWD closure
    b. Pull liner out .5”
    c. Without touching the ends of the grain, drop the two propellant tubes into the liner
    d. Press insulator disk on top, and push down until liner stops moving
5. Aft Closure Assembly
    a. Place the nozzle into the hole
    b. Place a greased o-ring into casing, over the nozzle, so it sits on top of the insulator disk
    c. Screw the aft closure over the nozzle/o-ring
6. Final Steps
    a. Place the plastic nozzles over the aft and fwd closures

Safety Officer Signature: ______________________________

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7.3. Setup on launcher

Procedure Title: Vehicle Setup on Launchpad

*Must have safety officer present

Safety Officer: _______________

Procedure

1. Connect two fill lines to the ground system
2. Have one person angle rail guide and another slide the rocket rail buttons into the rail guide
   a. Be sure to slide the rocket on carefully, and try to minimize impact with the bottom of the rail guide, as the jostled movement may cause the propellant to become misaligned or crack
3. Once the rocket is safely placed onto the rail, reposition the rail so the rocket is pointing vertically into the sky
4. With the ignition lines still not connected to the rocket motor, turn the power switches one at a time
   a. Listen for beeping that confirms altimeter connection to both the main and drogue deployment ejection charges
   b. Repeat for the other altimeter
5. Turn any additional power switches to activate remaining systems
6. Remove the plastic cap from the bottom of the motor and push the e-match up inside until it become lodged at the very top of the motor casing
7. Take team picture (very important)
8. Walk to the control station and await launchpad activation by the NAR or Tripoli officer

- -

7.4. Igniter Installation

Title: Ejection Charge Assembly and Testing

Min Personnel Requirements: 2 people

Materials (ref 6.4 Material Handling)
- FFFF Black Powder
- Fiberglass insulation
- 9V Battery

Safety Equipment Required
- Safety glasses
- Latex/Nitrile gloves
- P95 Respirator Mask

Assembling Charges
1. Sizing Charges
    a. Using body tube diameter, and length of parachute sections, utilize online ejection charge calculator to estimate the amount of black powder needed
        i. Note: 4-shear pin design requires approx 40lb shear force to break
        ii. Using P = F / A, calculate the pressure needed to cause an appropriate shear force
        iii. Use F = P * A to calculate the force on the bulkheads during ejection events
2. Bagging and Storage
    a. Black powder is plastic-safe, but easily corrodes metals, so be sure to store in a plastic container
    b. Black powder must be stored in a dry environment so ensure water-seal

3. Placing in Vehicle
    a. With the ejection wells oriented upward, carefully pour the black powder into each well
    b. With the leads twisted together, place an e-match in each well so that the igniter lies inside the black powder
    c. Pack fiberglass insulation into the well and place a strip of tape over the top to keep the assembly packed inside the well
    d. Untwist the leads on the e-matches, and place them into the correct holes in the terminal block on the bulkhead
    e. Screw down the wires to secure them into the terminal block

Testing Charges

1. Lead Extension
    a. Measure out two strips of at least 5 ft long 22 AWG wire, preferably of different colors
    b. Strip end of wire
    c. Route ends of wire into respective holes in terminal block to connect to one of the e-matches connected to the other end of the terminal block
2. Vehicle Assembly
    a. Route the extension wires out of an access hole
    b. Close sections of rocket, with parachutes packed inside and protected with kevlar sheets
    c. Insert shear pins
3. Vehicle Positioning
    a. Position vehicle so it lies on its side
    b. Ensure the bottom is placed against a wall, or other solid surface
    c. Ensure the trajectory is clear of obstacles
    d. Angle rocket slightly so nose does not aim toward the ground
    e. Preferably tested outside on grass to prevent damage to tubes during impact

4. Personnel Hazard Mitigation
    a. Test outside, in an open space (>50 ft radius without other people or obstacles around)
    b. Stand at least 5 ft away from the vehicle, to its side, when shorting the leads to create the ejection event
    c. Make sure there are no loose object in the compartments that are undergoing ejection charge testing to minimize risk of ejecting solid objects at high velocities away from the rocket
    d. Have a fire extinguisher nearby in the case that a fire results from the ejection event
5. Test
    a. Standing >5 ft to the side of the vehicle, short the leads of the extension wire across a 9V battery
    b. Watch for flames
    c. Wait approximately 30s before touching components of rocket, as they may be hot

Safety Officer Signature: ______________________________

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7.5. Vehicle Assembly

Title: Shear Pin / Rivet Installation

Min Personnel Requirements: 1 person

Materials (ref 6.4 Material Handling)

- Fiberglass (depending on tube material)

Safety Equipment Required

- Safety glasses
- >P90 Respirator (if fiberglass tubing used)
- Safety gloves (if fiberglass tubing used)

Procedure

1. Shear Pin Installation
    a. Assemble rocket
    b. Using permanent marker, create two “witness marks” across the separation line between two sections of the rocket (for consistent future orientation)
    c. Drill X number of 1/16” dia holes, equally spaced, around the perimeter of the tube
        i. Ensure that sections do not “wiggle” while drilling holes as may cause misaligned of previously drilled holes
        ii. Ensure that rocket tube is empty before drilling, as there is a high risk of drilling into parachute or shock cord and causing damage
    d. If tube is paper: place drop of glue inside to stiffen the walls of the hole
    e. If tube is hard (fiberglass, carbon fiber): tap the hole to create threads for the plastic screw, aka “shear pin”
    f. Thread or push shear pins into holes after aligning with the “witness marks”
2. Shear Pin Removal
    a. unscrew /pry out head of shear pin
    b. Use small drill bit to push in the other section of the pin lodged in the hole of the inner tube
3. Rivet Installation
    a. Repeat steps a & b from “Shear Pin Installation”, above
    b. Drill X number of 11/64” holes, equally spaced, around perimeter of tube
        i. Ensure that sections do not “wiggle” while drilling holes as may cause misaligned of previously drilled holes

        ii. Ensure that rocket tube is empty before drilling, as there is a high risk of drilling into parachute or shock cord and causing damage
    c. Assemble rocket sections
    d. Push shear pins into each of the holes
    e. Push heads of pins into the hole on top of each pin until it stops
4. Rivet Removal
    a. Pull head out of rivet
        i. May require flathead screwdriver to pry out
    b. Pry out rivet body

Safety Officer Signature: ______________________________

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7.6. Launch Procedure

Table 7.6.1 2017-2018 Launch Checklist

Prepare Rocket Payload	
	Ensure all batteries are new/fully charged and connect to system electronics.
	Ensure vital electronics are all connected correctly to each other and running properly.
	Ensure recovery system is wired redundantly and correctly. Ensure again.
	Insert payload electronics into the avionics bay.
	Connect all external switches and motor control outputs.
	Arm altimeter and ensure that proper startup sequence follows.
	Disarm Altimeter.
	Arm apogee targeting system and verify that startup runs as expected.
Prepare Rover	
	Ensure battery voltages are ~ 11.1 V
	Plug in rover deployment batteries
	Turn on radio transmitter and ensure that receiver status light is illuminated
	Test forward and reverse actuation
	Fully extend rover deployment system
	Place rover into deployment system
	Perform GPS pre-launch checklist
	Plug in rover batteries
	Connect wire that triggers rover movement
	Fully retract rover deployment system
Assemble Charges	
	Remove protective cover from e-match
	Place tape adhesive side up in fishtail shape >
	CAUTION: Black powder is highly flammable. Before measurement, make sure to keep away from all sources of flame and heat

	Measure amount of black powder decided in ejection charge testing using tared massing scale
	Place e-match on tape with adhesive side up at center of fishtail
	Pour black powder over e-match
	Seal tape in square pattern
Check Chute Connections	
	Ensure altimeters are disarmed
	Connect charges to ejection wells
	Turn on altimeters to verify continuity
	Disarm altimeters
Pack Parachutes	
	Connect ends of drogue shock cord to Booster and Avionics sections
	Attach drogue parachute to drogue shock cord using quick-link carabiner or bowline knot
	Fold parachute over itself until appropriate thickness is achieved
	Fold cord between carabiner and parachute over folded parachute
	Roll parachute tightly sleeping-bag style
	Insert rolled parachute into compartment between booster section and avionics bay
	Fold excess shock cord so it does not tangle
	Attach Nomex cloth to shock cord so it will enclose and shield the parachute while exposing only the Kevlar shock cord to ejection charge
	Ensure that parachute + cloth moves easily in/out of tube. If there is any undue resistance, remove parachute and repack tighter
	Insert cellulose wadding into drogue parachute bay between ejection charges and parachute
	Insert Avionics bay into Booster section, and secure with 4 shear pins
	Attach main parachute shock cord to eye-bolt on upper end of Avionics bay and U-bolt on bottom end of nose-cone
	Attach main parachute to main parachute shock cord via quick-link carabiner or bowline knot
	Fold parachute over itself until appropriate thickness is achieved
	Fold cord between carabiner and parachute over folded parachute
	Roll parachute tightly sleeping-bag style

	Ensure that parachute + cloth moves easily in/out of tube. If there is any undue resistance, remove parachute and repack tighter
	Insert cellulose wadding into main parachute bay between ejection charges and parachute
	Insert main parachute and shock cord into main parachute bay between avionics bay and nosecone section
	Fold excess shock cord so it does not tangle
	Attach Nomex cloth to shock cord so it will enclose and shield the parachute while exposing only the Kevlar shock cord to ejection charge
	Insert cellulose wadding into upper payload parachute bay between ejection charges and parachute
	Secure avionics bay and upper tube with 4 shear pins
Assemble motor	
	Note: Do not get grease on propellant grains or delay grain
	Note: Do not install igniter
	Follow manufacturer's instructions
	Note: ensure the motor remains vertically oriented until launch
	Unscrew motor retention cap and, while the rocket is in the upright position, slide in the assembled motor.
	Screw in motor retention cap to keep motor secure in rocket
	Check screws securing baseplate to the Booster tube to ensure they are not loose. If loose, apply a small amount of blue loctite and retighten
Altimeter Setup	
	Test altimeter continuity with multimeter
	Visually inspect altimeter for safety
	Test battery voltages with multimeter
	Arm ATS rotary switch (must be armed first to ensure proper serial connection)
	Arm rotary switches and verify beeps indicate appropriate altitude
Launch Vehicle Prep	
	Inspect launch vehicle, check CG and make sure it is within specified range
	Bring launch vehicle to Range Safety Officer(RSO) for inspection
	CAUTION: Keep igniter clips away from all flammable materials, as sparking will occur. Cover eyes, and skin to prevent burns.

	Touch igniter clips together to make sure they will not fire the igniter when connected
	Connect igniter clips to motor igniter
Launch	
	Watch flight so launch vehicle sections do not get lost
Post Launch Payload/Vehicle Recovery	
	Use GPS (eggfinder tx) to locate launch vehicle
	Recover Payload Section and tethered Body/Booster Section
	Disarm Altimeters if there are unfired charges
	Disassemble launch vehicle, clean motor case, other parts, and inspect for damage
	Record altimeter data

7.7. Troubleshooting

Disarming Procedure & Re-Setup on Launchpad

1. If motor does not ignite, remove ignition interlock
2. Wait approx one minute to allow gases to disperse
3. Walk out to launchpad
4. Disarm all electronics by turning off switches
5. Carefully remove rocket from pad
6. Reinstall e-match igniter
7. Remount rocket on guide (follow “Setup on Launch” procedure)
8. Re-arm electronics
    a. Listen for altimeter beeping to check for connection to deployment charges
9. Walk back to control station and retry launch

7.8. Post-flight inspection

Recovery

1. Inspect avionics bay housing for cracks and other damage
2. Inspect electrical connections for damage
3. Switch each altimeter on and off and check for error codes via audible signal
4. Pull the flight data from each altimeter using the programming cable.

ATS Inspection

1. Mechanical
    a. Check to make sure flaps are fully intact
    b. Check to see if flaps have bent (could be cause by impact with ground)
    c. Move flaps in and out by hand to ensure that they are still locked in sync with each other, proving the internal linkage mechanism has not failed
2. Data Collection
    a. Remove rivets holding ATS bay to Booster section
    b. Unscrew ATS unit from sides of tube
    c. With flaps fully recoiled, slide out ATS mechanism and the electronics equipment
    d. Interface computer with Raspberry Pi SD-card to pull data from the flight
    e. Check flight velocity and acceleration curves to see impacts of ATS on flight
    f. Check altitude curve to see how close apogee was to 5280 ft

GPS Inspection

1. Visually check GPS for damage
2. Check that the system can still maintain a GPS lock
3. Check that GPS can send data back to the ground station

Rover Inspection

1. Visually observe whether Rover deployed from tube or not
2. If it did, use a tape measure to record distance rover traveled from vehicle
3. Check to see if vehicle is intact, as landing impact may have damaged wheels/mounting
4. If rover was never deployed, try to trigger remote once again to see diagnose if it was a transmission range-related problem

5. If rover bay opened by rover was not deployed, observe what mechanical failure prevented rover vehicle from leave the rocket

Launch Vehicle Inspection

1. Check for visible cracks in the tubing or nose cone
2. Observe whether or not any piece came down, untethered to the rocket
3. Check parachutes for burn damage, indicating poor packing of protective material around them
4. Check shock cord for burn or fraying damage
5. Check bulkheads for cracks around the area where the u-bolts/eye-bolts are secured

8. Project Plan

8.1. Testing Plan

8.1.1. Airframe Testing and Results

Bulkhead Load Tests:

We constructed mockups of the different bulkheads to ensure that the bulkhead simulations were accurate. We made two different mockups: one for the avionics bay and another epoxied to the fiberglass body tube. For the avionics bay setup, we used the threaded rods, coupler and main bulkheads, and eye-bolts used in the actual rocket. These mockups would allow us to test the durability of the fiberglass bulkheads and the epoxy bond used in the rocket.

Using a waterjet, we cut a piece of fiberglass to the dimensions of its respective CAD model used for simulations. In addition, the waterjet was used to cut the plate to be used for the top. At the u-bolt locations at the top, four holes were drilled around the tube. Epoxy was used to connect the top plate and the tubing. In Figure 8.1.1, it is shown that using the epoxy, we created fillets. We tied the string to the u-bolt to simulate the force as it would be in the actual rocket.

Figure 8.1.1 Bulkhead after epoxy

Cord was strung through the four holes that were drilled into the side of the tubing to hold it down and testing simulate the force from the other side, which can be seen in Figure 8.1.2. This ensured that the u-bolt would fail as it had many points of contact, spreading pressure evenly along the tubing of the body. It would fail before the other side, which was the single point of contact that was being tested when put into the stress testing machinery.

Figure 8.1.2 Mockup with cord

For the avionics bay mockup, it was necessary to construct both sides of the avionics bay. This is because the two bulkheads are connected by threaded rods in the rocket. The bulkheads were waterjetted, accurately cutting both the coupler and main bulkheads. However, when the waterjet was used on the fiberglass, air bubbles formed in the fiberglass due to separation in the fiberglass layers caused by the high water pressure. The holes for the threaded rod and eyebolt had to be drilled by hand because of this.

The centers of the bulkheads were measured in multiple ways. For the first method, multiple chords were drawn across the bulkheads. Line segments from their midpoints were drawn, and their intersection was used as the center of the bulkhead. However, this was not accurate. Instead, we used a caliper and ruler to measure the widest section of the bulkhead, the diameter, and used the midpoint to determine the center. All four of the bulkheads (2 coupler and

2 main) were clamped together. The hole was drilled at the center multiple times, incrementally increasing drill bit sizes each time. Using measurements from the CAD model, the locations of the threaded rod holes were determined and replicated on the bulkheads using a caliper. Holes were drilled in the same fashion as the center hole was drilled, with the four bulkheads clamped together.

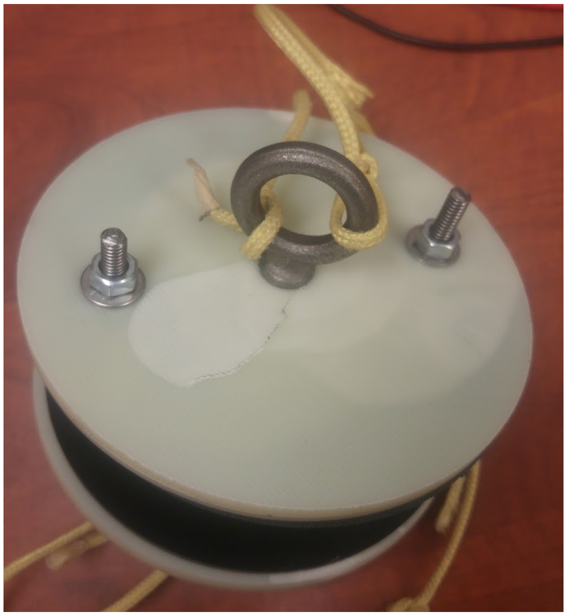

Figure 8.1.3 Bulkhead with Hole Locations

The bulkheads were placed 3 inches apart so that they wouldn’t interfere with each other while minimizing the length of the threaded rod used. The rods were inserted in their respective holes, and the bulkheads were fixed using nuts and washers. The eyebolts were fastened in the same way. Shock cords were tied to each eye bolt in order to simulate the parachute shock cord connection to the bulkheads. The final assembly is shown in Figure 8.1.4. The impulse from parachute deployment generated a larger force than the ejection charge detonation, so the parachute deployment force was chosen as the test force.

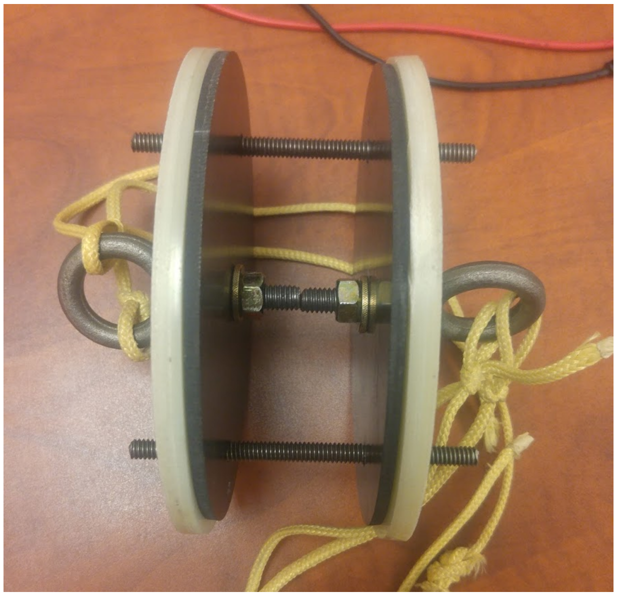

Figure 8.1.4 Avionics Bay Mockup

The mockups were tested in a tensile tester, which pulled them from both sides until they failed. A segment of the shock cord was tied to either side with a bowline knot, and the mockups were tested by attaching the shock cord to the tensile tester. The experiments were repeated with a doubled-up shock cord to provide additional strength. The figures below demonstrate the test setup.

Figure 8.1.5 Bulkhead Epoxy Test

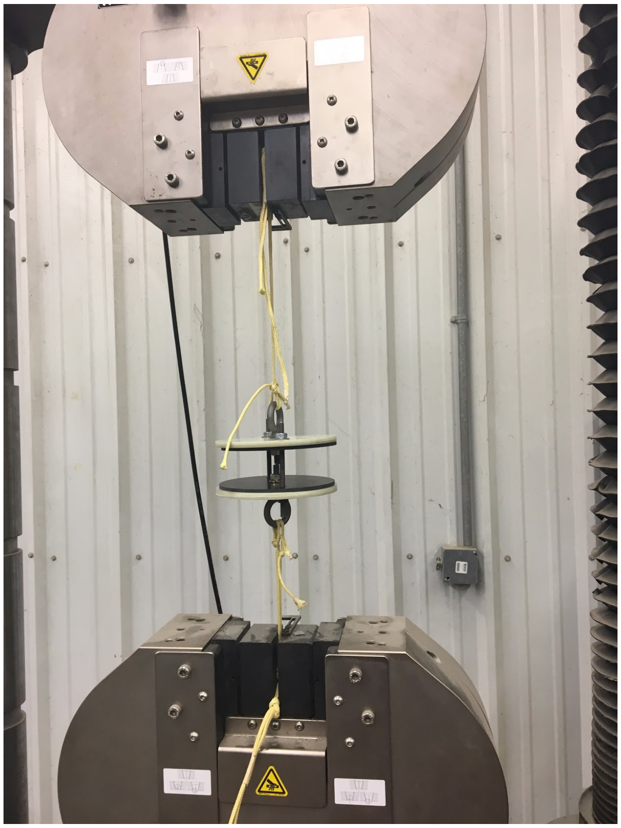

Figure 8.1.6. Avionics Bay Bulkhead Test

Figure 8.1.7. Deformation of fiberglass bulkheads

Failure in all instances occurred due to the shock cord breaking instead of the fiberglass or epoxy bond failing, as shown in Figures 8.1.6 and 8.1.7. The maximum force experienced in the simulations was 998.711 N, or 224.5 lbs. The loads approached near 500 lbs. during load testing, which is more than double the maximum theoretical force the rocket could experience. The shock cords, however, were rated to withstand up to 1500 lbs., meaning they failed much sooner than expected. This could be due to fraying caused by tying knots on the cord and clamping the knots in the tensile tester, as this would decrease the structural integrity of the cord. Also, at maximum load force, the fiberglass bulkheads were observed to begin to bend, showing elastic deformation. This is shown in Figure 8.1.7, as the centers of the bulkheads moved away from their equilibrium positions. Since the force was double what the rocket would experience, the deformation is not a problem. In addition, after testing, the bulkheads returned to their original configuration. Overall, all of the components tested passed the physical load tests as well as the simulations from the calculated forces and will perform as expected during the rocket's flight.

Bulkhead Failure Modes:

Without testing these simulations, there would be no way to support the durability of the rocket, which would allow for many points of breakage. The CAD models show the stress distribution across the bulkheads as well as their weakest points; the force simulation showed that each bulkhead was far more durable than the max force experienced from both the impulse of the parachute deployments, and the black powder explosions. Any force greater than this would have caused the bulkheads to immediately break away from the rocket, causing the launch vehicle to separate and accelerate past the maximum allowed velocity. This would affect either the nose cone or thruster section depending on the bulkhead, and the result would possibly injure people below. To support this claim, in accordance with the CAD models, if the bulkheads exceeded a force greater than the G10 fiberglass' maximum yield strength of 6.5 * 10^7 N/m^2, the bolts attached would break away, destroying the only connection between the main sections of the rocket.

Although bulkhead destruction is a major concern, the thread connection between the bulkhead and parachute is more likely to break. The thread would rip and cause the rocket to separate if 500 lbs. of force was created during the impulse of parachute deployment. To test thread failure, a tensile testing machine was used with an aluminum force transducer setup attached. The failure point of the transducer setup was first tested to determine the max load that could be accurately measured before necking occurred in the aluminum used to construct the instrument. The thread would break first, however, indicating that it is the rocket's weakest point. However, testing it allows us to know that it will not reach its maximum force load, thus keeping it intact, and ensuring that the rocket structure will not fail.

For ejection testing, the black powder explosion has the many points of errors. This is due both to its volatile nature and the direction that the explosion can be concentrated in. This could case breaches in the tubing of the rocket, altering the aerodynamics of the overall air flow. However, shown through simulations, the maximum force of the explosion is not close to the maximum load, ensuring the launch vehicle will safely make it through the flight.

The force simulations for the aluminum plates and brackets in the launch vehicle all indicated an ability to withstand much greater loads than they will be subjected to from flight. Tensile tests were performed on the aluminum stock to both ensure the accuracy of simulation data and to understand at what loading profile the aluminum would fail.

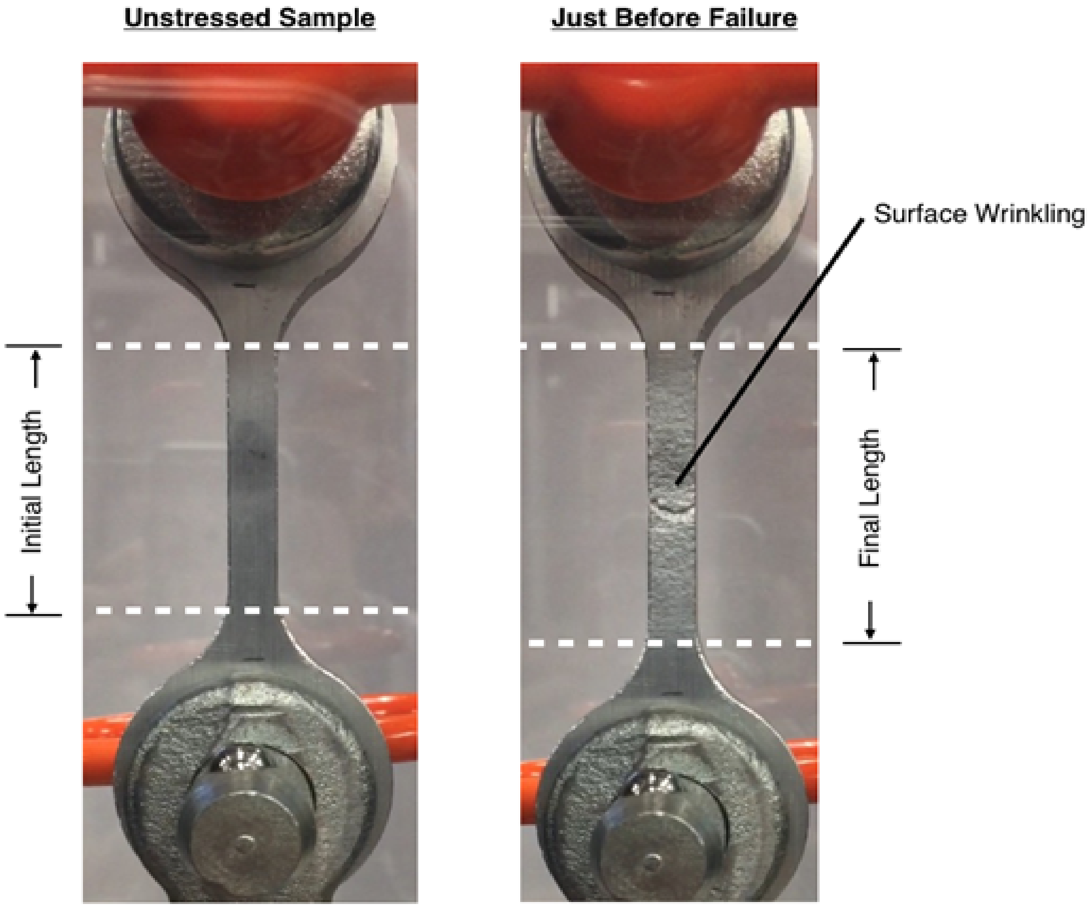

Figure 8.1.8 Aluminum Stress Tests

The figures above show images of the aluminum test piece before it had been stressed, and just before it has reached its ultimate tensile stress and failed. Through the figures, it is evident the workpiece was strained, as the uniform section is noticeably longer after being stressed along with a difference in surface appearance at the two moments. The surface becomes wrinkled and stressed, mostly affected toward the center where necking occurred at the moment of failure. This a result of stress overcoming the surface tension of the part, causing it to crack as it elongates.

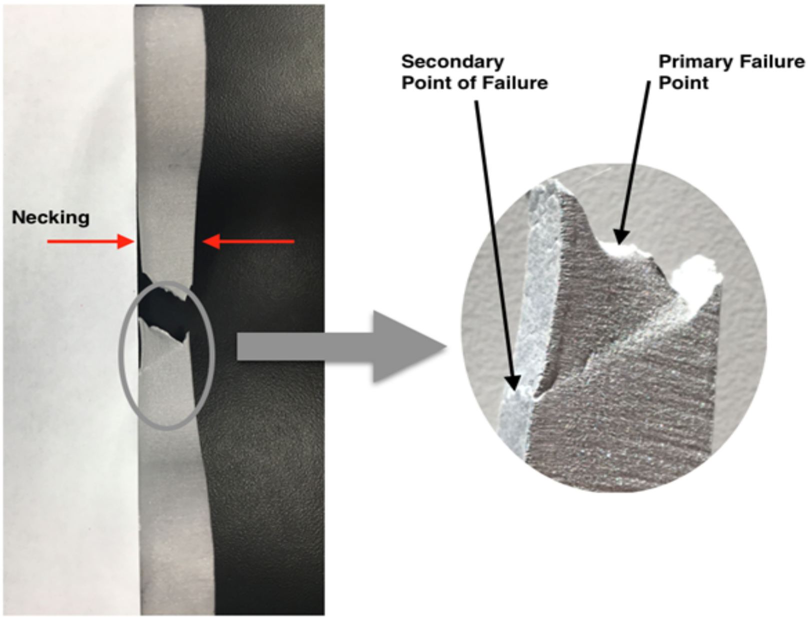

Figure 8.1.9: Aluminum Test Piece After Failure

Figure 8.1.9 shows the aluminum workpiece after failure. It is clear to see the curvature created during necking when lining the pieces up against a straight piece of paper. This occurred because the part needed to reduce cross sectional area in order to satisfy its conservation of volume as it was strained. There were two points of severe cracking that resulted in failure. The figure on the right shows the primary and secondary points of failure. The secondary point was very close to failing although the primary point was the final point of separation.

If the aluminum were to fail, any external parts attached would severely impact the flight profile of the rocket. These parts include the wing brackets (both the parts that rotate the flap and the parts that hold on to the fins) and the bottom most plate of the rocket. The brackets that hold the avionics tray in place and the gear that ensures synchronization of the flap motion are the only internal aluminum fixtures. If these failed, the avionics bay mounting tray with installed electronics would be free to move around the bay and be subject to modeled flight forces. This would damage control and recovery systems, and the vehicle would go ballistic and impact the ground at a detrimental rate. If the gear failed it is likely that at least one of the flaps would rotate out of sync and impart a significant torque that may lead to a ballistic trajectory back to Earth. If the bottom plate failed the motor would fall out of the rocket and back to Earth. If the fin brackets failed, then they would be subjected to a strong drag force and would subsequently depart from the vehicle and fall back to Earth.

The following is the summary of all the tests conducted for the airframe of the launch vehicle.

Table 8.1.1 Testing Chart for Airframe

Requirement Tested	Test Description	Pass/Fail Criteria	Status
Apogee altitude of 5,500 ft without ATS activation	Several test flights without the ATS fully activated will be done to measure the apogee	The rocket reaches an apogee of 5,500ft within 2% difference without ATS activated	Completed Failed
Recovery area of 2,500 ft	The launch vehicle will undergo several test flights to validate that it lands within 2500 ft radius from the launch pad	The rocket lands in the area less than 2,500 ft away from the launch pad	Completed Successful
Component load test	Load test of the centering ring, thrust plate, and bulkhead will be conducted to verify the FEA results that the component could withstand forces applied during the flight	The components do not break by the load applied	Completed Successful

8.1.2. ATS Testing and Results

Table 8.1.2 Testing Chart for ATS

Requirement Tested	Test Description	Pass/Fail Criteria	Status
Actuation test before mounting	The assembled system will be tested before it is mounted on the rocket to identify faulty assembly	The flap must be able to be extended and retracted repeatedly	Completed Successful
Actuation test after mounting	The assembled system will be tested before it is mounted on the rocket to identify faulty mounting and wiring	The flap must be able to be extended and retracted repeatedly	Completed Failed
Altimeter Serial Connection	Check for successful data transmission between the altimeter in the avionics bay and the raspberry pi in the ATS bay	The raspberry pi must receive altitude data	Completed Successful
Altitude and Accelerometer Check	Altimeter and accelerometer data is used to ensure actuation does not occur before burnout	Using lower values for the minimum altitude and acceleration, check that the software progresses as intended	Completed Successful
Data Output	The software should output timestamped data from all sensors and continue running if a nonvital sensor is disconnected.	Datalog files contain all relevant expected information	Completed Successful

8.1.3. Recovery Testing and Results

Table 8.1.3 Testing Chart for Recovery Subsystem

Requirement Tested	Test Description	Pass/Fail Criteria	Status
Ejection Charge Testing	Ejection charges will be measured and loaded along with an electric match. Parachutes will be folded and packed. Electric matches will be ignited with a 9 volt battery and two long strands of wire.	The sections must separate cleanly forcefully. No damage must be present to any part of the rocket upon inspection.	Completed Successful
Continuity Check	A multimeter will be used to check continuity between the pyro outputs on the altimeters and the terminal blocks on the bulkheads.	No faults can be detected in the wiring. It must be shown that the proper pyro ports are wired to the correct terminals on the terminal blocks.	Completed Successful
Altimeter Code Check	Altimeter will be powered up. Error codes will be checked.	No critical error codes may be present. If an issue with the barometer is indicated by the error code, this constitutes an instant failure of the test.	Completed Successful
Visual Inspection	The recovery system(electrical components, wiring, parachutes, knots, hardware) will be checked for faulty workmanship.	Frayed wires, cold solder joints, frayed shock cord, improperly tied knots, and lack of lock-tight on critical hardware, constitute failure of this test.	Completed Successful

8.1.4. GPS Testing and Results

When completing testing for the GPS, 2 out of the 3 requirements were met. The data transmission and the visual inspection tests were both passed, but the range test was failed due to unstable connection. Several factors, including assembly errors and interference, may have contributed to these results. Specifically, mounting the GPS too close to the metal support plate and other conductive parts within the rocket could result in poor range. Soldering errors on the TX or RX boards are another possibility. After first completing the range test on Georgia Tech's campus, it was originally thought that the poor range was the result of interference between the GPS and other devices operating in the area. However, this was ruled out as a probable cause since the same results were received after completing testing at the launch site in Alabama.

Table 8.1.4 GPS Testing Chart

Requirement Tested	Test Description	Pass/Fail Criteria	Status
Data Transmission Test	Transmitter and receiver will be powered up and connected to the computer	GPS data will be received and be accurate	Complete GPS data received and accurate
Visual Inspection	Inspect the assembled GPS module for solder bridges and misplaced components	No soldering faults are identified	Complete No soldering faults identified
Range Test	Transport GPS system and ground station to local park. Move GPS transmitter 2500 ft from the ground station	Connection remains stable with a 2500 ft line of sight distance between transmitter and receiver	Complete Poor Range

8.1.5. Rover FEA and Results

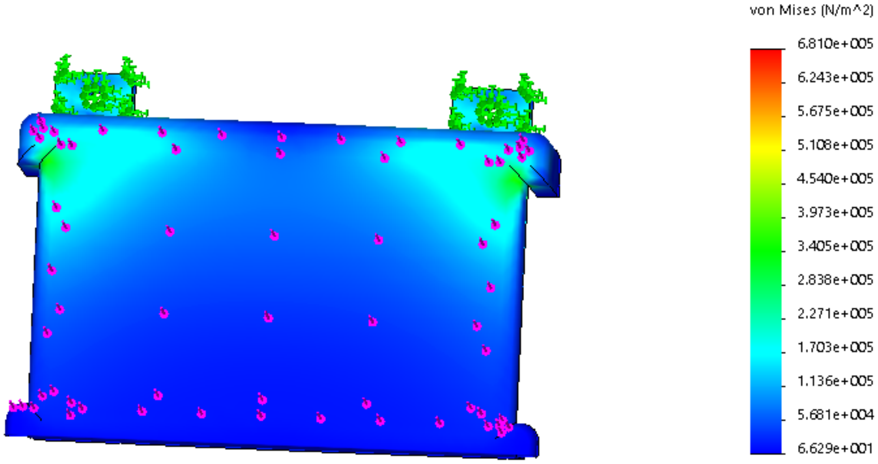

Figure 8.1.9 Stress Analysis of Body

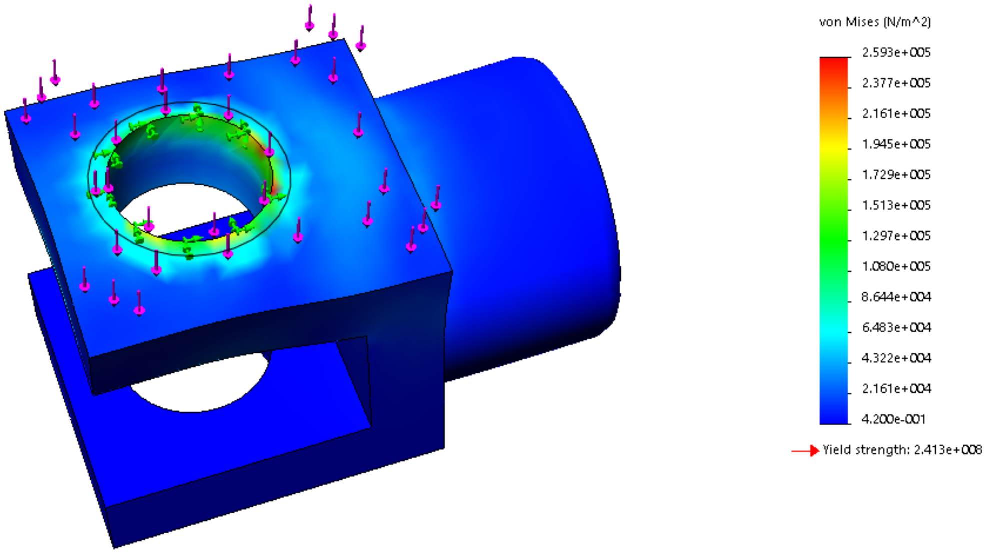

Figure 8.1.10 Stress Analysis of Two bolt mount

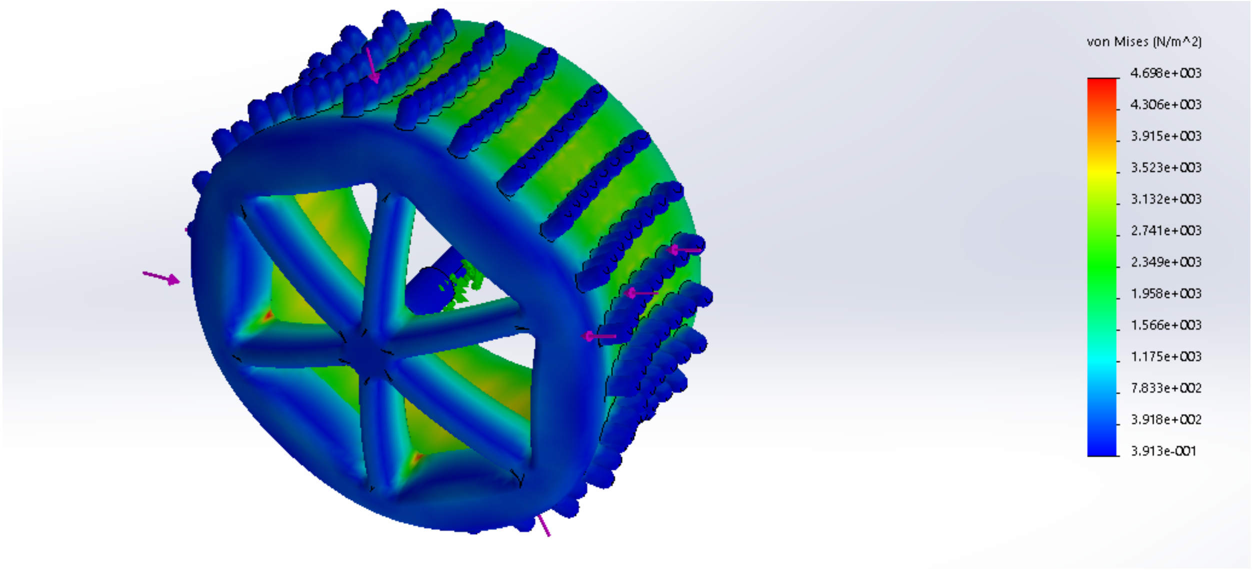

Figure. 8.1.11 Stress Analysis on Wheel

Table 8.1.5: Rover Testing and Results

Requirement Tested	Test Description	Pass/Fail Criteria	Status
Rover is not damaged by vibrations/landing	Rover will be enclosed in bay, and dropped from heights of 1 and 2 stories	Critical rover systems will remain intact after test	Incomplete, Scheduled for 3/26
The rover must deploy in the proper orientation	The deployment system will be triggered in several different orientations, three times each.	The rover will deploy in the proper orientation for all tests	Incomplete, Scheduled for 3/26
The rover can deploy regardless of rocket orientation	The rocket will be placed in several roll orientations. Each test will be conducted three times.	The rover will be successfully deployed at least 7/9 times, with no more than 1 unsuccessful deployment per orientation	Incomplete, Scheduled for 3/28
Deployment system functions at long range	The rocket will be placed at 1,000, 2,000, 3,000, and 4,000 ft away from the transmitter, and	The deployment system will function at all ranges	Incomplete, Scheduled for 3/29

	deployment will be triggered.		
Rover has enough torque for uneven terrain	The rover drivetrain will be tested on smooth dirt, uneven dirt, short grass, and long grass.	The rover will be able to move forward at least 5 ft on all terrains.	Incomplete, Scheduled for 3/29

Results:

As the assembly of the rover and integration into the launch vehicle has not yet been completed, the rover tests are incomplete. Due to this, the rover has not been proven flight-ready, and will not be flown in an active configuration for the competition flight. The rover will still be placed in the rocket in the correct location in order to prevent any mass discrepancies, but the electronic systems will not be armed or active. The team plans on proceeding with the assembly and testing of the rover to launch it in a fully active configuration at a future, competition-independent launch event.

8.1.6. Rover Deployment FEA and Results

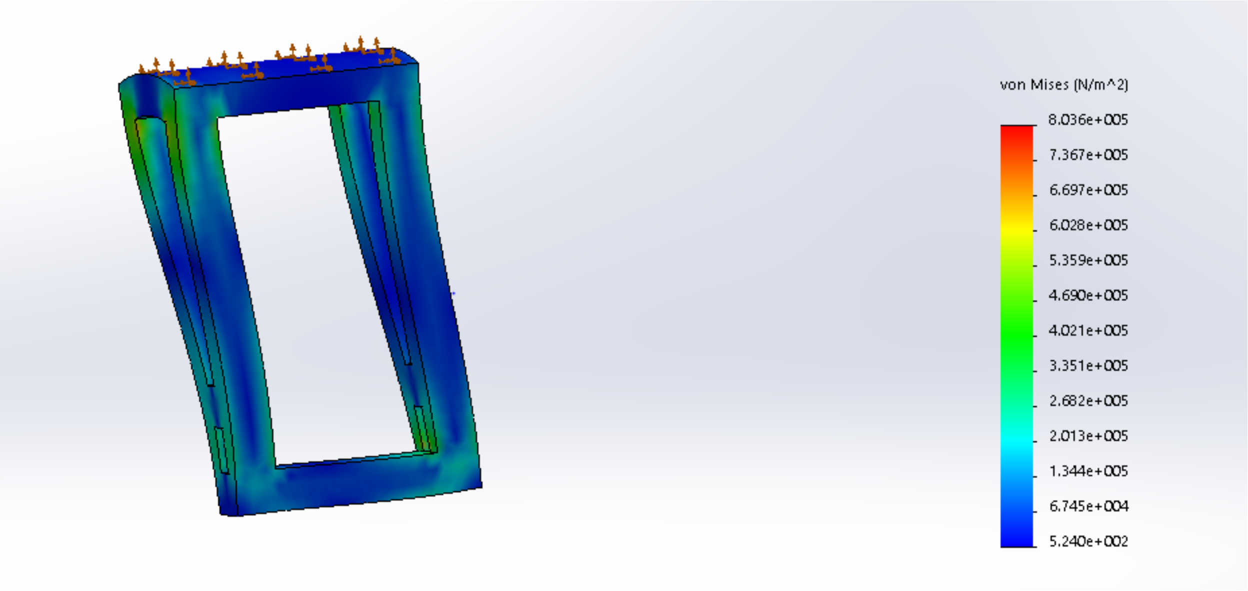

Figure 8.1.12: Stress Test on Rover Rail Bracket

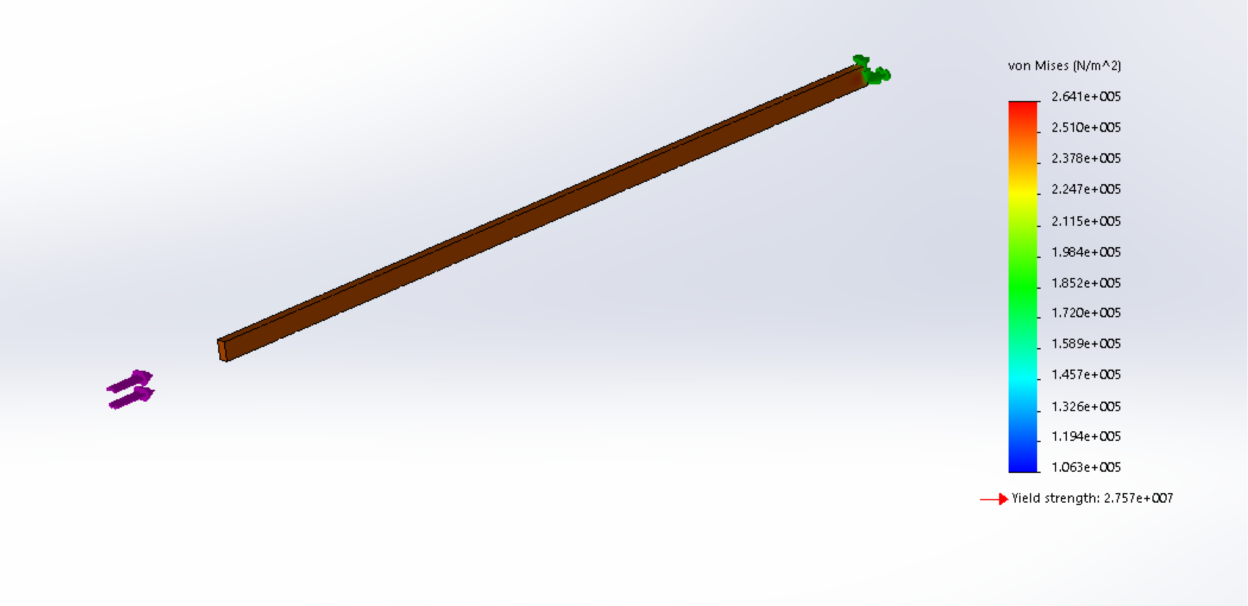

Figure 8.1.13: Stress Test on Rover Rail

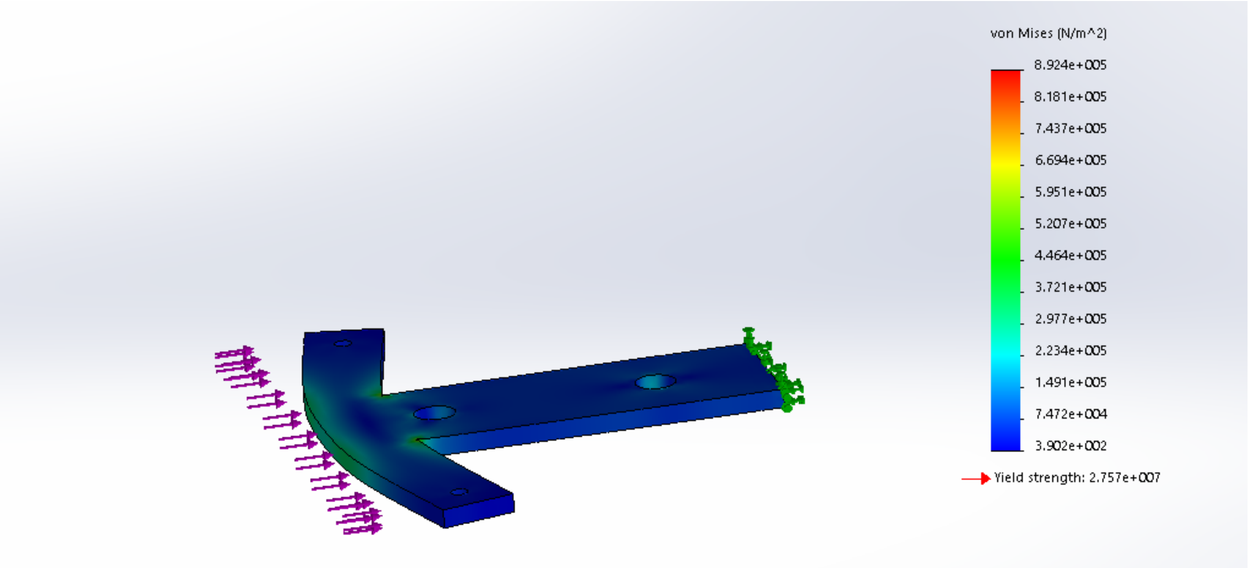

Figure 8.1.14: Stress Analysis on T-Bracket

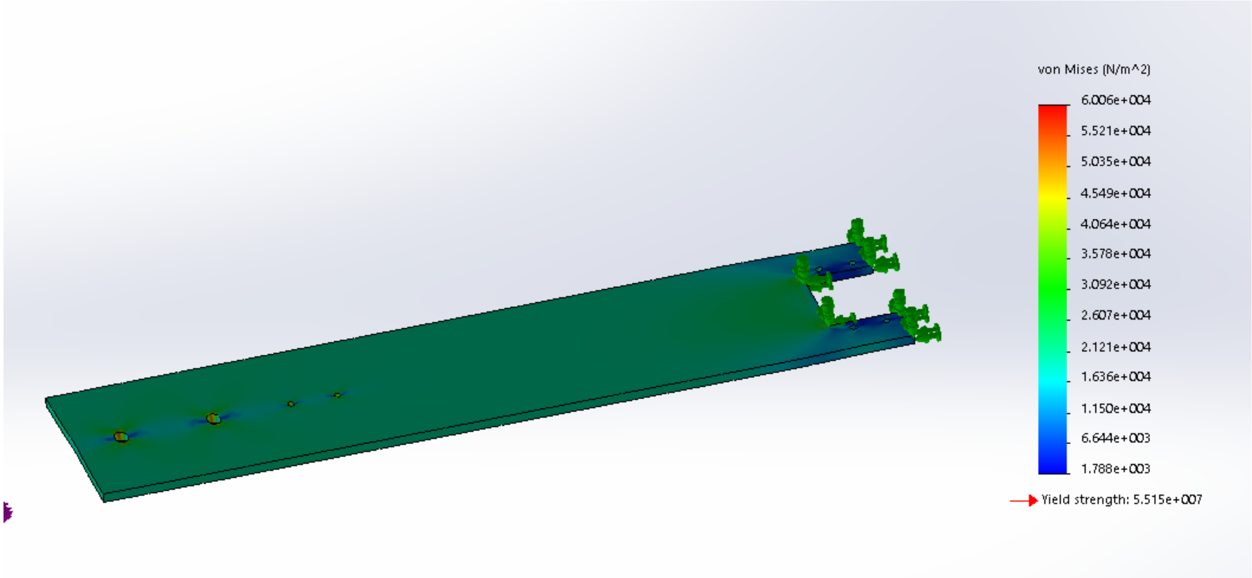

Figure 8.1.15: Stress Analysis on Support Plate

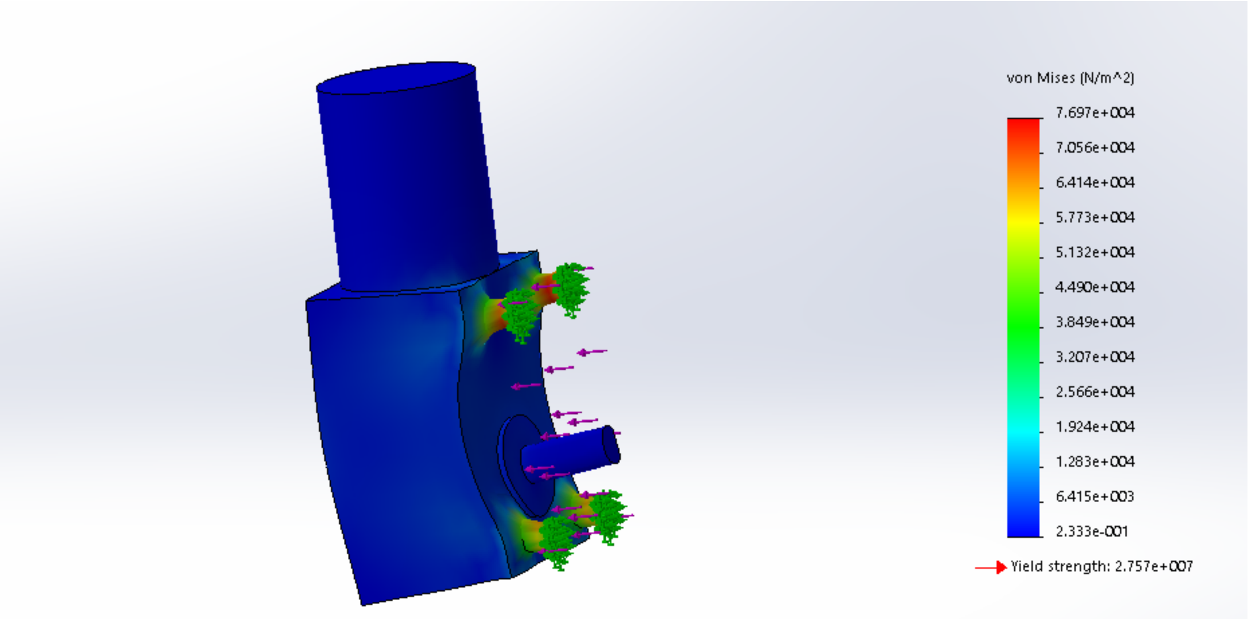

Figure 8.1.16: Stress Analysis Worm Gear Motor

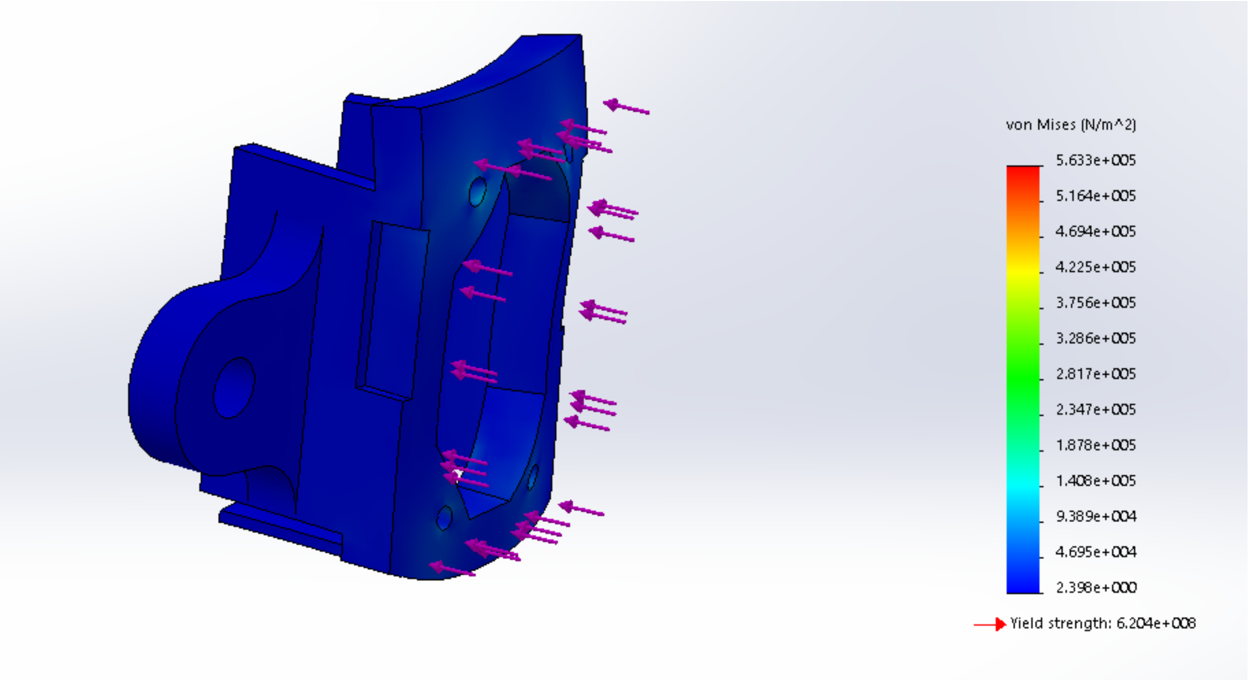

Figure 8.1.17: Stress Analysis on Worm Gear Motor Bracket

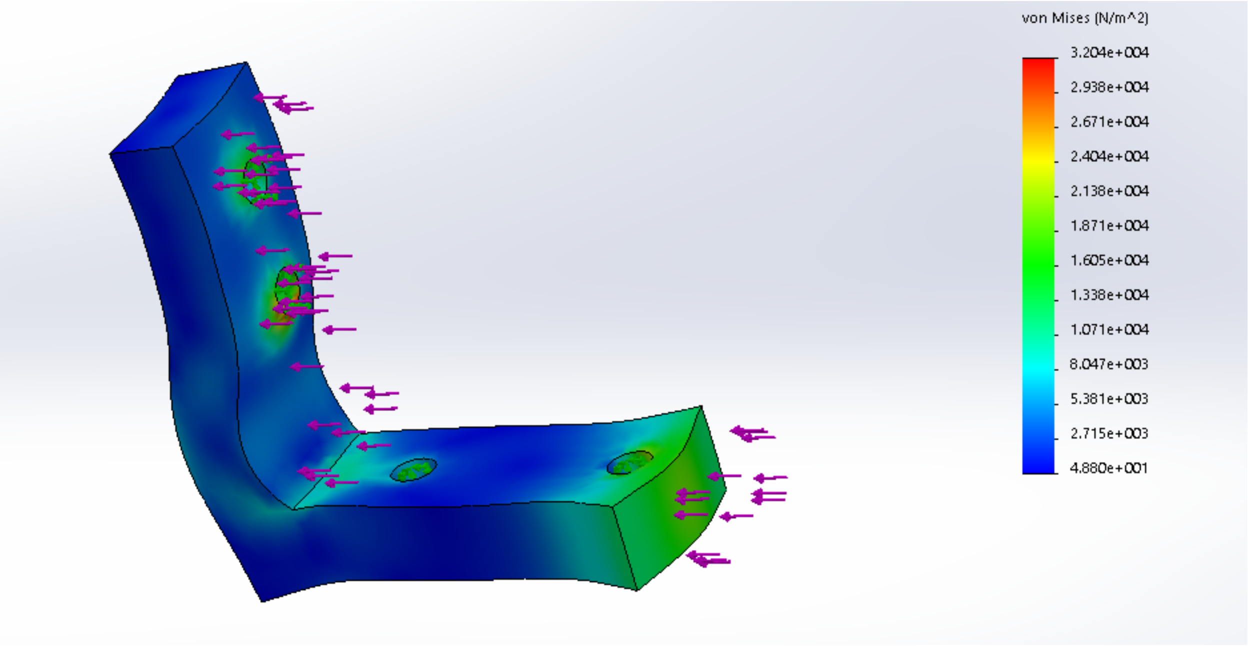

Figure 8.1.18: Stress Analysis on NC Pusher Support

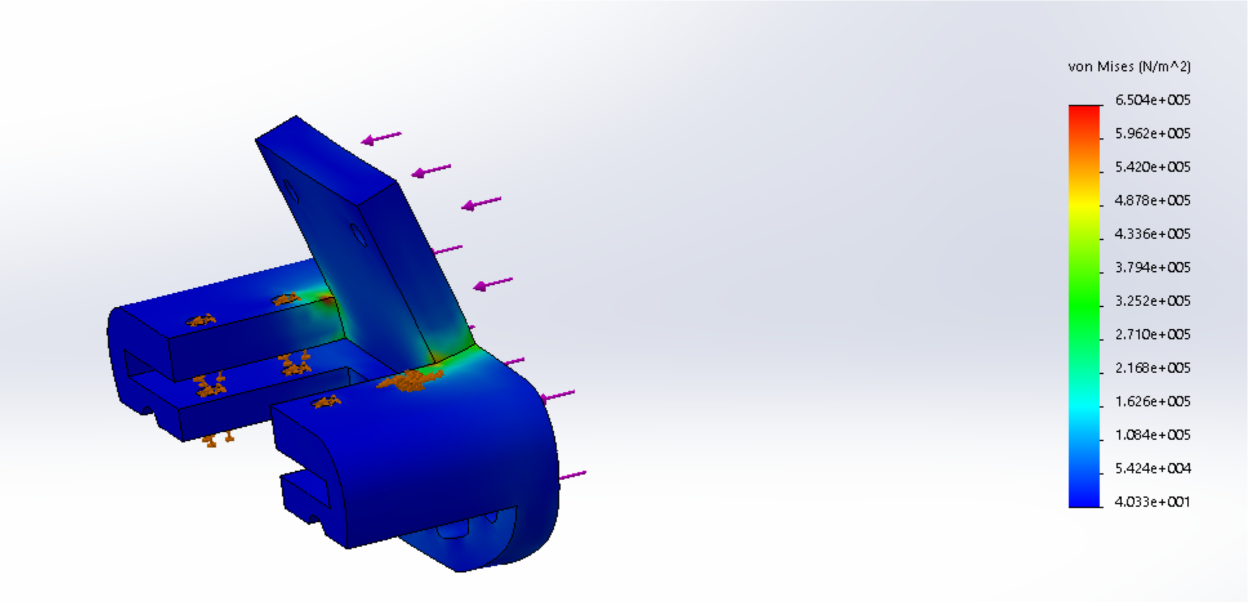

Figure 8.1.19: Stress Analysis on Carriage

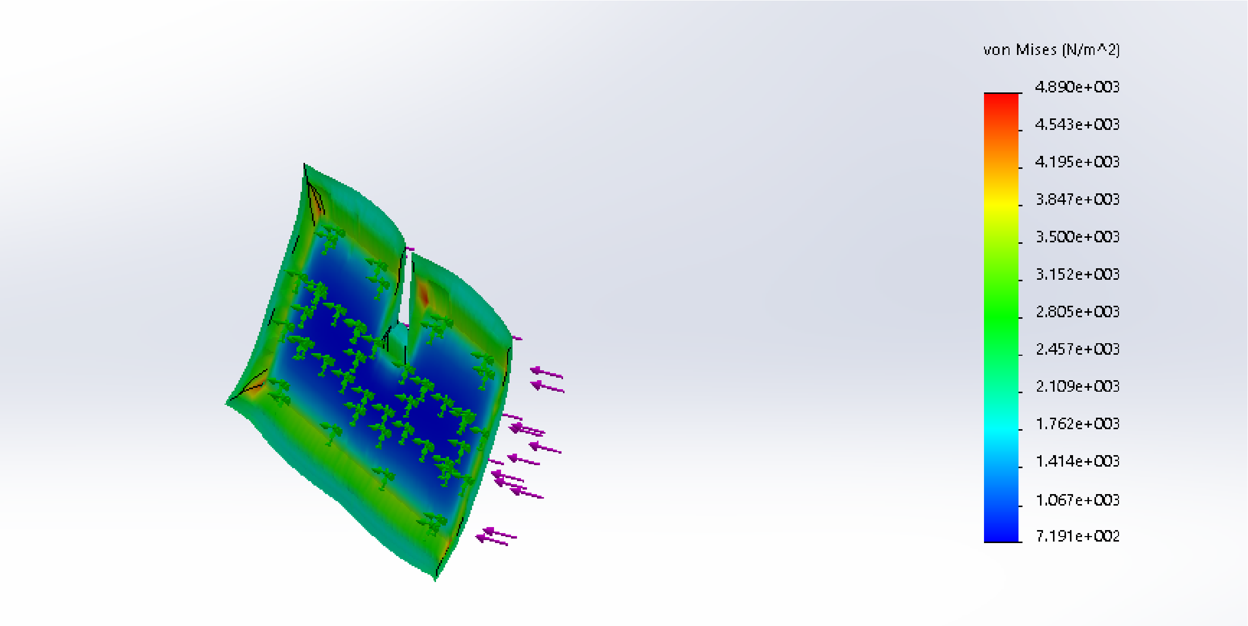

Figure 8.1.20: Stress Analysis on Pusher Foam

8.1.7. Rover Deployment Testing and Results

The purpose of rover deployment testing was to ensure that the system was both reliable and capable of deploying the rover, regardless of ground conditions. In order to complete these tests, the deployment system was mounted and wired, and was then triggered in various orientations, both with and without the nose cone mounted. These tests are summarized below:

Table 8.1.6 Rover Deployment Testing Chart

Requirement Tested	Test Description	Pass/Fail Criteria	Status
The rover deployment system must open the rocket	The deployment system will be triggered without the nose cone mounted	The rover tray will extend and retract completely when triggered	Completed on 2/16/18, Success
The rover deployment system must open the rocket	The deployment system will be triggered **with** the nose cone mounted	The rover tray will extend and retract completely when triggered	Completed on 2/23/18, Failure - Rescheduled for 3/26/18

The rover must deploy in the proper orientation	The deployment system will be triggered in several different orientations, three times each.	The rover will deploy in the proper orientation for all tests	Incomplete, Scheduled for 3/26/18
The rover can deploy regardless of rocket orientation	The rocket will be placed in several roll orientations. Each test will be conducted three times without the nose cone mounted.	The rover will be successfully deployed at least 7/9 times, with no more than 1 unsuccessful deployment per orientation	Completed on 2/23/18, Success
The rover can deploy regardless of rocket orientation	The rocket will be placed in several roll orientations. Each test will be conducted three times **with** the nose cone mounted.	The rover will be successfully deployed at least 7/9 times, with no more than 1 unsuccessful deployment per orientation	Completed on 2/23/18, Failure - Rescheduled for 3/26/18
Deployment system functions at long range	The rocket will be placed at 1,000, 2,000, 3,000, and 4,000 ft away from the transmitter, and deployment will be triggered.	The deployment system will function at all ranges	Incomplete, scheduled for 3/26/18

Results: As seen in the table above, the deployment system functioned as intended when the nose cone was not attached to the system. The system was able to extend and retract properly regardless of the rocket's orientation. However, once the nose cone was mounted, the deployment system was no longer functional. When the trigger sequence was initiated, there was no movement from the system, and as the nose cone was epoxied to the bracket, it was impossible to see where the issue specifically was. There are three possibilities: the LiPo battery powering the deployment sequence no longer had power, the wires and connections were damaged when the nose cone was epoxied, or the motor did not have enough torque to push the nose cone. Due to the lack of noise from the rover system, damaged connections or a lack of power seem like the most likely cause. However, due to time constraints regarding full scale launch dates and epoxy hardening times, the rover deployment system could not be tested again prior to the full scale test launch. Due to this, the team will fly an inactive rover deployment system for competition, and will fly the fixed active system at a competition-independent test launch.

8.2. NASA Requirement Verification

8.2.1. Vehicle Requirements

Table 8.2.1 NASA Vehicle Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
The vehicle will safely deliver the payload (deployable rover) to an apogee altitude of 5,280 feet AGL and return to ground	The motor will overshoot the rocket beyond target apogee of 5,280 ft and the ATS system will retract in response to the altimeter reading to reduce the apogee	Gathering data from flight altimeter after test launch	The vehicle reaches the apogee within 2%
The vehicle will carry altimeters to record data of the rockets ascent	The avionic bay will be housing two altimeters for recording the ascent	Inspection	Altimeter records data during flight
Each altimeter will be armed by a dedicated switch accessible from the outside of the rocket	Three key holes are made on the avionics bay which make the switch accessible from the exterior	Inspection	The altimeters are turned on by the key rotation
Each altimeter must be locked on during flight	Screws are used to lock each altimeter onto the avionics tray	Inspection after the launch of the vehicle	Altimeter still locked onto the avionics tray after the landing
The vehicle will be recoverable and reusable.	The vehicle will house two parachutes that will lower the kinetic energy at landing to minimize the damage onto the rocket	Inspection after the flight if the vehicle could have a new motor installed and is capable of flying again immediately	Vehicle can fly again with a replacement of the motor
The vehicle will have a maximum of four independent sections.	The rocket consists of the 3 independent sections after deployment of the parachutes:	Inspection that the vehicle has 3 sections after the parachutes are	The vehicle does not split into 4 sections during its flight

	1. Nose cone with rover tube 2. Avionics bay 3. ATS tube with Booster section		
The vehicle will contain a single motor, which will provide total impulse that will not exceed 5,120 Newtons - seconds	The rocket will use a commercial L-class motor, AeroTech L850W which has a total impulse of 3840 Ns	Inspection that there is only one motor installed in the rocket	Only one motor is used during the flight
The launch vehicle can be prepared within 3 hours of the FAA flight waiver opening	The rocket will be designed so that only the installation of motor will be need on the launch site	Inspection that at the launch site, only the motor is installed and no other change is made to the rocket	Only the motor is installed at launch site
The launch vehicle can be launched by the 12 volt firing system	The rocket will utilize a commercial L class motor that can be ignited with 12 volt firing system	Will check manufacturer's specifications	Meets requirement
The launch vehicle will use a commercially available APCP motor certified by the NAR, TRA, and/or CAR	Will purchase a APCP motor	Will check manufacturer’s details	Meets requirement
The pressure vessel will have a factor of safety of 4:1	No pressure vessel is used on the launch vehicle	Inspection	Meets requirement
Pressure vessel will have a pressure relief valve that can withstand the maximum pressure and flow rate of the tank	No pressure vessel is used on the launch vehicle	Inspection	Meets requirement
The launch vehicle will have a stability margin greater than 2.0 at the point of rail exit	The launch vehicle is designed to have a stability margin greater than 2.0 at the point of rail exit	Analysis: Simulation based on OpenRocket and hand calculations	Meets requirement

A subscale model must be launched and recovered and report the models apogee	The subscale rocket has altimeter like in the full scale that would record the altitude of the rocket	Test: After the subscale launch, the recordings of the altimeter will be read	The altimeter reads altitude values within %1 difference

8.2.2. Rover Requirements

Table 8.2.2 Rover System NASA Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
Teams will design a custom rover that will deploy from the internal structure of the launch vehicle	The rover will be housed within a separate bay in the rocket body	Inspection	The rover will successfully be placed in the launch vehicle
At landing, the team will remotely activate a trigger to deploy the rover from the rocket	The rover deployment system will be controlled by an RC receiver controlled switch. The receiver will be triggered by an RC transmitter.	Inspection	The rover will be remotely deployed from the rocket
After deployment, the rover will autonomously move at least 5 ft. from the launch vehicle	The rover wheels will be hard-coded to travel a distance of greater than 5 ft	Inspection	The rover will move at least 5 ft. from the launch vehicle
Once the rover has reached its final destination, it will deploy a set of foldable solar cell panels	Solar panels will be mounted on servos, which deploy the panels from the body of the rover	Inspection	Solar panels are deployed intact in the proper orientation

8.2.3. Recovery Requirements

Table 8.2.3 Recovery System NASA Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
The recovery system shall operate such that a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude	StratologgerCF altimeters will be programmed with PerfectFlight DataCap such that the drogue charge is ignited at apogee and the main charge is ignited at *altitude*	Altimeter settings will be verified prior to launch. Visual observation of full-scale test flight will confirm the requirement is met	Both pyro events are triggered at the proper location in the flight and the chutes are ejected properly by the pyro events
A successful ground ejection test for both the drogue and main parachutes must be performed prior to flight	Ejection charge tests will be performed prior to all flights	Visual observation will confirm the tests are successful	The sections separate cleanly above and below the avionics bay and the vehicle is undamaged.
At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf	The main and drogue parachutes will be sized to slow down the rocket to reduce the total kinetic energy at landing	"Analysis: the size and shapes of the parachutes will be modeled in OpenRocket to simulate the landing velocity, and kinetic energy can be calculated from there Test: The launch vehicle will undergo test flights to validate the landing speed will have a kinetic energy below the requirement "	The kinetic energy is below 75 ft-lbf
The recovery system shall operate such that	StratologgerCF altimeters will be	Altimeter settings will be verified prior to	Both pyro events are triggered at the proper

a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude	programmed with PerfectFlight DataCap such that the drogue charge is ignited at apogee and the main charge is ignited at 800 feet above ground level	launch.	location in the flight and the chutes are ejected properly by the pyro events
The recovery system electrical circuits will be completely independent of any payload electrical circuits	The recovery and payload systems will be designed such that they are electrically independent.	Design reviews will confirm that the recovery and payload systems will be electrically independent.	The recovery system is electrically isolated from the payload.
All recovery electronics will be powered by commercially available batteries	Altimeters have been chosen that can use commercially available 9 volt batteries	Ground testing will be performed to ensure the chosen altimeters function properly using commercially available 9 volt batteries	The recovery system is powered only by commercially available batteries
The recovery system will contain redundant, commercially available altimeters	The system was designed to use two StratologgerCF altimeters, one primary and one backup	Ground testing will ensure that both altimeters are fully functional	Two commercially available altimeters are used to trigger the pyro events
Motor ejection shall not be used	Motor ejection will not be used	Inspection	Motor ejection is not used
Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment	The parachute deployment will be controlled by removable shear pins	Inspection	The parachute deployment will be controlled by shear pins
Recovery area will be limited to a 2500 ft. radius from the launch pads	The altitude of the deployment of the parachutes are determined so that the ratio of time of drogue parachute and that of	Test: The launch vehicle will undergo several test flights to validate that it lands within 2500 ft radius from the launch pad	The rocket lands in the area less than 2,500 ft away from the launch pad

	main parachute is maximized while meeting the requirement of maximum kinetic energy at landing		
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	A GPS tracking device will be incorporated to transmit the real-time location of the launch vehicle. All sections of the vehicle will be tethered together	The GPS system shall undergo ground testing prior to launch.	The GPS system allows for safe location and recovery of the launch vehicle.
The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device or magnetic wave producing device	The system shall be designed such that no RF emitting devices are present in the avionics bay	Design reviews confirm that no RF emitting devices will be housed in the avionics bay	No RF emitting devices are housed in the avionics bay
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 recovery system is housed in a separate section from any RF emitting devices	It has been determined that physical distance is sufficient to shield the recovery system from onboard transmitting devices.	The recovery system is not adversely affected by other systems on the launch vehicle.

8.2.4. Safety Requirements

Table 8.2.4 NASA Safety Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
Each team will use a launch and safety checklist	The safety officer will be responsible to enforcing the safety checklist	The team will check that the safety officer has a safety checklist before launches	The safety checklist is used before every launch
Teams will abide by rules and guidance of the local rocketry club's RSO	The safety officer will communicate with the local rocketry club to ensure everybody is following the rocketry clubs rules	The local rocketry club will be contacted before launch to ensure Georgia Tech's rocket follows protocol	All rocketry club's rules are followed
Teams will abide by FAA rules	The safety officer will ensure the team is abiding by all FAA rules	Inspection	All FAA rules are followed

8.3. Team Derived Requirements Verification

8.3.1. Vehicle Requirements

The functions of our vehicle are divided into three different buckets: Vehicle Ascent, Vehicle Recovery, and Payload Delivery. This division displays that there are three different overarching goals that this rocket is to accomplish. It must ascent to 5,280 feet, recover safely from that apogee, and deploy its payload.

Vehicle Ascent:

Shown in the figure below is the first subset of functions that the rocket is to complete. It is to reach an apogee of 150- 400 feet above 1 mile. If the vehicle aims for one mile, the ATS is able to slow down the rocket to reach the exact 1 mile apogee. This main function can be broken down into three sub functions that enable this main function to proceed. It must produce minimal drag, fly the rocket safely, and fly true (in that it flies directly upward).

Producing minimal drag allows makes it much easier to reach the one mile apogee because it takes less force total to reach this target. If the rocket produced too much drag, the other sub functions would not matter given that the rocket could not reach the targeted apogee to begin with.

In order to fly safely the rocket must control the dangers that can put the rocket in an unsafe condition. If the rocket rotates during flight it is at risk of flexing, breaking, or drifting, all of which can lead to an unsuccessful mission where the rocket crashes into the ground. This means that the rocket must not twist around the X,Y,or Z axis. This also means that the motor must propel the rocket directly upward so it does not put any moment on the rocket body or frame as a whole. Lastly, the rocket must also ensure that motor remains stationary in regard to the Z axis. If the motor is free to move along the Z axis within the rocket, it is likely to shoot through the entire rocket and damage every single subsystem, which is obviously catastrophic failure.

The rocket must also fly true in order to reach the apogee. It must propel itself directly upward to ensure that the 1 mile apogee is reached. Aside from that, it must also maximize the ratio of burning time to drift time. During drift time, the rocket will be exposed to winds at upper altitudes that will take the rocket off course and out of the 2500 foot recovery radius. The further the rocket travels while the motor is burning the less time during the total ascent that the rocket will be exposed to winds that could take it off course.

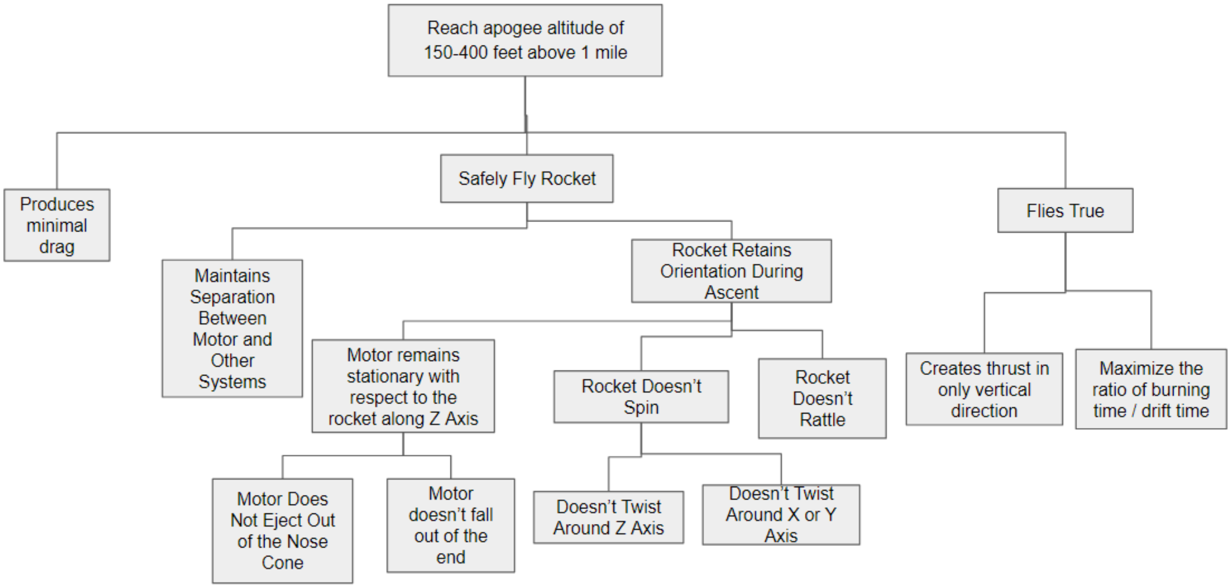

Figure 8.3.1 Vehicle Ascent Function Tree

Vehicle Recovery:

Once the rocket has reached its targeted 1 mile apogee, it must then deploy a recovery system that will allow it to return safely to the ground. The figure below shows the function tree associated with this recovery process.

The primary function of the recovery process is to return the rocket safely to the ground. Therefore, the most important sub function under this category is that the final landing impulse is minimized. Thus the rocket will be safely returned to the ground.

Next, the recovery system must also minimize the drifting time in order for the vehicle to remain within the 2500 foot recovery radius. In order to do so the decent time must be minimized to allow less time for drift to take place. A sub function of that is maximizing the time between when drogue parachute is deployed and when the main parachute is deployed; the rocket will fall for longer without drifting. Another aspect of minimizing drift is ensuring that the rocket is maintains a straight path downward by having symmetrical geometry.

Lastly, the recovery system must be able to safely deploy the parachutes, meaning they come out of the rocket untangled and undamaged. Without this the recovery system completely fails as the parachutes are the primary means of recovery.

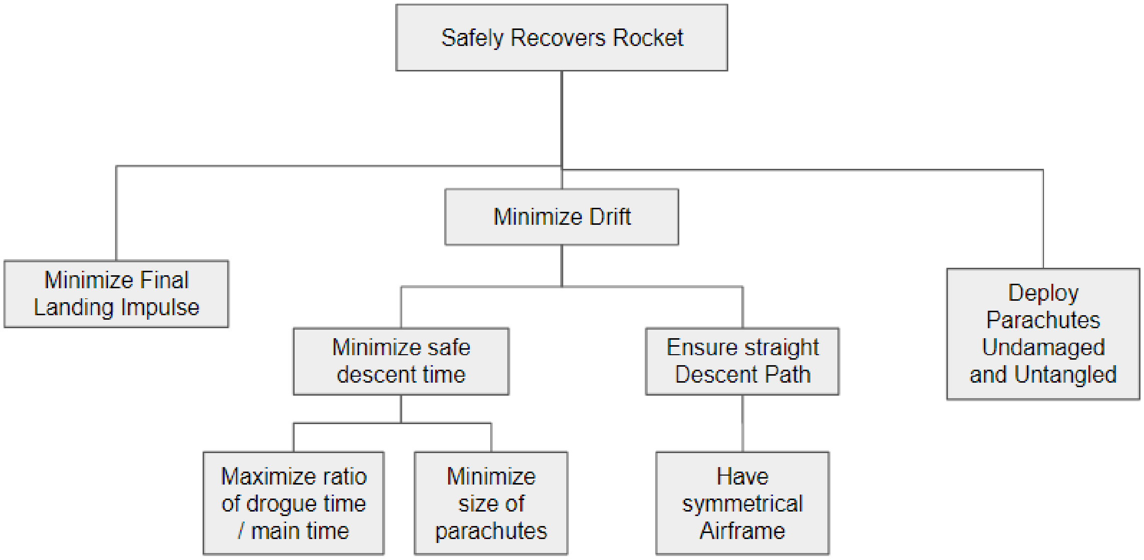

Figure 8.3.2 Vehicle Recovery System Function Tree

Payload Delivery:

The final subsystem of functions is the successful delivery of the payload. Shown in the figure below is the short function tree in which this system is entailed.

In order for the rover to successfully place solar panels it must be brought to apogee, recover with the rocket, and deploy from the rocket without damage. Since the rover is effectively a mass pinned between bulkheads in the rocket, it is a fairly simple process. The rover must be stationary relative to the rocket during the ascent and descent. After it returns to the ground the rocket then must incorporate some system that allows for the rover to leave the rocket unharmed.

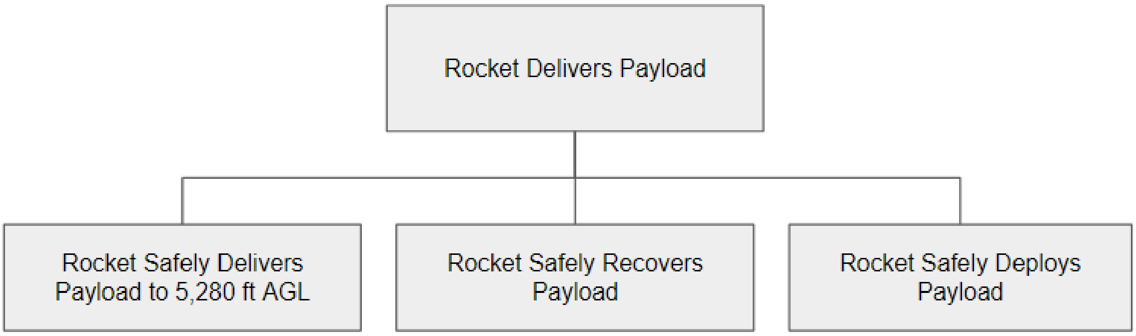

Figure 8.3.3 Payload Delivery Function Tree

These team-derived requirements are summarized in the table below.

Table 8.3.1 Airframe Team Derived Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
The rocket should have a capability to reach 5,500 ft safely without the ATS system activated	The materials of each component as well as the dimensions are chosen so that the total mass of the vehicle is minimized	1.Analysis: Simulation based on OpenRocket and hand calculation will conducted so that the rocket will theoretically ascent 5,500 ft 2. Test: Several test flights without the ATS activated will be done to measure the apogee altitude without ATS activated	The rocket reaches an apogee of 5,500ft within 2% difference without ATS activated
The thrust-to-weight will not below 7	The motor is chosen such that its average thrust will be more than 7 times the weight of the rocket	Analysis: Compare the weight of the rocket with the average thrust of the motor	The thrust-to-weight ratio is above 7
The rocket weight will not exceed 40 lb	The materials of each component as well as	Inspection: Weight of the rocket predicted	The weight of the rocket is below 40 lb

	the dimensions are chosen so that the total mass of the vehicle is minimized while still securing strength of each component	based on component material density and weight measurement of the actual weight of the rocket	
The launch vehicle will have a stability margin greater than 2.2 at the point of rail exit	The vehicle equips four fins that produces enough aerodynamic forces to keep the stability margin high	Analysis: Simulation using OpenRocket will be conducted to predict the static stability margin at the point of rail exit	The launch vehicle's stability margin at point of rail exit is above 2.2
The centering rings and the retention ring must have safety factor greater than 2 with applied force 950 N (in case one of the them breaks, the half of the maximum force will be applied to each ring)	The materials as well as the designs of these components are chosen to minimize mass while maintaining safety factor above 2 and below 10 with the applied force of 210 lbf	Analysis: FEA using SolidWorks will be conducted for each component	The factor of safety is in between 2 and 10
The thrust plate must have safety factor greater than 2 with applied force 300 pounds (maximum thrust provided by the motor)	The thrust plate uses 1/4 inch, dense plywood	Analysis: FEA using SolidWorks will be conducted with 300 pounds applied	The factor of safety is above 2

8.3.2. ATS Requirements

Table 8.3.2 ATS System Team Derived Requirements

Requirement	Approach	Requirement Verification	Success Criteria
All components in ATS must not experience material failure as a result of drag force	ATS component must have safety factor greater than 2	Analysis Using FEA, the factor of safety will be calculated	Factor of safety calculated by FEA must be over 2
ATS must be able to generate sufficient drag to decrease the apogee of the rocket by at least 300ft	ATS flaps will be sufficiently sized and actuated to induce sufficient drag	Analysis Using FEA, the maximum possible work done by the ATS will be calculated	The maximum work done by drag force should be equal to change in potential energy
ATS must be secured to the body tube in such a way that prevents motion/vibration	ATS will be secured using a combination of epoxy and mechanical constraints	Demonstration The body tube mounted with ATS will be shaken and held at different angles	ATS should not vibrate or move when it is shaken
All components in ATS must be secured using threadlocker	All components in ATS will be secured using threadlocker	Inspection All the screws that connects components will be inspected before installation on the body tube	Threadlocker on bolts/nuts must be visible
The motor driver must be connected to the Avionics bay	The motor driver will be connected to the Avionics bay using secure wire connections	Inspection Connection between Avionics bay and the motor board must be checked using multimeter	The board and the circuit should be wired without any break

ATS must be located below CG of burnout to prevent instabilities	ATS must be located below CG of burnout to prevent instabilities	Analysis The model of the rocket will be generated using open rocket	The location of ATS on Open Rocket Model must be below CG
Motor must be able to fully retract and extend all flaps without any hindrance	Slits will be cut in the body tube to allow the flaps to move without any hindrance	Test The motor will be actuated multiple times	The flaps should be able to fully extend and retract smoothly
All flaps must have synchronized motion	The ATS flaps will be linked to a single motor driver using a linkage mechanism	Test The motor will be actuated multiple times	The flaps should retract and extend at the same speed
ATS must not generate any moment on the vehicle when actuated	The flaps will be positioned opposite each other, so that the moments cancel	Analysis Using CFD, the pressure/ force on each flap will be calculated	Sum of moment generated by the flaps respect to center of gravity should be zero
ATS must have mechanical restraint to prevent flap misalignment	ATS will have at least one mechanical restraint to prevent flap misalignment	Inspection Existence of a mechanical restraint will be checked	There is one or more mechanical restraint that will prevent flap misalignment
ATS will not actuate before burn-out is reached	The ATS will be programmed to begin actuation after the microcontroller detects the end of burnout,which must be equal to or after the rated burn time of the motor	Inspection Programmed function to induce a wait equivalent to the rated burn time of the motor	Mechanism will remain dormant during burn time due to complex nature of motion-profile under large accelerations
ATS flaps will not create drag on launch vehicle when retracted	The ATS mechanism will have a mechanical hard stop, which holds the retracted flaps flush with the outer surface of the body tube	Analysis Mechanical hard stop implemented to prevent flaps from retracting too much	When retracted, the edges of the ATS flaps must be flush with the outer surface of the body tube

8.3.3. Rover Requirements

The rover system must perform three different functions to complete our task successfully as illustrated in the figure below. This task is most easily simplified into a few base functions: Deployment, Drivetrain, and Solar Panels. Each function category is further split into team-derived requirements.

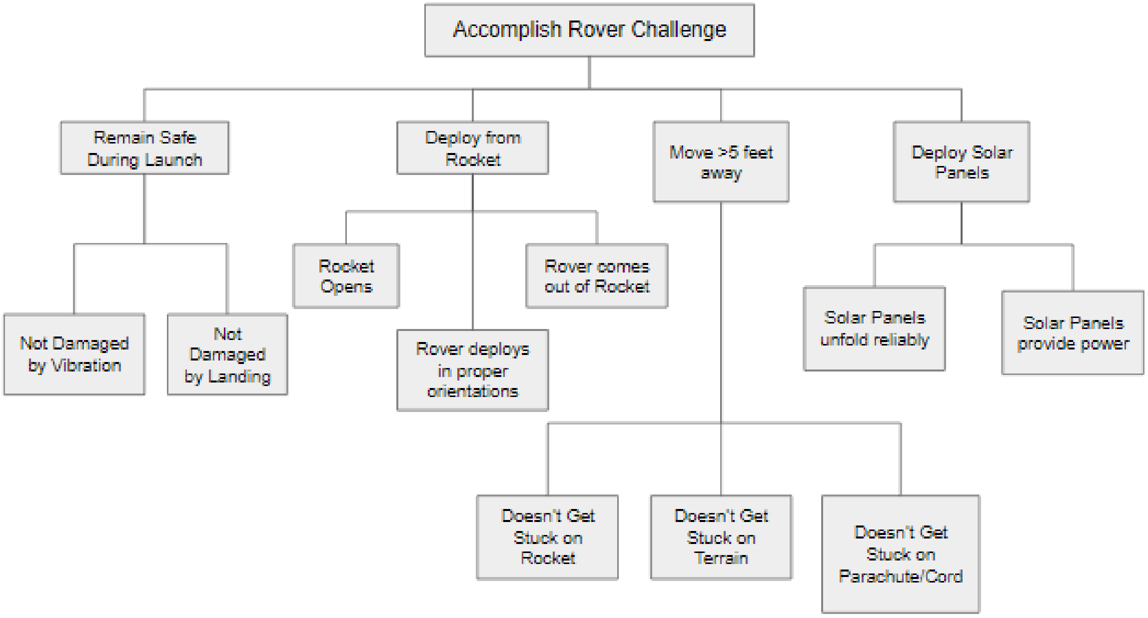

Figure 8.3.4 Rover Challenge Function Tree

Deployment

For the rover to accomplish any of the required tasks it, must first successfully deploy from the rocket after landing. This task can only be accomplished after taking into consideration the rocket orientation, terrain, and the potential of parachutes covering the deployment area as seen in the figure below.

The orientation of the rocket will be an unknown factor. The rover must be able to account for this and be able to exit the rocket regardless of its orientation. The terrain might be sloped in such a way that inhibits the separation of the nose cone and results in the rover being unable to deploy. There might also be a parachute or other obstructions the deployment system will have to push out of the way to allow the rover to deploy safely. The system should be designed to produce enough torque to move the entire rocket in order to ensure the rover is able to separate from the recovered vehicle.

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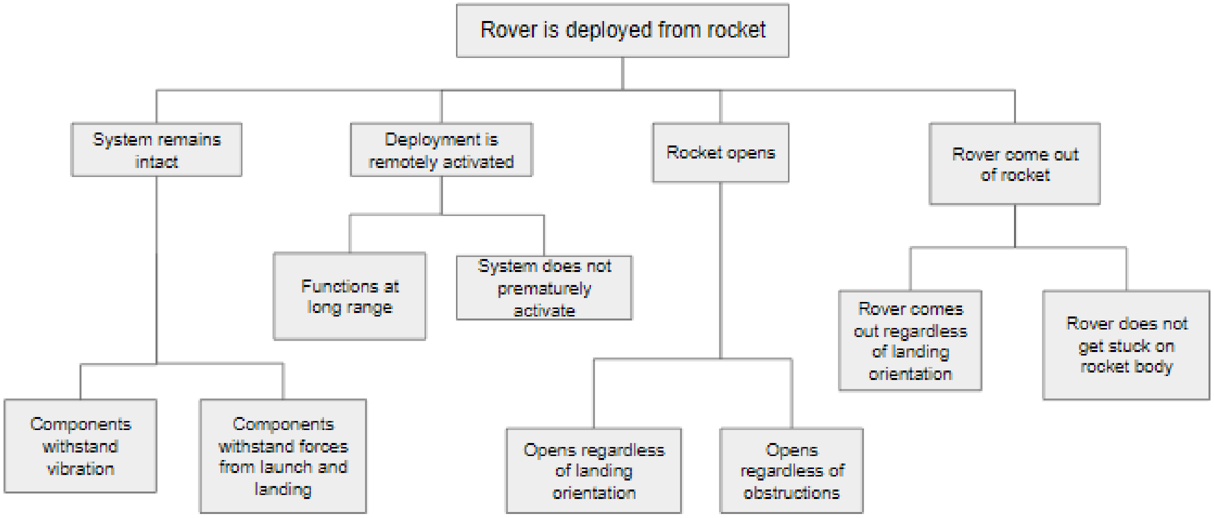


Figure 8.3.5 Rover Deployment Function Tree

Drivetrain

After a successful deployment, the rover must move a minimum of 5 feet away from the rocket. The figure below illustrates the challenges of remaining intact during flight, being able to overcome any terrain, and have the ability to not interfere with other components.

In order to move out of the rocket, the drivetrain must be intact upon landing. The best way to ensure the drivetrain system remains unharmed is to make the components unable to slip and fall off in the case of treads, and make them unable to interfere with other mechanical components. Interference with other components could cause component failure not exclusive to just the drivetrain. Such interference may result in deployment failure if the rover became entangled in its own deployment system resulting in component damage.

If the drivetrain remains intact, the rover must successfully exit the rocket. In order to do so the rover must be capable of exiting the rocket regardless of orientation without getting stuck on any deployment components, parachutes, or the rocket nose cone.

Next, the rover must drive more than 5 feet away from the rocket. For this task to reach successful completion, the rover must be capable of driving in its deployed orientation, and must be able to overcome getting stuck on any terrain such as the parachute, shock cords, or uneven terrain.

Lastly, the drivetrain mechanism will be relatively large and cannot interfere with other systems on the rover. Therefore they must be designed in such a way to keep compact, self contained, and out of the way of other systems such as the solar panels.

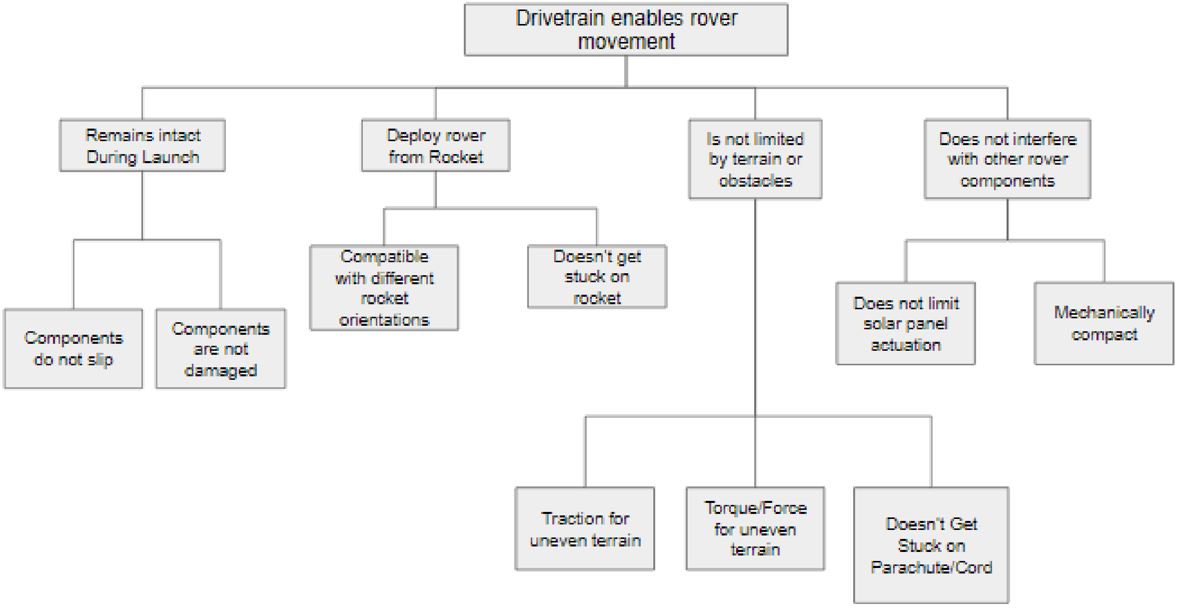


Figure 8.3.6 Drivetrain Function Tree

Solar Panels

Once the rover has reached a distance of five feet away from the rocket, the rover will stop and deploy its solar panels. The steps to accomplish this task are well illustrated in the figure below. For this to occur successfully, the solar panels must remain safe from vibrations and landing as well as keeping closed for the duration of the mission until instructed to open.

Assuming the solar panels remain safe and closed, they will need to be deployed per competition guidelines, and in an orientation that will receive sunlight. The deployment method as the competition states, requires the panels to fly in a folded configuration which requires the panels to endure not only flight forces but also the constant concentrated force of the unfolding mechanism throughout the flight. There is a risk that the deployment mechanism could crack or damage the panels during flight or recovery. Essentially, minimizing the impact and long duration loads that the solar panels must endure is paramount to keeping them in operating condition.

Lastly, for the final task to be completed the rover panels must generate power. For the power generation to be detected it is required that the connections must also remain safe during flight. Solid connections will allow the panels to transmit their generated power in order to light an LED as the final signal of mission accomplished.

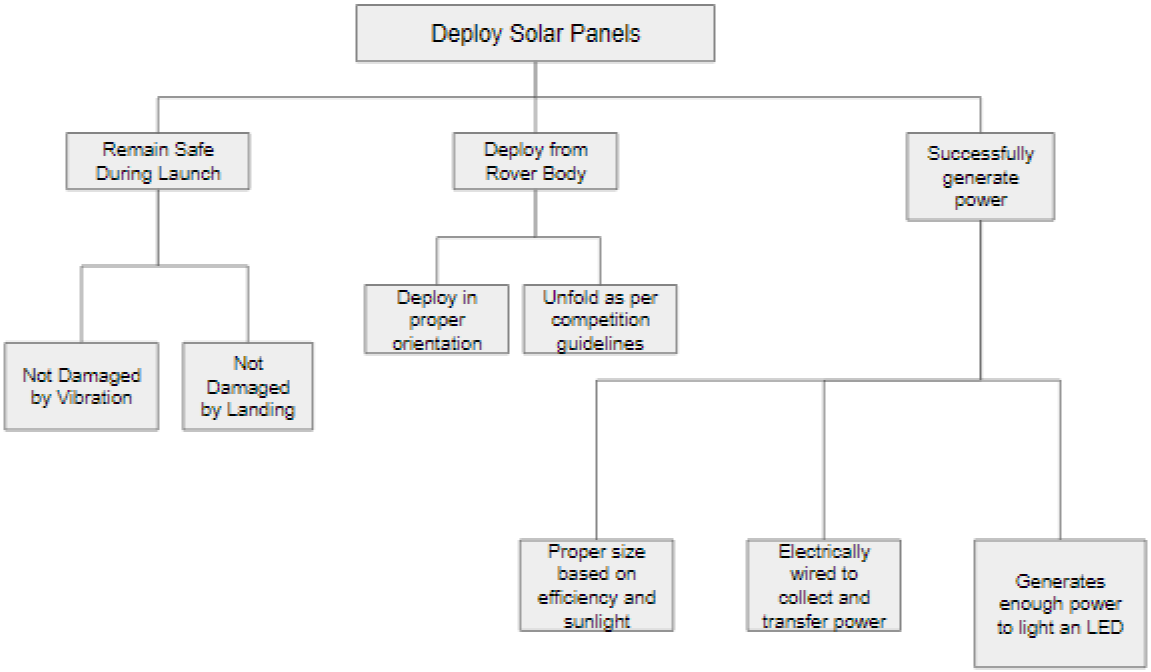


Figure 8.3.7 Solar Panels Function Tree

The requirements derived above are summarized in a table below, detailing the specific requirement, team approach, verification method, and success criteria.

Table 8.3.2 Rover System Team Derived Requirements

Requirement	***Design Feature***	***Verification***	***Success Criteria***
Rover is not damaged by vibrations/landing	The rover will be secured by foam pads to damp motion within the rover bay	Test: Rover will be placed in bay and dropped from two stories to ensure that it can withstand the impact	Critical rover components remain intact and functional after landing
The rocket must open	A motor will turn a lead screw, which separates the body tube. This in turn opens the rover bay	Inspection	The rocket body opens wide enough for the rover to exit
The rover must deploy in the proper orientation	The rover can rotate inside of the rocket, so it will always land	Test: The deployment system will be triggered in different	The rover will exit the rocket in a proper driving orientation

	right side up	orientations to ensure that the rover exits in the proper orientation	
The rover must come out of the rocket	The rover drivetrain will carry it out of the rocket body	Inspection	The rover entirely exits the rocket body
Rover must not get stuck on rocket/parachute/cord	Rover will have obstacle detection	Inspection	Rover successfully navigates away from rocket body
The rover can deploy regardless of rocket orientation	The rover is mounted on a rail within the bay, allowing it to rotate with the launch vehicle	Test: The deployment system will be triggered in multiple orientations	The rover can deploy regardless of the launch vehicle orientation
Deployment system functions at long range	Deployment system will utilize long-range transmitter	Test: Rocket will be placed at various distances and deployment system will be triggered	Deployment system is functional up to 4,000 ft away from the team transmitter
Deployment system does not deploy prematurely	Deployment will be controlled by an RC receiver controlled switch, which is only operated by the team-controlled transmitter	Demonstration	Deployment system is only triggered by the team at the intended time, not prematurely
Rover has enough torque for uneven terrain	Wheels have studs, and are operated by powerful motors to cross over uneven terrain	Test: Rover will be operated on different types of uneven terrain to ensure functionality	Rover can drive on all possible conditions expected at launch site

8.3.4. Recovery Requirements

Table 8.3.4 Recovery System Team Derived Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
The launch vehicle return will to earth in a safe and controlled manner	Parachutes are sized appropriately and the pyro events are triggered at appropriate locations in the flightpath	Full Scale Test flight and simulations.	Altimeters deploy charges at the proper altitudes and the vehicle is safely recovered
The rocket will be recovered quickly and efficiently	Parachute size is minimized and a GPS tracker is implemented.	Full scale test flight and drift calculations	The coordinates of the landing location are received from launch vehicle and the vehicle is retrieved in a timely manner
Ejection charges will be properly sized	Ejection charges will be sized to deploy the drogue parachute at apogee, and the main parachute 750 ft above ground	Ejection charge testing will be completed prior to all launches Analysis: the charges will be sized to separate the rocket at atmosphere conditions at apogee and 750 ft above ground	The ejection charge successfully separates the rocket at apogee, and again at 750 ft above ground
All pyrotechnic charges shall be isolated from the parachutes	The pyrotechnic charges shall be located in separate area of the recovery bay The parachutes will be packed with a thermal barrier between itself and the ejection charge	Inspection	The parachute is undamaged at deployment
The bulkheads must have safety factor of 2 with respect to all applied forces	The bulkheads are manufactured from G10 fiberglass which has high yield strength	Analysis: FEA on the bulkheads are conducted using SolidWorks	The safety of factor of the bulkheads are above 2

The shockcord must have a length to absorb 1500 ft/lb (1.5 times the kinetic energy at the deployment of the main parachute)	The length of shockcord is chosen based on its elastic module to satisfy the requirement	Analysis: Hand calculation is made to confirm the shockcord is capable to absorb the required kinetic energy Test: After each test flight, inspection will be made to confirm that the shockcord is not damaged by the deployment of the parachutes	The shockcord has a length that absorbs 1,500 ft/lb

8.4. Project Timeline

In order to meet all NASA deadlines as well as team-derived deadlines, GIT LIT has implemented a task management and timeline system, hosted on Zoho. This system allows the team to track high level milestones, such as NASA deadlines, as well as low level milestones, such as weekly team assignments and outreach activities. Status indicators attached to each milestone show the percentage of completion, so that the team can track the specific status of each milestone. This information is also displayed on a GANTT chart, which allows the team to easily visualize deadlines. The project timeline and list of tasks are found below in Appendix A.

8.5. Budget

The total budget for GIT LIT for the 2017-2018 competition cycle is $7,394.36, with Table 8.5.1 showing the breakdown between eight categories: ATS, Airframe, Avionics, Rover, Travel, Prototyping, Subscale Vehicle, and Outreach/Misc. This breakdown is shown further as a percentage distribution in Figure 8.5.1.

The team’s purchases for the competition cycle followed the budget, with no unexpected costs or complications.

Table 8.5.1 Team Budget Breakdown

Category	Cost
ATS	$113.10
Airframe	$632.19
Avionics	$479.95
Rover	$115.00
Travel	$3,268.00
Prototyping	$69.74
Subscale Vehicle	563.67
Outreach/Misc.	$2,152.71
Total	**$7,394.36**

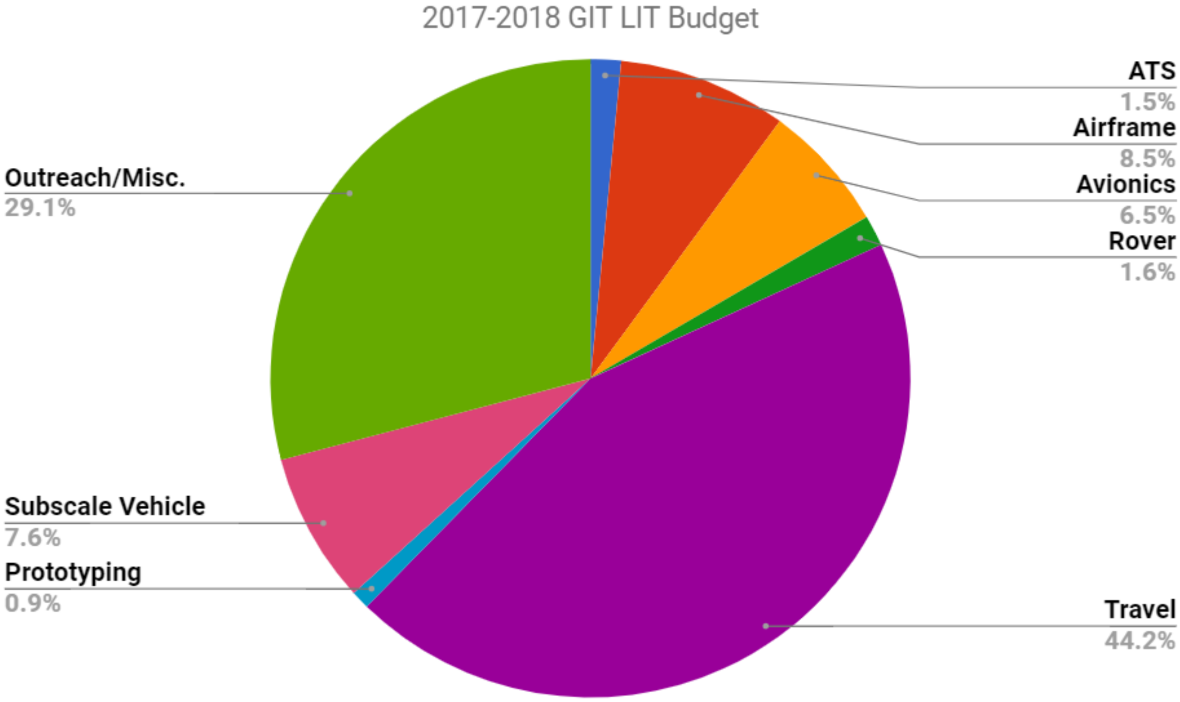


Figure 8.5.1 Team Budget Distribution

Tables 8.5.2 and 8.5.3 are comprehensive breakdowns of the subscale rocket costs and full year budget respectively. The components are sorted by the rocket system that they are a part of. This budget does not include leftover components from previous competition cycles, which the team did not have to purchase for the 2017-2018 competition cycle.

Table 8.5.2 Subscale Vehicle Costs

	Description	**Unit Cost**	**Qty**	**Total Cost**
Airframe	Nosecone	$20.79	1	$20.79
	Shear Pins	$3.10	1	$3.10
	Motor	0	0	$0.00
	Couplers	$4.13	2	$8.26
	Motor Mount Tube	$8.09	1	$8.09
	Black Powder	0	0	$0.00
	Ejection caps	$3.15	2	$6.30
	Rail Buttons	$3.22	2	$6.44
	Shock Cord (9/16 tubular nylon)	$8.75	1	$8.75
	Main Chute (58" TFR Std)	$31.95	1	$31.95
Rover	Screw-mount nuts	$10.74	1	$10.74
	4-40 1" screws	$4.43	1	$4.43
	4-40 lock nuts	$2.67	1	$2.67
	Motor	$12.99	1	$12.99
	Shaft Couplers (6mm to 1/4")	$4.99	1	$4.99
	1/8" thick x 1/2" x 12" 6061 Aluminum	$0.99	4	$3.96
	9V Batteries	$6.61	1	$6.61
	Receiver Controlled Switch	$13.91	1	$13.91
ATS	.125 x 4 x 12" 6061 Al Sheet	$14.59	1	$14.59
	Stepper Motor - NEMA 17	$16.95	1	$16.95
	.25 x 3 x 12" 6061 Al Bar	$7.32	1	$7.32
	2-56 .25" set screw 316 SS (5-pck)	$5.38	1	$5.38

	1/8" Diameter 1/4" Long Shoulder, 4-40 Thread	$1.64	5	$8.20
	M3, 8m long, low profile SHC screw	$5.71	1	$5.71
	1/8" Diameter 3/8" Long Shoulder, 4-40 Thread	$1.62	5	$8.10
	0.1875 x 4 x 12" 6061 Al Sheet	$6.83	1	$6.83
	Stepper Motor Driver	$8.95	2	$17.90
	DuPont Teflon Multi-Use Lubricant 11oz (add-on)	$6.69	1	$6.69
Avionics	RPI Sense Hat, includes several sensors (main appeal is IMU)	$37.99	1	$37.99
	Micro SD (8GB)	$6.99	1	$6.99
	RPI/ATS Battery	$10.80	1	$10.80
	Terminal Blocks, 5 pcs of 2 rows of 12 ports	$10.99	1	$10.99
	RPi/ATS battery 2	$14.61	1	$14.61
	Protoboards	$13.99	1	$13.99
	Silicone wire black/red	$1.98	1	$1.98
	bullet connectors	$2.30	1	$2.30
	heat shrink tubing	$6.99	1	$6.99
	arming switch	$5.95	3	$17.85
	4-40 standoffs	$8.32	1	$8.32
	M2.5 standoffs	$0.96	4	$3.84
	4-40 screws	$10.43	1	$10.43
	M2.5 screws	$11.90	1	$11.90
Motor	Complete 54mm Aerotech Motor Hardware (used)	$79.75	1	$79.75
	J250FJ Motor	$72.99	1	$72.99
			Total:	**$563.37**

Table 8.5.3 Comprehensive Team Budget

	Category	Description	Unit Cost	Qty	Total Cost
Rocket Materials	ATS	1/8" Al sheet (1x2ft)	$50.98	1	$50.98
		1/4" Al sheet (1x1ft)	$34.73	1	$34.73
		2-56 .25" set screw 316 SS (5-pck)	$5.38	1	$5.38
		1/8" Diameter 1/4" Long Shoulder, 4-40 Thread	$1.64	5	$8.20
		M3, 8m long, low profile SHC screw	$5.71	1	$5.71
		1/8" Diameter 3/8" Long Shoulder, 4-40 Thread	$1.62	5	$8.10
	Avionics				
		PerfectFlite stratologgerCF	$54.95	1	$54.95
		FS(fullscale) Battery	$25.00	1	$25.00
		FS Stepper Driver	$20.00	1	$20.00
		Stepper Motor	$40.00	1	$40.00
		Misc. Parts(wire, connectors, etc)	$50.00	1	$50.00
		Eggfinder GPS	$90.00	1	$90.00
		Weller Soldering Iron	$200.00	1	$200.00
	Rover				
		Rover electronics	$80.00	1	$80.00
		Motor	$15.00	1	$15.00
		Rover solar panel	$20.00	1	$20.00
	Airframe				
		75mm LOC tube	$14.95	1	$14.95
		3/8" Tubular Kevlar Shock Cord (per yard)	$2.50	12	$30.00
		Ejection Igniters (10 pack)	$15.79	2	$31.58
		5.5" G12 Coupler (12" length)	$54.11	1	$54.11
		2-56 Nylon Screws (Shear Pins) (#??)	$2.95	3	$8.85
		Parachute Protector	$10.95	1	$10.95

		Nosecone	$84.95	1	$84.95
		Complete 54mm Aerotech Hardware	$79.75	1	$79.75
		J250FJ Motor	$72.99	1	$72.99
		Aluminum for Ctr Rings	$51.58	1	$51.58
	Misc				
		Hardware	$150.00	1	$150.00
		Taps	$30.83	1	$30.83
		Electronics Box	$11.65	1	$11.65
Competition Expenses	Hotel	Hotel Rooms	$80.00	16	$1,280.00
	Rocket Fair	Poster (cost per foot, 36 inches)	$2.75	12	$33.00
		Display Stand	$30.00	1	$30.00
	Food		$100.00	16	$1,600.00
	Transportation	Gas for competition	$2.50	90	$225.00
		Trailer Rental	$20.00	5	$100.00
Prototyping	ATS				
		Nylon Bar	$35.36	1	$35.36
		2-56 .25" set screw 316 SS (5-pck)	$5.38	1	$5.38
		1/8" Diameter 1/4" Long Shoulder, 4-40 Thread	$1.64	5	$8.20
		M3, 8m long, low profile SHC screw	$5.71	1	$5.71
		1/8" Diameter 3/8" Long Shoulder, 4-40 Thread	$1.62	5	$8.10
	Avionics				
		Breadboard	$6.99	1	$6.99
Misc					
Mask	Safety		$22.49	1	$22.49
P100 Filter	Safety		$6.48	2	$12.96
Fire Extinguisher	Safety	FS	$19.29	1	$19.29

Fire Cabinet	Safety		$342.00	1	$342.00
Pens	Outreach		$0.62	250	$155.00
Stickers	Outreach	300 Stickers	$111.00	1	$111.00
T shirts			$18.00	20	$360.00
Whiteboard		6'x4'	$150.00	1	$150.00
Polo Shirts			$20.00	20	$400.00
Launch Transportation	Launch	Gas for launches	$60.00	9	$540.00
Drawer Safe			$39.97	1	$39.97
				Total:	**$6,830.69**

8.6. Funding Plan and Status

We are working closely with the Georgia Space Grant Consortium to receive most of the rocket materials budget as we have done in the past, and we have been allotted our expected budget of $4000 from them. This accounts for all of our rocket raw materials, which we place orders for through the Georgia Space Grant Consortium. In addition, we are accounting for Orbital ATK to cover our travel budget for up to $300, as this was also granted in previous competition cycles and has been confirmed for this competition cycle. Also, we are estimating a grant of $2500 in funding from the Georgia Institute of Technology Daniel Guggenheim School of Aerospace Engineering, as this amount was granted last year. This amount is still being finalized, and would account for a majority of our team's travel and accommodation expenses for competition. We hope to extend relations with other companies for further sponsorship. More specifically, we have reached out to companies GIT LIT members have interned with, local Atlanta companies, and established invested aerospace companies such as Orbital ATK, SpaceX, Lockheed Martin, etc.; we also plan on reaching out to Georgia Tech Aerospace alumni who could connect us more directly to companies. The Georgia Space Grant Consortium has offered to assist in connecting us with corporate sponsors. Table 8.6.1 shows our projected funding, which exceeds our cost estimates by over 25%, giving appropriate room for unanticipated costs. The Georgia Tech Ramblin' Rocket Club has generously offered the use of some of their tools, storage space, and facilitating the purchase of rocket motors. Georgia Tech has also offered us a room in the Engineering Science and Materials Building to use for construction, storage, and meeting space.

Table 8.6.1 Projected Funding

Sponsor	*Contribution*	*Date*
2016-2017 Unused Funds	$1,775.23	--
Georgia Space Grant Consortium	$4,000	November 2017
Alumni Donations	$200 (est.)	December 2017
Georgia Tech School of Aerospace Engineering	$2,500 (est.)	January 2018
Corporate Donations	$1,000 (est.)	January 2018
Orbital ATK Travel Stipend	$300	April 2018
Total	**$9,875.23 (est.)**	

Table 8.6.2 shows a final list of companies and organizations that the team plans has for advice, funding, and components. By dividing these categories amongst team leadership, our team was able to contact a wider range of companies, with better likelihood of success. In addition, by asking specific companies for specific components, we reduced the risk of ambiguity and confusion on the part of the sponsoring company.

Table 8.6.2 Preliminary Sponsorship Targets

Company	Component	Person Responsible
McMaster Carr	Scrap Aluminum	Kentez
Turnigy	3S Lipos	Lucas
	Transmitter/Receiver	Lucas
	LiPo Charger	Lucas
Mobius	Camera	Lucas
GoPro	Camera	Lucas
RedBull	Funding	Shravan
Northrop Grumman	Funding	Shravan
SpaceX	Funding/Experience/Advice	Shravan
Blue Origin	Funding	Shravan
Weller	Soldering Iron	Kentez
Formlabs	SL Printer	Walter
Carbon	SL Printer	Walter
Ultimaker	3D Printer	Walter
Polymaker	3D Printer Filament	Walter
Eagle Mfg	Flammable Cabinet	Daniel
Grainer	Flammable Cabinet	Daniel
Home Depot	Dremel	Kentez

	Drill Press	Kentez
Ace	Power Tools	Kentez
Loewes	Power Tools	Kentez
Flash Forge	3D Printer	Walter
Makerbot	3D Printer	Walter
Quartet	Whiteboard	Daniel
Epson	Mini Projector	Lucas
Microsoft	Monitors/Surfaces	Lucas
Craftsmen/Sears/Loewes	Tools	Kentez
	Toolbox	Kentez
	Tool Chest	Kentez
GTRI	Funding	Shravan
Advanced Circuits	Funding/Circuit Boards	Shravan/Lucas
Generation Orbit	Funding	Shravan
Trotec	Laser Cutter	Kentez
Canon/Nikon/Sony	Camera (DSLR)	Lucas
DJI	Quadcopter	Daniel
Cardibe 3D	Desktop CNC Mill	Kentez
Invention Studio/ME 2110	Mini Mills	Kentez

8.7. Sustainability Plan

Recognizing the experience and hands on practice that the NASA SL competition offers, GIT LIT has worked with the institute to offer Student Launch as a vertically integrated project within the VIP program (see 9. Educational Engagement). The VIP program provides an infrastructure that allows for a highly integrated design through utilizing resources from undergraduate students, graduate students, and professors from various engineering disciplines. Additionally, the VIP program adds further incentive by offering technical and elective course credits for team participation. These attributes establish the Student Launch program as a lasting and beneficial experience for students, preparing new students to become the future leaders of the team. In addition, through continuous marketing to all undergraduate students regardless of class level, the team is able to maintain a high level of diversity in terms of majors, class standing, and interests.

A new initiative started this year was the creation of a “New Members Guide” to the team and competition. This guide, made by the team leads and mentors from previous years, explains the basics of high power rocketry, competition guidelines, safe manufacturing techniques, and other relevant lessons learned by the team over various years. This guide allows new members to easily acclimate to the steep learning curve associated with building high power rockets for a competition, allowing them to contribute more to the team in less time. We plan on developing this guide further as the year progresses, adding sections such as competition etiquette, lessons learned from other teams, and areas that could still be improved.

9. Educational Engagement

9.1. Vertically Integrated Projects Program

One of the most valuable aspects of the GIT LIT is the pursuit of engagement in the Georgia Tech community. The Student Launch competition has been made into a highly integrated, class- based team project through Georgia Tech's Vertically Integrated Projects (VIP) Program. The VIP Program unites undergraduate education and faculty research in a team- based context. VIP extends the academic design experience beyond a single semester, allowing students to participate for up to three years. It provides the time and context to learn and practice professional skills, to make substantial contributions, and experience different roles on large multidisciplinary design/recovery teams. As a part of this experience, the Student Launch team takes on the responsibility to contribute in turn to the community and to promote scientific and engineering knowledge to over 200 students, age levels ranging from kindergarten to high school, through educational outreach.

As a part of the VIP program, students are taught how to maintain detailed research notebooks, which are then passed on to new students as an introduction to the team and project. In addition, the VIP team has a non-traditional class structure, with student-led general meetings as well as independently organized subteam meetings. The general meetings are designed to educate inexperienced members, through weekly assignments, technology demonstrations, and updates from each of the subteams; the subteam meetings, on the other hand, are where most of the rocket design and fabrication take place. Through presentations from the VIP teams to groups across campus, GIT LIT is able to continually educate both the members of the team as well as the Georgia Tech community.

9.2. Boy Scout Merit Badge

Last year, GIT LIT started a Boy Scout merit badge program, which consisted of inviting a local troop (Troop #433) to Georgia Tech, where the scouts were introduced to Aerospace Engineering facilities as well as different careers and opportunities in engineering. The badge program also included a presentation that introduced numerous examples of engineers' methods and mindsets, to give the scouts a window into the mind of an engineer. The team then took the troop on a tour of campus and the aerospace labs located in multiple buildings. This has created a large amount of interest in teaching more Engineering Merit Badge classes, as well as beginning programs with different merit badges, such as Astronomy, Aviation, and Robotics badges. By continuing the merit badge program, GIT LIT is striving to create the next leaders in STEM fields, particularly in Aerospace Engineering.

This year, the team is leading a Robotics merit badge, working alongside both the Boy Scout troop as well as local middle and high school robotics teams to provide a comprehensive educational experience. The robotics merit badge program, hosted on Saturday February 24, began with a group discussion of the challenges, advancements, and recent events of news in the field of robotics, focusing more on an open communicative environment rather than a lecture. Following this, the boy scouts were led on a tour of the robotics facilities at Georgia Tech, with the ability to ask questions and see all of the tools as well as projects being worked on in robotics. This tour concluded with a tour of GIT LIT's facility, where the full scale rocket was placed in a disassembled fashion so that the boy scouts were able to see the working interior. The students then saw a drone demonstration by an drone and robotics instructor who worked at the US Space and Rocket Center over the summer (Tom Hightower). The boy scouts learned about the building and operations of drones, as well as all the regulations and safety surrounding drones. Through this activity, the boy scouts were not only to learn about the theory and technology in the field of robotics, but also how this technology can be applied to the aerospace industry.

9.3. Peachtree Charter Middle School

GIT LIT has run an after school program at Frederick Douglass High School and Peachtree Charter Middle School for the past three years, teaching students the basics of rocketry and allowing them to design and build their own rockets. By working closely with the engineering instructor at both schools, our team has been able to expand our outreach to local Atlanta middle and high schools, where STEM is underrepresented.

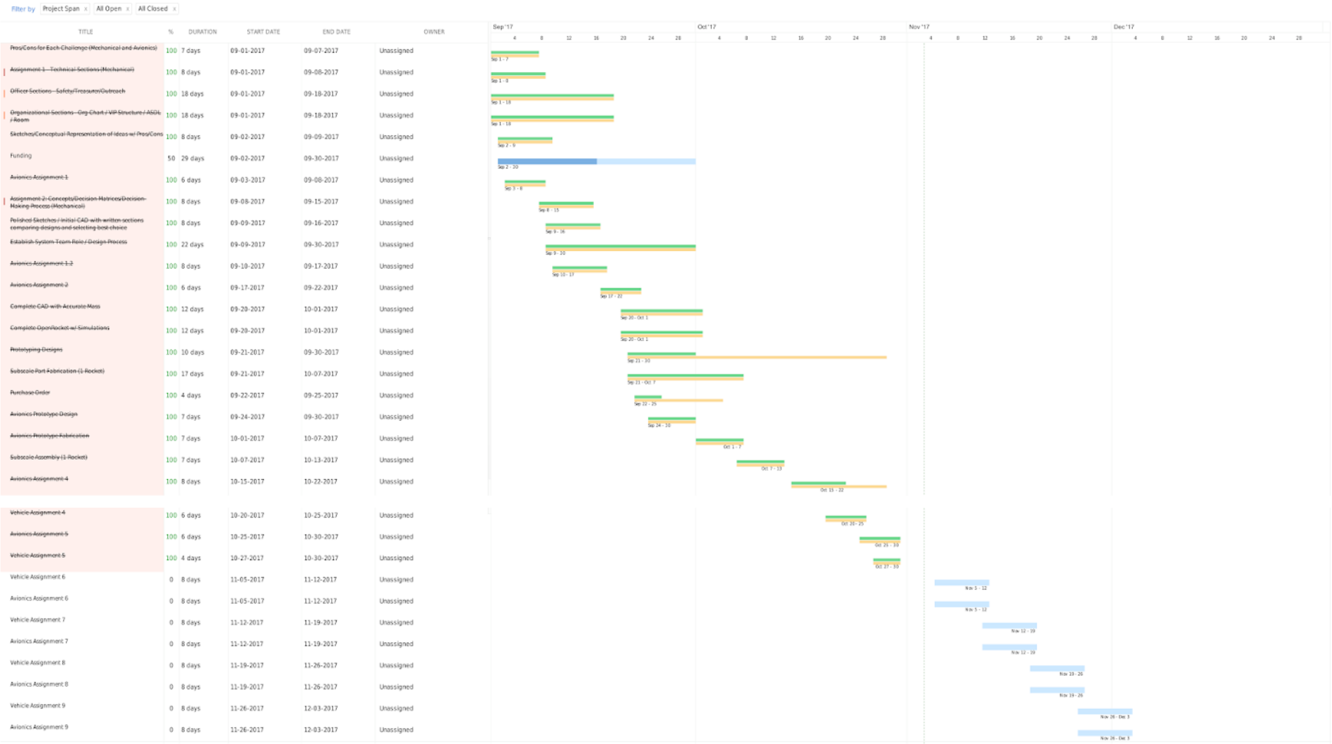
This year, the team worked with the STEM coordinator and 7th grade technology teacher for the school to facilitate a 3 week curriculum on rocketry and space. The team went to the school and taught each 7th grade class a lesson on rockets, trajectories, the engineering process and design cycle, and gave them hands on access to our subscale and full scale rockets. They were able to ask questions and learn about all the factors that go into an engineering design, what a career as an engineering student and an engineer overall would look like, and find out how the team and engineering teams in general are structured.

In addition, the team is working with the STEM coordinator of the school for a more in depth 10 week rocketry curriculum where every student would get to design their own small scale high powered rockets and launch them. This program would emphasize the design process involved in rocketry, with activities such as changing the mass and materials of different rocket components to see how the trajectory and performance of the rocket is affected. This program is still in the preliminary planning phase, and is expected to begin in September 2018.

Figure 9.3.1 Peachtree Charter Middle School Outreach

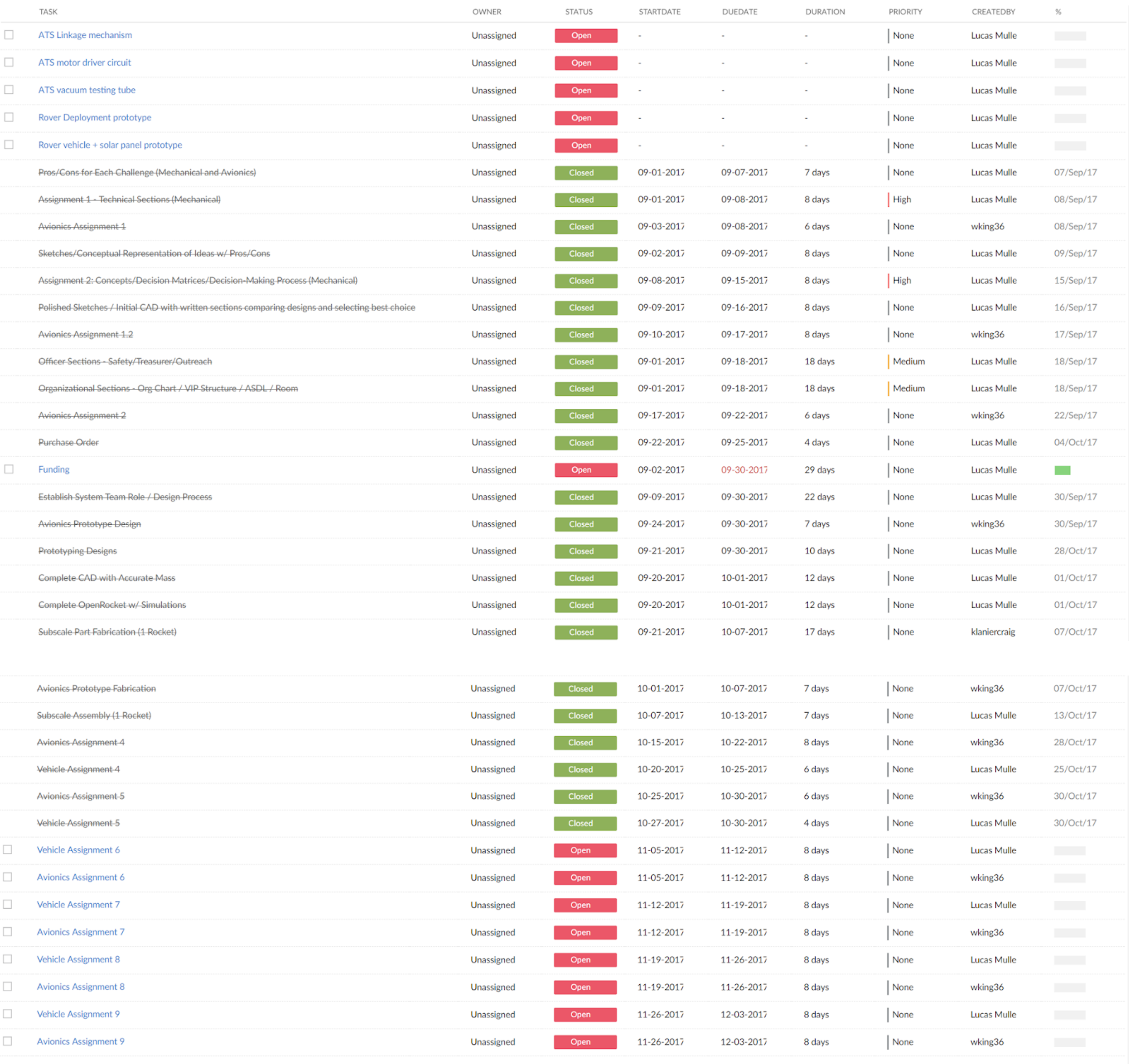
Appendix

A. Gantt Chart and Timeline



TITLE	%	DURATION	START DATE	END DATE	OWNER
~~Pros/Cons for Each Challenge (Mechanical and Avionics)~~	100	7 days	09-01-2017	09-07-2017	Unassigned
~~Assignment 1 - Technical Sections (Mechanical)~~	100	8 days	09-01-2017	09-08-2017	Unassigned
~~Officer Sections - Safety/Treasurer/Outreach~~	100	18 days	09-01-2017	09-18-2017	Unassigned
~~Organizational Sections - Org Chart / VIP Structure / ASDL / Room~~	100	18 days	09-01-2017	09-18-2017	Unassigned
~~Sketches/Conceptual Representation of Ideas w/ Pros/Cons~~	100	8 days	09-02-2017	09-09-2017	Unassigned
Funding	50	29 days	09-02-2017	09-30-2017	Unassigned
~~Avionics Assignment 1~~	100	6 days	09-03-2017	09-08-2017	Unassigned
~~Assignment 2: Concepts/Decision Matrices/Decision-Making Process (Mechanical)~~	100	8 days	09-08-2017	09-15-2017	Unassigned
~~Polished Sketches / Initial CAD with written sections comparing designs and selecting best choice~~	100	8 days	09-09-2017	09-16-2017	Unassigned
~~Establish System Team Role / Design Process~~	100	22 days	09-09-2017	09-30-2017	Unassigned
~~Avionics Assignment 1.2~~	100	8 days	09-10-2017	09-17-2017	Unassigned
~~Avionics Assignment 2~~	100	6 days	09-17-2017	09-22-2017	Unassigned
~~Complete CAD with Accurate Mass~~	100	12 days	09-20-2017	10-01-2017	Unassigned
~~Complete OpenRocket w/ Simulations~~	100	12 days	09-20-2017	10-01-2017	Unassigned
~~Prototyping Designs~~	100	10 days	09-21-2017	09-30-2017	Unassigned
~~Subscale Part Fabrication (1 Rocket)~~	100	17 days	09-21-2017	10-07-2017	Unassigned
~~Purchase Order~~	100	4 days	09-22-2017	09-25-2017	Unassigned
~~Avionics Prototype Design~~	100	7 days	09-24-2017	09-30-2017	Unassigned
~~Avionics Prototype Fabrication~~	100	7 days	10-01-2017	10-07-2017	Unassigned
~~Subscale Assembly (1 Rocket)~~	100	7 days	10-07-2017	10-13-2017	Unassigned
~~Avionics Assignment 4~~	100	8 days	10-15-2017	10-22-2017	Unassigned
~~Vehicle Assignment 4~~	100	6 days	10-20-2017	10-25-2017	Unassigned
~~Avionics Assignment 5~~	100	6 days	10-25-2017	10-30-2017	Unassigned
~~Vehicle Assignment 5~~	100	4 days	10-27-2017	10-30-2017	Unassigned
Vehicle Assignment 6	0	8 days	11-05-2017	11-12-2017	Unassigned
Avionics Assignment 6	0	8 days	11-05-2017	11-12-2017	Unassigned
Vehicle Assignment 7	0	8 days	11-12-2017	11-19-2017	Unassigned
Avionics Assignment 7	0	8 days	11-12-2017	11-19-2017	Unassigned
Vehicle Assignment 8	0	8 days	11-19-2017	11-26-2017	Unassigned
Avionics Assignment 8	0	8 days	11-19-2017	11-26-2017	Unassigned
Vehicle Assignment 9	0	8 days	11-26-2017	12-03-2017	Unassigned
Avionics Assignment 9	0	8 days	11-26-2017	12-03-2017	Unassigned

Figure A.1 Gantt Chart



	TASK	OWNER	STATUS	STARTDATE	DUEDATE	DURATION	PRIORITY	CREATEDBY	%
☐	ATS Linkage mechanism	Unassigned	Open	-	-	-	None	Lucas Mulle	
☐	ATS motor driver circuit	Unassigned	Open	-	-	-	None	Lucas Mulle	
☐	ATS vacuum testing tube	Unassigned	Open	-	-	-	None	Lucas Mulle	
☐	Rover Deployment prototype	Unassigned	Open	-	-	-	None	Lucas Mulle	
☐	Rover vehicle + solar panel prototype	Unassigned	Open	-	-	-	None	Lucas Mulle	
	~~Pros/Cons for Each Challenge (Mechanical and Avionics)~~	Unassigned	Closed	09-01-2017	09-07-2017	7 days	None	Lucas Mulle	07/Sep/17
	~~Assignment 1 - Technical Sections (Mechanical)~~	Unassigned	Closed	09-01-2017	09-08-2017	8 days	High	Lucas Mulle	08/Sep/17
	~~Avionics Assignment 1~~	Unassigned	Closed	09-03-2017	09-08-2017	6 days	None	wking36	08/Sep/17
	~~Sketches/Conceptual Representation of Ideas w/ Pros/Cons~~	Unassigned	Closed	09-02-2017	09-09-2017	8 days	None	Lucas Mulle	09/Sep/17
	~~Assignment 2: Concepts/Decision Matrices/Decision-Making Process (Mechanical)~~	Unassigned	Closed	09-08-2017	09-15-2017	8 days	High	Lucas Mulle	15/Sep/17
	~~Polished Sketches / Initial CAD with written sections comparing designs and selecting best choice~~	Unassigned	Closed	09-09-2017	09-16-2017	8 days	None	Lucas Mulle	16/Sep/17
	~~Avionics Assignment 1.2~~	Unassigned	Closed	09-10-2017	09-17-2017	8 days	None	wking36	17/Sep/17
	~~Officer Sections - Safety/Treasurer/Outreach~~	Unassigned	Closed	09-01-2017	09-18-2017	18 days	Medium	Lucas Mulle	18/Sep/17
	~~Organizational Sections - Org Chart / VIP Structure / ASDL / Room~~	Unassigned	Closed	09-01-2017	09-18-2017	18 days	Medium	Lucas Mulle	18/Sep/17
	~~Avionics Assignment 2~~	Unassigned	Closed	09-17-2017	09-22-2017	6 days	None	wking36	22/Sep/17
	~~Purchase Order~~	Unassigned	Closed	09-22-2017	09-25-2017	4 days	None	Lucas Mulle	04/Oct/17
☐	Funding	Unassigned	Open	09-02-2017	09-30-2017	29 days	None	Lucas Mulle	🟩
	~~Establish System Team Role / Design Process~~	Unassigned	Closed	09-09-2017	09-30-2017	22 days	None	Lucas Mulle	30/Sep/17
	~~Avionics Prototype Design~~	Unassigned	Closed	09-24-2017	09-30-2017	7 days	None	wking36	30/Sep/17
	~~Prototyping Designs~~	Unassigned	Closed	09-21-2017	09-30-2017	10 days	None	Lucas Mulle	28/Oct/17
	~~Complete CAD with Accurate Mass~~	Unassigned	Closed	09-20-2017	10-01-2017	12 days	None	Lucas Mulle	01/Oct/17
	~~Complete OpenRocket w/ Simulations~~	Unassigned	Closed	09-20-2017	10-01-2017	12 days	None	Lucas Mulle	01/Oct/17
	~~Subscale Part Fabrication (1 Rocket)~~	Unassigned	Closed	09-21-2017	10-07-2017	17 days	None	klaniercraig	07/Oct/17
	~~Avionics Prototype Fabrication~~	Unassigned	Closed	10-01-2017	10-07-2017	7 days	None	wking36	07/Oct/17
	~~Subscale Assembly (1 Rocket)~~	Unassigned	Closed	10-07-2017	10-13-2017	7 days	None	Lucas Mulle	13/Oct/17
	~~Avionics Assignment 4~~	Unassigned	Closed	10-15-2017	10-22-2017	8 days	None	wking36	28/Oct/17
	~~Vehicle Assignment 4~~	Unassigned	Closed	10-20-2017	10-25-2017	6 days	None	Lucas Mulle	25/Oct/17
	~~Avionics Assignment 5~~	Unassigned	Closed	10-25-2017	10-30-2017	6 days	None	wking36	30/Oct/17
	~~Vehicle Assignment 5~~	Unassigned	Closed	10-27-2017	10-30-2017	4 days	None	Lucas Mulle	30/Oct/17
☐	Vehicle Assignment 6	Unassigned	Open	11-05-2017	11-12-2017	8 days	None	Lucas Mulle	
☐	Avionics Assignment 6	Unassigned	Open	11-05-2017	11-12-2017	8 days	None	wking36	
☐	Vehicle Assignment 7	Unassigned	Open	11-12-2017	11-19-2017	8 days	None	Lucas Mulle	
☐	Avionics Assignment 7	Unassigned	Open	11-12-2017	11-19-2017	8 days	None	wking36	
☐	Vehicle Assignment 8	Unassigned	Open	11-19-2017	11-26-2017	8 days	None	Lucas Mulle	
☐	Avionics Assignment 8	Unassigned	Open	11-19-2017	11-26-2017	8 days	None	wking36	
☐	Vehicle Assignment 9	Unassigned	Open	11-26-2017	12-03-2017	8 days	None	Lucas Mulle	
☐	Avionics Assignment 9	Unassigned	Open	11-26-2017	12-03-2017	8 days	None	wking36	

Figure A.2 Task List