NASA STUDENT LAUNCH 2019

CRITICAL DESIGN REVIEW REPORT

1/4/2019

SOCIETY OF AERONAUTICS AND ROCKETRY

4202 East Fowler Avenue, MSC Box #197

Tampa, Florida 33620

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

TABLE OF EQUATIONS

1 SUMMARY OF PDR REPORT

1.1 TEAM SUMMARY

1.1.1 NAME AND ADDRESS

Society of Aeronautics and Rocketry (SOAR) at the **University of South Florida (USF)**

4202 East Fowler Avenue MSC Box 197
Tampa, Florida 33620
www.usfsoar.com / contact@usfsoar.com

1.1.2 TRA AFFILIATION

Tripoli Tampa Rocketry Association (TTRA)

P.O. Box 984
Kathleen, FL 33849
www.tripoli-tampa.com / ttra@earthlink.net

1.1.3 TEAM MENTOR

Jim West

Member, Tripoli Advisory Panel / Tripoli Member #0706 (Certification Level III)
(863) 712-9379 / jkwest@tampabay.rr.com

1.2 LAUNCH VEHICLE SUMMARY

SAOR has designed, and will build and launch, a large 6” diameter fiberglass high-powered rocket with two untethered sections, a fully redundant recovery subsystem, a payload descent leveling subsystem, a dynamic apogee adjustment subsystem, and an adjustable ballast subsystem. The final vehicle design prescribes a 141” long rocket that has an unloaded weight of 36.7 lb, and a liftoff weight of 53.9 lb. This vehicle will be designed to carry the payload to exactly 5,000 ft above ground level.

1.3 PAYLOAD SUMMARY

1.3.1 PAYLOAD TITLE

A deployable soil-collection rover has been selected. The rover is currently unnamed.

1.3.2 ROVER DESIGN SUMMARY

The competition rover design is inspired by the Recon Scout XT, a military camera robot with drive wheels on either side of a central body. The rover will contain an Arduino, batteries, soil recovery module, and advanced guidance sensors. The projected diameter is 5.92”; the internal diameter of the rocket body. The rover will be seated inside the vehicle payload bay during flight and held in place with high-strength solenoids. The rover will be deployed via a winch deployment system and will complete the mission objective after a remote initiation signal has been received.

2 CHANGES MADE SINCE PDR

2.1 CHANGES TO VEHICLE CRITERIA

Table 1: Changes to vehicle criteria since PDR.

Change Summary	Reason for Change	Section Reference
Changed forward altimeters to Missile Works RRC3 instead of RRC2+.	The RRC3 altimeters are more configurable, collect more data, and are compatible with the RTx tracking and flight diagnostics system.	4.3.4 Avionics
Switched 9V batteries to 3.5V LiPo batteries for all avionics.	The RTx avionics system requires significantly more power, and it is desirable to use one standard battery for all avionics systems.	4.3.4 Avionics
Changed Payload Descent Leveling System to use Tender Descender and RRC2+ Altimeter.	The Tender Descender was found to be more reliable, more configurable, and simpler to set up.	4.1.3.2.3 Payload Descent Levelling Subsystem (PDLS)
Switched main parachutes to Fruity Chutes Iris Compact line, rather than SkyAngle.	The Fruity Chutes parachutes are smaller and lighter, allowing for a larger payload capacity.	4.3.3 Parachutes
Changed 3D printed PLA altimeter sleds to CNC-cut carbon fiber.	Carbon fiber is significantly stronger than PLA, without adding much additional weight to the vehicle.	4.3.4.4.1 Sled Design
Added GPS tracking and live data streaming systems to avionics system.	These systems allow for the team to track the location of the rocket after it has landed and deployed the payload. The live data streaming system will allow the team to see how well the rocket is performing during flight.	4.3.4.1.2 GPS and Data Streaming System

Change Summary	Reason for Change	Section Reference
Changed airframe material to prefabricated fiberglass.	The vehicle team was unable to gain enough experience filament-winding and has much more experience with fiberglass airframes. Furthermore, fiberglass is RF-transparent and will not interfere with communications.	4.1.3.1.1 Airframe
Modified bulkhead design to use CNC routed 3/16" fiberglass sheets, instead of sandwiched ⅛" sheets.	The use of one solid sheet, rather than two epoxied sheets, will prevent the risk of delamination and make finite element analysis easier and more reliable.	4.3.6 Bulkheads
Inset motor retainer slightly into the lower airframe.	This will allow the rocket to stand on end more securely and protect the motor retainer from drops.	4.1.3.1.6 Motor Retainer
Increased overall rocket length, payload bay length, and upper section avionics bay length.	The increased dimensions stem from the desire for more working area for both the payload team and for places to put the subsystems that will be used in this rocket.	4.1.3 Vehicle Design Details
Changed motor to Cesaroni L2375 from L1410.	The L2375 motor is significantly more powerful, which compensates for the heavier rocket caused by the switch to fiberglass and increased length.	4.1.3.3 Motor

2.2 CHANGES TO PAYLOAD CRITERIA

Table 2: Changes to payload criteria since CDR.

Change Summary	Reason for Change	Section Reference
Design changed to a two-wheeled rover with a stability arm.	More efficient use of space, also will be simpler to build, easier to steer than previous model.	6 Payload Criteria

Change Summary	Reason for Change	Section Reference
Angular steering arm no longer needed.	New rover will now use differential steering.	6 Payload Criteria

2.3 CHANGES TO PROJECT PLAN

Table 3: Changes to project plan since CDR.

Change Summary	Reason for Change	Section Reference
Timeline events updated	Additional outreach events were added to the general timeline. The vehicle and payload timelines were updated as well.	8.2 Timeline
Sara Vlhova as additional Safety Officer	An additional safety officer will make overseeing all operations less complex.	3.1.7 Safety Officer
Leadership Personnel Changes	Former Operations Manager Sara Vlhova is now Project Manager. Evan Williams is no longer associated with project leadership.	3.1.4 Project Manager
Budget	The budget has been adjusted to account for changes made to the subscale, vehicle, and payload.	8.1 Budget

3 TEAM PERSONNEL

3.1 PRIMARY LEADERSHIP

3.1.1 USF FACULTY ADVISOR

Dr. Manoug Manougian

Director, USF STEM Education Center; Professor, USF College of Arts & Sciences
(813) 974-2349 / manoug@usf.edu

3.1.2 TEAM MENTOR

Jim West

Member, Tripoli Advisory Panel
Tripoli Member #0706 (Certification Level III)
(863) 712-9379 / jkwest@tampabay.rr.com

3.1.3 TEAM ADVISOR AND POINT OF CONTACT

The Team Advisor is a SOAR Executive Board member and acts as a liaison between the NASA Student Launch competition team, the SOAR Executive Board, and external organizations.

Ashleigh Stevenson

Chief of Operations, SOAR Executive Board
Undergraduate Senior, Mathematics
(727) 470-8081 / astevenson1@mail.usf.edu

3.1.4 PROJECT MANAGER

The Project Manager directly oversees project operations and sub-team collaboration.

Sara Vlhova

Undergraduate Junior, Chemical Engineering
(727) 331-5912 / saravlhova@mail.usf.edu

3.1.5 VEHICLE TEAM LEAD

Ian Sanders

Undergraduate Junior, Mechanical Engineering
(239) 324-9843 / iansanders@mail.usf.edu

3.1.6 PAYLOAD TEAM LEAD

Thomas Hall

Undergraduate Junior, Engineering
(815) 861-3634 / thall4@mail.usf.edu

3.1.7 SAFETY OFFICER

Ashley de Kort

Undergraduate Junior, Mechanical Engineering
(786) 521-0404 / ashleydekort@mail.usf.edu

Sara Vlhova

Undergraduate Junior, Chemical Engineering
(727) 331-5912 / saravlhova@mail.usf.edu

3.2 TEAM MEMBERS

SOAR's 2019 NASA Student Launch Initiative Team consists of 23 currently active student members. Team managers and leaders take attendance at each team meeting to ensure team members are engaged throughout the academic year. Attendance records are kept on BullSync, USF's distribution of the OrgSync student organization management software.

Table 4: Complete roster of project team members.

Name	Position
Phuc Nguyen	DAAS Subteam Engineer I
Naveen Kumare	DAAS Subteam Engineer II
Javian Hernandez	DAAS Subteam Lead
Tepie Meng	DAAS Subteam Member I
Madison Kozee	Outreach Coordinator
Ryan Carlomany	Payload Electrical Engineer I
Brian Alvarez	Payload Electrical Engineer II
John Russell	Payload Team Engineer I
Thomas Hall	Payload Team Lead
Grant Gurvis	Payload Computer Engineer I
Adheesh Shenoy	Payload Test Engineer
Ashleigh Stevenson	Project Advisor
Sara Vlhova	Project Manager
Ben Bortz	Rocket Production Lead
Arnold Perez	Senior Payload Computer Engineer
Dhairya Soni	Senior Vehicle Electrical Engineer
Mrudit Trivedi	Senior Vehicle Recovery Engineer

Name	Position
Katherine Tran	Vehicle Computer Engineer
Matthew Miller	Vehicle Team Engineer I
Ian Sanders	Vehicle Team Lead

3.2.1 FOREIGN NATIONAL TEAM MEMBERS

Foreign national team member information has been collected and sent to NASA per the competition requirements. Updates will continue to be sent to NASA as the list changes throughout the year.

3.2.2 TRAVEL TEAM MEMBERS

The list of travel team members will be finalized and sent to promptly after receipt of the travel team members submission form.

4 VEHICLE CRITERIA

4.1 DESIGN AND VERIFICATION OF LAUNCH VEHICLE

4.1.1 MISSION STATEMENT

The mission of this launch vehicle is to successfully carry the competition payload to the target altitude and deliver it to the ground in a manner that maximizes safety, accuracy, and probability of payload success.

4.1.2 MISSION SUCCESS CRITERIA

For the vehicle mission to be considered to be successful, the following criteria must be met. These criteria are derived from the requirements and derived requirements located in 7.2.2 Vehicle Requirements.

1. The rocket will leave the launch rail after motor ignition with a minimum velocity of 52 ft/s.
1. The rocket will reach an apogee between 4,950 and 5,050 feet.
2. All sections will impact the ground with a kinetic energy of less than 75 ft-lb_F.
3. The rocket will not be damaged in such a way that would render a second flight within 12 hours impossible.
4. The payload will be protected during flight and landing.
5. The payload bay will not be blocked by foreign debris upon landing.
6. No injuries or property damage whatsoever shall occur during flight or recovery.
7. All involved team members will gain valuable experience in engineering, rocketry, teamwork, communications, and general STEM skills.

4.1.3 VEHICLE DESIGN DETAILS

After researching and examining the proposed design alternatives, a final preliminary vehicle design has been compiled. Primary vehicle specifications are available in Table 5 below.

Table 5: Estimated primary launch vehicle characteristics, as designed or simulated.

Vehicle Property	Value as Designed
Diameter (in)	6
Length (in)	141
Unloaded Mass (without primary payload or motor) (lb)	36.7
Loaded (Liftoff) Mass (with payload and motor) (lb)	53.9
Allotted Payload Mass (lb)	8

Vehicle Property	Value as Designed
Airframe Material	Fiberglass
Bulkhead Material	Fiberglass Reinforced Plastic
Fin Material	Carbon Fiber

Note: static stability properties (center of gravity, center of pressure, and margin of static stability) are provided in Table 38, in 4.4.2 Static Stability.

This complex vehicle design features three parachutes, two avionics bays with a total of five altimeters, and three advanced subsystems (not including the payload itself). These subsystems include the Payload Descent Leveling Subsystem (PDLS), the Adjustable Ballast Subsystem (ABS), and the Dynamic Ascent Adjustment Subsystem (DAAS). The loaded launch vehicle is projected to reach an altitude of 5,000 feet when powered with a Cesaroni L2375 solid APCP rocket motor and controlled by the DAAS.

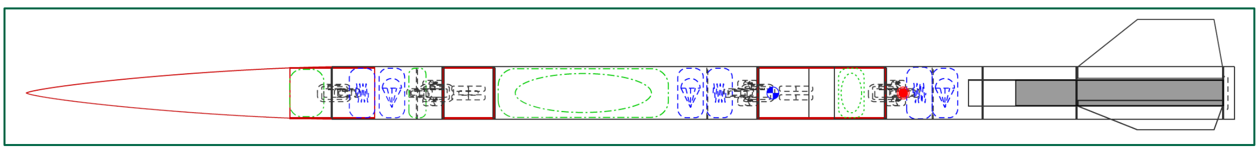


Figure 1: Layout drawing of vehicle design (loaded), with CG shown in blue and CP in red.

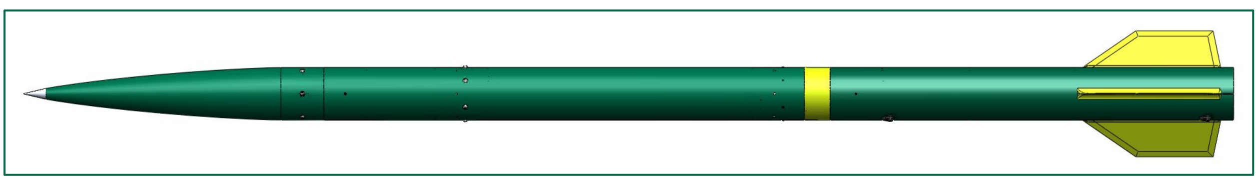


Figure 2: Illustrative render of launch vehicle design (not representative of final appearance).

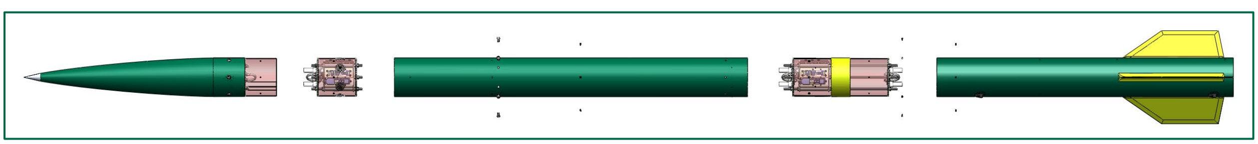


Figure 3: Exploded render of selected vehicle design, with avionics subsystems visible.

As is visible in Figure 3, the rocket is designed with two separate sections. The upper section consists of the three components on the right along with their recovery gear, which includes the following:

- Nose Cone
- Adjustable Ballast Subsystem (ABS)
- Upper Airframe
- Upper Section Avionics Bay

- Payload Bay
- Payload Descent Leveling Subsystem (PDLS)
- Upper Section Main Parachute

And the lower section consists of the following:

- Lower Section Avionics Bay
- Dynamic Apogee Adjustment Subsystem (DAAS)
- Lower Airframe
- Lower Section Main Parachute
- Drogue Parachute
- Fins
- Motor Mount

The mass of each component has been sourced from part specifications when possible and OpenRocket simulations when no specific part specifications are available.

Table 6: Estimated mass of launch vehicle sections and subsystems.

Vehicle Section	**Component / Subsystem**	**Mass** (lb)	**Total Section Mass** (lb)
Upper	Nose Cone and Recovery Hardware	5.8	23.2
	ABS	0.0	
	Upper Airframe	4.84	
	Upper Section Avionics Bay	2.5	
	Payload (allotted)	8.0	
	PDLS	0.5	
	Upper Section Main Parachute	1.56	
Lower	Lower Section Avionics Bay	5.99	21.5
	DAAS (allotted)	3.0	
	Lower Airframe	6.09	
	Lower Section Main Parachute	1.4	
	Drogue Parachute	0.312	
	Fins	3.77	

Vehicle Section	**Component / Subsystem**	**Mass** (lb)	**Total Section Mass** (lb)
	Motor Mount	0.941	
Total Mass (without motor)			44.7

Specific design decisions, selected specifications, and justifications for each are detailed in the following subsections.

4.1.3.1 LAUNCH VEHICLE STRUCTURE

The selected vehicle design is a composite fiberglass body with carbon fiber fins. The rocket consists of an upper and lower section, which are recovered under separate tethers.

4.1.3.1.1 AIRFRAME

The launch vehicle structure is composed of high-strength fiberglass tubes, designed specifically for use in high-powered rockets. The exterior consists of the upper and lower airframe and the transition band. There are also several fiberglass tubes on the interior of the rocket, which provide structural support and house crucial subsystems, including both avionics bays (described in 4.3.4 Avionics) and the ABS [described in 4.1.3.2.2 Adjustable Ballast Subsystem (ABS)].

4.1.3.1.1.1 DESIGN

The typical exterior diameter of the rocket will be 6.1”, and wall thicknesses of all tubes will be 0.09”. Interior tubes will be designed to easily press-fit into the exterior body, except for the motor mount tube. This 30” long, 3.3” diameter motor mount tube is sized to fit a 75mm motor casing and will be installed with centering rings as described in 4.1.3.1.4 Centering Rings. Lengths of each tube are shown in Figure 4 below.

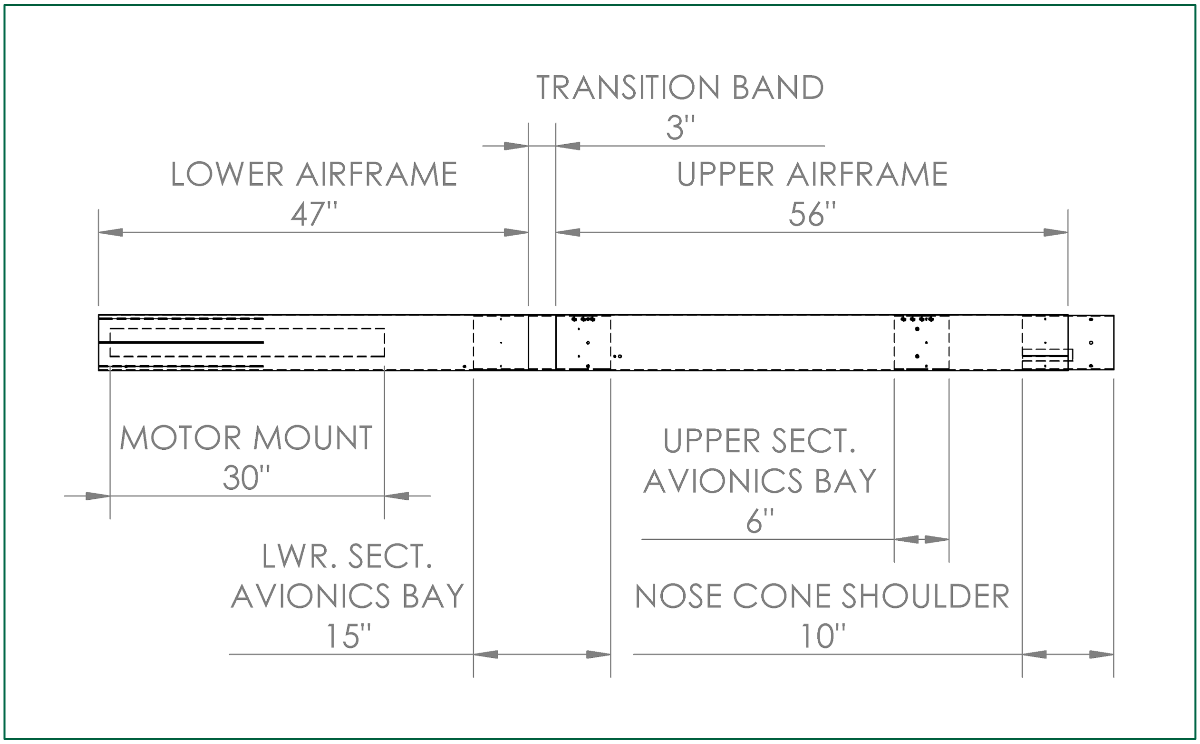


Figure 4: Size and purpose of all structural fiberglass tubes in the launch vehicle.

4.1.3.1.1.2 MATERIAL AND CONSTRUCTION

All airframe tubes utilized in the construction of the launch vehicle will be prefabricated fiberglass tubing. Fiberglass is an exceptionally strong, lightweight material, and has the additional advantage of being RF-transparent.

Earlier designs called for custom-wound carbon fiber tubing, however further development of this process has been deemed impractical at this point in the project development, therefore, affordable commercial tubes were selected. This selection does come with the disadvantage of increased overall weight, which is reflected in the motor selection.

4.1.3.1.1.3 STRUCTURAL ASSEMBLY

All structural bonds on the rocket will be completed with AeroPoxy, an extremely strong, lightweight epoxy intended for use in aerospace applications. This epoxy has proven to consistently bond strongly and effectively, most recently in the subscale rocket, where it performed flawlessly. Its reliability offsets the disadvantage of its long working time and high viscosity (which helps with forming fin reinforcing fillets). 30-Minute Epoxy may be used for some non-critical bonds when rapid cure time is a priority.

Prior to epoxying any component, surfaces will be prepared by sanding with low-grit sandpaper and then cleaning with denatured alcohol. After allowing the solvent to completely dry, the epoxy will be applied and allowed to dry for at least 24 hours (60 minutes in the case of non-critical 30-Minute Epoxy bonds) before handling.

4.1.3.1.1.4 DIAMETER

The 6″ nominal airframe diameter was selected largely based upon past experiences; in 2018, SOAR launched a smaller rocket and determined that this size was not sufficient to meet the requirements of the payload. This year, the payload team requested a larger diameter. Furthermore, a 6″ diameter rocket is the maximum feasible size that can be launched to the desired altitude, given the competition limitations on motor power.

4.1.3.1.2 NOSE CONE

4.1.3.1.2.1 DESIGN AND MATERIAL

The nose cone will be a filament-wound fiberglass Von Karman-profile nose cone sourced from Wildman Rocketry. This profile is constructed from the Haack series, and provides maximum-performance drag characteristics. The nose cone shoulder will be attached to the nose cone with six 5/16″-28 machine screws, allowing for convenient removal of the nose cone shoulder to access the interior of the nose cone. The nose cone weighs approximately 2.57 lb.

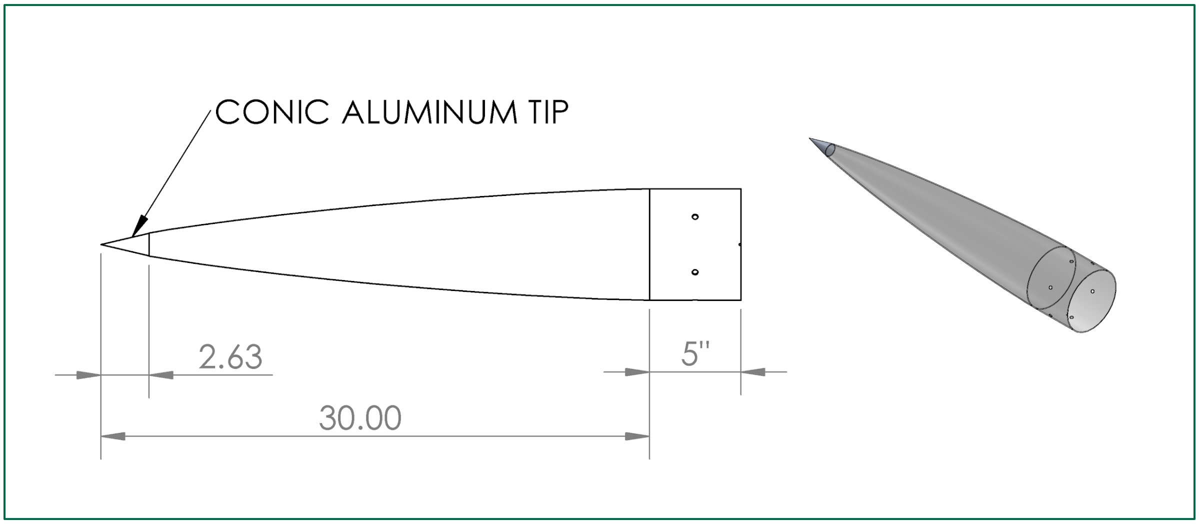


Figure 5: Launch vehicle nose cone design.

4.1.3.1.2.2 NOSE CONE SHOULDER

The nose cone shoulder is 10″ in length and has a wall thickness of 0.09″. It will also be constructed from filament-wound fiberglass tubing. Within this shoulder, the nose cone bulkhead will be epoxied using carbon-fiber reinforced AeroPoxy. As noted previously, the shoulder will be secured with six 5/16″ machine screws, allowing simple removal of the bulkhead to access and adjust the ABS.

4.1.3.1.3 FINS

Three backswept trapezoidal tapered carbon fiber fins will provide static stability for the rocket while under powered flight.

4.1.3.1.3.1 LOCATION

To move the center of pressure as low as possible (therefore maximizing the margin of static stability), the fins will be located as close as possible to the bottom edge of the rocket. When the fins are mounted flush to the lower centering ring, the lower corner of the fins will be 1.375" from the bottom of the rocket.

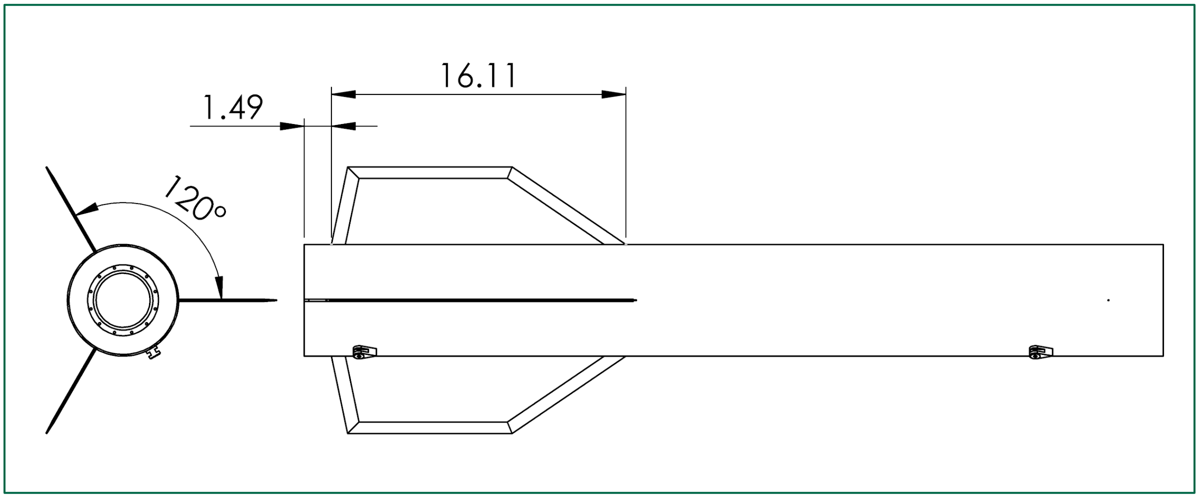


Figure 6: Location of fins on the launch vehicle lower section.

4.1.3.1.3.2 NUMBER OF FINS

After considering several alternatives for the number of fins on the rocket, it was ultimately decided that three fins would be optimal for maximizing stability while minimizing drag. With less than three fins, it is impossible to obtain full stability about the entire primary axis of the rocket, and any more than three fins simply causes an increase in drag with little to no measurable benefits. Therefore, this rocket will have three fins, spaced evenly about the rocket body.

4.1.3.1.3.3 DESIGN DETAILS

The fins are a backswept trapezoidal shape, which has been carefully tuned to provide a pre-launch margin of static stability between 2 and 3.5 calipers. The fins will be tapered at all flow edges to improve drag characteristics.

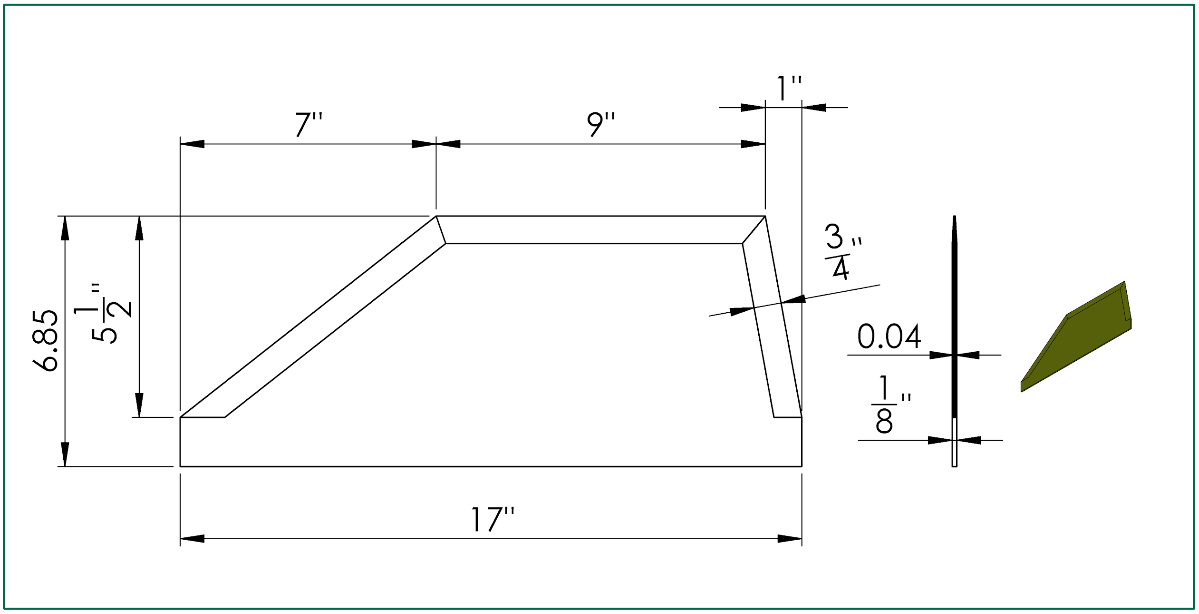


Figure 7: Backswept trapezoidal fin design.

4.1.3.1.3.4 MATERIAL AND CONSTRUCTION

Carbon fiber has been selected for the fin material due to its high rigidity and strength for its weight. In a situation where any sort of resonant flutter could be catastrophic, a rigid material is essential. Furthermore, the fins must be as light as possible in order to prevent increasing mass below the center of gravity.

The fins will therefore be cut from ⅛" carbon fiber sheets using a CNC router. After cutting, an even, shallow chamfer will be sanded into to all exposed edges to decrease drag.

Fins will be installed by epoxying to the motor mount, at which point the motor mount will be slid into the lower airframe. This assembly is shown in Figure 8 below. After the motor mount is installed in the lower airframe, a ¾" structural fillet will be applied using AeroPoxy.

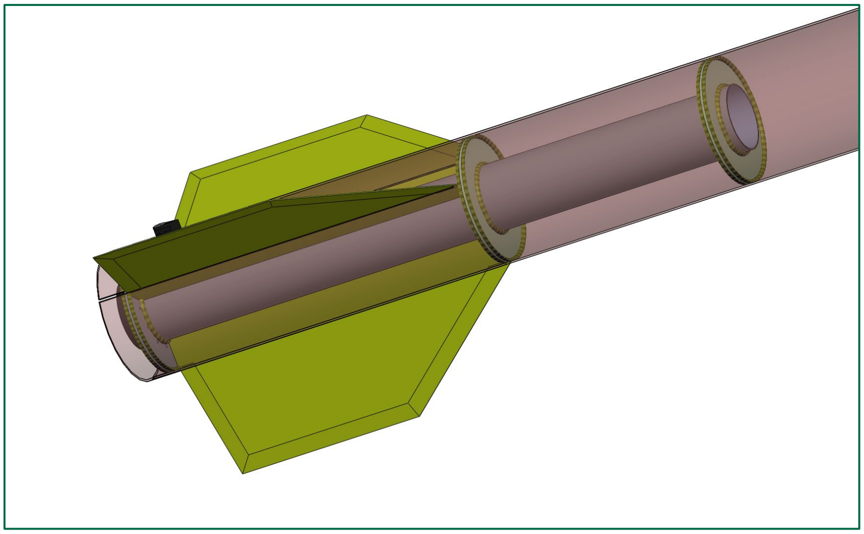


Figure 8: Fin can assembly with centering rings (epoxy fin fillets not shown).

4.1.3.1.4 CENTERING RINGS

The strength and accuracy of the three centering rings is paramount to mission success. If the centering rings fail or are inaccurately cut, the rocket could veer off course or, in a worst-case scenario, the motor could eject through the rocket. Therefore, great care has been taken in designing these deceptively simple components.

4.1.3.1.4.1 LOCATION

The lower two centering rings will be located flush with the ends of the fins as shown in Figure 8 above, while the forward centering ring will be positioned ½" from the top of the motor tube. This positioning will assist in accurately positioning fins, and the location of the forward centering ring will allow for epoxying without risking epoxy blocking the motor tube. The location of the rear centering ring is shown in Figure 11.

4.1.3.1.4.2 DESIGN DETAILS

The forward and middle centering ring designs are identical; both are simply rings with a small cutout for the drogue parachute shock cord to pass through to be epoxied to the motor mount tube.

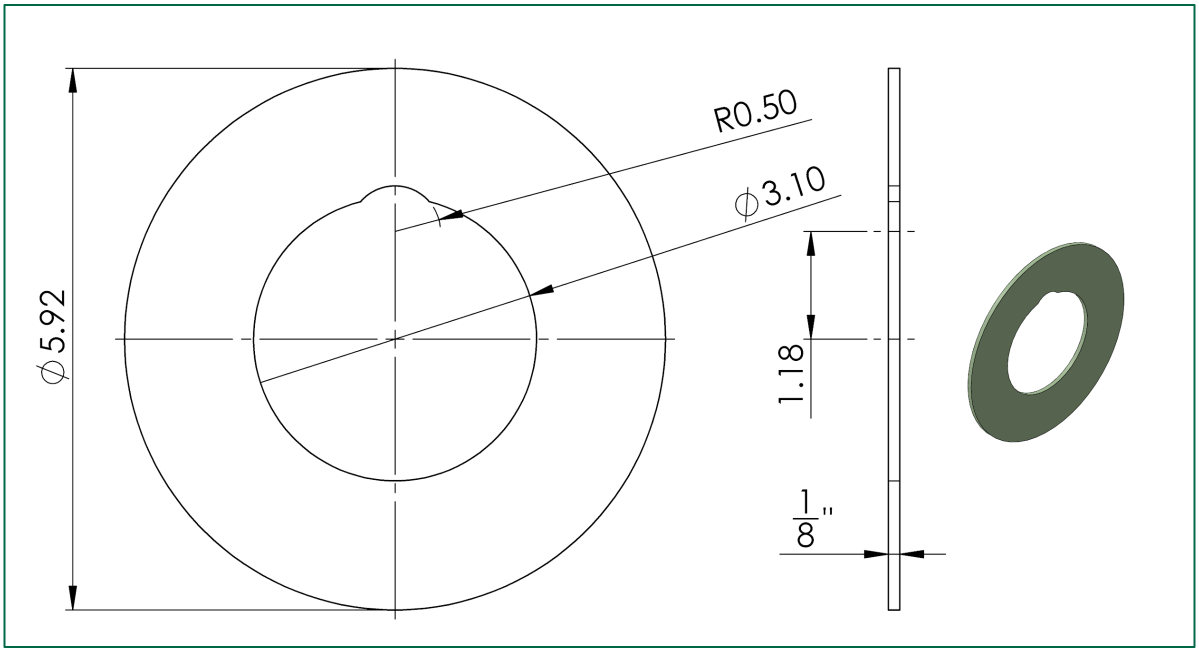


Figure 9: Forward and middle centering ring design.

The lower centering ring does not contain a cutout for the drogue shock cord, but instead has 12 holes, in which metal thread taps will be screwed and epoxied. These thread taps will be used to secure the removable 75mm motor retainer.

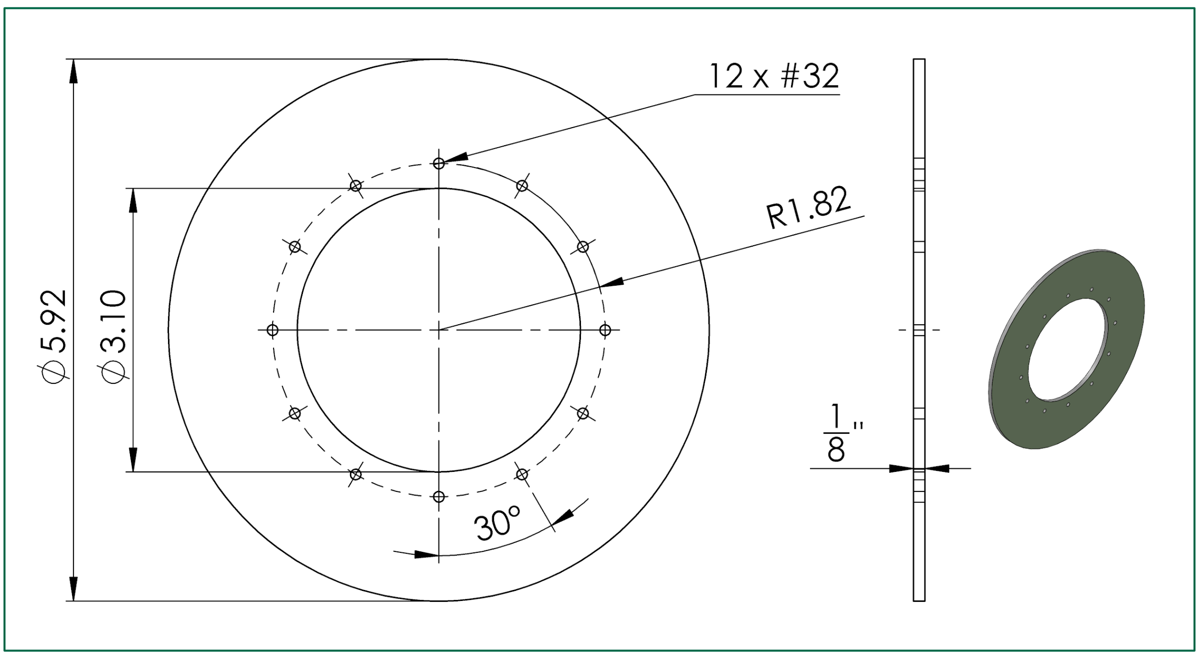


Figure 10: Lower centering ring design, with motor retainer hole pattern.

4.1.3.1.4.3 MATERIAL AND CONSTRUCTION

If any of these bulkheads were to yield under load, the results would be potentially catastrophic. Therefore, each centering ring will be milled using a precision CNC router from structural ⅛" FRP sheets and epoxied to the lower airframe and motor tube with AeroPoxy, using ¼" fillets at all bond points.

4.1.3.1.5 LAUNCH RAIL LUGS

Two launch rail lugs (visible in Figure 11) will be installed on the lower airframe. These rail lugs will be specifically designed to fit a 1515 rail and will be machined from Delrin plastic.

4.1.3.1.6 MOTOR RETAINER

In order to ensure safety and security of the rocket motor after burnout, an Aero Pack 75mm screw-on flanged motor retainer will be installed at the lower end of the rocket. The use of a screw-on motor retainer will allow for simple removal if the retainer is damaged. The motor will be secured directly to the rear centering ring, which will be installed far enough inside the rocket that the full assembled motor retainer will not protrude. This will protect the retainer from drops and scrapes, while allowing the rocket to stand on end for display when necessary.

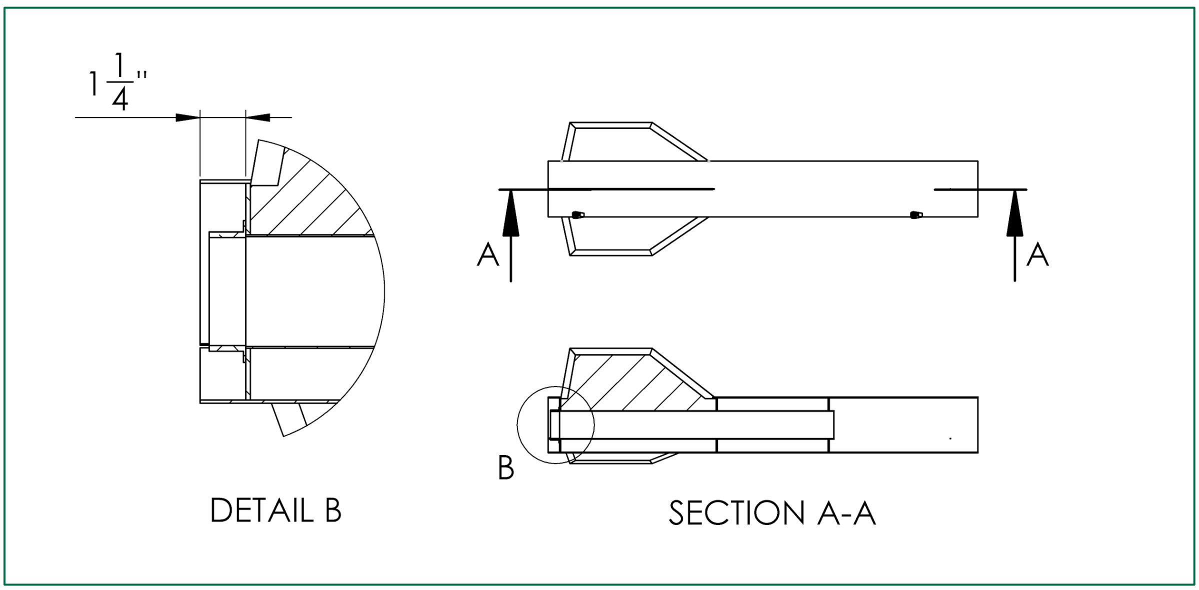


Figure 11: Motor retainer installation location and design. Motor retainer itself is approximate model.

Table 7: Aero Pack 75mm screw-on flanged motor retainer properties[1].

Motor Retainer Property	Value
Manufacturer	Aero Pack
Model Number	24069
Nominal Size (mm)	75
Weight (lb)	0.304

4.1.3.2 SUBSYSTEMS

4.1.3.2.1 DYNAMIC APOGEE ADJUSTMENT SUBSYSTEM (DAAS)

4.1.3.2.1.1 MISSION STATEMENT

The mission of the Dynamic Apogee Adjustment Subsystem (DAAS) is to increase accuracy in targeted vehicle apogee in a safe and reliable manner.

4.1.3.2.1.2 MISSION SUCCESS CRITERIA

After motor burnout, there are only two forces acting on the mass of the rocket; gravity and atmospheric drag. The ABS already adjust vehicle mass to modify the force of gravity, but as the vehicle mass cannot be dynamically modified during flight, the DAAS must instead be able to predict and adjust the force of drag on the launch vehicle.

To be considered successful, the DAAS must:

- Bring the final apogee of the launch vehicle within ±50 feet of the targeted apogee.
- Not induce flight instability (e.g., significant modifications to margin of stability).
- Not exist in a location forward of the center of gravity after motor burnout.
- Not exceed the allotted weight of 3 lb.

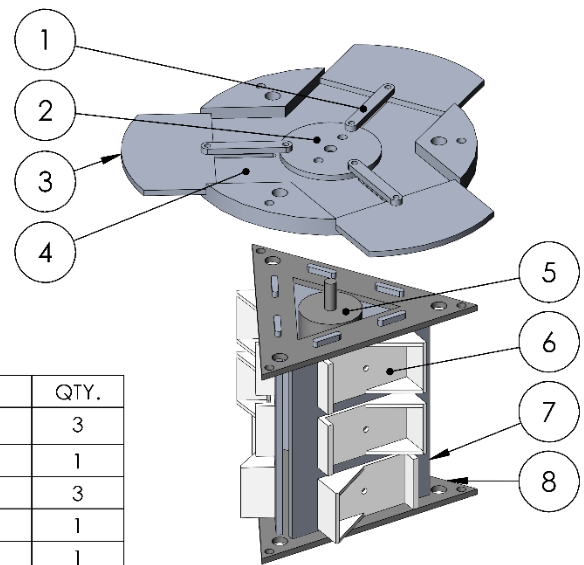
4.1.3.2.1.3 LOCATION

The fin slots will be centered in the 3” transition band, visible as a bright green band in Figure 2 and annotated in Figure 4. A rotary switch located in-line with the switches on the lower section avionics bay will control system power, thus conserving power during launch preparations. All electronics and mechanical components will be located in the allocated lower half of the lower section avionics bay, visible as an empty space in Figure 3.

[1] Source: (Apogee Components 2018)

4.1.3.2.1.4 MECHANICAL DESIGN

The DAAS will consist of three equally spaced, dynamically deployed fins. These fins will be controlled by a stepper motor and crank-slider mechanism, which in turn will be controlled by a high-performance microcontroller based on sensor inputs. Power will be supplied by a bank of 9V batteries.



ITEM NO.	PART NAME	QTY.
1	Connecting Rod	3
2	Crank	1
3	Fin	3
4	Retainer	1
5	Motor	1
6	Battery Retainer	6
7	Electronics Sled	3
8	Eelectronics Cap	2

Figure 12: Primary component index of DAAS.

4.1.3.2.1.4.1 Fins and Control Mechanism

Due to concerns about the strength of the airframe at the fin exit point, a maximum of 50% of the airframe circumference will be cut. The number of DAAS fins installed will be the same as the number of static fins on the launch vehicle, thereby simplifying the design process somewhat. In order to maximize effectiveness, DAAS fins will be oriented to fall directly in between the static vehicle fins. To control extension of the fins (and therefore control the drag forces on the rocket), a simple crank-slider mechanism will be implemented. This ensures a constant change in fin velocity per unit length extended and maximizes fully extended fin size.

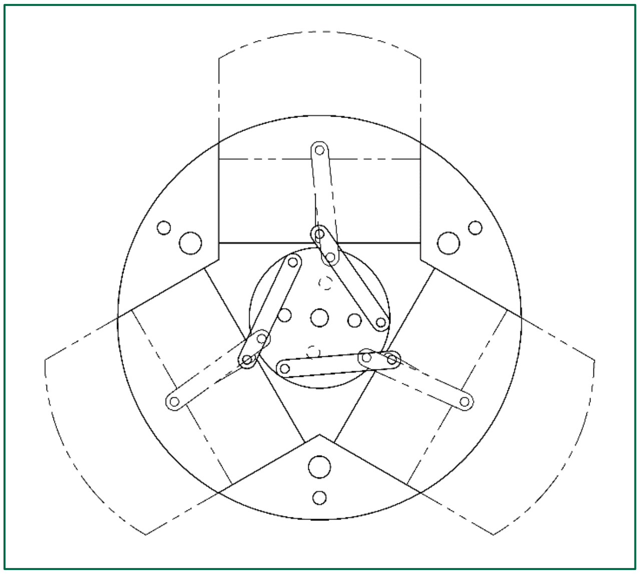


Figure 13: Retracted (solid) and extended (dashed) positions of DAAS fins.

4.1.3.2.1.4.2 Cover and Retainer

Cover and retainer plates will hold fins and deployment mechanisms stable during flight, even under significant aerodynamic forces. Three 5/16" diameter holes match the threaded rod pattern of the avionics bay design, while another three holes will be used to lock the cover and retainer plates together. The outer diameter of both plates fits flush within the inner diameter of the avionics bay in which they will be installed.

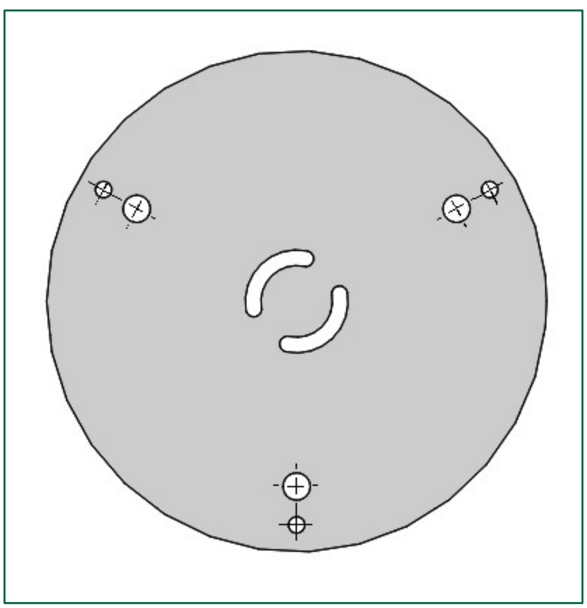


Figure 14: DAAS cover plate design.

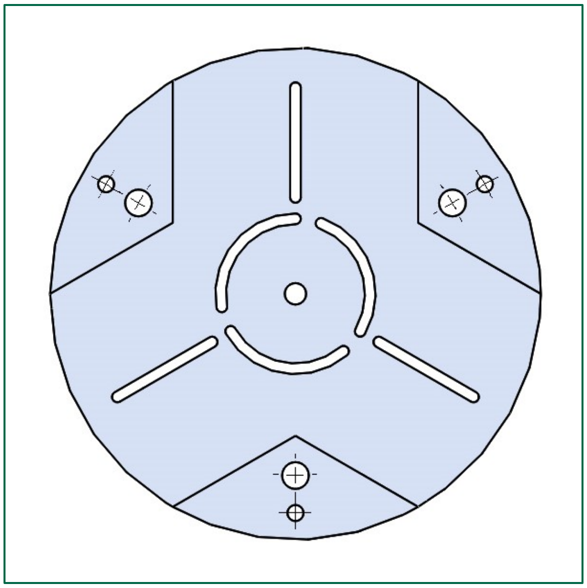


Figure 15: DAAS retainer plate design.

4.1.3.2.1.4.3 Electronics Sled

All DAAS electronics will be securely mounted on a custom-designed electronics sled, similar to the sleds used to mount the altimeters in the avionics bays of the launch vehicle (described in 4.3.4.4.1 Sled Design). This triangular sled assembly will consist of a top plate, bottom plate, and three sled plates. On two of the sled plates, three 9V battery holders will be mounted, for a total of nine battery holders. The remaining plate will provide space for the microcontroller and other electronics to be mounted. Inside the triangle sits the motor, which will be secured to both the top and bottom plates.

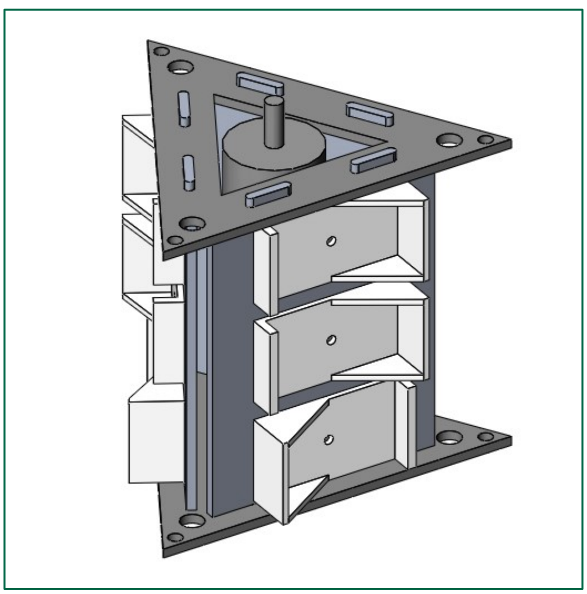


Figure 16: DAAS battery mounting and electronics sled design.

4.1.3.2.1.5 ELECTRICAL DESIGN

An Adafruit BNO055 internal measurement unit (IMU) and BMP280 pressure sensor will collect acceleration, pressure (altitude), orientation, and angular rotation during flight. For redundancy, a SparkFun LSM9DS1 IMU breakout board will be used to help correct any error. An Arduino microcontroller will process the data to control a motor controller powering a 960oz-inch, 12V, planetary geared DC motor with encoder. Additionally, voltage regulators will protect sensitive electronics from batteries. Hall Effect sensors will be placed along the slot of the fins, giving redundant systems for all degrees of freedom. Six lithium 9V batteries will power both the motor and the electronics. Two batteries will be wired in parallel to give 9V and 1.2 Ah capacity to the Arduino and sensors. Four batteries in a series-parallel configuration will provide 18V and 2.4 Ah battery capacity to the control motor.

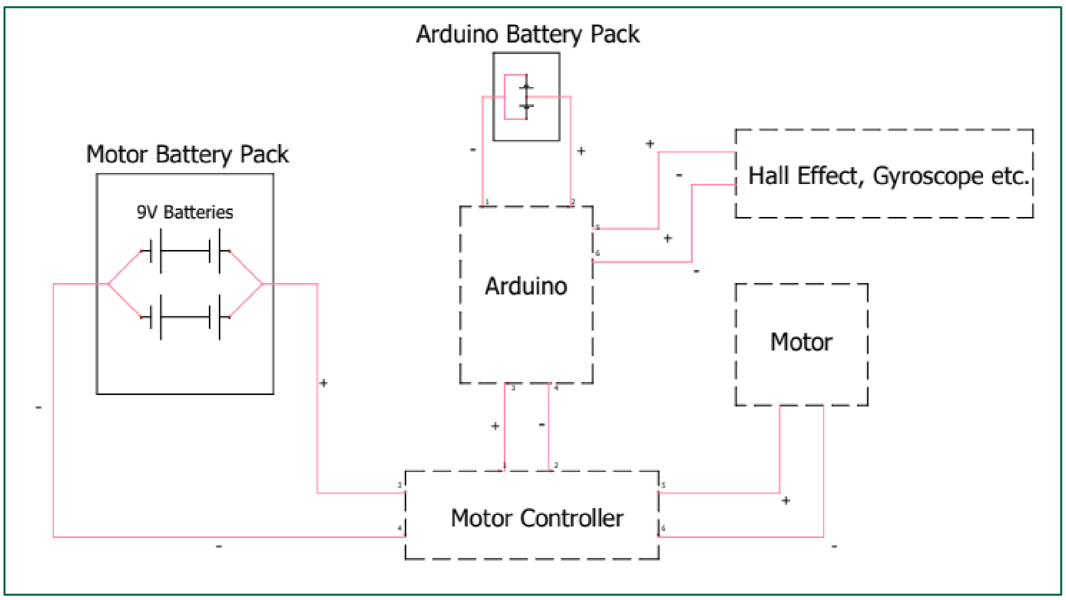


Figure 17: DAAS electrical schematic.

4.1.3.2.1.6 MATERIALS AND FABRICATION

To withstand the extreme aerodynamic forces applied to the fins during flight, 1/8" aluminum alloy plates will form the fins, retainer, and cover plate. Electronics sleds need not withstand such forces; however, they still need to be lightweight and durable. Therefore, the electronics sled system will be formed from 1/8" FRP sheets in the same manner as the avionics sleds. All components will be milled using a precision CNC router.

4.1.3.2.1.7 CALCULATIONS

4.1.3.2.1.7.1 Apogee Prediction

With a constant reference area and minimal changes in air density, drag force is directly proportional to the velocity of the launch vehicle. As the rocket is self-stabilizing, the total acceleration of the vehicle fluctuates to accommodate for disturbances during flight, resulting in a linear change in velocity.

This concept leads to Equation 1, which will be used to predict the final altitude of flight. By using an averaged value for the acceleration and common computational methods during flight, a microcontroller will perform extremely rapid iterations of the calculation and use the output data to actuate the DAAS.

$$h_{MAX} = \frac{v_b^2}{2 \cdot \left(g - \frac{A \cdot C_D \cdot \rho_{\text{air}} \cdot \Delta v^2}{2m}\right)} - h_b$$

Equation 1: Altitude prediction to be used by DAAS in-flight computer.

Symbols in Equation 1 are defined as follows:

- h_{MAX}: Predicted apogee.
- v_b: Motor burnout velocity.
- h_b: Motor burnout altitude.
- g: Gravitational acceleration.
- C_D: Vehicle coefficient of drag.
- ρ_{air}: Density of air.
- m: Mass of launch vehicle.
- Δv: Change in vehicle vertical velocity.
- A: Cross sectional area of launch vehicle.

4.1.3.2.1.7.2 Fin Extension Behavior

The length and exposed area were calculated for each angle of crank rotation, at which point a graph was created and a best-fit formula calculated through least-squares regression. Additionally, the instantaneous velocity of the fin, per unit time, based on the "crank" having a constant angular velocity of 1 rad/s, was calculated, and plotted in the same manner. The results of both calculations are shown in the graphs and equations below. When fully extended each fin has an exposed cross-sectional area of 2.962 in^2, resulting in a maximum of 31% increase to the rocket's cross-sectional area.

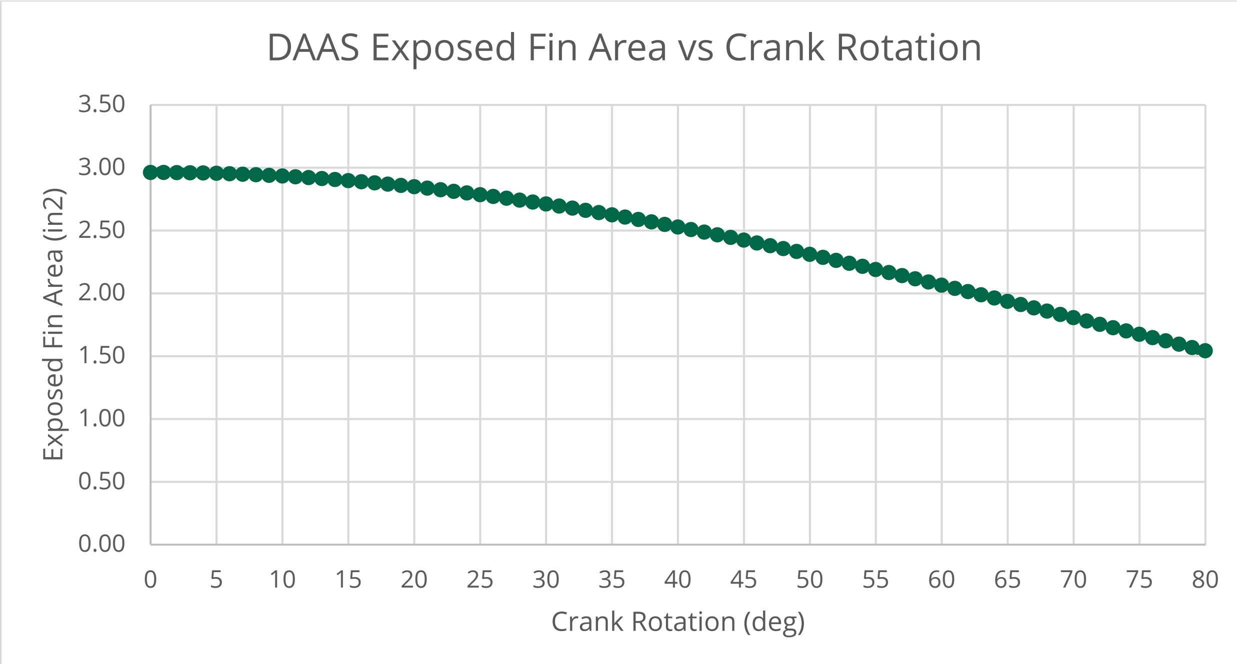


Figure 18: Plot of exposed fin area as a function of DAAS crank rotation.

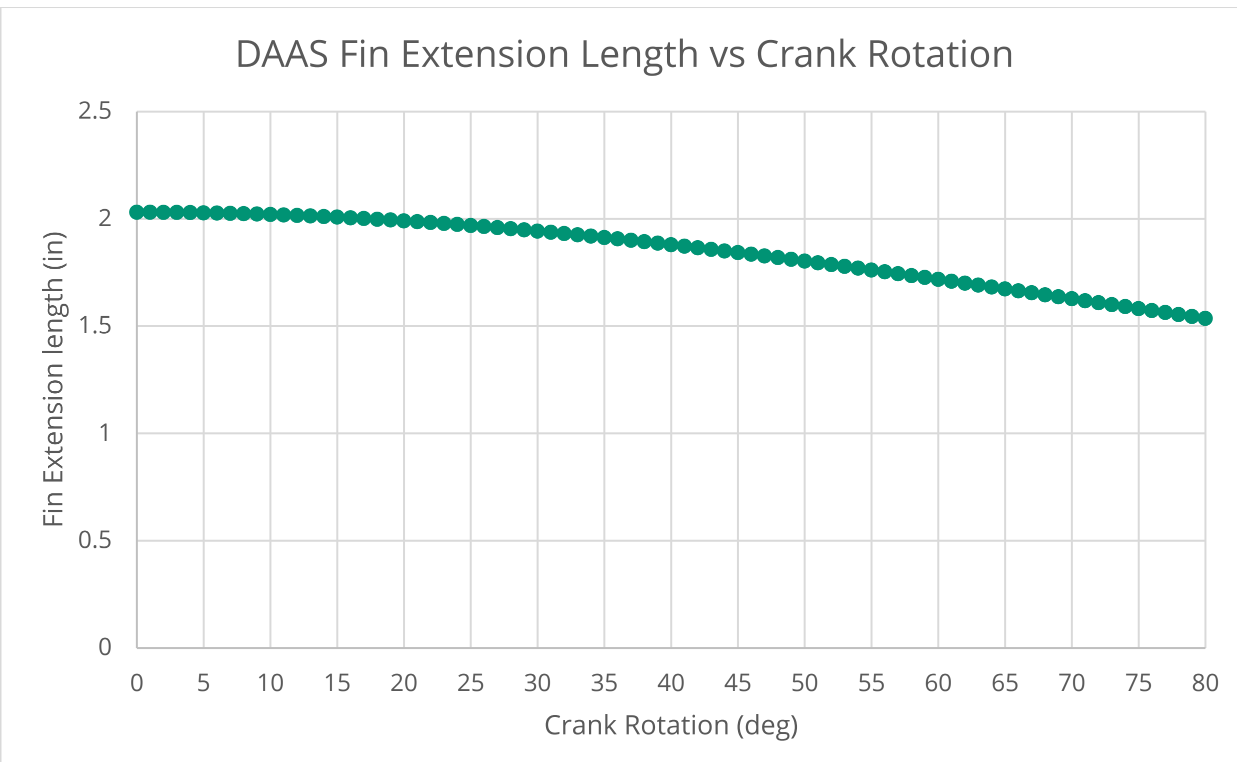


Figure 19: Plot of exposed fin length as a function of DAAS crank rotation.

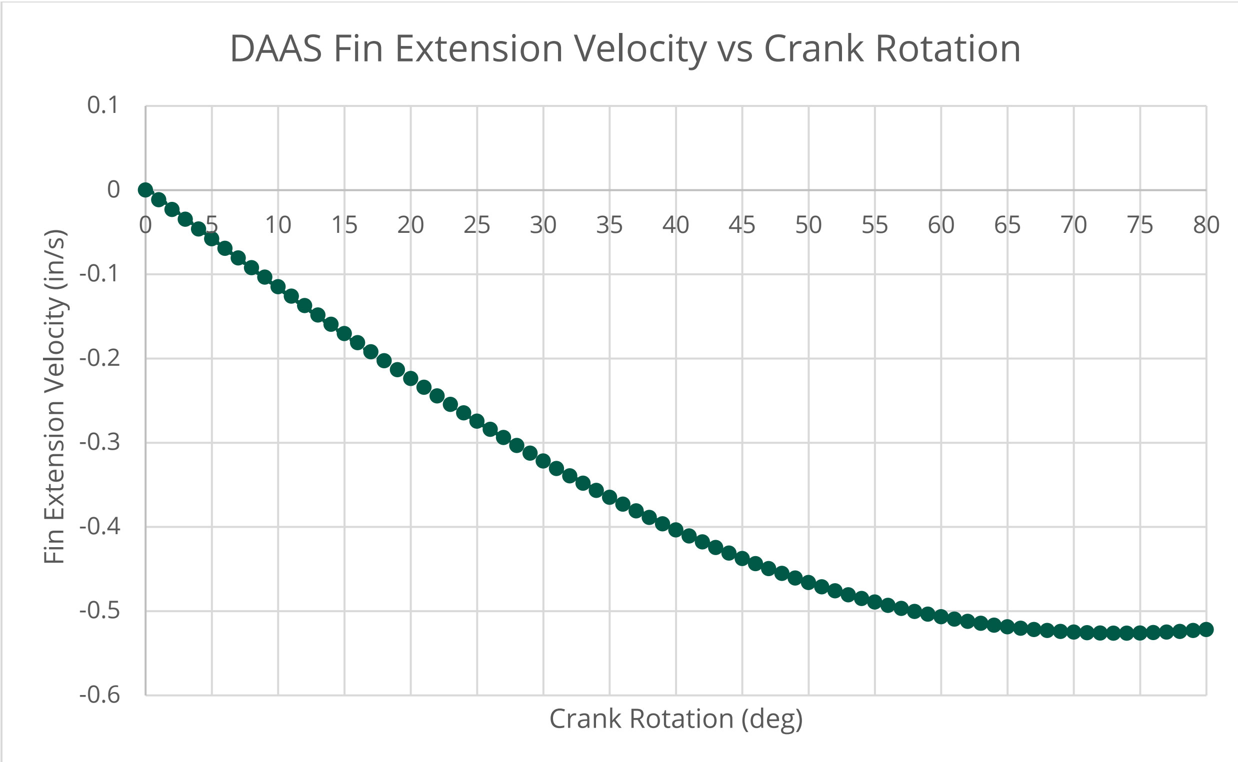


Figure 20: Plot of fin extension velocity as a function of DAAS crank rotation.

$$A(\theta) = -0.0002\theta^2 - 0.0049\theta + 2.9972$$

Equation 2: Best-fit DAAS fin area as a function of crank rotation.

$$l(\theta) = -(6 \times 10^{-5})\theta^2 - 0.0018\theta + 2.0436$$

Equation 3: Best-fit DAAS fin length as a function of crank rotation.

$$v(\theta) = (9 \times 10^{-5})\theta^2 - 0.0141\theta + 0.015$$

Equation 4: Best-fit DAAS fin extension velocity as a function of crank rotation.

4.1.3.2.1.8 SIMULATIONS

Basic flow simulation was performed with SolidWorks on the fin design to give a predicted overview on how the brakes should perform. Figure 21 shows the simulated fluid flow on the cross-sectional area of just the rocket body, without DAAS fins deployed. Figure 22 shows flow over the cross-sectional area of the rocket body with the fins fully deployed. In both simulations air was used as the fluid and given a velocity of 328 ft/s. That velocity is slightly more than the average velocity recorded during the subscale vehicle test launch. The air pressure and density were set to pressure and density at STP. The results show that the difference between the drag force between fully extended and retracted is 32.97N (34.1% increase) and the change in C_D is 0.03 (2.96% increase). Further testing and simulation will be performed at various wind speeds and temperatures, as well as different fin extension lengths. These simulations can be used to develop an exact function relating fin deployment length to vehicle coefficient of drag.

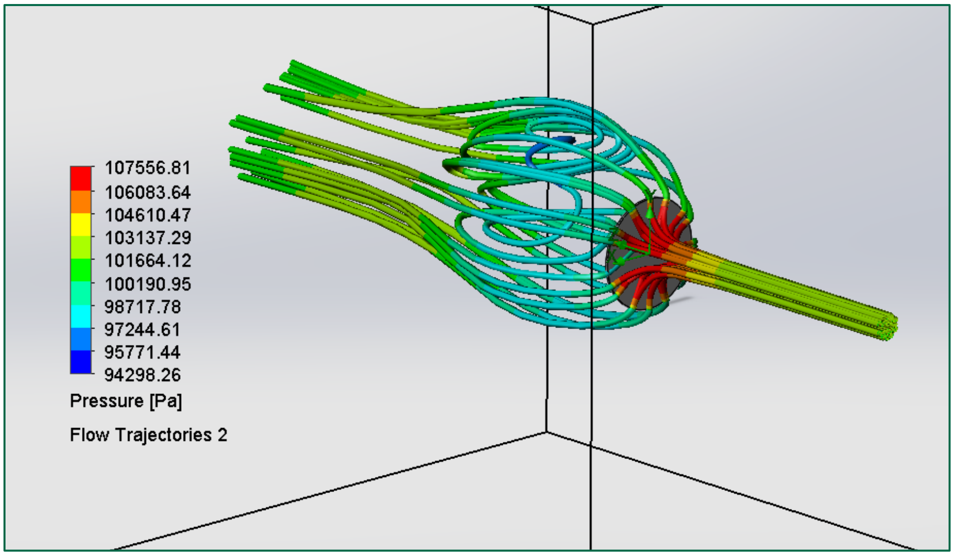


Figure 21: Simulated fluid flow over cross-sectional area of launch vehicle.

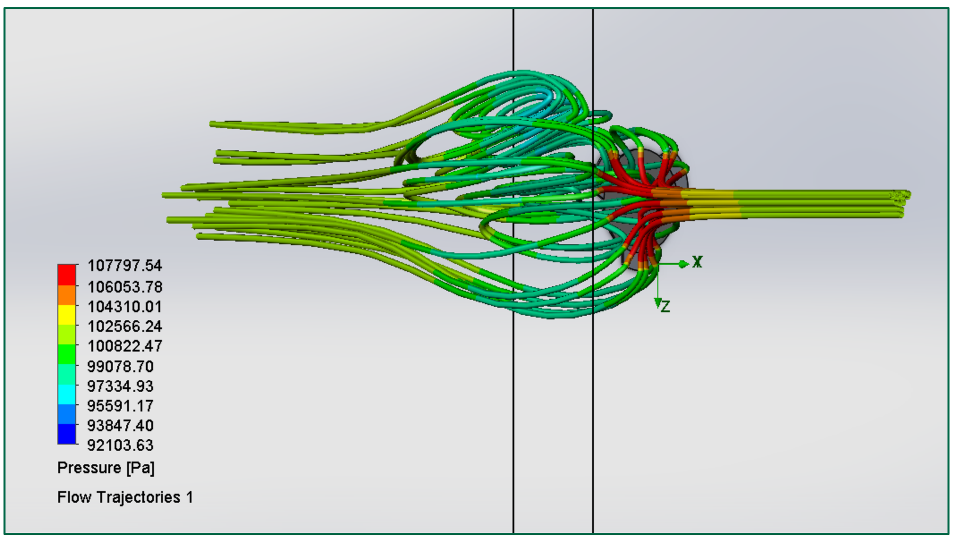


Figure 22: Simulated fluid flow over cross-sectional area of launch vehicle with DAAS fins deployed.

4.1.3.2.2 ADJUSTABLE BALLAST SUBSYSTEM (ABS)

4.1.3.2.2.1 MISSION STATEMENT

The mission of the adjustable ballast subsystem is to enable rapid, specific fine-tuned adjustment of the launch vehicle's mass and center of gravity.

4.1.3.2.2.2 LOCATION

The adjustable ballast subsystem will be installed inside the nose cone, in front of the nose cone bulkhead. This allows the weight to be placed as far forward as possible, bringing the center of gravity forward (increasing the margin of static stability) with any increase in ballast.

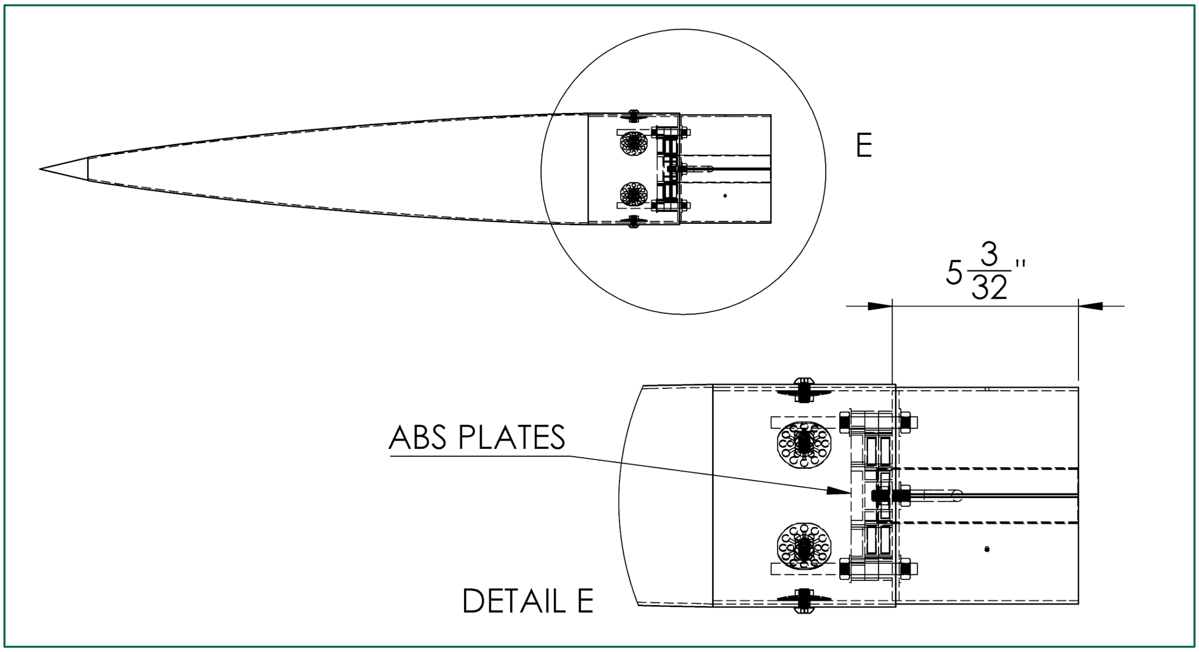


Figure 23: Location of the ABS in the nose cone assembly.

4.1.3.2.2.3 DESIGN DETAILS

The ABS design consists of several stackable, removable ballast plates. Each plate has several slots, into which standard 1-oz. weights can be placed. These sleds slide onto two 5/16" stainless steel threaded rods and are secured with hex nuts and washers. There are two different plate designs in order to accommodate the protruding reverse side of the U-bolt installed in the nose cone bulkhead. The two lowest plates have rectangular holes in the center and can fit up to 6 ounces of weights, while all plates above those are efficiently designed to hold up to 8 ounces of weight. The plates themselves weigh approximately 1.92 ounces each (for both varieties), based on material density and volume. One solid end cap plate will also be cut to secure the top layer of weights during flight and recovery.

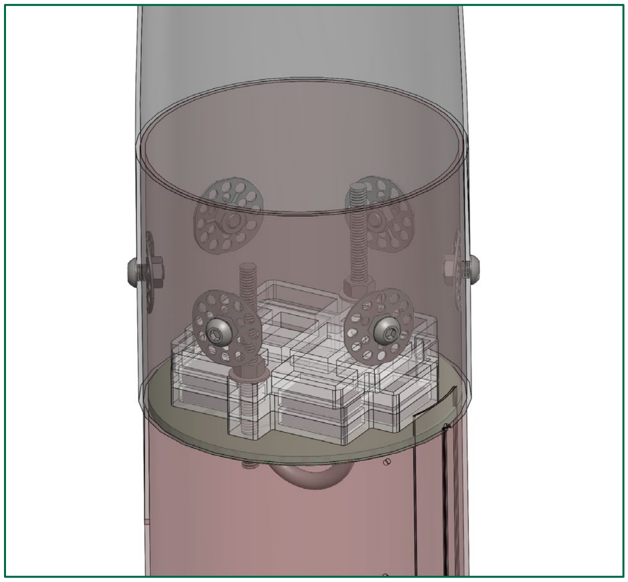


Figure 24: Assembled adjustable ballast system installed in nose cone assembly.

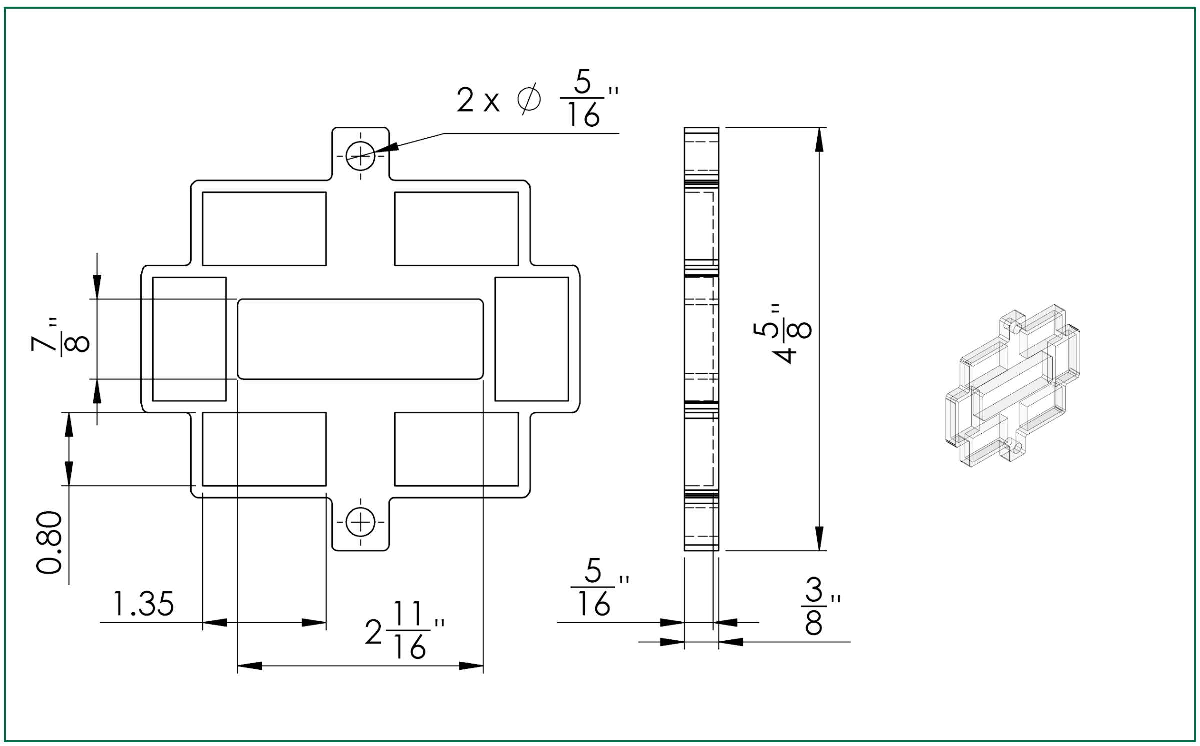


Figure 25: Modified adjustable ballast system plate design, intended to fit around protruding U-bolt.

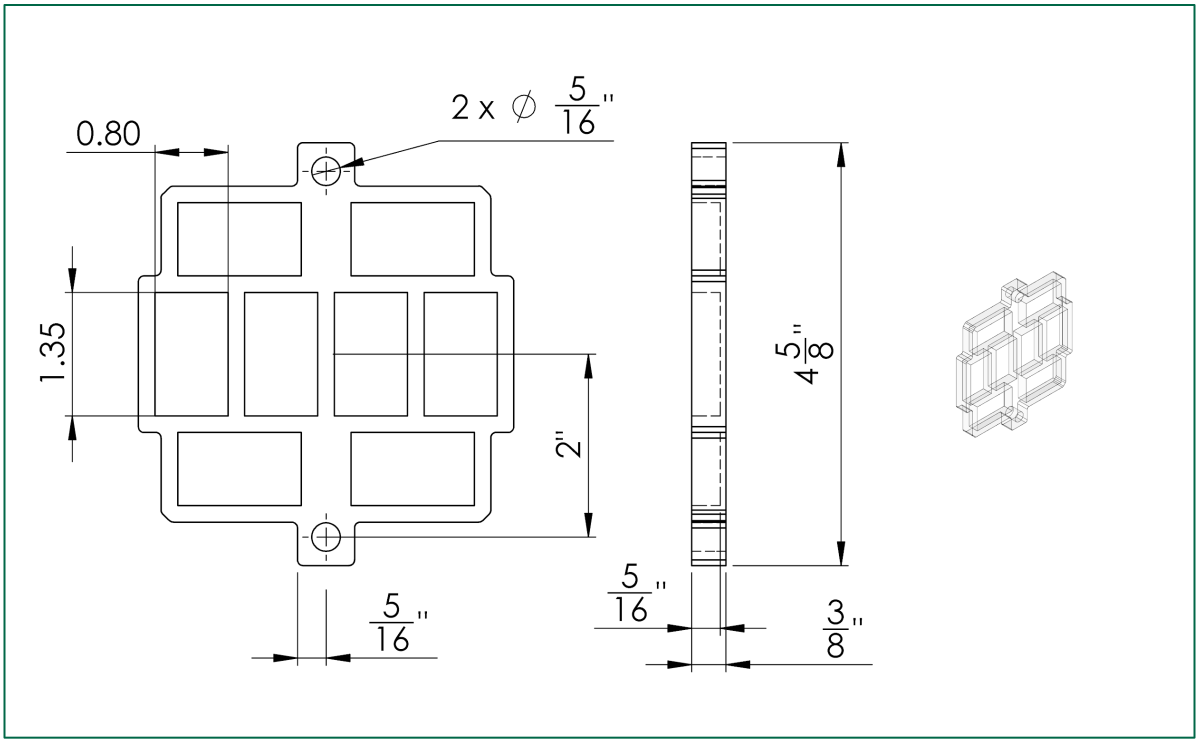


Figure 26: Standard adjustable ballast system plate design.

4.1.3.2.2.4 MATERIAL AND CONSTRUCTION

The adjustable ballast system plates will be CNC-milled from clear acrylic with a fine end-mill tool. This clear material is strong enough to hold the weights securely while allowing simple identification of installed ballast mass without requiring disassembly.

4.1.3.2.3 PAYLOAD DESCENT LEVELLING SUBSYSTEM (PDLS)

4.1.3.2.3.1 MISSION STATEMENT

The mission of the payload descent leveling subsystem is to ensure a clear path for payload deployment by preventing foreign debris from entering the payload exit end of the upper airframe.

Figure 27: SOAR's 2018 NASA Student Launch competition payload bay post-launch, highlighting significant foreign debris preventing successful payload deployment.

4.1.3.2.3.2 LOCATION

The payload levelling system be primarily located at the upper end of the upper section avionics bay; however, one component will run along the exterior of the rocket down to the lower end of the upper airframe.

4.1.3.2.3.3 MECHANICAL DESIGN

4.1.3.2.3.3.1 Leveling Wire

The PDLS will consist of a 1/16" stainless steel stranded wire, which will attach to the lower end of the upper airframe by securely threading into a standard 5/16" stainless steel epoxy nut as shown in Figure 28. This attachment method is fully removable in case the wire needs to be replaced or the system modified. This wire will run along the exterior of the upper airframe to the nose cone shoulder, at which point it will enter the forward end of the upper airframe through a slot cut in the nose cone shoulder, between the airframe interior and the shoulder exterior. This slot will be internally reinforced to prevent fracture and is shown in Figure 29.

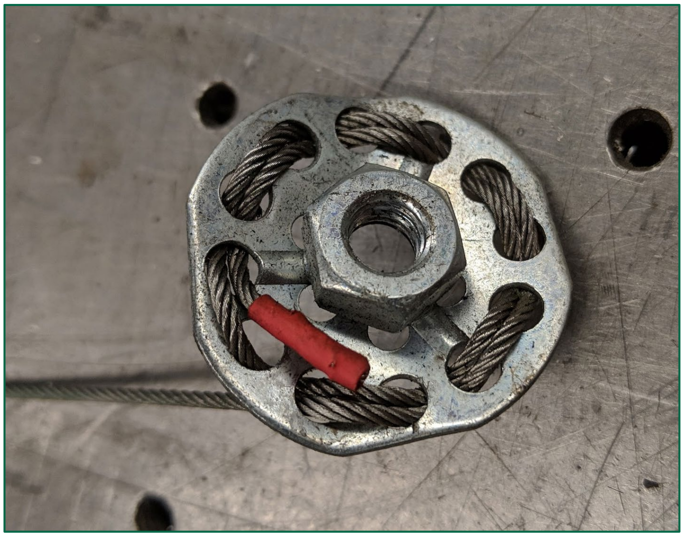


Figure 28: PDLS wire friction attachment method, using epoxy nut.

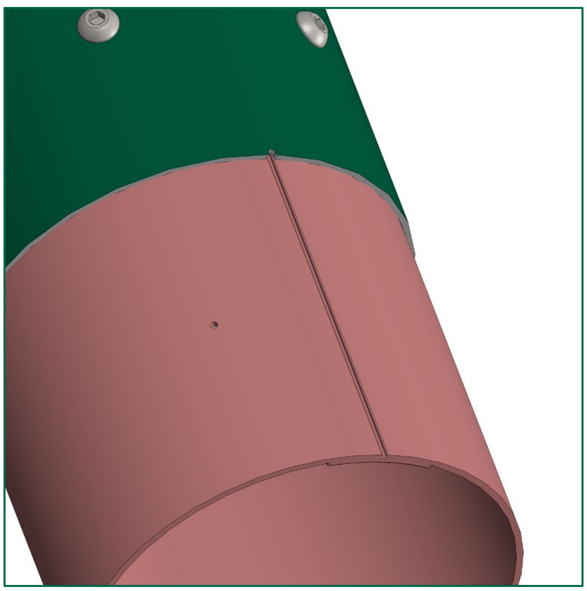


Figure 29: Reinforced nose cone shoulder slot for PDLS wire entry.

After entering the upper airframe just below the nose cone, the wire will attach to the upper section parachute shock cord using a quick link and loop formed with standard adjustable wire clamps. The entire exterior portion of the wire will be taped to the airframe using masking tape in order to prevent any possibility of entanglement with the launch rail or other equipment at launch. Upon deployment, the masking tape will simply tear away.

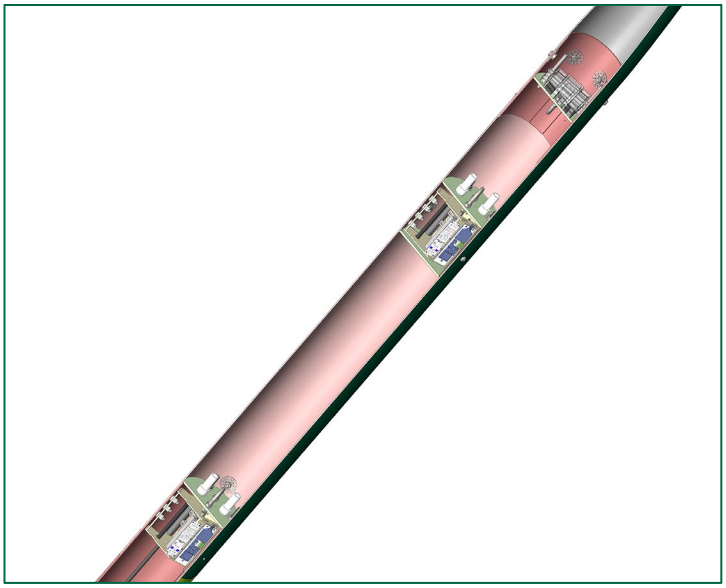


Figure 30: Vehicle cross-section, showing PDLS wire attachment point location just above lower section avionics bay.

4.1.3.2.3.3.2 Deployment Mechanism

The system as described above would alone be enough to level the upper airframe during descent, however, a small 1/16" wire is not strong enough to withstand the shock of parachute deployment, nor does it have the shock-absorption capabilities of Kevlar tubing. Therefore, a mechanism was devised that will allow for delayed deployment of the PDLS.

This mechanism implements a Fruity Chutes Tender Descender device, which can be thought of as a programmable quick link -- when assembled, it acts like a standard quick link, but it contains a small black powder charge and E-match. When the E-match ignites the charge, the device separates, releasing the quick link.

The deployment process using the Tender Descender is as follows:

A. The upper section main deployment charges fire, separating the nose cone from the upper airframe and deploying the main parachute.
B. The main parachute opens as normal. Enough shock cord is initially released that the parachute deployment process will not be affected if the PDLS fails to initiate. This is step "D" in Figure 53 and 4.3.2 Recovery Process.
    - At this point, the Tender Descender prevents the full length of shock cord from deploying; one end of the Tender Descender is attached to the U-bolt at the upper end of the upper section avionics bay, while the other end is attached approximately 6.5' up the shock cord, thus shortening 6.5' of shock cord to just 6".

C. At the altitude detailed in 4.3.2 Recovery Process, the Tender Descender charge is deployed, separating the Tender Descender and releasing all of the extra 6.5' of shock cord.

D. The upper airframe 'drops' from a vertical to horizontal position. This is step "E" in Figure 53.
   - The PDLS system is fully capable of catching the rocket from a short drop, which results in a much lower shock force than a full main parachute deployment. This prevents any damage to the wire or any attachment points.

4.1.3.2.3.4 ELECTRICAL DESIGN

The PDLS will use an additional altimeter installed in the upper section avionics bay to control the Tender Descender deployment charge. This altimeter will be completely electrically isolated from the recovery system so as not to interfere with recovery operations in any way. As all that is needed is a single deployment charge at a predefined altitude, a Missile Works RRC2+ will be sufficient for this purpose. For ease of use and assembly, the altimeter will be powered by the same battery and controlled by the same switch as all other avionics systems on board the rocket. These components are detailed in 4.3.4 Avionics.

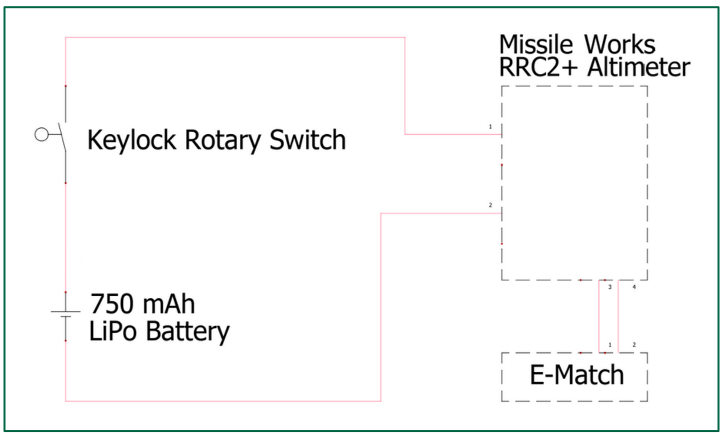


Figure 31: Electrical schematic for PDLS control system.

4.1.3.2.3.5 TESTING

The PDLS system was tested in the subscale rocket as PDLS-S in December 2018. The test was a complete success; the system performed exactly as designed. Detailed test results can be found in 4.2.6.3 Payload Descent Leveling Subsystem.

4.1.3.3 MOTOR

The Cesaroni L2375 "White Thunder" rocket motor has been selected to launch this relatively heavy launch vehicle to a sufficient altitude. The use of this motor, in combination with the DAAS, will support the attainment of the target altitude of 5,000 ft AGL. The motor is certified, commercially available, uses APCP as the propellant, and does not eject titanium sponges.

Table 8: Cesaroni L2375 "White Thunder" motor properties[2].

Manufacturer	Cesaroni Technology
Common Name	L2375
Diameter (in)	2.95
Length (in)	24.4
Total Weight (lb)	9.17
Propellant Weight (lb)	5.12
Average Thrust (lbf)	551
Maximum Thrust (lbf)	629
Liftoff Thrust (lbf)	551
Total Impulse (lbf-s)	1093
Burn Time (s)	1.9
Case Info	Pro75-4G
Propellant Info	White Thunder
Certifying Body	Canadian Association of Rocketry

The thrust curve for this motor is shown in 4.4.1.4 Motor Thrust Curve.

4.1.3.3.1 VEHICLE THRUST-TO-WEIGHT RATIO

Taking into account the total vehicle weight and reported motor thrust characteristics, a lift-off thrust-to-weight ratio R_{TW} is established with Equation 5:

$$R_{TW} = \frac{T}{w} = \frac{551}{53.9} = 10.22$$

Equation 5: Launch vehicle thrust-to-weight ratio.

[2] Source: (ThrustCurve 2014)

4.2 SUBSCALE LAUNCH VEHICLE AND TEST ANALYSIS

Prior to submission of the CDR report, a subscale version of the launch vehicle was designed, constructed, launched, and analyzed. This subscale process provided valuable data and experience for improving the full-scale vehicle design.

Figure 32: Assembled subscale launch vehicle and NSL team prior to subscale test launch.

4.2.1 SUBSCALE VEHICLE DESIGN

SOAR constructed a ⅔ scale rocket (*Apis III-S*), which is functionally identical to the full-scale design, albeit with shorter dimensions. The subscale vehicle is a 4” diameter rocket with two unbound sections and three parachutes.

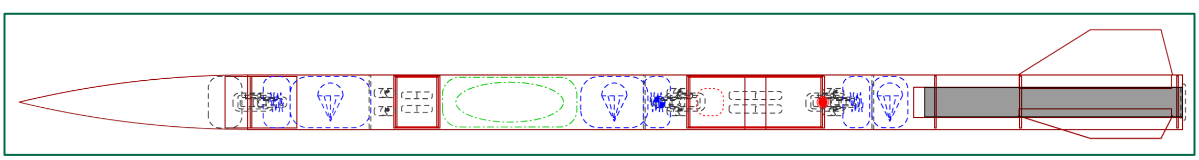


Figure 33: Loaded subscale vehicle layout, with CG shown in blue and CP in red.

4.2.1.1 VEHICLE DIMENSIONS

The subscale was dimensionally two-thirds the size of the full-scale rocket design at the time of development. Therefore, the length of each component as well as the overall rocket diameter were scaled to two-thirds, or 66.67%. As some adjustments have been made to the full-scale rocket dimensions based on updated requirements and subscale flight results, these dimensions may not reflect an exact scaling at the time of this report.

Table 9: Length and mass of subscale launch vehicle components and subsystems.

Components	**Length** (in)	**Mass** (lb)
Upper Section (without avionics bay or payload)	37.0	5.43
Upper Section Avionics Bay	4.00	1.57
Simulated Payload	10.0	6.00
Lower Section Avionics Bay	10.0	2.50
Lower Section (without avionics bay)	31.0	4.38

4.2.1.2 SUBSCALE MOTOR

For the subscale rocket, Cesaroni "Classic" K570 was selected as the subscale vehicle test motor. This motor was selected to simulate an altitude of approximately ⅔ of the target altitude of the full-scale rocket.

Table 10: Cesaroni 5G Classic K570 motor properties[3].

Motor Property	**Value**
Motor	Cesaroni K570
Manufacturer	Cesaroni Technology
Common Name	K570
Diameter (mm [in])	54 [2.126]
Length (in)	19.2

[3] Source: (ThrustCurve 2014)

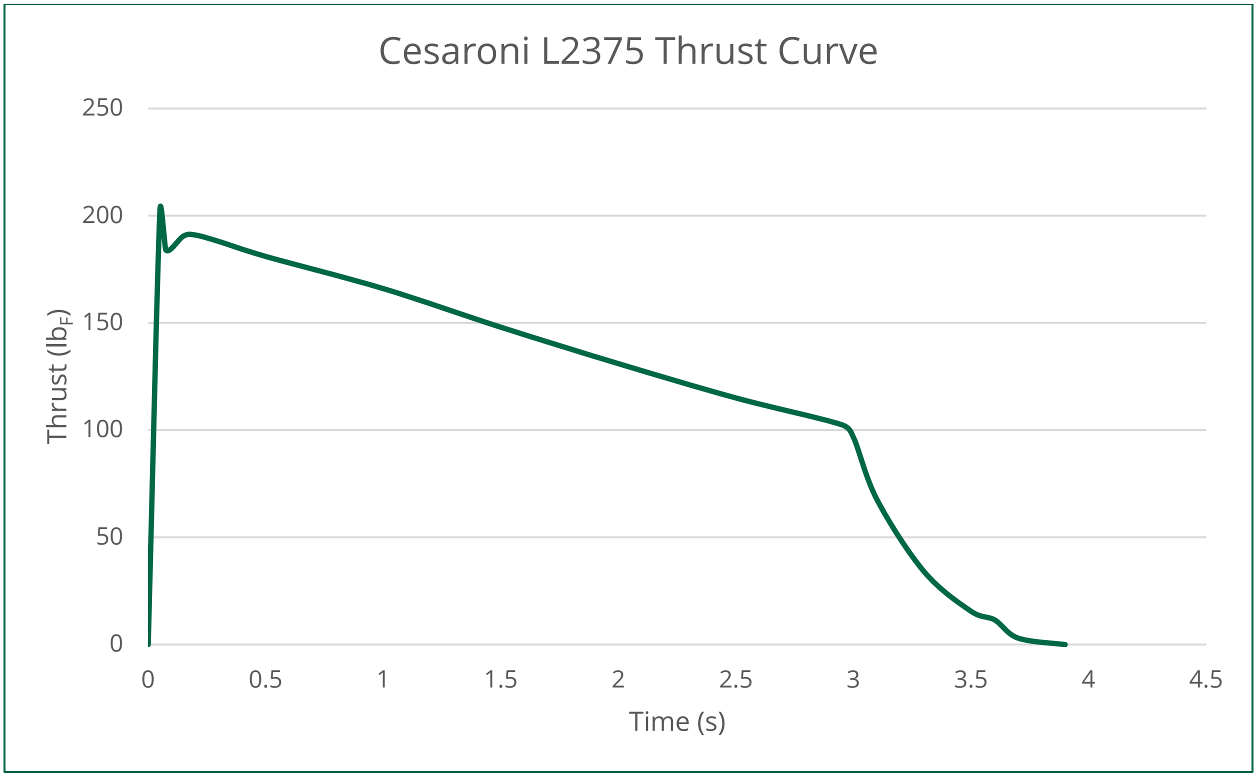
Motor Property	Value
Total Weight (lb)	3.71
Propellant Weight (lb)	2.18
Maximum Thrust (lb_F)	200.69
Total Impulse (lb_F)	463.8
Burn Time (s)	3.6

4.2.1.3 STABILITY

The subscale launch vehicle is statically stable, as is the full-scale. The locations of the centers of pressure and gravity are available in Table 11 below and shown in Figure 33.

Table 11: Subscale launch vehicle stability characteristics.

Subscale Stability Property	Value
Center of Gravity (in, from tip)	47.64
Center of Pressure (in, from tip)	59.80
Static Stability Margin (calipers)	3.04



4.2.1.4 SIMULATED PAYLOAD

The payload for the subscale vehicle was a simulated mass, intended to represent the approximate scaled mass and location of the full-scale payload. This payload had no active components, however the 9V batteries for the upper section avionics bay were housed in the payload bay.

4.2.1.5 SUBSCALE RECOVERY SUBSYSTEM

The subscale recovery process mirrors the full-scale process in every way, therefore, a more detailed description can be found in 4.3 Recovery Subsystem. Notable differences include the altimeters and parachutes used. The lower section altimeters are still both Missile Works RRC3s, however the upper section altimeters are the smaller Missile Works RRC2+ systems. This allowed a third altimeter to fit in the small upper section avionics bay, enabling the PDLS-S system to be actively tested. Batteries for the upper section altimeters were installed in the payload bay, rather than the avionics bay, due to lack of space.

4.2.1.5.1 PARACHUTES

The subscale rocket implements a SkyAngle Classic 20" drogue, SkyAngle CERT-3 L parachute for the lower section main, and a Fruity Chutes Iris Ultra 60" for the upper section main. Originally, both sections' main parachutes were intended to be SkyAngle CERT-3 L parachutes, however there was not enough space in the constructed vehicle, necessitating a change in design.

Table 12: SkyAngle Classic 20" parachute properties[4].

Parachute Property	Value
Manufacturer	SkyAngle
Model	Classic 20"
Diameter (in)	20
Drag Coefficient	0.80
Mass (lb)	0.312

Table 13: SkyAngle CERT-3 L parachute properties[5].

Parachute Property	Value
Manufacturer	SkyAngle
Model	CERT-3 L
Diameter (in)	102
Drag Coefficient	1.26
Mass (lb)	2.13

Table 14: Fruity Chutes Iris Ultra 60" parachute properties[6].

Parachute Property	Value
Manufacturer	Fruity Chutes
Model	Ultra 60" Standard
Diameter (in)	60

[4] Source: (b2 Rocketry Company n.d.)
[5] Source: (b2 Rocketry Company n.d.)
[6] Source: (Fruity Chutes n.d.)

Parachute Property	Value
Drag Coefficient	2.2
Mass (lb)	0.681

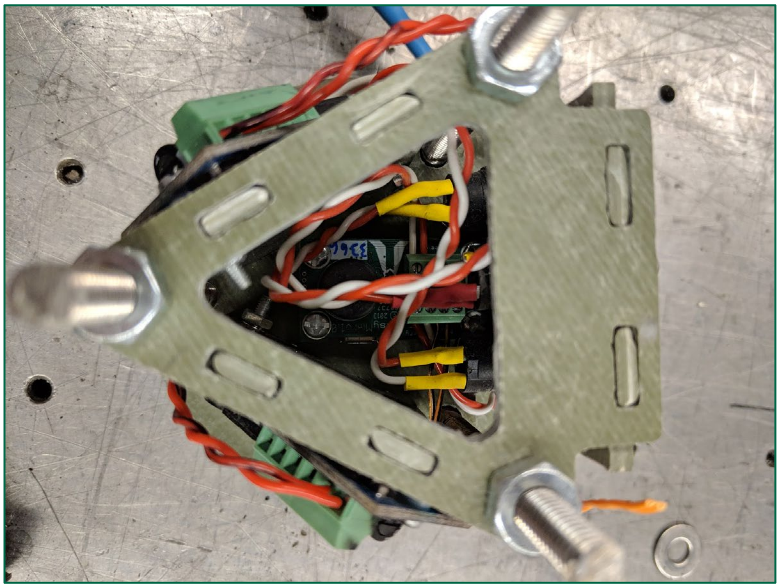


Figure 34: Subscale upper section avionics bay design.

4.2.1.5.2 AVIONICS BAYS

The lower section subscale avionics bay uses 3D printed altimeter sleds, a decision that will not be repeated on the full-scale due to their lack of durability and inefficient use of space. Instead, the full-scale rocket will use CNC-milled FRP sleds, as were used in the upper-section subscale avionics bay.

4.2.1.5.3 DEPLOYMENT CHARGES

The following deployment charges were used to separate each section of the subscale rocket and deploy parachutes. The sizes of these charges are based on the results of the testing described in 7.1.1.1 Parachute Deployment Ground Tests.

Table 15: Subscale deployment charge black powder charge sizes.

Deployment Charge Location	**Mass of Black Powder** (oz [g])
Lower Section Drogue	0.0529 [1.5]
Lower Section Main	0.1058 [3.0]

Deployment Charge Location	Mass of Black Powder (oz [g])
Upper Section	0.07055 [2.0]

4.2.1.6 SUBSCALE PAYLOAD DESCENT LEVELING SUBSYSTEM (PDLS-S)

The subscale launch vehicle implements a Payload Descent Levelling Subsystem that is almost identical to the full-scale descent leveling subsystem described in 4.1.3.2.3 Payload Descent Levelling Subsystem (PDLS). The only differences are that a smaller Tender Descender model is installed in the subscale, and an Altus Metrum EasyMini altimeter was used instead of the Missile Works RRC2+, due to the limited space available in the upper section avionics bay. In all other aspects, the system is exactly the same.

4.2.2 LAUNCH CONDITIONS AND SIMULATIONS

4.2.2.1 LAUNCH LOCATION

The launch took place near 5313-6799 Varn Rd, Plant City, FL 33565. Per request of the launch site owner, exact coordinates are intentionally not published.

4.2.2.2 LAUNCH DAY CONDITIONS

The subscale launch took place on Saturday, December 15th at Varn Ranch in Plant City, FL. The overall temperature for the day ranged from 61 to 74 degrees Fahrenheit. It was a cloudy day with winds averaging to 10 mph. Light drizzles were experienced at the time of launch.

Table 16: Subscale launch day conditions.

Condition	Launch Day Value
Average Windspeed (mph)	10
Wind Direction (deg)	45
Temperature (°F)	68
Pressure (mbar)	1012
Latitude (°N)	28.1
Longitude (°E)	-82.2
Altitude (ft)	5
Launch Rod Length (in)	40

Note: All weather conditions on the launch day were provided to us by Regional Orlando Applied Rocketry (ROAR)[7].

4.2.2.3 LAUNCH SIMULATION RESULTS

A simulation was performed with OpenRocket using the launch day conditions found in Table 16 above, yielding the following results:

Table 17: Subscale launch simulation results, based on launch day conditions.

Flight Characteristic	Value
Apogee (ft)	3199
Maximum Velocity (ft/s)	418
Maximum Acceleration (ft/s^2)	194
Time to Apogee (s)	15.2
Descent Time (s)	45
Main Descent Rate (ft/s)	31.0

[7] Information available at: http://flroar.space/

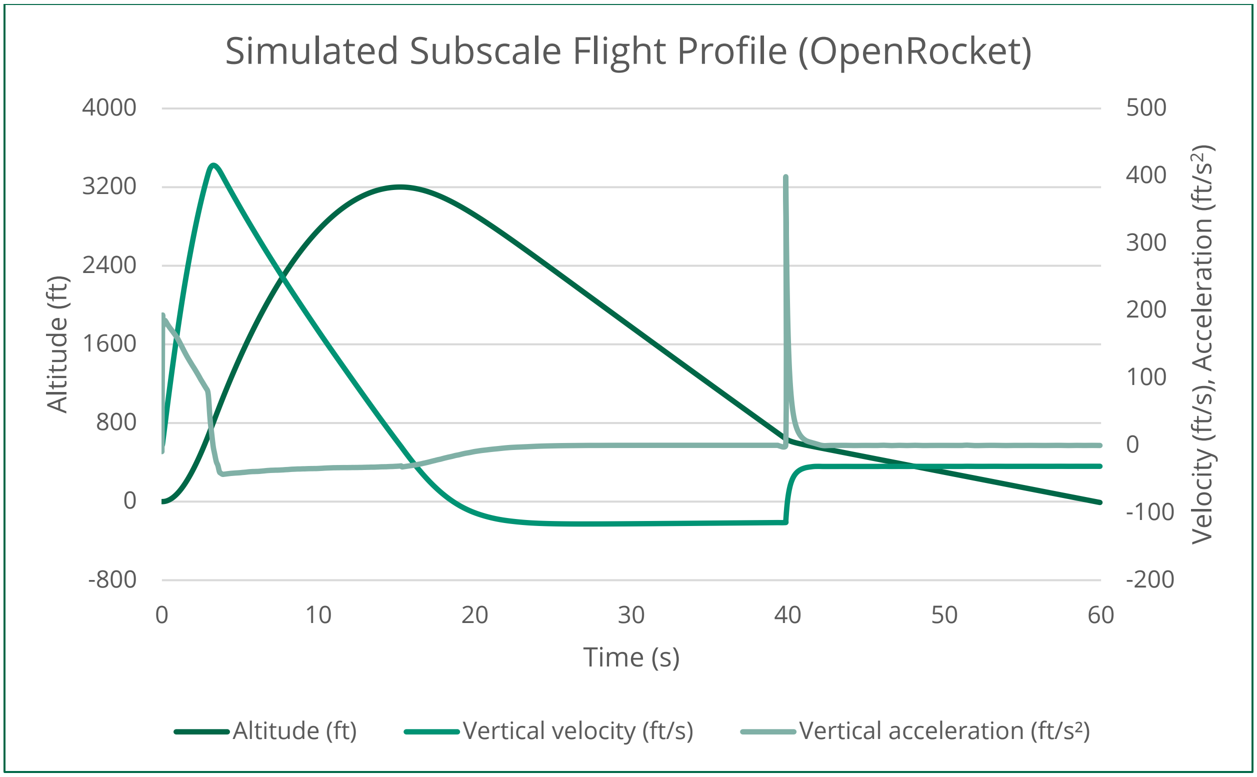


Figure 35: Plot of simulated subscale launch.

4.2.3 FABRICATION PROCESS REVIEW

The subscale launch vehicle was fabricated over several weeks during the fall semester. The fabrication process was mostly efficient and smooth; however, some setbacks were encountered that can be avoided during the full-scale build. The most significant of these was that the avionics bays were not created until the last week before launch, so many last-minute modifications had to be made to the bay design. Also, during a test assembly one week prior to launch, it was determined that the upper section main parachute would not fit in its intended location. Fortunately, an alternative chute was available for use.

Moving forward with the full-scale build process, a number of specific improvements will be made:

- Increase the frequency of build days throughout the process, allowing more progress to be made earlier.
- Develop more detailed modeling and simulations to create more accurate plans.
- Wire, test, and program crucial avionics systems early in the process.
- Order all supplies, tools, and materials early so that shipping delays are not an issue.

4.2.4 LAUNCH PREPARATION REVIEW

While the launch preparation was successfully completed in time for the launch window, several avoidable issues were encountered. First, the Fruity Chutes parachutes require a significantly more complex folding process than the SkyAngle parachutes, and this process was not known ahead of time by any of the team members. Also, properly inserting the avionics bay and payload section into the upper airframe was made exceptionally difficult due to the lack of alignment markings on the rocket and avionics bay. Steps were often overlooked or completed out of order due to the lack of a launch checklist. Finally, it was difficult to determine which of the five altimeters were armed successfully when they were all beeping at the same time.

Future launches will avoid these issues by making the following improvements:

- A pre-launch checklist will be created with detailed steps that must be completed prior to launching the vehicle.
- A launch binder will be assembled with instruction manuals for all flight computers, parachutes, motors/motor casings, and any other components with assembly instructions available.
- Alignment markings will be created and documented on rocket components.
- LEDs, different buzzers, or some other method to distinguish different altimeters will be implemented in the recovery subsystem design.

4.2.5 FLIGHT REVIEW

The subscale rocket, Apis III-S, had a very successful flight and every component of the rocket was recovered successfully. Every component of the subscale was in a good condition after the landing and can be easily assembled and launched again. The rocket reached an altitude higher than what was expected from the simulations, which is an acceptable result, as our Dynamic Apogee Adjustment Subsystem (DAAS) will be able to dynamically decrease the apogee during full-scale flights. At the time of landing, the rocket was separated in two sections, and the payload containing main body tube landed horizontally without debris entering the payload bay, signifying successful deployment of the PDLS-S.

4.2.5.1 FLIGHT CHARACTERISTICS

4.2.5.1.1 VISUAL ANALYSIS

The launch took on a slight (approximately 5°) angle immediately upon leaving the launch rail but proceeded to stabilize and flew smoothly to apogee[8]. Upon regaining visual contact with the rocket, the main parachutes deployed cleanly and the PDLS-S functioned as expected, dropping the upper airframe into a horizontal position.

[8] Flight video available at: https://www.instagram.com/p/BrbBWhCgEAj/

4.2.5.1.2 REPORTED FLIGHT DATA

Table 18: Subscale flight data from onboard altimeters.

Altimeters	Altitude (ft)	Peak Velocity (ft/s)	Time to Apogee (s)	Descent Time (s)	Main Descent Rate (ft/s)
RRC3 (A)	3598	423	15	N/A (lost power)	
RRC3 (B)	3599	423	15	64	7
RRC2+ (A)	3598	N/A (not collected)			
RRC2+ (B)	3600				
EasyMini	3605.6	410.1	15.4	69.2	13.2
Average	3600.1	418.7	15.1	66.6	10.1

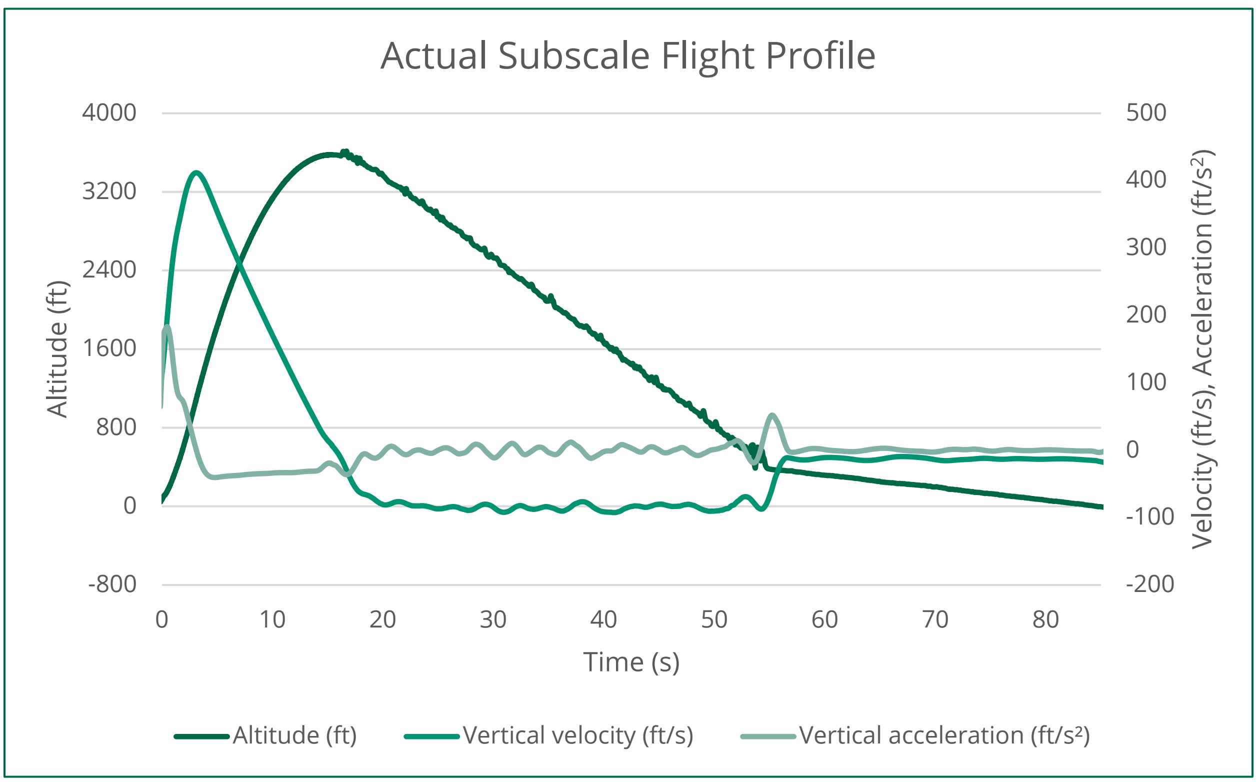


Figure 36: Plot of reported subscale flight data.

4.2.5.1.3 FLIGHT DATA ANALYSIS

After flight, the average relative true error for each flight metric was calculated using Equation 6 below, where S is the simulated value and $\overline{T}$ is the true average value:

$$\overline{E} = \frac{|S - \overline{T}|}{\overline{T}}$$

Equation 6: Average relative true error definition.

Table 19: Relative error of subscale flight simulation vs subscale flight data.

Flight Characteristic	Relative Error in Simulation (%)
Altitude	11.14
Peak Velocity	0.17
Time to Apogee	0.66
Descent Time	32.43
Main Descent Rate	206.93

The full-scale flight resulted in a significantly different altitude than expected, which is a result that must be improved if at all possible. This was possibly caused by running the simulation with inaccurate weights. The significant error in the descent time is certainly related to this error in altitude, whereas the main descent rate discrepancy cause is wholly unknown. Further subscale flights will help to clarify the issues with these simulations.

A simulated altitude correction coefficient, C_A, can be established that may be a reasonable method for increasing the accuracy of simulated altitudes, however this is a purely hypothetical method that must be tested with future flights before being used for actual vehicle designs. This coefficient is calculated in Equation 7 below.

$$C_A = \frac{S}{\overline{T}} = \frac{3600.1}{3199} = 1.125$$

Equation 7: Experimental simulated altitude correction coefficient.

4.2.5.2 RECOVERY SUBSYSTEM PERFORMANCE

The recovery subsystem of the subscale launch vehicle performed exactly as designed, with the entire launch vehicle being recovered successfully without significant damage. All three parachutes were successfully deployed at their programmed altitudes. However, one deployment charge failed to ignite due to the loss of altimeter power; this failure was successfully mitigated by the fully redundant altimeter system setup.

Figure 37: Subscale lower section main parachute at recovery site.

Figure 38: Subscale lower section at recovery site with main parachute and drogue deployed.

4.2.5.3 PAYLOAD DESCENT LEVELING SUBSYSTEM PERFORMANCE

The mission of the PDLS-S was to make a horizontal landing of the rocket to enable a theoretical future payload to deploy without any foreign debris blocking the vehicle exit. This system performed exactly as designed. The rocket successfully made a horizontal landing, and no blockage was present on the payload exiting side, despite the soft earth. On the other end of the upper airframe, the entire opening was packed with mud. This is expected and desired behavior.

Figure 39: Payload exit side of subscale upper airframe after launch, highlighting lack of blocking debris.

Figure 40: Subscale upper airframe opposite payload exit, showing significant debris and soft mud.

4.2.5.4 DISCUSSION OF FLIGHT RESULTS

The flight was almost perfect, with the single notable exception of the initial angle immediately upon leaving the launch rail. This issue will be mitigated in the full-scale design with more careful placing of launch rail lugs.

4.2.6 POST-LAUNCH VEHICLE CONDITION

After launch, the subscale launch vehicle was disassembled and inspected, with each component and subsystem reviewed and photographed. Observations were made and noted as to the condition of each individual component or subsystem. This inspection was made generally from the nose cone of the rocket down to the fins, in that order. Notable observations (which have or will result in changes to the full-scale criteria) have been italicized.

4.2.6.1 NOSE CONE AND SHOULDER

Figure 41: Subscale nose cone, shoulder, and recovery hardware post-launch.

- Some corrosion observed on black oxide fasteners
- No indication of bearing failure at fastener points
- No indication of weakening, bending, cracking, or movement of bulkhead
- No bending, pitting, cracking, or other significant wear present on U-bolt
- No indication of cracking or bending at leveling system wire channel or carbon fiber channel reinforcement

4.2.6.2 UPPER SECTION RECOVERY SUBSYSTEM

4.2.6.2.1 PARACHUTE

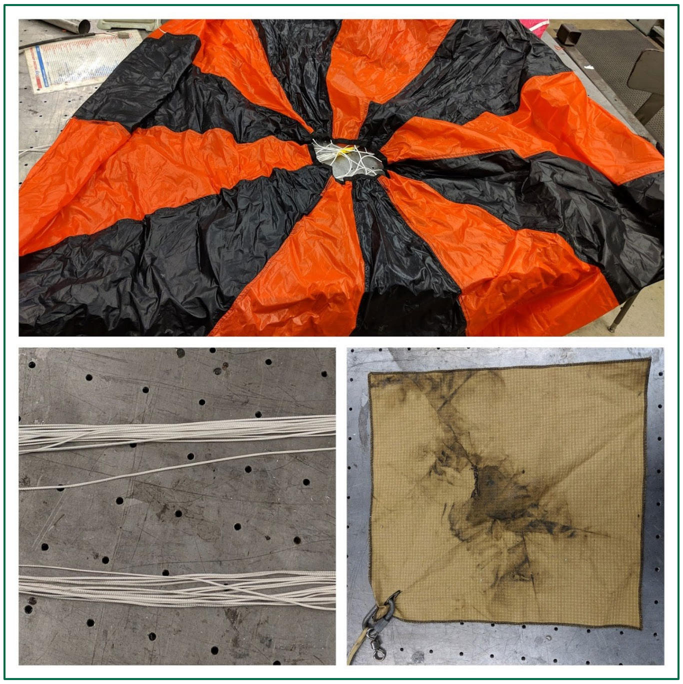


Figure 42: Subscale upper section recovery subsystem parachute components post-launch.

- Nomex functioned as expected, no holes or tears present on fabric
- No damage or wear to parachute lines
- No holes, tears, or other damage to parachute

4.2.6.2.2 SHOCK CORD AND HARDWARE

- No fraying or wear (besides soot and dirt) observed at any point on shock cords
- No bending or cracking of quick links, all still open and close as designed

4.2.6.3 PAYLOAD DESCENT LEVELING SUBSYSTEM

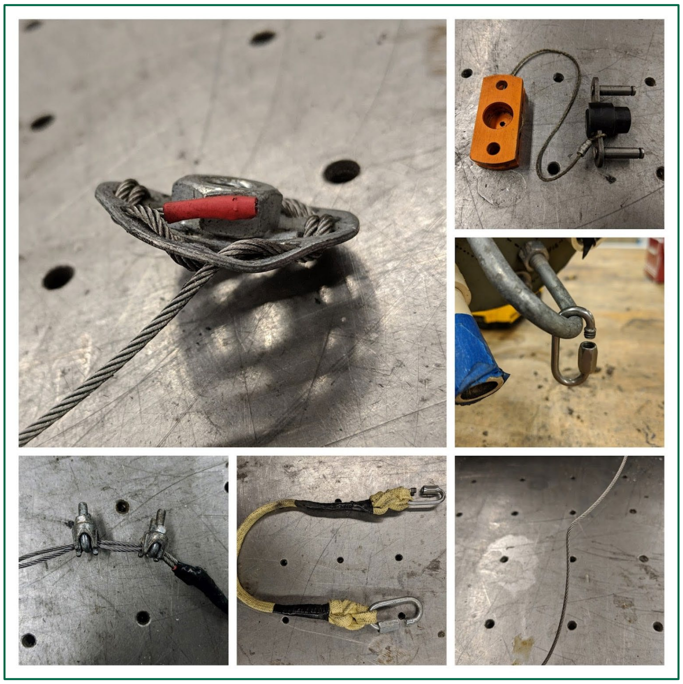


Figure 43: Subscale PDLS-S components post-launch.

- E-match fired successfully
- No damage present on Tender Descender
- No fraying or wear on Tender Descender retainer line
- No bending or cracking on small quick links, both still open and close as designed
- No fraying or other wear observed on leveling system wire
- Kinks (deformation) in wire are present where wire entered airframe
- No indication of damage or slipping at wire clamps
- No indication of slippage at airframe attachment nut
- Airframe attachment nut experienced some bending, but no cracking or weld failure, and bending was anticipated

4.2.6.4 UPPER AIRFRAME

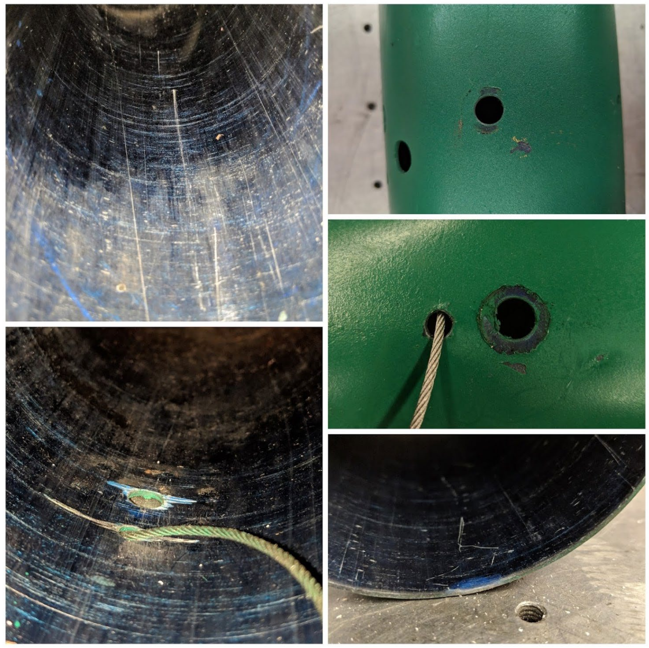


Figure 44: Subscale upper airframe highlights post-launch.

- No bearing failure observed at any fastener point
- Shear pins sheared cleanly, indicating properly sized holes and pins
- No cracking or bending at ground impact points
- Very minor (almost cosmetic) scratches caused by leveling system wire at deployment
- *Some thinning / weakening of airframe wall at leveling system wire upper exit point*
- No damage at all observed at leveling system wire lower attachment point
- No observable damage caused by deployment charges
- No observable damage caused by deployment of the Tender Descender

4.2.6.5 UPPER SECTION AVIONICS BAY

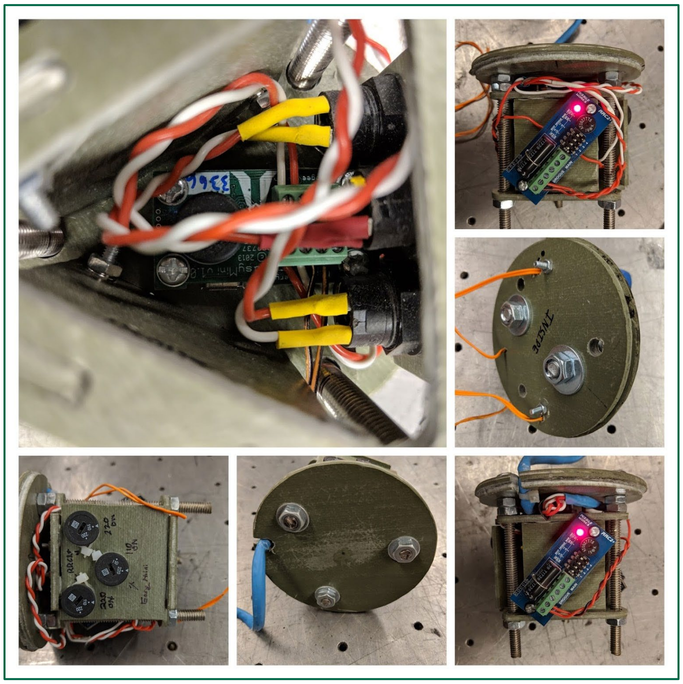


Figure 45: Subscale upper section altimeters and altimeter sleds post-launch.

- Both forward recovery system deployment charges fired as expected
- One recovery charge container lost, expected and easily replaceable
- No cracking or damage to exterior of payload bay
- No bearing failure at attachment points
- No bending or cracking of bulkheads, with special care taken to observe threaded rod attachment points
- No bending, pitting, cracking, or other significant wear present on U-bolt
- No cracking or bending present on altimeter sleds
- No bending, cracking, necking, or other damage to threaded rods, nuts, and washers
- No fraying, stretching, melting, or other damage to any wiring
- No damage to altimeter switches
- No damage to altimeters, all altimeters still power on, all altimeters are still firmly attached to altimeter sleds

4.2.6.6 PAYLOAD

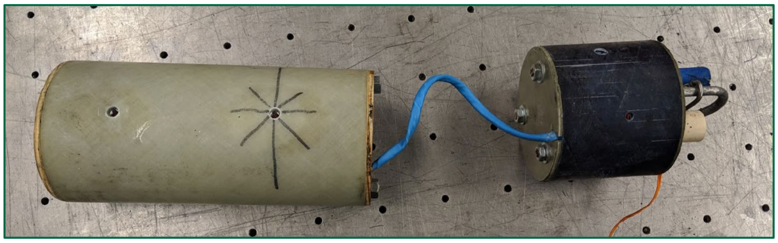


Figure 46: Subscale payload and upper section avionics bay post-launch.

- No damage to power connection wire or battery connections
- All batteries still supply at least 8V
- No damage to bulkheads (besides cracking which was present before the launch)
- No bearing failure at attachment points
- No damage to threaded rods

4.2.6.7 LOWER SECTION RECOVERY SUBSYSTEM

4.2.6.7.1 PARACHUTE

Figure 47: Subscale lower section recovery subsystem parachute components post-launch.

- Nomex functioned as intended; no holes, tears, or other wear present
- No tears, holes, or burns on parachute
- No damage to parachute lines

4.2.6.7.2 SHOCK CORD

- No fraying or wear on shock cord
- Quick links are not damaged and open and close as designed

4.2.6.8 LOWER SECTION AVIONICS BAY

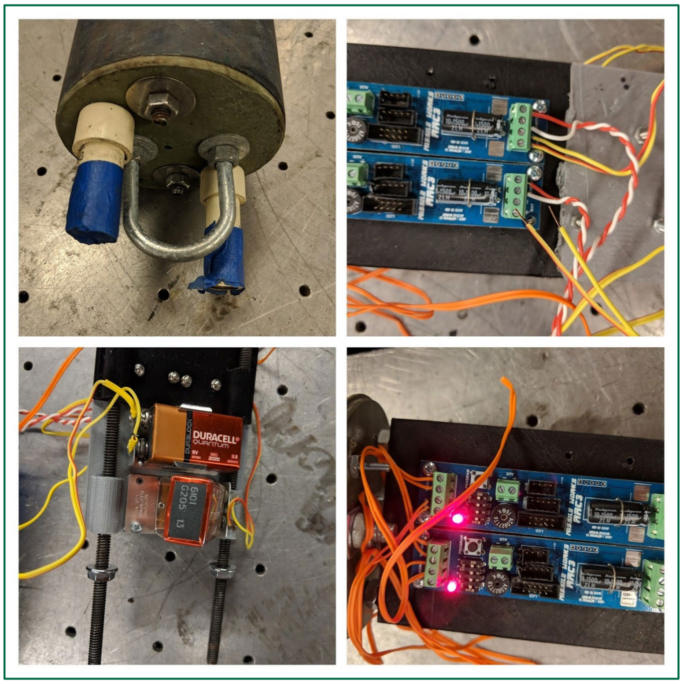


Figure 48: Subscale lower section avionics bay, altimeters, and altimeter sleds post-launch.

- Both bulkheads show no signs of bending or cracking
- No damage on coupler tubing or altimeter switch band
- Threaded rods are not bent, stretched, or cracked
- *Forward D-link is loose (wasn't tightened sufficiently) and bent*
- Lower D-link shows no damage
- Drogue deployment charges fired as expected
- Only one main deployment charge fired, the other was safely disposed of
- *One battery became detached from the battery holder, and the same battery holder's wires became detached from the altimeter*
- The same altimeter has some damage around the communications ports
- Both altimeters power on successfully
- Wiring and switches show no damage, fraying, scraping, or failure
- *Some deployment charge bolts were loosened, likely due to not being tightened sufficiently*
- No cracking, melting, or bending of 3D printed altimeter sleds

4.2.6.9 DROGUE RECOVERY SUBSYSTEM PARACHUTE

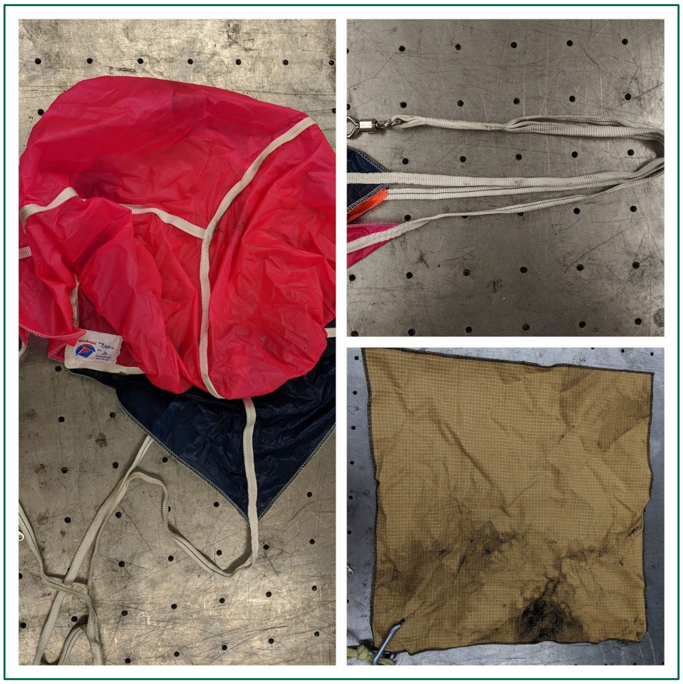


Figure 49: Subscale drogue recovery subsystem parachute components post-launch.

- Nomex functioned as designed, with no holes or tears
- *Burn marks are off-center, indicating improper packing*
- No stretching, tears, or fraying on parachute lines
- No holes, tears, or fraying of parachute
- Soot marks present on parachute fabric, but no burns or melting

4.2.6.9.1 SHOCK CORD

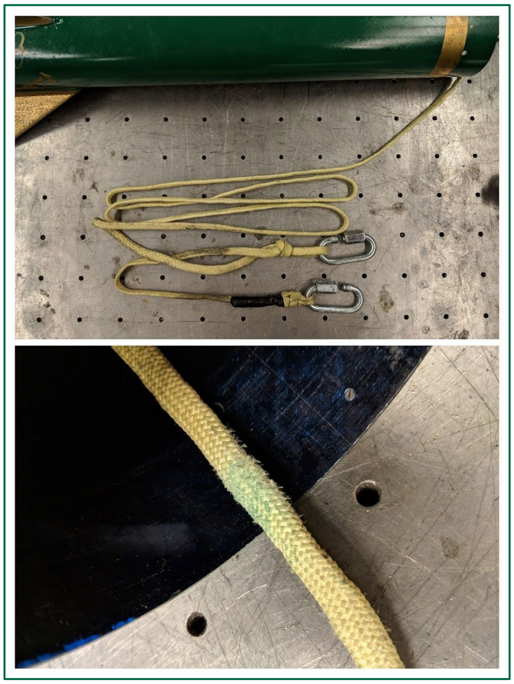


Figure 50: Subscale drogue recovery subsystem shock cord post-launch.

- Shock cord is still securely attached to fin can
- Mild fraying present where shock cord exits fin can
- D-links are not damaged and still open and close as designed

4.2.6.10 LOWER AIRFRAME

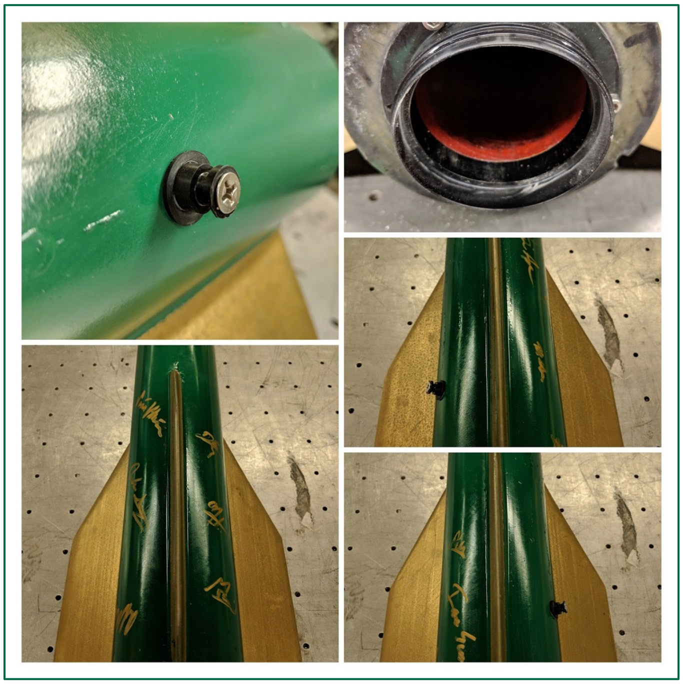


Figure 51: Subscale lower airframe highlights post-launch.

- No cracking or bending of airframe, no internal scratches or wear
- No damage to launch rail lugs
- Shear pins functioned as expected
- No cracking, scrapes, or burns on fin can / motor mount
- Fins are not bent or cracked
- Fin fillets show no signs of damage or wear
- Retaining ring is still solidly attached and threads function as intended

4.2.6.11 MOTOR AND CASING

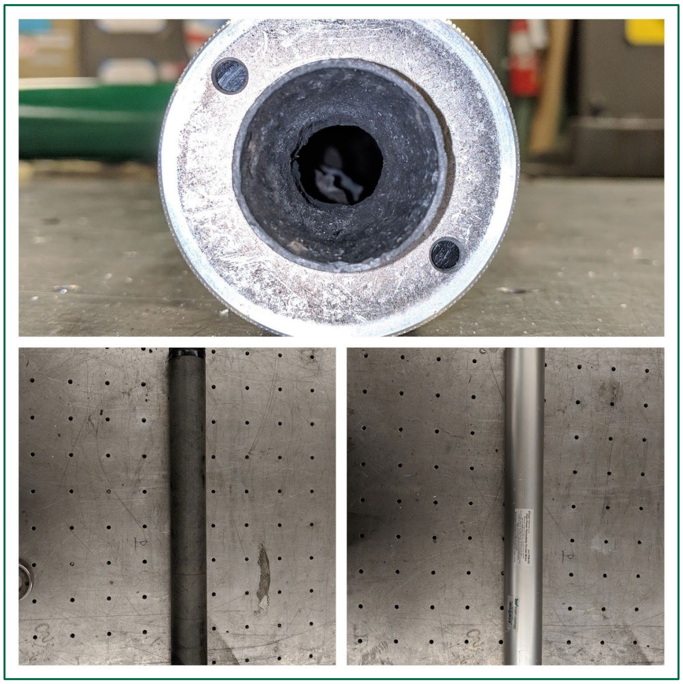


Figure 52: Subscale motor components post-launch.

- Motor casing is not cracked, melted, or bent; still easily slides into and out of rocket
- Motor nozzle burned on center
- Rear closure removed easily and is not bent, melted, or damaged
- Motor casing and rocket could be reloaded and launched without any further preparation

4.2.6.12 DISCUSSION OF POST-FLIGHT VEHICLE CONDITION

Based on the subscale post-flight vehicle condition analysis, several changes have been made to the rocket design. The updated design is detailed in 4.1 Design and Verification of Launch Vehicle, but specific changes made based on subscale flight results include:

- All structural metal hardware onboard the rocket will be a naturally corrosion resistant material, such as stainless steel or aluminum.
- Batteries will be secured using a custom retention design, optimized for rocket flights and specifically fit for the new LiPo batteries.
- All electrical connections will be inspected for security prior to flight; this has been added to the pre-launch checklists.
- Parachute packing instructions will be added to the launch folder and brought to every launch.

4.3 RECOVERY SUBSYSTEM

A comprehensive, redundant, and reliable recovery system has been implemented in the launch vehicle design. This recovery system will not only protect all launch vehicle components and subsystems but will also allow for real-time vehicle tracking and flight diagnostics.

The recovery subsystem will be a dual deployment system consisting of three parachutes and two separate sections (each with its own avionics bay). Two altimeters, each completely electrically separate from each other, will control a total of 6 deployment charges for a fully redundant recovery system. Each altimeter will be separately armed after installation on the launchpad.

4.3.1 MISSION STATEMENT

The mission of the launch vehicle recovery subsystem is to completely protect the launch vehicle components and payload from ground impact forces and enable the efficient locating and retrieval of all such components.

4.3.2 RECOVERY PROCESS

The recovery subsystem will function according to the process illustrated in Figure 53 and outlined below:

A. The launch vehicle will fly under motor power until the motor fuel is expended, at which point it will coast to apogee.
B. At apogee, the lower airframe will separate from the lower section avionics bay and deploy the drogue parachute.
   - After a 1-second delay, the backup drogue deployment charge will fire, ensuring that the drogue parachute has deployed.
C. At 750 ft, the upper section will separate from the lower section avionics bay and deploy the lower section main parachute.
   - At 735 ft, the backup lower section main deployment charge will fire.
D. At 725 ft, the nose cone will separate from the upper airframe and deploy the upper section main parachute. This delay will ensure that enough distance has formed between the two sections to deploy the parachute without risk of entanglement.
   - At 710 ft, the backup upper section main deployment charge will fire.
E. At 550 ft, the Tender Descender in the payload descent leveling subsystem will separate, dropping the upper airframe into a horizontal position. This is not technically a task completed by the recovery subsystem but is included for clarity. This design is described in detail in 4.1.3.2.3 Payload Descent Levelling Subsystem (PDLS).
F. After landing, the rocket will continue to transmit its GPS location until recovered.

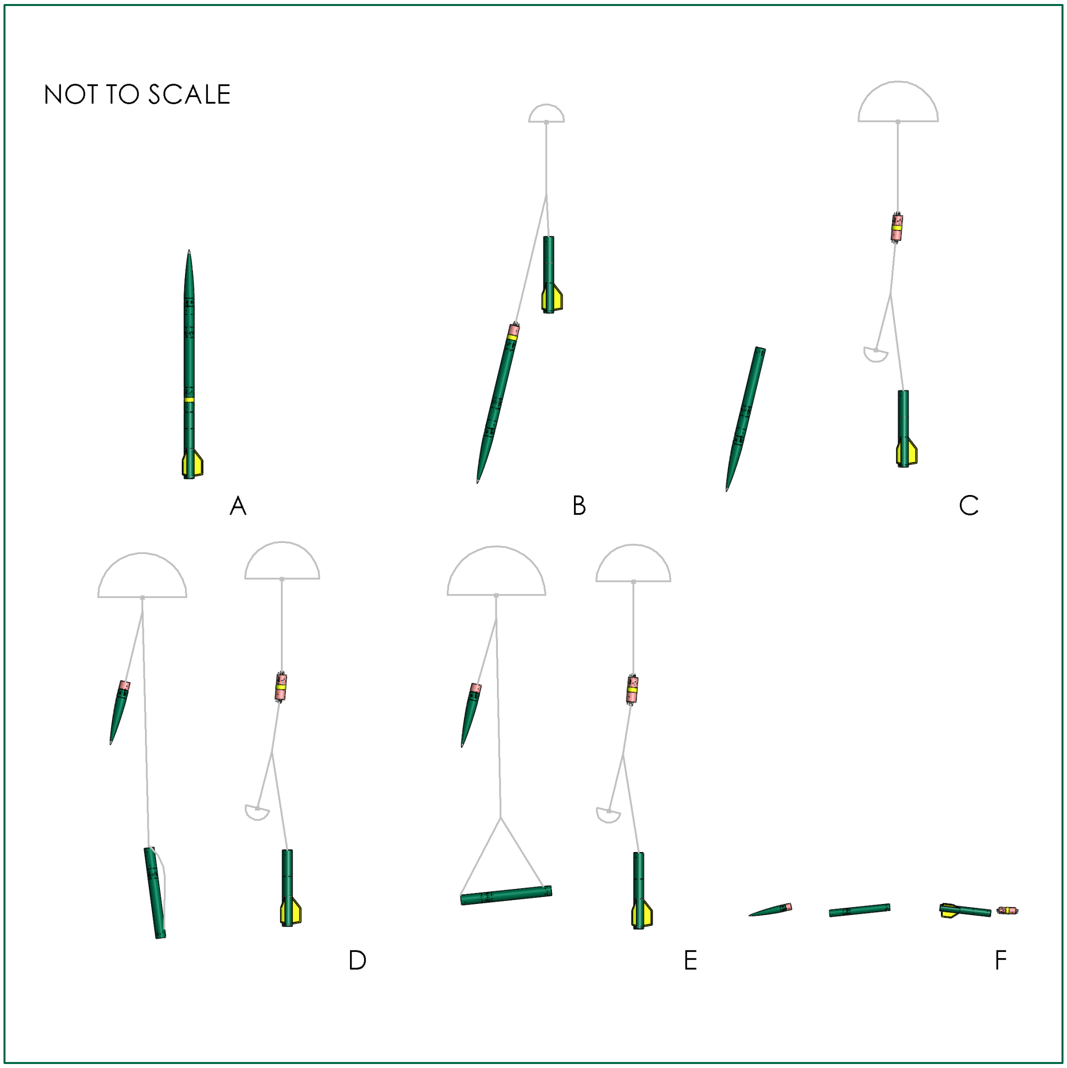


Figure 53: Launch vehicle recovery process illustration (not to scale).

4.3.3 PARACHUTES

Due to the lack of space for SkyAngle parachutes in the subscale launch vehicle, the full-scale vehicle design was modified to use the significantly smaller and lighter weight Fruity Chutes Iris Ultra Standard parachute line. This has the additional benefit of increased space and weight capacity for the payload, however, because these parachutes are thinner and more fragile, extra care must be taken when packing them.

4.3.3.1 DROGUE PARACHUTE

A small circular durable SkyAngle parachute will be used as the drogue parachute, slowing the rocket sufficiently for the main parachutes to deploy.

4.3.3.1.1 PROPERTIES

Table 20: SkyAngle Classic 20" parachute properties[9].

Parachute Property	Value
Manufacturer	SkyAngle
Model	Classic 20"
Diameter (in)	20
Shape	Circular
Drag Coefficient	0.80
Mass (lb)	0.312
Packed Volume (in^3)	78

4.3.3.2 UPPER SECTION MAIN PARACHUTE

The upper section main parachute is a high-efficiency, lightweight toroidal chute manufactured by Fruity Chutes.

4.3.3.2.1 PROPERTIES

Table 21: Fruity Chutes Iris Ultra Standard 96" parachute properties[10].

Parachute Property	Value
Manufacturer	Fruity Chutes
Model	Iris Ultra Standard
Diameter (in)	96"
Shape	Toroidal
Drag Coefficient	2.2

[9] Source: (b2 Rocketry Company n.d.)
[10] Source: (Fruity Chutes 2017)

Parachute Property	Value
Manufacturer	Fruity Chutes
Mass (lb)	1.53
Packed Volume (in^3)	139.5

4.3.3.3 LOWER SECTION MAIN PARACHUTE

The lower section main parachute is nearly identical to the upper section main parachute; however, it is smaller to account for the smaller mass of the lower section.

4.3.3.3.1 PROPERTIES

Table 22: Fruity Chutes Iris Ultra Standard 84" parachute properties[11].

Parachute Property	Value
Manufacturer	Fruity Chutes
Model	Iris Ultra Standard
Diameter (in)	84"
Shape	Toroidal
Drag Coefficient	2.2
Mass (lb)	1.5
Packed Volume (in^3)	105.1

4.3.4 AVIONICS

Both sections of the launch vehicle contain full-featured avionics systems, including real-time GPS tracking, real-time flight characteristics streaming, and dual redundant parachute deployment systems. In order to ensure consistency, reliability, and compatibility, all avionics computers are sourced from Missile Works. Both the upper and lower section feature

[11] Source: (Fruity Chutes 2017)

identical avionics configurations, with the exception of the drogue deployment charges, which are only present in the lower section.

4.3.4.1 COMPONENTS

4.3.4.1.1 ALTIMETERS

The Missile Works RRC3 altimeters are fully programmable and collect numerous data points during flight, which can later be used to analyze mission performance. In order to ensure completely redundant deployment systems, two of these altimeters will be included in the upper section avionics bay.

Table 23: Missile Works RRC3 altimeter properties[12]*.*

Altimeter Property	Value
Model	RRC3 “Sport”
Manufacturer	Missile Works
Mass (oz)	0.60
Length (in)	3.92
Maximum Altitude (ft)	40,000
Sampling Rate (Hz)	20
Time Delay for Redundancy	Yes
CPU	16MHz 16-bit MSP430 Series mCU
Memory	8Mbit SST Flash
Pressure Sensor	MSI MS5607
Data Options	Peak altitude, peak speed, acceleration, time to apogee, ejection altitudes, flight duration. Beeps, Bluetooth, USB, and LCD screen availa-ble

[12] Source: (Missile Works n.d.)

4.3.4.1.2 GPS AND DATA STREAMING SYSTEM

Remote GPS tracking and real-time flight data streaming will be enabled with the use of the Missile Works RTx telematics system. This system contains its own GPS module and radio transmitter and will link with one RRC3 altimeter for in-flight data collection and transmission. A Linx 916 MHz whip antenna will be used for data transmission to increase range and reliability.

Table 24: Missile Works RTx telematics system properties[13].

Property	Value
Microcontroller	16 MHz 16-bit MSP430 Series mCU
Onboard Flight Memory	8Mbit SST Flash Memory
GPS Operational Ranges	Altitude: 16,042 ft Velocity: 1640 fps
Radio Operational Ranges (MHz)	902 - 928 (Ranges up to 9 miles)
Operational Voltage (V)	3.5 - 10
Operational Current (mA)	190 (peak) at 9 Volts
Dimensions (in)	1.125” x 4.5”

Table 25: Linx 916 MHz whip antenna properties[14].

Antenna Property	Value
Manufacturer	Linx Technologies
Model	ANT-916-CW-HW
Frequency Group	UHF (300 MHz - 1 GHz)
Frequency (Mhz)	916

[13] Source: (Missile Works n.d.)
[14] Source: (Linx Technologies 2013)

Antenna Property	Value
Frequency Range (MHz)	900 - 930
Number of Bands	1
Gain (dBi)	1.2
Height (in)	4.724

4.3.4.1.3 POWER SOURCES

Kinexsis 3.7V, 750 mAh lithium polymer (LiPo) batteries will be used to power all avionics computers and deployment charges. These batteries carry a significantly increased capacity over the 9V batteries used in the subscale rocket, and therefore support an increased launch pad wait time if necessary. One of these rechargeable batteries will be used for each individual flight computer, thus maximizing redundancy and reliability. If any single battery dies, the recovery system will still function as expected.

Table 26: Kinexsis 3.7V LiPo battery properties[15].

Battery Property	Value
Manufacturer	Kinexsis
Model	KXSB0008
Material	Lithium Polymer
Voltage (V)	3.7
Capacity (mAh)	750
Dimensions (in)	3.7 x 0.71 x 0.24
Weight (oz)	0.70
Standard Charge Rate (A)	0.2
Watt hours (Wh)	2.77

[15] Source: (Tower Hobbies n.d.)

4.3.4.1.4 SWITCHES

E-Switch keyed rotary switches will individually control power to each flight computer.

Table 27: E-Switch rotary switch properties[16].

Switch Property	Value
Manufacturer	E-Switch
Model	KO106A
Material	Copper / Zinc Alloys
Circuit Type	SPST
Number of Positions	2
Voltage Rating (V, AC)	125
Current Rating (A, at rated voltage)	1

4.3.4.1.5 WIRING

Insulated 20 AWG solid-core wire will be used for all electrical wiring. Wires will be well-organized, labeled and color-coded to prevent confusion and allow for rapid continuity checking.

4.3.4.2 TRANSMISSION CHARACTERISTICS

The Missile Works RTx computer uses a standard X-Bee PRO 900 MHz transmitter, to which a Linx ANT-916 antenna will be attached. Both the upper and lower sections utilize this configuration.

Table 28: Avionics transmission characteristics.

Transmission Property	Value
Frequency Group	UHF
Frequency Range (MHz)	902-928

[16] (E-Switch n.d., 222)

Transmission Property	Value
Frequency Band (MHz)	916
Range (mi)	9 (w/ 2.1 Dipole Antenna)
Power (mW)	250
Antenna Gain (dBi)	1.2

4.3.4.3 ELECTRICAL SCHEMATICS

The upper and lower section avionics bays share almost identical electrical schematics, with the notable exception that the drogue parachute E-matches are not present in the upper section electronics.

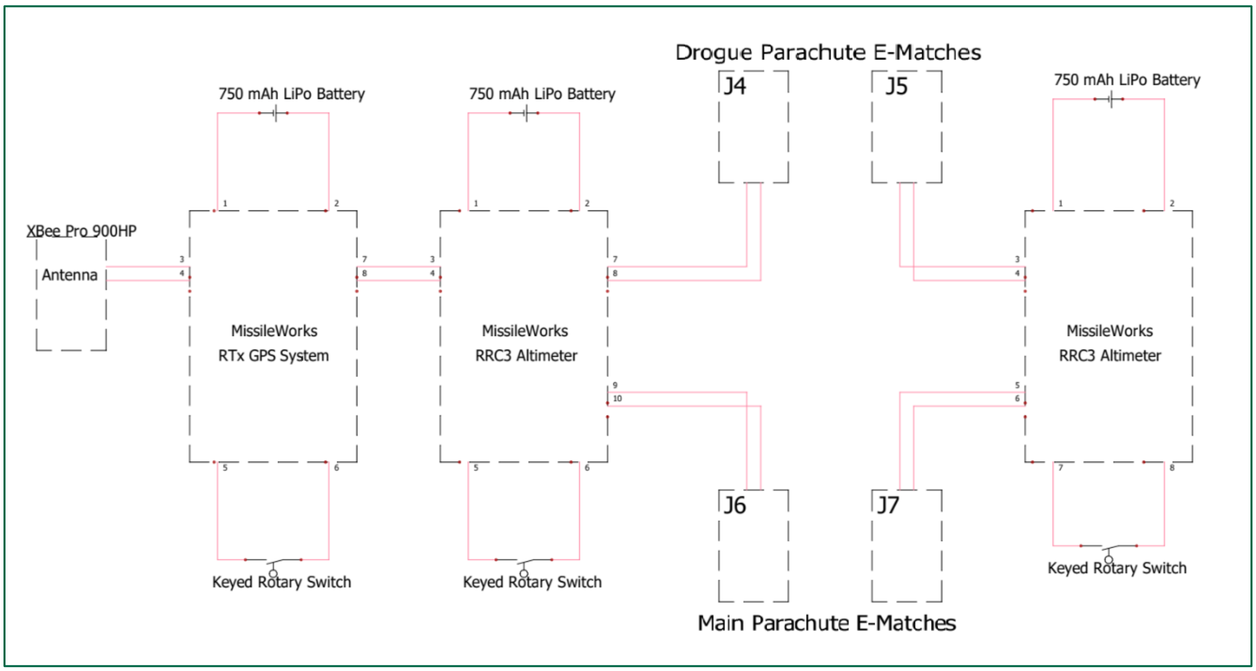


Figure 54: Recovery subsystem avionics electrical schematic.

4.3.4.4 PHYSICAL DESIGN

Both avionics bays share the same internal diameter and threaded rod support structure, allowing the same basic design to be reused for both bays. Altimeters and batteries will be mounted to custom-designed FRP removable sleds, as described below.

4.3.4.4.1 SLED DESIGN

Both bays will use identical sleds, cut from fiberglass-reinforced plastic (FRP) using a CNC router. These interlocking sleds will fit the threaded rod layout defined by the avionics bay bulkheads. As both bays use the same sled design, one extra switch, battery, and altimeter mounting location are present in the lower section avionics bay. This extra altimeter (a Missile Works RRC2+) in the upper section avionics bay is used to control the PDLS described in 4.1.3.2.3 Payload Descent Levelling Subsystem (PDLS) and is not related to or connected with the recovery subsystem.

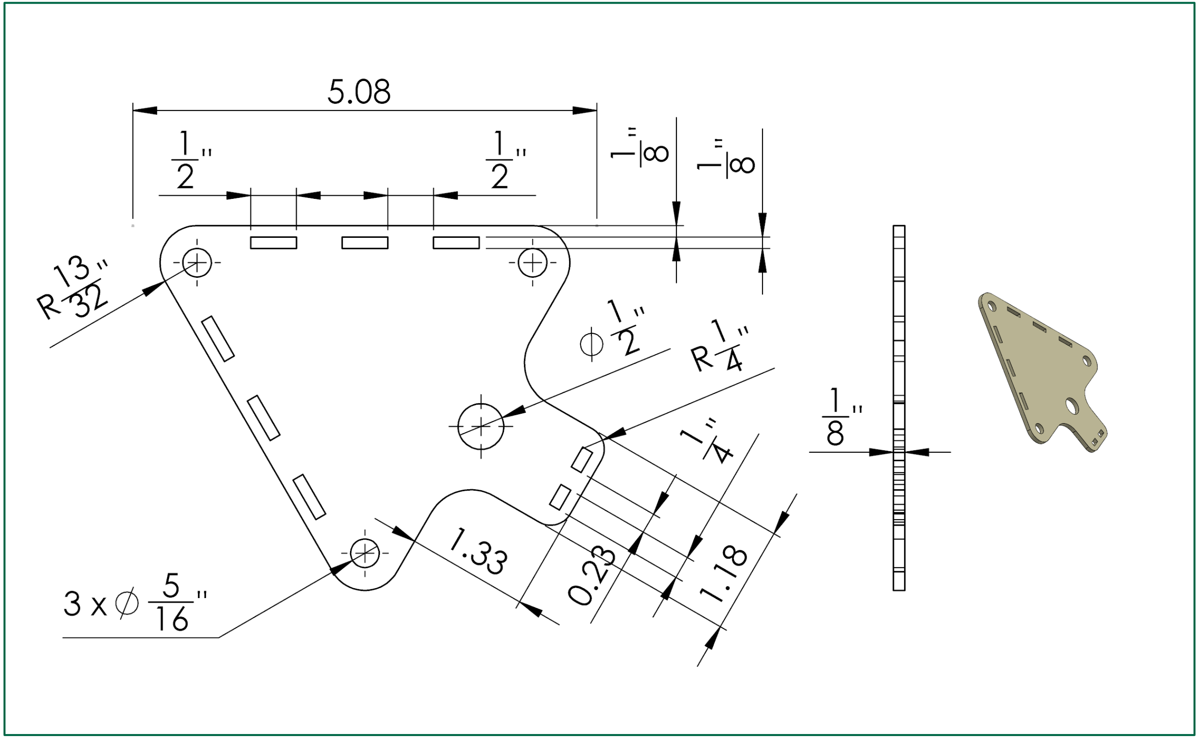


Figure 55: Avionics bay sled assembly lower cap, with opening for antenna clearance.

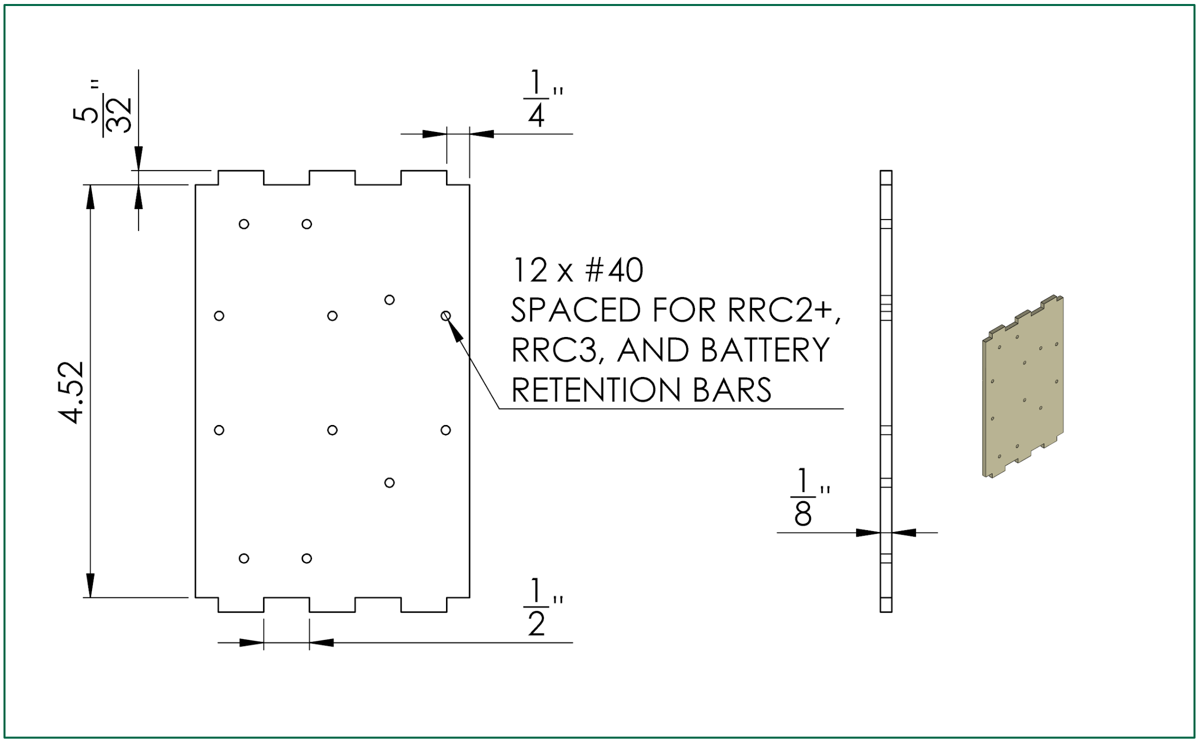


Figure 56: Avionics bay sled assembly side "A", with RRC3 and RRC2+ mounting holes.

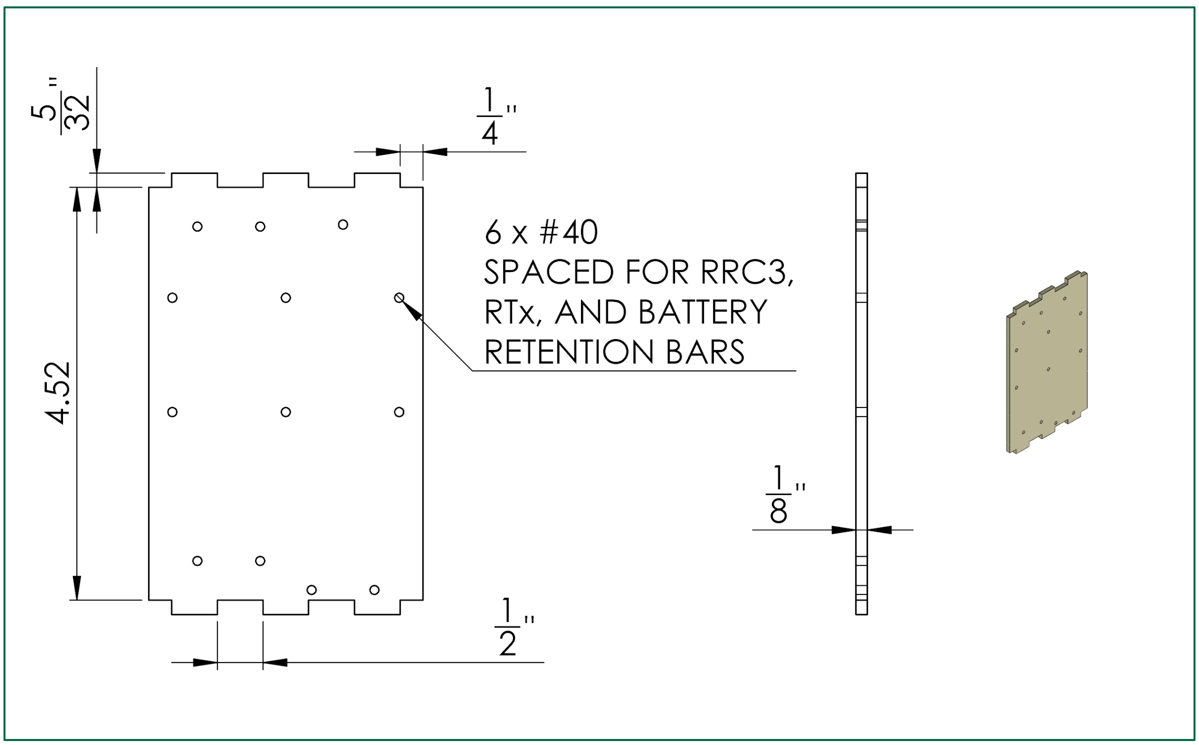


Figure 57: Avionics bay sled assembly side "B", with RRC3 and RTx mounting holes.

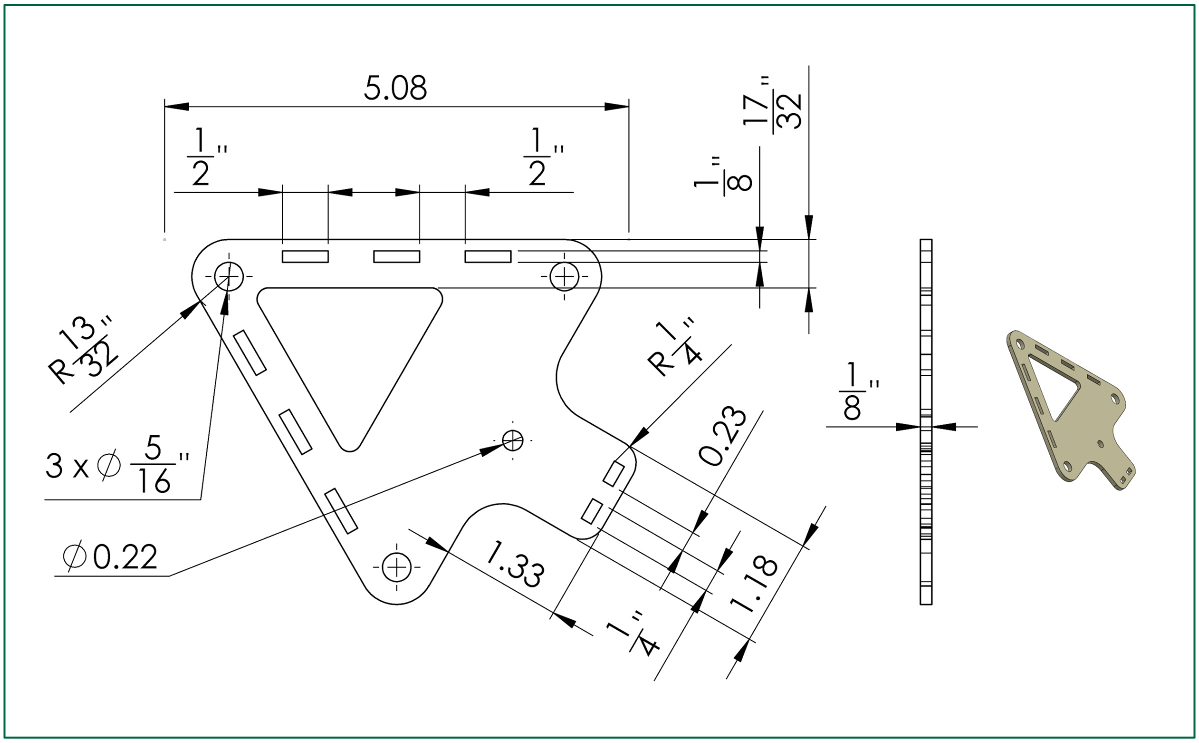


Figure 58: Avionics bay sled assembly upper cap, with access opening and antenna mount.

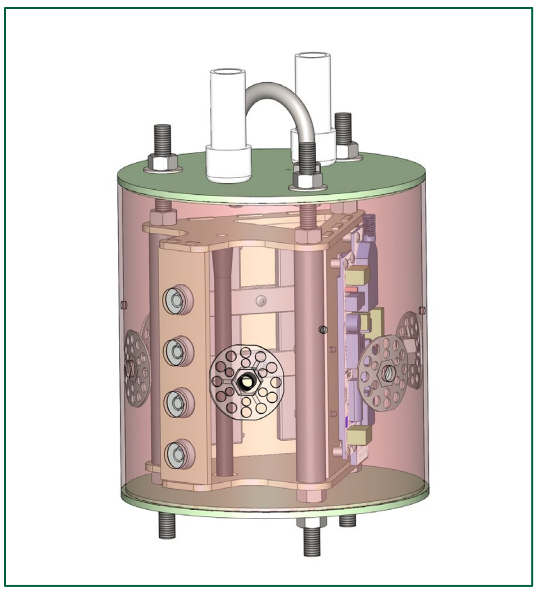


Figure 59: Assembled upper section avionics bay (with identical sled design to lower section avionics bay).

4.3.4.4.2 ALTIMETER AND BATTERY MOUNTING

Altimeters will be offset from the non-conductive FRP sleds using nylon standoffs, allowing for sufficient space for cooling and insulation. Batteries will be installed on the interior of the sled system to maximize battery protection, even in the event of a bulkhead failure. Batteries will be offset using nylon standoffs and secured using machined steel bars in order to prevent slipping (this is a design change from the 9V battery clips, which failed in the subscale launch vehicle test). Securement bars will be filleted to avoid sharp edges near the LiPo batteries, and altimeter mounting screws will be sufficiently short to prevent any possibility of contact with the batteries. Altimeters and batteries will be mounted using stainless steel 4-40 machine screws with split lock washers to prevent movement caused by vibration.

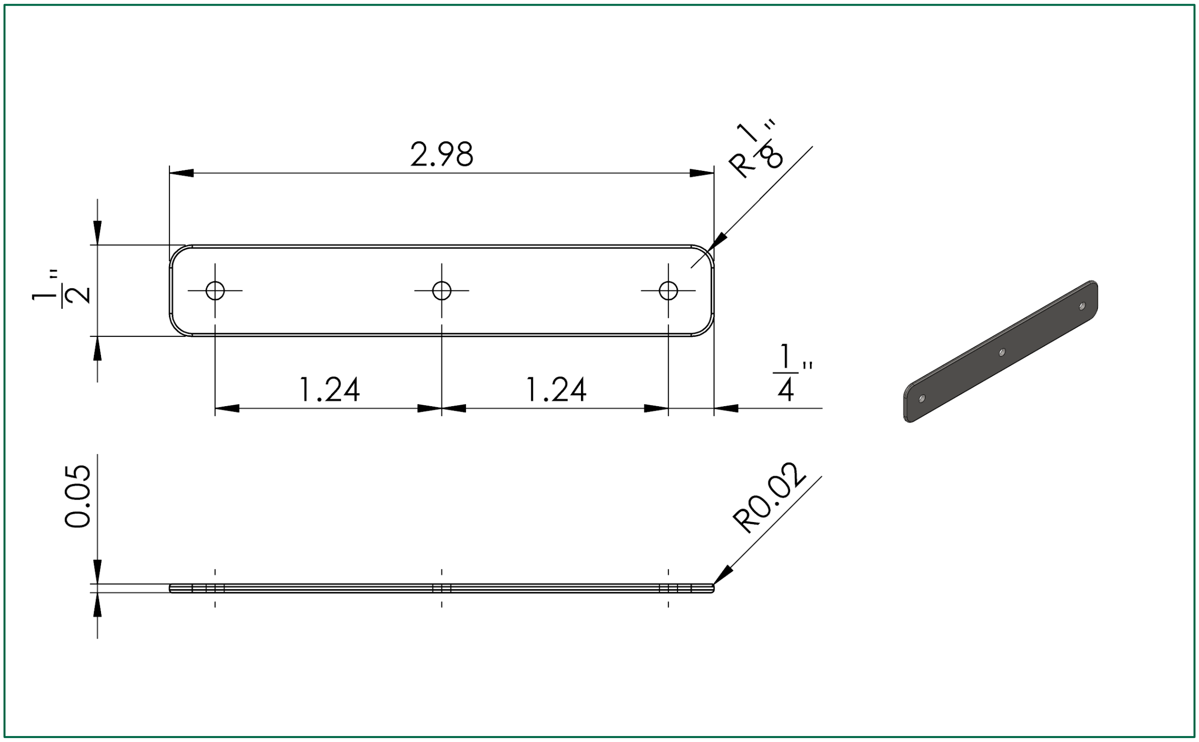


Figure 60: Avionics battery retention bar design.

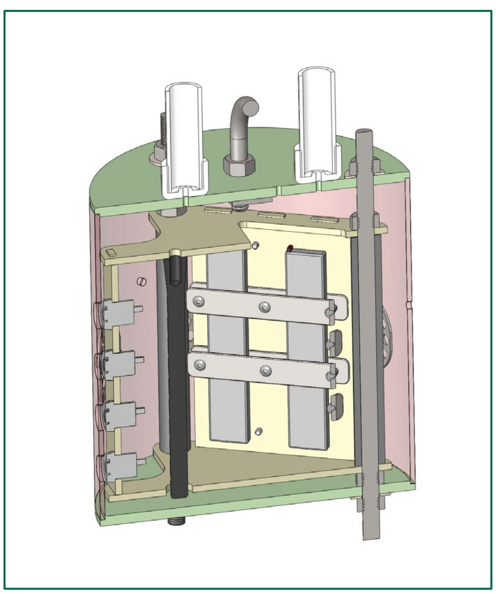


Figure 61: Cutaway view of upper section avionics bay, highlighting battery protection and retention design.

4.3.4.4.3 ELECTRICAL CONNECTIONS

Wire-to-wire electrical connections will be created using the NASA-standard Lineman's Splice[17], with the modification that soldering the connection will be optional. All wire-to-wire connections will be protected with sufficient heat-shrink tubing to cover the entire exposed conductors.

All other connections will be made according to the connector design, with required soldering whenever permanent connections are made. Whenever possible, exposed conductors will be insulated with heat-shrink tubing. All screw terminals will be checked before launch for sufficient security.

4.3.5 ATTACHMENT HARDWARE

Based on the observations made when analyzing the subscale vehicle post-launch condition in 4.2.6 Post-Launch Vehicle Condition, stainless steel will be used for all metal recovery attachment hardware. Use of this metal will maximize strength and prevent corrosion from moisture or black powder deployment charges. A minimum factor of safety of 3 has been mandated by the vehicle team in order to ensure success of the recovery subsystem, as noted in 7.3.1 Derived Vehicle Requirements. In order to promote standardization across the launch vehicle, all similar attachment hardware components will be the same model (e.g., all quick links will share the same model, despite differing loads).

4.3.5.1 FACTOR OF SAFETY CALCULATION METHODS

Factors of safety have been calculated with manual calculations, computational finite element analysis, or both when feasible. Manual calculations implement Equation 8 below, where S_F denotes failure stress, and S_{A_MAX} denotes maximum applied stress. Given the definition of stress provided in Equation 9 (where A is the area over which the applied load is distributed), 'stress' in Equation 8 can be used interchangeably with 'load'.

$$N = \frac{S_F}{S_{A_{MAX}}} = \frac{L_F}{L_{A_{MAX}}}$$

Equation 8: Factor of safety definition.

$$N = \frac{S_F}{S_{A_{MAX}}} = \frac{L_F}{L_{A_{MAX}}}$$

Equation 9: Definition of mechanical stress.

For all recovery hardware calculations, the maximum applied load is taken to be the maximum parachute deployment shock force of any deployment event on the vehicle, as described and calculated in 4.4.3 Parachute Deployment Shock Force.

[17] Source: (NASA 2016, 71)

4.3.5.2 SHOCK CORD

½" tubular Kevlar will be used to attach all parachutes to the rocket. This material allows for significant stretching without weakening, allowing the cord to absorb much of the parachute deployment shock and prevent damage upon deployment.

Table 29: ½" tubular Kevlar properties[18].

Shock Cord Property	Value
Manufacturer	Top Flight Recovery LLC
Material	Tubular Kevlar
Size (in)	½
Tensile Strength (lb)	7200

4.3.5.2.1 ATTACHMENT METHOD

When attaching shock cord to quick links, care will be taken to ensure that attachments cannot loosen or weaken during flight. Therefore, all shock cord will be attached using bowline knots with at least a 3" tail. Finally, knots will be secured by shrinking heat-shrink tubing over the entire knot and tail.

4.3.5.2.2 CALCULATIONS

The tensile yield strength of the selected shock cord is listed in Table 29; given this, the factor of safety is calculated in Equation 10.

$$N_{\text{shock cord}} = \frac{7200\text{ lb}}{61.93\text{ lb}} = 116.25$$

Equation 10: Factor of safety for recovery subsystem shock cord.

This factor of safety is exceptionally high due to the shock-absorptive properties of tubular Kevlar; it is not only intended to withstand the shock force, but also to reduce it by stretching somewhat.

4.3.5.3 SWIVELS

Swivels will be used as connections between the parachute quick links and shock cord to prevent twisting of the parachute shock cord from spinning the rocket. The swivels used will be fabricated from 316 Stainless Steel.

---

[18] Source: (Top Flight Recovery, LLC n.d.)

Table 30: ¼" swivel hardware capacity[19].

Swivel Property	Value
Manufacturer	McMaster-Carr
Model Number	3714T92
Thickness (in)	¼
Eye Inside Length (in)	⅝
Eye Inside Diameter (in)	$^{9}/_{16}$
Length (in)	2 ⅛
Capacity (lb)	600

4.3.5.3.1 CALCULATIONS

The swivel factor of safety can be simply derived from the rated load:

$$N_{\text{swivel}} = \frac{600 \text{ lb}}{61.93 \text{ lb}} = 9.688$$

Equation 11: Factor of safety for recovery subsystem swivel component.

The Factor of Safety for the swivel is sufficiently above 3.0 and the component is large enough to connect to the quick link, therefore this model is adequate for use in the recovery subsystem.

4.3.5.4 QUICK LINKS

The quick links that will be used are ½" thick, 316 Stainless Steel quick links, which were selected to have a factor of safety greater than 3.0 when the maximum shock force from parachute deployment occurs.

[19] Source: (McMaster-Carr n.d.)

Table 31: ¼" 316 stainless steel quick link properties[20].

Quick Link Property	Value
Manufacturer	McMaster-Carr
Model Number	3711T34
Thickness	¼
Opening Width (in)	9/16
Inside Length (in)	2 5/16
Inside Width (in)	9/16
Capacity (lb)	1,200

4.3.5.4.1 CALCULATIONS

4.3.5.4.1.1 MANUAL CALCULATION

The factor of safety for the quick link can be simply calculated using the rated load, as shown in Equation 12.

$$N_{\text{quick link}} = \frac{1200\ \text{lb}}{61.93\ \text{lb}} = 19.37$$

Equation 12: Factor of safety for recovery subsystem quick links.

4.3.5.4.1.2 FINITE ELEMENT ANALYSIS

To confirm this value and gain further insight, a CAD model was built to resemble the quick links that will be used in the full-scale vehicle. Finite element analysis was then performed on the model using symmetric conditions and maximum shock load. The results of this analysis are shown in Figure 62, Figure 63, and Figure 64.

[20] Source: (McMaster-Carr n.d.)

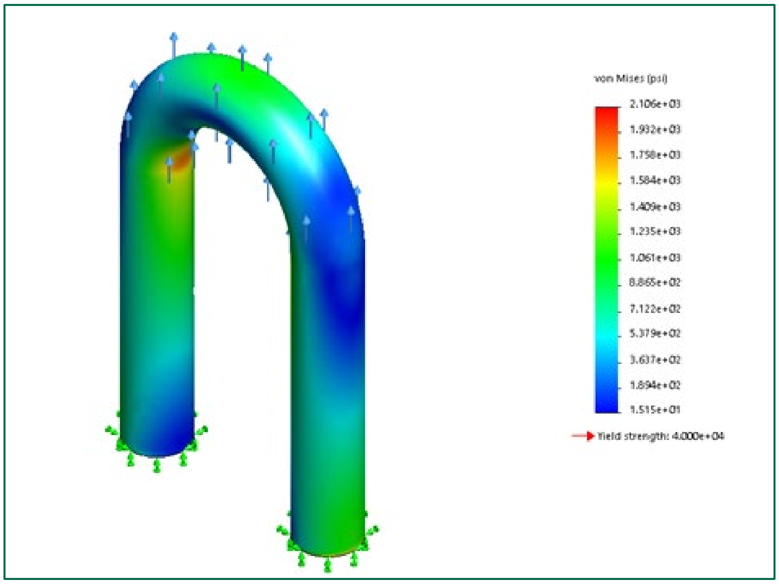


Figure 62: Stress distribution model for recovery subsystem quick links.

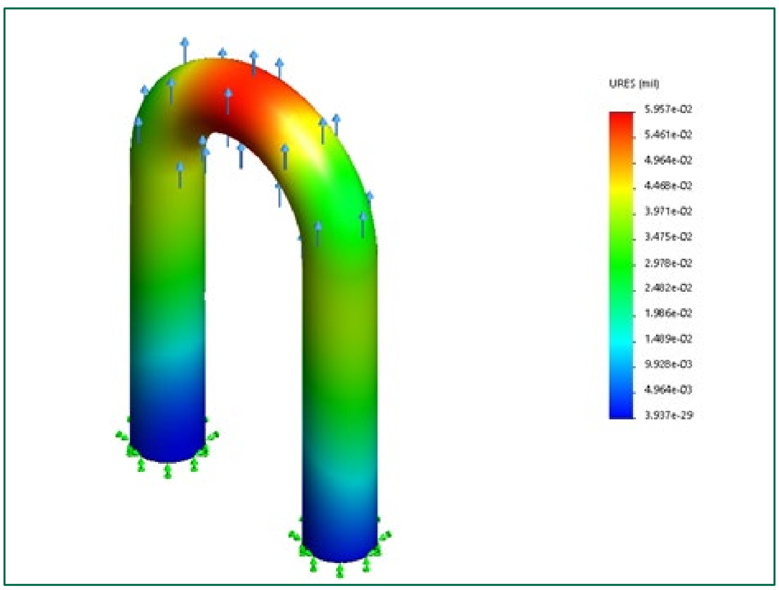


Figure 63: Displacement distribution model for recovery subsystem quick links.

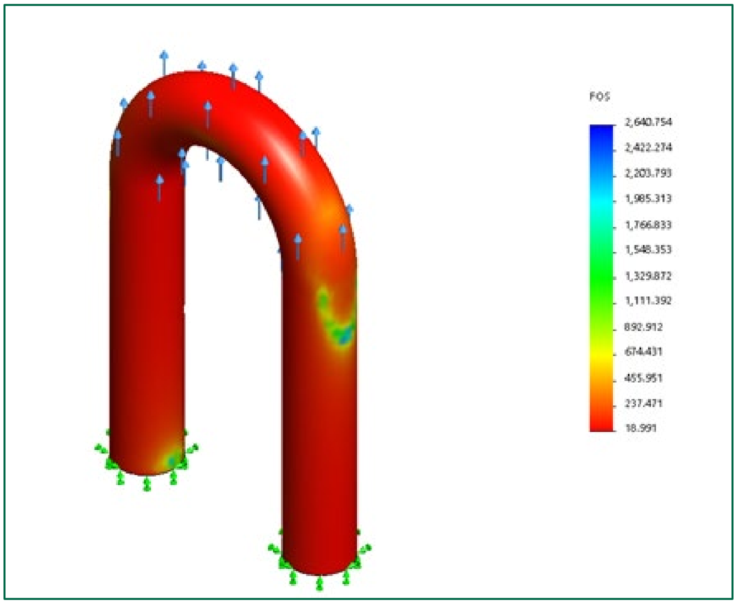


Figure 64: Factor of safety distribution model for recovery subsystem quick links.

The factor of safety of 18.991 found using the SolidWorks FEA is slightly lower than the hand calculations. This is most likely due to the material data on SolidWorks not being entirely accurate but could also be caused by the more robust analysis that SolidWorks performs. However, in both instances, the factor of safety is sufficiently greater than 3.0 and therefore acceptable.

4.3.5.5 U-BOLTS

The selected 5/16" stainless steel U-bolts are sufficiently sized to endure maximum parachute deployment forces, and materials have been selected such that corrosion will be minimized or eliminated.

Table 32: 304 stainless steel U-bolt properties[21].

U-Bolt Property	Value
Manufacturer	McMaster-Carr
Model Number	8896T71
Material	304 Stainless Steel

[21] (McMaster-Carr n.d.)

U-Bolt Property	Value
Inner Diameter (in)	1 ½
Height (in)	2 $^{3}/_{16}$
Thread Length (in)	1
Thickness (in)	$^{5}/_{16}$
Capacity (lb)	600

4.3.5.5.1 CALCULATIONS

4.3.5.5.1.1 MANUAL CALCULATION

As with the swivel hardware, the factor of safety can be simply calculated from the rated capacity and applied load.

$$N_{\text{U-bolt}} = \frac{600}{61.93} = 9.688$$

Equation 13: Factor of safety for recovery subsystem U-bolts.

4.3.5.5.1.2 FINITE ELEMENT ANALYSIS

The U-bolt CAD model was downloaded directly from McMaster-Carr; therefore, the model is identical to the U-bolt that will be used in the launch vehicle. Results of FEA are shown in Figure 65, Figure 66, and Figure 67.

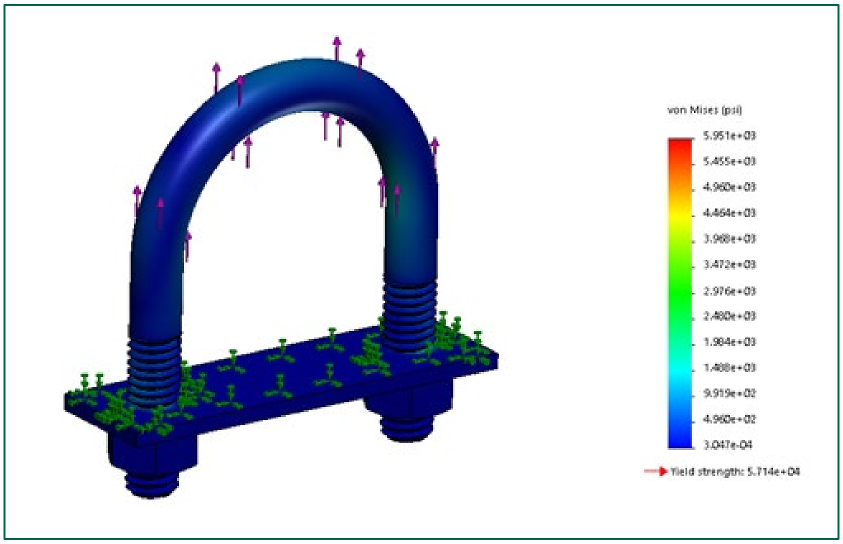


Figure 65: Stress distribution model for recovery subsystem U-bolts.

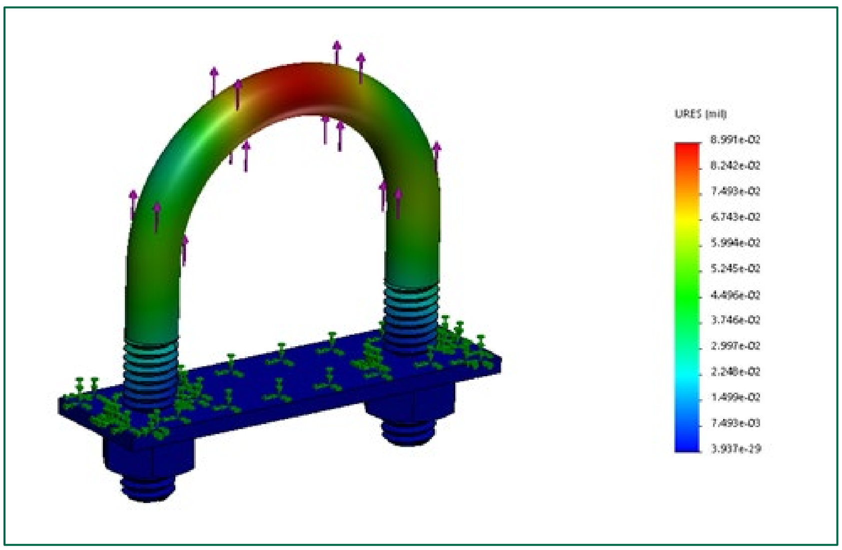


Figure 66: Deformation distribution model for recovery subsystem U-bolts.

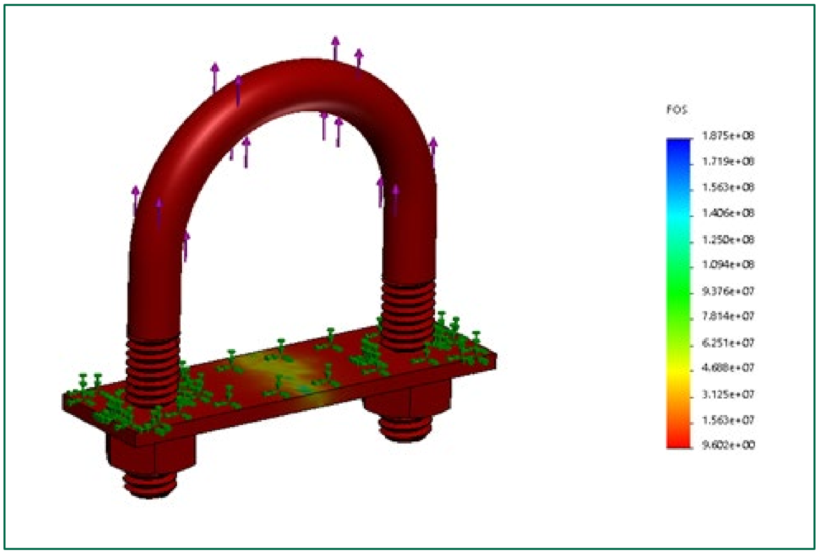


Figure 67: Factor of safety distribution model for recovery subsystem U-bolts.

The factor of safety calculated by SolidWorks (9.602) is slightly lower than the hand calculations, however the value is close enough that this difference can be disregarded. In both instances, the resultant value is significantly greater than 3.0.

4.3.5.6 THREADED RODS

In order to secure avionics bay bulkheads and transfer forces to opposite end of bays, three 5/16" threaded rods will be installed through each avionics bay. Threaded rods will be cut to exact length using a cut-off saw.

Table 33: 5/16" threaded rod properties[22].

Threaded Rod Property	Value
Manufacturer	McMaster-Carr
Product Number	98805A031
Material	18-8 Stainless Steel
Diameter (in)	5/16
Tensile Strength (psi)	70,000

[22] Source: (McMaster-Carr n.d.)

4.3.5.6.1 CALCULATIONS

4.3.5.6.1.1 MANUAL CALCULATION

For hand calculations, the threaded rod was treated as a homogenous cylindrical bar. The only forces being experienced by the threaded rods are tensile in nature, therefore all calculations can be made using the tensile stress (note that three rods run through each bay; therefore, the cross-sectional area is multiplied by three).

$$S_{A_{MAX}{}_{\text{threaded rod}}} = \frac{61.93\ \text{lb}}{3\left(\frac{1}{4}\pi\left[{}^{5}\!/_{16}\ \text{in}\right]^{2}\right)} = 67.28\ {}^{\text{lb}}\!/_{\text{in}^2} = 67.28\ \text{psi}$$

Equation 14: Maximum applied normal stress on recovery subsystem threaded rods.

$$N_{\text{threaded rod}} = \frac{70{,}000\ \text{psi}}{67.28\ \text{psi}} = 1{,}040$$

Equation 15: Factor of safety for recovery subsystem threaded rods.

4.3.5.6.1.2 FINITE ELEMENT ANALYSIS

FEA was run using the threaded rod 3D CAD model downloaded from McMaster-Carr. Symmetric conditions were used, and the tensile force was applied to the rod. The results of this analysis are shown in Figure 68, Figure 69, and Figure 70.

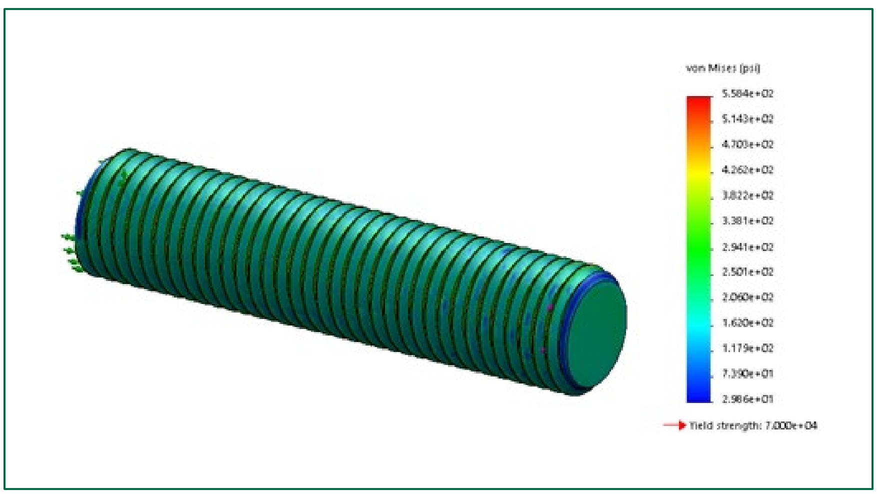


Figure 68: Stress distribution model for recovery subsystem avionics bay threaded rods.

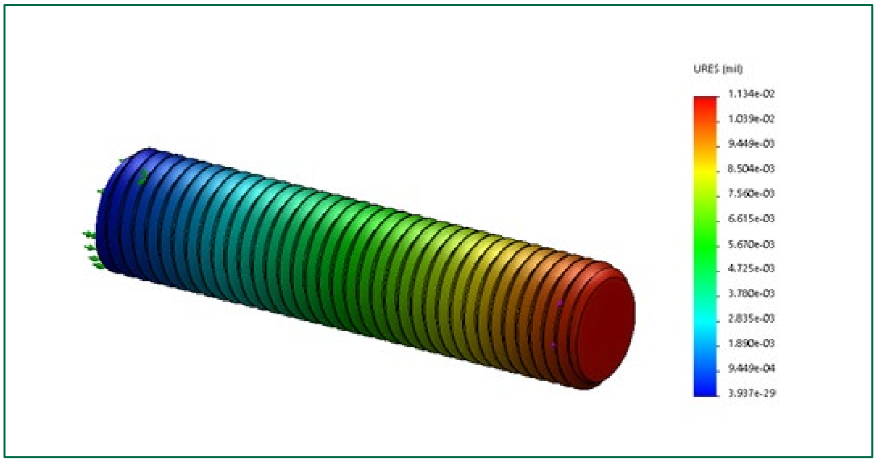


Figure 69: Deformation distribution model for recovery subsystem avionics bay threaded rods.

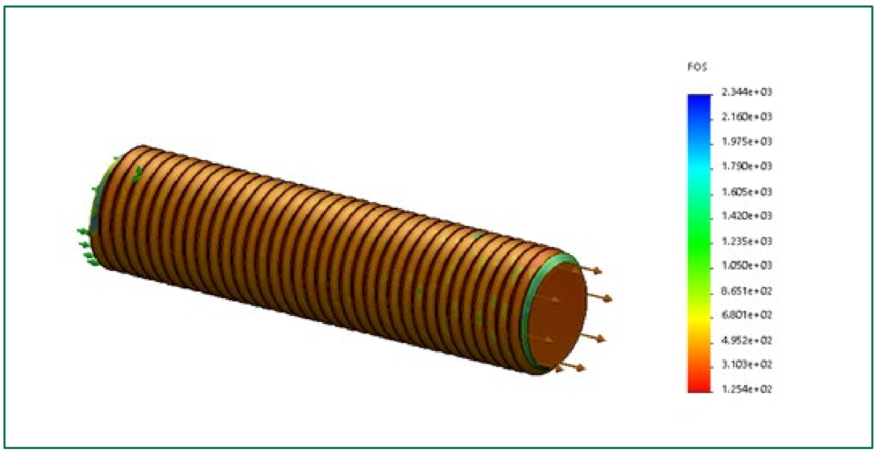


Figure 70: Factor of safety distribution model for recovery subsystem avionics bay threaded rods.

The factor of safety value of 125.4 derived from the finite element analysis provides very different values than the hand calculations. This is likely due to the threading on the rod, which creates stress concentrations throughout the entirety of the rod due to the constantly changing cross-sectional geometry. However, in both hand calculations and computer simulation, the factor of safety is significantly greater than 3.0, therefore this discrepancy can be safely disregarded.

4.3.6 BULKHEADS

All bulkheads will be constructed from sheets of 3/16"-thick fiberglass-reinforced plastic (FRP), a strong, lightweight, and RF-transparent material that can be easily milled using a CNC router. U-Bolts will be centrally located on bulkheads and attached with bearing plates to distribute loads.

On bulkheads installed at the avionics bays, three 3/8" stainless steel threaded rods will secure each bulkhead tightly while transferring support loads to the opposite end of the bay on which loads are applied. A small 1/16" CNC-milled channel around the edge of each bulkhead will ensure that they remain exactly centered within the rocket when installed in the avionics bays.

The bulkhead installed in the nose cone shoulder will be attached using a high-strength AeroPoxy bond reinforced with carbon-fiber additive.

Table 34: Fiberglass-reinforced plastic bulkhead material properties[23].

FRP Property	Value
Manufacturer	McMaster-Carr
Impact Strength (ft-lb/in)	20
Tensile Strength (psi)	24,000
Compressive Strength (psi)	24,000
Flexural Strength (psi)	35,000

[23] Source: (McMaster-Carr n.d.)

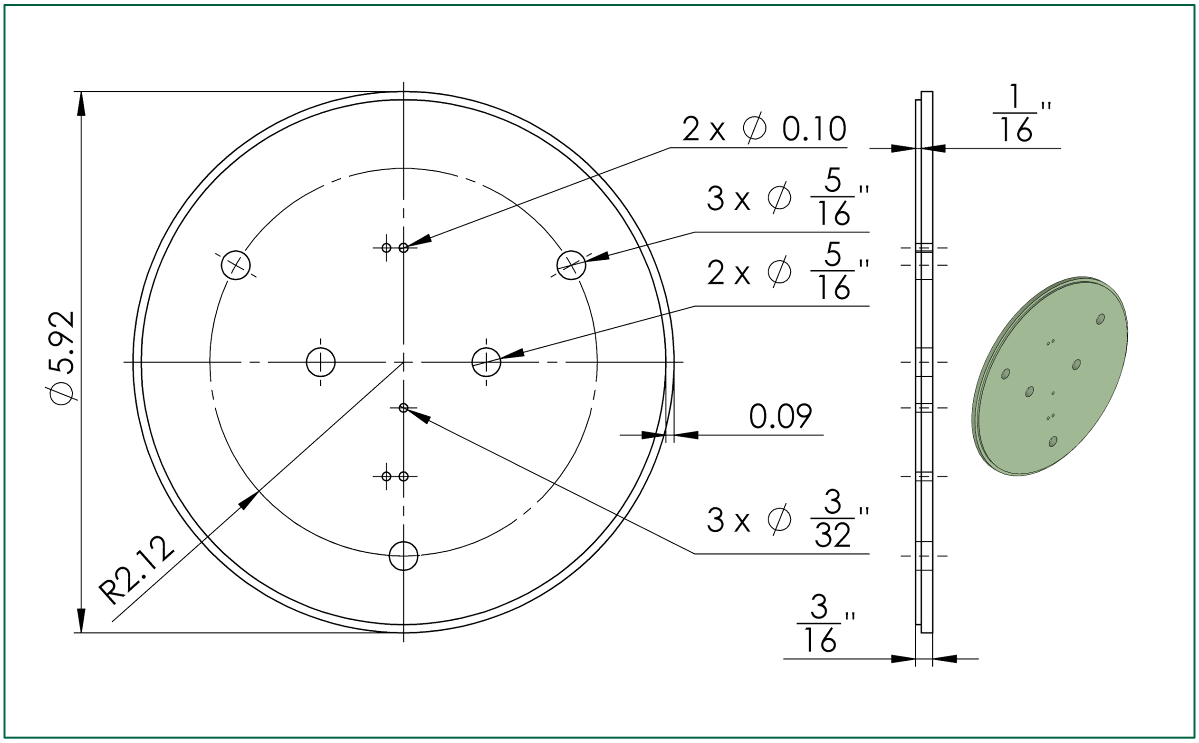


Figure 71: Typical avionics bay bulkhead design.

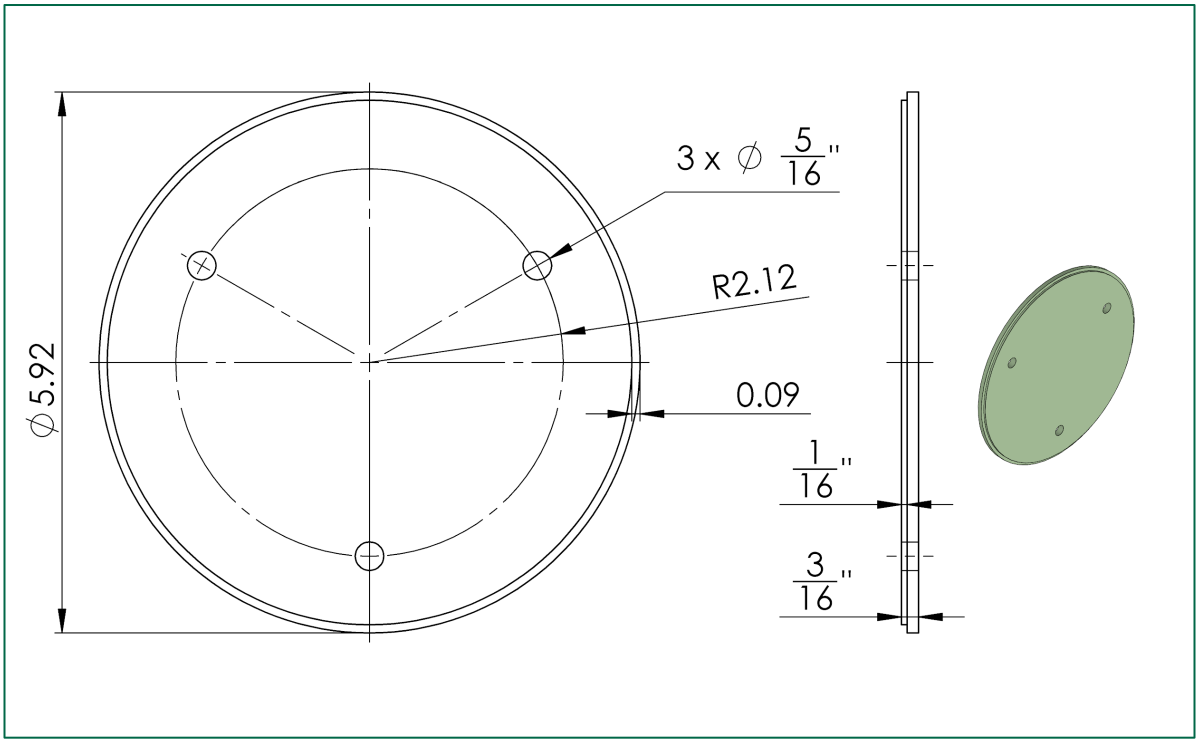


Figure 72: Upper avionics bay lower bulkhead design.

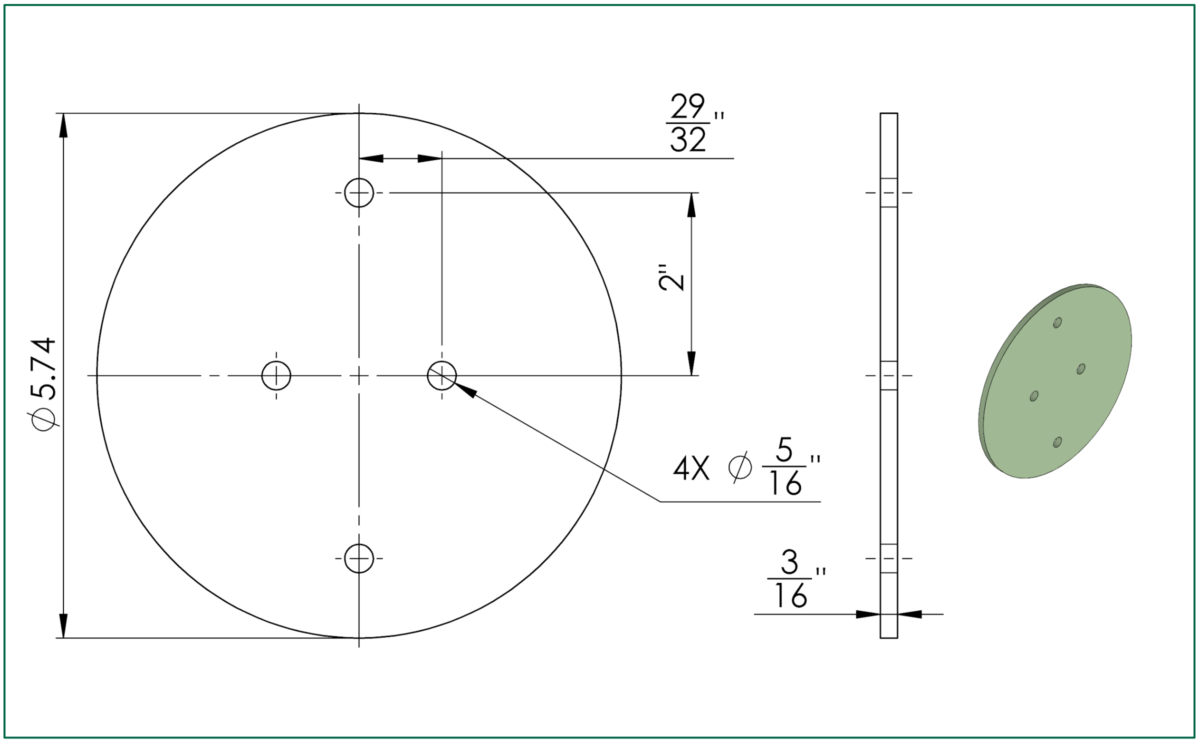


Figure 73: Nose cone bulkhead design.

4.3.6.1 CALCULATIONS

The calculations for the bulkheads were done exclusively using SolidWorks finite element analysis due to the complex interplay of applied loads. The system has constraints applied around the edges where it will be secured to the avionics bay. The force was applied to a rectangular cross section on the bottom of the bulkhead with the same dimensions as the mounting plate of the U-bolt, in order to represent the resultant distributed load. Reaction forces were applied over a circular area to account for the use of washers installed to distribute stresses.

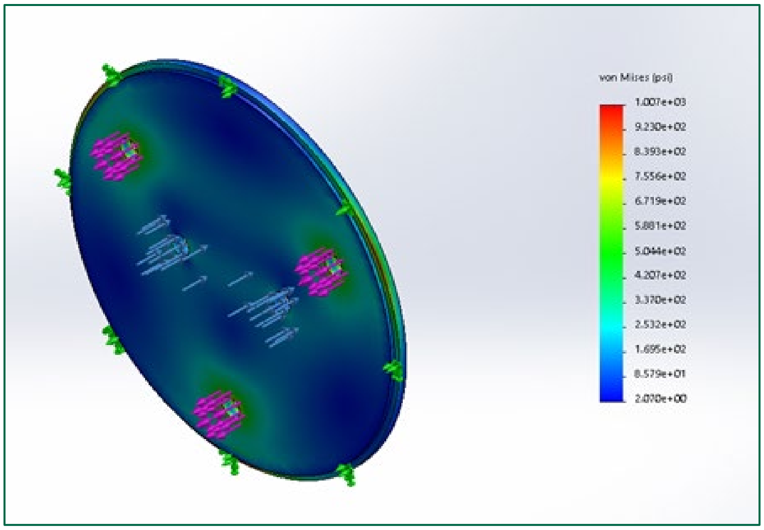


Figure 74: Stress distribution model for bulkheads with U-bolts installed.

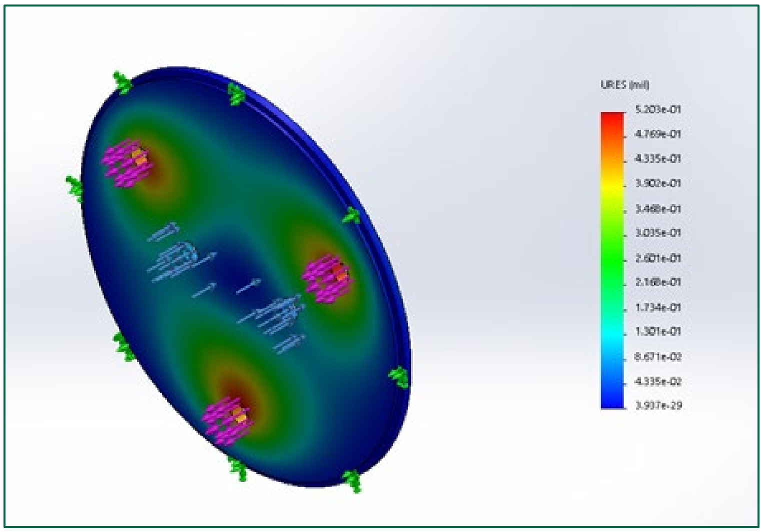


Figure 75: Deformation distribution model for bulkheads with U-bolts installed.

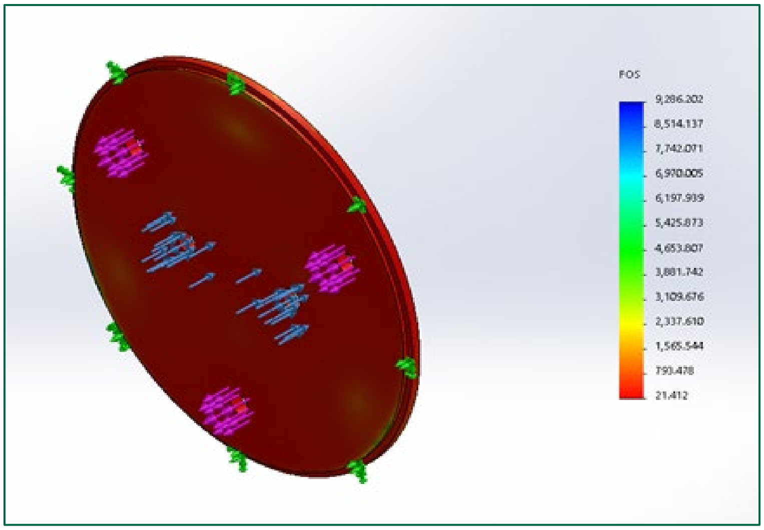


Figure 76: Factor of safety distribution model for bulkheads with U-bolts installed.

The calculated factor of safety of 21.412 for the bulkhead is above 3.0 and is sufficiently safe for use in the rocket.

As the bulkhead model analyzed has the strongest loads and most fastener points, all other bulkheads can be assumed to have factors of safety greater than or equal to that of the one analyzed.

4.4 MISSION PERFORMANCE PREDICTIONS

4.4.1 FLIGHT PROFILE

4.4.1.1 SIMULATED FLIGHT CHARACTERISTICS

Flight simulations were performed using the OpenRocket design software and a custom Simulink model, yielding the flight characteristics listed in Table 35 below. The custom Simulink model does not yet support multiple recovery sections or calculation of the velocity off rod.

Table 35: Simulated full-scale flight characteristics.

Flight Characteristic	OpenRocket	Simulink	Average
Velocity Off Rod (ft/s)	76.7	N/A	76.7
Maximum Velocity (ft/s)	608	613.9	610.95
Maximum Acceleration (ft/s^2)	328	312.8	320.4
Ascent Time (s)	17.9	12	14.95

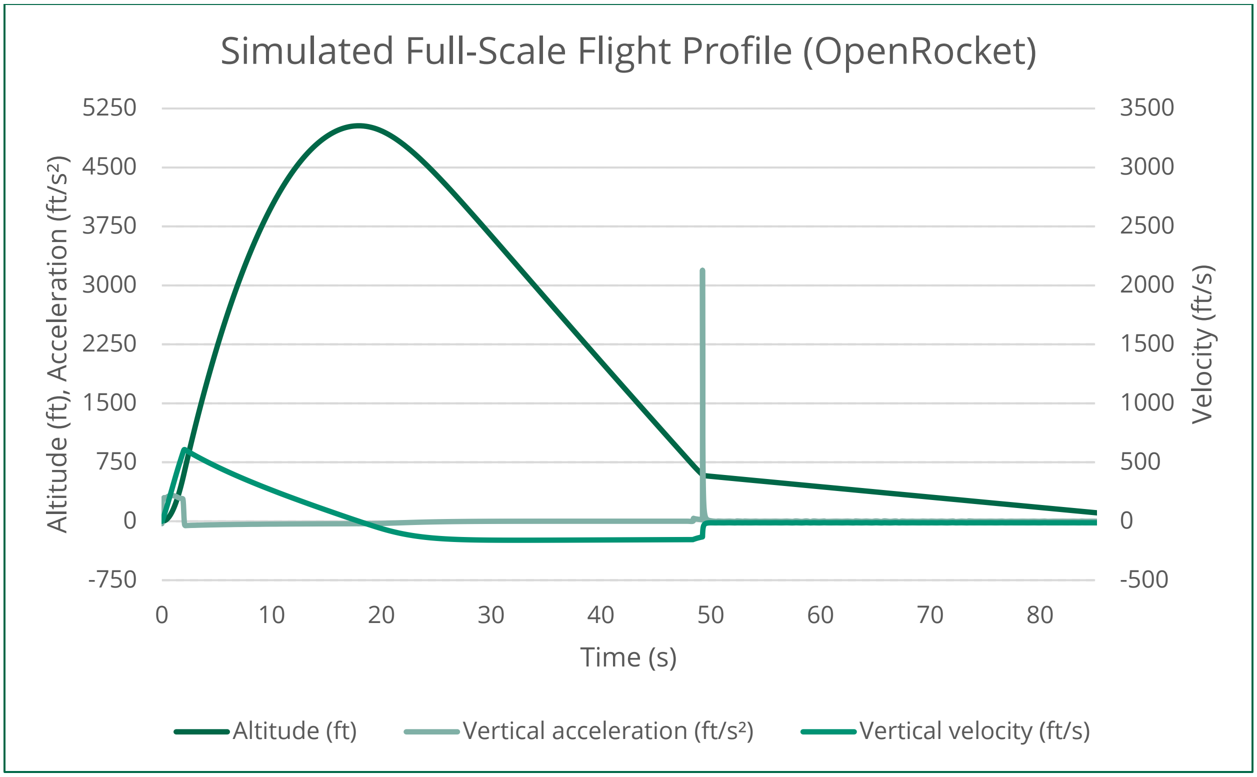


Figure 77: Plot of simulated full-scale launch profile.

4.4.1.2 ALTITUDE PREDICTION

Altitude predictions were made using both OpenRocket simulations and Simulink. The vehicle is intentionally designed to fly higher than 5,000 ft (the target altitude) in order to allow for the DAAS to lower the apogee dynamically.

Table 36: Simulated full-scale apogee predictions.

Simulation Method	**Apogee** (ft)
OpenRocket	5025
Simulink	3814

As significant deviation exists between the two simulation methods, the Simulink value will not be considered in making vehicle design decisions at this time. This is because the Simulink model is still experimental and also only calculates values every ½ second.

4.4.1.2.1 EXPERIMENTAL ALTITUDE PREDICTION ADJUSTMENT

Using the altitude adjustment factor calculated in Equation 7, adjusted altitude predictions have been calculated. As this adjustment factor is only supported by a single flight, these values are considered highly experimental and not to be used for any design decisions. Calculation of these values is purely to compare to flight results and examine validity of the adjustment method. Over time, these adjusted values will be made more accurate with the use of a larger dataset.

Table 37: Experimental adjusted simulated apogee predictions.

Simulation Method	**Resultant Apogee** (ft)
OpenRocket	5653
Simulink	4291

4.4.1.3 COMPONENT WEIGHTS

Table 6 lists the approximate masses of each general component, as used for flight simulations. For a more detailed breakdown of individual components exactly as input into OpenRocket, see Appendix D: OpenRocket 'Parts Detail' Report.

4.4.1.4 MOTOR THRUST CURVE

The Cesaroni L2375 specifications are listed in Table 8. The thrust curve for this motor is available below.

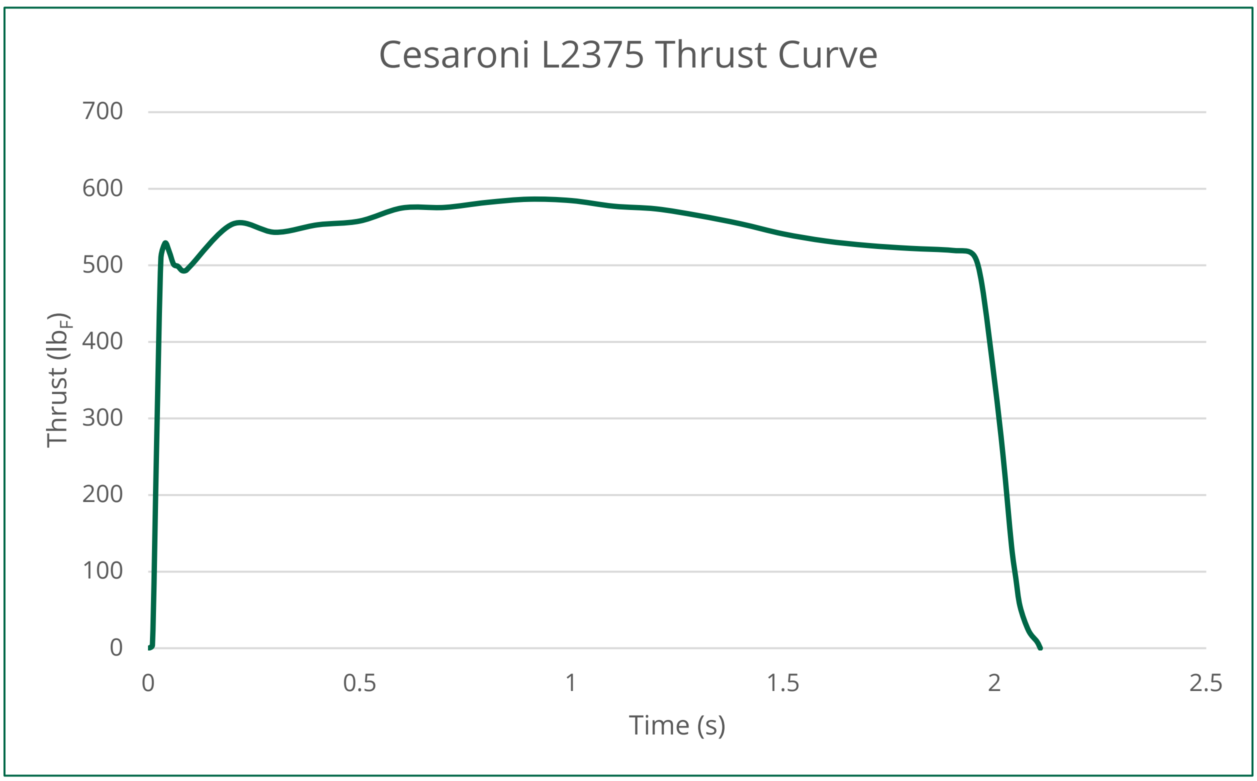


Figure 78: Cesaroni L2375 thrust curve[24].

4.4.1.5 VEHICLE ROBUSTNESS

This vehicle design has proven to be adequately robust enough to handle flight loads, based upon the results found in 4.2.6 Post-Launch Vehicle Condition. For further confirmation on full-scale-specific individual vehicle components, see 4.1.3 Vehicle Design Details, 4.3.5 Attachment Hardware, and 4.3.6 Bulkheads.

4.4.2 STATIC STABILITY

This launch vehicle is statically stabilized; therefore, the center of pressure must be located at least two calipers below the center of pressure. Furthermore, to prevent arcing into the wind, the rocket must not be over-stable (have a stability margin of greater than four calipers). The following vehicle stability characteristics were calculated using OpenRocket and confirmed with RockSim.

Table 38: Simulated vehicle stability characteristics on launch pad.

Property	**Value**
Center of Pressure (in, from tip)	102
Center of Gravity (in, from tip)	87.6
Stability Margin (calipers)	2.4

At the time of rail exit, the vehicle is moving at 76.7 ft/s as stated in Table 35, and has expelled some mass in order to gain this momentum, however it still must maintain stability as it exits the rail. This stability is maintained, as shown in Table 39 below.

Table 39: Simulated vehicle stability characteristics at rail exit.

Property	**Value**
Center of Pressure (in, from tip)	102
Center of Gravity (in, from tip)	87.1
Stability Margin (calipers)	2.48

[24] Data Source: (ThrustCurve 2014)

4.4.3 PARACHUTE DEPLOYMENT SHOCK FORCE

In order to predict the performance of recovery subsystem components, an estimate for the maximum instantaneous shock force applied at parachute deployment was required. As OpenRocket estimates of acceleration at parachute deployment are purely illustrative, and creation of a from-scratch simulation requires significant complex analysis and wind tunnel data, it was decided to instead scale the shock force experienced by the subscale launch vehicle.

The estimated force in the full-scale shock cord was found by scaling the mass of the sub-rocket up by 50% (as the subscale rocket was ⅔ the size of the full-scale) and using the acceleration data collected by the Altus Metrum EasyMini altimeter. From this data, the maximum acceleration of the rocket at main parachute deployment was found to be 31, and from Table 9, the weight of the subscale upper section is 13 lb. Therefore, the mass of the upper section is 0.406 lb_M. Applying a mass scaling factor of 1.5 yields 0.609 lb_M, while the acceleration will remain approximately constant upon scaling[25]. Therefore, according to Newton's Second Law, the maximum load can be calculated by multiplying the scaled mass and unscaled acceleration, as in Equation 16.

$$L_{MAX} = 0.609\ \mathrm{lb_M} \cdot 31\ {}^{\mathrm{ft}}\!/_{\mathrm{s}^2} = 61.93\ \mathrm{lb_F}$$

Equation 16: Estimated full-scale maximum parachute deployment shock force.

As this force calculation uses the most massive section of the launch vehicle, conservative calculations can be performed for the entire rocket using this value (all other parachute deployments must result in a smaller shock cord, so any components designed to withstand this force will also withstand other deployments.

4.4.4 KINETIC ENERGY AT LANDING

The parachute selection depends on the mass of the rocket and velocity at descent so that it lands on the ground safely. To ensure that the rocket does not exceed the maximum kinetic energy requirement of 75 ft-lb_F at landing, the maximum velocity of a section with mass m is calculated using Equation 17.

$$v_{MAX} = \sqrt{2\frac{75\ \mathrm{ft} \cdot \mathrm{lb_F}}{m}}$$

Equation 17: Maximum allowable velocity of a vehicle section at the instant of ground impact.

A per-parachute constant value a can be used to select a parachute, where a is defined in Equation 19 as a function of the parachute's coefficient of drag C_D and area A.

[25] Source: (Richard 1967)

$$a = A \cdot C_D$$

Equation 18: Definition of the parachute selection constant.

The minimum value for a can be calculated using a form of the parachute descent velocity equation[26].

$$a_{MIN} = \frac{2gm}{\rho_{\text{air}} \cdot v_{MAX}^2}$$

Equation 19: Minimum value for parachute selection constant.

Taking the density of air ρ_{air} at STP to be 0.07967 lb/ft^3, the minimum a value is calculated for each section and listed in Table 40.

Table 40: Minimum parachute selection constant value per launch vehicle section.

Section	***a*** (ft^2)
Upper	93.7
Lower	80.5

4.4.5 EXPECTED DESCENT TIME

4.4.5.1 PRIMARY CALCULATION METHOD

With the primary descent time calculation method, the per-section descent time is calculated using the parachute descent velocity formula solved for v and dividing the vertical distance traveled under the parachute (i.e., the height of parachute deployment) by this value.

$$v = \sqrt{\frac{2gm}{\rho_{\text{air}} \cdot a}}$$

Equation 20: Velocity of a launch vehicle section descending under parachute.

$$t = {}^{h}/_{v}$$

Equation 21: Descent time of a launch vehicle section under parachute.

[26] Source: (Benson n.d.)

Table 41: Descent velocity and time per section using primary calculation method.

Section	**Descent Velocity** (ft/s)	**Descent Time** (s)
Upper	14.44	51.94
Lower	14.99	43.36

4.4.5.2 ALTERNATE CALCULATION METHOD

Alternative values were extracted directly from OpenRocket simulation data.

Table 42: Descent velocity and time per section using alternate method.

Section	**Descent velocity** (ft/s)	**Descent time** (s)
Upper	13	55.38
Lower	13	46.15

4.4.6 DRIFT

4.4.6.1 PRIMARY CALCULATION METHOD

The primary method for calculating drift of the launch vehicle is by extracting values from OpenRocket simulation data, as listed in Table 43 and Table 44.

4.4.6.1.1 LOWER SECTION

Table 43: Drift analysis of lower section at various wind speeds.

	Simulation 1	**Simulation 2**
Wind Speed (mph)	**Drift** (ft)	**Drift** (ft)
0	0	0
5	538.76	533.62
10	1,095.85	1,067.25
15	1,614.80	1,600.87
20	2,161.62	2,134.5

4.4.6.1.2 UPPER SECTION

Table 44: Drift analysis of upper section at various wind speeds.

	Simulation 1	Simulation 2
Wind Speed (mph)	**Drift** (ft)	**Drift** (ft)
0	0	0
5	551.95	548.30
10	1,104.65	1,099.80
15	1,654.40	1,651.10
20	2,193.88	2,193.90

4.4.6.2 ALTERNATE CALCULATION METHOD

Calculations were then conducted by using the OpenRocket lateral position at main parachute deployment and subtracting the drift distance d defined in Equation 22.

$$d = v_{\text{wind}} \cdot t$$

Equation 22: Alternate calculation method drift distance formula.

All the drift distances calculated in this manner were consistently slightly larger than those calculated with OpenRocket simulations. This is likely because the simple formula does not take into account the parasite or friction drag on the rocket components and even the parachute itself.

4.4.6.2.1 LOWER SECTION

Table 45: Alternate drift analysis of lower section at various wind speeds.

	Simulation 1	Simulation 2
Wind Speed (mph)	**Drift** (ft)	**Drift** (ft)
0	0	0
5	5,98.13	5,99.28

	Simulation 1	**Simulation 2**
Wind Speed (mph)	**Drift** (ft)	**Drift** (ft)
10	1,196.26	1,200.10
15	1,794.40	1,796.50
20	2,392.50	2,396.73

4.4.6.2.2 UPPER SECTION

Table 46: Alternate drift analysis of upper section at various wind speeds.

	Simulation 1	**Simulation 2**
Wind Speed (mph)	**Drift** (ft)	**Drift** (ft)
0	0	0
5	616.45	616.38
10	1,232.91	1,233.42
15	1,849.36	1,851.60
20	2,465.80	2,467.40

5 SAFETY

Safety is the most critical and necessary component in any and all activities, and especially the handling and construction of rockets and its hazardous counterparts. The Society of Aeronautics and Rocketry is dedicated to promoting the concept of space exploration through amateur rocketry, while ensuring our members are informed and safe during every process and step.

5.1 SAFETY OFFICER INFORMATION

See 3.1.7 Safety Officer for updated team safety officer contact information.

5.2 SAFETY OFFICER DUTIES & RESPONSIBILITIES

The safety officer will oversee ensuring the team and launch vehicle is complying with all NAR safety regulations. The following is the list of the Safety Officer's responsibilities:

1. Ensure all team members have read and understand the NAR and TRA safety regulations.
2. Provide a list of all hazards that may be included in the process of building the rocket and how they are mitigated, including MSDS, personal protective equipment requirements, and any other documents applicable.
3. Compile a binder that will have all safety related documents and other manuals about the launch vehicle.
4. Ensure compliance with all local, state, and federal laws.
5. Oversee the construction and testing of all related subsystems.
6. Ensure proper purchase, transportation, and handling of launch vehicle components.
7. Identify and mitigate any possible safety violations.
8. Identify safety violations and take appropriate action to mitigate the hazard.
9. Establish and brief the team on a safety plan for various environments, materials used, and testing.
10. Establish a risk matrix that determines the risk level of each hazard based off of the probability of the occurrence and the severity of the event. Ensure that this type of analysis is done for each possible hazard.
11. Enforce proper use of Personal Protective Equipment (PPE) during construction, ground tests, and test flights of the rocket.

5.3 NAR AND TRA SAFETY

5.3.1 PROCEDURES

The following launch procedure will be followed during each test launch. This procedure is designed to outline the responsibilities of the NAR/TRA personnel and the members of the team.

1. A Level II certified member and an NAR/TRA personnel will oversee any test launch of the vehicle and flight tests of the vehicle.
2. The launch site Range Safety Officer (RSO) will be responsible for ensuring proper safety measures are taken and for arming the launch system.
3. If the vehicle does not launch when the ignition button is pressed, then the RSO will remove the key and wait 90 seconds before approaching the rocket to investigate the issue. Only the Vehicle Team Lead, Project Manager and Safety Officer will be permitted to accompany the RSO in investigating the issue.
4. The RSO will ensure that no one is within 100 ft. of the rocket and the team will be behind the RSO during launch. The RSO will use a 10 second countdown before launch.
5. A certified member will be responsible for ensuring that the rocket is directed no more than 20 degrees from vertical and ensuring that the wind speed is no more than 20 mph. This individual will also ensure proper stand and ground conditions for launch including but not limited to launch rail length and cleared ground space. This member will ensure that the rocket is not launched at targets, into clouds, near other aircraft, nor take paths above civilians. Additionally, this individual will ensure that all FAA regulations are abided by.
6. Another certified member will ensure that flight tests are conducted at a certified NAR/TRA launch site.
7. The safety officer will ensure that the rocket is recovered properly according to TRA and NAR guidelines.

5.3.2 SAFETY CODES

SOAR conducts launches under both NAR[27] and TRA[28] codes and will abide by the appropriate high-power rocketry safety code requirements during all operations.

5.4 HAZARDOUS MATERIALS

5.4.1 LISTING OF HAZARDOUS MATERIALS

SOAR will maintain a list of all hazardous chemicals used on-site. The Safety Officer will ensure that material safety data sheets are requested and obtained from the supplier of any new product ordered by the SOAR. The Safety Officer will maintain a master listing of all hazardous materials and SDS for all materials.

---

[27] NAR Safety Code available at: http://www.nar.org/safety-information/model-rocket-safety-code/
[28] TRA Safety Code available at: http://www.tripoli.org/Portals/1/Docu-ments/Safety%20Code/HighPowerSafetyCode%20-%202017.pdf

5.4.2 LABELS

Material received by SOAR must have intact, legible labels. These labels must include the following:

- The name of the hazardous substance(s) in the container
- A hazard warning
- The name and address of the manufacturer or other responsible party

5.4.3 TRAINING

A Safety Officer will be appointed by SOAR's Executive Board will insure that all members at sites where hazardous materials are kept or used receive training on hazardous material handling. The training program will include the following:

- The location and availability of the SDS and files
- Methods and procedures that the employee may use to detect the presence or accidental release or spill of hazardous materials in the work area, including proper clean up
- Precautions and measures employees can take to protect themselves from the hazardous materials

Annual training will be conducted for all members who deal with hazardous materials. Each new member will be trained in the handling of hazardous materials at the possible opportunity. Training must be conducted for all members when any new chemical or hazardous material enters the work site. This training must occur before the chemical or hazardous material is used by any member. After each training session, the trainer will certify a roster of all participants. Included with the roster will be a list of all hazardous materials included in the training.

5.4.4 HEALTH, SAFETY, AND EMERGENCY PROCEDURES

The following information will be available at the work site, if requested or required:

- A list of all hazardous materials used on site
- Unusual health and environmental hazards (both air and water) that may result from the release of specific quantities of hazardous substances

5.5 SAFETY BRIEFING

5.5.1 HAZARD RECOGNITION

The team Safety Officer will orchestrate all potentially hazardous activities, as well as brief the members who may participate in such activities on proper safety procedures and ensuring that they are familiar with any personal protective equipment which must be worn during those activities. If a member fails to abide by the safety procedures, he/she will not be permitted to participate in the potentially hazardous activities. In addition to briefing the members on safety procedures, the team Safety Officer must remain in the immediate vicinity of the hazardous activity as it is occurring, to mitigate any potentially dangerous incidents and answer any safety questions which may arise.

5.5.2 ACCIDENT AVOIDANCE

It will be the duty of the team Safety Officer to verify, in advance, that procedures planned for testing or construction of materials by team members satisfy safety requirements. If the Safety Officer judges a planned procedure to be unsafe, said procedure will thus be revised or eliminated.

5.5.3 LAUNCH PROCEDURES

At the team meeting most closely preceding the launch, the Safety Officer will be given time to help the members review launch safety and precautionary measures. Topics discussed at this time include but are not limited to: laws and regulations mandated by the Federal Aviation Administration (FAA), the National Fire Protection Association (NFPA), and Florida State Statutes; prohibited launchpad activities and behaviors; maintaining safe distances; and safety procedures pertaining to any potentially hazardous chemicals which will be present during the launch. All team leaders must attend this briefing, and they are obliged to address the other members with any further safety concerns they are aware of that were not mentioned by the Safety Officer. At this time, launch procedures will be scrutinized, paying special attention to the parts involving caution.

5.6 TRAINING

Any activities involving an elevated level of risk will only be performed by trained individuals. Electronic records of these training are stored in Google Drive and readable by all members, however, only the Safety Officer or those designated as representatives of the Safety Officer will be permitted to modify the records. Printed copies of the records will be kept on-site where the activities are to be performed, however, the electronic records will take precedent when a conflict arises.

5.7 LEGAL COMPLIANCE

The Safety Officer and Project Manager have read all relevant laws and regulations that apply to this project to ensure compliance with these laws. As well, the team members will also be briefed on these laws as they apply to the project. The material reviewed includes:

5.7.1 FEDERAL AVIATION REGULATIONS (FARS)

- 14 CFR: Aeronautics and Space, Chapter 1, Subchapter F, Part 101, Subpart C: Amateur Rockets[29]

[29] Available at: https://www.law.cornell.edu/cfr/text/14/part-101/subpart-C

- 27 CFR: Part 55: Commerce in Explosives[30]
- NFPA 1127 "Code for High Power Rocket Motors"[31]

5.7.2 STATE OF FLORIDA LAWS AND REGULATIONS

- Florida Statute: Title XXV: Aviation, Chapter 331: Aviation and Aerospace Facilities and Commerce[32]
- Florida Statute: Title XXXIII: Regulation of Trade, Commerce, Investments, and Solicitations, Chapter 552: Manufacture, Distribution, and Use of Explosives [33]

5.8 PURCHASE, TRANSPORTATION AND STORAGE OF MOTOR

The motor will be purchased and stored by one of our organization's mentors. This person is certified for the purchase of high powered rocket propellant and well versed in the storage and safety procedures of high explosive motors. The propellant will be stored in an off-campus garage, where several other rocket components have been stored carefully. There will be a clear indication that there is propellant in the room, by large lettering on the magazine and yellow/black caution tape. There will also be a clear indication to keep away, in addition to warning about fire in the area. Our mentor shall maintain primary access to the propellant upon storage and shall prep it for transportation. It will be secured carefully within a vehicle, bound down to avoid unnecessary motion and without the risk of any other object resting or falling on top of it.

5.9 STATEMENT OF COMPLIANCE

All team members understand and will abide by the following safety regulations from the competition handbook:

1.6.1. 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.

1.6.2. 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.

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

5.10 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Through past years of rocket design and competition, as well as efforts that are currently underway, SOAR has developed the risk matrices in this section that shall continue to grow and be edited by the safety officer throughout the project.

---

[30] Available at: https://www.law.cornell.edu/cfr/text/27/part-555

[31] Available at: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1127

[32] Available at: https://www.flsenate.gov/Laws/Statutes/2018/Chapter331

[33] Available at: https://www.flsenate.gov/Laws/Statutes/2017/Chapter552

5.10.1 RISK LEVEL DEFINITIONS

5.10.1.1 SEVERITY

The severity of each potential risk is determined by comparing the possible outcome to criteria based on human injury, vehicle and payload equipment damage, and damage to environment. Severity is based on a 1 to 3 scale, with 1 being the most severe. The severity criteria are provided below.

Table 47: Risk severity level definitions.

Description	Personnel Safety and Health	Facility or Equipment	Range Safety	Project Plan	Environmental
– 1 – Catastrophic	Loss of life or a permanent disabling injury.	Loss of facility, systems or associated hardware that result in being unable to complete all mission objectives.	Operations not permitted by the RSO and NFPA 1127 prior to launch. Mission unable to proceed.	Delay of mission critical components or budget overruns that result in project termination.	Irreversible severe environmental damage that violates law and regulation.
– 2 – Critical	Severe injury or occupational related illness.	Major damage to facilities, systems, or equipment that result in partial mission failure.	Operations not permitted by the RSO and NFPA 1127 occur during launch. Mission suspended, or laws and regulations are violated.	Delay of mission critical components or budget overruns that compromise mission scope.	Reversible environmental damage causing a violation of law or regulation.
– 3 – Marginal	Minor injury or occupational related illness.	Minor damage to facilities, systems or equipment that will not compromise mission objectives.	Operations are permitted by the RSO and NFPA 1127, but hazards unrelated to flight hardware design occur during launch.	Minor delays of non-critical components or budget increase.	Mitigatable environmental damage without violation of law or regulations where restoration activities can be accomplished.

Description	Personnel Safety and Health	Facility or Equipment	Range Safety	Project Plan	Environmental
– 4 – Negligible	First aid injury or occupational-related illness.	Minimal damage to facility, systems, or equipment.	Operations are permitted by the RSO and NFPA 1127, and hazards unrelated to flight hardware design do not during launch.	Minimal or no delays of non-critical components or budget increase.	Minimal environmental damage not violating law or regulation.

5.10.1.2 PROBABILITY

The probability of each potential risk has been assigned a level between A and E, A being the most certain. The scale of probabilities is determined by analyzing the risks and estimating the possibility of the accident to occur. Table depicts the levels of probability for each risk.

Table 48: Risk probability levels and definitions.

Description	Qualitative Definition	Quantitative Definition	Letter
– A – Frequent	High likelihood to occur immediately or expected to be continuously experienced.	Prob. (P) > 90%	A
– B – Probable	Likely to occur or expected to occur frequently within time.	90% ≥ P > 50%	B
– C – Occasional	Expected to occur several times or occasionally within time.	50% ≥ P > 25%	C
– D – Remote	Unlikely to occur but can be reasonably expected to occur at some point within time.	25% ≥ P > 1%	D
– E – Improbable	Very unlikely to occur and an occurrence is not expected to be experienced within time.	1% ≥ P	E

5.10.2 RISK ASSESSMENT LEVELS

Each risk is finally assigned a risk assessment code (RAC) based upon a combination of the risk severity and probability. From the RAC, a color-coded risk level is assigned. These levels range from high (**red**) to minimal (**white**) and are assigned using Table 49 and Table 50.

Table 49: Risk assessment classification criteria.

Probability	Severity			
	– 1 – Catastrophic	– 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

Table 50: Risk assessment classifications definitions.

Level of Risk	Definition
High Risk	Highly Undesirable. Documented approval from the RSO, NASA SL officials, team faculty adviser, team mentor, team leads, and team safety officer.
Moderate Risk	Undesirable. Documented approval from team faculty adviser, team mentor, team leads, team safety officer, and appropriate sub-team lead.
Low Risk	Acceptable. Documented approval by the team leads and sub-team lead responsible for operating the facility or performing the operation.

Level of Risk	Definition
Minimal Risk	Acceptable. Documented approval not required, but an informal review by the sub-team lead directly responsible for operating the facility or performing the operation is highly recommended.

5.10.3 RISK MATRIX

The risk matrix in Table 51 encompasses all safety risks that the team may encounter during this project. Each risk has a Pre RAC value, which is the RAC prior to mitigation; and a Post RAC value, which is the RAC after mitigation. Post RAC values may only fall under Low or Medium risk level. The risk matrix is not sorted in any significant manner.

Table 51: Project risk matrix, created using FMEA format.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Chemical pollutants	Improper disposal of batteries or chemicals.	Impure soil and water can have negative effects on the environment that in turn, affect humans and animals, causing illness.	2E	Batteries and other chemicals will be disposed of properly in accordance with the MSDS sheets. Should a spill occur, proper measure are to be followed in accordance with the MSDS sheets and any EHS standards.	2E	Safety officer will oversee maintenance of MSDS and disposal of any chemicals, storing records of any actions thereof. Reference: 5.4 Hazardous Materials, 5.1 Safety Officer Information
Environmental	Spray painting.	The rocket will be painted.	Water contamination. Emissions to environment.	3D	All spray painting operations will be performed in a paint booth by trained individuals. This prevents any overspray from entering into the water system or the air. Additionally, when possible, painting will be conducted by trained professionals rather than SOAR members.	3E	Paint booth will be inspected by safety officer prior to use. Member training will be documented and reported. Reference: 5.1 Safety Officer Information, 5.6 Training

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Plastic and fiberglass waste material.	Plastic used in the production of electrical components and wiring, and fiberglass used in production of launch vehicle components.	Plastic or fiberglass material produced when shaving down or sanding components could harm animals if ingested by an animal. Plastic could find its way down a drain and into the water system.	**3D**	All plastic material will be disposed of in proper waste receptacles. When sanding or cutting fiberglass, vacuum dust collection equipment will be used.	**4E**	Safety officer will ensure that vacuum equipment is used and will inspect worksites after activities for the presence of any remaining waste particles. Reference: 5.1 Safety Officer Information
Environmental	Wire waste material.	Wire material used in the production of electrical components.	Sharp bits of wire being ingested by an animal if improperly disposed of.	**3D**	All wire material will be disposed of in proper waste receptacles.	**4E**	Disposal of waste materials will be overseen by the safety officer. Reference: 5.1 Safety Officer Information
Logistic	Parts fail or break.	Normal wear and tear. Improper installation. Improper handling.	Project delay. Damage to launch vehicle.	**2C**	When practicable, maintain suitable replacement parts on hand.	**2E**	Relevant team lead will sign off on every step of all launch procedures. This will ensure that parts are sufficiently inspected prior to launch. Reference: 5.11 Launch Operation Procedures

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Logistic	Not enough time for adequate testing.	Failure to create a precise timeline.	Imprecision in the launch vehicle design and less verification of design.	3C	Create a rigorous timeline and ensure everyone stays on schedule. Make due dates at least three days in advance for deliverables. Use shared calendar to keep all personnel apprised of deadlines. A more detailed schedule was created to make sure the team remains on track. Each task has a description and expected deliverables. Full-scale completion date moved earlier in the schedule to allow more testing. Alternate launch site (Bunnell) may be used if needed.	3E	Project manager will actively communicate with project teams to track progress and remind leads of upcoming deadlines. Reference: 8.2 Timeline, 3.1.4 Project Manager
Payload	The deployment system fails to operate.	Payload is stuck in airframe.	Payload cannot exit the vehicle, mission failure.	2D	The deployment system will be tested extensively with different variables.	2E	Deployment system ground testing and full-scale payload test launch. Reference: 7.1.2 Payload Testing

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Logistic	Parts ordered late or delayed in shipping.	Long shipping times and delays, failure to order parts in timely fashion.	Project schedule delayed. Selected functions unavailable.	2C	Shared calendar will be used to keep all personnel apprised of deadlines. Reminder notifications will be sent to technical leads well in advance of deadlines. When possible, suitable substitute parts will be maintained on hand. Finance managers will be recruited and trained to track budget and parts ordering.	2E	Project manager will actively communicate with project teams to track progress and remind leads of upcoming deadlines. Financial officer will track progress of purchases and updating the purchasing database, so that all team leads are aware of purchase statuses. Reference: 8.2 Timeline, 3.1.4 Project Manager, 8.1 Budget
Pad	Unstable launch platform.	Uneven terrain or loose components.	If the launch pad is unstable while the rocket is leaving the pad, the rocket's path will be unpredictable.	2E	Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR. Ensure that the launch pad is stable and secure prior to launch.	3E	Launch procedures will be followed carefully, and vehicle team lead will be responsible for signing each step. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Pad	Unleveled launch platform.	Uneven terrain or improperly leveled launch tower.	The launch tower could tip over during launch, making the rocket's trajectory unpredictable.	1E	Inspect launch pad prior to launch to confirm level. Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR.	1E	Launch procedures will be followed carefully, and vehicle team lead will be responsible for signing each step. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead
Pad	Rocket gets caught in launch tower or experiences high friction forces.	Misalignment of launch tower joints. Deflection of launch platform rails. Friction between guide rails and rocket.	Rocket may not exit the launch tower with a sufficient exit velocity or may be damaged on exit.	2E	During setup, the launch tower will be inspected for a good fit to the rocket. The launch vehicle will be tested on the launch rail. If any resistance is noted, adjustments will be made to the launch tower, allowing the rocket to freely move through the tower.	2E	Launch procedures will be followed carefully, and vehicle team lead will be responsible for signing each step. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Pad	Sharp edges on the launch pad.	Manufacturing processes.	Minor cuts or scrapes to personnel working with, around, and transporting the launch tower.	3D	Sharp edges of the launch pad will be filed down and de- burred if possible. If not possible, personnel working with launch tower will be notified of hazards.	4E	Launch procedures will be followed carefully, and vehicle team lead will be responsible for signing each step. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead
Pad	Pivot point bearings seize.	Load is larger than specifications. Debris enters bearings.	Launch platform will experience higher resistance to motion causing a potential hindrance the vehicle raising.	2D	Bearings will be sized based on expected loads with a minimum factor of safety. The launch platform will be cleaned following each launch and will be cleaned prior to each launch. Proper lubrication will be applied to any point expected to receive friction.	2E	Launch procedures will be followed carefully, and vehicle team lead will be responsible for signing each step. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Payload	Failure of on board electronics	Overheating from compacted space, direct sunlight.	Payload cannot operate properly, mission failure.	2D	Various ventilation holes will be put around payload body but will have filters to keep dirt and other debris out.	4E	Payload team lead will inspect payload prior to launch, using pre-launch inspection checklist (to be developed before payload launch). Reference: 3.1.6 Payload Team Lead
Payload	Deployment system accidental operation during flight.	G-forces from flight and weight from the payload stress the system enough to break it, causing it to "deploy" early and come out of the rocket.	Mission failure. Possible damage to launch vehicle.	1D	Extensive testing will be performed prior to lunch. Strong solenoids will be used.	3E	Payload team lead will inspect payload prior to launch, using pre-launch inspection checklist (to be developed before payload launch). Reference: 3.1.6 Payload Team Lead
Recovery	Parachute deployment failure.	Altimeter failure. Electronics failure. Parachutes snag on shock cord.	Parachute deployment failure. Sections fail to separate. Damage to the launch vehicle.	2D	Shroud lines and shock cord will be measured for appropriate lengths. Altimeter and electronics check will be conducted with checklist several hours prior to launch. Deployment bags will be secured low on shroud lines to prevent entanglement. Main parachutes will deploy at different altitudes.	2E	Subscale test launch resulted in successful recovery deployment with no entanglement. Full-scale testing will be conducted. Reference: 7.1.1 Launch Vehicle Testing

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Recovery	Sections fail to separate at apogee or at other designated altitudes.	Black powder charges fail or are inadequate. Shear pins stick. Launcher mechanics obstruct separation. Altimeter programming incorrect.	Parachute deployment failure. Sections fail to separate. Damage to the launch vehicle.	2D	Correct amount of black powder needed for each blast charge will be calculated. Black powder will be measured using scale. Altimeter and electronics check will be conducted with checklist several hours prior to launch. Couplings between components will be sanded to prevent components from sticking together. Fittings will be tested prior to launch to ensure that no components are sticking together. In the event that the rocket does become ballistic, all individuals at the launch field will be notified immediately.	2E	Subscale deployment and launch tests verified that the amount of black powder is adequate. Full-scale deployment tests will be completed prior to launch and recorded for verification. Reference: 7.1.1 Launch Vehicle Testing

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Recovery	Sections separate prematurely.	Construction error. Premature firing of black powder due to altimeter failure or incorrect programming.	Structural failure, loss of payload, target altitude not reached.	1D	Use multiple shear pins to prevent drag separation. Verify altimeter altitudes. Use launch preparation checklist when preparing for launch.	1E	In subscale test launch, all sections successfully separated at designated altitudes. Altimeters performed correctly. Full-scale deployment and flight tests will verify continued success on full-scale vehicle. Reference: 7.1.1 Launch Vehicle Testing
Recovery	Altimeter or e-match failure.	Parachutes will not deploy.	Rocket follows ballistic path, becoming unsafe.	2E	Dual altimeters and e-matches are included in systems for redundancy to eliminate this failure mode. E-matches will be tested for continuity prior to installation. Should all altimeters or e-matches fail, the recovery system will not deploy and the rocket will become ballistic, becoming unsafe. All personnel at the launch field will be notified immediately.	2E	In subscale ground testing, e-matches successfully ignited separation charges. In subscale test launch, primary and backup altimeters and black powder charges performed successfully. Full-scale ground and launch testing to be conducted. Reference: 7.1.1 Launch Vehicle Testing

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Recovery	Rocket descends too quickly.	Parachute is improperly sized.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2E	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Extensive ground testing was performed to verify the coefficient of drag is approximately that which was used during analysis.	2E	Design calculations conducted prior to launch verify that the no section will have excessive energy upon landing. Flight tests will further verify accuracy of calculations. Reference: 4.4.4 Kinetic Energy at Landing, 7.1.1 Launch Vehicle Testing
Recovery	Rocket descends too slowly.	Parachute is improperly sized.	The rocket will drift farther than intended, potentially facing damaging environmental obstacles.	3E	The parachutes have each been carefully selected and designed to safely recover its section of the rocket. Extensive ground testing was performed to verify the coefficient of drag is approximately that which was used during analysis.	3E	Design calculations conducted prior to launch verify that the no section will drift outside the allowable zone. Flight tests will further verify accuracy of calculations. Reference: 4.4.6 Drift, 7.1.1 Launch Vehicle Testing

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Recovery	Parachute has a tear or ripped seam.	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2E	Through careful inspection prior to packing each parachute, this failure mode will be eliminated. One spare large parachute will be on hand. Deployment bags will be used to prevent damage from black powder charges. In the incident that a small tear occurs during flight, the parachute will not completely fail.	2E	During subscale launch, all parachutes performed without damage. Full-scale deployment and launch testing to be completed. Reference: 4.2.6 Post-Launch Vehicle Condition, 7.1.1 Launch Vehicle Testing
Recovery	Recovery system separates from the rocket.	Bulkhead becomes dislodged. Parachute disconnects from the U-bolt.	Parachute completely separates from the component, causing the rocket to become ballistic.	1E	The cables and bulkhead connecting the recovery system to each segment of the rocket are designed to withstand expected loads with an acceptable factor of safety. Launch preparation checklist will be used for launch preparation. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.	1E	During subscale test launch, all parachutes remained attached to components and all U-bolts and bulkheads performed sufficiently so that all sections landed safely. Full-scale testing to be conducted. Reference: 4.2.6 Post-Launch Vehicle Condition, 7.1.1 Launch Vehicle Testing

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Recovery	Lines in parachutes become tangled during deployment.	Parachute becomes unstable or does not open. Parachute cord becomes caught in landing device.	The rocket has a potential to become ballistic, resulting in damage to the rocket upon impact.	1E	Deployment bags will be used between parachutes to avoid entaglement. Ground testing will be performed to ensure that the packing method will prevent tangling during deployment prior to test flights. Parachutes will be deployed at different altitudes.	1E	During subscale launch tests parachute lines did not become entangled. Full-scale testing will be conducted. Parachute-folding manuals will be followed carefully, according to pre-flight checklists. Reference: 4.2.6 Post-Launch Vehicle Condition, 7.1.1 Launch Vehicle Testing, 5.11 Launch Operation Procedures
Recovery	Parachute does not inflate.	Parachute lines become entangled.	Parachute does not generate enough drag.	2E	Parachute lines will be carefully folded in accordance with checklist. Nomex covers will be secured at lower end of shroud lines.	2E	During subscale launch tests parachute lines did not become entangled. Full-scale testing will be conducted. Parachute-folding manuals will be followed carefully, according to pre-flight checklists. Reference: 4.2.6 Post-Launch Vehicle Condition, 7.1.1 Launch Vehicle Testing, 5.11 Launch Operation Procedures
Shop	Using power tools and hand tools such as blades, saws, drills, etc.	Improper use of PPE. Improper training on the use of equipment.	Mild to severe cuts or burns to personnel. Damage to rocket or components of the rocket. Damage to equipment	3C	Individuals will be trained on the tool being used. Those not trained will not attempt to learn on their own and will find a trained individual to instruct them. Proper PPE must be worn at all times. Shavings and debris will be swept or vacuumed up to avoid cuts from debris.	4D	Training will be conducted and carefully documented. Team leads and safety officer will not allow untrained individuals to use tools. Reference: 3.1 Primary Leadership, 5.6 Training

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Shop	Sanding or grinding materials.	Improper use of PPE. Improper training on the use of equipment.	Mild to severe rash. Irritated eyes, nose or throat with the potential to aggravate asthma. Mild to severe cuts or burns from a Dremel tool and sanding wheel.	**2C**	Long sleeves will be worn at all times when sanding or grinding materials. Proper PPE will be utilized such as safety glasses and dust masks with the appropriate filtration required. Individuals will be trained on the tool being used. Those not trained will not attempt to learn on their own and will find a trained individual to instruct them.	**4E**	Training will be conducted and carefully documented. Team leads and safety officer will not allow untrained individuals to use tools. Reference: 3.1 Primary Leadership, 5.6 Training
Shop	Damage to equipment while soldering.	Soldering iron is too hot. Prolonged contact with heated iron.	The equipment could become unusable. If parts of the payload circuit become damaged, they could become inoperative.	**3C**	The temperature on the soldering iron will be controlled and set to a level that will not damage components. For temperature sensitive components sockets will be used to solder ICs to. Only personnel trained to use the soldering iron will operate it.	**4D**	Training will be conducted and carefully documented. Team leads and safety officer will not allow untrained individuals to use tools. Reference: 3.1 Primary Leadership, 5.6 Training

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Shop	Working with chemical components resulting in mild to severe chemical burns on skin or eyes, lung damage due to inhalation of toxic fumes, or chemical spills.	Chemical splash. Chemical fumes.	Mild to severe burns on skin or eyes. Lung damage or asthma aggravation due ot inhalation.	2C	MSDS documents will be readily available at all times and will be thoroughly reviewed prior to working with any chemical. All chemical containers will be marked to identify appropriate precautions that need to be taken. Chemicals will be maintained in a designated area. Proper PPE will be worn at all times when handling chemicals. Personnel involved in motor making will complete the university's Lab and Research Safety Course. All other individuals will be properly trained on handling common chemicals used in constructing the launch vehicles.	3E	Training will be conducted and carefully documented. Team leads and safety officer will not allow untrained individuals to use tools. Reference: 3.1 Primary Leadership, 5.6 Training, 5.4 Hazardous Materials

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Shop	Dangerous fumes while soldering.	Use of leaded solder can produce toxic fumes.	Team members become sick due to inhalation of toxic fumes. Irritation could also occur.	**3D**	The team will use well ventilated areas while soldering. Fans will be used during soldering. Team members will be informed of appropriate soldering techniques.	**4E**	Training will be conducted and carefully documented. Team leads and safety officer will not allow untrained individuals to use tools. Reference: 3.1 Primary Leadership, 5.6 Training
Shop	Overcurrent from power source while testing.	Failure to correctly regulate power to circuits during testing.	Team members could suffer electrical shocks which could cause burns or heart arrhythmia.	**1D**	The circuits will be analyzed before they are powered to ensure they don't pull too much power. Power supplies will also be set to the correct levels. Team members will use documentation and checklists when working with electrical equipment.	**2E**	Training will be conducted and carefully documented. Team leads and safety officer will not allow untrained individuals to use tools. When possible, an electrical engineering specialist will oversee electrical operations. Reference: 3.1 Primary Leadership, 5.6 Training

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Shop	Use of white lithium grease.	Use in installing motor and on ball screws.	Irritation to skin and eyes. Respiratory irritation.	3D	Nitrile gloves and safety glasses are to be worn when applying grease. When applying grease, it should be done in a well ventilated area to avoid inhaling fumes. All individuals will be properly trained on handling common chemicals used in constructing the launch vehicles.	4E	Training will be conducted and carefully documented. Team leads and safety officer will not allow untrained individuals to use tools. Reference: 3.1 Primary Leadership, 5.6 Training
Shop	Metal shards.	Using equipment to machine metal parts.	Metal splinters in skin or eyes.	1D	Team members will wear long sleeves and safety glasses whenever working with metal parts. Individuals will be trained on the tool being used. Those not trained will not attempt to learn on their own and will find a trained individual to instruct them.	4D	Training will be conducted and carefully documented. Team leads and safety officer will not allow untrained individuals to use tools, and will ensure proper air filtering equipment is used. Reference: 3.1 Primary Leadership, 5.6 Training

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Stability	Motor CATO (catastrophic failure) (on launch pad or while in flight).	Improper motor manufacturing. Injury to personnel.	Launch vehicle is destroyed and motor has failed. Moderate explosion.	1D	Ensure nozzle is unimpeded during assembly. Inspect motor for cracks and voids prior to launch. Ensure all team members are a safe distance away from the launch pad upon ignition of the rocket. Wait a specified amount of time before approaching the pad after a catastrophe. All fires will be extinguished before it is safe to approach the pad.	2E	Pre-flight checklist will be followed and signed by vehicle team lead. Motor preparation manual will be followed carefully. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead
Stability	Motor Retention Failure.	The drogue parachute ejection charge applied a sufficient force to push the motor out the back of the launch vehicle.	The motor is separated from the launch vehicle without a parachute or any tracking devices.	1D	Ensure that the centering rings have been thoroughly epoxied to both the motor mount and to the inner walls of the airframe. Ensure that motor is properly secured using motor mount adapter and retainer ring.	1E	During subscale launch test, drogue parachute charge was not sufficient to eject motor. Motor mount adapter and retainer successfully ring prevented motor from ejecting. Motor preparation checklist will be utilized to inspect motor prior to launch. Manufacturer's instructions will be followed in assembling the motor. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead, 4.2.6 Post-Launch Vehicle Condition

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Stability	Loss of stability during flight.	Damage to fins or launch vehicle body, poor construction.	Failure to reach target altitude, destruction of vehicle.	1D	The CG of the vehicle will be measured prior to launch. Launch vehicle will be inspected prior to launch. Proper storage and transportation procedures will be followed.	2E	Launch operations checklist will be followed and signed by vehicle team lead before, during, and after flight. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead
Stability	Change in expected mass distribution during flight.	Payload shifts during flight, foreign debris is deposited into the PEM along with the payload.	Decrease in stability of the launch vehicle, failure to reach target altitude, destruction of vehicle.	1D	The payload will be centered inside the launch vehicle and secured. Inspection will be conducted to ensure parachutes and shock cord do not move freely in the airframe.	2E	Launch operations checklist will be followed and signed by vehicle team lead before, during, and after flight. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead.
Stability	Motor retention failure.	Design of retention fails. Retention assembly failure.	Motor falls out of booster section while propelling body forward and launch vehicle fails to achieve 5280 ft altitude.	2D	Retention rings will be machined using designs from SolidWorks to ensure proper dimensions. Robust material such as fiberglass will be used to ensure the integrity of the design.	2E	During subscale launch test, drogue parachute charge was not sufficient to eject motor. Motor mount adapter and retainer successfully ring prevented motor from ejecting. Motor preparation checklist will be utilized to inspect motor prior to launch. Manufacturer's instructions will be followed in assembling the motor. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead, 4.2.6 Post-Launch Vehicle Condition

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Stability	Mass increase during construction.	Unplanned addition of components or building materials.	Launch vehicle does not fly to correct altitude. All sections land with high kinetic energy. Possible minor damage to rocket body and/or fins.	2C	Record will be maintained of mass changes. Launch vehicle simulations will be repeated for each mass change. Additional launch vehicle simulations will be performed at plus 5% of calculated mass. Subscale and full-scale launches will be performed with accurate mass.	3E	Subscale flight was stable and surpassed projected altitude significantly. Full-scale testing will be performed. Mass estimates will be continuously updated throughout the fabrication process as actual flight components are obtained. This will be verified by the vehicle team lead. Reference: 7.1.1 Launch Vehicle Testing, 3.1.5 Vehicle Team Lead, 4.2.6 Post-Launch Vehicle Condition
Stability	Motor fails to ignite.	Faulty motor. Delayed ignition. Faulty e-match. Disconnected e-match.	Rocket will not launch. Rocket fires at an unexpected time.	1D	Checklists and appropriate supervision will be used when assembling. NAR safety code will be followed, and personnel will wait a minimum of 60 seconds before approaching rocket. If there is no activity after 60 seconds, safety officer will check the ignition system for a lost connection or a bad igniter.	1E	Igniter Installation checklist will be used when installing igniter and signed by vehicle team lead. During subscale test launch, igniter performed as expected. Reference: 7.1.1 Launch Vehicle Testing, 3.1.5 Vehicle Team Lead, 4.2.6 Post-Launch Vehicle Condition

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Stability	Rocket doesn't reach high enough velocity before leaving the launch pad.	Rocket is too heavy. Motor impulse is too low. High friction coefficient between rocket and launch tower.	Unstable launch.	1E	Too low of a velocity will result in an unstable launch. Simulations have been and will continue to be run to verify the motor selection provides the necessary exit velocity. Ful scale testing will be conducted to ensure launch stability. Should the failure mode still occur, the issue should be further examined to determine if the cause was due to a faulty motor or in the booster needs to be redesigned.	1E	Subscale testing resulted in sufficient velocity. Motor and booster performed as expected. Simulations predict full-scale vehicle will reach required velocity on launch. Full-scale testing will verify. Reference: 7.1.1 Launch Vehicle Testing, 3.1.5 Vehicle Team Lead, 4.2.5 Flight Review, 4.4.1.1 Simulated Flight Characteristics

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Stability	Internal bulkheads fail during flight.	Forces encountered are greater than the bulkheads can support.	Internal components supported by the bulkheads will no longer be secure. Parachutes attached to bulkheads will be ineffective.	2E	The bulkheads have been designed to withstand the force from takeoff with an acceptable factor of safety. Additional epoxy will be applied to ensure security and carbon fiber shreds will be added where appropriate. Electrical components will be mounted using fasteners that will not shear under the forces seen during the course of the flight. Full-scale testing will be conducted and bulkheads inspected after each flight.	2E	During subscale flight, all bulkheads performed as expected. Full-scale testing will be conducted. Finite element analysis has been performed on all recovery hardware to a factor of safety of greater than 3.0. Reference: 7.1.1 Launch Vehicle Testing, 4.3.5 Attachment Hardware, 4.2.6 Post-Launch Vehicle Condition
Stability	Motor retainer falls off.	Joint did not have proper preload or thread engagements.	Motor casing and spent motor fall out of rocket when the main parachute opens.	2E	Checklists and appropriate supervision will be used when assembling.	2E	Standard commercial motor retainer will be used and manufacturer's instructions will be followed per the launch operations checklist. Reference: 3.1.5 Vehicle Team Lead, 4.2.6 Post-Launch Vehicle Condition

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Low cloud cover.	N/A	Unable to test entire system.	3C	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system.	3E	Weather conditions will be tracked during launch week and on launch day. If vehicle team lead, safety officer, or RSO recommend cancelling launch, launch will be cancelled or postponed. Reference: 3 Team Personnel
Environmental	Rain.	N/A	Unable to launch. Damage electrical components and systems in the rocket.	3C	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. Have a plan to place electrical components in water tight bags. Have a location prepared to store the entire rocket to prevent water damage. Electronics on the ground station are all stored in water tight control boxes to seal out any moisture.	3E	Weather conditions will be tracked during launch week and on launch day. If vehicle team lead, safety officer, or RSO recommend cancelling launch, launch will be cancelled or postponed. Reference: 3 Team Personnel

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Thunderstorms.	N/A	Damage due to electrical shock on system.	2D	When planning test launches, the forecast should be monitored in order to launch on a day where the weather does not prohibit launching or testing the entire system. Should a storm roll in, the entire system should be promptly packed and removed from the premise to avoid having a large metal object exposed during a thunderstorm. In the event that the system cannot be removed, personnel are not to approach the launch pad during a thunderstorm.	2E	Weather conditions will be tracked during launch week and on launch day. If vehicle team lead, safety officer, or RSO recommend cancelling launch, launch will be cancelled or postponed. Reference: 3 Team Personnel

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	High winds.	N/A	Have to launch at high angle, reducing altitude achieved. Increased drifting. Unable to launch.	2D	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. If high winds are present but allowable for launch, the time of launch should be planned for the time of day with the lowest winds.	2E	Weather conditions will be tracked during launch week and on launch day. If vehicle team lead, safety officer, or RSO recommend cancelling launch, or winds exceed 20 mph, launch will be cancelled or postponed. Reference: 3 Team Personnel, 5.3 NAR and TRA Safety, 4.4.6 Drift
Environmental	Trees.	N/A	Damage to rocket or parachutes. Irretrievable rocket components.	2D	Launching with high winds should be avoided in order to avoid drifting long distances. Drift calculations have been computed, so we can estimate how far each component of the rocket will drift with a particular wind velocity. The rocket should not be launched if trees are within the estimated drift radius.	2E	Vehicle team lead and calculations specialist will verify drift calculations prior to launch. GPS will track during launch and record location. Reference: 4.4.6 Drift, 3.1.5 Vehicle Team Lead, 4.3.4.1.2 GPS and Data Streaming System

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Swampy ground.	N/A	Irretrievable rocket components.	2D	With the potential of the ground being extremely soft at local launch sites and in Huntsville, the rocket should not be launched if there is swampy ground within the predicted drift radius that would prevent the team from retrieving a component of the rocket.	2E	Vehicle team lead and calculations specialist will verify drift calculations prior to launch. GPS will track during launch and record location. Reference: 4.4.6 Drift, 3.1.5 Vehicle Team Lead, 4.3.4.1.2 GPS and Data Streaming System
Environmental	Ponds, creeks, and other bodies of water.	N/A	Loss of rocket components. Damaged electronics.	2D	Launching with high winds should be avoided in order to avoid drifting long distances. The rocket should not be launched if a body of water is within the estimated drift radius. Should the rocket be submerged in water, it should be retrieved immediately and any electrical components salvaged. Electrical components are to be tested for complete functionality prior to reuse.	2E	Vehicle team lead and calculations specialist will verify drift calculations prior to launch. GPS will track during launch and record location. Reference: 4.4.6 Drift, 3.1.5 Vehicle Team Lead, 4.3.4.1.2 GPS and Data Streaming System

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Extremely cold temperatures.	Batteries discharge quicker than normal. Shrinking of fiberglass.	Completely discharged batteries will cause electrical failures and fail to set off black powder charges, inducing critical events. Rocket will not separate as easily.	3D	Batteries will be checked for charge prior to launch to ensure there is enough charge to power the flight. Should the flight be delayed, batteries will should be rechecked and replaced as necessary. If the temperatures are below normal launch temperature, black powder charges should be tested to ensure that the pressurization is enough to separate the rocket. If this test is successful, the rocket should be safe to launch.	3E	Weather conditions will be tracked during launch week and on launch day. If vehicle team lead, safety officer, or RSO recommend cancelling launch, launch will be cancelled or postponed. Batteries will be tested and signed off by payload and vehicle team leads, per launch operations checklists. Reference: 3 Team Personnel, 5.11 Launch Operation Procedures, 6.3 Electrical Design, 4.3.4 Avionics
Environmental	Humidity.	N/A	Motors or black powder charges become saturated and don't ignite.	2D	Motors and black powder should be stored in an water resistant container.	2E	Vehicle team lead will sign off on launch operations checklist, which requires moisture-proof transportation containers. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	UV exposure.	Rocket left exposed to sun for long periods of time.	Possibly weakening materials or adhesives.	3D	Rocket should not be exposed to sun for long periods of time. If the rocket must be worked on for long periods of time, shelter should be sought.	3E	Vehicle team lead will ensure that all fabrication is performed in enclosed, air-conditioned workshop. Vehicle will be inspected per launch operations procedures. Reference: 5.11 Launch Operation Procedures, 3.1.5 Vehicle Team Lead
Payload	Electrical failure.	Electrical connection fails.	Rover cannot operate properly, mission failure.	2D	Every every major connection will be soldered. Thorough impact testing will be conducted, proving that the wiring can hold up to a launch and a harder-than-projected landing. Pre-launch checklist will be used and electrical connections checked prior to earch launch.	3E	Use Payload checklist when preparing for launch.
Payload	Signal connection between rover and ground station fails.	Signal not strong enough. Distance to rocket from ground station too far.	Rover cannot operate properly, mission failure.	2C	External antenna will be used, which has several miles of range. Extensive testing will be conducted to determine maximum range. Ensure batteries are fully charged.	3E	Use Payload checklist when preparing for launch. Test signal strenght prior to launch.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Payload	Rover becomes stuck on ground obstacle.	Uneven terrain. Low ground clearance.	Rover cannot operate properly, mission failure.	2C	Sensors will be installed to determine if rover is successfully moving forward and will trigger redirection if not.	3E	Payload team lead will inspect payload prior to launch, using pre-launch inspection checklist (to be developed before payload launch). Reference: 3.1.6 Payload Team Lead
PDLS	Electrical interference with avionics subsystem.	PDLS electronics negatively interact with recovery electronics.	Main parachute fails to deploy. Launch vehicle becomes ballistic.	2D	PDLS system is completely electrically isolated from recovery subsystem.	4E	Vehicle design. Subscale launch was successful, and all electronics performed as expected. Full-scale testing to be completed. Reference: 4.1.3.2.3 Payload Descent Levelling Subsystem (PDLS), 4.2.1.6 Subscale Payload Descent Leveling Subsystem (PDLS-S), 7.1.1.3 Payload Descent Leveling Subsystem Tests, 7.1.1.2 Tender Descender Stress Test
PDLS	Damage to recovery subsystem components.	PDLS deployment charge burns or otherwise damages shock cord or recovery attachment hardware.	Recovery system fails. Launch vehicle becomes ballistic.	2D	PDLS deployment charges will be kept to minimal size and contained within separate Nomex enclosure.	4E	Vehicle design. Subscale launch was successful, and all electronics performed as expected. Full-scale testing to be completed. Reference: 4.1.3.2.3 Payload Descent Levelling Subsystem (PDLS), 4.2.1.6 Subscale Payload Descent Leveling Subsystem (PDLS-S), 7.1.1.2 Tender Descender Stress Test
PDLS	Damage to rocket at PDLS wire exit points.	PDLS wire abrades on fiberglass at airframe exit points.	Wear and damage to airframe.	3D	Wire will be wrapped in non-abrasive material at exit points.	4E	Vehicle design. Subscale launch was successful, and all electronics performed as expected. Full-scale testing to be completed. Reference: 4.1.3.2.3 Payload Descent Levelling Subsystem (PDLS), 4.2.1.6 Subscale Payload Descent Leveling Subsystem (PDLS-S), 7.1.1.3 Payload Descent Leveling Subsystem Tests,

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
PDLS	Damage to rocket at PDLS wire attachment point.	PDLS wire will not stretch to absorb shock force.	Damage to airframe.	3D	Extensive testing of attachment mechanism; sufficient distribution of force to prevent damage.	4E	Vehicle design. Subscale launch was successful, and all electronics performed as expected. Full-scale testing to be completed. Reference: 4.1.3.2.3 Payload Descent Levelling Subsystem (PDLS), 4.2.1.6 Subscale Payload Descent Leveling Subsystem (PDLS-S), 7.1.1.3 Payload Descent Leveling Subsystem Tests,
PDLS	Failure of PDLS wire or small Tender Descender quick links.	Improperly sized hardware or excessive deployment shock force.	PDLS system fails and rocket descends vertically, as normal.	3D	Engineering analysis of hardware and wire; drop testing prior to launch.	4E	Vehicle design. Subscale launch was successful, and all electronics performed as expected. Full-scale testing to be completed. Reference: 4.1.3.2.3 Payload Descent Levelling Subsystem (PDLS), 4.2.1.6 Subscale Payload Descent Leveling Subsystem (PDLS-S), 7.1.1.3 Payload Descent Leveling Subsystem Tests, 7.1.1.2 Tender Descender Stress Test
DAAS	Fins cause rocket to become unstable.	The center of pressure and center of mass are too close together.	Launch vehicle becomes unstable and flight path unpredictable.	1D	Make fins out of lightweight material to make sure safety caliper is between 1 and 3	4E	Vehicle design and simulations verified by vehicle team lead and DAAS subteam lead. Verified by subscale and full-scale test launches. Reference: 3 Team Personnel, 4.1.3.2.1 Dynamic Apogee Adjustment Subsystem (DAAS), 4.4.2 Static Stability, 7.1.1.5 DAAS Test
DAAS	Fins get jammed.	Motor doesn't have enough torque.	Launch vehicle fails to reach correct apogee.	2D	Use lubricants on all rubbing surfaces to minimize friction.	4E	DAAS subteam lead will sign and verify preflight checklist. Also verified by subscale and full-scale test launches. Reference: 3 Team Personnel, 4.1.3.2.1 Dynamic Apogee Adjustment Subsystem (DAAS), 7.1.1.5 DAAS Test

5.11 LAUNCH OPERATION PROCEDURES

The procedures in this section will be brought to all launches and followed carefully every time.

5.11.1 CAUTION STATEMENTS

Warnings, cautions, and notes are used to emphasize important and critical instructions and are used for the following conditions. These caution statements will be used to emphasize crucial elements of launch operations procedures.

5.11.1.1 WARNING

Warning

An operating procedure, practice, etc., which, if not correctly followed, could result in personal injury or loss of life.

Warnings will be shown in red and appear just prior to the step, procedure, or equipment to which they apply, the warning will include possible consequences of failure to heed warning and list any appropriate personal protective equipment required.

5.11.1.2 CAUTION

Caution

An operating procedure, practice, etc., which, if not strictly observed, could result in damage to or destruction of equipment.

Cautions will be typed in orange and appear just prior to the step, procedure, or equipment to which they apply, the caution will include possible consequences of failure to heed caution.

5.11.1.3 NOTE

Note

An operating procedure, condition, etc., which is essential to highlight.

Notes will be typed in bold black and appear just prior to the step, procedure, or equipment to which they apply.

5.11.1.4 PPE REQUIRED

PPE Required

Denotes proper protective equipment that must be worn prior to initiating the following steps.

PPE Required notices will be typed in green and appear prior to the step, procedure, or equipment to which they apply.

5.11.2 FIELD PACKING LIST

All items in this packing list should be brought to every launch.

- Tools
  - ☐ Power drill and drill bits
  - ☐ Dremel tool with attachments
  - ☐ Sheet sander
  - ☐ Screwdrivers
  - ☐ Wire cutters/strippers
  - ☐ Scissors
  - ☐ Small funnel
  - ☐ 1-gram scoop
  - ☐ Pliers
  - ☐ Wrenches
  - ☐ PVC cutters
  - ☐ Launch operations binder with printed operations checklists and component manuals
- Parts
  - ☐ Vehicle components
  - ☐ Quick links
  - ☐ Motor casing
  - ☐ Motors (in water resistant container)
  - ☐ E-matches
  - ☐ Igniter (in water resistant container)
  - ☐ Parachutes
    - Main × 2
    - Drogue × 1
    - Fruity Chutes folding jig
  - ☐ Shock cords
  - ☐ Parachute deployment bags Nomex protectors
  - ☐ Spare parts toolkit (nuts, bolts, washers, etc.)
  - ☐ Shear pins (2-56, 4-40)
  - ☐ Motor retainer adapter
  - ☐ Batteries
- Consumables
  - ☐ Charge insulation (in fireproof, water resistant container)
  - ☐ Black powder (in fireproof, water resistant container)
  - ☐ Duct tape
  - ☐ Electrical tape
  - ☐ Sandpaper
  - ☐ Electrical wire
  - ☐ Silicone
  - ☐ Graphite powder
  - ☐ White lithium grease
  - ☐ Rail lubricator
  - ☐ Extra CPVC
  - ☐ Extra launch lug

5.11.3 GENERAL PRE-FLIGHT INSPECTION CHECKLIST

Table 52: Launch vehicle pre-flight inspection checklist.

Task	SO Verification
Airframe	
Inspect fins for damage and security	

Task	SO Verification
Inspect rocket body for dents, cracks, or missing parts	
Inspect bulkheads for cracked epoxy or epoxy separation from airframe tube	
Inspect motor retaining ring for security or cracked epoxy	
Clean all components of debris and carbon residue	
Recovery	
Inspect parachutes for holes and parachutes cords for abrasions or tears	
Fold all parachutes in accordance with parachute folding instructions[34, 35]	
Insert parachutes into deployment bags[36]	
Inspect shock cords for abrasion or tearing	
Inspect all quick links for operation, corrosion, or damage and replace if necessary	
Attach all quick links to respective shock cords using secure knots and duct tape if desired OR If quick links are already installed, inspect all quick links for attachment knot and/or tape security and condition	
Inspect all bulkhead U-bolts for security	

[34] Fruity Chutes Iris folding instructions available at:
https://fruitychutes.com/files/How_to_Fold_an_Iris_Chute_Pictorial_Guide.pdf
[35] SkyAngle Classic folding instructions available at:
http://www.b2rocketry.com/PDF%20files/Classic%20How%20to%20fold.pdf
[36] Fruity Chutes deployment bag instructions available at:
https://fruitychutes.com/help_for_parachutes/how_to_pack_a_deployment_bag.htm

Task	SO Verification
Test altimeters for operation and continuity	
Check altimeter programming for correct altitudes, using altimeter manuals[37]	
Prepare and test RTx connection, power on to begin collecting satellites[38]	
Electrical	
Check all batteries for full charge	
Check electrical connections for continuity and security	
PDLS	
Check cable for fraying, damage, or corrosion	
Check battery for full charge	
Check electrical connections for continuity and security	
Test altimeters for operation and continuity	
Check altimeter programming for correct altitudes[39]	
Check connection hardware: quick links and U-bolts	
DAAS	
Check battery for full charge	
Check electrical connections for continuity and security	

[37] Missile Works RRC3 manual available at: https://www.missileworks.com/app/download/965482691/RRC3+User+Manual+v1.60.pdf
[38] Missile Works RTx manual available at: https://www.missileworks.com/app/download/965465589/RTx+User+Manual.pdf
[39] Missile Works RRC2+ manual available at: https://www.missileworks.com/app/download/956770097/RRC2plus+User+Manual.pdf

Task	SO Verification
Payload	
Check battery for full charge	
Check electrical connections for continuity and security	

5.11.4 FINAL ASSEMBLY AND LAUNCH PROCEDURE CHECKLIST

Table 53: Final assembly and launch checklist.

Task	Notes	SO Verification
Recovery Preparation		
Warning: E-matches may ignite during test. **PPE Required**: Eye protection, latex gloves.		
Perform continuity check of all E-matches	Parachutes may fail to deploy. Mission failure.	
Recovery Preparation – Lower Avionics Bay		
Connect E-matches to altimeters	Ensure E-matches are dry. Parachutes may fail to deploy. Mission failure.	
Warning: Keep black powder away from flames or sparks, including potential electrical spark sources. E-matches may ignite during test. Black powder may ignite during preparation. Only required personnel should be present. **PPE Required**: Eye protection, gloves.		
Measure two portions of black powder and deposit in each of the CPVC tube inserts on lower section side of avionics bay.	Amount of charge to be determined during ground testing. Ensure black powder is dry. Insufficient charge will result in failure of separation or ejection. Parachutes may fail to deploy. Mission failure.	

Task	Notes	SO Verification
Pack insulation tightly on top of black powder and secure with pressure sensitive tape.	Ensure insulation is dry. Packing too loosely may result in insufficient force to separate or eject. Parachutes may fail to deploy. Mission failure.	
Measure two portions of black powder and deposit in each of the CPVC tube inserts on upper section side of avionics bay.	Amount of charge to be determined during ground testing. Ensure black powder is dry. Insufficient charge will result in failure of separation or ejection. Parachutes may fail to deploy. Mission failure.	
Pack insulation tightly on top of black powder and secure with pressure sensitive tape.	Ensure insulation is dry. Packing too loosely may result in insufficient force to separate or eject. Parachutes may fail to deploy. Mission failure.	
Recovery Preparation – Upper Avionics Bay		
Connect E-matches to altimeters	Ensure E-matches are dry. Parachutes may fail to deploy. Mission failure.	
Warning: Keep black powder away from flames or sparks, including potential electrical spark sources. **PPE Required**: Eye protection, gloves.		
Measure two portions of black powder and deposit in each of the CPVC tube inserts.	Amount of charge to be determined during ground testing. Ensure black powder is dry. Insufficient charge will result in failure of separation or ejection. Parachutes may fail to deploy. Mission failure.	

Task	Notes	SO Verification
Pack insulation tightly on top of black powder and secure with pressure sensitive tape.	Ensure insulation is dry. Packing too loosely may result in insufficient force to separate or eject. Parachutes may fail to deploy. Mission failure.	
Measure one portion of black powder and prepare Tender Descender in accordance with manufacturer instructions.	See Tender Descender manual.	
Caution: During assembly, ensure that all launch vehicle body sections fit snugly but not tightly. If fit is too tight, sand with fine grit sandpaper until fit is properly adjusted and apply a small amount of graphite powder if necessary.		
Lower Section		
Weave lower section drogue shock cord into deployment bag in accordance with manufacturer's instructions.		
Attach quick link to drogue parachute swivel.	Ensure parachute remains properly folded during this process.	
Attach quick link to U-bolt on lower section side of avionics bay.		
Close quick link locking gate securely.		
Completely insert booster section lower shock cord into lower section.		
Insert the drogue parachute into the lower section.	Ensure that Nomex protector completely covers parachute.	

Task	Notes	SO Verification
Slide avionics bay into lower section.	Ensure that shear pin holes are aligned.	
Insert shear pins in shear pin holes.	Number and type of shear pins to be determined during ground testing. Please reference ground test report.	
Weave lower section main shock cord into deployment bag in accordance with manufacturer's instructions.		
Secure quick link to U-bolt on upper side of altimeter.		
Close quick link locking gate securely.		
Secure quick link to swivel of lower section main parachute.		
Close quick link locking gate securely.		
Set aside lower section assembly.		
Upper Section		
Weave upper section main shock cord into deployment bag in accordance with manufacturer's instructions.		
Attach upper section shock cord quick link to U-bolt on upper avionics bay.		

Task	Notes	SO Verification
Close quick link locking gate securely.		
Slide the payload and payload avionics bay into the upper section of the airframe.	Ensure screw, air pressure, and access holes are aligned.	
Warning: Arming altimeters early significantly increases risk of black powder igniting prior to launch. Do not arm altimeters until launch vehicle is installed on the launch pad and non-required personnel have left the vicinity.		
Ensure arming switches are visible and accessible through access hole.		
Insert machine screws into designated holes to secure upper avionics bay to upper section of airframe.		
Nose Cone		
Calculate ballast needed based on wind and atmospheric conditions.		
Load ballast weights onto ballast sleds.		
Slide ballast sleds onto threaded rod in nose cone shoulder as needed.		
Secure ballast sleds to threaded rod with threaded nuts.		
Secure nose cone shoulder to nose cone with screws.		

Task	Notes	SO Verification
Attach quick link to U-bolt on nose cone.		
Attach nose cone quick link to swivel of upper section main parachute.		
Close quick link locking gate securely.		
Weave upper section main shock cord into deployment bag in accordance with manufacturer's instructions.		
Slide upper section main parachute and shock cord into the upper section.	Ensure parachute remains properly folded and shroud lines are unencumbered. Ensure Nomex protector completely covers parachute.	
Slide nose cone into upper section.	Ensure shear pin holes are aligned.	
Insert shear pins in shear pin holes.	Number and type of shear pins to be determined during ground testing. Please reference ground test report.	
Retrieve lower airframe assembly.		
Weave upper section main shock cord into deployment bag in accordance with manufacturer's instructions.		

Task	Notes	SO Verification
Slide upper main parachute and shock cord into the upper section.	Ensure parachute remains properly folded and shroud lines are unencumbered. Ensure Nomex protector completely covers parachute.	
Slide upper side of main avionics bay into upper section of airframe.	Ensure shear pin holes are aligned.	
Insert shear pins in shear pin holes.	Number and type of shear pins to be determined during ground testing. Please reference ground test report.	
Motor		
Assemble the motor in accordance with manufacturer's instructions.[40]		
Insert completed motor assembly into the booster section.		
Securely screw on motor retainer ring.		
Just Prior to Flight		
Have the launch vehicle inspected by the RSO		
Be sure power is turned off from launch control.	Motor may ignite prematurely causing critical injury to personnel and equipment damage.	

[40] Cesaroni Pro75 instructions available at: http://www.pro38.com/pdfs/Pro75_Instructions.pdf

Task	Notes	SO Verification
Inspect launch pad and rail for debris, corrosion, and stability.	Adjust as necessary. Lubricate as necessary.	
Place the launch vehicle on the rail.	Test launch vehicle on launch rail for resistance or friction. Adjust as necessary. Lubricate as necessary.	
Warning: After altimeters and igniters are prepared, the launch vehicle presents a significant safety risk to all surrounding personnel. Only strictly required personnel are permitted near the launch vehicle when arming altimeters and preparing motor igniter.		
Turn on all five altimeters and listen for startup sequences.	Parachutes may fail to deploy. Mission failure.	
Insert ignitor into the launch vehicle	Ensure that the igniter is inserted up the motor until it reaches a dead-end and then pull back about 1-2 in. Failed or delayed ignition possible.	
Use the manufacturer cap to secure the igniter cord to the motor retainer.	Conduct final check to ensure security of igniter.	
Ensure igniter wires attached to power source.		
Arrange wires carefully to ensure continued attachment to igniter throughout launch sequence.		
Ensure ignitor power switch is on at launch control.		
Ensure all personnel are at safe standoff distance.		

Task	Notes	SO Verification
Ensure ignitor power switch is on at launch control.		
During Flight		
Monitor drift and locate launch vehicle after flight.	Ensure launch vehicle is recovered in a timely manner.	
Measure drift from launch pad.		
After Flight		
Warning: Be aware that undeployed charges may be present. Deactivate all altimeters prior to handling launch vehicle.		
Deactivate all altimeters.		
Caution: Ground and vegetation between launch and recovery sites may be hazardous. **PPE Required**: Close-toed shoes, long pants.		
Recover launch vehicle.		
Deactivate all electronics.		

5.11.5 POST-FLIGHT INSPECTION CHECKLIST

Table 54: Post-flight inspection checklist.

Task	SO Verification
Warning: Be aware that undeployed charges may be present. Deactivate all altimeters prior to post-flight inspection. **PPE Required**: Eye protection, gloves.	
Check altimeter black powder charges for undeployed charges and carefully dispose of unused black powder	
Inspect fins for damage and security.	

Task	SO Verification
Caution: Cracked or warn fiberglass can be extremely skin-irritating. **PPE Required**: Gloves.	
Inspect rocket body for dents, cracks, or missing parts.	
Inspect parachutes for holes and parachutes cords for abrasions or tears.	
Inspect shock cords for abrasion or tearing.	
Clean all components of debris and carbon residue.	
Check batteries with voltmeter.	
Caution: Motor becomes extremely hot during flight. Wait sufficient time for motor to cool before handling.	
Remove motor from motor casing.	
Disassemble motor casing.	
Remove all O-rings	
Place components except for motor casing tube into soapy water to remove carbon residue.	
After soaking, clean components with neutral cleaner, dry and reassemble.	
Download and analyze data from altimeters.	

6 PAYLOAD CRITERIA

The deployable rover / soil collection payload has been chosen. Significant design revisions have been made to bring the 2019 competition payload closer to the previously designed 2018 payload, instead of the design presented in the PDR report. These changes were implemented to increase chances of mission success by building on previous experience, rather than starting from the beginning.

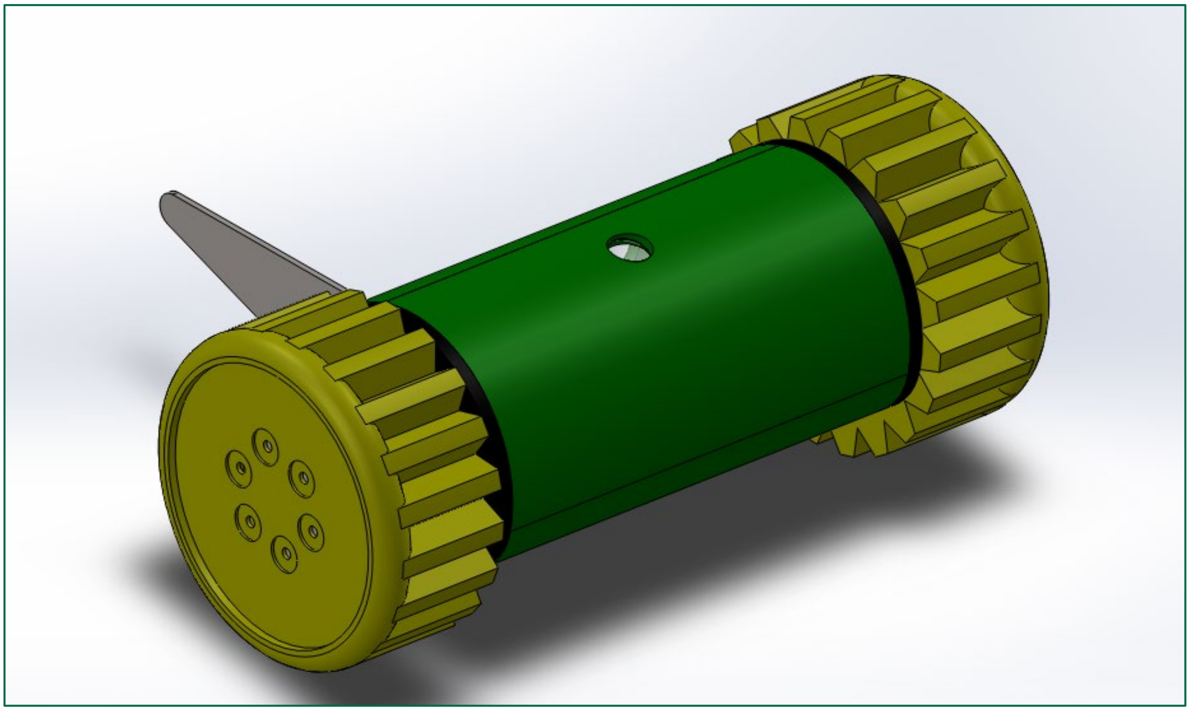


Figure 79: 3D render of updated rover design, with soil-collection port visible.

6.1 VEHICLE INTEGRATION

The rover will sit lengthwise inside the vehicle body, inside the upper airframe just below the upper section avionics bay. A deployment control system will be installed between the payload and avionics bay.

6.1.1 PAYLOAD RETENTION

Two large solenoids attached to the deployment system will secure the deployment system piston inside the rocket. The solenoids will be selected such that, if power is not supplied, they will remain extended in a failsafe position.

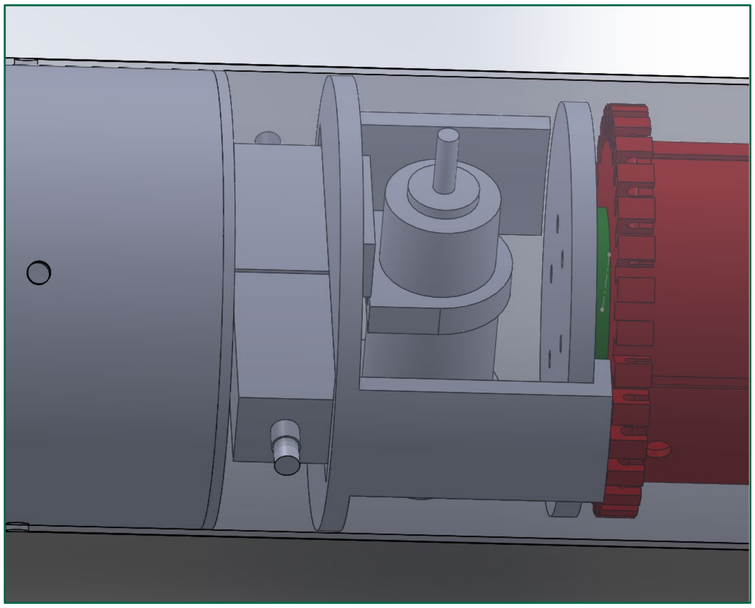


Figure 80: Render of payload installed in rocket, with retention system engaged and deployment motors visible.

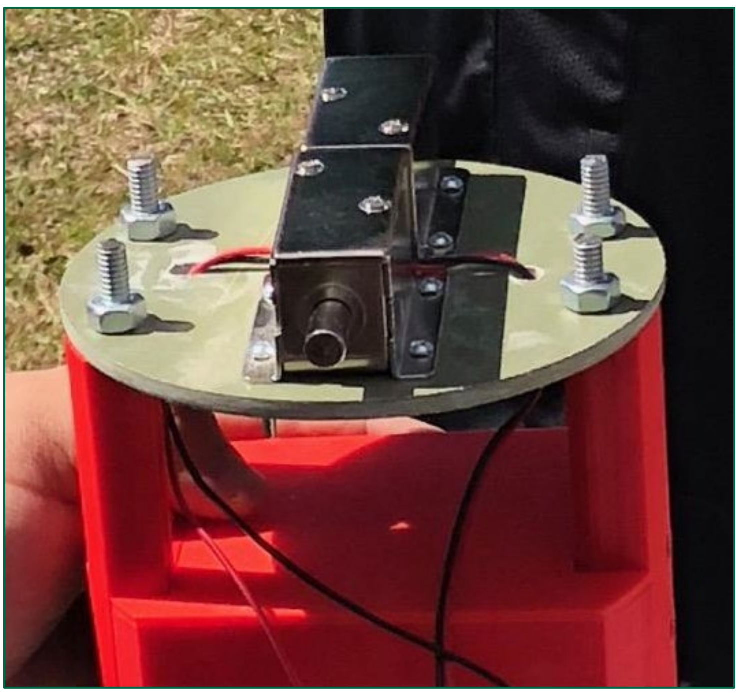


Figure 81: Image of previous competition retention mechanism, which has been tested and proven multiple times.

6.1.2 PAYLOAD DEPLOYMENT MECHANICS

The rover will be deployed by a winch-and-piston system. A motor (the 'winch' component) will have a spool of high-test, lightweight braided fishing line, which will run along the inside of the rocket body tube between the rover and the airframe. When the motor engages, the fishing line will be retracted into the spool.

The motor itself will be installed on a moving plate (the 'piston'), which, when the fishing line is retracted, will pull itself out of the rocket, thereby pushing the rover out. In this manner, no deployment mechanism must be present on the payload itself. Figure 82, Figure 83, and Figure 84 show the SOAR 2018 NASA Student Launch deployment system (which this system is modeled after) in action.

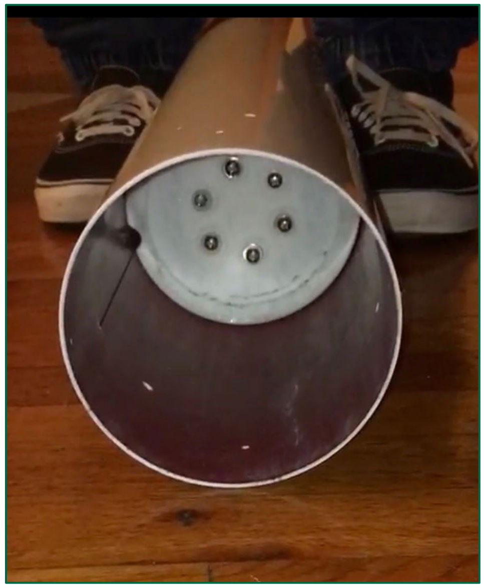


Figure 82: 2018 competition rover in retained (undeployed) position.

Figure 83: 2018 competition rover mid-deployment.

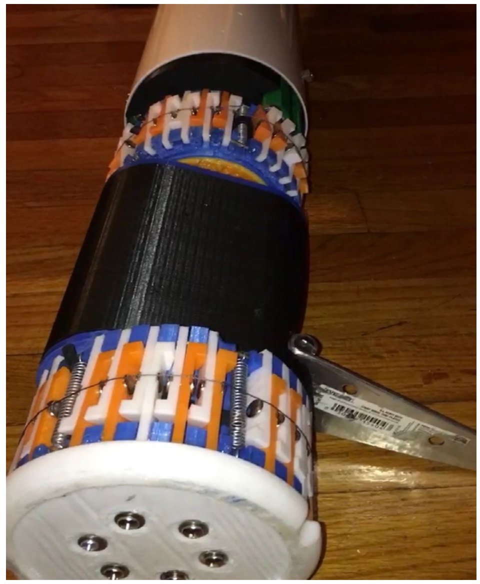


Figure 84: 2018 competition rover fully deployed, with stabilization arm deployed.

6.2 MECHANICAL DESIGN

6.2.1 BODY

To allow for increased clearance while driving across rough terrain, the rover body will be built off-center. The body is shaped to maximize internal space for electronics, sensors, batteries, and other internal components. A section of the rover body wall will be hinged and latching to allow for convenient access to rover internals (this is a significant change from the previous designs, in which only a small access port is available). The rover will be constructed from a combination of milled fiberglass sheets (for structural components) and 3D-printed PLA (for complex and non-structural components).

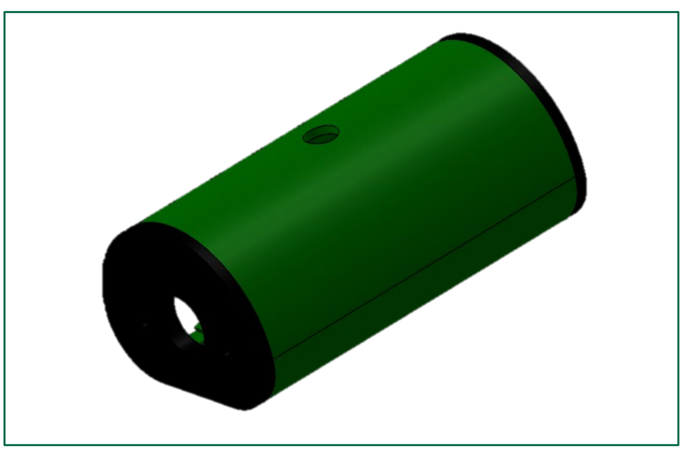


Figure 85: Render of rover body, with vacuum and motor shaft openings visible.

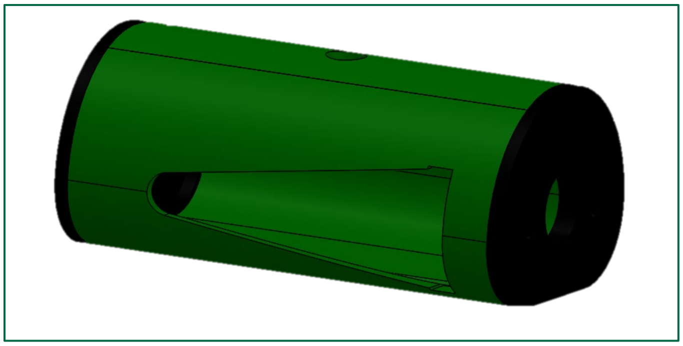


Figure 86: Render of rover body reverse, with stabilization leg cutout and motor shaft opening visible.

6.2.2 WHEELS

The rover wheels are optimized to gain traction in rough and uneven terrains. The rover will be modular, such that multiple wheel designs can be fabricated and switched out prior to launch. The wheel treads will be printed from PLA in order to customize exact tread design.

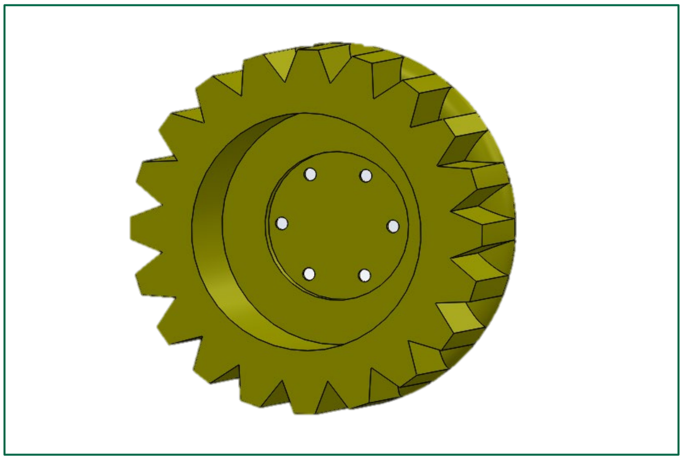


Figure 87: Render of rover wheel interior.

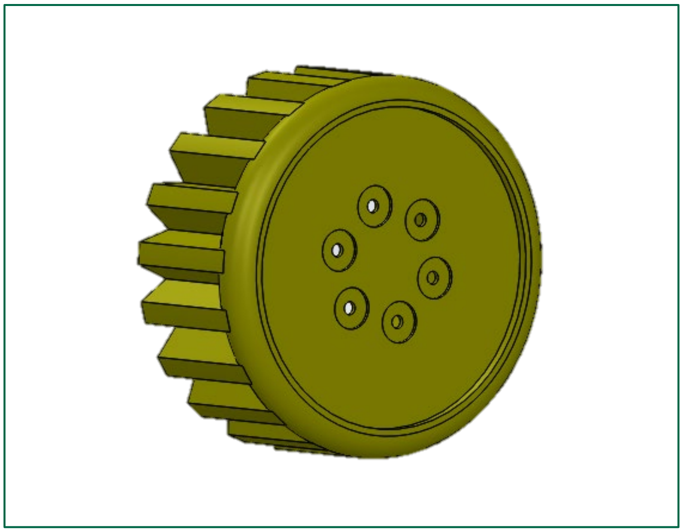


Figure 88: Render of rover wheel exterior.

6.2.3 STABILIZATION ARM

A collapsible lightweight fiberglass stabilization arm will prevent the rover from rotating when in motion. The arm will be spring loaded, such that it can be collapsed to fit inside the airframe and then automatically mechanically deployed upon exiting the launch vehicle.

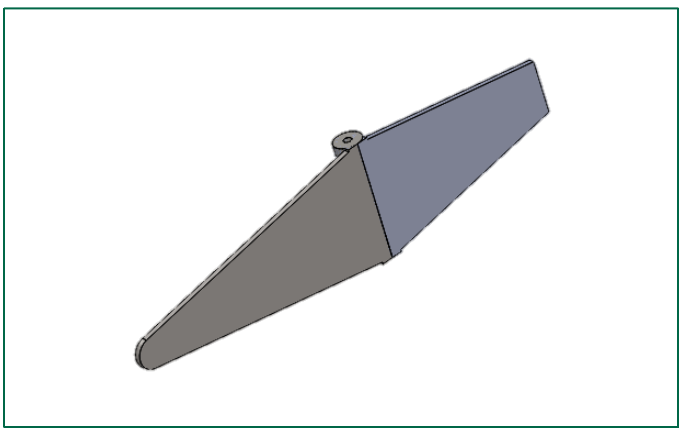


Figure 89: Render of rover stabilization arm.

6.2.4 MOTORS

The wheels will be attached to the rover body by the motor shafts through the exact center of the wheel, enabling strong, centered rotation. The specific motor model has not yet been determined, as multiple motors are being tested to find the optimal torque-to-power ratio. High torque is prioritized over high speed, as the rover distance can be traveled over a significant amount of time.

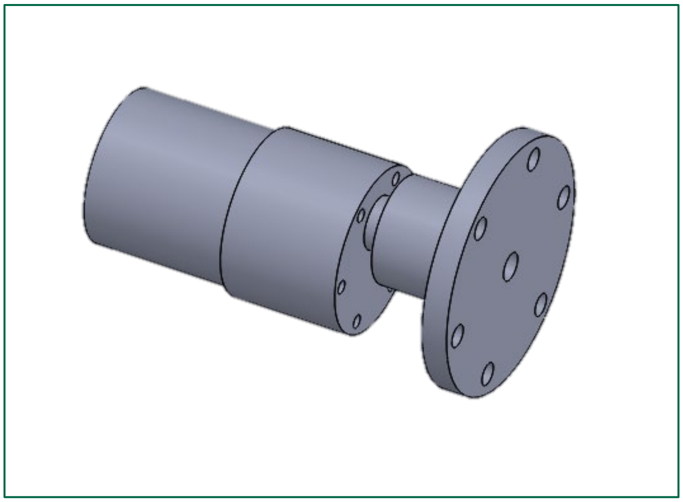


Figure 90: Render of rover motor, with wheel attachment installed.

6.2.5 VACUUM SOIL COLLECTION SYSTEM

The soil collection system will be constructed from components of a portable hand vacuum, with the addition of a large, sealed collection bin. A filter will be used to prevent soil from reaching the vacuum impeller, and a valve on the inside of the collection bin will be designed to automatically close when suction is removed. The intake hole will be mounted on the top of the rover body; therefore, the rover will flip over to engage the soil collection mode. This will enable the hole to be placed as close to the soil as possible when engaged, while still allowing for significant under-body clearance when in motion.

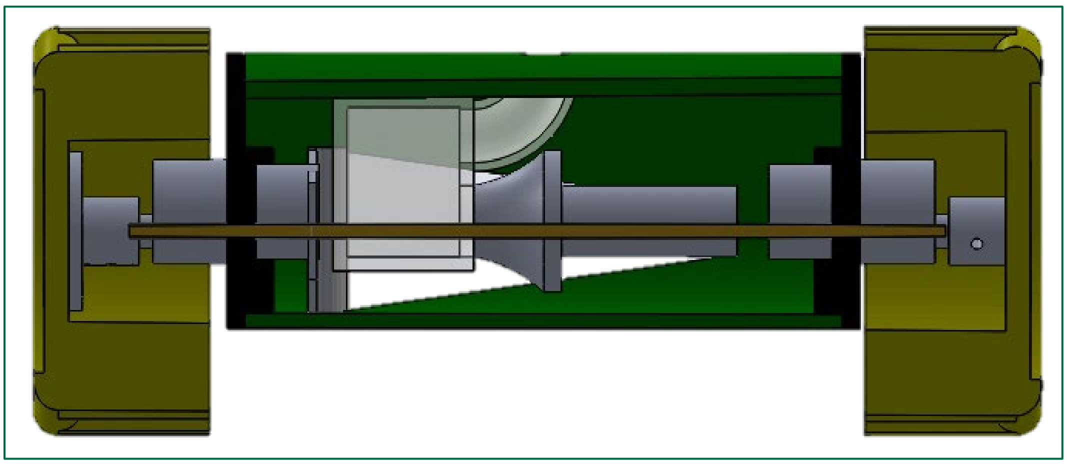


Figure 91: Rover body cross-section, highlighting the vacuum-based soil collection system.

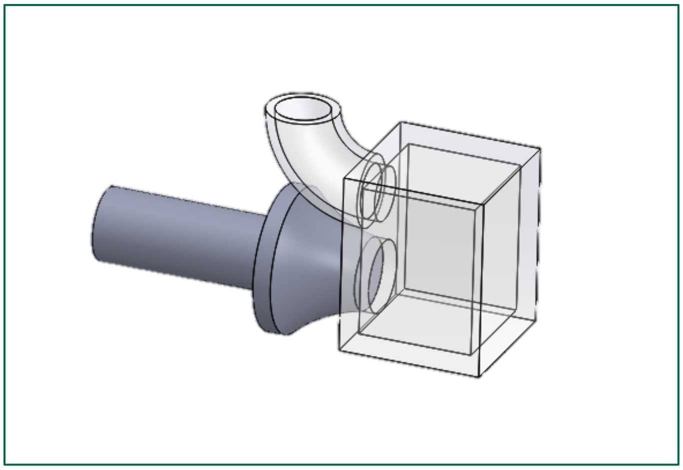


Figure 92: Render of rover soil collection mechanism.

6.3 ELECTRICAL DESIGN

6.3.1 DEPLOYMENT ELECTRONICS

The main deployment system will utilize two XBee RF transceiver; one each on the base station and rover. The base station will consist of one XBee transceiver and a computer, which will connect to the transceiver through a USB connection. The onboard deployment system will have an XBee transceiver connected to a shield that is designed to be attached an Arduino. Upon activation from the base station signal, the Arduino will give power to the solenoids (retracting them) and then activate the winch system. The motor will rotate for a predetermined amount of time, and then shut down. After the deployment sequence is finished, the deployment system will communicate with the rover via Bluetooth to initiate itself.

The solenoids operate on a 12V current and can safely handle being retracted for less than 5 seconds before they begin to overheat. As both the solenoids and the motors have very high demands for power (especially when they are both operating), a relay shield will allow the Arduino to safely control them both. Bluetooth and Xbee signals have very little degradation in the presence of magnetic fields, which both the solenoids and the motor will produce.

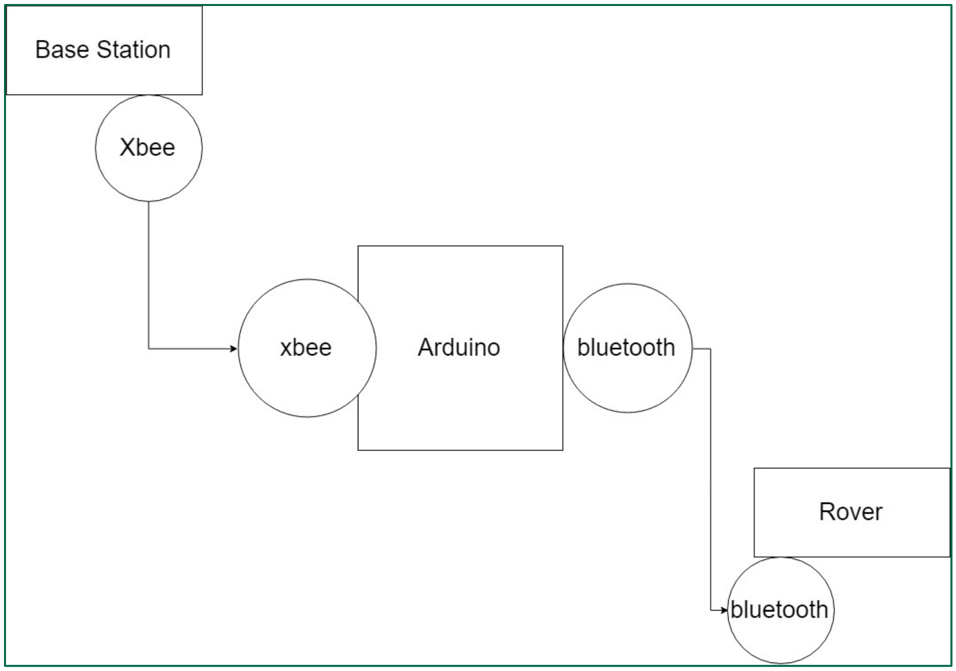


Figure 93: Rover communications schematic.

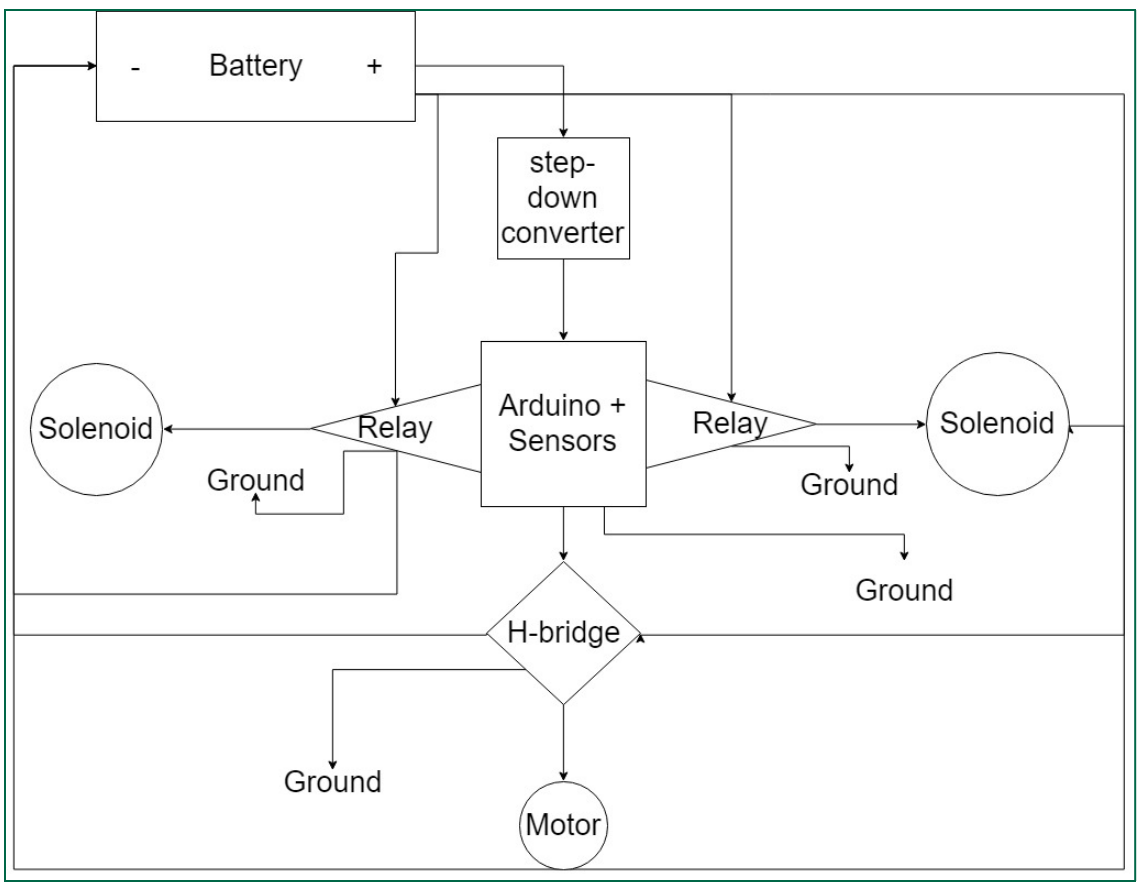


Figure 94: Rover power distribution schematic.

6.3.2 ROVER BODY ELECTRONICS

6.3.2.1 OVERVIEW

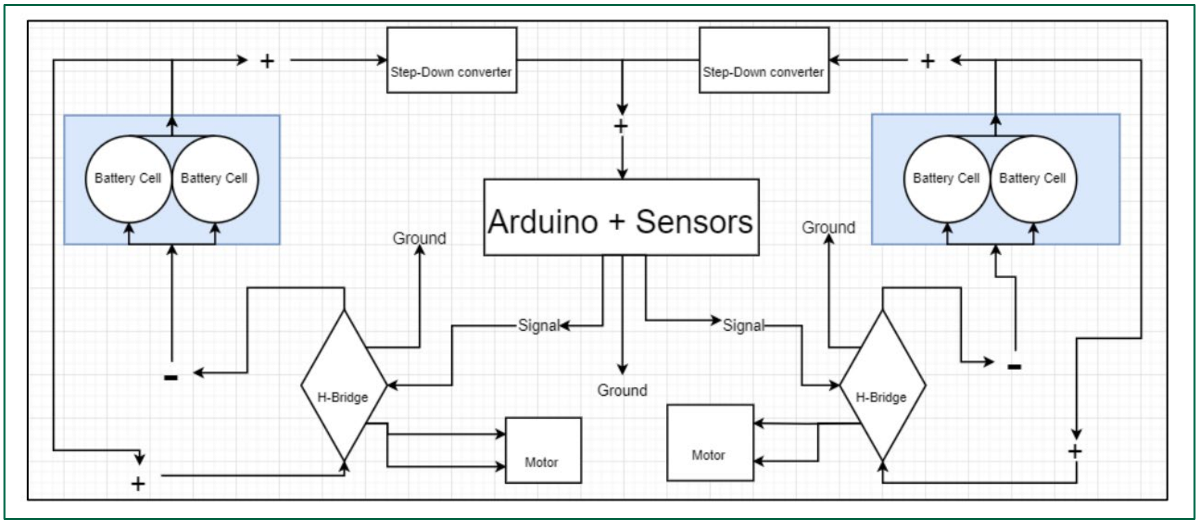


Figure 95: Rover propulsion electrical schematic.

Table 55: Power consumption and size of rover electrical components.

Component	**Voltage** (V)	**Current** (mA)	**Size** (in × in × in)
12V 100RPM 583 oz-in Brushed DC Motor	12	68	1.46 × 1.46 × 2.5
Velotech Magic Multirotor Speed Controller	5	BEC Output: 2000 Constant: 30,000	1.89 × 1.02 × 0.39
XBee Pro S3B	2.4 - 3.6	Tx: 215 Rx: 26 Sleep: 0.0025	1.29 × 0.961 × 0.215

6.3.2.2 HALL EFFECT SENSOR

The AH3362 is an AECQ100 qualified high voltage high sensitivity Hall Effect Unipolar switch IC designed for position and proximity sensing which will detect a magnet that will be located within the wheel assembly of the rover. The sensor will operate at 3.5V which is managed by the Arduino and this operating voltage will also minimize the amount of current leakage from the IC. The sensor will keep track of the amount of rotations over a given period of time. Its primary purpose is to make sure the rover wheels/motors are turning and will double as a method of distance determination (along with the accelerometer. Equation 24 will be used to estimate the distance traveled using this information, given the radius of the wheel r, the time elapsed t, and the revolutions per minute (from the Hall Effect system) R.

$$d = t\omega r = trR\frac{60}{2\pi}$$

Equation 23: Rover distance traveled as a function of time, wheel radius, and RPM.

6.3.2.3 DIGITAL ACCELEROMETER

The ADXL345 accelerometer will be used to verify that the rover is moving. This verification will be used in addition to the Hall Effect sensor, such that if the rover is moving it will keep the Hall Effect sensor active and will continue counting. The accelerometer data will be used with Equation 5 to estimate the distance traveled, given time elapsed t and acceleration a from the sensor.

$$d = \frac{1}{2}at^2$$

Equation 24: Rover distance traveled as a function of time and acceleration.

The sensor will be set to the lowest sensitivity setting (2g) in order to account for any variation of acceleration from the rover.

6.3.2.4 BLUETOOTH MODULE

In order to communicate with the rocket, and ultimately with the ground team, a wireless Bluetooth connection will be used. Since this Bluetooth module has a range of roughly 30 feet, the module will serve as a last-resort method to ensure mission success.

6.3.2.5 MICROCONTROLLER

The Arduino Mega 2560 Microcontroller Revision 3 is the brains of the rover. It has 54 digital I/O pins and 16 analog I/O pins, rated at a maximum voltage of 5V per pin.

6.4 DESIGN JUSTIFICATION

Table 56: Justification behind considerations in rover design.

Category	Specific Decision	Justification
Dimensions	Maximum diameter of payload	Inner airframe diameter of 5.74”, giving room for deployment
	Length of payload, and deployment system	19” total length given for all payload subsystems

Category	Specific Decision	Justification
Materials	Mix of carbon fiber, fiberglass, PLA to create a single rover	Different materials will be used in different aspects of the rover body, depending on the specifics of the piece (e.g., can't use CF around the avionics, given CF is RF blocking).
	Body will be mostly constructed out of 2D sheets secured together, created individually a CNC mill and/or laser cutter	Allows very tight tolerances not possible with human construction, and ease of adjustment if a piece needs to be adjusted dimensionally
	Wheel material will be PLA	Will test what soil type each design excels, may choose to install on launch day based on driving conditions
Steering Mechanism	Will use differential steering controlled by a motor driver breakout board	Allows us to rotate 180 degrees on our central axis, giving full freedom to maneuver as necessary
	Design will allow rover to maneuver around detected obstacles, allowing it to continue on its mission	We cannot predict or control the rover once deployed, so obstacle detection is needed to reverse, turn, continue mission
Communication	Will use RF via XBee wireless antenna/receiver	Can be used with an external antenna to extend range, team has prior experience with XBee specifically for RF transmission
	On board microcontroller will have multiple preloaded instruction sets to accomplish the mission, and one can be triggered within our activation signal	Allows flexibility post launch to tweak the path of the rover, depending on external conditions (Ex. a slower motor speed given sloppy conditions)

Category	Specific Decision	Justification
Microprocessor	Currently using an Arduino Mega, may potentially switch to a Raspberry Pi if needed	Arduino is currently being used for prototyping for its ease of use, Raspberry Pi may be installed if the computing power is needed once fully assembled and coded

7 PROJECT PLAN

7.1 TESTING

7.1.1 LAUNCH VEHICLE TESTING

7.1.1.1 PARACHUTE DEPLOYMENT GROUND TESTS

7.1.1.1.1 TEST OBJECTIVE

The objective of this test is to determine the amount of black powder is necessary to eject the parachutes and other components from the airframe. There are three parachutes on board each launch vehicle; therefore, three deployment charges are required: one each for the drogue parachute, upper section main parachute, and lower section main parachute (which also separates the rocket into two separate sections).

7.1.1.1.2 TESTED ITEMS

1. Quantity of black powder used to separate the main altimeter bay and lower airframe to deploy the drogue parachute.
2. Quantity of black powder used to separate the main altimeter bay and the upper section to deploy the lower section main parachute.
3. Quantity of black powder used to separate the nosecone and upper airframe to deploy the upper section main parachute

The full-scale and subscale launch vehicles are tested separately.

7.1.1.1.3 MOTIVATIONS

- To ensure the correct amount of black powder is used to properly separate the vehicle sections and deploy parachutes without damaging vehicle components.
- To ensure no vehicle component falls ballistically.
- To prevent vehicle components from being damaged on landing.
- To protect nearby personnel and property from the risk of falling vehicle components.
- To verify that the amount of black powder used will be sufficient in deploying the parachutes.
- The failure of this test will cause for the vehicle team to increase the quantity of black powder used for deployment until a sufficient but safe amount is used.

7.1.1.1.4 SUCCESS CRITERIA

Table 57: Parachute deployment ground test success criteria.

Unique ID	Description	Pass/Fail Criteria
VT1	Ground tests to determine if the amounts of black powder are sufficient to separate the two sections and deploy the parachute	**Pass**: The complete separation of each section and deployment of the parachute without any damage to the components being tested **Fail**: If pass criteria are not met or if the vehicle body or parachute is damaged in this test the test is a failure and the construction and materials used with have to be reviewed and replaced or less black powder needs to be used

7.1.1.1.5 TESTING PROCEDURES

7.1.1.1.5.1 EQUIPMENT

Equipment required for this test is as follows:

- ☐ Launch vehicle
- ☐ Black powder
- ☐ 1-gram black powder scoop
- ☐ E-matches
- ☐ Cellulose insulation
- ☐ Wire
- ☐ 9V battery
- ☐ Wire cutters/strippers
- ☐ Electrical tape
- ☐ Blue tape
- ☐ Multimeter
- ☐ Screwdriver
- ☐ Shear pin

7.1.1.1.5.2 SETUP

The section being tested will be placed onto a secure stand at an angle with open end raised. Weight will be placed behind the stand to secure the stand and prevent vehicle backfire from displacing and damaging the rocket or surrounding area. All E-matches are to be tested for continuity with the multimeter beforehand.

7.1.1.1.5.3 SAFETY NOTES

- Proper PPE is to be used when handling black powder
- No personnel should be standing in front or behind the rocket as the test is being conducted so they do not end up getting hit by one of the sections
- No personnel are to be within 10 feet of the vehicle when the test as the test is being conducted
- There is to be a minimum of 10 feet of wire between the vehicle body and the battery that will discharge the black powder

- The battery cannot be in any contact with the e-match or connecting wire until all personnel are at a safe distance away and the test is about to be conducted
- All electrical components are to be kept away from the e-match once the black powder is loaded into the section

7.1.1.1.5.4 PROCEDURE

1. Prepare sections to be tested. Fold and load parachutes into Nomex chute protectors and then place the wrapped parachute and shock cord into section. Parachute folding instructions are linked in 5.11.4 Final Assembly and Launch Procedure Checklist.
2. Place an e-match into the black powder cap and run the wire through to the opposite side of the altimeter bay. Separate the end of the e-match wire and strip it of 1 inch of insulation. Cut at least 10 feet of wire, separate the 2 sides at least 6 inches from each other and strip both ends of 1 inch of insulation. Connect the e-match to the 10 feet long wire by entwining the bare wire. Wrap the entwined exposed wire in electrical tape so it is insulated.
3. Load black powder and then cellulose insulation into the black powder cap. Use blue tape to secure the top of the cap so no insulation or black powder can spill.
4. Join the two sections being tested and place them onto the stand with the end that is to be expelled forward raised. Make sure any sections that need to be covered or taped over are covered or tapped over.
5. Secure sections with shear pins.
6. Ensure all participants are at least 10 feet away.
7. Touch one wire to the battery's positive end and then touch the other wire to the battery's negative end.
8. Survey section to determine success or failure as well as for any damage.
9. If the sections fail to separate, repeat the procedure with more black powder until enough black powder is used to successfully separate the two sections and deploy the parachute.

7.1.1.1.6 RESULTS

All subscale ground tests were successfully completed on December 14th, 2018. Test results are described in the following sections.

7.1.1.1.6.1 SUBSCALE DROGUE

The subscale drogue parachute test was successfully completed using 1.5 grams of black powder.

Figure 96: Subscale drogue parachute deployment test with 1.5 grams of black powder.

7.1.1.1.6.2 SUBSCALE UPPER SECTION MAIN

The subscale upper section main parachute deployment test was successfully completed with 2 grams of black powder.

Figure 97: Subscale upper section main parachute deployment test with 2 grams of black powder.

7.1.1.1.6.3 SUBSCALE LOWER SECTION MAIN

The subscale lower section main parachute deployment test was successfully completed with 3 grams of black powder.

Figure 98: Subscale lower section main parachute deployment test with 3 grams of black powder.

7.1.1.1.6.4 FULL-SCALE PLANS

The full-scale PDLS test is awaiting the construction of the full-scale launch vehicle to be completed.

7.1.1.2 TENDER DESCENDER STRESS TESTS

7.1.1.2.1 TEST OBJECTIVE

The objective of this test is to determine the durability of the Tender Descender (described in detail in 4.1.3.2.3 Payload Descent Levelling Subsystem (PDLS)) and determine if it will remain intact after use.

7.1.1.2.2 TESTED ITEMS

1. Tender Descender component durability.

7.1.1.2.3 MOTIVATIONS

- To ensure the durability of the Tender Descender.
- To ensure the Payload Descent Leveling Subsystem does not fail.
- To ensure no debris blocks the exit of the payload section.
- To ensure the payload is able to exit the payload section.
- The success of this test will verify that the Tender Descender will level the rocket so that when the vehicle lands the end where the payload will exit the body is free of any debris.
- The failure of this test will cause the vehicle team to look at a component that can withstand more impact, or another design for the PDLS.

7.1.1.2.4 SUCCESS CRITERIA

Table 58: Tender Descender stress test success criteria.

Unique ID	Description	Pass/Fail Criteria
VT2	The Tender Descender will be launched in the vehicle and activated	**Pass**: The Tender Descender will have no cracks or damage to it after launch **Fail**: If the pass criteria are not met

7.1.1.2.5 TESTING PROCEDURES

7.1.1.2.5.1 EQUIPMENT

The equipment needed for this the full assembled vehicle, including PDLS, assembled as described in 5.11.4 Final Assembly and Launch Procedure Checklist.

7.1.1.2.5.2 SETUP

The vehicle will be full assembled and prepared to launch.

7.1.1.2.5.3 SAFETY NOTES

- If the Tender Descender were to break during flight, it should create no new safety concerns, due to the design of the system.
- Follow all steps, notices, warnings, and cautions in the launch checklists provided in 5.11 Launch Operation Procedures.
- Ensure safety officer completes a safety check before launch, and vehicle team leads signs all lines on launch checklist.

7.1.1.2.5.4 PROCEDURE

1. Prepare the vehicle for launch, including the entire PDLS system, as described in the launch operations procedures.
2. Launch the vehicle.
3. Examine Tender Descender on landing.

7.1.1.2.6 RESULTS

7.1.1.2.6.1 SUBSCALE RESULTS

The subscale payload descent leveling subsystem test was competed December 15th, 2018 during the first launch of the subscale vehicle. Results of this test are presented in 4.1.3.2.3.5 Testing.

7.1.1.2.6.2 FULL-SCALE PLANS

The full-scale PDLS test is awaiting the construction of the full-scale launch vehicle to be completed.

7.1.1.3 PAYLOAD DESCENT LEVELING SUBSYSTEM TESTS

7.1.1.3.1 TEST OBJECTIVE

The objective of this test is to determine whether the PDLS will lower the rocket so that the payload exit is clear of debris that might impede the payload from leaving the vehicle. This will be verified through demonstration.

7.1.1.3.2 TESTED ITEMS

1. Angle at which the PDLS lowers the payload section so the payload exit is above zero degrees from the horizontal and has minimal risk of landing before end attached to the upper section main parachute.
2. Amount of debris blocking the payload deployment exit.

7.1.1.3.3 MOTIVATIONS

- To ensure there do not need to be adjustments in the cord used, the length of the cords used, or if a new design needs to be implemented.
- The success of this test will verify the effectiveness in the current PDLS design.
- The failure of this test will result in the design of the PDLS to be altered so that the payload exit is free of debris.

7.1.1.3.4 SUCCESS CRITERIA

Table 59: PDLS test success criteria.

Unique ID	Description	Pass/Fail Criteria
VT3	The PDLS will be launched in the vehicle and activated	**Pass**: Upon landing the payload exit will be clear and free of all debris **Fail**: If the pass criteria are not met

7.1.1.3.5 TESTING PROCEDURES

7.1.1.3.5.1 EQUIPMENT

The equipment needed for this is the full assembled vehicle with the PDLS in place and masking tape.

7.1.1.3.5.2 SETUP

Prepare the vehicle for launch with the PDLS secured and in place. Ensure all wires are safely secured and fastened.

7.1.1.3.5.3 SAFETY NOTES

- If the Tender Descender were to break during flight, it should create no new safety concerns, due to the design of the system.

- Follow all steps, notices, warnings, and cautions in the launch checklists provided in 5.11 Launch Operation Procedures.
- Ensure safety officer completes a safety check before launch, and vehicle team leads signs all lines on launch checklist.

7.1.1.3.5.4 PROCEDURE

4. Prepare the vehicle for launch, including the entire PDLS system, as described in the launch operations procedures.
5. Launch the vehicle.
6. Examine PDLS components and payload exit side of upper airframe on landing.

7.1.1.3.6 RESULTS

7.1.1.3.7 SUBSCALE RESULTS

The subscale payload descent leveling subsystem test was competed December 15th, 2018 during the first launch of the subscale vehicle. Results of this test are presented in 4.1.3.2.3.5 Testing.

7.1.1.3.8 FULL-SCALE PLANS

The full-scale PDLS test is awaiting the construction of the full-scale launch vehicle to be completed.

7.1.1.4 PAYLOAD RETENTION TEST

7.1.1.4.1 TEST OBJECTIVE

The objective of this test is to ensure the retention of the payload within the vehicle body during launch and while airborne. This will be done through demonstration.

7.1.1.4.2 TESTED ITEMS

1. Both payload solenoid components.
2. The remote signal which will activate the solenoids.

7.1.1.4.3 MOTIVATIONS

- To ensure the rover will be retained within the vehicle utilizing a fail-safe active retention system.
- To ensure that the retention system is durable enough to retain the rover.
- The success of this test will ensure the payload does not fall ballistically.
- The failure of this test will mean that the solenoids were not robust enough and will have to be replaced or there was an error in the wiring, programming or in the remote signal that will need to be resolved.

7.1.1.4.4 SUCCESS CRITERIA

Table 60: Payload retention test success criteria.

Unique ID	Description	Pass/Fail Criteria
VT4	A mock payload will be placed within the vehicle and will be launched with solenoids holding it in place	**Pass**: The retention of the payload in the vehicle body while airborne **Fail**: If the pass criteria are not met

7.1.1.4.5 TESTING PROCEDURES

7.1.1.4.5.1 EQUIPMENT

The equipment needed for this is as follows:

- ☐ Fully assembled launch vehicle
- ☐ Mock payload
- ☐ Fishing line, rated at 100 lb
- ☐ Threaded rods
- ☐ 12-volt battery
- ☐ Insulated wire

7.1.1.4.5.2 SETUP

Prepare the vehicle for launch with a mock payload in place of the rover. Solder insulated wire to the solenoids and place them in the preplanned spot. Feed the threaded rods through the mock payload. Ensure solenoids are secure.

7.1.1.4.5.3 SAFETY NOTES

- Ensure solenoids are placed in a failsafe position
- Use mock payload so there is no risk of damaging the real payload
- A braided failsafe fishing line, rated at 100 lb, is used to prevent the mock payload from exiting the rocket body prematurely. This is done by securing the entire system to the bulkhead. The fishing line is just long enough to not contribute to the holding force of the retention system of the deployment system but not too long where the mock payload will have enough slack to be partially/fully outside the launch vehicle if the solenoids fail.
- Personnel shall carefully watch and be aware of the potential for the payload to fall at terminal velocity.
- Follow all steps, notices, warnings, and cautions in the launch checklists provided in 5.11 Launch Operation Procedures.
- Ensure safety officer completes a safety check before launch, and vehicle team leads signs all lines on launch checklist.

7.1.1.4.5.4 PROCEDURE

1. Secure 4 prong extension to the bulkhead. Tie fishing line to the U-bolt and mock payload.
2. Retract solenoids with battery pack and slide mock payload through the rocket body.
3. Remove power to solenoids and tug on payload to make sure it is secure.
4. Prepare the vehicle for launch.
5. Launch the rocket.
6. Examine solenoids upon landing.

7.1.1.4.6 RESULTS

7.1.1.4.6.1 SUBSCALE PLANS

The subscale solenoid retention test will be completed during the second subscale launch in January.

7.1.1.4.6.2 FULL-SCALE PLANS

The full-scale retention test is awaiting the construction of the full-scale launch vehicle to be completed.

7.1.1.5 DAAS TEST

7.1.1.5.1 TEST OBJECTIVE

The objective of this test is to see how much the DAAS will affect the altitude. If the DAAS deploys but fails to change the altitude, then a new design will need to be used. If the DAAS does not deploy, then the component preventing it from fully deploying needs to change. This will be verified through demonstration.

7.1.1.5.2 TESTED ITEMS

1. The change in altitude with the deployment of the DAAS

7.1.1.5.3 MOTIVATIONS

- To ensure the integrity of the DAAS and increase the accuracy of the altitude.
- The success of this test will verify the necessity of the DAAS and allow for a full-scale version to be constructed.
- The failure of this test will mean that the DAAS is not effective in decreasing altitude and that the system is redundant or a component of the DAAS design needs to be modified or fixed.

7.1.1.5.4 SUCCESS CRITERIA

Table 61: DAAS test success criteria.

Unique ID	Description	Pass/Fail Criteria
VT5	The DAAS will be launched in the vehicle and remain inactive for one flight and in a sequential flight will be activated	**Pass**: The DAAS will decrease the altitude of the vehicle by at least 2 feet. **Fail**: If the pass criteria is not met.

7.1.1.5.5 TESTING PROCEDURES

Two launches will we completed on the same day with the same size motor so that launch conditions are as similar as possible. The second launch of the vehicle will occur after the recovery, post launch inspection, vehicle reassembly and safety check. For the first launch the DAAS will not be activated but will remain in the vehicle and for the second launch it will be activated.

7.1.1.5.5.1 EQUIPMENT

The equipment needed for this is the full assembled vehicle with the DAAS in place.

7.1.1.5.5.2 SETUP

Prepare the vehicle for launch with the DAAS secured and in place. Disconnect the DAAS from the batteries for the control flight and reattach them for the test flight.

7.1.1.5.5.3 SAFETY NOTES

- Wear proper PPE when handling the black powder and motor before launch
- Ensure all systems are NOT armed when placing vehicle on launch pad
- Ensure all personnel are a safe distance away from the launch pad when systems are armed, and the vehicle is launched
- Ensure all parachutes are properly folded and attached
- Ensure SO does a safety check before launch

7.1.1.5.5.4 PROCEDURE

1. Prepare the vehicle for launch.
2. Launch the rocket with the DAAS inactive.
3. Upon landing, collect altimeter data.
4. Prepare the vehicle for a second launch with the DAAS activated.
5. Launch the rocket.
6. Upon landing, collect altimeter data.

7.1.1.5.6 RESULTS

7.1.1.5.7 SUBSCALE PLANS

The subscale DAAS test is to be completed during the second subscale launch in January.

7.1.1.5.8 FULL-SCALE PLANS

The full-scale DAAS test is awaiting the completion of the construction of the full-scale and launch to be performed.

7.1.2 PAYLOAD TESTING

7.1.2.1 WET CONDITIONS TEST

The objective of this test is to determine which wheels and soil collection method is necessary for our payload to be able to operate in water saturated terrain. The success criteria for this test is fulfilled if the payload is able to move 10 ft in a water saturated terrain and collect the 10 mL of soil. The test variables are the type of wheels that will be used on the payload and the type of soil collector that will be used. The methodology we will be using is performance testing. This test is necessary in determining the durability of the payload to withstand different conditions due to unknown launch day terrain conditions and the soil that the payload must traverse may be wet. The success of this test will verify the choice in wheel type and soil collection method. The failure of this test will result notify the payload team as to whether they must change the wheel type and/or the soil collection method.

This test is to be completed by the March full-scale launch.

7.1.2.2 ROUGH TERRAIN TEST

The objective of this test is to determine which wheels and soil collection method is necessary for the payload to be able to operate in rough terrain. The success criteria for this test will be fulfilled if the payload is able to move 10 ft. in the rough terrain and collect the 10ml of soil. Rough terrain being defined as coarse, uneven, and bumpy terrain. The test variables are the type of wheels used on the payload and the type of soil collector used. The methodology we will be using is functional testing. This test is necessary because the payload may deploy in rough terrain. It is necessary to ensure the payload is able to traverse the rough terrain. The success of this test will verify the choice in wheel type and soil collection method. The failure of this test will notify the payload team to change the wheel type and/or the soil collection method.

This test is completed by the March full-scale launch.

7.1.2.3 BATTERY LIFE

The objective of this test is to determine how long the battery can last in the payload once it has been turned on. The success criteria for this test is that the batteries will last at least 4 hours after being turned on. The test variables are the duration of the batteries. The methodology we will be using is performance testing. This test is necessary because it may take a while for the team to launch the vehicle once the batteries are turned on, so this will ensure that they will be able to function properly even after extended hours of delay. The success of this test will verify the batteries chosen are durable and can withstand the necessary time delays. The failure of this test will result in the payload team looking into batteries that will last longer.

This test is to be completed by the March full-scale launch.

7.1.2.4 SIGNAL STRENGTH TEST

The objective of this test is to determine how far the signal strength of the payload rover goes. The success criteria for this test is that the payload has a signal strength of at least 100ft. The test variables are the signal receiver on the rover. The methodology we will be using is performance testing. This test is necessary because the rover needs to be able to be remotely activated (per 7.2.3 Payload Requirements). The success of this test will verify that the signal receiver and signal transmitter are adequate for starting the payload deployment process. The failure of this test will result in the payload team looking for another signal receiver or transmitter.

This test will be completed by the March full-scale launch.

7.2 PROJECT REQUIREMENTS

7.2.1 GENERAL REQUIREMENTS

Table 62: General requirements and verifications.

Req. No.	Requirement	Method	Verification	Verification Status
1.1	*Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation except for assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).*	Demonstration	USF SOAR is a student-only organization. Team leads will monitor all operations and construction of the rocket and payload to ensure all work is done by the student members. Safety Officer will monitor that all handling of explosive items, electric matches or igniters, and motor assembly are conducted by the team mentor.	Verified during Project Proposal submission. Will continue to be verified throughout the course of the project until final launch day. Reference: 3.2 Team Members
1.2	*The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.*	Demonstration	Team leader and project manager will work with subteam leaders to construct a project timeline that includes project milestones. Project manager will designate a finance officer to monitor and create the project budget. Safety officer will build checklists, as well as risk/mitigation charts. Project manager will designate an outreach coordinator to build educational engagement opportunities. SOAR has hired a Marketing Manager to handle all community support efforts for the organization and this project. Project manager will maintain an organizational chart of all assigned personnel.	Verified with submission of Proposal. Will continue to be verified throughout the course of the project as more documents are submitted. Reference: 7 Project Plan, 3 Team Personnel, 9 Educational Engagement, 5 Safety

1.3	*Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during certain activities.*	Documentation	SOAR will submit information on foreign national students no later than submission of the PDR. A team roster is being kept with information on all Foreign Nationals, this data will be sent to the correct personal no later than the due date of the PDR.	Verified 10/29/18 when email confirmation was received that Frederick Kepner and Zachary Koch received the list of Foreign Nationals.
1.4	*The team must identify all team members attending launch week activities by the Critical Design Review (CDR).*	Documentation	SOAR will submit information on team member attendees no later than submission of the CDR.	Verified with submission of CDR. Reference: 3.2 Team Members
1.4.1	*Students actively engaged in the project throughout the entire year.*	Documentation	SOAR's NSL Team will take attendance at each meeting to track team members who are actively engaged throughout the academic year. A team roster is being kept with information regarding each member activity level, which will be used to identify team members to travel during competition week.	Verified with submission of CDR. Reference: 3.2 Team Members

1.4.2	*One mentor (see requirement 1.13).*	Documentation	SOAR has a designated mentor who meets the requirements of Section 1.13 of the NASA Student Launch 2019 Handbook. The mentor has agreed to travel with the team during launch week.	Verified with project proposal. Reference: 3.1.2 Team Mentor
1.4.3	*No more than two adult educators.*	Documentation	SOAR will identify no more then two adult educators who will be attending launch week.	Verified with submission of team roster by CDR.
1.5	*The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. An educational engagement activity report will be completed and submitted within two weeks after completion of an event.*	Demonstration	SOAR has designated an Outreach Coordinator to organize and handle all outreach events. Multiple outreach events are scheduled, and the Operations Manager has been designated to schedule further events.	Verified with submission of CDR as the team has reached over 650 students. Reference: 9.1 Completed Events
1.6	*The team will establish a social media presence to inform the public about team activities.*	Demonstration	SOAR has established social media accounts on Facebook, Twitter, Instagram, and LinkedIn. The NSL team will utilize these established accounts to inform the public about team activities. The Team Lead has access to all of these accounts which she will keep updated with NSL material.	Verified with submission of social media handles to Ryan Connelly on 10/9/18.

1.7	*Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient.*	Demonstration	The NSL Team Leader will be responsible to send the documentation to NASA project management for each milestone. In addition, each report will be posted on our website to the following page: http://www.usfsoar.com/projects/nsl-2018-2019/	Will be verified upon submission of documents for each milestone.
1.8	*All deliverables must be in PDF format.*	Inspection	One team member has been designated to format and proofread all documents before submission. They will inspect that each deliverable will be in PDF format.	Will be verified upon submission of documents for each milestone.
1.9	*In every report, teams will provide a table of contents including major sections and their respective subsections.*	Inspection	One team member has been designated to format and proofread all documents before submission. They will inspect that each report contains a table of contents.	Will be verified upon submission of documents for each milestone.
1.10	*In every report, the team will include the page number at the bottom of the page.*	Inspection	One team member has been designated to format and proofread all documents before submission. They will inspect that each report has a page number at the bottom of the page.	Will be verified upon submission of documents for each milestone.

1.11	*The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. Cellular phones can be used for speakerphone capability only as a last resort.*	Demonstration	The SOAR team has access to computers, speaker phones, Wi-Fi connection, and a video camera for teleconference purposes. The Team Lead is responsible for booking an adequate conference room and renting all necessary equipment for the presentation.	Will be verified during milestone presentations.
1.12	*All teams will be required to use the launch pads provided by Student Launch's launch service provider. No custom pads will be permitted on the launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.*	Demonstration	The Launch vehicle will be designed to utilize the standard rails made available on the NSL launch site. Full-scale launches will be conducted in a similar way in order to mimic launch day conditions.	Verified with submission of documents which include launch vehicle design. Reference: 4.1.3.1.5 Launch Rail Lugs
1.13	*Each team must identify a "mentor."*	Documentation	SOAR's NSL Team has identified a mentor who meets the qualifications specified in the NASA Student Launch 2019 Handbook.	Verified with submission of project proposal. Reference: 3.1.2 Team Mentor

7.2.2 VEHICLE REQUIREMENTS

Table 63: Vehicle criteria requirements and verifications.

Req. No.	Requirement	Method	Verification	Verification Status
2.1	*The vehicle will deliver the payload to an apogee altitude between 4,000 and 5,500 feet above ground level (AGL). Teams flying below 3,500 feet or above 6,000 feet on Launch Day will be disqualified and receive zero altitude points towards their overall project score.*	Demonstration	We have identified a target apogee of 5,000 feet. Subscale analysis will be conducted to compare the apogee with the respective motor. Calculations will be done to ensure our chosen full-scale motor will deliver us to the targeted 5,000 feet.	Will be verified on Launch Day for Full-Scale Vehicle.
2.2	*Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score during Launch Week.*	Documentation	The target goal will be determined using OpenRocket simulation following any changes to the rocket prior to PDR submission.	Verified with submission of PDR. Reference: Section 5.5 Flight Characteristics in PDR Report[41].

[41] Available at: http://www.usfsoar.com/projects/nsl-2018-2019/

Req. No.	Requirement	Method	Verification	Verification Status
2.3	*The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner.*	Demonstration	The vehicle will feature five altimeters in two separate avionic bays, capable of deploying charges and recording the flight apogee.	Verified with submission of PDR. Reference: Section 5.5.2 Recovery System in PDR Report.
2.4	*Each altimeter will be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.*	Inspection	Each altimeter will have an arming switch via a keyed electronic rotary switch. There will be two switches in the transition bay of the main avionics bay, and two switches in the payload avionics bay. All switches will be visible and physically accessible when the rocket is on the rail.	Full-scale construction is not yet complete, will be verified in FRR.
2.5	*Each altimeter will have a dedicated power supply.*	Demonstration	One 3.5V LiPo battery will be installed for each altimeter.	Full-scale construction is not yet complete, will be verified in FRR.
2.6	*Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).*	Inspection	There are two settings to the electronic rotary switch. The switch itself has mechanical components that force it to remain in its set position.	Full-scale construction is not yet complete, will be verified in FRR.

Req. No.	Requirement	Method	Verification	Verification Status
2.7	*The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.*	Testing/ Inspection	The launch vehicle will contain parachutes on every separate or tethered part of the rocket that will be deployed with sufficient time to slow the rocket adequately. After each launch the Safety Officer will inspect the vehicle to identify it as recoverable and reusable.	Full-scale construction is not yet complete, will be verified in FRR.
2.8	*The launch vehicle shall have a maximum of four (4) independent sections.*	Demonstration	The launch vehicle will consist four sections: the nose cone, rover compartment, main avionics bay, and the booster section. The nose cone and rover compartment will be tethered together, as will the avionics bay and booster, thus resulting in two independent sections.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3 Vehicle Design Details
2.8.1	*Coupler/ airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.*	Demonstration	The coupler connecting the upper and lower sections will extend at least 6" into the airframes.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3 Vehicle Design Details

Req. No.	Requirement	Method	Verification	Verification Status
2.8.2	*Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.*	Demonstration	The nose cone shoulder will extend 5" into the upper airframe.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3 Vehicle Design Details
2.9	*The launch vehicle shall be limited to a single stage.*	Demonstration	Launch vehicle will contain only one motor to light and start the flight.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3 Vehicle Design Details
2.10	*The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the Federal Aviation Administration flight waiver opens.*	Testing	There will be Final Assembly and Launch Procedure Checklist before the test flights of the subscale rocket and the full-scale rocket that will be timed to ensure we complete the list safely and within the time of 2 hours.	Wil be verified by FRR after full-scale launch timing test.
2.11	*The launch vehicle will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components.*	Testing	The launch vehicle and the electronic components within will be properly connected and sealed to prevent anything from causing it to disconnect or be damaged. The batteries will have a life long enough to be at the launch pad for an hour without losing any power.	Wil be verified by FRR after full-scale launch timing test.

Req. No.	Requirement	Method	Verification	Verification Status
2.12	*The launch vehicle shall be capable of being launched by a standard 12-volt direct current firing system.*	Demonstration	The ignitor used in the rocket will be able to fire with a standard 12-volt DC firing system.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3 Vehicle Design Details
2.13	*The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch.*	Demonstration	The only required external circuitry will be the 12-volt direct current firing system that is compatible with the ignitor in the launch vehicle.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3 Vehicle Design Details
2.14	*The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).*	Demonstration	The selected motor is a commercially available certified standard APCP solid-fuel motor.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3.3 Motor
2.14.1	*Final motor choices will be declared by the Critical Design Review (CDR) milestone.*	Documentation	Preliminary motor has been selected; any changes will be noted and justified in CDR.	Verified by submission of CDR. Reference: 4.1.3.3 Motor

Req. No.	Requirement	Method	Verification	Verification Status
2.14.2	*Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing the safety margin. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.*	Documentation	No motor change is expected after the CDR Report is submitted.	To be verified with further documents.
2.15	*Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria.*	Documentation	Our design does not contain a pressure vessel.	Verified with submission of Project Proposal.
2.15.1	*The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.*	Documentation	Our design does not contain a pressure vessel.	Verified with submission of Project Proposal.

Req. No.	Requirement	Method	Verification	Verification Status
2.15.2	*Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.*	Documentation	Our design does not contain a pressure vessel.	Verified with submission of Project Proposal.
2.15.3	*Full pedigree of the tank will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.*	Documentation	Our design does not contain a pressure vessel.	Verified with submission of Project Proposal.
2.16	*The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).*	Analysis	The motor chosen is not bigger than an L class motor..	Verified with submission of selected motor Reference: 4.1.3.3 Motor

Req. No.	Requirement	Method	Verification	Verification Status
2.17	*The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.*	Analysis	The rocket has been simulated in OpenRocket to have a loaded static stability margin greater than 2.0. Will be further verified with physical balance tests after fabrication.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.4.2 Static Stability
2.18	*The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.*	Analysis	The motor that was chosen for the rocket will allow the rocket to achieve a minimum of 52 fps at rail exit..	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.4.1.1 Simulated Flight Characteristics
2.19	*All teams shall successfully launch and recover a subscale model of their rocket prior to CDR.*	Testing	Our team successfully launched and recovered a subscale vehicle on December 15th 2018. The subscale information will be documented in the CDR.	Verified with submission of CDR. Reference: 4.2 Subscale Launch Vehicle and Test Analysis
2.19.1	*The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model.*	Demonstration	The subscale model was constructed to resemble the full-scale model as accurately as possible given finances and fabrication techniques. The CDR will provide information regarding the scaling of the full-scale in order to create the subscale rocket.	Verified with submission of CDR. Reference: 4.2 Subscale Launch Vehicle and Test Analysis

Req. No.	Requirement	Method	Verification	Verification Status
2.19.2.	*The subscale model will carry an altimeter capable of recording the model's apogee altitude.*	Demonstration	The avionics bay on the subscale rocket will include an altimeter that will record the subscales apogee.	Verified with submission of CDR. Reference: 4.2 Subscale Launch Vehicle and Test Analysis
2.19.3	*The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.*	Demonstration	The subscale rocket will be newly constructed rocket, designed and build at a scale unique to the full-scale rocket.	Verified with submission of CDR. Reference: 4.2 Subscale Launch Vehicle and Test Analysis
2.19.4	*Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.*	Documentation	An altimeter will be attached to the subscale rocket so that altimeter data can be used to prove a successful launch.	Verified with submission of CDR. Reference: 4.2 Subscale Launch Vehicle and Test Analysis
2.20	*All teams will complete demonstration flights as outlined below.*			

Req. No.	Requirement	Method	Verification	Verification Status
2.20.1	*All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day.*	Testing	The full-scale rocket will be built and launched as well as recovered prior to the FRR and it will be the same rocket flown on launch day.	Will be verified by FRR after full-scale demonstration flight is complete.
2.20.1.1	*The vehicle and recovery system will have functioned as designed.*	Inspection	The vehicle and recovery system will be observed during and after full-scale launch to ensure it functions as designed.	Will be verified by FRR after full-scale demonstration flight is complete.
2.20.1.2	*The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.*	Demonstration	The full-scale rocket will be newly constructed rocket, designed and build at a scale unique to the full-scale rocket.	Will be verified by FRR after full-scale demonstration flight is complete.
2.20.1.3	*The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:*			

Req. No.	Requirement	Method	Verification	Verification Status
2.20.1.3.1	*If the payload is not flown, mass simulators will be used to simulate the payload mass.*	Demonstration	If a rover is not ready to fly, we will construct a simulated mass in order to act as dead weight in place of the rover.	Will be verified with payload demonstration flight.
2.20.1.3.2	*The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.*	Inspection	The mass simulators will be in the upper airframe of the launch vehicle and will be attached to the upper section avionics bay.	Will be verified with payload demonstration flight.
2.20.1.4	*If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale demonstration flight.*	Documentation	The PDLS will be active during the full-scale demonstration flight.	Verified with submission of CDR.
2.20.1.5	*Teams shall fly the launch day motor for the Vehicle Demonstration Flight. The RSO may approve use of an alternative motor if the home launch field cannot support the full impulse of the launch day motor or in other extenuating circumstances.*	Testing	The launch day motor will be the one declared in the CDR and flown in the vehicle demonstration flight as well as any other full-scale launch flights conducted.	Will be verified by FRR after full-scale demonstration flight is complete.

Req. No.	Requirement	Method	Verification	Verification Status
2.20.1.6	*The vehicle must be flown in its fully ballasted configuration during the full-scale test flight.*	Inspection	The fully ballasted configuration will be used in the full-scale demonstration flight.	Will be verified by FRR after full-scale demonstration flight is complete.
2.20.1.7	*After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).*	Documentation	After completing the full-scale demonstration flight, no components will be changed.	Will be verified by FRR after full-scale demonstration flight is complete.
2.20.1.8	*Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement.*	Documentation	Complete flight analysis and altimeter data will be included in the FRR report to prove successful flight apogee have been achieved.	Will be verified by FRR after full-scale demonstration flight is complete.

Req. No.	Requirement	Method	Verification	Verification Status
2.20.1.9	*Vehicle Demonstration flights must be completed by the FRR submission deadline. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. This extension is only valid for re-flights, not first-time flights. Teams completing a required re-flight must submit an FRR Addendum by the FRR Addendum deadline.*	Demonstration	Full-scale vehicle demonstration flight is currently planned for February 16th, 2019, prior to the FRR submission deadline	Will be verified by FRR after full-scale demonstration flight is complete. Reference: 8.2.2 Vehicle Timeline
2.20.2	*Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The following criteria must be met during the Payload Demonstration Flight:*			

Req. No.	Requirement	Method	Verification	Verification Status
2.20.2.1	*The payload must be fully retained throughout the entirety of the flight, all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair.*	Documentation	The payload is designed to be fully retained with a solenoid system. The solenoids will be attached to the payload or payload deployment system. The solenoids will be set to a locked position, only unlocking if power is supplied. This prevents any failure of the rover exiting the launch vehicle prematurely.	Will be verified with Payload Demonstration flight. Reference: 6.1.1 Payload Retention
2.20.2.2	*The payload flown must be the final, active version.*	Demonstration	The payload will be flown in the final active version.	Will be verified with Payload Demonstration Flight.
2.20.2.3	*If the above criteria is met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.*	Demonstration	If the above criteria is met during the Vehicle Demonstration Flight then we will submit no other information and will detail results in FRR.	Will be verified with Payload Demonstration Flight.

Req. No.	Requirement	Method	Verification	Verification Status
2.20.2.4	*Payload Demonstration Flights must be completed by the FRR Addendum deadline. No extensions will be granted.*	Demonstration	The Payload Demonstration Flight will be completed by the FRR Addendum deadline.	Will be verified with Payload Demonstration Flight.
2.21	*An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA-required Vehicle Demonstration Re-flight after the submission of the FRR Report.*	Documentation	SOAR will submit an FRR addendum if a payload demonstration flight is not completed by the payload demonstration flight deadline.	Wil be verified with Payload Demonstration flight.
2.22	*Any structural protuberance on the rocket will be located aft of the burnout center of gravity.*	Inspection	Designs place all protrusions aft of the center of gravity (including the airbrakes system). Further verification will be performed at the full sale balance test.	Will be verified with construction completion of full-scale rocket.

Req. No.	Requirement	Method	Verification	Verification Status
2.23	*The team's name and launch day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe.*	Inspection	The launch vehicle team will apply this information to each individual section, as well as the payload.	Will be verified with construction completion of full-scale rocket.
2.24	*Vehicle Prohibitions*			
2.24.1	*The launch vehicle will not utilize forward canards. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.*	Documentation	Our design does not utilize forward canards.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3 Vehicle Design Details
2.24.2	*The launch vehicle will not utilize forward firing motors.*	Documentation	Our design does not utilize forward motors.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3 Vehicle Design Details

Req. No.	Requirement	Method	Verification	Verification Status
2.24.3	*The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)*	Documentation	Our design does not utilize motors that expel titanium sponges.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3.3 Motor
2.24.4	*The launch vehicle will not utilize hybrid motors.*	Documentation	Our design utilizes a single solid-fuel commercial off-the-shelf standard motor.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3.3 Motor
2.24.5	*The launch vehicle will not utilize a cluster of motors.*	Documentation	Our design utilizes a single solid-fuel commercial off-the-shelf standard motor.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3.3 Motor
2.24.6	*The launch vehicle will not utilize friction fitting for motors.*	Documentation	Our design utilizes a standard Cesaroni motor casing with rear closure and motor retainer.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3.3 Motor
2.24.7	*The launch vehicle will not exceed Mach 1 at any point during flight.*	Documentation	Our design does not exceed Mach 1 at any point in flight.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3.3 Motor

Req. No.	Requirement	Method	Verification	Verification Status
2.24.8	*Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with and unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).*	Docu-mentation	Any vehicle ballast will not exceed 10% of the total unballasted weight of the rocket.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.1.3 Vehicle Design Details
2.24.9	*Transmissions from onboard transmitters will not exceed 250 mW of power.*	Docu-mentation	Transmission from onboard transmitters do not exceed 250 mW of power.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.3.4.2 Transmission Characteristics
2.24.10	*Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of light- weight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.*	Docu-mentation	The vehicle design will not use excessive or dense metal.	Verified with submission of Launch Vehicle Design in PDR. 4.1.3.1.1.2 Material and Construction

7.2.2.1 RECOVERY SUBSYSTEM REQUIREMENTS

Table 64: Recovery system requirements and verification.

Req. No	Requirement	Method	Verification	Verification Status
3.1	*The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.*	Demonstration	Design Parameters: The launch vehicle is designed to deploy the drogue parachute at apogee (nominally 5,000 ft) using no delay. The main parachutes will deploy at 750 and 725 ft.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.3.2 Recovery Process
3.1.1	*The main parachute shall be deployed no lower than 500 feet.*	Demonstration	The lower section main parachute will deploy at 750 ft, while the upper section main parachute will deploy at 725 ft.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.3.2 Recovery Process
3.1.2	*The apogee event may contain a delay of no more than 2 seconds.*	Demonstration	The primary apogee event contains no delay; the backup apogee event contains a 1.0-second delay.	Verified with submission of Launch Vehicle Design in PDR. Reference: 4.3.2 Recovery Process
3.2	*Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.*	Testing	A ground ejection test for the drogue and main parachutes was conducted for the subscale vehicle and will be conducted once full-scale construction is complete.	Subscale ground testing verified, full-scale to be completed after fabrication. Reference: 7.1.1 Launch Vehicle Testing

Req. No	Requirement	Method	Verification	Verification Status
3.3	*At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft·lbf*	Analysis	The correct and appropriate parachute size will be chosen in order to slow the launch vehicle down enough to ensure a kinetic energy of less than 75 ft·lbf. Multiple tests will be simulated. Calculations in this report detail the descent rate and kinetic energy at impact.	Verified with submission of Launch Vehicle Criteria - Recovery Subsystem in PDR. 4.4.4 Kinetic Energy at Landing
3.4	*The recovery system electrical circuits shall be completely independent of any payload electrical circuits.*	Inspection	Recovery electrical system is connected only to the recovery system altimeters. Payload design incorporates a separate power supply. Inspection will be conducted by the safety officer during construction.	Will be verified once fabrication is complete.
3.5	*All recovery electronics will be powered by commercially available batteries.*	Inspection	All recovery electronics will be inspected to ensure they are commercially bought batteries.	Will be verified once fabrication is complete.
3.6	*The recovery system shall contain redundant, commercially available altimeters.*	Inspection	The current design includes redundant, commercially available altimeters. The rocket will use a total of four altimeters, each powered by a separate battery that will not power any other equipment.	Verified with submission of PDR. Reference: 4.3.4 Avionics

Req. No	Requirement	Method	Verification	Verification Status
3.7	*Motor ejection is not a permissible form of primary or secondary deployment.*	Inspection	The launch vehicle design does not include motor ejection as means of deployment.	Verified with submission of PDR.
3.8	*Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.*	Inspection	The launch vehicle has been designed with shear pins at each separation point. Modifications will be made as construction moves along.	Will be verified when construction is complete.
3.9	*Recovery area will be limited to a 2500 ft. radius from the launch pads.*	Analysis/Testing	Drift calculations will be performed to verify that the rocket will not drift outside the landing zone. Testing will be conducted during subscale and full-scale flights to check accuracy of drift calculations.	Preliminary analysis complete. Verification dependent on testing and analysis. of actuals vs theoretical values. Reference: 4.4.6 Drift
3.10	*Descent time will be limited to 90 seconds (apogee to touch down).*	Analysis/Testing	Decent time calculations will be performed and compared to actual flight results to check accuracy of calculations.	Preliminary analysis complete. Verification dependent on testing and analysis. of actuals vs theoretical values. Reference: 4.4.5 Expected Descent Time

Req. No	Requirement	Method	Verification	Verification Status
3.11	*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.*	Inspection	A loud audible beacon transmitter will be included in both altimeters bays separate from the recovery electronics. The beacon will produce a high enough decibel that will allow us to locate the separate sections.	Will be verified when construction is complete.
3.11.1	*Any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.*	Inspection	A loud audible beacon transmitter will be included in both altimeters bays separate from the recovery electronics. The beacon will produce a high enough decibel that will allow us to locate the separate sections.	Will be verified when construction is complete.
3.11.2	*The electronic tracking device will be fully functional during the official flight on launch day.*	Inspection	The sounding beacons will be installed within the avionics bays and will be functional on launch day.	Will be verified when construction is complete.

Req. No	Requirement	Method	Verification	Verification Status
3.12	*The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).*	Testing	The recovery electronics will be housed in avionics bays which will contain no other onboard electronics. Testing will be done to ensure no other electronics affect the recovery electronics.	Will be verified when constructionand testing is complete.
3.12.1	*The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.*	Inspection	The recovery electronics will be housed in avionics bays which will contain no other onboard electronics.	Will be verified when construction is complete.
3.12.2	*The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.*	Inspection	The current design includes no other transmitting devices. Safety Officer will monitor updates to design and all payload and launch operations.	Will be verified when construction is complete.
3.12.3	*The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.*	Inspection	The recovery electronics will be housed in avionics bays which will contain no other onboard electronics. Testing will be done to ensure no other electronics affect the recovery electronics.	Will be verified when construction is complete.

Req. No	Requirement	Method	Verification	Verification Status
3.12.4	*The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.*	Inspection	The airbrakes subsystem and selected payload electronics systems will not interfere or interact in any way with the recovery subsystem.	Will be verified when construction is complete.

7.2.3 PAYLOAD REQUIREMENTS

Table 65: Payload criteria requirements and verification.

Req. No.	Requirement	Method	Verification	Verification Status
4.3.1	*Teams will design a custom rover that will deploy from the internal structure of the launch vehicle.*	Testing	We have designed the rover to be deployed from the internal structure of the launch vehicle using a specially design deployment system.	Verified with submission of payload design. 6.1.2 Payload Deployment Mechanics
4.3.2	*The rover will be retained within the vehicle utilizing a fail-safe active retention system. The retention system will be robust enough to retain the rover if atypical flight forces are experienced.*	Testing	The current design uses a solenoid that will secure the rover in place using magnetic induction. This retaining method was used for our rover last year and was tested during competition week, so we know that it is a valuable design. More testing will be done to test the security of this year's rover design. All testing will be recorded and addressed for success and failure which will be inspected and approved by the safety officer.	Will be verified when testing is conducted. Reference: 6.1.1 Payload Retention

Req. No.	Requirement	Method	Verification	Verification Status
4.3.3	*At landing, and under the supervision of the Remote Deployment Officer, the team will remotely activate a trigger to deploy the rover from the rocket*	Testing	Multiple communication systems are being tested and designed. Multiple wireless communications tests will be conducted. All results will be recorded to effectively choose the best materials to use.	Will be verified when testing is conducted Reference: 6.3.1 Deployment Electronics
4.3.4	*After deployment, the rover will autonomously move at least 10 ft. (in any direction) from the launch vehicle. Once the rover has reached its final destination, it will recover a soil sample.*	Testing	Test will be conducted to measure the capabilities of the rover. We will perform electrical, obstacle detection, and power consumption tests. Each of these tests will contribute to the rovers capability of moving a successful 10 feet.	Will be verified when testing is conducted.
4.3.5	*The soil sample will be a minimum of 10 milliliters (mL).*	Testing	Tests will be conducted in order to measure the amount of soil that the rover can collect.	Will be verified when testing is conducted.

Req. No.	Requirement	Method	Verification	Verification Status
4.3.6	*The soil sample will be contained in an onboard container or compartment. The container or compartment will be closed or sealed to protect the sample after collection.*	Testing	The rover design will include an onboard container in order to protect the soil sample. Testing will be done to test the capabilities of the onboard compartment.	Will be verified when testing is conducted.
4.3.7	*Teams will ensure the rover's batteries are sufficiently protected from impact with the ground.*	Testing	The rover is designed to protect all electrical components. Stress tests will be conducted to ensure the batteries can withstand impact with the ground. In addition to stress test we will use subscale and full-scale flight results to ensure the rover batteries are sufficiently protected and able to survive impact.	To be tested during full-scale launches.
4.3.8	*The batteries powering the rover will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other rover parts.*	Inspection	Proper supplies will be used to ensure that the batteries for the rover are secure, safe for transport, and are distinguishable from other rover components. Shipping guidelines and recommendations from IATA and PHMSA will be considered when marking, labeling, and protecting batteries from impact.	Will be verified during construction of the rover.

7.2.4 SAFETY REQUIREMENTS

Table 66: Safety requirements and verifications.

Req. No.	Requirement	Method	Verification	Verification Status
5.1	*Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.*	Demonstration	Team will use launch and safety checklists. Subscale launch lists and checklists will be made. Final checklists will be included in FRR report and used during LRR and all launch day operations.	Will be verified by FRR.
5.2	*Each team must identify a student safety officer who will be responsible for all items in section 5.3.*	Demonstration	The Safety Officer has been identified and will ensure safety of participants, spectators and other safety procedures as mentioned in the "Launch Safety" section of NSL Student Handbook. All team activities mentioned in section 5.3 will be supervised to meet specific safety requirements	Verified with submission of Project Proposal. Reference: 3.1.7 Safety Officer
5.3	*The role and responsibilities of each safety officer will include, but are not limited to:*			
5.3.1	*Monitor team activities with an emphasis on Safety during:*			

Req. No.	Requirement	Method	Verification	Verification Status
5.3.1.1	*Design of vehicle and payload*	Demon-stration	A safety officer will overview the final de-signs created by the ve-hicle and payload teams and confirm the designs before con-struction begins.	Will be verified over the course of the project.
5.3.1.2	*Construction of vehicle and pay-load*	Demon-stration	A safety officer will be present and monitor teams during the con-struction of the vehicle and payload.	Will be verified when ve-hicle and payload con-struction is complete.
5.3.1.3	*Assembly of vehi-cle and payload*	Demon-stration	A safety officer will be present and monitor teams during the as-sembly of the vehicle and payload.	Will be verified when ve-hicle and payload as-sembly is complete.
5.3.1.4	*Ground testing of vehicle and pay-load*	Demon-stration	A safety officer will be present and monitor teams during ground testing of the vehicle and payload.	Will be verified during vehicle and payload testing.
5.3.1.5	*Subscale launch test(s)*	Demon-stration	A safety officer will be present and monitor teams during subscale launch tests.	Verified with subscale launch test on Decem-ber 15th 2018.
5.3.1.6	*Full-scale launch test(s)*	Demon-stration	A safety officer will be present and monitor teams during full-scale launch tests.	Will be verified during full-scale launch tests.

Req. No.	Requirement	Method	Verification	Verification Status
5.3.1.7	*Launch day*	Demonstration	A safety officer will be present and monitor teams during Launch Day.	Will be verified on launch days.
5.3.1.8	*Recovery activities*	Demonstration	A safety officer will be present and monitor teams during all recovery activities.	Will be verified over the course of the project.
5.3.1.9	*STEM Engagement Activities*	Demonstration	A safety officer will be review and approve of all STEM Activities and will present if there are any safety concerns	Will be verified over the course of the project.
5.3.2	*Implement procedures developed by the team for construction, assembly, launch, and recovery activities.*	Demonstration	The most updated checklist will be completed during every launch. Safety Officer will supervise all operations using the checklist. All SOAR members will abide by the Safety SOP.	Will be verified throughout completion of project milestones. Reference: 5.11 Launch Operation Procedures
5.3.3	*Manage and maintain current revisions of the team's hazard analyses, failure modes analysis, procedures, and MSDS/chemical inventory data.*	Demonstration	The Safety Officer will make sure the MSDS/chemical inventory data is up to date and participants are aware of the safety hazards that could occur.	Will be verified throughout completion of project milestones. Reference: 5.10 Failure Modes and Effects Analysis (FMEA)

Req. No.	Requirement	Method	Verification	Verification Status
5.3.4	*Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.*	Demonstration	Safety Officer will be present throughout the construction of the vehicle and payload which will help guide to write and develop all safety documents and procedures.	Will be verified throughout completion of project milestones. Reference: 5.10 Failure Modes and Effects Analysis (FMEA)
5.4	*During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.*	Demonstration	Safety Officer or designated team lead will supervise all operations to ensure rules and guidance are followed. Before proceeding to test flights, all requirements will be inspected to make sure teams are working accordingly. Effective communication will be taken so the project can run smoothly.	Will be verified throughout the project.

Req. No.	Requirement	Method	Verification	Verification Status
5.5	*Teams will abide by all rules set forth by the FAA.*	Demonstration	Teams will be knowledgeable of all rules from the FAA. The Safety Officer will ensure these rules are being met throughout the whole timeline of the project. Training records for safety training sessions will be maintained on the SOAR share drive.	Will be verified throughout the project. Reference: 5.7 Legal Compliance

7.3 DERIVED REQUIREMENTS

Note: Requirement number is associated with the General Requirements. Each derived requirement number stems from the General Requirement parent. For example, the derived requirement "2.1.1" has the parent general requirement "2.1".

7.3.1 DERIVED VEHICLE REQUIREMENTS

Table 67: Vehicle derived requirements and verifications.

Req. No.	Requirement	Method	Verification	Verification Status
Derived Requirement 2.1.1	The team will design an airbrake system to control the altitude of the rocket to ensure an apogee within 50 feet of the targeted 5,000 feet.	Demonstration	DAAS has been designed to slow down the velocity of the rocket so that it can within ±50 ft. accuracy in altitude.	Verified with submission of CDR. 4.1.3.2.1 Dynamic Apogee Adjustment Subsystem (DAAS)
Derived Requirement 2.1.2	The team will construct and launch the airbrake system prior to FRR to verify systems functionality.	Demonstration	The team will submit final airbrakes design by CDR and complete construction and testing prior to launch day in February.	Will be verified by FRR once full-scale construction and launches have been completed.

Req. No.	Requirement	Method	Verification	Verification Status
Derived Requirement 2.1.3	The batteries powering the airbrakes subsystem will be brightly colored, clearly marked as a fire hazard, and easily distinguishable.	Inspection	Airbrakes subsystem batteries will be contained in a bright, fireproof container.	Will be verified with construction of airbrake system and full-scale vehicle.
2.5.1 Derived Requirement	The batteries powering the altimeters will be brightly colored, clearly marked as a fire hazard, and easily distinguishable.	Inspection	Batteries will be colored in bright red or orange.	Will be verified with construction of full-scale vehicle.
Derived Requirement 2.20.1.1.1	The vehicle subsystems including the Payload Compartment Leveling System and the Airbrake System will have function as designed.	Inspection	The vehicle and recovery system will be observed during and after full-scale launch to ensure it functions as designed.	Will be verified with full-scale demonstration flight.
Derived Requirement 2.20.1.3.1.1	If the airbrake system is not flown, mass simulators will be used to simulate the airbrake system mass.	Demonstration	If an airbrake system is not ready to fly, a simulated mass will be constructed.	Will be verified with full-scale demonstration flight.

7.3.2 DERIVED RECOVERY REQUIREMENTS

Table 68: Recovery Derived requirements and verifications.

Req. No.	Requirement	Method	Verification	Verification Status
Derived Requirement 3.1.1	All launch vehicle recovery subsystem hardware will meet a minimum factor of safety of 3.0.	Analysis	Manual calculations and finite element analysis was conducted to calculate the factor of safety based on component design and material properties.	Verified with completion of CDR. Reference: 4.3.5 Attachment Hardware

7.3.3 DERIVED PAYLOAD REQUIREMENTS

Table 69: Payload Derived requirements and verifications.

Req. No.	Requirement	Method	Verification	Verification Status
Derived Requirement 4.3.1	The rover will implement a deployment system that will successfully eject the rocket from the launch vehicle.	Testing	The team will develop and test a deployment system that will successfully deploy the rover. The payload team will also work with the vehicle team to ensure the rocket comes down in the best way possible for rover deployment.	Will be verified when testing is conducted.
Derived Requirement 4.3.4	The rover will implement an autonomous control system to maximize efficiency in movement.	Testing	Preliminary prototypes have been made to test electrical and mechanical components to ensure driving and steering capabilities can be achieved.	Will be verified when testing is conducted.

Req. No.	Requirement	Method	Verification	Verification Status
Derived Requirement 4.3.5	The rover will utilize a soil compartment of 20 mL in order to ensure sufficient soil collection capacity.	Testing	Tests will be conducted in order to measure the amount of soil that the rover can collect based on the designs tested.	Will be verified when testing is conducted.

8 PROJECT BUDGET AND TIMELINE

8.1 BUDGET

The budget has been constructed based on material costs, planned test launches, subscale launches, and prior years expenses. These are projected costs and are subject to change as the need arises. The budget has been adjusted since the PDR to account for new developments.

Note: A full line-item list of purchases to date can be found in Appendix B: Purchases to Date.

Table 70: Estimated project budget.

Materials	**Budgeted Amount** ($)
Launch Vehicle Materials	5,190.00
Competition Launch Motors	250.00
Test Launch Motors	750.00
Subscale Launch Vehicle Materials	1,508.00
Subscale Test Launch Motor	177.00
Payload	1,275.00
Miscellaneous Hardware	250.00
Travel	1,500.00
Total	*10,400.00*

Budget

TOTAL BUDGET	TOTAL EXPENSES	PERCENT REMAINING
$ 9,433.96	$ 2,579.56	**72.66%**
PERCENT OF YEAR REMAINING	**AMOUNT REMAINING**	**ADJ. % REMAINING (ON TRACK = 100%)**
49.45%	$ 6,854.40	146.93%

PROJECT SHEET	NSL

Categories

CATEGORY	EXPENSES
Uncategorized	$ 39.98
Vehicle Supplies	$ 384.54
Vehicle Tools	$ 212.42
Payload Supplies	$ 420.43
Payload Tools	$ 14.16
NSL General	$ -
Subscale Supplies	$ 1,508.03
Travel	$ -
	$ -
	$ -
	$ -
	$ -
TOTAL	**$ 2,579.56**

Figure 99: Current project budget status overview as of January 1, 2019.

8.2 TIMELINE

8.2.1 GENERAL TIMELINE

Table 71: General project timeline.

Date	Item Due	Team Responsible	Status
August 29th, 2018	NSL General Team Meeting	Payload Team, Vehicle Team	Complete
September 5th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
September 6th, 2018	NSL Handover Meeting	Entire NSL Team	Complete
September 12th, 2018	NSL General Team Meeting	Entire NSL Team	Complete

Date	Item Due	Team Responsible	Status
September 14th, 2018	NSL Proposal Group Writing Session	Entire NSL Team	Complete
September 19th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
September 19th, 2018	NSL Project Proposal Due	Entire NSL Team	Complete
September 26th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
October 3rd, 2018	NSL General Team Meeting	Entire NSL Team	Complete
October 9th, 2018	Outreach Event: Transfer Day	Entire NSL Team	Complete
October 10th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
October 13th, 2018	Outreach Event: Stampede	Entire NSL Team	Complete
October 17th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
October 24th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
October 31st, 2018	NSL General Team Meeting	Entire NSL Team	Complete
November 2nd, 2018	NSL PDR Due Date	Entire NSL Team	Complete
November 7th, 2018	NSL PDR Presentation	NSL Team Presenters	Complete

Date	Item Due	Team Responsible	Status
November 9th, 2018	Outreach Event: Manatee County Engineering Day	Entire NSL Team	Complete
November 10th, 2018	Outreach Event: MOSI Drone Event	Entire NSL Team	Complete
November 13th, 2018	Great American Teach-In Planning Meeting	Entire NSL Team	Complete
November 14th, 2018	Outreach Event: Great American Teach-In Pinellas County	Entire NSL Team	Complete
November 15th, 2018	Outreach Event: Great American Teach-In Hillsborough County	Entire NSL Team	Complete
November 16th, 2018	Outreach Event: Mount Calvary Junior Academy School Visit	Entire NSL Team	Complete
November 17th, 2018	Outreach Event: Bulls Unite Day	Entire NSL Team	Complete
December 14th, 2018	CDR Writing Session 1	Entire NSL Team	Complete
December 17th, 2018	CDR Writing Session 2	Entire NSL Team	Complete
December 28th, 2018	CDR Content due for Formatting	Entire NSL Team	Complete
January 1st, 2018	Complete Formatted CDR due to Team Lead	Designated Formatting Team Member	Complete
January 2nd, 2018	Complete CDR Presentation Due to Team Lead	Project Manager	Complete
January 4th, 2019	NSL CDR Due to NASA	Entire NSL Team	Complete

Date	Item Due	Team Responsible	Status
January 5th, 2019	Submit Purchase Order for All Additional Vehicle Full-Scale parts	Vehicle Team	
January 5th, 2019	Submit Purchase Order for All Additional Payload parts	Payload Team	
January 8th, 2018	Outreach Event: Spring Student Organization Showcase	Entire NSL Team	
January 9th, 2019	Girl Scouts Planning Meeting	Entire NSL Team	
January 17th, 2019	Outreach Event: Pinellas County Engineering Day	Entire NSL Team	
January 24th, 2019	FRR Q & A	Entire NSL Team	
January 25th, 2019	FRR outline due	Student Advisor	
January 25th, 2019	FRR writing session 1	Entire NSL Team	
January 26th, 2019	Outreach Event: Girl Scouts of West Central Florida	Entire NSL Team	
January 27th, 2019	Outreach Event: Girl Scouts of West Central Florida	Entire NSL Team	
January 29th, 2019	CDR Presentation	Entire NSL Team	
February 1st, 2019	FRR writing session 2	Entire NSL Team	
February 2nd, 2019	Outreach Event: Bulls Unite Day	Entire NSL Team	

Date	Item Due	Team Responsible	Status
February 3rd, 2019	Outreach Event: Girl Scouts of West Central Florida	Entire NSL Team	
February 6th, 2019	NSL General Team Meeting	Entire NSL Team	
February 8th, 2019	FRR writing session 3	Entire NSL Team	
February 9th, 2019	Outreach Event: Girl Scouts of West Central Florida	Entire NSL Team	
February 9th, 2019	Full-Scale Vehicle and Payload Construction Complete	Vehicle Team and Payload Team	
February 13th, 2019	NSL General Team Meeting	Entire NSL Team	
February 15th, 2019	Outreach Event: Engineering Expo	Entire NSL Team	
February 16th, 2019	Outreach Event: Engineering Expo	Entire NSL Team	
February 16th, 2019	Full-Scale and Payload Test Launch 1	Entire NSL Team	
February 17th, 2019	FRR writing session 4	Entire NSL Team	
February 20th, 2019	NSL General Team Meeting	Entire NSL Team	
February 22nd, 2019	FRR content due for Formatting	Entire NSL Team	
February 27th, 2019	NSL General Team Meeting	Entire NSL Team	

Date	Item Due	Team Responsible	Status
February 27th, 2019	FRR Formatting due to Team Lead	Designated Formatting Team Member	
March 1st, 2019	FRR Presentation due to Team Lead	Project Manager	
March 4th, 2019	NSL FRR Due Date	Entire NSL Team	
March 6th, 2019	NSL General Team Meeting	Entire NSL Team	
March 13th, 2019	NSL General Team Meeting	Entire NSL Team	
April 3rd, 2019	Team Leaves for Huntsville	Entire NSL Team	
April 6th, 2019	Competition Day	Entire NSL Team	
April 12th, 2019	PLAR writing session 1	Entire NSL Team	
April 13th, 2019	PLAR writing session 2	Entire NSL Team	
April 18th, 2019	PLAR Content due for formatting to Team Lead	Entire NSL Team	
April 25th, 2019	PLAR Formatting Completed to Team Lead	Designated Formatting Team Member	
April 26th, 2019	NSL Post-Launch Assessment Review Due Date	Entire NSL Team	

8.2.2 VEHICLE TIMELINE

Table 72: Vehicle-specific project timeline.

Date	Item Due	Team Responsible	Status
August 31th, 2018	NSL Vehicle Team Meeting	Vehicle Team	Complete
September 10th, 2018	X-Winder Training Session	Vehicle Team	Complete
September 24th, 2018	Order All Materials for Initial Carbon Fiber Testing	Vehicle Team	Complete
September 27th, 2018	Subscale Design Finalized	Vehicle Team	Complete
September 30th, 2018	Order Materials and Hardware for Subscale Launch Vehicle	Vehicle Team	Complete
October 30th, 2018	Order Motors and Parachutes for Subscale Launch Vehicle	Vehicle Team	Complete
November 18th, 2018	Construction of Subscale Launch Vehicle	Vehicle Team	Complete
November 20th, 2018	Vehicle Team Meeting	Vehicle Team	Complete
November 25th, 2018	Construction of Subscale Launch Vehicle	Vehicle Team	Complete
November 27th, 2018	Vehicle Team Meeting	Vehicle Team	Complete
November 28th, 2018	Vehicle Team Meeting	Vehicle Team	Complete
December 2nd, 2018	Construction of Subscale Launch Vehicle	Vehicle Team	Complete

Date	Item Due	Team Responsible	Status
December 9th, 2018	Construction of Subscale Launch Vehicle	Vehicle Team	Complete
December 10th, 2018	Construction of Subscale Launch Vehicle	Vehicle Team	Complete
December 11th, 2018	Construction of Subscale Launch Vehicle/Team Meeting	Vehicle Team	Complete
December 12th, 2018	Construction of Subscale Launch Vehicle/Team Meeting	Vehicle Team	Complete
December 13th, 2018	Construction of Subscale Launch Vehicle/Team Meeting	Vehicle Team	Complete
December 14th, 2018	Subscale Launch Prep	Vehicle Team	Complete
December 15th, 2018	Subscale Launch Day & Ground Testing	Vehicle Team	Complete
December 16th, 2018	Subscale Post-Launch Inspection	Vehicle Team	Complete
December 19th, 2018	Vehicle Team Meeting	Vehicle Team	Complete
January 6th, 2019	Begin Vehicle full-scale construction	Vehicle Team	
January 19th, 2019	Second Subscale Test Launch	Vehicle Team	
January 20th, 2019	Post-Launch Subscale Inspection	Vehicle Team	
February 16th, 2019	Full-Scale Initial Test Launch, Ground Testing, Airbrakes Test, and Payload Launch Test	Vehicle Team, Payload Team, DAAS Subteam	

Date	Item Due	Team Responsible	Status
February 17th, 2019	Post-Launch Full-Scale Rocket Inspection	Vehicle Team, Airbrakes Subteam	
March 15th, 2019	Prepare Full-Scale Rocket for Relaunch	Vehicle Team	
March 16th, 2019	Full-Scale Payload & Airbrakes Second Test Launch	Vehicle Team, Payload Team, DAAS Subteam	
March 17th, 2019	Post-Launch Full-Scale Rocket Inspection	Vehicle Team, DAAS Subteam	
March 30th, 2019	Prepare Full-Scale Rocket for Competition Week	Vehicle Team	

8.2.3 PAYLOAD TIMELINE

Table 73: Payload-specific project timeline.

Date	Item Due	Team Responsible	Status
August 23rd, 2018	NSL Payload Team Meeting	Payload Team	Complete
August 30th, 2018	NSL Payload Team Meeting	Payload Team	Complete
September 6th, 2018	NSL Payload Team Meeting	Payload Team	Complete
September 13th, 2018	NSL Payload Team Meeting	Payload Team	Complete
September 20th, 2018	NSL Payload Team Meeting	Payload Team	Complete

Date	Item Due	Team Responsible	Status
September 20th, 2018	NSL Payload Team Meeting	Payload Team	Complete
October 4th, 2018	NSL Payload Team Meeting	Payload Team	Complete
October 10th, 2018	Wireless Communications tests will be conducted for RF components	Payload Team	Complete
October 25th, 2018	NSL Payload Team Meeting / complete initial prototype of the rover	Payload Team	Complete
November 1st, 2018	NSL Payload Team Meeting	Payload Team	Complete
November 8th, 2018	NSL Payload Team Meeting	Payload Team	Complete
January 3rd, 2018	NSL Payload Team Meeting	Payload Team	Complete
January 10th, 2018	NSL Payload Team Meeting	Payload Team	
January 17th, 2018	NSL Payload Team Meeting	Payload Team	
January 19th, 2019	Second Subscale Rocket Test Launch/Payload Test	Vehicle Team, Payload Team	
January 21st, 2019	Post-Launch Payload Inspection	Payload Team	
January 24th, 2018	NSL Payload Team Meeting	Payload Team	
January 31st, 2018	NSL Payload Team Meeting	Payload Team	

Date	Item Due	Team Responsible	Status
February 7th, 2018	NSL Payload Team Meeting	Payload Team	
February 14th, 2018	NSL Payload Team Meeting	Payload Team	
February 16th, 2019	Full-Scale Rocket Test Launch/Test Payload	Vehicle Team, Payload Team	
February 17th, 2019	Post-Launch Full-Scale Payload Inspection	Payload Team	
February 21st, 2018	NSL Payload Team Meeting	Payload Team	
February 28th, 2018	NSL Payload Team Meeting	Payload Team	
March 7th, 2018	NSL Payload Team Meeting	Payload Team	
March 14th, 2018	NSL Payload Team Meeting	Payload Team	
March 21st, 2018	NSL Payload Team Meeting	Payload Team	
March 28th, 2018	NSL Payload Team Meeting	Payload Team	

9 EDUCATIONAL ENGAGEMENT

The Society of Aeronautics and Rocketry participates in multiple educational events for our university and surrounding communities. Plans are in place to organize events with local schools and clubs to inform students on our projects and teach them the importance of STEM Education.

9.1 COMPLETED EVENTS

As of January 1, 2018, 6 outreach events were completed and a total of 657 students had been engaged with.

Table 74: Completed outreach events.

Event	Date	Participants	Description
Stampede	Oct 13, 2018	200	For this event, there was a College Facility Tour with visits to student organization/research tables on the tour. Members of our team set up a booth to talk to local high school students about our organization and the various projects we work on. We brought some of our rockets to display. We explained to students how different disciplines and majors are incorporated into our projects to fill the engineering, business, and administrative aspects of our teams.

Event	Date	Partici-pants	Description
Manatee County Engineering Day	Nov 09, 2018	50	For this event, there was college lab tours and demonstrations with visits to student organization/research tables. Members of our team set up a booth to talk to local high school students about our organization and the various projects we work on. We brought some of our larger rockets that were built for specific competitions and one of our Tripoli Level 1 certification rockets. We showed students the parts of the rockets including the parachutes, fins, and nosecones. We discussed the specific design of each rocket and what its function was. We shared with students what possibilities our university and organization can provide for them especially when it comes to valuable hands-on STEM experience. We explained to students how different disciplines and majors are incorporated into our projects to fill the engineering, business, and administrative aspects of our teams.
Museum of Science and Industry Drone Event	Nov 10, 2018	200	Our team was asked to participate at MOSI's drone event and work with some of their students who are a part of their Maker's Club. We had a table and showcased some of our rockets at the Drone Event.
Great American Teach in Pinellas County at Carwise Middle School	Nov 14, 2018	20	For this event, USF SOAR went to Carwise Middle School, a school in Pinellas County, to demonstrate and engage students in a hands-on STEAM activity. We taught the students how to make stomp rockets and launched them.
Great American Teach in Hillsborough County at McLane Middle School	Nov 15, 2018	51	For this event, USF SOAR went to McLane Middle School, a school in Pinellas County, to demonstrate and engage students in a hands-on STEAM activity. We taught the students how to make stomp rockets and launched them.

Event	Date	Partici-pants	Description
Mount Calvary Junior Academy School Visit	Nov 16, 2018	61	For this event SOAR went to the school Mount Calvary Junior Academy in order to teach them about rocketry and STEM education. We taught the students how to make stomp rockets and launched them.
Bulls Unite Day	Nov 17, 2018	75	For this event, there was a College Facility Tour with visits to student organization/research tables on the tour. Members of our team set up a booth to talk to local high school students about our organization and the various projects we work on.

9.2 UPCOMING EVENTS

There are multiple outreach events planned for the spring 2019 semester.

Table 75: Upcoming outreach events.

Event	Date	Projected Partici-pants	Description
Spring Student Organization Showcase	Jan 8, 2019	TBD	For this event, students at USF will be able to see student organization/research tables that they may be interested in joining. Members of our team will set up a booth to talk to other students about our organization and the various projects we work on. We will bring some of our rockets. We will explain to students how different disciplines and majors are incorporated into our projects to fill the engineering, business, and administrative aspects of our teams.

Event	Date	Projected Partici-pants	Description
Pinellas County Engineering Day	Jan 17, 2019	120	For this event, there will be college lab tours and demonstrations with visits to student organization/research tables. Members of our team will set up a booth to talk to local high school students about our organization and the various projects we work on. We will bring some of our rockets. We want to share with students what possibilities our university and organization can provided for them especially when it comes to valuable hands-on STEM experience. We will explain to students how different disciplines and majors are incorporated into our projects to fill the engineering, business, and administrative aspects of our teams.
Girl Scouts of West Central Florida	Jan 26, 2019	40	Girl Scout Troops will be coming to USF to learn the basics of Rocketry and how to create and launch their very own stomp rocket. Through this lesson the Girl Scouts will be able to earn their Mechanical Engineering: Fling Flyer Badge.
Girl Scouts of West Central Florida	Jan 27, 2019	45	Girl Scout Troops will be coming to USF to learn the basics of Rocketry and how to create and launch their very own stomp rocket. Through this lesson the Girl Scouts will be able to earn their Mechanical Engineering: Fling Flyer Badge.
Bulls Unite Day	Feb 02, 2019	150	For this event, there will be a College Facility Tour with visits to student organization/research tables on the tour. Members of our team will set up a booth to talk to local high school students about our organization and the various projects we work on. We will bring some of our rockets. We will explain to students how different disciplines and majors are incorporated into our projects to fill the engineering, business, and administrative aspects of our teams.

Event	Date	Projected Partici-pants	Description
Girl Scouts of West Central Florida	Feb 3, 2019	35	Girl Scout Troops will be coming to USF to learn the basics of Rocketry and how to create and launch their very own stomp rocket. Through this lesson the Girl Scouts will be able to earn their Mechanical Engineering: Fling Flyer Badge.
Girl Scouts of West Central Florida	Feb 9, 2019	45	Girl Scout Troops will be coming to USF to learn the basics of Rocketry and how to create and launch their very own stomp rocket. Through this lesson the Girl Scouts will be able to earn their Mechanical Engineering: Fling Flyer Badge.
Engineering Expo	Feb 14-15, 2019	TBD	The Engineering Expo is a two-day event that features hands-on exhibits and shows that help encourage more students to pursue careers in the STEM fields. This event provided us with an opportunity to teach local students about our organization and how the value of a STEM education and experience. We plan to engage these students with an interactive activity that will inspire them to seek a future in STEM and hopefully rocketry.

10 ABBREVIATIONS

ABS
: Adjustable Ballast Subsystem

AGL
: Above Ground Level

APCP
: Ammonium Perchlorate Composite Propellant

Apis III
: Full-scale launch vehicle

Apis III-S
: Subscale launch vehicle

CAD
: Computer Aided Design

CAR
: Canadian Association of Rocketry

CDR
: Critical Design Review

CF
: Carbon Fiber

CFR
: Code of Federal Regulations

CG or C_G
: Center of Gravity

CNC
: Computer Numerical Control

CP or C_P
: Center of Pressure

DAAS
: Dynamic Apogee Adjustment Sub-system

dBi
: Decibels-isotropic

deg
: Degrees

E-Match
: Electronic match

FAR
: Federal Aviation Regulations

FEA
: Finite Element Analysis

FMEA
: Failure Modes and Effects Analysis

FOS
: Factor of Safety

fps
: Feet per second

FRP
: Fiberglass-Reinforced Plastic

FRR
: Flight Readiness Review

LiPo
: Lithium Polymer

MSDS
: Materials Safety Data Sheet

NAR
: National Association of Rocketry

NASA
: National Aeronautics and Space Administration

NFPA
: National Fire Protection Agency

PDLS
Payload Descent Leveling Subsystem

PDLS-S
Payload Descent Leveling Subsystem - Subscale

PDR
Preliminary Design Review

PLAR
Post Launch Assessment Review

PVC
Polyvinyl Chloride

RAC
Risk Assessment Category

Req. No.
Requirement Number

ROAR
Regional Orlando Applied Rocketry

RF
Radiofrequency

RSO
Range Safety Officer

SDS
Safety Data Sheet; equivalent to MSDS

SO
Safety Officer

SOAR
Society of Aeronautics and Rocketry

STP
Standard Temperature and Pressure

TRA
Tripoli Rocketry Association

USF
University of South Florida

11 BIBLIOGRAPHY

Apogee Components. 2018. *AeroPack 75mm Retainer (Flanged).* Accessed December 31, 2018. https://www.apogeerockets.com/Building_Supplies/Motor_Retainers_Hooks/Screw-On_Retainers/75mm_AeroPack_Retainer_Flanged.

b2 Rocketry Company. n.d. "SkyAngle Classic / Classic II Series." *b2 Rocketry.* http://www.b2rocketry.com/Classic.htm.

Benson, Tom. n.d. *Velocity During Recovery.* Accessed December 31, 2018. https://www.grc.nasa.gov/www/k-12/VirtualAero/BottleRocket/airplane/rktvrecv.html.

E-Switch. n.d. *Series KO Switches Catalog.* Accessed December 31, 2018. https://www.e-switch.com/system/asset/product_line/data_sheet/20/KO.pdf.

Fruity Chutes. n.d. *Iris Ultra 60" Standard Parachute.* Accessed January 1, 2018. https://fruitychutes.com/buyachute/iris-ultra-standard-chutes-c-29/iris-ultra-60-standard-parachute-19lbs-20fps-p-87.html.

—. 2017. *Iris Ultra 84" Standard Parachute.* Accessed December 31, 2018. https://fruitychutes.com/buyachute/iris-ultra-standard-chutes-c-29/iris-ultra-84-standard-parachute-39lbs-20fps-p-144.html?zenid=272da9b0ed54b291bc3cbe3eb7dc8d59.

—. 2017. *Iris Ultra 96 Standard Parachute.* Accessed December 31, 2018. https://fruitychutes.com/buyachute/iris-ultra-standard-chutes-c-29/iris-ultra-96-standard-parachute-50lbs-20fps-p-145.html.

Linx Technologies. 2013. *ANT-916-CW-HW Data Sheet.* Merlin, November 18. https://linxtechnologies.com/wp/wp-content/uploads/ant-916-cw-hw.pdf.

McMaster-Carr. n.d. *18-8 Stainless Steel Threaded Rod.* Accessed December 31, 2018. https://www.mcmaster.com/98805A031.

—. n.d. *Eye-to-Eye Swivel.* Accessed December 31, 2018. https://www.mcmaster.com/3714t92.

—. n.d. *Oval Shaped Threaded Connecting Link.* Accessed December 21, 2018. https://www.mcmaster.com/3711t34.

—. n.d. *Structural Fiberglass Sheet.* Accessed December 31, 2018. https://www.mcmaster.com/8537k24.

—. n.d. *View catalog page.* Accessed December 31, 2018. https://www.mcmaster.com/8896t71.

Missile Works. n.d. *RRC3 Altimeter System.* Accessed December 31, 2018. https://www.missileworks.com/rrc3/.

—. n.d. *RTx/GPS System.* Accessed December 31, 2018. https://www.missileworks.com/rtx/.

NASA. 2016. "Workmanship Standard for Crimping, Interconnecting Cables, Harnesses, and Wiring." Technical Standard, Washington, DC. https://nepp.nasa.gov/files/27631/NSTD87394A.pdf.

Richard, Barton L. 1967. *Scale Factors for Parachute Opening.* Technical Note, Manned Spacecraft Center, NASA, Houston: CFSTI. Accessed December 31, 2018. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19670026449.pdf.

ThrustCurve. 2014. "Cesaroni K570." *ThrustCurve.* June 26. Accessed December 31, 2018. http://www.thrustcurve.org/motorsearch.jsp?id=330.

—. 2014. "Cesaroni L2375." *ThrustCurve.* July 26. Accessed December 31, 2018. http://www.thrustcurve.org/motorsearch.jsp?id=611.

Top Flight Recovery, LLC. n.d. *Shock Cords.* Accessed December 31, 2018. https://topflightrecoveryllc.homestead.com/harnesses.html.

Tower Hobbies. n.d. *Kinexsis 3.7V 500mAh 1S 25C LiPo: Blade.* Accessed December 31, 2018. https://www.towerhobbies.com/cgi-bin/wti0001p?&I=LXHBUE.

Appendix A: CONTRIBUTORS

- **Report Editing and Formatting**
  - Ian Sanders
- **Project Plan**
  - Sara Vlhova
  - Ashleigh Stevenson
- **Vehicle**
  - Ian Sanders
  - Dhairya Soni
  - Mrudit Trivedi
  - Benjamin Bortz
  - Javian Hernandez
  - Jackson Stephenson
  - Stefan Johnson
- **Payload**
  - Thomas Hall
  - Arnold Perez
  - John Russell
  - Brian Alvarez
  - Ryan Carlomany
- **Educational Engagement**
  - Sara Vlhova
  - Madison Kozee
  - Ashleigh Stevenson
- **Safety**
  - Sara Vlhova
  - Ashley De Kort
  - Stephanie Baumann

Appendix B: PURCHASES TO DATE

This page intentionally left blank. Table begins on following page.

Item Description	Supplier	Unit Price	Quantity	Total Price	Category
Copper Tubing for Drinking Water, 2 feet, 1 1/8" OD, Low Pressure	McMaster-Carr	$9.12	1	$9.12	Vehicle Tools
Raspberry Pi 3.0 B+	Amazon	$39.70	1	$39.70	Payload Supplies
TB6612 Motor Driver Breakout Board	Amazon	$7.49	1	$7.49	Payload Supplies
DROK Voltage Stepdown Converter	Amazon	$11.58	1	$11.58	Payload Supplies
Raspberry Pi Case	Amazon	$5.59	1	$5.59	Payload Supplies
Grafix R05DC4025 Clear .005 Dura-Lar 40-Inch-by-25-Feet, Roll	Amazon	$32.78	1	$32.78	Vehicle Supplies
CROWN Mold Release and Protector 13 oz. Aerosol Can	Huron Industrial Supply	$5.90	2	$11.80	Vehicle Supplies
Scotch Heavy Duty Shipping Packaging Tape, 1.88 inches x 800 inches, 6 Rolls with Dispenser, 1.5 inch Core (142-6)	Amazon	$11.64	1	$11.64	Vehicle Supplies
820Resin Gal 824Slow Hardnr 0.2Gal pumps 114.99USD	Soller Composites	$114.99	1	$114.99	Vehicle Supplies
FNC4.0-4.5-1-VK-FW-MT	Wildman Rocketry	$69.00	1	$69.00	Subscale Supplies
G12CT-4.0	Wildman Rocketry	$2.60	24	$62.40	Subscale Supplies
G12-4.0 / 4 Foot Piece	Wildman Rocketry	$93.40	2	$186.80	Subscale Supplies
Structural Fiberglass Sheet / 24" Wide x 24" Long, 1/8" Thick	McMaster-Carr	$42.49	1	$42.49	Subscale Supplies
U-Bolt / with Mount Plate, Zinc-Plated Steel, 3/8"-16 Thread Size, 1-1/2" ID	McMaster-Carr	$1.85	4	$7.40	Subscale Supplies

Item Description	Supplier	Unit Price	Quantity	Total Price	Category
Oval Shaped Threaded Connecting Link / Zinc-Plated Steel, 5/16" Thickness, 3/8" Opening, Not for Lifting	McMaster-Carr	$2.44	4	$9.76	Subscale Supplies
RRC2+ Altimeter	Missile Works	$44.95	2	$89.90	Subscale Supplies
RRC3 Sport Altimeter	Missile Works	$69.95	2	$139.90	Subscale Supplies
1/4" Tubular Kevlar Shock Cord	Top Flight Recovery	$2.50	17	$42.50	Subscale Supplies
FCP18X18	Wildman Rocketry	$10.95	3	$32.85	Subscale Supplies
2-Pole Rotary Switch	Missile Works	$4.75	4	$19.00	Subscale Supplies
Battery Holder / for 9V Battery, Snap Holder	McMaster-Carr	$2.86	4	$11.44	Subscale Supplies
Adhesive-Mount Nut / Zinc-Plated Steel, 5/16"-18 Thread Size	McMaster-Carr	$7.46	1	$7.46	Subscale Supplies
Thread-Locking Button Head Hex Drive Screws / Alloy Steel, 5/16"-18 Thread, 1/2" Long	McMaster-Carr	$3.12	1	$3.12	Subscale Supplies
RA54	Wildman Rocketry	$38.00	1	$38.00	Subscale Supplies
G12-2.1 / 2 Foot Piece	Wildman Rocketry	$28.80	1	$28.80	Subscale Supplies
18-8 Stainless Steel Countersunk Washer / for 5/16" Screw Size, 0.38" ID, 0.891" OD	McMaster-Carr	$7.37	1	$7.37	Subscale Supplies

Item Description	Supplier	Unit Price	Quantity	Total Price	Category
Female Threaded Hex Standoff / Zinc-Plated 12L14 Steel, 3/16" Hex, 1/2" Long, 4-40 Thread	McMaster-Carr	$1.50	10	$15.00	Subscale Supplies
High-Strength Steel Nylon-Insert Locknut / Grade 8, 3/8"-16 Thread Size	McMaster-Carr	$3.20	1	$3.20	Subscale Supplies
Cast Wire Rope Clamp - Not for Lifting / Zinc-Plated Iron, for 1/16" Rope Diameter	McMaster-Carr	$0.37	4	$1.48	Vehicle Supplies
18-8 Stainless Steel Wire - Not for Lifting / Extra Flexible, 7x19 Construction, 1/16" Diameter	McMaster-Carr	$9.70	1	$9.70	Vehicle Supplies
TowerPro MG90S Mirco Servo	Amazon	$8.99	1	$8.99	Payload Supplies
4 Channel Relay	Amazon	$7.59	4	$30.36	Payload Supplies
Battery Charger	Amazon	$31.44	1	$31.44	Payload Supplies
1300 mAh Batteries	Amazon	$23.43	3	$70.29	Payload Supplies
130 pack jumper wires	Amazon	$7.89	1	$7.89	Payload Tools
Alligator clips 10 pack	Amazon	$6.27	1	$6.27	Payload Tools
12V DC 250N Electric Lifting Magnet	Amazon	$11.59	3	$34.77	Payload Supplies
Hand Vacuum	Amazon	$19.99	1	$19.99	Payload Supplies
Pulley,Gear,belt kit	Amazon	$7.99	1	$7.99	Payload Supplies
IR Remote Control Kit	Amazon	$5.58	1	$5.58	Payload Supplies
L298N Motor Driver 2 pack	Amazon	$9.89	1	$9.89	Payload Supplies
IR Proximity Sensor	Amazon	$9.99	1	$9.99	Payload Supplies
Collision sensor	Amazon	$5.16	1	$5.16	Payload Supplies
PhotoResistors	Amazon	$5.35	1	$5.35	Payload Supplies
Smart Electronics 3pin KEYES KY-017 Mercury Switch Module for Arduino diy Starter Kit KY017	Newegg	$4.48	1	$4.48	Payload Supplies

Item Description	Supplier	Unit Price	Quantity	Total Price	Category
Pressure/Altitude/Temperature Sensor	Amazon	$11.99	1	$11.99	Payload Supplies
1 Kg PLA Spool - Gray	Amazon	$19.99	2	$39.98	Uncategorized
High Performance Solid Carbide Fiberglass and Composite Cutting AlTiN Coated End Mill Router Bits / 1/8" End Mill	Tools Today	$23.50	1	$23.50	Vehicle Tools
High Precision Steel Router Collet Reducers / 1/4" - 1/8"	Tools Today	$10.85	1	$10.85	Vehicle Tools
Cesaroni K570-17A Classic Rocket Motor	Chris' Rocket Supplies	$151.99	1	$151.99	Subscale Supplies
20" SkyAngle Classic	Chris' Rocket Supplies	$20.00	1	$20.00	Subscale Supplies
Cert-3 Large SkyAngle	Chris' Rocket Supplies	$139.00	1	$139.00	Subscale Supplies
51" SkyAngle Classic	Chris' Rocket Supplies	$75.00	1	$75.00	Subscale Supplies
VNH5019 Motor Driver Carrier	Pololu	$24.95	2	$49.90	Payload Supplies
Sparkfun XBee Explorer Dongle	Amazon	$24.95	2	$49.90	Payload Supplies
Fusion Climb Aluminum Figure 8 Descender Rigging Plate Black Heavy Duty	Amazon	$9.95	1	$9.95	Subscale Supplies
Epic Peak Rescue Figure 8 Descender Large Bentear, Belaying and Rappelling with Free Decal	Amazon	$17.99	1	$17.99	Subscale Supplies
6 INCH FILAMENT WOUND 5 TO 1 VON KARMAN NOSECONE WITH METAL TIP	Wildman Rocketry	$129.00	1	$129.00	Vehicle Tools
Cesaroni 54-5 Grain Case	Chris' Rocket Supplies	$107.99	1	$107.99	Subscale Supplies

Item Description	Supplier	Unit Price	Quantity	Total Price	Category
Cesaroni 54mm Rear Closure	Chris' Rocket Supplies	$47.99	1	$47.99	Subscale Supplies
2-Pole Rotary Switch	Missile Works	$4.75	1	$4.75	Subscale Supplies
RRC2+ Altimeter	Missile Works	$44.95	1	$44.95	Subscale Supplies
RTx/RRC3 Bluetooth Master Module	Missile Works	$14.95	2	$29.90	Subscale Supplies
LCD Terminal	Missile Works	$39.95	1	$39.95	Vehicle Tools
18-8 Stainless Steel Socket Head Screw 4-40 Thread Size, 1/4" Long	McMaster-Carr	$3.92	1	$3.92	Subscale Supplies
Female Threaded Hex Standoff Zinc-Plated 12L14 Steel, 3/16" Hex, 1/2" Long, 4-40 Thread	McMaster-Carr	$1.50	10	$15.00	Subscale Supplies
Flanged Wing Nut 1/4"-20 Thread Size, 1" Wide	McMaster-Carr	$9.52	1	$9.52	Subscale Supplies
Clear High-Strength UV-Resistant Acrylic 24" x 24" x 1/8"	McMaster-Carr	$23.61	1	$23.61	Vehicle Supplies
Extreme-Temperature Powder Lubricant 0.21 oz. Tube	McMaster-Carr	$2.31	1	$2.31	Vehicle Supplies
Rotary Shaft 12L14 Carbon Steel, 1/8" Diameter, 3" Long	McMaster-Carr	$2.93	6	$17.58	Vehicle Supplies
Keyed Rotary Shaft 1045 Carbon Steel, 5/16" Diameter, 12" Long	McMaster-Carr	$16.33	1	$16.33	Vehicle Supplies
Set Screw Shaft Collar for 1/8" Diameter, Zinc-Plated 1215 Carbon Steel	McMaster-Carr	$1.03	12	$12.36	Vehicle Supplies

Item Description	Supplier	Unit Price	Quantity	Total Price	Category
Clamping Shaft Collar for 5/16" Diameter, Black-Oxide 1215 Carbon Steel	McMaster-Carr	$2.20	6	$13.20	Vehicle Supplies
Battery Holder for 9V Battery, Snap Holder	McMaster-Carr	$2.86	10	$28.60	Vehicle Supplies
Clear High-Strength UV-Resistant Acrylic 24" x 24" x 5/16"	McMaster-Carr	$64.87	1	$64.87	Vehicle Supplies
Clear High-Strength UV-Resistant Acrylic 24" x 24" x 1/16"	McMaster-Carr	$15.85	1	$15.85	Vehicle Supplies
18-8 Stainless Steel Button Head Hex Drive Screw 4-40 Thread, 2" Long	McMaster-Carr	$7.44	1	$7.44	Vehicle Supplies
18-8 Stainless Steel Hex Nut 4-40 Thread Size	McMaster-Carr	$2.91	1	$2.91	Subscale Supplies
Nylon Unthreaded Spacers 1/2" OD, 1" Long, Black	McMaster-Carr	$5.39	2	$10.78	Subscale Supplies

Appendix C: MILESTONE REVIEW FLYSHEET

This page intentionally left blank. Flysheet begins on following page.

Milestone Review Flysheet 2018-2019

Institution	University of South Florida	Milestone	CDR

Vehicle Properties

Total Length (in)	141
Diameter (in)	6
Gross Lift Off Weight (lb)	53.9
Airframe Material(s)	Fiberglass
Fin Material and Thickness (in)	Carbon Fiber, 1/8
Coupler Length(s)/Shoulder Length(s) (in)	6 (Typ.), 5 (Nose Cone)

Motor Properties

Motor Brand/Designation	Cesaroni L2375
Max/Average Thrust (lb)	629, 551
Total Impulse (lbf-s)	1093
Mass Before/After Burn (lb)	9.17, 4.05
Liftoff Thrust (lb)	551
Motor Retention Method	75mm Aero Pack Flanged Retainer

Stability Analysis

Center of Pressure (in. from nose)	102
Center of Gravity (in. from nose)	87.6
Static Stability Margin (on pad)	2.40
Static Stability Margin (at rail exit)	2.48
Thrust-to-Weight Ratio	10.22
Rail Size/Type and Length (in)	Type 1515, 144
Rail Exit Velocity (ft/s)	76.7

Ascent Analysis

Maximum Velocity (ft/s)	608
Maximum Mach Number	0.54
Maximum Acceleration (ft/s^2)	328
Target Apogee (ft)	5000
Predicted Apogee (From Sim.) (ft)	5025

Recovery System Properties - Overall

Total Descent Time (s)	84.1
Total Drift in 20 mph winds (ft)	2466.65

Recovery System Properties - Energetics

Ejection System Energetics (ex. Black Powder)		Black Powder
Energetics Mass - Drogue Chute (grams)	Primary	TBD (with ejection tests)
	Backup	TBD (with ejection tests)
Energetics Mass - Main Chute (grams)	Primary	TBD (with ejection tests)
	Backup	TBD (with ejection tests)
Energetics Mass - Other (grams) - If Applicable	Primary	TBD (with ejection tests)
	Backup	TBD (with ejection tests)

Recovery System Properties - Recovery Electronics

Primary Altimeter Make/Model	MissileWorks RRC3
Secondary Altimeter Make/Model	MissileWorks RRC3
Other Altimeters (if applicable)	(2) RRC3, (1) RRC2+
Rocket Locator (Make/Model)	MissileWorks RTx
Additional Locators (if applicable)	MissileWorks RTx
Transmitting Frequencies (all - vehicle and payload)	See pages 3 & 4.
Describe Redundancy Plan (batteries, switches, etc.)	All altimeters will have fully redundant backup systems, with completely isolated batteries, switches, wiring, electronic matches, and deployment charges.
Pad Stay Time (Launch Configuration)	Up to 180 minutes, using 3.5V, 750 mAh LiPo batteries.

Recovery System Properties - Drogue Parachute

Manufacturer/Model		SkyAngle		
Size or Diameter (in or ft)		20"		
Main Altimeter Deployment Setting		Apogee		
Backup Altimeter Deployment Setting		Apogee + 1.0s		
Velocity at Deployment (ft/s)		0		
Terminal Velocity (ft/s)		136		
Recovery Harness Material, Size, and Type (examples - 1/2 in. tubular Nylon or 1 in. flat Kevlar strap)		1/2" Tubular Kevlar		
Recovery Harness Length (ft)		25		
Harness/Airframe Interfaces		SS Swivels, 1/4" SS Quick Links, 5/16" SS U-Bolts, 3/16" FRP bulkheads		
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	6754.66			

Recovery System Properties - Main Parachute

Manufacturer/Model		Fruity Chutes Iris Standard		
Size or Diameter (in or ft)		96" (Upper), 84" (Lower)		
Main Altimeter Deployment Setting (ft)		750 (Upper), 725 (Lower)		
Backup Altimeter Deployment Setting (ft)		735 (Upper), 710 (Lower)		
Velocity at Deployment (ft/s)		136 (Upper & Lower)		
Terminal Velocity (ft/s)		13.25 (U), 14.84 (L)		
Recovery Harness Material, Size, and Type (examples - 1/2 in. tubular Nylon or 1 in. flat Kevlar strap)		1/2" Tubular Kevlar		
Recovery Harness Length (ft)		33.5		
Harness/Airframe Interfaces		SS Swivels, 1/4" SS Quick Links, 5/16" SS U-Bolts, 3/16" FRP bulkheads		
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	65.56	73.52		

Milestone Review Flysheet 2018-2019

Institution	University of South Florida	Milestone	CDR

Payload	
Payload 1 (official payload)	**Overview** Our new payload design is a two-wheeled, horizontonally-orientated rover. The rover will contain an Arduino, batteries, soil recovery module, and all guidance sensors. The projected diameter is 5.67"; the internal diameter of the rocket body. The rover will be seat-ed inside a reserved section alongside the leveling system that will prevent deployment issues. The rover will be deployed via a whiched deployment system and complete the mission objective after an initiating signal has been received.
Payload 2 (non-scored payload)	**Overview** The secondary payload installed in the launch vehicle will be a dynamic apogee adjustment subsystem. This system is a form of airbrakes and will be used to slow the rocket during ascent in order to accurately reach the desired target altitude. The airbrakes system will dynamically modify the coefficient of drag during flight, extending or retracting dynamic fins as necessary using a stepper motor.

Test Plans, Status, and Results	
Ejection Charge Tests	Subscale ejection tests completed, yielding: 1.5g for drogue, 2g for lower section main, 3g for upper section main. Full-scale ejection tests scheduled for initial test launch on February 16, 2019.
Sub-scale Test Flights	Initial subscale launch succesfully completed on November 17, 2018, full analysis available in CDR Report. Two more subscale test flights scheduled for January 19, 2019.
Vehicle Demon-stration Flights	Full scale initial test launch scheduled for February 16, 2019.
Payload Demon-stration Flights	Full scale demonstration flight with active payload scheduled for March 16, 2019.

Milestone Review Flysheet 2018-2019

Institution	University of South Florida	Milestone	CDR

Transmitter #1			
Location of transmitter:	Upper Section Avionics Bay		
Purpose of transmitter:	Real-time flight data and GPS location.		
Brand	Digi	RF Output Power (mW)	250
Model	XBee-PRO 900HP	Specific Frequency used by team (MHz)	902-928
Handshake or frequency hopping? (explain)	Frequency Hopping Spread Spectrum (FHSS) w/ software selectable channels		
Distance to closest e-match or altimeter (in)	2.2 (from antenna to RRC3)		
Description of shielding plan:	Significant spacing and 1/8" FRP barriers between transmitter and altimeters / e-matches, and thick nylon tubes around nearby threaded rods.		

Transmitter #2			
Location of transmitter:	Lower Section Avionics Bay		
Purpose of transmitter:	Real-time flight data and GPS location.		
Brand	Digi	RF Output Power (mW)	250
Model	XBee-PRO 900HP	Specific Frequency used by team (MHz)	902-928
Handshake or frequency hopping? (explain)	Frequency Hopping Spread Spectrum (FHSS) w/ software selectable channels		
Distance to closest e-match or altimeter (in)	2.2 (from antenna to RRC3)		
Description of shielding plan:	Significant spacing and 1/8" FRP barriers between transmitter and altimeters / e-matches, and thick nylon tubes around nearby threaded rods.		

Transmitter #3			
Location of transmitter:	Payload		
Purpose of transmitter:	To communicate with the payload, sending activation trigger remotely as instructed		
Brand	Digi	RF Output Power (mW)	250
Model	XBee-Pro 900HP	Specific Frequency used by team (MHz)	902-928
Handshake or frequency hopping? (explain)	Frequency Hopping Spread Spectrum (FHSS) w/ software selectable channels		
Distance to closest e-match or altimeter (in)	12		
Description of shielding plan:	Walls of the payload will be lined with carbon fiber to prevent interference		

Transmitter #4			
Location of transmitter:			
Purpose of transmitter:			
Brand		RF Output Power (mW)	
Model		Specific Frequency used by team (MHz)	
Handshake or frequency hopping? (explain)			
Distance to closest e-match or altimeter (in)			
Description of shielding plan:			

Milestone Review Flysheet 2018-2019

Institution	University of South Florida	Milestone	CDR

Transmitter #5			
Location of transmitter:			
Purpose of transmitter:			
Brand		RF Output Power (mW)	
Model		Specific Frequency used by team (MHz)	
Handshake or frequency hopping? (explain)			
Distance to closest e-match or altimeter (in)			
Description of shielding plan:			

Transmitter #6			
Location of transmitter:			
Purpose of transmitter:			
Brand		RF Output Power (mW)	
Model		Specific Frequency used by team (MHz)	
Handshake or frequency hopping? (explain)			
Distance to closest e-match or altimeter (in)			
Description of shielding plan:			

Additional Comments

Appendix D: OPENROCKET 'PARTS DETAIL' REPORT

Note: Masses are estimated based on component volumes and material densities or reported product masses from manufacturers. Some components are combined to simplify simulations, while some components (the PDLS, DAAS, and Payload) are 'allocated masses;' these subsystems must be less than the allocated masses, and additional mass will be added with ballast to account for any significant differences. This should not be considered a vehicle components breakdown, but rather a parameter of simulations.

Report begins on following page.

Parts Detail

Upper Section

Nose Cone	Fiberglass (1.07 oz/in³)	Haack series	Len: 35 in	Mass: 2.57 lb
Shoulder	Kraft phenolic (0.549 oz/in³)	Dia_{in} 5.74 in Dia_{out} 5.92 in	Len: 10 in	Mass: 0.566 lb
Adjustable Ballast Subsystem (ABS)		Dia_{out} 5.5 in		Mass: 0 lb
Bulkhead	Carbon fiber (1.03 oz/in³)	Dia_{out} 5.74 in	Len: 0.187 in	Mass: 0.312 lb
U-Bolt		Dia_{out} 2 in		Mass: 0.2 lb
Quick Link		Dia_{out} 1 in		Mass: 0.15 lb
Shock Cord	Kevlar (9/16 inch & 2000 lb strength) (0.082 oz/ft)		Len: 300 in	Mass: 0.129 lb
Upper Section Main Parachute (FruityChutes Iris Ultra Standard 96")	Ripstop nylon (0.22 oz/ft²)	Dia_{out} 96.063 in	Len: 4 in	Mass: 1.56 lb
Shroud Lines	Braided nylon (2 mm, 1/16 in) (0.011 oz/ft)	Lines: 12	Len: 96 in	
Nomex		Dia_{out} 6 in		Mass: 0.312 lb
Upper Airframe	Fiberglass (1.07 oz/in³)	Dia_{in} 5.92 in Dia_{out} 6.1 in	Len: 56 in	Mass: 6.36 lb
Payload Descent Leveling Subsystem (PDLS)		Dia_{out} 5.75 in		Mass: 0.5 lb
Upper Section Altimeter Bay	Kraft phenolic (0.549 oz/in³)	Dia_{in} 5.74 in Dia_{out} 5.92 in	Len: 6 in	Mass: 1 lb
Upper Section Main Deployment Charge A		Dia_{out} 0.984 in		Mass: 0.044 lb
Upper Section Main Deployment Charge B		Dia_{out} 0.984 in		Mass: 0.044 lb
Forward Bulkhead	Carbon fiber (1.03 oz/in³)	Dia_{out} 5.83 in	Len: 0.187 in	Mass: 0.322 lb
Upper Section Main Altimeter A (RRC3)		Dia_{out} 0.6 in		Mass: 0.132 lb
Upper Section Main Altimeter B (RRC3)		Dia_{out} 0.6 in		Mass: 0.132 lb
RTx Telematics System		Dia_{out} 0.6 in		Mass: 0.132 lb
DAAS Altimeter (RRC2+)		Dia_{out} 0.5 in		Mass: 0.022 lb

Rear Bulkhead	Carbon fiber (1.03 oz/in^3)	Dia_{out} 5.83 in	Len: 0.187 in	Mass: 0.322 lb
U-Bolt		Dia_{out} 2 in		Mass: 0.2 lb
Quick Link		Dia_{out} 1 in		Mass: 0.15 lb
Payload		Dia_{out} 5.66 in		Mass: 8 lb
Lower Section				
Altimeter Bay Switch Band	Fiberglass (1.07 oz/in^3)	Dia_{in} 5.92 in Dia_{out} 6.1 in	Len: 3 in	Mass: 0.341 lb
Lower Section Altimeter Bay	Fiberglass (1.07 oz/in^3)	Dia_{in} 5.74 in Dia_{out} 5.92 in	Len: 15 in	Mass: 2 lb
Lower Section Main Parachute (FruityChutes Iris Ultra Standard 84")	Ripstop nylon (0.22 oz/ft^2)	Dia_{out} 84 in	Len: 5 in	Mass: 1.5 lb
Shroud Lines	Braided nylon (2 mm, 1/16 in) (0.011 oz/ft)	Lines: 12	Len: 83.858 in	
Nomex		Dia_{out} 6 in		Mass: 0.312 lb
Shock Cord	Kevlar (9/16 inch & 2000 lb strength) (0.082 oz/ft)		Len: 300 in	Mass: 1.12 lb
Quick Link		Dia_{out} 1 in		Mass: 0 lb
U-Bolt		Dia_{out} 2 in		Mass: 0.2 lb
Lower Section Main Deployment Charge A		Dia_{out} 0.984 in		Mass: 0.044 lb
Lower Section Main Deployment Charge B		Dia_{out} 0.984 in		Mass: 0.044 lb
Forward Bulkhead	Carbon fiber (1.03 oz/in^3)	Dia_{out} 5.83 in	Len: 0.25 in	Mass: 0.429 lb
Lower Section Main Altimeter A (RRC3)		Dia_{out} 0.6 in		Mass: 0.132 lb
Lower Section Main Altimeter B (RRC3)		Dia_{out} 0.6 in		Mass: 0.132 lb
RTx Telematics System		Dia_{out} 0.6 in		Mass: 0.132 lb
Dynamic Apogee Adjustment Subsystem (DAAS)		Dia_{out} 5.75 in		Mass: 3 lb
Rear Bulkhead	Carbon fiber (1.03 oz/in^3)	Dia_{out} 5.83 in	Len: 0.187 in	Mass: 0.322 lb
Drogue Deployment Charge A		Dia_{out} 0.984 in		Mass: 0.044 lb

Drogue Deployment Charge B		Dia_{out} 0.984 in		Mass: 0.044 lb
U-Bolt		Dia_{out} 2 in		Mass: 0.2 lb
Drogue Parachute Quick Link		Dia_{out} 1 in		Mass: 0 lb
Shock Cord	Kevlar (9/16 inch & 2000 lb strength) (0.082 oz/ft)		Len: 300 in	Mass: 0.129 lb
Nomex		Dia_{out} 6 in		Mass: 0.312 lb
SkyAngle Classic 20" (Drogue Parachute)	Ripstop nylon (0.22 oz/ft²)	Dia_{out} 20 in	Len: 3 in	Mass: 0.312 lb
Shroud Lines	Tubular nylon (14 mm, 9/16 in) (0.172 oz/ft)	Lines: 3	Len: 20 in	
Booster Section	Fiberglass (1.07 oz/in³)	Dia_{in} 5.92 in Dia_{out} 6.1 in	Len: 47 in	Mass: 5.34 lb
Trapezoidal fin set (3)	Carbon fiber (1.03 oz/in³)	Thick: 0.187 in		Mass: 3.77 lb
Motor Mount / Fin Can	Fiberglass (1.07 oz/in³)	Dia_{in} 3 in Dia_{out} 3.098 in	Len: 30 in	Mass: 0.941 lb
75mm Flanged Motor Retainer		Dia_{out} 3.9 in		Mass: 0 lb
Forward Centering Ring	Carbon fiber (1.03 oz/in³)	Dia_{in} 3.098 in Dia_{out} 5.92 in	Len: 0.187 in	Mass: 0.241 lb
Middle Centering Ring	Carbon fiber (1.03 oz/in³)	Dia_{in} 3.098 in Dia_{out} 5.92 in	Len: 0.187 in	Mass: 0.241 lb
Rear Centering Ring	Carbon fiber (1.03 oz/in³)	Dia_{in} 3.098 in Dia_{out} 5.92 in	Len: 0.187 in	Mass: 0.241 lb