UNIVERSITY OF SOUTH FLORIDA

NASA STUDENT LAUNCH 2018

Flight Readiness Review Report

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SOCIETY OF AERONAUTICS AND ROCKETRY

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Tampa, Florida 33620

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1 Team Summary

1.1 Team Name & Mailing Address

Society of Aeronautics and Rocketry (SOAR) at University of South Florida (USF)
4202 East Fowler Avenue, MSC Box #197
Tampa, Florida 33620

1.2 Team Personnel

1.2.1 Team Mentor

Team mentor: Jim West, Tripoli 0706 (Tripoli advisory panel member), Certification Level 3, 863-712-9379, jkwest@tampabay.rr.com

1.2.2 Team Academic Advisor

Team academic advisor: Dr. Manoug Manougian, Professor & Director of STEM Education Center, 813-974-2349, manoug@usf.edu

1.2.3 Safety Officer

Team Safety Officer: Kevin Kirkolis, Sophomore Undergraduate, Mechanical Engineering, 708-217-3737, kirkolis@mail.usf.edu

1.2.4 Student Team Leader

Student Team Leader: Stephanie Bauman, Junior Undergraduate, Physics, 334-549-9144, sbauman1@mail.usf.edu

1.2.5 Team Structure and Members

1.2.5.1 Team Leadership and Organization Chart

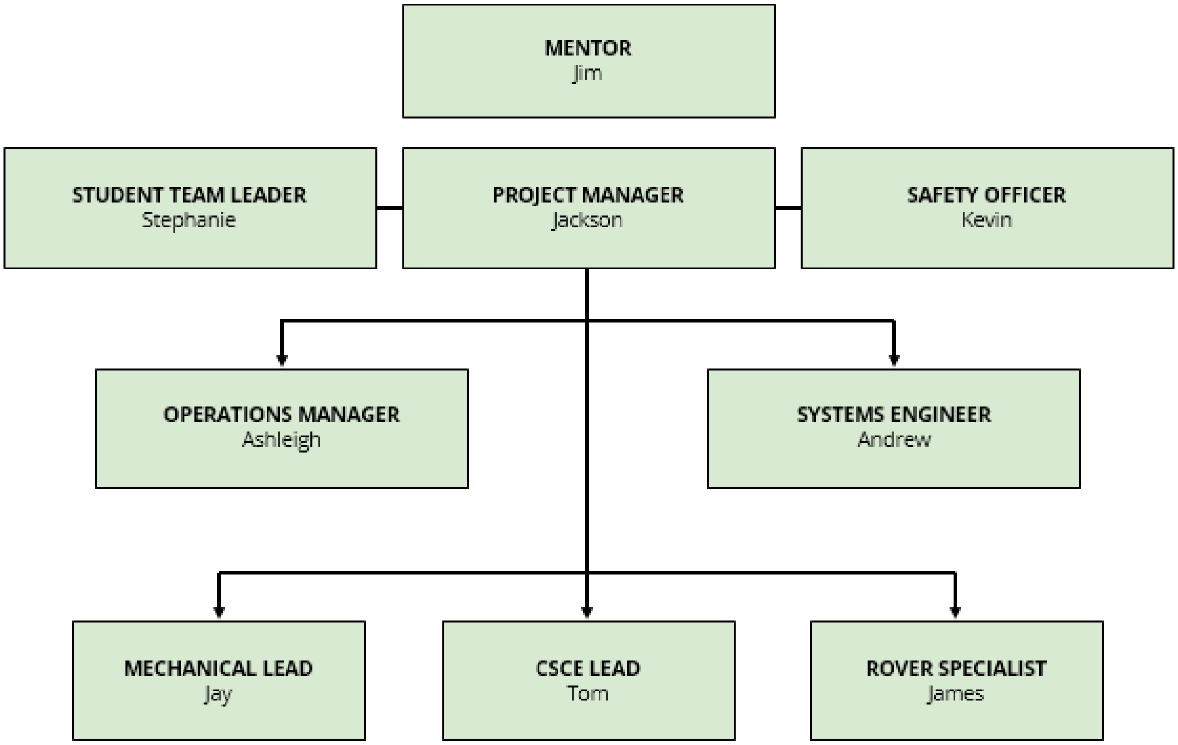


Figure 1: Team organization chart.

1.2.5.2 Team Members

SOAR's 2018 NASA Student Launch Initiative Team consists of approximately 25 members, including the leaders listed above in the organizational chart. Additionally, team members are also organized under the functional teams detailed below.

Table 1: Functional teams and descriptions.

Functional Team	Team Lead	Description
Rocketry Team	Kevin Kirkolis	Rocketry Team is responsible to design, build, test, and modify launch vehicle and all recovery systems.

Functional Team	Team Lead	Description
Rover Team	James Waits	Rover Team is responsible to develop, design, test, and prepare the rover payload system. The team will implement all mechanical, electrical, and computer engineering designs and systems necessary for a rover that meets all design criteria.
Deployment System Team	Javian Hernandez	Deployment System Team is responsible to design, fabricate and test a rover deployment system capable of safely ejecting the payload from within the rocket body. The team will communicate with the CSCE and Rover Teams to ensure complete integration and feasibility, all while meeting project guidelines.
CSCE Team	Tom Hall	CSCE Team is responsible to design all computer hardware and software needs for the design of the rover and rocket. They will work closely with the electrical engineer lead to ensure system will have continuity. The team lead will remain in close contact with the systems engineer to make sure that all systems function properly.

1.2.5.3 Additional Duties

Additional duties are positions that are functionally designated to better assist the team in accomplishing its goals and requirements.

1.2.5.3.1 Rover Design Specialists: James Waits and Chris Purdie. Primary design stakeholders for rover design.

1.2.5.3.2 CSCE Contributors: Thomas Hall, Simon Wilson, Lott Lalime. Coders and Programmers for various onboard electronics and devices.

1.2.5.3.3 Outreach Coordinator: Ashleigh Stevenson. Develops and organizes outreach events.

1.3 NAR/TRA Affiliates

The Society of Aeronautics and Rocketry at the University of South Florida will seek guidance and collaboration with the Tampa Prefecture (#17) of the Tripoli Rocket Association (TRA) for the design and construction of this year's NSL rocket. The local TRA chapter also provides a site for sub-scale and full-scale launches under experienced supervision.

2 Launch Vehicle Summary

SOAR's full-scale launch vehicle purchased 5" G10 fiberglass tubing, a nose cone and a 75mm motor mount tube from Wildman Rocketry, a reliable vendor. The bulkheads, fins and centering rings are custom cut by SOAR members using ⅛" structural FRP fiberglass from McMaster-Carr. For the recovery equipment, SkyAngle Classic II 60" and 20", and Fruity Chutes Iris Ultra 60" parachutes will be used with sections of ½" and ¼" tubular Kevlar shock cord. The epoxy variants used on the full-scale build will range from standard 30-minute epoxy, epoxy mixed with fine-cut carbon fiber fabric and Aeropoxy.

2.1 Vehicle Size and Mass

Table 2: Launch vehicle size and mass.

Diameter (in)	5.148
Length (in)	111
Unloaded Weight (lb)	36.9
Loaded No Ballast Weight (lb)	44.4
Minimum Ballasted Weight (lb)	46.4
Fully Ballasted Weight (lb)	48.7
Launch Motor	Aerotech 4G L1420
Airframe Material	G12 Fiberglass

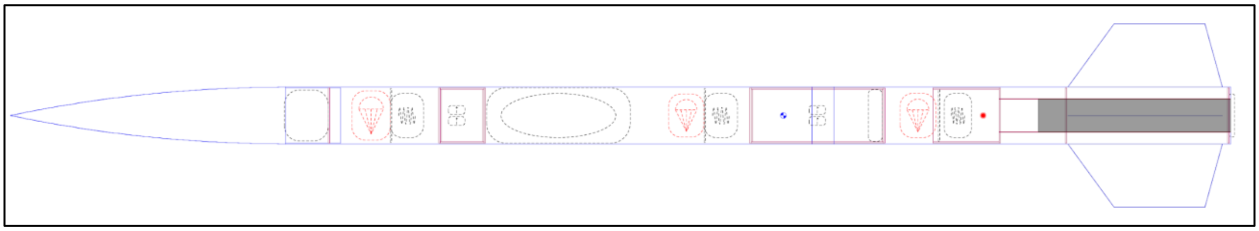


Figure 2: Overview drawing of launch vehicle assembly.

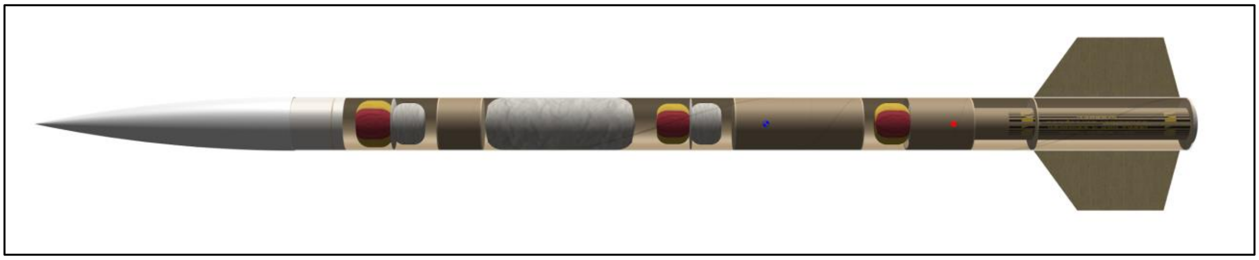


Figure 3: Overview 3D render of launch vehicle assembly.

2.2 Motor Choice

The final motor decision for use in the full-scale launch vehicle is the Aerotech L1420 75mm motor. This motor was chosen because the thrust available guaranteed the launch vehicle to easily exceed the goal apogee of 5,280 feet. To reach the target apogee of 5,280 feet, fine adjustment of projected apogee through alteration of fin design, and the design of a removable ballast system is feasible and possible. Also, these motors, under most configurations, exceed the target apogee altitude and, in addition to the adjustable balance system, in our previous experience, the constructed rocket is most often somewhat heavier than the simulated weight due to epoxy and parts not accounted for in the simulation software.

Table 3: Functional teams and descriptions.

Motor	Aerotech L1420
Average Thrust (N)	1420
Maximum Thrust (N)	1814
Total Impulse (N·s)	460

Burn Time (s)	3.2
Case	CTI Pro75-4G

2.3 Recovery System

A dual deployment system, activated at apogee, 950 feet, and 800 feet AGL upon descent, will be used to follow NSL guidelines and to accommodate the rocket design. The first parachute deployment will be a drogue at apogee via separation initiated by a black powder charge. There are two main parachute deployments; one at 950 feet to separate the main altimeter bay and booster section from the rocket, and the other at 800 feet to separate the nosecone from the rover compartment airframe. There will be two separate altimeter bays; the main altimeter bay responsible for deploying the drogue and one main, and the payload altimeter bay for the main parachute responsible for recovering the payload and its consequent launch vehicle sections. The rocket will use a total of four altimeters, and all will be the Altus Metrum EasyMini due to their size, ease of use and their capability to record multiple points of data.

2.4 Rail Size

The launch vehicle will use a 96-inch 15x15 launch rail.

2.5 Milestone Review Flysheet

Please see Appendix 15.2.

3 Payload Summary

3.1 Payload Title

The Deployable rover payload has been chosen and will be referred to as the Sidewinder, or as Rover throughout this document.

3.2 Rover Design Summary

The concept of the Sidewinder came from the need to maximize the space within the payload section of the launch vehicle making more efficient use of it. We referred to an entry into *Journal of Terramechanics* “Experimental study and analysis on driving wheels’ performance for planetary exploration rovers moving in deformable soil” and concluded that both a larger diameter and a larger surface area contacted with the ground for our rover wheel is needed to effectively maneuver over rough terrain. Additionally, to maximize the space we had within the rocket body we used a converged to a “sideways” approach design/thought process.

4 Changes Made Since CDR

4.1 Changes Made to Vehicle Criteria

To strengthen the section of fiberglass airframe further, a coupler has been added and epoxied to the inside of the Booster Section for added support and reinforcement. Details about this change are explained in Section 5. Further, the parachute selection has been changed due to increased weight of the launch vehicle.

4.2 Changes Made to Payload Criteria

4.2.1 Expanding Wheel

As a result of rover tests we make a wheel extending mechanism that stretches the diameter of the rover wheel previously from 5” to (after it has exited the rocket body) 8.5”. This is done with a series of 30 lever arms

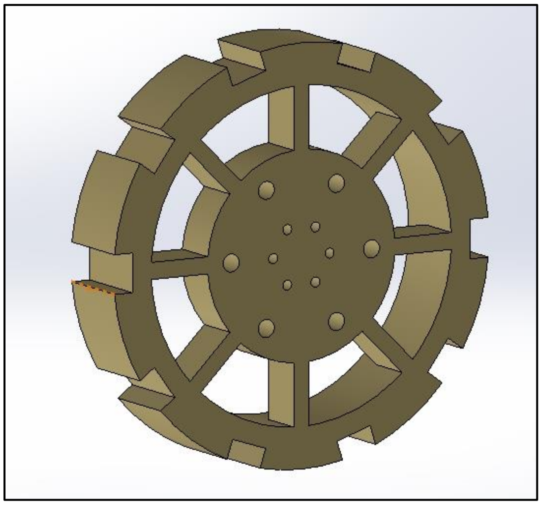


Figure 4: Prior 5-inch diameter wheel design.

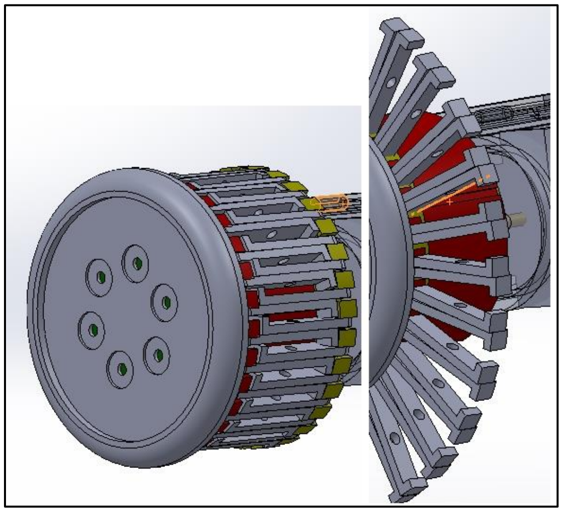


Figure 5: New 5-inch to 8.5-inch expanding wheel design.

4.2.2 Newtonian Leg

From the result of prototype construction the new Newtonian leg allows for a more solid contact with the ground surface. It is also less flexible and secured better to the Rover than the previous design.

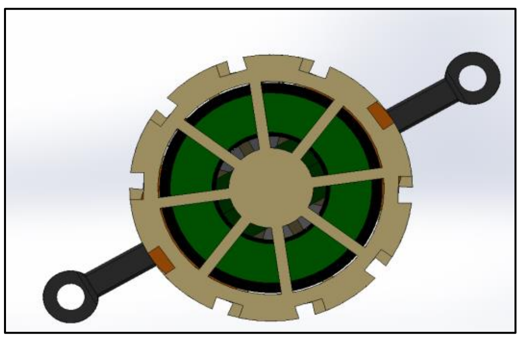


Figure 6: Prior rover leg design, featuring two smaller legs.

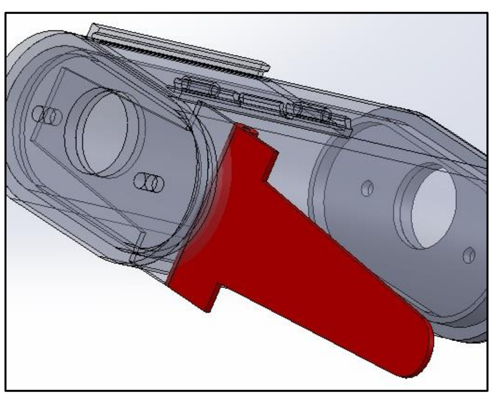


Figure 7: New rover leg design, featuring a single larger leg.

4.2.3 Rover Deployment

The rover deployment method has stay relatively the same. The major changes include removing the sled from the previous design and replacing it with a conical wheel and to remove the guiding railings. Reasons for change will be discussed, however, with our tests, we have determined that railings were unnecessary. We are using beefier solenoids to hold the rover in place and changed the way the rocket will communicate with the ground team.

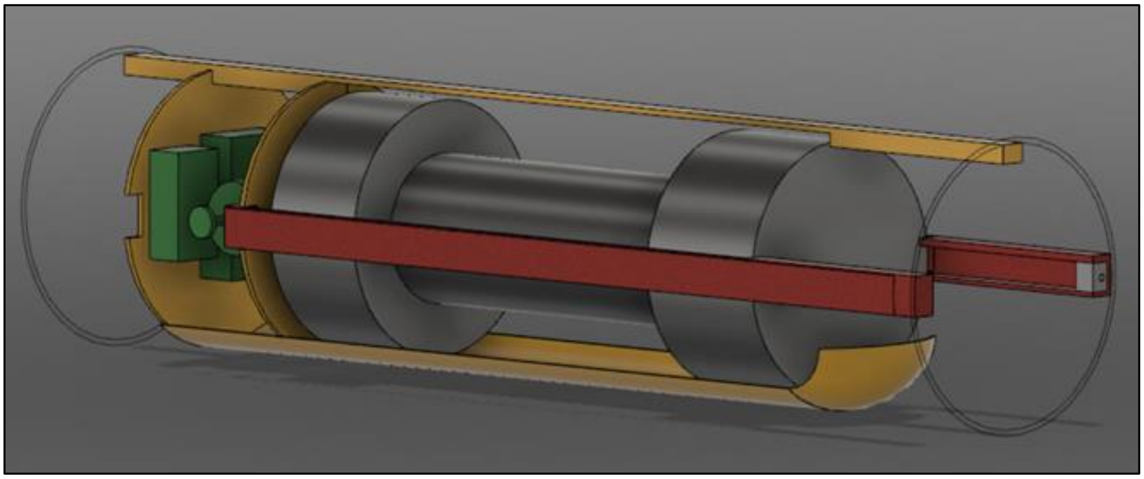


Figure 8: Prior rover deployment system, with a gear and track mechanism.

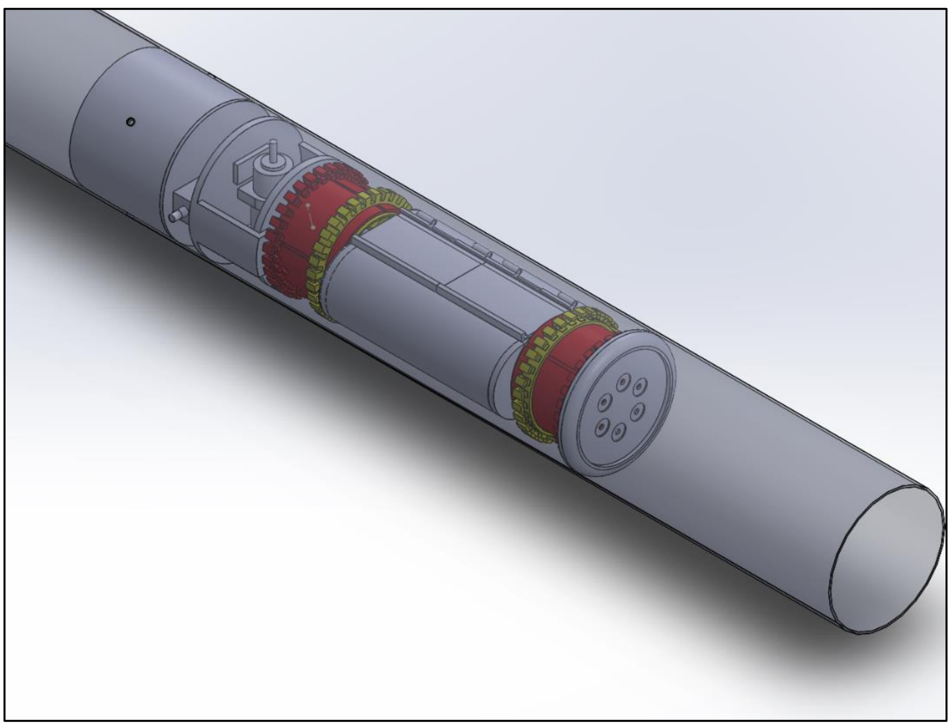


Figure 9: New rover deployment system, with simpler winch and sled system.

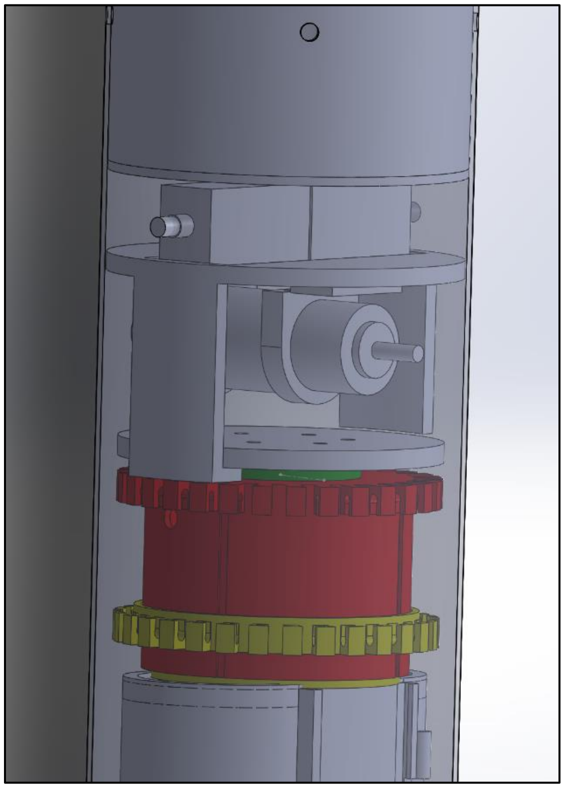


Figure 10: Detail view of new rover deployment system.

4.3 Changes Made to Project Plan

Changes to the project plan include an update to the timeline, requirements verification, and test plan. The timeline was updated to include time allocated to the design and construction of the changes made to payload design. Through completion of testing the requirements verification and testing plans have been updated. Educational Engagement has also been updated to include information regarding the events completed since submission of CDR. The Booster Section received potential abrasion on January 27th in Bunnell, providing another concern for the structural integrity and thus a reason for installing a coupler for support and reinforcement.

5 Design and Construction of Vehicle

5.1 Changes Made Since CDR

Before the maiden flight for Apis II on January 27th, the launch vehicle sections and components were weighed to provide a more accurate flight simulation. It was found that the Booster Section weighed 9 pounds instead of 6.5 pounds as predicted. Thus, concern for the structural integrity of the airframe was considered, given the thickness is 0.074 inches. There are approximately 10.5 inches of the airframe that are not reinforced (5 inches reinforced by the main altimeter bay coupler and the other 20.5 by three centering rings). The 20.5 inch portion is estimated to be 7.5

pounds of the 9 pound total Booster Section weight. To strengthen the section of fiberglass airframe further, a coupler has been added and epoxied to the inside of the Booster Section for added support and reinforcement.

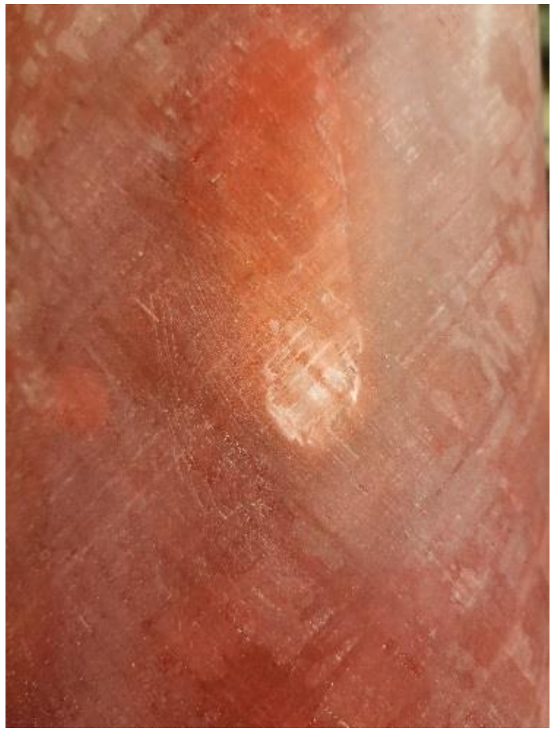


Figure 11: Close up view of frame abrasion.

5.2 Launch and Recovery Features

5.2.1 Structural Elements

5.2.1.1 Fins

The final dimensions of the fin design are as follows, an extra ¼" was cut off the 6" height under the notion that ideal conditions are rare therefore adding safety despite our calculations checking out;

1. Height (From Exterior Airframe Surface) - 5.75"
2. Root Chord - 14"
3. Tip Chord - 8.25"
4. Sweep Length - 4.19"

With these specific dimensions after the final cuts, the projected fin flutter velocity ranges from 806 to 809 feet per second. The max velocity of the rocket under this fin design given the dimensions above is 748 feet per second. The disparity between max fin flutter and vehicle velocity is desirable and preferable to accommodate safety standards, and allow for the safe ascent of the launch vehicle.

5.2.1.2 Adjustable Ballast System

In order to maximize the potential for reaching exactly 5280 feet for the competition launch under any conditions, an adjustable ballast system has been designed that it can be loaded in the nose cone shoulder. If maximum ballast is needed, it is designed in such a way that it can be added in a balanced manner so that the stability margin remains between three and six calipers, preferably in the lower portion of that range.

The ballast system is designed as several layered circular modular elements that stack on top of each other. The system is made of 3D printed layers and removable 1-ounce weights. The system is also broken up into three different sections for the nosecone shoulder. The first section accounts for the presence of the bulkhead's U-bolt. It is comprised of 2 layers each 0.35" tall, and 4.3" in diameter. The second section is composed of 11 layers each 0.4" tall and 4.3" in diameter. The third section is the final capping layer. It is a slightly smaller diameter as the nose cone shoulder at 4.7" and is designed to secure the first two sections and the entire nose cone ballast system to the respective bulkhead with ¼" threaded rods with lock nuts at one end and wing nuts on the other.

The design of the nosecone ballast system layers are pictured below. The first section can hold a total weight of 8-ounces (0.25 pounds), 4-ounces in each layer and the second section can hold in total weight 66-ounces, with 6-ounces (0.375 lbs) in each layer. The third section is designed to not hold any weight. The entire nosecone ballast system stands 5.35" tall.

To keep the static stability margin below 4 calibers, the removable ballast is split between the nosecone shoulder and the Main Altimeter Bay. The layers in the Main Altimeter Bay are circular and hold 9 ounces each. Four layers have been printed and total to 40 ounces (2.5 pounds). To keep the static stability margin below four, the Main Altimeter Bay will be filled first, with the remaining amount of ballast then added to the nosecone section.

Under the worst environmental conditions permitted (20 mph winds), the main altimeter bay ballast system will be loaded with 2 lbs of ballast, given that the payload rover and deployment system weighs 7 lbs. Default loaded weight will be adjusted based on the final verified weight of the rover and further full scale testing. Further adjustable ballast will be added in accordance with Table 8.

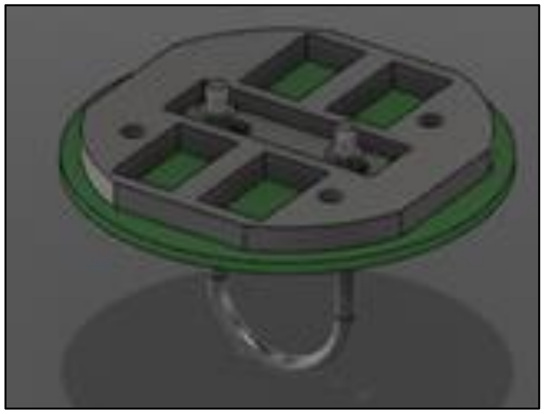


Figure 12: Render of ballast system (section one, 1st and 2nd layers).

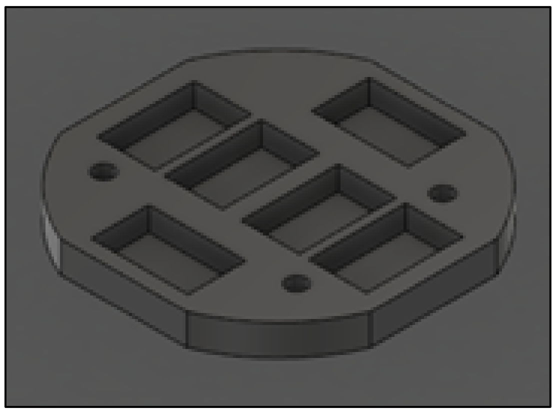


Figure 13: Render of ballast system (section two, 3rd through 11th layers).

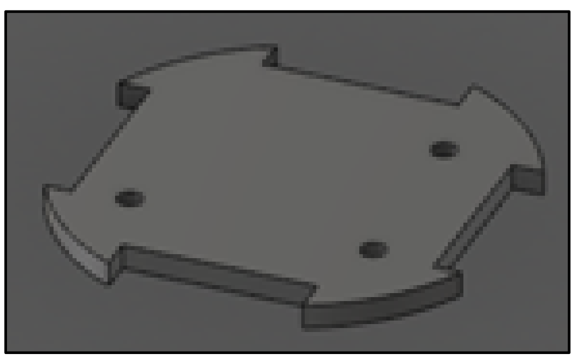


Figure 14: Render of ballast system (section three, 12th layer).

Figure 15: Render of assembled nosecone ballast system.

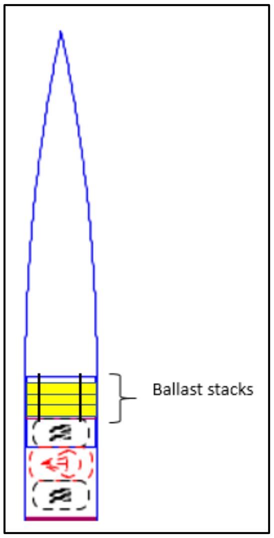


Figure 16: Drawing of installed nosecone ballast system

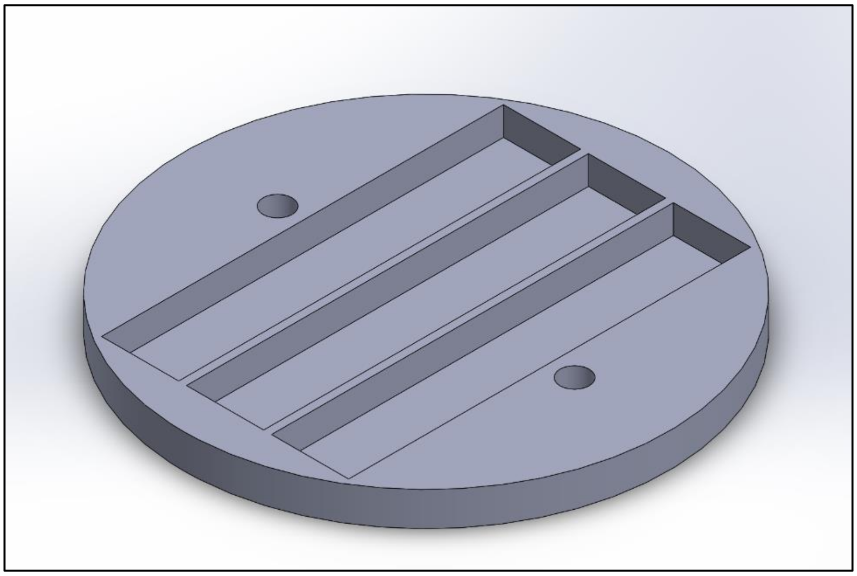


Figure 17: Single main altimeter bay ballast layer.

5.2.1.3 Booster Section

The final specifications of the fins after fin flutter analysis will leave the root chord at 14”, but the new height (from external airframe) to be 5.75”, the tip chord at 8.25”. The booster section is 36” long, with the motor mount at 21” long. This subsystem is tethered to the main altimeter bay with a 30’ length of ½” tubular kevlar shock cord, and deploys a 28” drogue parachute at apogee via a black powder charge from the lower half of the main altimeter bay. A coupler is epoxied to the inside of the Booster Section airframe above the uppermost centering ring, and below the Main Altimeter Bay to provide added support and reinforcement since this section is over a third heavier than predicted to be. The coupler is 8 inches long, and although it adds roughly a pound to the overall weight, it increases the thickness of the airframe from 0.074” to 0.247”. The effect of this added support will not adversely affect the launch vehicles flight performance, since the Aerotech L1420 motor provides more than enough thrust necessary to reach the target apogee of 5,280 feet.

5.2.1.4 Main Altimeter Bay

The main altimeter bay houses 2 of 4 on-board altimeters to control deployment and separation, and acts as a critical coupling component to the entire launch vehicle. The main altimeter bay is a 4.753” x 4.987” fiberglass tube, and is 12” long. The bay is capped with bulkheads composed of two layers (one with 4.987” diameter, the other with 4.753” diameter) of ⅛” fiberglass. There will be two vertical slots cut to extend the channels of the deployment system to the end of the airframe The main altimeter bay will use the Atlus Metrum EasyMini altimeters, and will detonate black powder charges at apogee and at 950 feet upon descent. The first charge at apogee will disconnect the 2-56 size shear pins securing the booster section to the lower half of the altimeter bay, deploying the drogue parachute. At 950 feet upon descent, the second wave of charges will detonate and separate from the Rover Compartment airframe and deploy the Fruity Chutes Iris Ultra Light 66” main parachute and 20 feet of ¼” tubular kevlar shock cord used for the booster section and main altimeter bay.

5.2.1.5 Rover Compartment

The rover compartment is the section of airframe that houses the rover, payload altimeter bay and electronics, payload deployment system, and the recovery hardware used for both this subsystem and the nosecone. This airframe is 45.75” long and is secured to the rocket with shear pins to the upper half of the Main Altimeter Bay. The payload altimeter within the rover compartment is secured in an area between 14” to 18” from the top of this airframe using an arrangement of four ¼”-20 screws that are accessible from the exterior of the rocket. Below this is the payload deployment system, a winch and sled combination will use a small high torque stepper motor to wind a set of small cords attached to the exit end of the payload compartment, which will propel the motor, faceplate, and rover out of the tube. This deployment system, will be held motionless inside the payload compartment during launch by a set of 8mm diameter push/pull solenoids that will act as pins holding the deployment system and rover inside the body compartment until the ejection sequence is triggered after descent and touchdown. The nose cone, Rover Compartment airframe, Payload Altimeter Bay, the payload, and the recovery equipment stored in between the nose cone and Payload Altimeter Bay, will separate from the Main Altimeter Bay and Booster Section at 800 feet AGL upon descent.

5.2.1.6 Payload Altimeter Bay

The Payload Altimeter Bay is a unique and important subsystem for the Deployable Rover payload. This altimeter bay is the same type of coupler as the Main Altimeter Bay (ID: 4.753” x OD: 4.987”) and house the other two Altus Metrum EasyMini altimeters. These altimeters control black powder charges (2g & 1.75g) programmed to detonate at an altitude of 800 feet AGL, lower than the main parachute deployment in the Main Altimeter Bay at 950 AGL, to avoid issues with shock cord entanglement and to separate the tethered sections. The bay is capped with bulkheads composed of two layers (one with 4.987” diameter, the other with 4.753” diameter) of ⅛” fiberglass. The altimeter bay will be secured in place using a combination of ¼”-20 t-nuts and screws. This arrangement will allow the Payload Altimeter Bay to be easily accessible and fixed during flight. The top bulkhead will have the ejection canisters responsible for deploying the SkyAngle Classic II 60” parachute and the 20 feet of ½” tubular kevlar shock cord.

5.2.1.7 Bulkheads

Like the custom fins, ⅛” structural FRP fiberglass sheets, supplied by McMaster-Carr, were chosen to construct the bulkheads for the altimeters bays. Two sheets were used to create a single bulkhead to cap and secure altimeters, electronics and any other components stored within the altimeter bay. The inside fiberglass sheet has a diameter of 4.753", matching the inner diameter of the G12 fiberglass coupler used as the altimeter bay. The outer sheet has a diameter of 4.987" which caps the G12 coupler and fits inside the 5" diameter of the main airframe. This material has been used for the construction of our vehicles several times and has shown reliability during flight and recovery.

5.2.1.8 Attachment Hardware

As quick links, D-rings, and U-bolts are readily available, very inexpensive, and contribute very little to the overall weight of the launch vehicle, it is preferred to select components that are dependable and have proven capabilities. For this reason, 5/16" zinc-plated U-bolts and locking D-rings have been chosen as the recovery device interface apparatus for this design. The team has previously used these components with success over several launches, and, as stated above, have been used under more aggressive circumstances than the present project encompasses.

5.2.1.9 Materials used for fins, bulkheads, and structural elements

The material used for the fins, bulkheads and centering rings is Structural FRP Fiberglass (⅛" thickness). This material is comparatively lightweight for its strength, making it a good option to use in critical structural components while minimizing excess weight. The tensile strength and compressive strength are at 24,000 psi, and the flexural strength rests at 35,000 psi. This fiberglass type offered by McMaster-Carr, is non-conductive and can withstand temperatures up to 140 degrees Fahrenheit. The components that utilize this specific type of fiberglass are the fins, altimeter bay bulkheads, and the nosecone bulkhead. Due to the long length of shock cord (at least 20 feet for every recovery section), the high load capacity of both the ¼" and ½" tubular kevlar, and the parachute selection delivering the launch vehicle to less than 75 ft-lb force upon landing, this material proves useful and appropriate for the mission at hand.

5.2.1.10 Sufficient motor mounting and retention

A 75mm G12 fiberglass tube and three ⅛" centering rings (ID: 2.95" & OD: 5") are attached together using a carbon fiber-epoxy composite. The centering rings are positioned (from the aft forward) 0.125", 14.75" and 21" from the base of the motor mount. A 75mm flanged motor retainer is fixed to the base centering ring using an array of 4-40 stainless steel screws, and a layer of Aeropoxy. The motor mount is secured to the Booster Section airframe using Aeropoxy fillets on the surfaces adjacent to the 14.75" fin slots and the fins themselves. There is a recessed space 0.125" inside from the base of the airframe, to limit the protrusion of the motor retainer. Carbon fiber epoxy fillets are applied to the root chord of the fins and added as a extra fillet for the motor retaining centering rings.

5.2.2 Electrical Elements

5.2.2.1 Wiring

Electronic matches used to detonate the black powder are common pyro igniters, and are purchased through various vendors with the same quality and results. They are incredibly reliable, and thus are the primary choice. They work by completing a current through the wiring, passing the chemical-infused tip. They have a resistance of 1.2 ohms, and work off of a 500 mA current which is easily triggered by the 9V batteries used within the launch vehicle. The electronic match designated for a drogue parachute deployment is connected to the "Apogee" space, and to the "Main" space for parachute deployments at 950 and 800 feet respectively.

Figure 18: Picture of E-match used for pyro-ignited black powder charges.

5.2.2.2 Switches

The "Switch" space will be occupied by a common mechanical rotary switch, that works by allowing and canceling current in a circuit. The off position is labeled by "110" and the on by "220". The resistance of all the prongs on the switch was tested in both positions and was found to be roughly 1 ohm when on and "closed" when off.

Figure 19: Picture of rotary key switches used to activate altimeters before flight.

5.2.2.3 Battery Retention

All four Altus Metrum EasyMini altimeters will be powered using standard 9V alkaline batteries. These batteries are attached to special battery harnesses that come installed with a short wire for both the positive and negative terminal to make extending the wires manually easier. The battery compartment ensures there are no unsecured components in the altimeter bays.

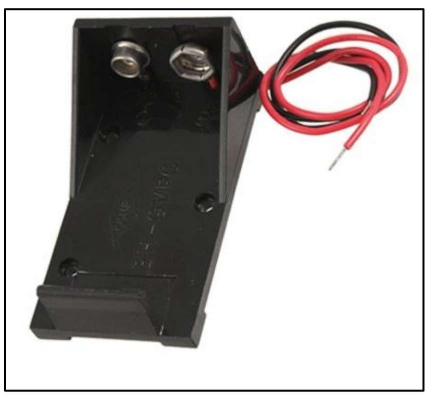


Figure 20: Picture of battery harness used for all 9V batteries on-board the launch vehicle.

5.2.2.4 Transmitter

The rocket locators are the SB1 from Adept Rocketry; a 90 db, 4000 Hz sounding beacon powered by a single 12V lighter battery (commonly in an Energizer A23). The SB1 is not connected to the altimeters or payload electronics, and will be activated via a "jumper" upon parachute deployment (physical circuit blocker that is detached under stress). Two locators are used in the launch vehicle to locate each major tethered section and are stored in the Payload and Main Altimeter Bay.

5.2.2.5 Altimeters

The EasyMini altimeters from Atlus Metrum, have a terminal block that contains space for a "Main", "Apogee", "Switch" and "Battery" circuits. The altimeter itself runs on a voltage from 3.7 to 12 using the "Battery" space in the terminal block, and is polarity protected in the case of improper setup. The EasyMini altimeter will identify the moment of apogee, and a signal will be sent to a charge which will shear the pins and separate the booster section from the main altimeter bay, releasing the drogue parachute. The same EasyMini altimeter will then identify the moment when the launch vehicle is 950 feet above ground, and a signal will be sent to the second charge to separate the rover compartment from the main altimeter bay, fully separating the booster section and main altimeter bay from the rest of the rocket. This separation releases the main parachute for these two sections allowing the launch vehicle to be safely recovered. The altimaters are housed in specially designed sleds that ensure they are secured during flight.

Figure 21: Picture of Atlus Metrum EasyMini altimeter, equipped with a terminal block, barometric sensor and micro USB port for flight data extraction.

5.2.3 Drawings and Schematics

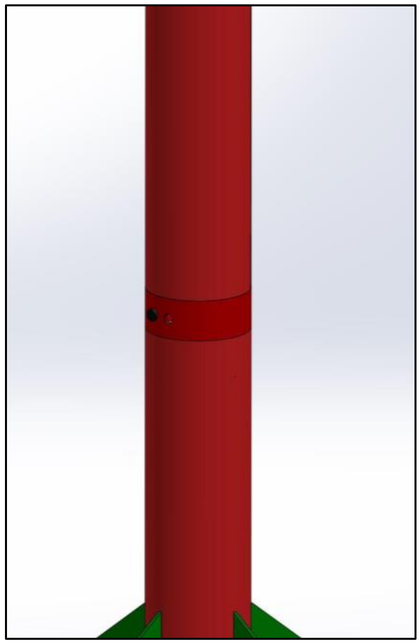


Figure 22: Rendering of exterior of main altimeter bay assembly.

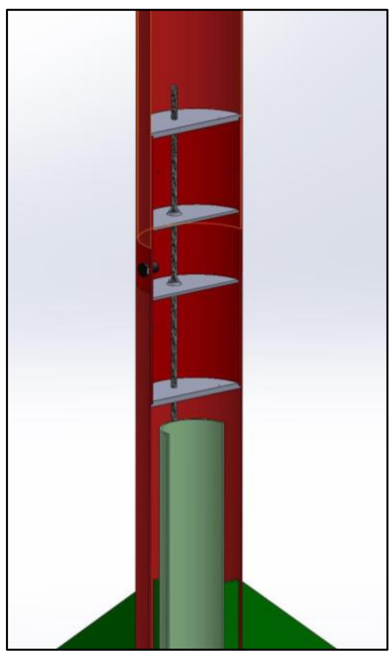


Figure 23: Cutaway rendering of main altimeter bay assembly.

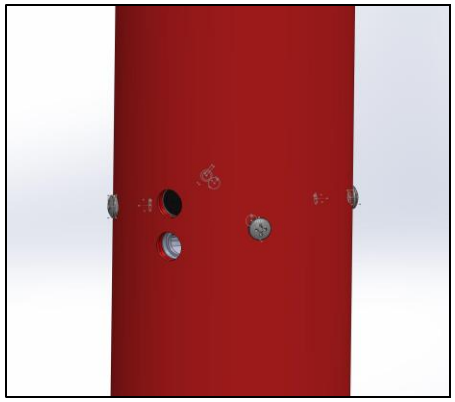


Figure 24: Rendering of exterior of payload altimeter bay.

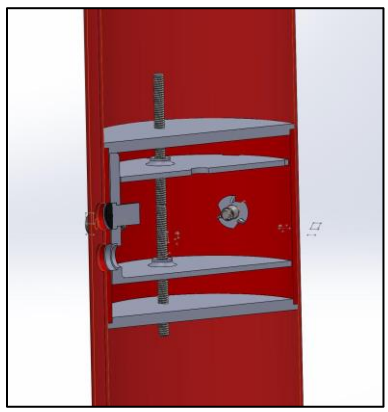


Figure 25: Cutaway rendering of payload altimeter bay.

5.3 Flight Reliability

The launch vehicle, Apis II, constructed appropriately and effectively for the mission of the NASA Student Launch Initiative. Early in the project timeline, multiple elements and materials of the eventual rocket and its deployable rover payload were evaluated carefully. The materials selected for construction exemplify proficiency in strength and durability, while performing with a relatively low weight. The fiberglass materials were G10, G12 and Structural FRP; all with high tensile and compressive strengths exceeding into tens of thousands in terms of psi. Adhesives and hardware were of the highest quality and industrial grade, from Aeropoxy to cast-steel bolts. Designs, calculations, analysis and guidance from our Level 3 mentor ensured that all components within the launch vehicle would withstand multiple tests and flights. This is evident with two flights and two ground tests using a total of over two dozen grams of black powder charges, and the unfortunate but important events of recovery failures. The launch vehicle, Apis II, is robust and can ascend and descend even in the most undesirable scenarios and able to fly again.

5.4 Vehicle Construction

5.4.1 Nosecone

The nosecone was purchased from Wildman Rocketry, and only one fiberglass style was available for a 5" diameter airframe; 5:1 Karman. This nosecone was paired with a 7" piece of G10 fiberglass coupler (4.987" OD & 4.753" ID) to create a shoulder that protruded 5 inches from the base of the nosecone. On the inside of the shoulder, four ¼"-20 t-nuts were positioned equally on the inner diameter and matching holes were made on the outside surface on the nosecone. The t-nuts and screws used to attach the shoulder and nosecone together are zinc-plated steel pieces. This allows the shoulder to be taken off and removable ballast to be easily accessible and adjustable. A fiberglass bulkhead was installed 2 inches from the base of the shoulder (28 inches from the nosecone tip) using the carbon fiber - epoxy composite on both sides. A central 5/16" zinc-plated U-bolt and washer was attached to this bulkhead, along with three ¼"-20 rods, at 6" length, for securing the nosecone ballast. During the recovery phase, the majority of the forces and stress will be focused on the the carbon fiber - epoxy ring and the screws fixated to the t-nuts.

Figure 26: Carbon fiber-epoxy composite being applied to bulkhead within shoulder.

5.4.2 Rover Compartment

The Rover Compartment was cut from a single 60" long, 5" diameter piece of G12 fiberglass tubing. A table saw, equipped with a 200-teeth blade was used to cut the tube into 47.75" and 12.25" sections. The 12.5" section was set aside, and was used as a test fit piece for the rover. The 47.75" section is now the designated Rover Compartment airframe. Four, equally-spaced ¼" holes cut around the diameter (perpendicular to the 45.75" length), and two 9/16" holes (parallel to the 45.75" length, separated from each other by 15/16") were cut using a power drill, with a pilot hole and the appropriate drill bit sizes. The line of reference for placing and drilling these holes was 16” from the nosecone end of the airframe. The side of the tubing that was cut from the saw is sanded with 110 grit and 220 grit sandpaper to ensure smooth and even end that becomes flush with the nosecone base.

5.4.3 Payload Altimeter Bay

The Payload Altimeter Bay was constructed using the same tubing as the Main Altimeter Bay and Nosecone shoulder; G10 fiberglass coupler (ID: 4.753” x 4.987”). The 4” length was cut from an original length of 12” using a table saw equipped with a 200-teeth blade. To match the four ¼” holes in the Rover Compartment, four equally-spaced holes around the outer circular surface of the coupler in order to line up properly. Again, a pilot and ¼” drill bit used with a power drill were used to cut the holes. Zinc-plated ¼”-20 t-nuts were aligned on the inside with the ¼” holes and secured with the carbon fiber-epoxy composite that solidified after 10 minutes, and finally hardened after 30 minutes. Two ¼”-20 threaded rods are installed through the bulkheads, Bulkheads are then used to cap the ends of the coupler to complete the altimeter bay construction.

5.4.4 Booster Section

The booster section is composed of the 5” x 5.148” airframe, fins and the 75mm inner motor mount. The motor mount will be secured to the inside of the airframe using three ⅛” fiberglass center rings (approximately ID: 2.95” x OD: 5”) with carbon fiber epoxy fillets and joints. The fins are ⅛” fiberglass sheets, and their measurements are respective to the outer airframe diameter (5.148”, or 2.574” from center) in terms of tip and root chord, sweep length and height. The fins have a recessed area equivalent to the root chord, and approximately 26 mm (about 1”) deep that will be secured to the motor mount with carbon fiber epoxy fillets and the centering rings described above. A common DeWalt jigsaw was sufficient and successful in cutting the ⅛” fiberglass. Proper eye and skin protection was used for members cutting this material. The rail buttons were 1515 size and placed 4” and 24” from the bottom of the airframe, respectively.

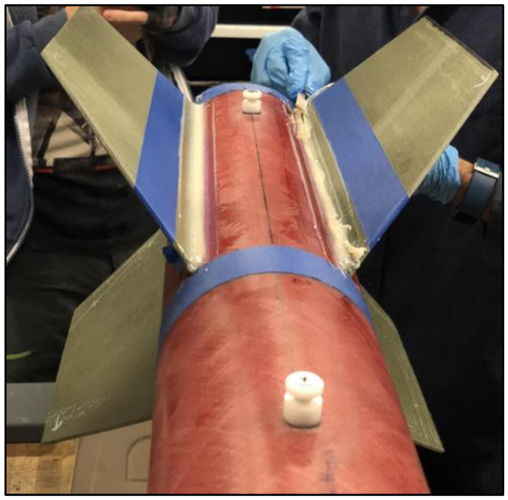


Figure 27: Precision placement of rail buttons will ensure proper orientation relative to the launch rail.

Figure 28: Aeropoxy is applied to bond the motor retaining ring to the aft centering ring, using clamps to prevent leakage.

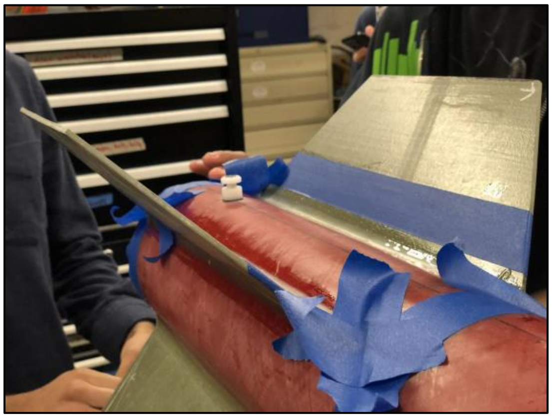


Figure 29: Aeropoxy applied as a fillet for fin securement and reinforcement. Tape is used to set boundaries.

5.4.4.1 Camera Mount

The camera mount design was modeled in SolidWorks using the dimensions acquired from the Spy Tec Mobius Action Camera. There are two main parts; the housing and closure. The housing is attached to the external surface of the Booster Section, thus before the Center of Gravity, using two steel 2-56 screws and a shared 2-56 screw to attach the closure to the housing.

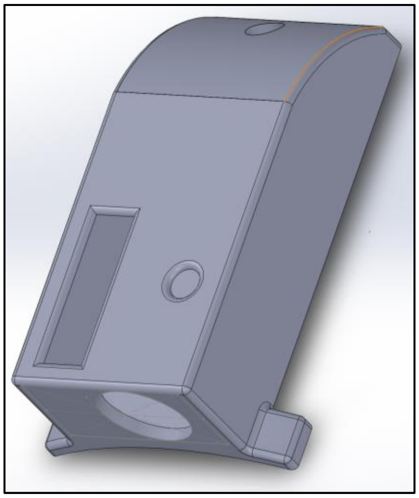


Figure 30: Render of 3D printed camera mount.

Figure 31: Camera mount installed on airframe.

5.4.4.2 Bulkheads

To construct the bulkheads, two individual circular cuts were made with distinct diameters; one at 4.753" and the other at 4.987". Each bulkhead is constructed by attaching the 4.753" and 4.987" together with 5 grams of 30-minute epoxy, and centering them appropriately to ensure a fit onto the fiberglass coupler. Once the epoxy is hardened, holes of ¼" and 5/16" diameter were drilled into the bulkheads for threaded rod and U-bolt placement. A last set of holes made for 4-40 screws was drilled for ejection charge caps.

Figure 32: Installation of ejection charge caps.

5.5 As Built Schematics

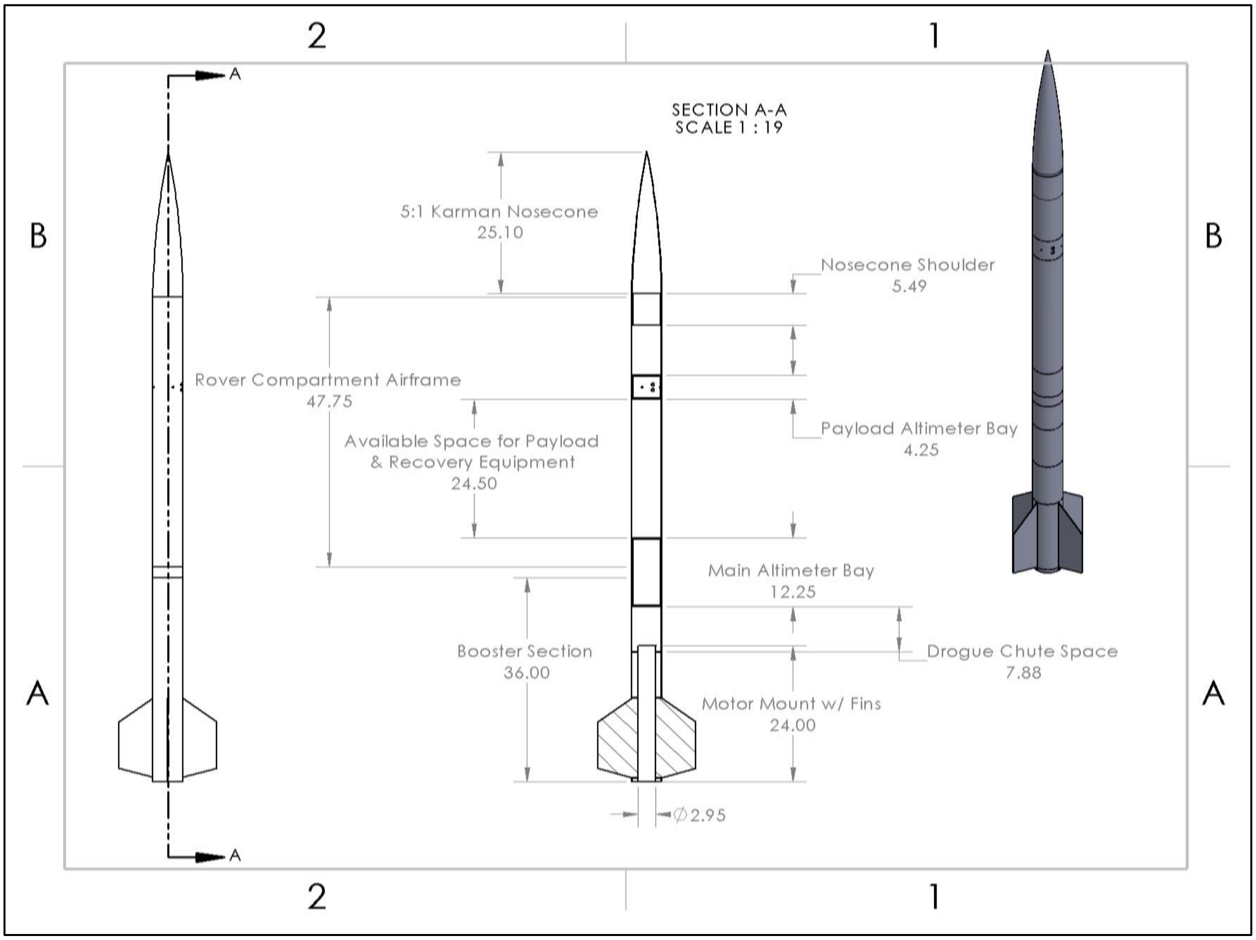


Figure 33: Launch vehicle general measurements and schematics.

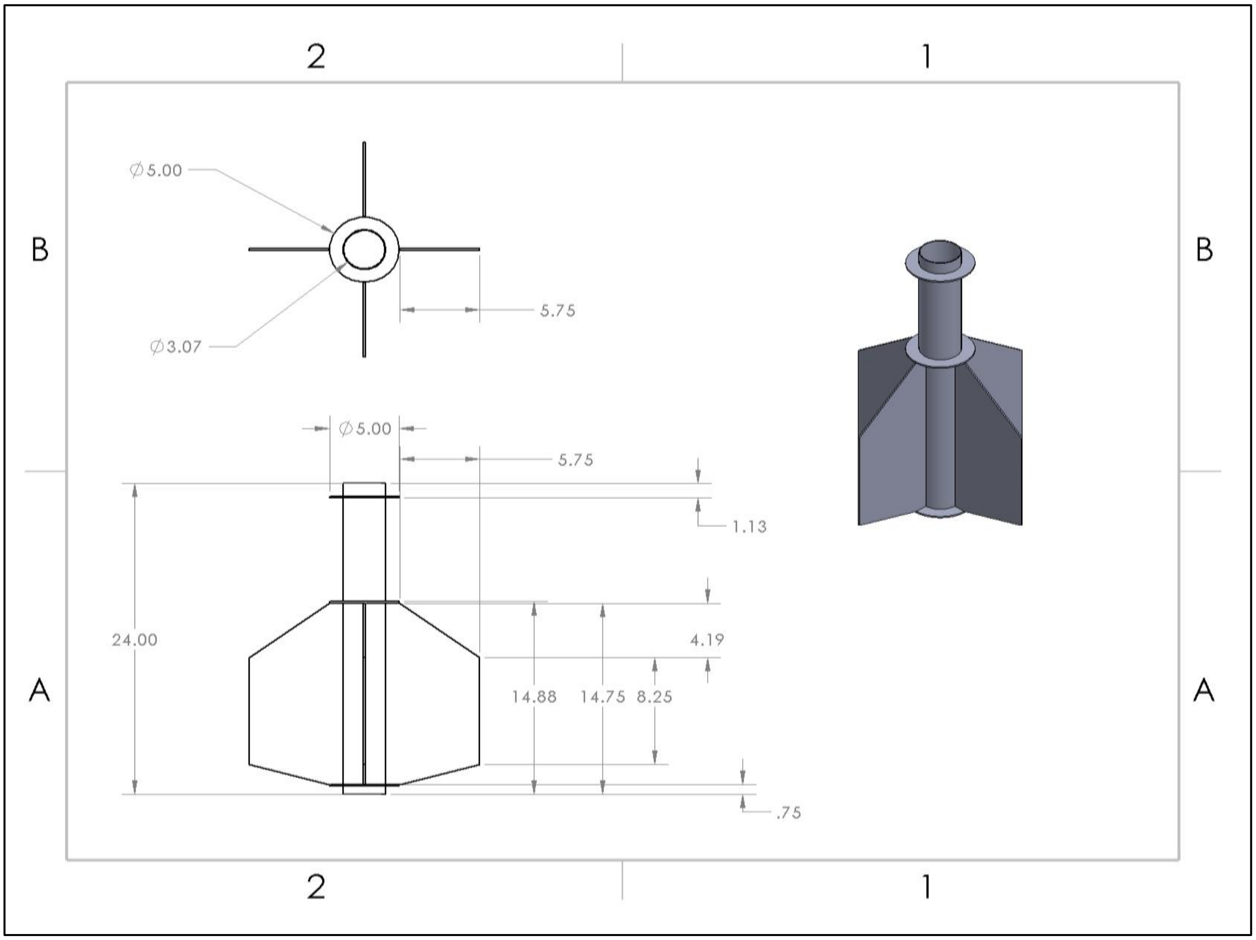


Figure 34: Motor mount measurements and schematics.

5.6 Differences from earlier models

The final constructed launch vehicle differs from earlier models in three main areas. The weight of the constructed launch vehicle is much heavier than predictions based on PDR and CDR designs, especially the Booster Section due to aeropoxy and adhesive applications. The fin design changed immensely over the course of the project. The total area of the fins reduced from, roughly, 100 in^2 to 64 in^2. The last major difference from earlier designs is the shear pin configuration. During both subscale and the first fullscale flight, the shear pin configuration aboard the launch vehicle did not allow for a preferred method of separation. The shear pin configuration was changed to two 2-56 and two 4-40 polystyrene pins, unconventional but proved successful in the second full scale flight.

6 Recovery Subsystem

6.1 Structural Elements

6.1.1 Shock Cord Harnesses

For shock cord, the team prefers to side with proven performance of components unless it is clear that other options need to be considered. Since the team's previous NSL rocket design was nearly twice the weight of this year's design and the design weight is not critical, the ½" tubular Kevlar has once again been chosen as the preferred shock cord for this design for the nosecone and payload main parachute and also for the booster and altimeter drogue parachute. Kevlar tubing is tested for 7200 lb shock, which is more than sufficient for the purposes to which it will be applied. In order to reduce weight and increase available space, however, ¼" tubular Kevlar will be used for the booster and altimeter bay main parachute. The relatively small yet strong shock cord allows for easy storability within the airframe, without adding any unnecessary risks. All shock cord sections will be attached to the the bulkheads via 5/16" D-rings and will be folded using a layered Z-fold as seen below.

Figure 35: Layered Z-fold of shock cord within airframe section.

6.1.2 Bulkheads

Like the custom fins, ⅛" structural FRP fiberglass sheets, supplied by McMaster-Carr, were chosen to construct the bulkheads for the altimeters bays. Two sheets were used to create a single bulkhead to cap and secure altimeters, electronics and any other components stored within the altimeter bay. The inside fiberglass sheet has a diameter of 4.753", matching the inner diameter of the G12 fiberglass coupler used as the altimeter bay. The outer sheet has a diameter of 4.987" which caps the G12 coupler and fits inside the 5" diameter of the main airframe. This material has been used for the construction of our vehicles several times and has shown reliability during flight and recovery.

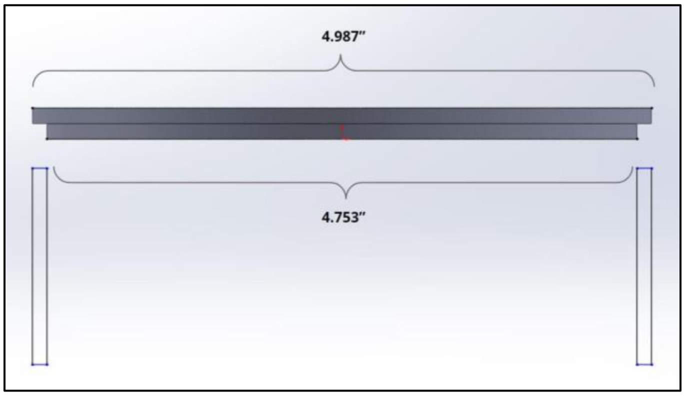


Figure 36: Full-scale bulkhead dimensions.

6.1.3 Hardware

As quick links, D-rings, and U-bolts are readily available, very inexpensive, and contribute very little to the overall weight of the launch vehicle, it is preferred to select components that are dependable and have proven capabilities. For this reason, 5/16" zinc-plated U-bolts and locking D-rings have been chosen as the recovery device interface apparatus for this design. The team has previously used these components with success over several launches, and, as stated above, have been used under more aggressive circumstances than the present project encompasses. These recovery hardware elements have been attached to the fiberglass bulkheads used on both altimeter bays. The high shear and compressive strength of the fiberglass, along with the cross-sectional area of the bulkheads, the recovery hardware is compatible.

6.2 Electrical Elements

6.2.1 Altimeters

Although there are numerous available types and brands of altimeter available to be purchased, the team generally prefers to utilize technology that has been proven in other applications, especially when there is no compelling reason to choose another option. Additionally, we rely on the advice of our team mentor and his evaluation of components based on his almost 30 years of experience with high powered rockets. Although the MissileWorks RRC3 "Sport" Altimeters are the primary choice, the limited space in the Payload Altimeter Bay and the addition of removable ballast in the Main Altimeter Bay rendered the RRC3 to be not practical due to its size. After further research into other altimeters, the Altus Metrum EasyMini became the choice. This altimeter has dual-deployment capabilities, runs on a wide range of voltage, has a cubic volume of less than a single inch, and can be programmed to deploy a charge to intervals of one meter. These altimeters proved reliable after one subscale and two full scale flights.

6.2.2 Switches

The "Switch" space will be occupied by a common mechanical rotary switch, that works by allowing and canceling current in a circuit. The off position is labeled by "110" and the on by "220". The resistance of all the prongs on the switch was tested in both positions and was found to be roughly 1 ohm when on and "closed" when off.

6.3 System Redundancy

Each subsystem within the overall recovery system will operate with redundant and parallel altimeters, operating independent of each other and all other onboard electronics. The EasyMini altimeter will identify the moment of apogee, and a signal will be sent to a charge which will shear the pins and separate the booster section from the main altimeter bay, releasing the drogue parachute. In the event of a failure of the main charge, another signal will be sent to a seperate powder charge and a redundant EasyMini altimeter to ensure that the pins shear and the section separates. The same EasyMini altimeter will then identify the moment when the launch vehicle is 950 feet above ground, and a signal will be sent to the second charge to separate the rover compartment from the main altimeter bay, fully separating the booster section and main altimeter bay from the rest of the rocket. This separation releases the main parachute for these two sections. There is a simultaneous redundant charge to ensure the separation and main parachute deployment. Further, two EasyMini altimeters will be installed in the payload altimeter bay for the purpose of separation of the nose cone from the rover compartment. These charges will be set to 800 feet above the ground, and will be signaled separately and simultaneously. Each altimeter located within both altimeter bays will be powered by a separate 9-volt battery, and operate independent of all other altimeters.

6.4 Parachutes

All parachute data is based on L1420R-P motor flight simulation and under conditions detailed previously.

One SkyAngle Classic II 60 and one Fruity Chutes Iris Ultra 66" HP Compact Chute will be used from main parachute descent, along with a 28 inch SkyAngle Classic II drogue that deploys at Apogee. The SkyAngle and Fruity Chute series of parachutes are extremely reliable, easy to fold and pack, and have been extensively tested and reviewed. Further, specific instructions on folding the parachutes are readily available, making it even easier to utilize for the project. No such tests are available for many other commercially available parachutes.

In order to calculate the drift, first it was necessary to determine the maximum descent speed for each section that would result in a maximum kinetic energy at landing of 75 ft. lb. force. For this, the formula for the relationship between energy and velocity was used.

$$v = \sqrt{\frac{2E}{m}}$$

Equation 1: Relationship between energy and velocity.

In order to calculate the parachute coefficient of drag and canopy area needed to achieve the desired descent velocities, the following formula for parachute size and drag was used.

$$A \cdot C_d = \frac{2gm}{\rho v^2}$$

Equation 2: Parachute descent velocity formula.

Calculations specified that the product of the parachute surface area and coefficient of drag is required to be a minimum of the following for the two sections.

Table 4: Minimum parachute $A \cdot C_D$ values.

Section	**Minimum $A \cdot C_D$** (ft^2)
Nosecone and Payload Section	49.17
Booster and Altimeter	71.09

This result was compared to the manufacturer specified data for various parachutes and the selected parachutes have the following characteristics.

Table 5: Rover compartment and nosecone main parachute characteristics.

SkyAngle Classic II 60	
Deployment Altitude (ft)	800 ft
Area × Drag Coefficient ($A \cdot C_D$) (ft^2)	74.277
Material	Zero-porosity 1.9 oz. silicone-coated balloon cloth

SkyAngle Classic II 60	
Surface Area (*A*) (ft^2)	39.3
Diameter	60”
Drag Coefficient	1.89
Number of Lines	3
Line Length (in)	60
Line Material	3/8” tubular nylon (950-lb)
Attachment Type	Heavy-duty 1,500 lb. size 12/0 nickel-plated swivel

Table 6: Booster section main parachute characteristics.

Fruity Chutes Iris Ultra-Light 66” Chute	
Deployment Altitude (ft)	950 ft
Area × Drag Coefficient ($A \cdot C_D$) (ft^2)	50.815
Material	0.66oz ripstop nylon
Surface Area (*A*) (ft^2)	47.5
Diameter (in)	66 in. (86.805 in. equivalent flattened)
Drag Coefficient (C_D)	2.2

Fruity Chutes Iris Ultra-Light 66" Chute	
Number of Lines	10
Line Material	200# Spectra Nanoline

Table 7: Drogue parachute characteristics.

28" SkyAngle Classic II drogue	
Deployment Altitude	Apogee
Area × Drag Coefficient ($A \cdot C_D$) (ft^2)	8.0
Material	Zero-porosity 1.9 oz. silicone-coated balloon cloth
Surface Area (A) (ft^2)	8.6
Diameter	28
Drag Coefficient (C_D)	.93
Line Length	28"
Number of Lines	3
Line Material	3/8" tubular nylon (950 lbs)

28" SkyAngle Classic II drogue	
Attachment Type	Heavy-duty 1,500 lb. size 12/0 nickel-plated swivel

6.5 Drawings and Schematics

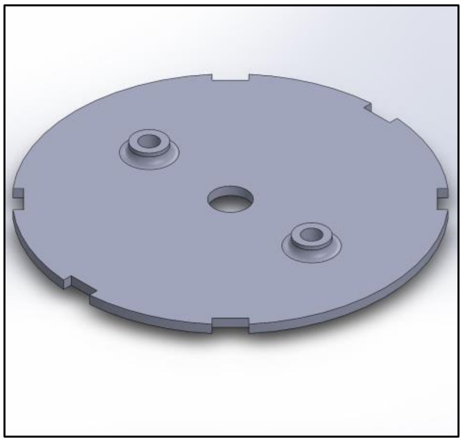


Figure 37: Rendering of main altimeter sled design.

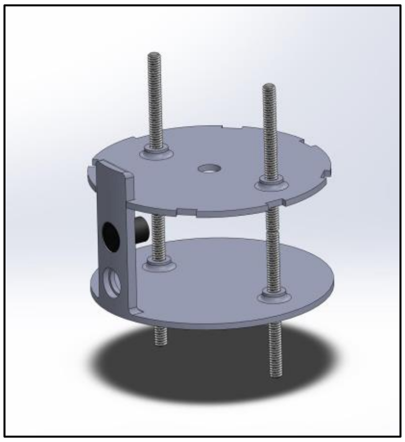


Figure 38: Rendering of payload altimeter sled design.

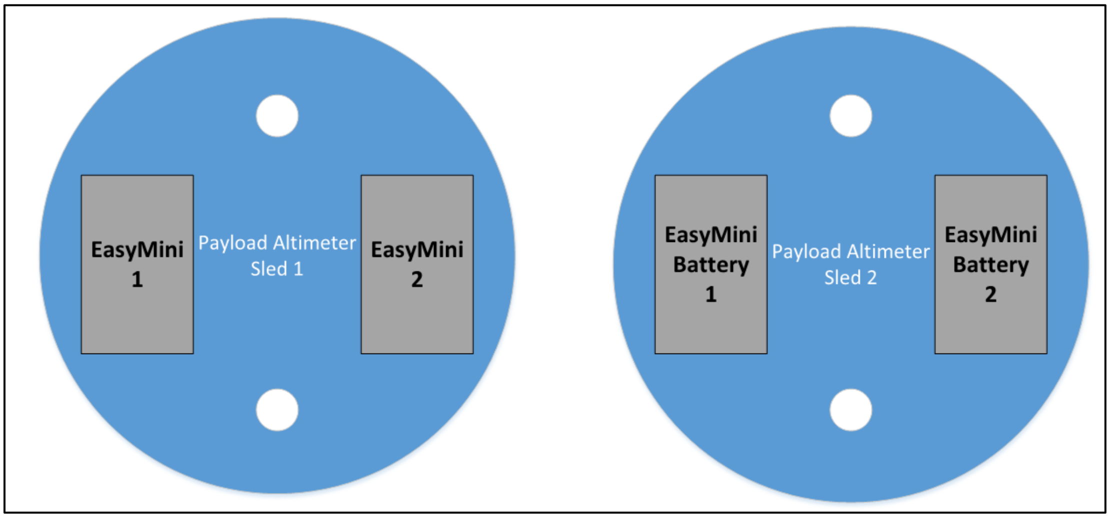


Figure 39: Payload altimeter sled layout drawing.

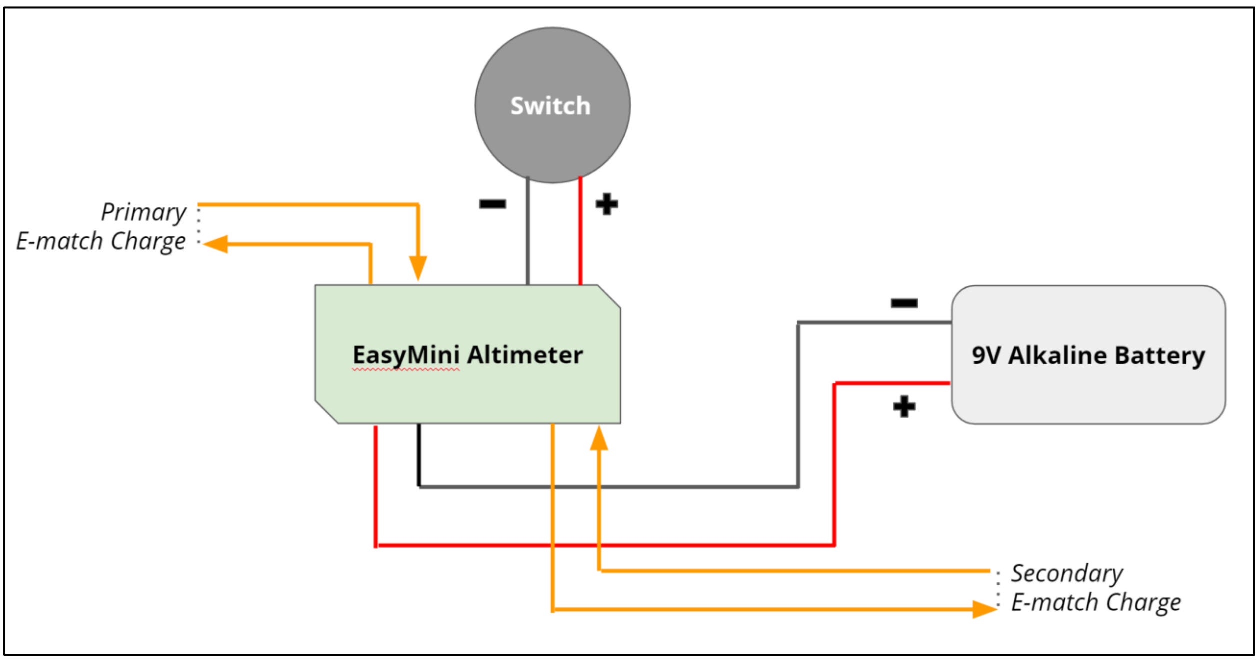


Figure 40: Payload recovery system wiring diagram.

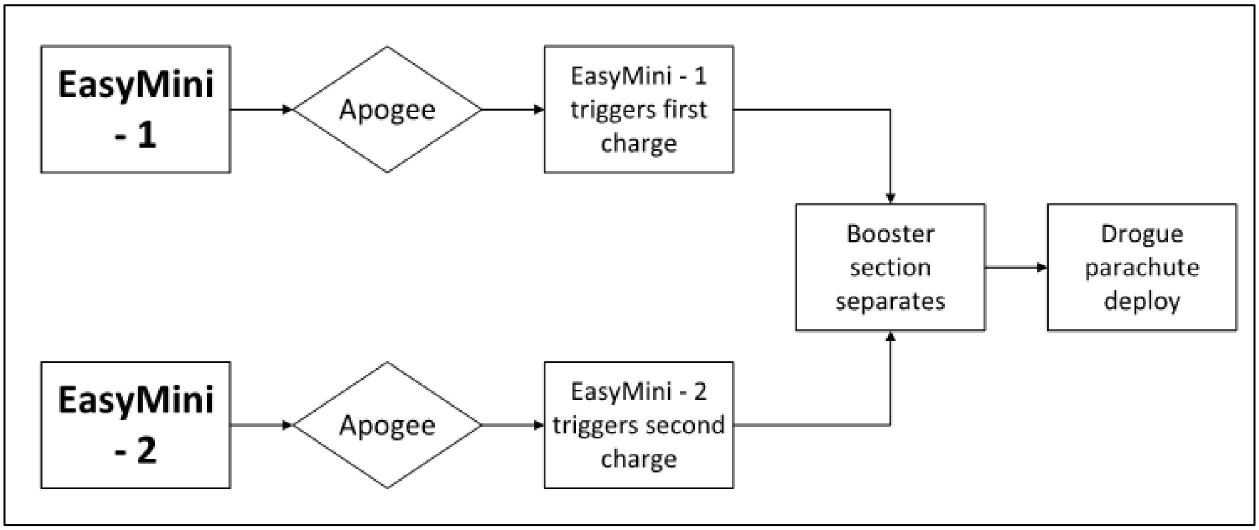


Figure 41: Drogue parachute deplyoment sequence.

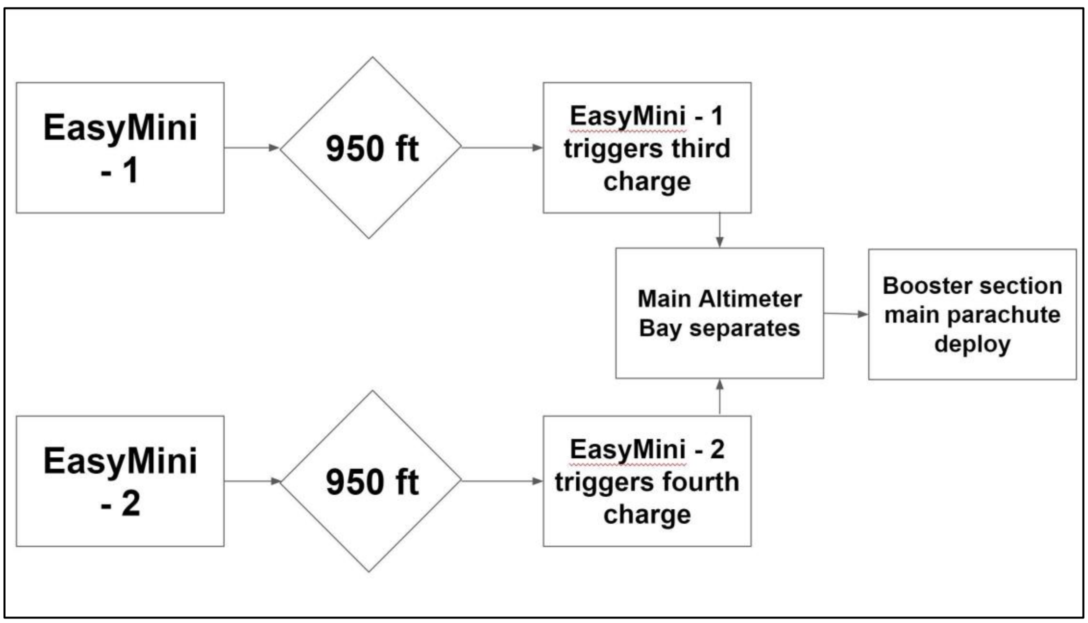


Figure 42: Booster section main parachute deployment sequence.

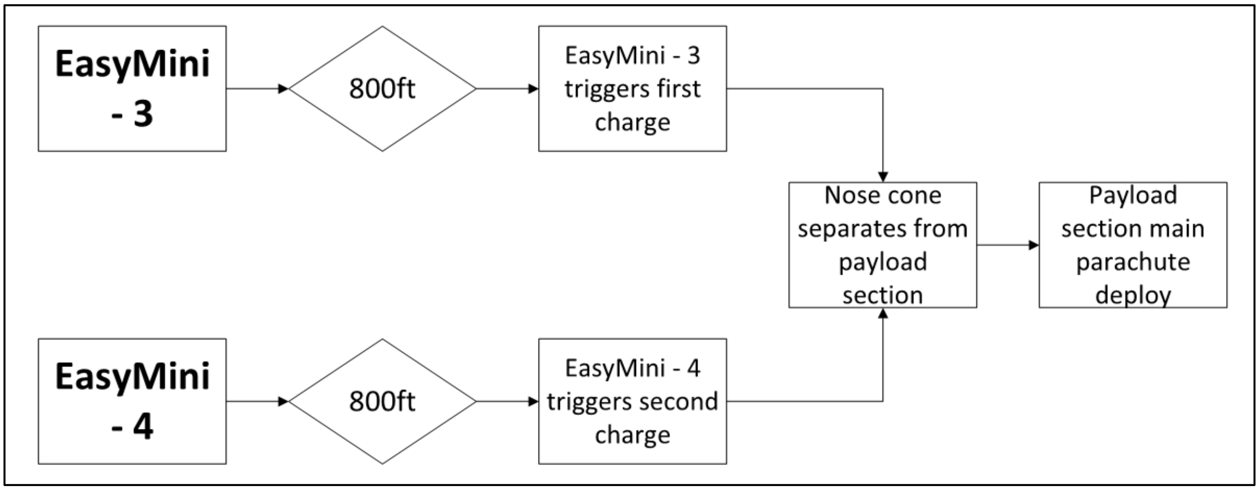


Figure 43: Payload section main parachute deployment sequence.

6.6 Locating Transmitters

The rocket tracking devices on board are the SB1 Sonic Location Beacon from Adept Rocketry. It operates on a 12V alkaline battery, and emits a 4000 Hz tone at 90 decibels. The device itself is small, a total volume of 0.666 cubic inches and weighing at less than half an ounce. There is a manual switch on the SB1 that activates when a "jumper" wire is disconnected. The "jumper" is connected to the main parachute via a long wire, and when the parachutes deploy then the "jumper" will disconnect and turn the beeper on. Two locators are used in the launch vehicle to locate each major tethered section and are stored in the Payload and Main Altimeter Bay.

6.7 Electronic Sensitivity

To ensure nominal performance of all recovery system electronics, each altimeter bay shall be lined with copper tape for EMI shielding from the payload electronics. The primary source of any EMI is the Xbee transmitter used for the remote triggering of the payload upon landing of the rocket. The other main source of EMI is the motors located inside of the rover. However during the ascent and descent periods, the rover electronics will be in a low power mode to preserve payload battery power and reduce any EMI from payload electronics. The EMI shielding tape and payload electronics kept in a low power mode during the flight ensure that all recovery system electronics shall be safe from adverse effects due to EMI.

7 Mission Performance Predictions

7.1 Flight

7.1.1 Flight Profile Simulations

A projected apogee of 5,304 ft was calculated based on OpenRocket simulation data using the below parameters and procedures and with the launch vehicle loaded with maximum ballast.

Table 17: L1420R-P motor default simulation with zero wind.

Simulation Parameters	
Average Windspeed (mph)	0
Standard Deviation (m/s)	0.0
Turbulence Intensity (%)	10 *(Medium)*
Wind Direction (°)	90
Launch Rod Length (in)	96
Launch Rail Angle (°)	0
Atmospheric Conditions	International Standard Atmosphere
Calculation Method	Extended Barrowman
Simulation Method	6-DOF Runge-Kutta 4

7.1.1.1 Apogee Notes

In calculating the estimated apogee, several steps are necessary to obtain an accurate result.

1. Configure the weights and measurements of the launch vehicle in OpenRocket to match as closely as possible to the actual weights and measurements.
2. Create and run a simulation that duplicates the launch day conditions.
3. If necessary, change the surface texture of the launch vehicle design so that the raw simulated apogee matches the actual launch apogee as closely as possible.
4. Compare the raw simulated apogee to the actual apogee to obtain a multiplication factor that reflects the discrepancy between the two.
5. Create and run a simulation under standard reportable conditions and record the apogee.
6. Multiply that apogee by the multiplication factor to obtain the calculated estimated apogee.

In the case of this launch vehicle, the multiplication factor was determined to be 1.0022675.

As we have proceeded through two test flights, the calculated apogee has conformed more and more to the actual apogee of the launch vehicle, as the team narrowed down weight, balance, and ballast details.

As of Test Launch Number 2, the raw simulated apogee for the standard report configuration is approximately 5,292 feet. Converted with the multiplication factor, the calculated estimated apogee is 5,304 feet. This is slightly higher than the target 5,280 feet but will account for any turbulence or fluctuation in winds.

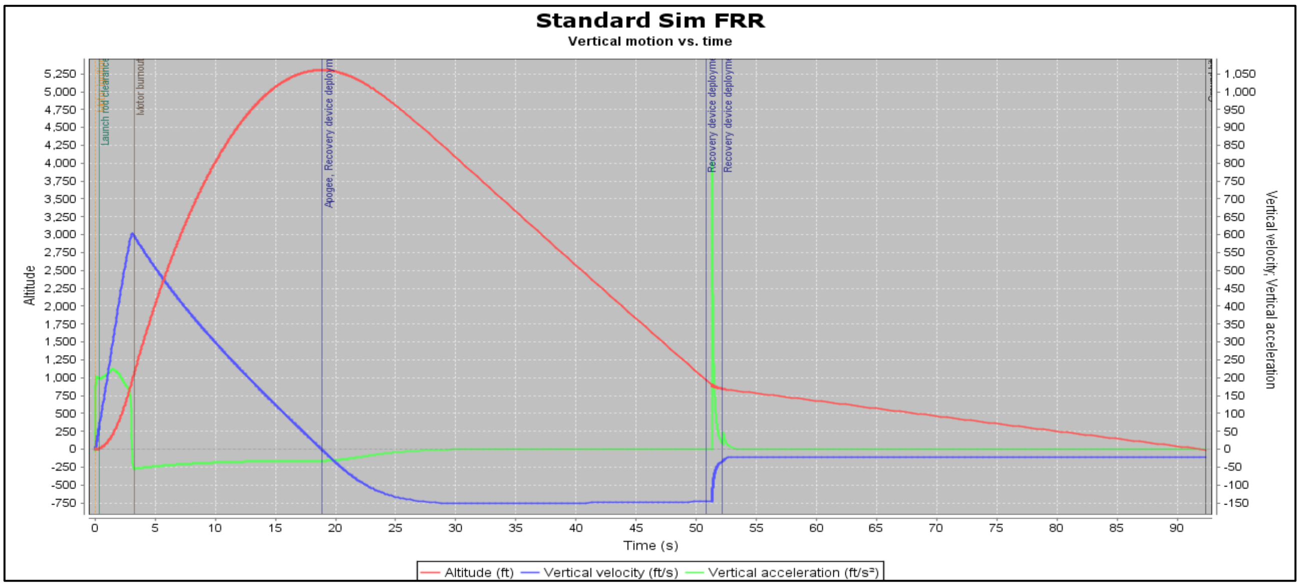


Figure 44: Graph of flight profile under Aerotech L1420R-P motor.

7.1.2 Altitude Predictions (including complications not listed above)

Table 8: Altitude predictions for ballast configurations.

Wind Speed (mph)	**Total Ballast Weight** (lb)	**Projected Apogee** (ft)
0	4.2500	5283
1	4.1875	5284

Wind Speed (mph)	**Total Ballast Weight** (lb)	**Projected Apogee** (ft)
2	4.1250	5285
3	4.1000	5285
4	4.0000	5283
5	3.8750	5301
6	3.8125	5285
7	3.6875	5289
8	3.6250	5282
9	3.5000	5282
10	3.3750	5287
11	3.2500	5289
12	3.1250	5288
13	3.0000	5289
14	2.8750	5289
15	2.7500	5288
16	2.6250	5288

Wind Speed (mph)	**Total Ballast Weight** (lb)	**Projected Apogee** (ft)
17	2.5000	5288
18	2.3750	5289
19	2.2500	5291
20	2.0000	5288

7.1.3 Component Weights

Below is a summary of the component weights of the constructed launch vehicle.

Table 9: Final launch vehicle overview mass statement.

System Name	**Weight (max ballast)** (lb)	**Weight (min ballast)** (lb)
Ballast Allocated	**4.25**	**0**
Loaded Rocket (motor & max ballast)	48.7	44.45
Nosecone (bulkhead & G10 shoulder)	5.5	3.5
Rover Compartment (airframe, payload altimeter bay, rover)	14.9	14.9
Booster Section (airframe, motor mount & recovery equipment)	10.125	10.125
Main Altimeter Bay (G10 coupler, bulkheads, altimeters, and recovery equipment)	7.175	4.925

System Name	Weight (max ballast) (lb)	Weight (min ballast) (lb)
Parachutes	1.5	1.5
Aerotech 75mm L1420 Motor (Total / Propellant)	9.5	9.5

7.1.4 Simulated Motor Thrust Curve

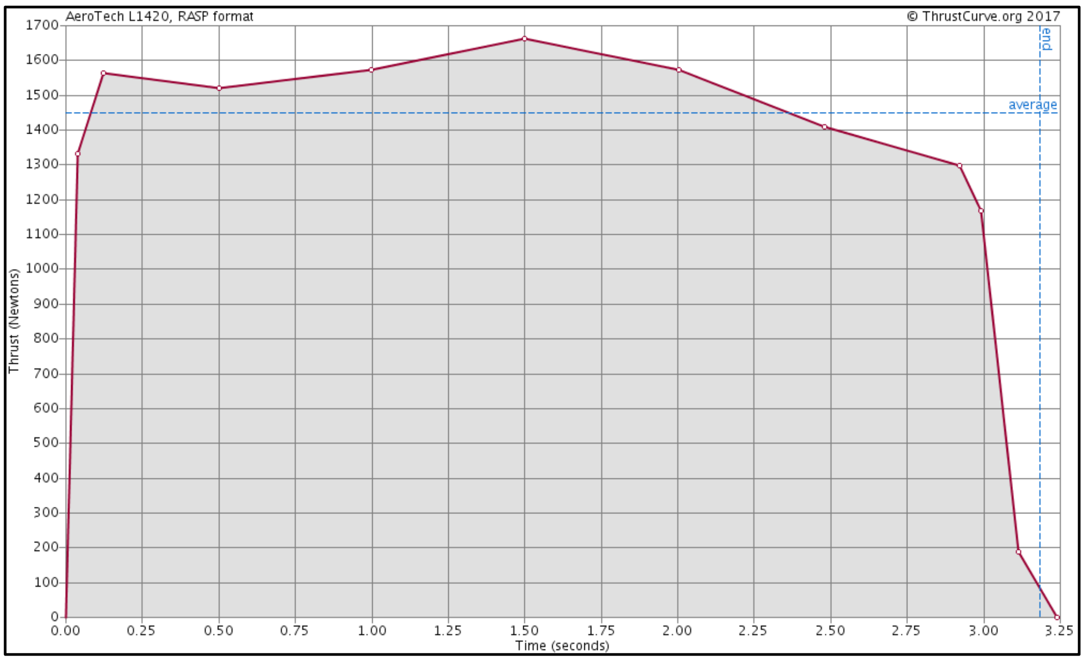


Figure 45: Aerotech 75mm 4G L1420 thrust curve.

7.2 Stability

7.2.1 Stability Margin

Table 10: Stability margin with L1420 motor and maximum ballast.

Max Ballast (lb)	4.25
Center of Pressure (in)	88.308

Center of Gravity (in)	68.34
Static Stability Margin (cal)	3.88

Table 11: Stability margin with L1420 motor and minimum ballast.

Min Ballast (lb)	2
Center of Pressure (in)	88.308
Center of Gravity (in)	70.072
Static Stability Margin (cal)	3.54

7.2.2 Stability margin, CP, and CG

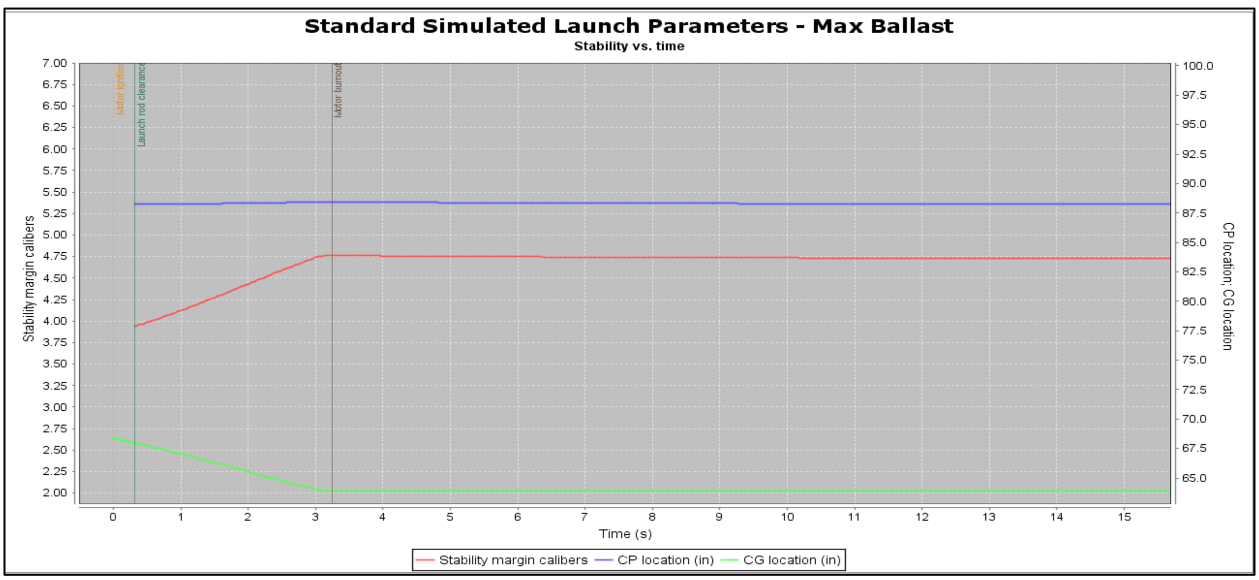


Figure 46: Stability over time graph, with maximum ballast.

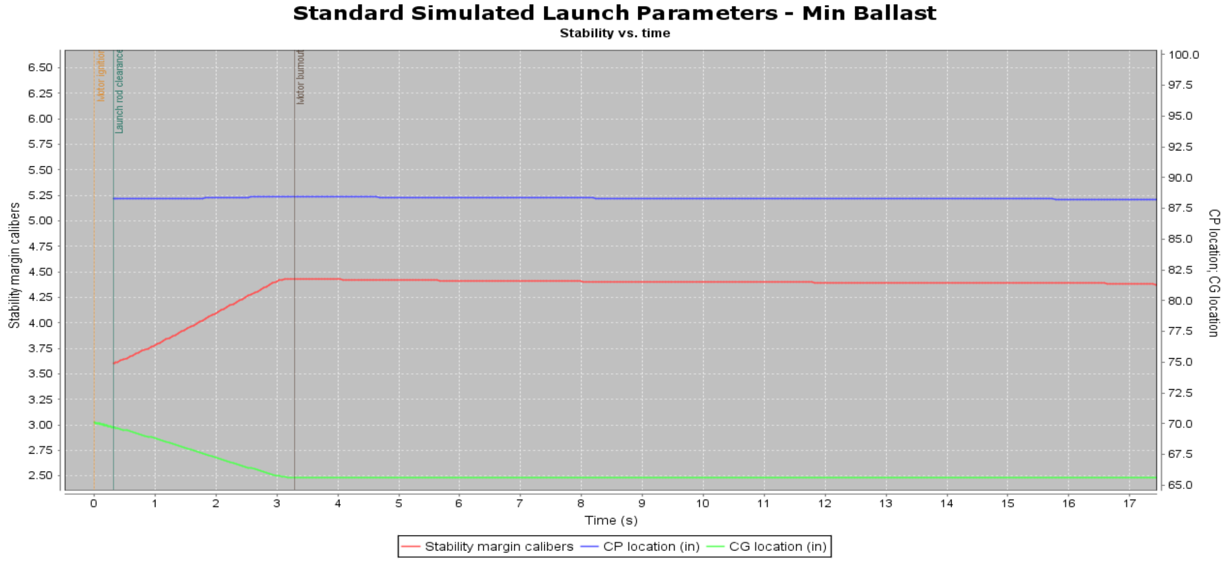


Figure 47: Stability over time graph, with minimum ballast.

7.3 Kinetic Energy at Landing

Calculations based on the formula for the relationship between parachute drag and velocity, the same as calculated in the Recovery Subsystem section give the following results.

Table 12: Descent velocity of rocket components.

Rocket Component	**Velocity** (m/s)	**Velocity** (ft/s)
Nosecone and Payload	5.08	16.68
Booster and Altimeter Bay	4.61	15.13

From the velocity, the kinetic energy at landing can be calculated using the below formula.

$$KE = \frac{1}{2}mv^2$$

Equation 3: Definition of kinetic energy.

Table 13: Kinetic energy at landing.

Rocket Component	**Kinetic Energy** (ft lbf)
Nosecone and Payload	72.60
Booster and Altimeter Bay	71.80

7.4 Drift

The drift of the launch vehicle is calculated by multiplying the descent time, as calculated by the online descent rate calculator located at https://descentratecalculator.onlinetesting.net/, by the wind speed. The drift is calculated for each separate section of the rocket.

The descent time is calculated by adding the descent time under the drogue to the descent time under the main separately in order to provide the most accurate descent time.

The booster section and altimeter will descend under a Fruity Chutes Iris Ultra 36" HP Compact Chute and has a total descent time of 82 seconds when opening at 950 feet. The nosecone and rover compartment will descend under a SkyAngle Classic 60 parachute and has a total descent time of 80 seconds when opening at 800 feet. The drogue parachute is a SkyAngle 28 Classic parachute. The justification for the parachute selection is discussed under the Recovery Subsystem section 6.

Table 14: Drift analysis of booster section and altimeter at various wind speeds.

Wind Speed (mph)	**Wind Speed** (ft/s)	**Drift** (ft)
0	0	0
5	7.33	601.33
10	14.67	1202.67
15	23.46	1804.00
20	29.33	2405.33

Table 15: Drift analysis of nosecone and rover compartment at various wind speeds.

Wind Speed (mph)	**Wind Speed** (ft/s)	**Drift** (ft)
0	0	0
5	7.33	586.67
10	14.66	1173.33
15	23.46	1760.00
20	29.33	2346.67

7.5 Alternate Calculation Methods

Alternate calculations were conducted using the descent time from Rocket Reviews descent rate calculator located at https://www.rocketreviews.com/descent-rate-calculator.html. Under the same parachute, the descent time of the booster section and altimeter was 67 seconds. Also using the same parachute, the descent time for the nosecone and payload was 68 seconds.

Table 16: Alternate drift analysis of booster section and altimeter at various wind speeds.

Wind Speed (mph)	**Wind Speed** (ft/s)	**Drift** (ft)
0	0	0
5	7.33	491.33
10	14.66	982.67
15	23.46	1474.00

Wind Speed (mph)	**Wind Speed** (ft/s)	**Drift** (ft)
20	29.33	1965.33

Table 17: Alternate drift analysis of nosecone and rover compartment at various wind speeds.

Wind Speed (mph)	**Wind Speed** (ft/s)	**Drift** (ft)
0	0	0
5	7.33	498.67
10	14.66	997.33
15	23.46	1496.00
20	29.33	1994.67

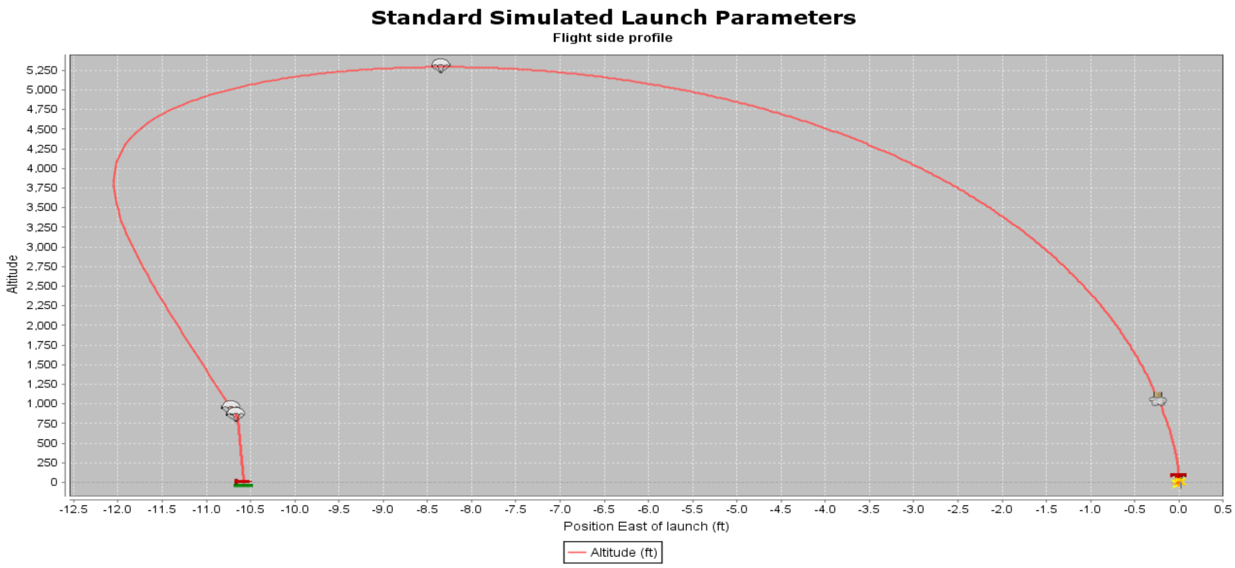
7.6 Discrepancies

Discrepancies between the drift calculations can largely be explained by the fact that the first mentioned descent rate calculator was specially designed for the SkyAngle parachutes and the second calculator is not. In order to obtain a descent calculation in the second one, it is necessary to estimate the equivalent diameter of the SkyAngle parachutes. In the case of the Fruity Chutes parachute, the equivalent diameter given by the manufacturer was used to calculate the drift in both cases. Here, the discrepancy is not so easily explained, especially since the calculation methods are not available for examination. However, as both calculations place the drift area well within the designated parameters, this should not be a significant issue.

7.7 Simulations

See Appendix 15.4 for drift analysis exported data.

Table 18: Graph of flight profile under Aerotech L1420R-P motor.



8 Full Scale Flight

8.1 Test Flight 1 - 1/27/18

A separate report was sent in for Test Flight Number 1 following the CDR presentation in order to ensure that our launch vehicle would not exceed the height waiver set at the competition launch site in Huntsville.

The goal of the launch on January 27th was to test the functionality and phases of the flight, as well as prove our launch vehicle can reach a reasonable apogee. The payload (rover and/or deployment system) was not included for this flight. However, the same coupler used for ground testing on January 26th, was equipped with a 3D printed cylinder that contained a mixture of metal BBs and 30-minute epoxy. This coupler acted as a simulated payload ballast. NASA officials from the CDR presentation requested a launch with no removable ballast (stationed in the Nosecone shoulder) because the predicted launch vehicle in the CDR report was 6695 feet, which exceeds the 5600-foot altitude waiver at the Huntsville launch site. The flight results given by the four on-board altimeters prove that our rocket with a reasonable payload weight delivers the vehicle below the 5600-foot altitude waiver with an ability to lower this apogee further to as close to a mile as possible.

The flight conditions on the day in question were relatively unstable. It was a clear day with minimal cloud cover and the temperature was 68ºF (20ºC). Winds were approximately 14 mph, gusting to 20. Wind data was obtained from the Weather Channel online at the time of the launch.

Table 19: Mass statement at time of Full-Scale Test Flight 1.

System Name	**Actual Weight** (lbs)
Nose Cone	3.00
SkyAngle Classic II 60	1.10
Nomex Protective Fabric	0.21
Nose Cone Shock Cord	0.90
Rover Compartment Airframe	4.30
Payload Altimeter Bay (incl. batteries and altimeters)	2.50
Simulated Ballast	9.20
SkyAngle Cert-3 Medium Parachute	0.80
Nomex Protective Fabric	0.21
Main Altimeter/Booster Shock Cord	0.70
Main Altimeter Bay (incl. batteries and altimeters)	3.80
Drogue Parachute	0.22
Nomex Protective Fabric	0.21
Booster Section (incl shock cord and d-ring)	8.90
Total	**36.05**

For the full scale launch, four Altus Metrum EasyMini altimeters were used.

Table 20: Apogee data from each of the four altimeters used in the Full-Scale Test Flight 1.

Altimeter	Statistics Screen	Exported Data	Graph (Approx.)
Altimeter #3 (m)	1696.2	1696.23	1696
Altimeter #4 (m)	1695.7	1695.72	1697
Altimeter #5 (m)	1710.1	1710.06	1710
Altimeter #6 (m)	1699.0	1698.97	1699
Mean (m)	**1700.25**	**1700.245**	**1700.5**
Mean (ft)	**5578.25**	**5578.23**	**5579.07**

8.2 Test Flight 2 - 2/17/18

8.2.1 Launch Day Conditions

The second flight of Apis II took place on February 17th at Varn Ranch in Plant City Florida. The launch site was encased in a dense morning fog, but cleared out around 10:30 am. Launch procedures and preparations began and the rocket was on the pad by 2:30pm. The winds steadily picked up throughout the day and averaged from 8 to 10 mph during the time of launch. The high and low temperatures that day were 84 degrees and 61 degrees Fahrenheit respectively.

8.2.2 Launch Day Conditions Simulation

Before and after completing the second test flight, simulations were conducted to mimic the launch day conditions in order to compare the actual performance to the simulated data and extrapolate information to apply to the next test launch and competition flight. Below are the simulated conditions used.

Simulation Parameters	
Average Windspeed (mph)	10
Standard Deviation (mph)	2.0
Turbulence Intensity (%)	20 *(Very High)*
Wind Direction (°)	90
Launch Rod Length (in)	96
Launch Rail Angle (°)	2
Atmospheric Conditions	International Standard Atmosphere
Calculation Method	Extended Barrowman
Simulation Method	6-DOF Runge-Kutta 4

Several simulations were conducted, and the average apogee returned by the simulations was 5,395 feet. By comparison, the average of all altimeters for the test flight showed an actual apogee of 5,407 feet.

8.2.3 Flight Analysis

The ascent of the launch vehicle went well. Given the data received from the EasyMini altimeters on board showed the max acceleration to be 4.12 Gs during the boost phase and the time to apogee at around 28.1 seconds. The drogue chute slowed the launch vehicle to a steady descent rate 77 feet per second until the first main parachute deployment at 950 feet AGL. At this point, the Booster and Main Altimeter Bay separate from the rest of the launch vehicle and descended at an average rate of 28 feet per second for 31 seconds until touchdown. The main parachute responsible for deploying at 800 feet AGL to recover the Nosecone and Rover Compartment airframe was not attached properly, allowing these sections to descend at an unsafe rate. Fortunately, there was no damage to the launch vehicle or electronics stored within the Payload Altimeter Bay.

8.2.4 Simulation and Actual Flight Comparison

Predicted flight model data were extremely close to actual performance, resulting in virtually identical apogees.

8.2.5 Error Discussion

The small amount of error between the simulation and actual apogee can likely be explained by the fact that OpenRocket does not allow for exact adjustment of the coefficient of friction, so we were unable to adjust that factor precisely.

8.2.6 Discussion

Both full scale test flights, in January and February, are similar to the subscale flight in December in terms of unsuccessful and undesired events of recovery. This was evident through the shear pin configuration, which was either too weak or strong. In the case of a weak configuration, premature separation occurred which happened on the first full scale flight, allowing the booster section to drift a large distance. In the case of an excessively strong configuration, there is the high possibility and risk that sections will not separate sufficiently from each other. This happened for the subscale flight, when the black powder charges could not break the four 4-40 shear pins, thus deterring the Rover Compartment from separating from the Main Altimeter Bay. The shear pin configuration was successful for the second test flight, with distinct separations happening at their designated altitudes. However, the parachute was not attached properly but a post-flight inspection revealed the problem and it is a simple fix.

9 Payload Design

9.1 Payload Design Summary

Table 21: Final Rover characteristics, excluding deployment system.

Weight (lb)	**Height (compacted)** (in)	**Height (expanded)** (in)	**Length** (in)	**Motor**
7	5	8.5	14.5	12V DC

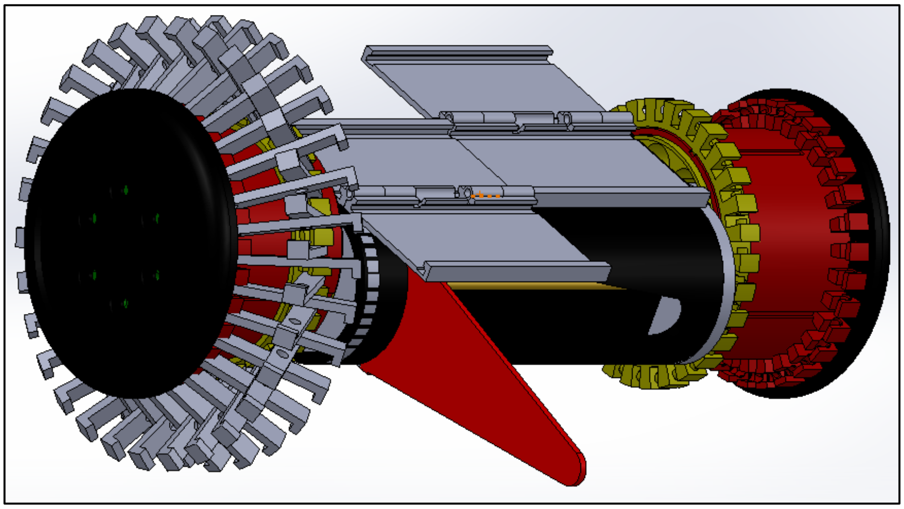


Figure 48: Rendering of Sidewinder rover, with right wheel hidden.

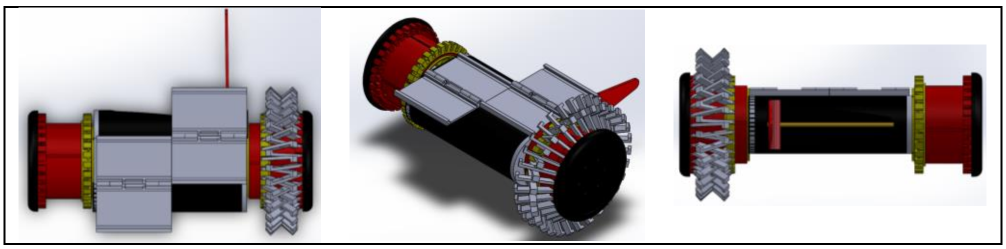


Figure 49: Sidewinder rover alternative renderings.

9.2 Changes Since CDR

9.2.1 Expanding Wheel

While testing the Rover prototype we came across issues with the previously designed wheels (shown in Figure 4) being slippery, and we also noticed that the rover body had less than 3/4" of ground clearance when traveling. The proved to be a design flaw since there is a large likelihood that there will be debris that can easily prevent the rover from moving forward. In order to ensure the mission criteria will be met an expanding wheel system was created. This new design (shown in Figure 5) allows for more traction because of the spike-like treading and a larger diameter wheel to raise the body up from the ground. The wheel design expands from a 5 inch diameter to an 8.5 inch diameter wheel using a set of 30 scissoring leg links that are distributed evenly across the circumference of the each wheel core. We created a sliding ring with notches that "slide" along the wheel core. The rotation of the wheel unlocks the leg link mechanisms. This prevents one wheel opening up before another and getting caught in the deployment process from the rocket body.

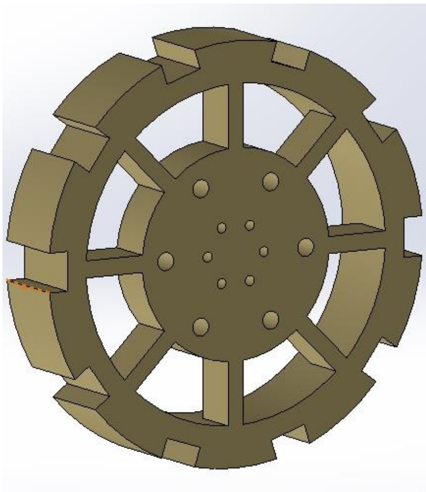
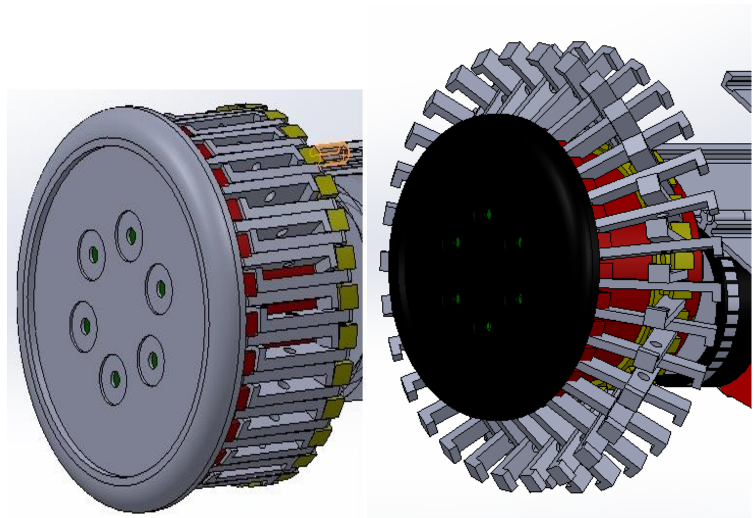
5" Diameter Wheel	5" - 8.5" Expanding Wheel
	

Figure 50: CDR and FRR rover wheel designs.

As a result of the expanding wheel design, adjustments to other parts of the rover were made:

9.2.1.1 Structure Rods

The overall diameter of the wheel core is smaller and in order to properly secure the rover together we had to use only 2 structural rods spaced 2.5" apart from the center of the wheel axle which differs from the 4 previously.

9.2.1.2 Battery Compartment

Since the wheel core and the battery compartment are concentric the battery compartment was re-made with a smaller diameter and only 2 holes for the structural rods.

9.2.1.3 Side Body Connector

Two holes for the support rods were removed which required the side body connecter to be redesigned. The new design also incorporates a hook for the expanding wheel lock.

9.2.2 Newtonian Leg

The original design of the internal Newtonian leg with two small sliding legs (shown in Figure 6) has been replaced with a larger single leg (shown in Figure 7 and Figure 52) that mounts on the side of the rover body. This was necessary because previously the two legs were too flexible, and did not provide consistent leg extension. We replaced the leg with a metal gate hinge which opens up in a different orientation. This allows for a solid contact to the ground at all times with the added benefit of resisting flexion from normal rover operations. The new leg stands roughly 4.5” extending from the rover body. The body sits roughly at an angle of 30 degrees relative to the horizontal.

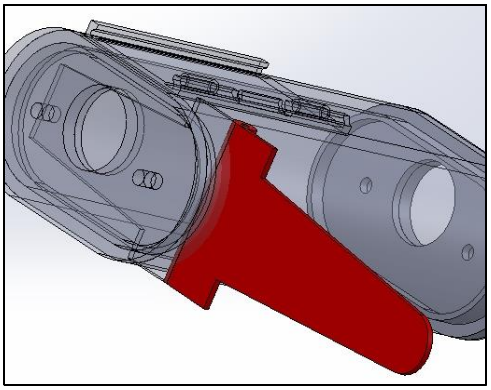


Figure 51: Rover Newtonian leg drawing.

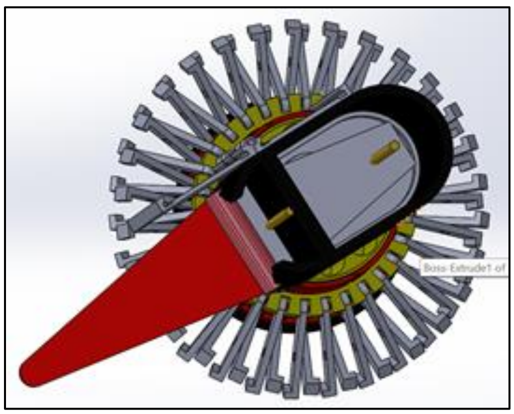


Figure 52: Alternative rendering of new rover leg design.

9.2.3 Main Body Design

In order to make the rover more streamlined and to ensure the Newtonian leg will not catch itself on anything while in the rocket and deployment system sequence, the main body now has a recess for the hinge to placed in. The slot has enough room to allow the hinge to move 90 degrees freely. The leg is being pushed open away from the body by a torsion spring and the recess acts as a stopping point for the Newtonian leg so it will not overextend to cause damage to the rover components and to maintain the best contact with the terrain. The best contact is when the leg is perpendicular to the rover body. With the combination of the recess, the torsion spring, and no locking mechanism the Newtonian leg is self correcting and will adjust if need be.

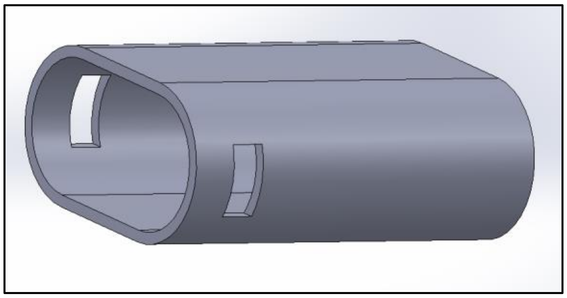


Figure 53: Prior rover body design, with two openings for the Newtonian leg system.

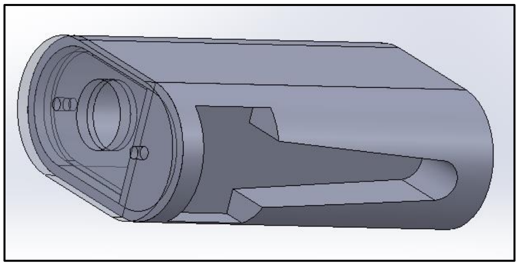


Figure 54: New rover body design, featuring a single larger opening for the Newtonian Leg.

9.3 Payload Features

9.3.1 Component Deployment System

(Solar, Newtonian Leg, Wheel Leg Links)

Figure 55: Experimental test setup for wire cut.

The rover includes components (the Newtonian leg, solar mechanism, and expandable wheels) that are under tension from springs. In order to ensure mission success the components need to be controlled by a deployment method to be initiated at a specific time interval. The method of deployment uses a set of e-matches and Dyneema wire.

9.3.2 Safety and design

The e-matches we are using are Estes Model Rocket starters. From multiple tests we determined that the igniters require a minimum voltage of 2V and 2.6A of current in order to properly ignite. This data is supported by "*Electrical Current Requirements of Model Rocket Igniters*" by Robert Briody. In order to prevent any mishaps we identified four potential causes that can prematurely ignite an ematch: Shock, induced current, friction and short circuits.

The e-match is designed to fit inside a metal bullet casting, covered with petroleum jelly on the inside walls. The casting will have a small slit in which the Dyneema braided fishing line will pass through. The bullet casing will then placed inside a 3D printed plastic container which will be stuffed with non-flammable packing foam.

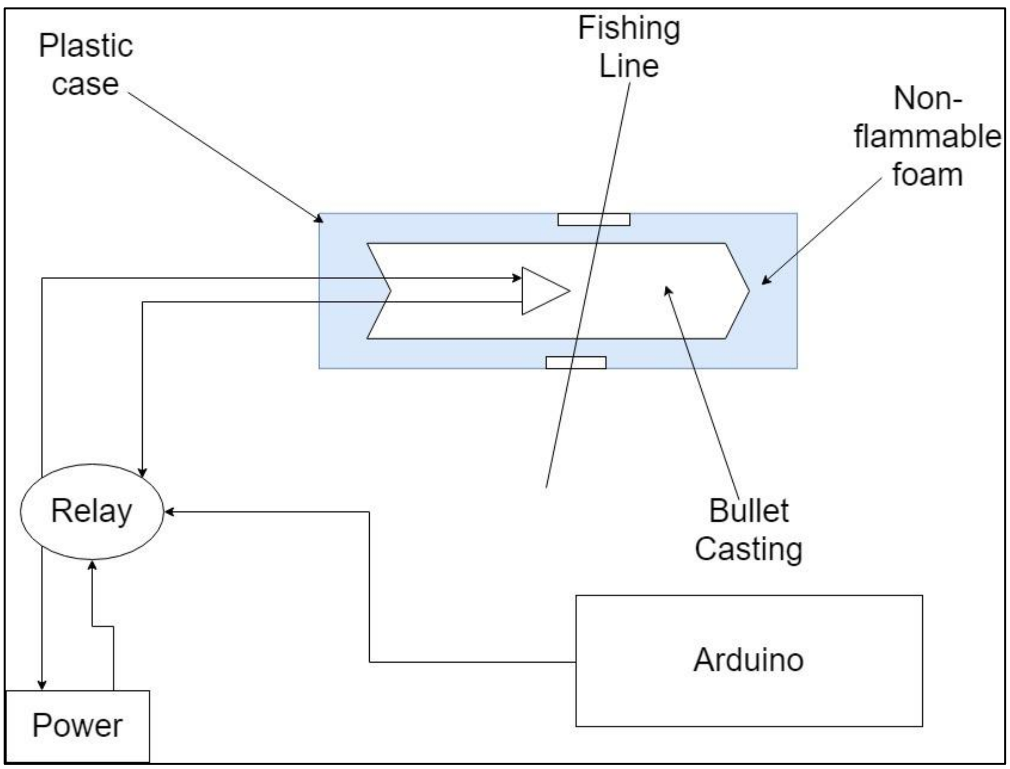


Figure 56: Electronic diagram of solar panel release system.

The packing foam reduces the impact force the e-match will experience where as the PLA plastic container will eliminate the induction of current from any potential rover devices (especially the DC motors). The bullet casting(extremely high melting temperature) and petroleum jelly (fire retardant) is specifically designed to prevent the spread any potential fire. We are using Dyneema fishing wire which has a melting temperature of 125 degrees centigrade with a flash point temperature of 440 degree centigrade. The idea is to use the e match to "cut" the dyneema fishing line by melting it to the point where it fails to counteract the spring force on the rover components and the parts “spring” open. The e-matches having a peak temperature of 660 degrees centigrade which poses a threat of the fishing line catch on fire. However, with our tests we have completed, the fishing line melts too quickly to catch on fire, and any flames that did appear were quickly put out from the fast whipping recoil of the release mechanisms. Additionally, PLA plastic (which makes up the majority of the rover construction) has a melting temperature of 220 degrees centigrade and should be noted that PLA plastic is NOT flammable. If any flames were to bypass all of our safety precautions the rover will not burn.

Dyneema has a coefficient of static friction of 0.1 based on data from “*Friction Coefficient of UHMWPE During Dry Reciprocating Sliding*“ study which gives the probability of friction being the cause of premature ignition is extremely low.

On top of all the safety precautions we have created the ematches are packaged with a protective shroud which the manufacture uses to further mitigate premature ignition.

The “biggest” threat we will have to deal with is any short circuits. The matches will be hooked up to an electrical relay which is grounded to the rover body. Any stray current has an extremely low probability of passing into match until it is signaled by the Arduino.

9.3.3 Structural Elements

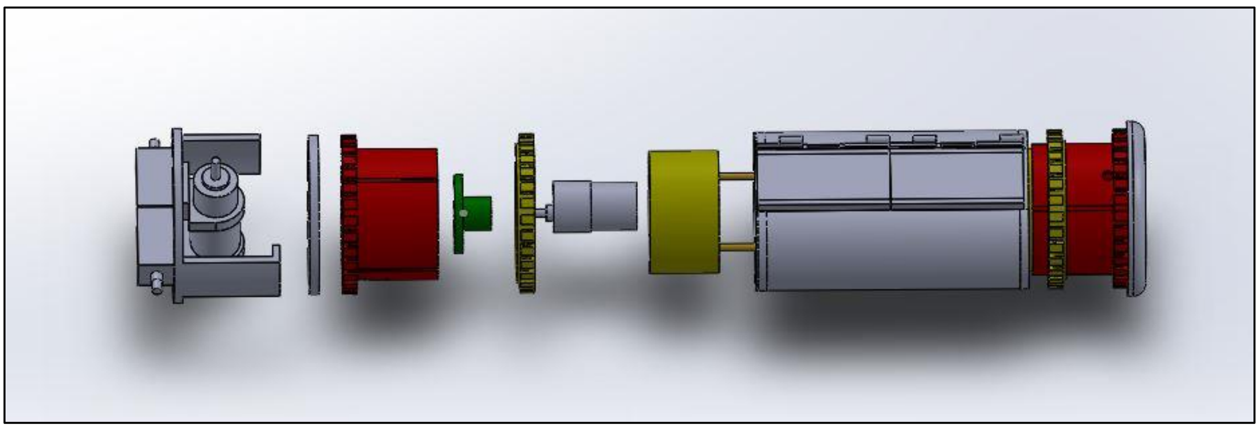


Figure 57: Exploded diagram of rover.

9.3.3.1 Objective of the Deployment system

The deployment system should meet the following objectives:

1. Initiate when commanded by the ground safety officer.
2. Move a 10 lb payload beyond the exterior of the vehicle.
3. Secure the payload prior to activation.
4. Release the payload when beyond the exterior of the vehicle.

9.3.3.2 Deployment thought process

In addition to meeting the above requirements, the design needs to take into consideration other variables

The simplicity of the design prevents an over complicated design from failing upon launch. The more simplistic the design, the better. This means relying more on as few electronic components as possible.

The weight of the deployment system cannot be too large, or the rocket will not reach the desired Apogee. The maximum weight for the rover and deployment system is set at 10lbs. For this reason, alternative materials such as 3D printed parts are preferable to metal as they are lighter and do not have large forces being applied.

The size is important because it must fit within the frame of the rocket and compress to allow for as large of a rover as possible. This also affects the weight of the system as a larger system tends to be heavier.

Ease of loading and unloading the rover into the vehicle. Not only does the system have to deploy the rover, it must be able to load and secure the rover. It must be capable of loading while the rocket is assembled. Taking safety into consideration is very important for this, a sensitive system may launch the rover prior to being set and secured.

9.3.3.3 Winch System

4.3.4.3 The Rover will be deployed by a winch like system. The motor will have a spool in which a line of fishing wire that is stretched across on two points at the end of the rocket tube can rotate about. The rotation of the motor will essentially pull the rover out of the launch vehicle to continue on with its mission. In order for the system to remain in place we are using solenoids which will stick themselves into the rocket body and prevent any movement during flight. We are using a planetary geared motor with a relative encoder on the back to consistently provide the necessary movements to ensure success. The motor is rated at a torque of 146kg-cm which will provide enough torqueing power to overcome both friction and small hiccups. The deployment system attaches to the rover via a hook around the rover hub-caps.

9.3.4 Electrical Elements

9.3.4.1 Deployment Systems Electronics

The main deployment system will utilize two XBee RF transceivers that communicate between the base station and onboard system. The base station will consist of one XBee transceiver and a computer which will be connected by USB. The onboard deployment system will have the XBee transceiver connected to a shield that is designed to be attached an Arduino. These xbee transceivers have a range of roughly a mile.

Upon activation from the base station signal, the Arduino will give power to the solenoids (retracting them) and then starting up the winch system. Using the encoder on the motor it will be programmed to rotate until a certain distance which is the length of the payload section of the rocket body. Since the motor is roughly 2" away from the very beginning of the rover any sources of error will be eliminated in the distance calculation will be overcome. After the deployment sequence is finished the rocket will communicate with the rover via bluetooth to initiate its rover sequence

The solenoids we are using operate on a 12V current and can safely handle being retracted for less than 5 seconds before the start to get hot. Since both the solenoids and the motors have very high demands for power, especially when they are both operating a relay shield is being used which 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.

To properly supply power to this beast a battery with a high amount of ampere-hour is needed.

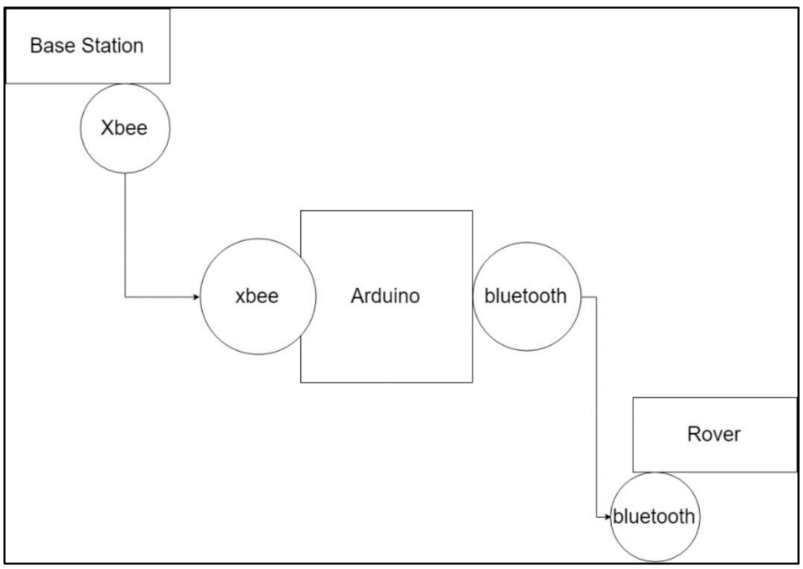


Figure 58: Rover communications schematic.

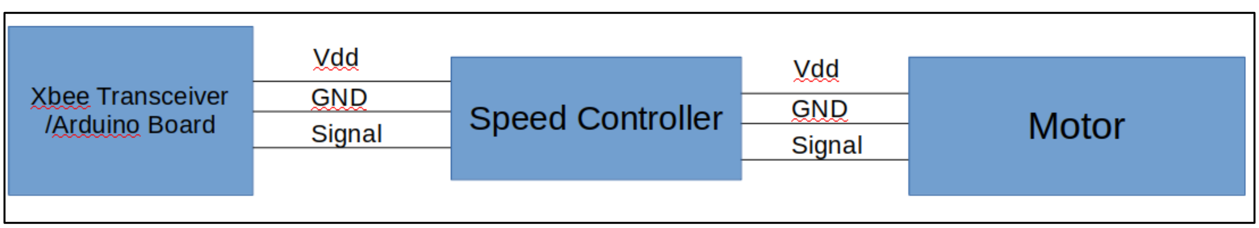


Figure 59: Rover deployment system electronics diagram.

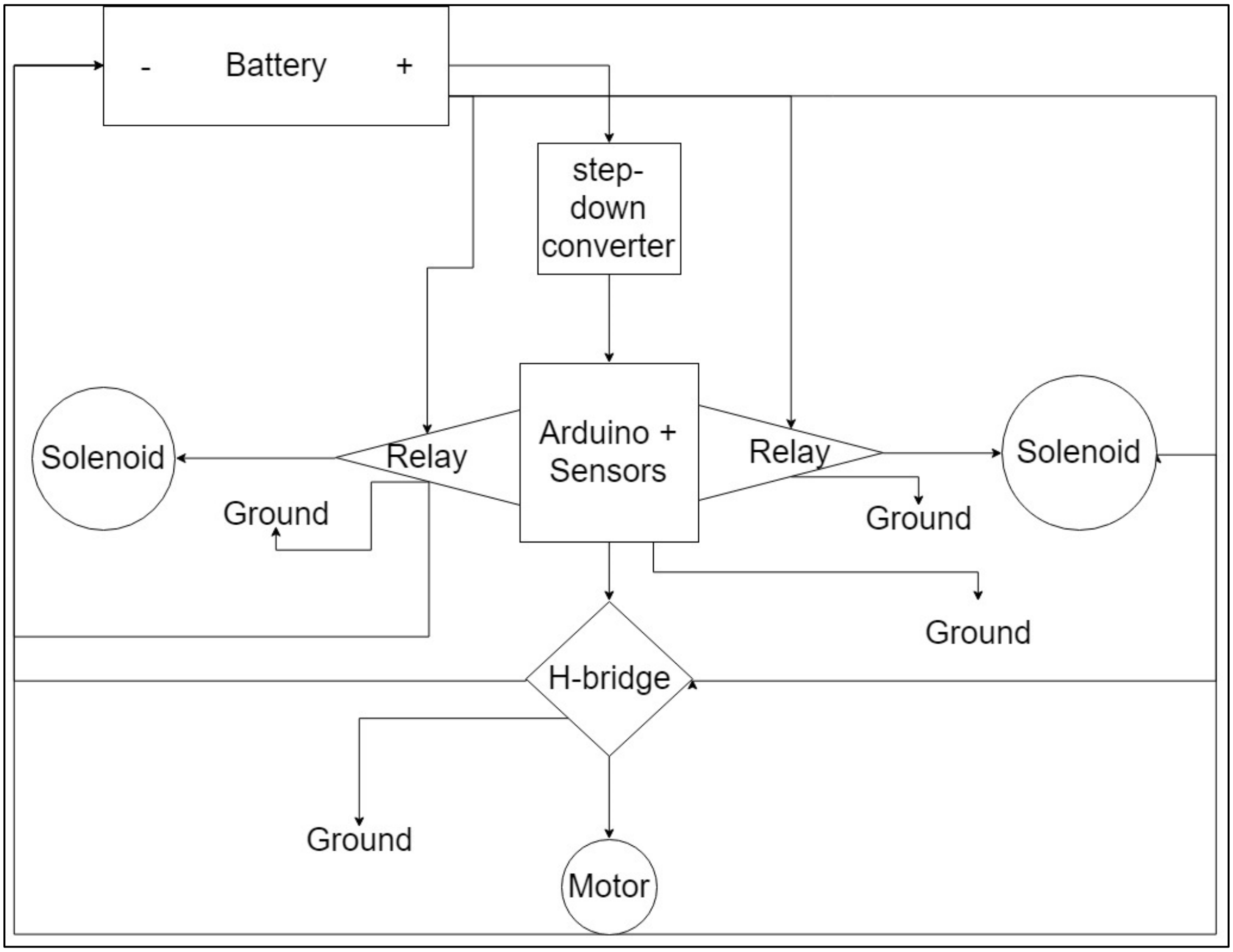


Figure 60: Rover power distribution schematic.

9.3.4.2 Rover Body Electronics

The rover body electronics can be best summarized with the following diagram:

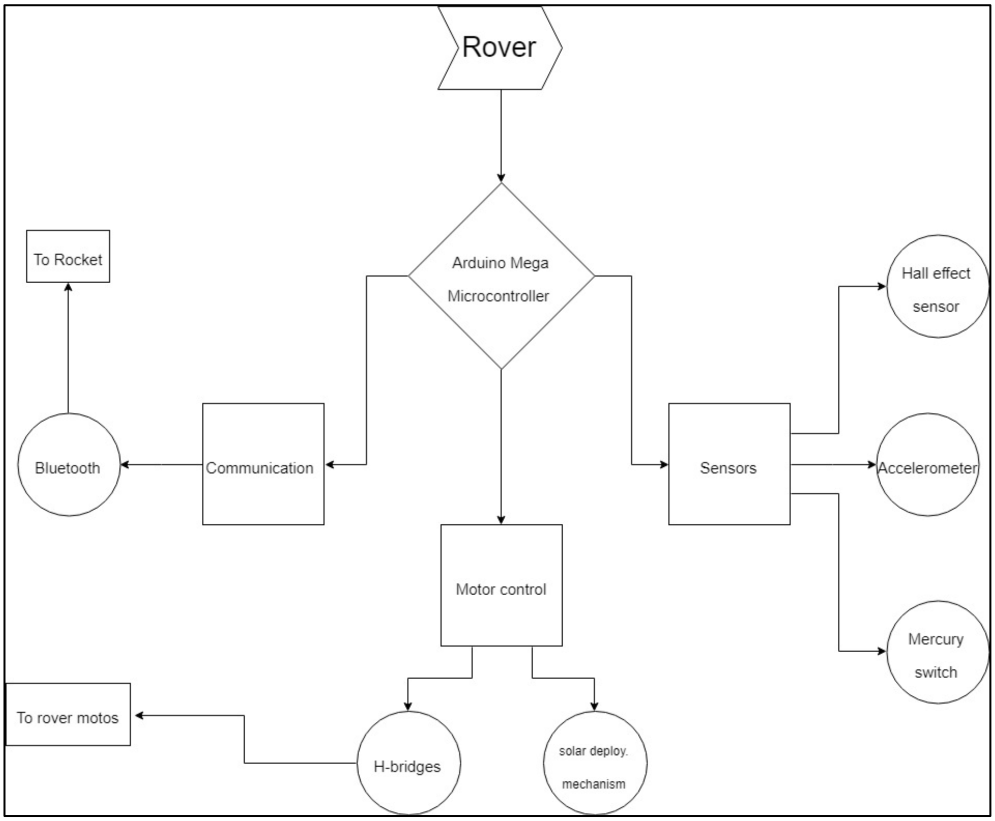


Figure 61: Rover body electronics and sensors overview schematic.

9.3.4.3 MicroController

The Arduino Mega 2560 Microcontroller Rev3 is the brains of the rover. It has 54 digital i/o pins and 16 analog i/o pins it is rated at a maximum voltage of 5V per pin. As shown in the diagram above the microcontroller will house the sensors and communications modules and control the motors as well. Each will be discussed more in detail.

9.3.4.4 Power

There are 16 batteries in the rover (8 on each wheel) that are being used to power the motors and the microcontroller. They are each spread evenly within the battery compartment. Each battery is rated at 3.3V and 600mAh. Since we are using rated 12V DC motors to move the rover we divided the batteries into "cells" with 4 batteries in each cell making a total of 4 cells. The individual batteries in each cell is connected in series while the individual cells in each wheel are connected in parallel. This gives a projected total of 12V and 1200 mAh in each wheel to power its motors.

The motors are rated at 0.68A which gives a projected runtime of 1.75 hours with the batteries being fully charged at the start and the motor running continuously at a constant speed.

9.3.4.5 Step down converter + H-Bridges

Because the Arduino is rated at a max of 5V and 40mA the motors and the Arduino cannot be connected directly together. The motors will draw in too much power to the board burning out the microcontrollers components. To solve this an H-bridge is being used. The H-bridge can do two things: 1) they can vary the amount of current flowing into the motors which effectively controls the speed and 2) switch the polarity of the motors which effectively switch the rotation of the motors.

The batteries and the motors are being connected directly to the H-Bridge since it can handle a maximum of 35V and 3A each. And since the current cannot backflow into the Arduino it is connected directly to the H-bridge as well. In order for the H-bridge (and the other components in the rover) to be controlled the Arduino needs power. To protect the Arduino from any potential backflow a step-down converter lowers the 12V coming from the batteries to its operating voltage of 5V. To prevent any shorts the H-bridges and the Arduino will be connected to ground.

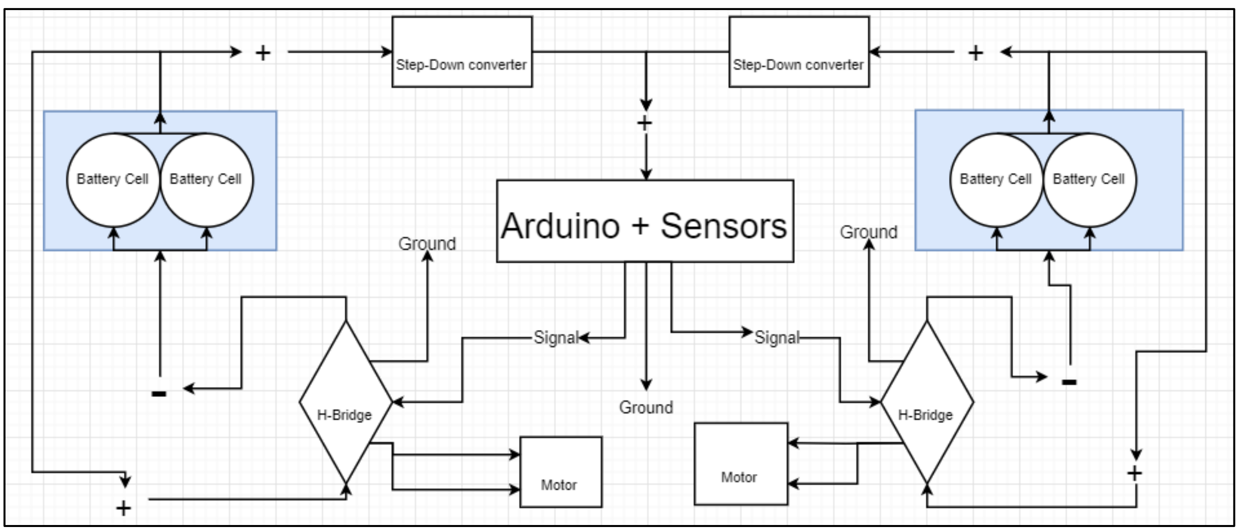


Figure 62: Rover body motor control system electronics schematic.

9.3.4.6 Solar panels

As an added bonus our foldable solar cells will be able to charge our rover batteries. We designed to fit 12 solar cells with each having an operating voltage of 5V and working current of 30mA. To maximize the solar cells efficiency they are connected in a similar fashion as the batteries. There are 2 groups of 6 solar cells with 3 solar cells grouped into one set. Each individual cell inside a set connected in parallel and each each individual set inside a group connected in series. This gives projected of 15V and 90mA of power flowing into the batteries allowing each group to fully charge the (dead) batteries in 10 hours. To regulate the charge coming in from the solar panels and to prevent overcharging a charge controller is going to be used.

9.3.4.7 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 main 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 4 will be used to estimate the distance traveled using this information.

$$d = vt = \omega rt = \frac{rpm \cdot 2\pi}{60} \cdot rt$$

Equation 4: Equation to calculate distance traveled given time (t), rpm, and radius (r) of a wheel.

9.3.4.8 ADXL345 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 so that way 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.

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

Equation 5: Equation used to calculate distance traveled given time (t) and acceleration (a).

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

9.3.4.9 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. We programmed the rover to stop its motors and deploy the foldable solar panels after it loses connection with the rocket (after a specific time delay).

9.3.4.10 Mercury Switch

Due to our current design the rover will need to be oriented a specific way for the solar deployment to work (which then ultimately means for the mission to be a success as well). To ensure that the rover is positioned exactly how we want it to a mercury switch is being used. The use of this sensor is reflected in our program.

9.3.5 Drawings and Schematics

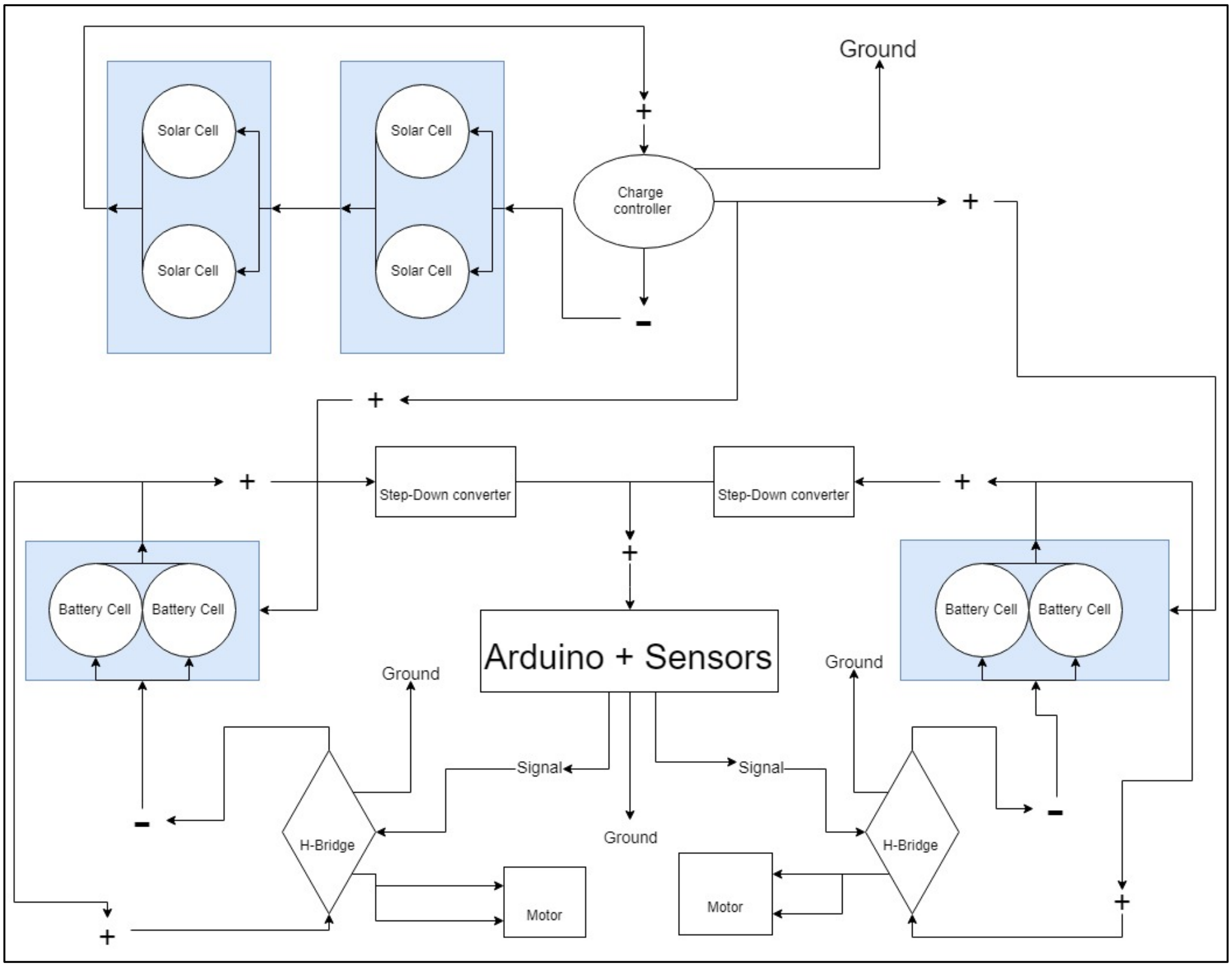


Figure 63: Rover body detailed electronics system schematic.

Below is the logic behind the programming for the rover and it demonstrates how all the sensors and motor controllers come together to accomplish the mission. There are multiple loops the make sure that the rover is actually moving along the ground. If the rover where to get stuck there is a loop that helps get it to go around the obstacle. As mentioned before as a failsafe the rover will stop its motors and deploy its solar panels to prevent the rover from traveling too far, and too long as a mission failure.

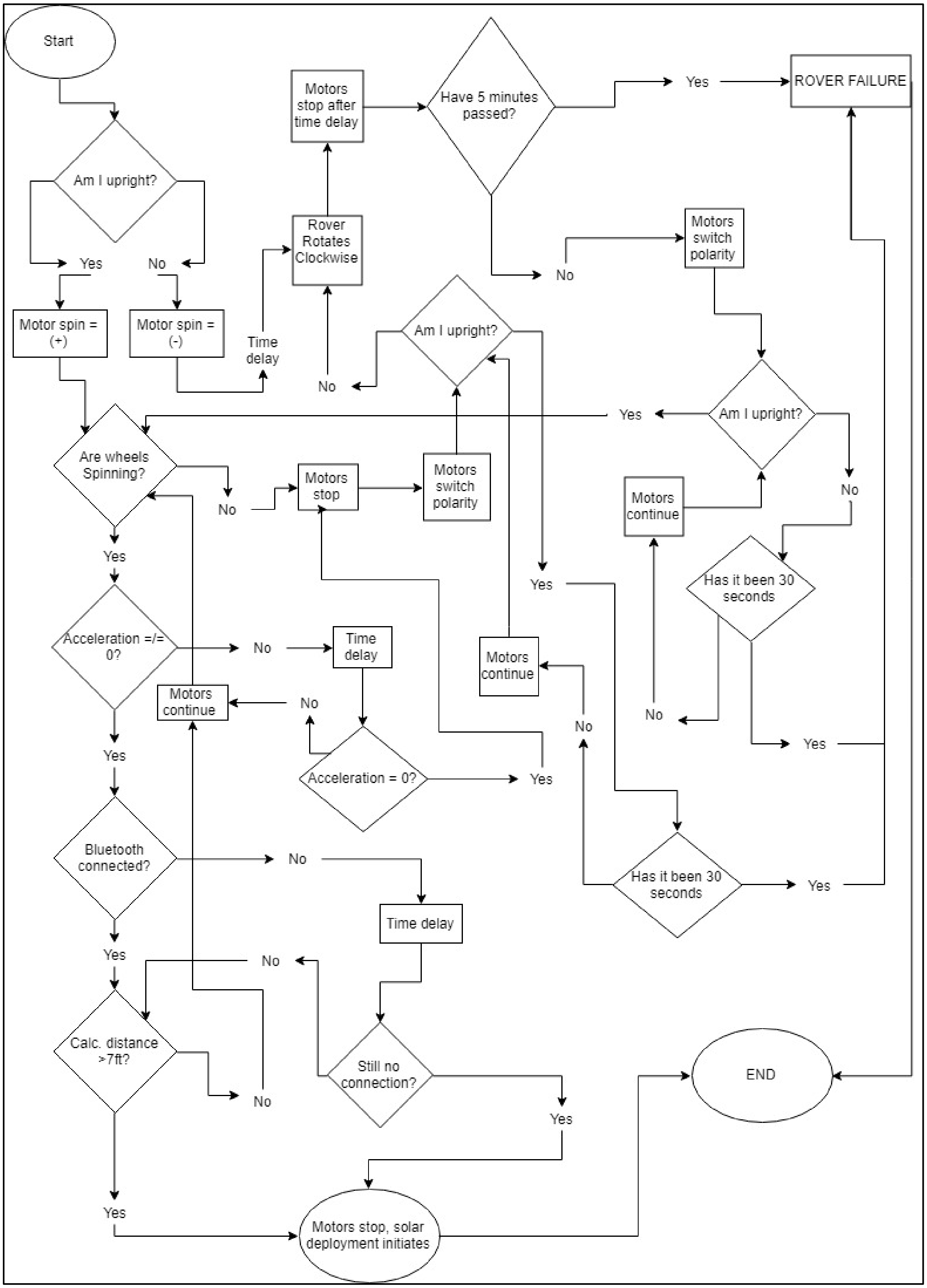


Figure 64: Logical operation flowchart for rover programming.

9.4 Flight Reliability

The deployable rover was designed and constructed specifically to the terrain to be experienced at the Huntsville launch site. The internal hardware components consist of zinc-plated steel threaded rods, nuts, screws and washers. The strength of these internal components and their makeup of the essential structure provide superior reinforcement and support for the outer components. These outer components are designed and modeled in the CAD program SolidWorks, and 3D printed in DFX labs. The printer material is PLA and if available in any infill (density) desired. The 3D printed parts on the rover will range from 15% to 30% infill, keeping the it lightweight yet strong to withstand the forces exerted upon itself. The deployment system will be printed in 100% infill, which is very dense and strong with very mild flexibility.

9.5 Payload Construction

The items described below describe the construction of the prototype rover. As noted in changes since CDR there have been a few design changes which are currently being worked on and will continued to be worked on in the upcoming weeks. The final rover is projected to be completed before our projected March launch.

9.5.1 Main Body

The prototype main body is made out of PLA plastic which is 3D printed from our university's printer in our DFX laboratory. The main body consisted of two separate outer pieces connected by an inner bulkhead. In order to allow for more room we have designed the final Rover to be made of one piece which eliminates the connector.

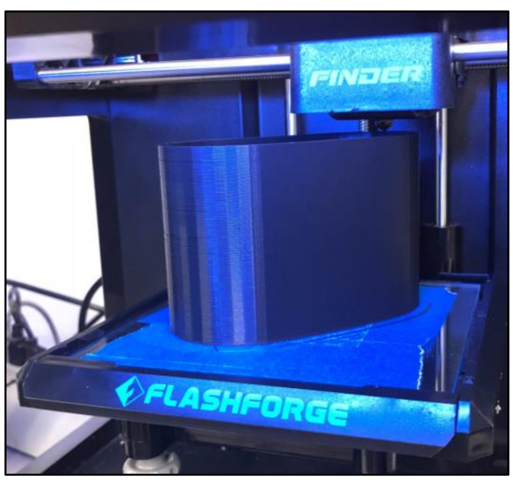


Figure 65: Picture of rover body being 3D printed.

Figure 66: Picture of 3D printed rover body half being smoothed to fit with body connector.

Figure 67: Picture of body connected being sanded to ensure a tight fit with rover body pieces.

9.5.2 Side Body

The prototype side body was 3D printed with PLA plastic and consists of two seperate pieces connected to the main body. The side body pieces were printed with twelve holes with four for structure rods, eight for batteries, and one for a motor. Each side contains eight 3V cells wired in series parallel to make 12V cells. The final rover side body has been redesigned which is detailed in the changes section 9.

Figure 68: Picture of rover batteries being loaded into side body.

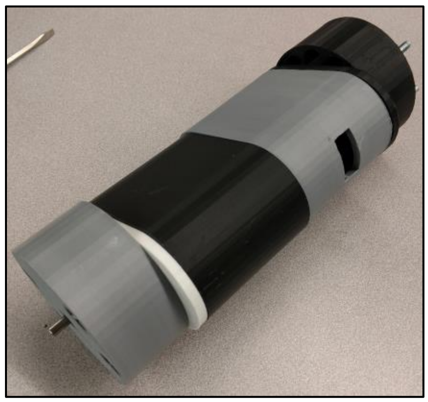


Figure 69: Picture of first assembled rover prototype.

9.5.3 Wheels

The prototype wheels were printed with PLA plastic and constructed at a subscale size where the diameter was similar to the design but the depth was smaller for testing purposes.

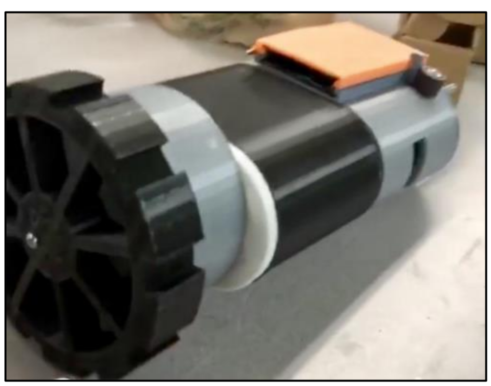


Figure 70: Picture of prior wheel design prototype attached to rover side body.

9.5.4 Newtonian Leg

The solar Newtonian leg that was tested with the prototype was constructed with a wood dowel that went through the holes that were created for the Newtonian leg. While the

Newtonian leg worked good for this design, the redesigned wheel has called for a new Newtonian leg design.

Figure 71: Video still of rover prototype test, with makeshift Newtonian leg.

9.5.5 Solar Panel Subsystem

The solar panel plates were printed using PLA plastic and then connected with a hinge and linear spring. The two plates hinged together then made a “book fold”. One plate was then mounted to the Rover body and then the entire “book” was then secured down with a trigger latch. The trigger latch could be pushed to allow for opening of the “book” thus activating the solar panels.

Figure 72: Picture of bi-fold solar panels location on top of rover main body.

Figure 73: Picture of bi-fold solar panel holder with solar cells shown.

9.6 As Built Schematics

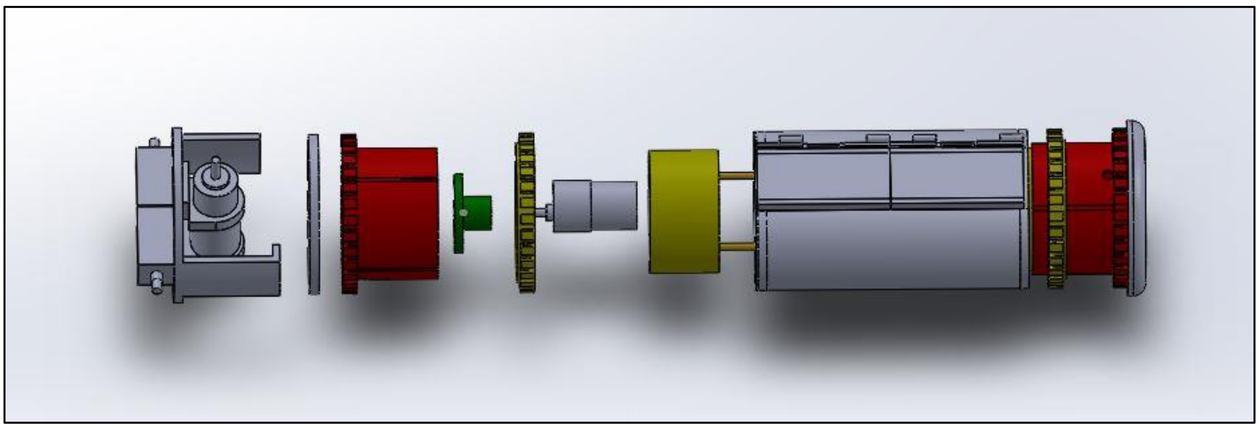


Figure 74: Schematic of payload.

9.7 Changes from earlier models

The constructed prototype was longer than previous models sitting at a length of 14 inches. As described in the “Changes from CDR” section 4 the reasoning came mostly from the redesign of the wheel and Newtonian leg and the construction of the solar panel mechanism. The measurements of certain components of the rover have been changed which is reflected in the schematics and “changes from CDR” section 4 as well.

As discussed in the previous changes the deployment system has undergone a minor redesign consisting of compacting the area where electronics and other equipment are being held.

10 Safety

Safety is a critical and necessary component in any STEM activity, 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.

10.1 Safety Officer Duties & Responsibilities

The safety officer will be in charge of 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 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.
12. Ensure that the flight inspection checklist is strictly followed in order to prevent any mishaps due to safety guidelines being overlooked.

10.2 NAR/TRA Safety

10.2.1 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 2 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 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 Project Manager and Safety Officer will be allowed 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 5 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 Tripoli and NAR guidelines.

10.2.2 Safety Codes

SOAR conducts launches under both NAR and TRA codes and will abide by the appropriate High-Power Rocketry Safety Code Requirements during all operations.

10.2.2.1 NAR Safety Code (Appendix 15.5)

10.2.2.2 TRA Safety Code (Appendix 15.6)

10.3 Hazardous Materials

10.3.1 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 MSDS for all materials.

10.3.2 Labels

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

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

10.3.3 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:

1. The location and availability of the MSDS and files

2. 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
3. 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.

10.3.4 Health, Safety, and Emergency Procedures

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

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

10.4 Safety Briefing

10.4.1 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, so as to mitigate any potentially dangerous incidents and answer any safety questions which may arise.

10.4.2 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. In the event that the Safety Officer judges a planned procedure to be unsafe, said procedure will thus be revised or eliminated.

10.4.3 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 be in attendance at 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.

10.5 Caution Statements

10.5.1 Definitions

Warnings, cautions, and notes are used to emphasize important and critical instructions and are used for the following conditions.

10.5.1.1 Warning

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

10.5.1.2 Caution

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

10.5.1.3 Note

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

10.6 Safety Manual

10.6.1 Warnings

Warnings will be typed in red and will 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.

10.6.2 Cautions

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

10.6.3 Notes

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

10.7 Legal Compliance

The Safety Officer and Project Manager have read all relevant laws and regulations that apply to this project in order 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:

10.7.1 Federal Aviation Regulations (FARs)

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

27 CFR: Part 55: Commerce in Explosives

NFPA 1127 "Code for High Power Rocket Motors"

10.7.2 State of Florida Laws and Regulations

Florida Statute: Title XXV: Aviation, Chapter 331: Aviation and Aerospace Facilities and Commerce

Florida Statute: Title XXXIII: Regulation of Trade, Commerce, Investments, and Solicitations, Chapter 552: Manufacture, Distribution, and Use of Explosives

10.8 Purchase, Transportation & 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 is well versed in storage. 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.

10.9 Statement of Compliance

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

- 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.

10.10 Hazard Analysis

10.10.1 Hazard Categories

10.10.1.1 Controls Risk Assessment

The hazards outlined in this section will discuss the risks associated with the launch vehicle mechanical and electrical controls. This is critical as failures in any system will result in a failed mission.

10.10.1.2 Hazards to Environment Risk Assessment

The hazards outlined in are risks that construction, testing or launching of the rocket can pose to the environment.

10.10.1.3 Logistics Risk Assessment

The hazards outlined are risks to the schedule associated with parts ordering, milestone accomplishment, and project completion. These hazards may also be associated with the physical movement of the launch vehicle from its current location to the launch site.

10.10.1.4 Launch Pad Functionality Risk Assessment

The hazards outlined are risks linked to the launch pad functionalities.

10.10.1.5 Payload Capture Device Risk Assessment

The hazards outlined in this section will discuss the risks associated with the payload capture device. The payload capture device interfaces with multiple systems, making it prone to hazards.

10.10.1.6 Recovery Risk Assessment

The hazards outlined are risks associated with the recovery. Since there are three recovery systems onboard, many of the failure modes and results will apply to all of the systems but will be stated only once for conciseness.

10.10.1.7 Shop Risk Assessment

Construction and manufacturing of parts for the rocket will be performed in both on-campus and off-campus shops. The hazards assessed are risks present from working with machinery, tools, and chemicals in the lab.

10.10.1.8 Stability and Propulsion Risk Assessment

The hazards outlined are risks associated with stability and propulsion. The team has multiple members of the team with certifications supporting that they can safely handle motors and design stable rockets of the size that the team will be working with. This area is considered a low risk for the team, but it is still important to address any potential problems that the team may face throughout the project.

10.10.2 Risk Level Definitions

10.10.2.1 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, 1 being the most severe. The severity criteria are provided below.

Table 22: Risk severity level definitions.

No.	Description	Personnel Safety and Health	Facility / 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 and/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 NSPA 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 laws or regulations where restoration activities can be accomplished.

10.10.2.2 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 23: Risk probability level definitions.

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

10.10.3 Risk Assessment Levels

Each risk is finally assigned a risk level based upon a combination of the risk's severity and probability. These levels range from high (red) to minimal (white) and are defined in Table 24. The meaning of each risk level is given in Table 25.

Table 24: Risk assessment level classifications.

Probability	**Severity**			
	1 (Catastrophic)	**2 (Critical)**	**3 (Marginal)**	**4 (Negligible)**
A (Frequent)	1A	2A	3A	4A

Probability	Severity			
	1 (Catastrophic)	2 (Critical)	3 (Marginal)	4 (Negligible)
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 25: Risk assessment level 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.
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.

10.10.4 Current and Probable Risk

Through past years of rocket design and competition, as well as what orders are already underway below is a table of risk that shall continue to grow and be edited by the safety officer throughout the project.

10.10.5 Personnel Hazard Analysis

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	Use the Launch Procedure checklist when placing launch vehicle on launch rail.
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	Use the Launch Procedure checklist when placing launch vehicle on launch rail.
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 documented for designated individuals.
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 documented for designated individuals.
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 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	3E	Training will be documented for designated individuals. Certificates will be kept on file for trained individuals until the individuals graduate and leave the organization.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
	chemical spills.				handling common chemicals used in constructing the launch vehicles.		
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 documented for designated individuals.
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	When available, an electrical engineering student will supervise electrical operations.
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 documented for designated individuals.
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 on this equipment is provided by the university through the Design for X Labs orientation and safety training program.

10.10.6 Failure Modes and Effects Analysis (FMEA) Analysis

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 schedule has been set with sufficient buffer time to absorb delays. Subscale testing was conducted according to the project plan. Two full scale launch tests have taken place, with another scheduled launch on 3/17/18.
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 schedule has been shared to all team members. Backwards plans were created to visualize team progress and track construction milestones. Multiples of common construction items have been ordered.
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	Use checklist when assembling launch vehicle. Ensure technical lead supervision in handling of parts.
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	Use the Launch Procedure checklist when placing launch vehicle on launch rail.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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	Use the Launch Procedure checklist when placing launch vehicle on launch rail.
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	Use the Launch Procedure checklist when placing launch vehicle on launch rail.
Payl oad	The rover deployment system fails to operate.	Rover sled is stuck. Fishing line is cut.	Rover cannot exit the vehicle, mission failure.	2D	The deployment system will be tested extensively with different variables. A guide will be put into place for the fishing wire and the sled will be sanded to remove any bumps.	2E	Deployment system tested during full scale test launch on 1/27/18 and 2/17/18.
Payl oad	Failure of on board electronics	overheating from compacted space, solar panels, direct sunlight.	Rover cannot operate properly, mission failure.	2D	Various ventilation holes will be put around rover body but will have filters to keep dirt and other debris out.	4E	Inspection by Safety Officer. Ground and full scale launch testing.
Payl oad	Deployment system accidental operation during flight.	G-forces form flight and weight from the payload stress the system enough to break it,	Mission failure. Possible damage to launch vehicle.	1D	Extensive testing will be performed prior to lunch. Strong solenoids will be used.	3E	Use Prior to Departure checklist when departing for launch field.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
		causing it to "deploy" early and come out of the rocket.					
Reco very	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. Nomex shields will be secured low on shroud lines to prevent entanglement. Main parachutes will deploy at different altitudes.	2E	Full scale testing conducted under new configuration on 1/27/18 and 2/17/18. Parachutes deployed successfully, and all sections seperated correctly.
Reco very	Sections fail to separate at apogee or at 1000 feet.	Black powder charges fail or are inadequate. Shear pins stick. Launcher mechanics obstruct separation.	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. Inside of rocket body will be coated with graphite powder in areas of launcher mechanics. 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	Full scale ground and launch tests verified that the amount of black powder is adequate. All black powder charges successfully ignited, full separation of booster main parachute was achieved. Launch Vehicle Assembly checklist was used when assembling launch vehicle at full scale launches.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Reco very	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.	1E	In full scale launches, all sections successfully separated at designated altitudes. Altimeters performed correctly.
Reco very	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 full scale ground testing, e-matches successfully ignited separation charges. In full scale test launch, primary and backup altimeters and black powder charges performed successfully.
Reco very	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	The website http://descentratecalculator.onlinetesting.net/ was used to calculate theoretical descent values. Subscale and full scale testing resulted in no damage to rocket components.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Reco very	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 particular section of the rocket. Extensive ground testing was performed to verify the coefficient of drag is approximately that which was used during analysis.	3E	The website http://descentratecalculator.online testing.net/ was used to calculate theoretical descent values. Subscale and full scale testing resulted in no damage to rocket components.
Reco very	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. Rip stop nylon was selected for the parachute material. This material prevents tears from propagating easily. In the incident that a small tear occurs during flight, the parachute will not completely fail.	2E	During full scale testing and launch, new parachutes and large Nomex protectors were used. Parachutes remained undamaged through full scale launches.
Reco very	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. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.	1E	During full scale test launch, main parachute was never attached to nosecone by swivel and D-link. The nosecone took no damage on impact. Special precautions will take place to ensure it does not happen again. However, all U-bolts and bulkheads performed sufficiently.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Reco very	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	Nomex protection cloths 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	Full scale testing was conducted under new configuration and settings. Parachutes deployed correctly and untangled. Launch Vehicle Assembly and Parachute Folding checklists were used when assembling launch vehicle.
Reco very	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	Full scale test launch verified that the folding and packing technique are appropriate. Launch Vehicle Assembly and Parachute Folding checklistswere used when assembling launch vehicle.
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 documented for designated individuals.
Stabi lity	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	2E	Motor preparation checklist will be utilized to inspect motor prior to launch. Manufacturer's instructions will be followed in assembling the motor.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
					extinguished before it is safe to approach the pad.		
Stabi lity	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	Motor preparation checklist will be utilized to inspect motor prior to launch. Manufacturer's instructions will be followed in assembling the motor. During full flight test, drogue parachute charge was not sufficient to eject motor. Motor mount adapter and retainer ring prevented motor from ejecting.
Stabi lity	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	General Pre-Flight Inspection will be conducted prior to launch. Final Assembly and Launch Procedures Checklists will be used during assembly and launch. Launch vehicle will be cleaned and inspected in accordance with Post-Flight Checklist.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Stabi lity	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	Final Assembly and Launch Procedure Checklists will be used to assemble launch vehicle and to fold and insert parachutes.
Stabi lity	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 aluminum will be used to ensure the integrity of the design.	2E	During full scale launch test, motor mount adapter and retainer ring prevented motor from ejecting.
Stabi lity	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 maintaned of mass changes. Launch vehicle simulations will be repeated for each mass change. Additional launch vehicle simulations will be performed at plus 5% of caclulated mass. Subscale and full scale launches will be performed with accurate mass.	3E	During full scale test launch, launch vehicle exceeded the planned altitude. The team has allowed for a heavier payload in order to help reduce max altitude.
Stabi lity	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 ingiter. During subscale test launch, igniter performed as expected.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Stabi lity	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	Full scale testing resulted in sufficient velocity. Motor and booster performed as expected.
Stabi lity	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 full scale flight, all bulkheads performed as expected.
Stabi lity	Motor retainer falls off.	Joint did not have proper preload or thread engagements.	Motor casing and spent motor fall out of rocket during when the main parachute opens.	2E	Checklists and appropriate supervision will be used when assembling.	2E	Motor preparation checklist will be utilized to inspect motor prior to launch. Manufacturer's instructions will be followed in assembling the motor.

10.10.7 Environmental Concerns Analysis

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification

Environmental	Harmful substances permeating into the ground or water.	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	MSDS sheets will be kept on hand in the shop and at the launch field.
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 marked with appropriate signage for hazardous material. Training will be documented for designated individuals.
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. Personnel will used protective equipment when sanding or cutting plastic and fiberglass.	4E	Waste receptacles will be available and properly marked. Protective equipment is on hand.
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	Waste receptacles will be available and properly marked.
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	Monitor local weather and verify on launch day

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	Monitor local weather and verify on launch day
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	Monitor local weather and verify on launch day
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	Monitor local weather and verify on launch day. Adjustable ballast system is designed to be adjustable to different wind conditions. Full scale flight testing was conducted and ballast system was adjusted to accomadate the wind conditions during the launch.

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	Drift calculations conducted using planned parachutes predict that launch vehicle will remain within the allowed drift range, which is free of trees.
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	Drift calculations conducted using planned parachutes predict that launch vehicle will remain within the allowed drift range, which is free of bodies of water.
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	Drift calculations conducted using planned parachutes predict that launch vehicle will remain within the allowed drift range, which is free of bodies of water.
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	Use Final Assembly and Launch Procedure Checklists when assembling launch vehicle. Test all batteries prior to installation and as close in time as practicable to the launch time.

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	Use Field Packing List when preparing tools, parts, and consumables to go to the field. Black powder will be kept in commercially approved packages, which are designed to prevent moisture buildup.
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	Rocket is constructed and maintained in an air conditioned workshop.

11 Launch Operations Procedures

11.1 Checklists

11.1.1 Warnings

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

11.1.2 Cautions and Notes

Each checklist will include a column labeled Caution/Note. This column will display the caution or note associated with the relevant step in the checklist. Cautions will be typed in orange.

11.1.3 Field Packing List

- ◻ Tools
  - ◻ Power drill and drill bits
  - ◻ Dremel tool with attachments
  - ◻ Sheet sander
  - ◻ Screwdrivers
  - ◻ Wire cutters/strippers
  - ◻ Scissors
  - ◻ Small funnel
  - ◻ Pliers
  - ◻ Wrenches
  - ◻ PVC Cutters
- ◻ Parts
  - ◻ Rocket components
  - ◻ Quick links
  - ◻ Motor casing
  - ◻ Motors (in water resistant container)
- ◻ Parts (cont.)
  - ◻ E-matches
  - ◻ Igniter (in water resistant container)
  - ◻ Parachutes
    - ◻ Main x 2
    - ◻ Drogue × 1
  - ◻ Nomex protectors
  - ◻ Spare parts toolkit (nuts, bolts, washers, etc.)
  - ◻ Shear pins
  - ◻ Motor retainer adapter
- ◻ Consumables
  - ◻ Charge insulation (in water resistant container)
  - ◻ Black powder (in water resistant container)
  - ◻ Duct tape
- ◻ Consumables (cont)
  - ◻ Electrical tape
  - ◻ Sandpaper
  - ◻ Electrical wire
  - ◻ Silicone
- ◻ Graphite powder
- ◻ Consumables (cont)

- ◻ White lithium grease
- ◻ 9V batteries
- ◻ Rail lubricator
- ◻ Extra CPVC
- ◻ Extra launch lugs

11.1.4 General Pre-Flight Inspection Checklist

Table 26: General pre-flight inspection checklist.

Task	SO Verification
Inspect fins for damage and security	
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	
Inspect bulkheads and U-bolts for security	
Clean all components of debris and carbon residue	

11.1.5 Final Assembly and Launch Procedure Checklist

Table 27: Final assembly and launch checklist.

Task	Warning/Caution	SO Verification
1. Prior to Departure		
Ensure all tools and materials needed for launch are available.		
Ensure all required personnel		

are present.		
Prepare new batteries for the recovery systems.	Parachutes may fail to deploy. Mission failure.	
2. Recovery Preparation – Main Altimeter Bay		
Install new 9V batteries into altimeter bay	Parachutes may fail to deploy. Mission failure.	
Ensure altimeter bay is programmed to deploy at the correct height	Parachutes may fail to deploy. Mission failure.	
Perform continuity check of e-matches	Parachutes may fail to deploy. Mission failure.	
Connect e-matches to altimeters	Ensure e-matches are dry. Parachutes may fail to deploy. Mission failure.	
Warning: Keep away from flames. **PPE Required**: Eye protection, gloves.		
Measure two portions of black powder and deposit in each of the CPVC tube inserts on side of altimeter bay to be inserted into booster section.	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.		
Measure two portions of black powder and deposit in each of the CPVC tube inserts on side of altimeter bay to be inserted into upper airframe.	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	Ensure insulation is dry. Packing too loosely may result	

with pressure sensitive tape.	in insufficient force to separate or eject. Parachutes may fail to deploy. Mission failure.	
2.1. Recovery Preparation – Payload Altimeter Bay		
Install new 9V batteries into altimeter bay	Parachutes may fail to deploy. Mission failure.	
Ensure altimeter bay is programmed to deploy at the correct height	Parachutes may fail to deploy. Mission failure.	
Perform continuity check of e-matches	Parachutes may fail to deploy. Mission failure.	
Connect e-matches to altimeters	Ensure e-matches are dry. Parachutes may fail to deploy. Mission failure.	
Warning: Keep away from flames. **PPE Required**: Eye protection, gloves.		
Measure two portions of black powder and deposit in each of the CPVC tube inserts.	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.	
3. Launch Vehicle Assembly		
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.		

Inspect all parachutes for abrasions, rips, tears, or frayed shroud lines.	Parachute may not create enough drag. Launch vehicle section lands with excessive kinetic energy. Damage to launch vehicle.	
Fold all parachutes in accordance with parachute packing instructions.	Shroud lines may become entangled. Launch vehicle section lands with excessive kinetic energy. Damage to launch vehicle.	
3.1. Booster section		
Inspect booster section lower shock cord for damage or fraying.		
Inspect booster section lower shock cord quick link attachment knot and tape for security and condition.		
Inspect quick link for corrosion and clean or replace if necessary.		
Attach quick link to booster section lower shock cord.		
Fold booster section lower shock cord in Z-type fashion.		
Insert booster section lower shock cord part way into the booster section and attach quick link to drogue parachute swivel.	Ensure parachute remains properly folded during this process.	
Attach quick link to U-bolt on booster section side of altimeter bay.		

Close quick link locking gate securely.		
Completely insert booster section lower shock cord into booster section.		
Insert the drogue parachute into the booster section.	Ensure that Nomex protector completely covers parachute.	
Slide altimeter bay into booster 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.	
Inspect booster section upper shock cord for damage or fraying.		
Inspect booster section upper shock cord quick link attachment knots and tape for security and condition.		
Inspect quick links for corrosion and clean or replace if necessary.		
Attach quick link to one end of booster section upper shock cord.		
Secure quick link to U-bolt on booster section upper side of altimeter.		
Close quick link locking gate securely.		

Secure quick link to swivel of main parachute #1.		
Close quick link locking gate securely.		
Set aside lower airframe assembly.		
3.2. Payload		
Inspect payload to payload altimeter bay quick link for corrosion and clean or replace if necessary.		
Use quick link to attach payload and payload altimeter bay U-bolts together.		
Inspect payload section shock cord for damage or fraying.		
Inspect both payload section shock cord quick link attachment knots and tape for security and condition.		
Inspect quick links for corrosion and clean or replace if necessary.		
Attach quick links to both ends of payload section shock cord.		
Attach shock cord quick link to U-bolt on upper side of payload altimeter bay.		
Close quick link locking gate securely.		

Slide the payload and payload altimeter bay into the payload section of the airframe.	Ensure screw, air pressure, and access holes are lined up.	
Ensure arming wires are visible and accessible through access hole.		
Insert machine screws into four designated holes to secure payload altimeter bay to payload section of airframe.		
3.3. Nose Cone		
Inspect quick link on upper end of payload section shock cord for corrosion and clean or replace if necessary.		
Attach quick link to U-bolt on nose cone.		
Attach nose cone quick link to swivel of #2 main parachute.		
Close quick link locking gate securely.		
Slide #2 main parachute into the payload section of airframe.	Ensure parachute remains properly folded and shroud lines are unencumbered. Ensure Nomex protector completely covers parachute to prevent entanglement with landing module parachute.	
Fold payload section shock cord in Z-type fashion.		
Insert payload section shock cord part way into the booster section.	Ensure parachute remains properly folded during this process.	

Slide nose cone into payload section of altimeter bay.	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.	
3.4. Final Vehicle Assembly		
Retrieve lower airframe assembly.		
Fold payload section shock cord in Z-type fashion.		
Insert booster section upper shock cord part way into the booster section.	Ensure parachute remains properly folded during this process.	
Slide #1 main parachute into the lower side of payload section of airframe.	Ensure parachute remains properly folded and shroud lines are unencumbered. Ensure Nomex protector completely covers parachute to prevent entanglement with landing module parachute.	
Slide upper side of main altimeter bay into payload 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.	
4. Motor Preparation		
Warning: Keep away from flames. Inspect motor for cracks and voids. Refer to MSDS for white lithium grease. **PPE Required**: Eye protection, gloves.		

Assemble the motor in accordance with manufacturer's instructions.	https://www.youtube.com/watch?v=d0xjmJ-Yur8	
Insert completed motor assembly into the booster section.		
Securely screw on motor retainer ring.		
5. Setup on Launcher		
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.	
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.	
Turn on altimeters and get continuity confirmation.	Parachutes may fail to deploy. Mission failure.	
6. Igniter Installation		
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 e-match cord to the	Conduct final check to ensure security of e-match.	

motor retainer.		
Ensure igniter wires attached to power source.		
Arrange wires carefully to ensure continued attachment to igniter throughout launch sequence.		
7. Launch Sequence		
Ensure ignitor power switch is on at launch control.		
Ensure all personnel are at safe standoff distance.		
Ensure ignitor power switch is on at launch control.		
8. Post Launch Procedure		
Monitor drift and locate launch vehicle after flight.	Ensure launch vehicle is recovered in a timely manner.	
Measure drift from launch pad.		
Recover launch vehicle, determine altitude, and deactivate altimeters		
Deactivate all electronics.		

11.1.6 Post-Flight Inspection Checklist

Table 28: Post-flight inspection checklist.

Task	SO Verification
Listen to record altimeter for apogee altitude.	
Inspect fins for damage and security.	
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.	
Check batteries with voltmeter.	
Clean all components of debris and carbon residue.	
Remove motor from motor casing after it has cooled long enough to be handled but before completely cooled.	
Disassemble motor casing after it has cooled long enough to be handled but before completely cooled.	
Remove all O-rings	
Place components except for motor casing tube into soapy water to remove carbon residue.	

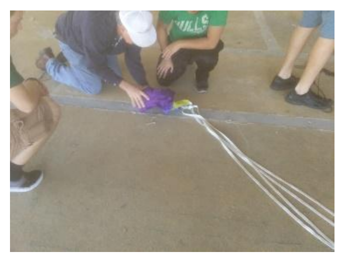
Task	SO Verification
After soaking, clean components with neutral cleaner, dry and reassemble.	

11.1.7 Parachute Folding Instructions

11.1.7.1 SkyAngle Parachutes

Table 29: SkyAngle Parachute folding instructions and figures.

Step No.	Instructions	Figure
1	Lay parachute out neatly on the long axis and pull taut.	
2	Inspect parachute for rips, tears, or abrasions.	
3	Arrange the canopy so it lays flat on the floor. Then line up suspension line seams of parachute and stack neatly lengthwise.	
4	Compress parachute to ensure air pockets are removed.	

Step No.	Instructions	Figure
5	Fold along the long axis using Z-type fold of approximately 6 in. width, beginning with the side opposite the suspension line seams.	
6	Compress parachute to ensure air pockets are removed.	
7	Fold along the length of the parachute using Z-type fold of approximately the below lengths, depending on the parachute size, beginning with the top of the parachute. XL – 8 in. to 10 in. Large – 6 in. to 8 in. Drogue – 6 in. or less	
8	Continue folding in this fashion up to the point where the shroud lines connect to the parachute.	
9	Ensure shroud lines are untangled. Pull the shroud lines taut while maintaining the parachute fully folded.	
10	Fold the shroud lines, using Z-type fold on top of the folded parachute until only about 4 to 6 in. remain extended beyond the folded parachute.	

Step No.	Instructions	Figure
11	Attach appropriately sized Nomex protector to end of shroud line near swivel. Wrap electrical tape around shroud line above Nomex protector to ensure Nomex protector does not slip during flight or ejection.	
12	When inserting the parachute into the respective launch vehicle section, roll the folded parachute slightly upward around the shroud lines to ensure security.	

11.1.7.2 Fruity Chutes Parachutes

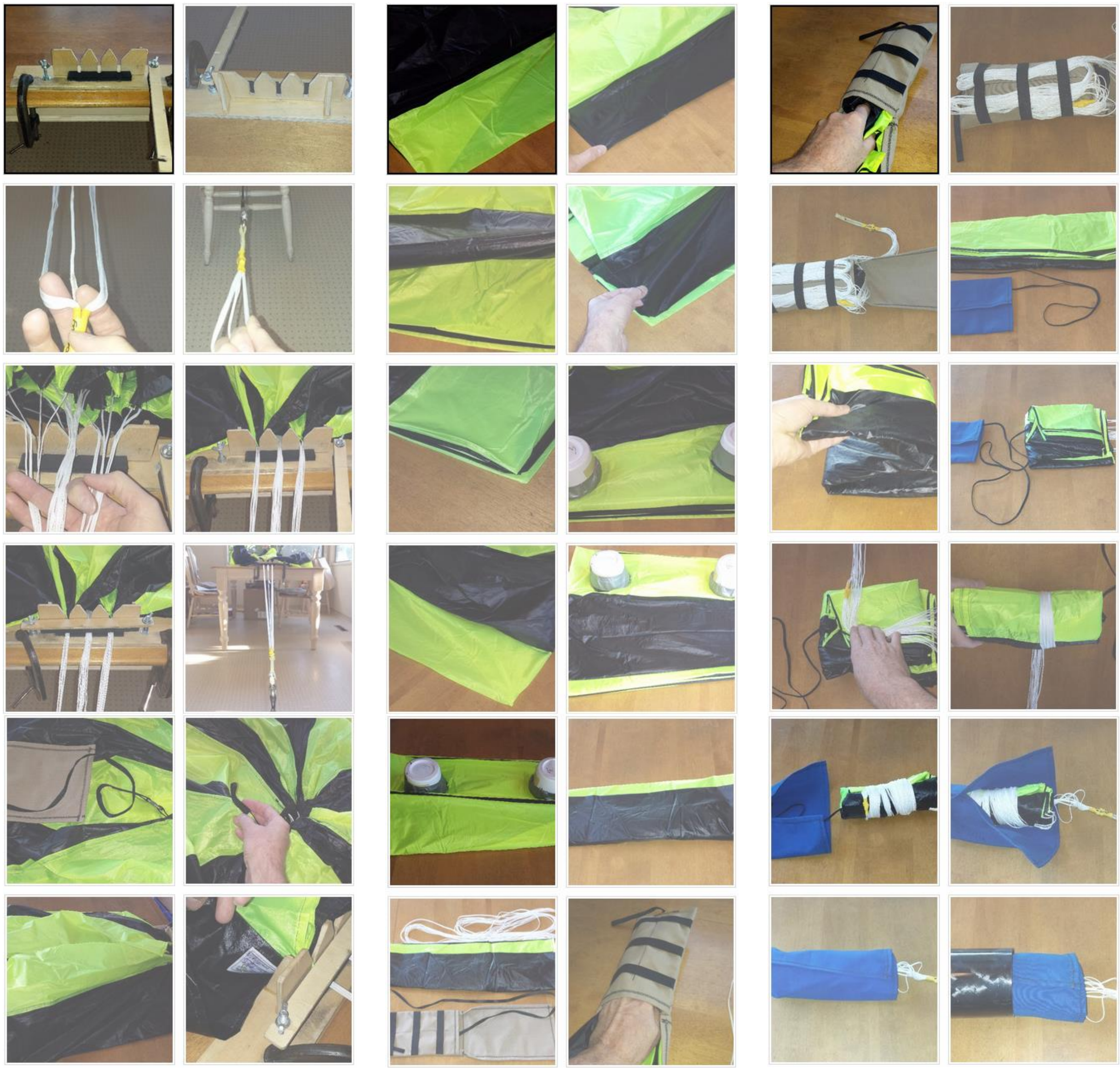


Figure 75: Fruity Chutes parachute folding steps.

(Read from left to right, then down, in three separate columns.)

11.1.8 Motor Assembly Instructions

Our launch vehicle is using the Aerotech L1420 with Cesaroni hardware. The team has been using a video on youtube in order to integrate these two materials. The team has used the video for both full scale launches and plans on also using it in the future. Here is a link to the video: https://www.youtube.com/watch?v=d0xjmJ-Yur8

12 Project Plan

12.1 Testing

12.1.1 Launch Vehicle

12.1.1.1 Ground Test

Objective

This test will determine the vehicle's ability to separate with various shear pin sizes and black powder amounts. This test will allow us to determine the proper materials needed to allow for successful separation during flight along with an appropriate recovery.

Reason for testing

Due to deployment failures encountered during the subscale flight, extensive separation test will be conducted to ensure we do not encounter the same failure during the full scale launch.

Components to be tested

- Booster Section
- Nosecone Section
- Rover Compartment

Pass/Fail Criteria

Pass Criteria

The test will be considered a success if all tested sections properly separate and parachutes with shock cord are ejected from the tested section with no damage.

Failure criteria

The test will be considered a failure if either scenarios occur: the tested sections do not separate, the tested sections separate but the parachutes are not ejected.

Pre-Test

Required Equipment

- Full Scale Vehicle Components will be used except for the electronics compartment which will be replaced by an alternate section to prevent damage.
- Shear pins, black powder, cellulose insulation, electronic matches
- A stand to hold the section along with some form of weight to keep the section from moving.

During Test

Setup

- Details regarding exact configurations are provide in the table below.
- The section being tested will have an appropriate stand to ensure the section is safely secured.
- A weighted object will be placed behind the stand to prevent movement of the section being tested.

Procedure

1. Prepare section about to be tested.
2. Load parachute and shock cord into section.
3. Equip section with black powder and cellulose insulation.
4. Load section onto stand.
5. Place weight behind stand.
6. Designate one participant to ignite electronic match.
7. Ensure all participants are at least 10 feet away.
8. Countdown to ignition.
9. Survey section to determine success or failure as well as for any damage.

Safety Measures

- Properly handling of all black powder will be practiced.
- Participants will be required to stand approximately ten feet away and out of the projected ejection area.

Post-Test

Results

Two successful ground tests have been conducted, one prior to each test flight.

January 26th - These ground tests were performed on a SOAR member's private property, the day before the maiden launch in Bunnell on January 27th. The first section to be tested was the drogue parachute, and thus ensure its proper separation. The ground test coupler was prepared with 2 grams of black powder in standard CPVC canisters, and attached to the Booster Section with two 2-56 nylon shear pins. The charges were activated with an e-match powered via a 9V battery. This test was a success; the 1/2" tubular shock cord became fully extended and the ground test coupler cleared the Booster Section. The second to be tested was the Nosecone from the Rover Compartment airframe. The Payload Altimeter Bay's CPVC canisters used 2 grams like the drogue section to break three 2-56 nylon shear pins in the Nosecone shoulder. To test the true capability of the 2 gram charge to break an extra shear pin, the SkyAngle 60" (designed to be packed within this section) was folded along with the 20' of 1/2" shock cord. The charges were detonated using an e-match and a 9V battery. The Nosecone and its shoulder came clean off, with the parachute and shock cord entirely exposed. The third and final section to be tested was the separation point between the Rover Compartment and Main Altimeter Bay. The ground test coupler was used in place of the Main Altimeter Bay to preserve it and its embedded electronics for the launch the next day. Four 2-56 pins were tested against 4 grams of black powder, and separation was confirmed after the event of detonation.

February 9th - Due to the recovery failure experienced in the maiden flight, premature separation of the Rover Compartment from the Main Altimeter Bay at 4600 feet AGL, leading to an elongated drift, the shear pin configuration of this separation point / recovery event was changes from four 2-56 into two 2-56 and two 4-40 shear pins. The reason that four 4-40s were not used was due to this specific configuration would not break on the subscale flight that took place on December 16, 2017. In this test, 4 grams of black powder were used to break the new layout of two 2-56 and two 4-40 shear pins and proved successful based upon the separation of the ground test coupler from the Rover Compartment airframe. The second flight proved, from visual confirmation, that this new layout was capable of securing the Main Altimeter Bay to the Rover Compartment during descent until the parachute deployment at 950 feet AGL.

Table 42: Ground testing shear pin recording table

Point of Separation	Shear Pin Size	# of Shear Pin & Arrangement	Grams of Black Powder
Nosecone & Rover Compartment			
Main Alt Bay & Booster			
Rover Compartment & Main Alt Bay			

12.1.1.2 Full Scale Flight Test

Objective

To test the Full Scale Vehicles capability of reaching an altitude of one mile as well as being safely recovered with little to no structural or electrical damage.

Reason for testing

This test is being conducted in order to fulfill requirements set forth by the NASA Student Launch Competition Guidelines as well as Team Derived Requirements. The test results will also provide insight on whether of not the launch vehicle needs any improvements or adjustments.

Components to be tested

- Constructed Full Scale Vehicle
- Recovery Electronics
- Recovery Equipment

Pass/Fail Criteria

Pass Criteria

The test will be deemed a success if the launch vehicle successfully launches and reaches an altitude a mile, or close to a mile, and is recovered safely with no damage.

Failure Criteria
The test will be deemed a failure if any of the following are not met: the launch vehicle does not launch, the launch vehicle suffers a catastrophic event, the launch vehicle is not able to be recovered.

Pre-Test
Equipment
- Refer to section 6.1for checklist regarding launch day equipment.
- Launch rails provided by launch site.

During Test
Setup
Refer to section 6.1 for checklist regarding setup of the launch vehicle.

Procedure
Refer to section 6.1 for checklist regarding procedure for the launch vehicle.

Safety Measures
- A safety officer will be present to ensure the team is following safety guidelines.
- Safety officer will follow launch procedure checklist to ensure safety guidelines are being met.

Post-Test
Results
Refer to Full-Scale Flight Analysis for detailed results.

12.1.2 Payload Deployment System

12.1.2.1 Solenoid Test

Objective
This test will measure the integrity and strength of the deployment system solenoids ability to withstand launch/flight forces

Reason for testing
This test is being conducted in order to fulfill requirements set forth by the NASA Student Launch Competition Guidelines as well as Team Derived Requirements. The test results will also provide insight on whether of not the deployment system will be able to safely hold the rover in place while the launch sequence is initiated.

Components to be tested
- 2x push/pull solenoids. (3mm diameter rod)

Pass/Fail Criteria

Pass Criteria

The test will be deemed a success if the solenoids maintain connection with rocket and do not have any physical deformations.

Failure Criteria

The test will be deemed a failure if there are physical deformations to the solenoids and/or if the solenoids lose connection with the rocket body.

Pre-Test

Equipment:

- Fishing line, rated at 100 lbs
- pronged extension
- Simulated weight/canister
- Lead bb's
- Epoxy
- 2 x 0.25" threaded rods + lock nuts/washers
- 12-volt battery
- Insulated wire

During Test

Setup

1. Fill lead bb's and epoxy in the pre-planned slots inside the canister. Make sure the total weight equals the total simulated weight.
2. Solder the insulated wire to the solenoids and place them in the preplanned spot.
3. Feed the threaded rods through the entire canister and layers
4. Measure out distance from bottom if 4 prong extension and middle of solenoid rod. Mark and cut out with ⅛" drill bit.

Procedure

1. Secure 4 prong extension to the bulkhead. Tie fishing line to the U-bolt and canister.
2. Retract solenoids with battery pack and slide canister through the rocket body.
3. Remove power to solenoids and tug on canister to make sure it is secure.

Safety Measures

A braided fishing line, rated at 100 lbs is used to prevent the payload canister from exiting the rocket body prematurely. This is done by securing the entire system the the bulkhead. The fishing line is just long enough t not contribute to the holding force of the retention system of the deployment system but not too long where the canister will have enough slack to be partially/fully outside the launch vehicle if the solenoids fail. During our test we used approximately 1.5 feet of fishing line.

Post-Test

Results

This solenoid test was a failure, after post flight inspection it was noted that the pins were forced out of their sockets and one was bent at a critical angle close to 45 degrees.

Action Plan

The deployment retention system needs to be updated with bigger/thicker solenoids with the potential of using 4 solenoids instead of three.

12.1.3 Payload

12.1.3.1 Autonomous Rover Test

Objective

This test will determine the rover's ability to travel five feet away, autonomously, from the rocket body once the vehicle safely lands. The same test will be used to test if the rover can travel ten feet in order to meet Payload Team Derived Requirement.

Reason for testing

The test will be conducted in order to meet requirements set forth by the NASA Student Launch Competition Payload Requirements as well as Payload Team Derived Requirements.

Components to be tested

- Motor Strength
- Wheel traction
- Programing
- Deployment System

Pass/Fail Criteria

Pass Criteria

The test will be deemed a success if after the autonomous switch is triggered, the Rover is deployed from the launch vehicle and travels five feet (ten feet for Team Derived Test).

Failure Criteria

The test will be deemed a failure if one of the following does not occur: the rover does not deploy from the launch vehicle, the rover does not move five feet.

Pre-Test

Equipment

- Launch Vehicle in launch ready conditions
- Final Rover
- Rover communication equipment

During Test

Setup:

1. Prepare the launch vehicle

2. Prepare the Rover
3. Prepare the communication equipment

Procedure

1. Once the vehicle is ready for launch, load the rover into the deployment system.
2. Load vehicle onto the launch rail.
3. Launch vehicle.
4. Once vehicle safely lands activate the trigger that starts the deployment system.
5. Communicate with the Rover on how far it has traveled.
6. Recover the launch vehicle and Rover.

Safety Measures

- Refer to safety section 11.1 for safety information regarding the setup of the launch vehicle.
- The deployment system has multiple points of connection to the Rover to ensure the Rover cannot exit its section until the deployment system is activated.
- Refer to safety section 11.1 for safety information regarding the recovery of the launch vehicle.

Post-Test

Results

This test is yet to be completed, we project to conduct this test during our full scale launch in March where we will conduct the test as if it were competition day.

Action Plan

If the test fails and the rover does not move autonomously at least five feet then the team will look back over system electronics and programming to determine the issue in order to resolve it before the competition.

12.1.3.2 Mobility Test

Objective

This test will determine the rover's ability to travel over various terrain and obstacles.

Reason for testing

The test will be conducted in order to make sure the rover has the capability to pass the autonomous drive test.

Components to be tested

- Motor Strength
- Wheel traction

Pass/Fail Criteria

Pass Criteria

The test will be deemed a success if after the Rover drive over various terrain with ease and is able to move around for a set period of time.

Failure Criteria

The test will be deemed a failure if the Rover struggles to drive over various terrain and is not able to move around for a set period of time.

Pre-Test

Equipment:

- Testing Box - 6ft long, 1.75ft wide, 4in tall, box filled with sand and other soil mixtures.
- Clear testing area outside of testing box in order to test on grass and other natural terrain.
- Constructed Rover.
- Controller to handle Rover.

During Test

Setup

1. Locate a clear area to place the Rover.
2. Prepare the Rover.
3. Configure controller for the Rover

Procedure:

1. Place rover on designated area.
2. Drive vehicle over terrain.
3. Record any difficulties.

Post-Test

Results

After conducting this test we found that the wheel design was slippery and could not maintain traction. We also found that the Rover did not have enough clearance form the ground to travel over any debris or obstacles.

Action Plan

In order to allow for better wheel traction and clearance an expanding wheel has been designed.

12.2 General Requirements

Table 30: General mission requirements and verification plans.

Requirement	Verification Method	Verification Plan	Verification Status
Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	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.

Requirement	Verification Method	Verification Plan	Verification Status
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 assigned, educational engagement events, and risks and mitigations.	Demonstration	Team leader and project manager will work with sub- team 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,PDR, and CDR. Will continue to be verified throughout the course of the project as more documents are submitted.
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 these activities.	Demonstration	SOAR has submitted information on foreign national students who are a member of the team as of the date of this report. Team leads will continue to monitor membership and ensure that all foreign national students are recognized.	Verified with submission of PDR as stated in requirement.

Requirement	Verification Method	Verification Plan	Verification Status
The team must identify all team members attending launch week activities by the Critical Design Review (CDR).	Demonstration	Project manager and team leads will designate potential launch week participants who have been actively engaged throughout the project. A list of attending participants has been provided with this document. .	Verified with submission of CDR as stated in the requirement.
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. So far over 200 students have been reached and we expect to reach more with our spring events. All educational engagement forms are submitted to proper officials no more than two weeks after an event.	Verified on 12/20/17 when SOAR's outreach event reached 400 participants.
The team will develop and host a website for project documentation.	Demonstration	SOAR has developed a website which is currently up to date with current project documentation.	Verified as current website is up and running with current documentation.

Requirement	Verification Method	Verification Plan	Verification Status
Teams will post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.	Demonstration	SOAR will create deadlines to ensure all deliverables are completed and uploaded on time.	Verified with submission of Proposal, PDR, and CDR. Will continue to be verified upon submission of upcoming documents.
All deliverables must be in PDF format.	Inspection	A selected team member will be in charge of reviewing all documentation before submission and will be in charge of ensuring all deliverables will be in PDF format.	Verified with submission of Proposal, PDR, and CDR. Will continue to be verified upon submission of upcoming documents.
In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Inspection	One team member has been designated to format and submit all documentation and is familiar with the requirement for table of contents, sections, and subsections.	Verified with submission of Proposal, PDR, and CDR. Will continue to be verified upon submission of upcoming documents.
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 submit all documentation and is familiar with the requirement for page numbers.	Verified with submission of Proposal, PDR, and CDR. Will continue to be verified upon submission of upcoming documents.

Requirement	Verification Method	Verification Plan	Verification Status
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.	Verified with previous presentation for PDR and CDR. Will continue to be verified with upcoming presentations for FRR.
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	Launch vehicle will be designed to utilize standard rails made available on the NSL launch site.	Verified with submission of previous documents which include launch vehicle design.
Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194)	Inspection	SOAR will thoroughly read and adhere to the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards.	Verified with submission of Project Proposal.

Requirement	Verification Method	Verification Plan	Verification Status
Each team must identify a "mentor."	Demonstration	Jim West, Tripoli 0706 (Tripoli advisory panel member), Certification Level 3 has been designated as the team mentor.	Verified with submission of Project Proposal.

12.3 Vehicle Requirements

Table 31: Vehicle mission requirements and verification plans.

Requirement	Method	Verification	Verification Status
The vehicle will deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL).	Testing/ Demonstration	The rocket will utilize the Aerotech L1420 motor as the propulsive factor and we can alter the flight path with the adjustable ballast system in order to achieve apogee altitude closest to one mile.	Verified on 1/27/18 when Flight 1 reached 5574 feet and on 2/17/18 when flight 2 reached 5407. Will be further verified in March with another flight as well as on competition day.
The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner.	Inspection	Rocket will feature four altimeters, capable of deploying charges and recording the flight apogee. NSL Inspection as well as inspected and approved by the safety officer. Full-scale testing, pre-launch checklist.	Operation of selected altimeters verified at subscale vehicle launch and full scale vehicle launch 1 and 2.

Requirement	Method	Verification	Verification Status
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/ Demonstration	Each altimeter will have an arming switch via an electronic rotary switch. There will be two protruding switches in the switchband of the main altimeter bay, and two inset switches in the payload altimeter bay. All four switches will be visible and physically accessible.	Operation of selected switches verified at subscale launch and full scale vehicle launch 1 and 2.
Each altimeter will have a dedicated power supply.	Inspection	One standard 9V Alkaline batteries will be configured to each altimeter and be sufficient in supplying power to enable function. During subscale and full scale launch testing, each altimeter was connected to a separate 9-volt battery, which were tested prior to flight, and both altimeters initiated the charges reliably at the correct altitudes.	Operation of selected batteries verified at subscale launch and full scale vehicle launch 1 and 2.
Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Testing/ Inspection	There are two settings to the electronic rotary switch. The switch itself has small mechanical components that allow it to remain in its set position. During subscale and full scale launch testing, rotary switches that lock in the “ON” position were used, and were in the “ON” position during recovery.	Operation of selected switches verified at subscale launch and full scale vehicle launch 1 and 2.

Requirement	Method	Verification	Verification Status
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/ Demonstration/Inspection	The launch vehicle will contain parachutes on every separate or tethered part of the rocket that will be released at apogee, 950 feet, and 800 feet that will allow it time to open up properly and safely.	Verified on 1/27/18 and 2/17/18 the dates of the full scale launch tests.
The launch vehicle shall have a maximum of four (4) independent sections.	Inspection	The rocket will be broken up into four sections: the nose cone, rover compartment, main altimeter bay, and the booster section. The nose cone and rover compartment will be tethered together, as will the altimeter bay and booster. Subscale launch vehicle constructed to these specifications. Full scale constructed to same specifications.	Verified with completion of subscale and full scale vehicles.
The launch vehicle shall be limited to a single stage.	Inspection	Launch vehicle will contain only one motor to light and start the flight. Subscale launch vehicle constructed to these specifications. Full scale constructed to same specifications.	Verified with completion of subscale and full scale vehicles.

Requirement	Method	Verification	Verification Status
The launch vehicle shall be capable of being prepared for flight at the launch site within 3 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 3 hours. During subscale and full scale launch, launch vehicle preparation was completed in less than two hours.	Verified on 1/27/18 and 2/17/18 the dates of the full scale launch tests.
The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	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. Subscale rocket remained on pad for 30 minutes and performed properly. Full scale rocket remained on pad for 25 minutes and performed properly.	Verified on 1/27/18 and 2/17/18 the dates of the full scale launch tests.
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 withstand a 12-volt DC firing system. Firing system used during subscale launch was 12-volt DC. Full scale launch vehicle met specifications during test launch.	Verified on 1/27/18 and 2/17/18 the dates of the full scale launch tests.

Requirement	Method	Verification	Verification Status
The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch.	Inspection/ 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. During subscale launch, no external circuitry or special ground support equipment was used. Full scale launch vehicle constructed to same specifications.	Verified on 1/27/18 and 2/17/18 the dates of the full scale launch tests.
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).	Inspection	The motor being used in the launch vehicle will be a Aerotech L1420, which is certified by the National Association of Rocketry and it made of ammonium perchlorate.	Aerotech L1420 motors has been used for both full scale flight tests. The same motor will be used for competition day.
Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria.	Inspection	Our design does not contain a pressure vessel.	Verified with submission of Project Proposal.
The total impulse provided by a University launch vehicle shall not exceed 5,120 N·s.	Inspection	The motor chosen is not bigger than an L class motor and has a total impulse of 4603 N-s.	Inspection of manufacturer's specifications complete.

Requirement	Method	Verification	Verification Status
The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	Analysis/ Demonstration	The center of pressure and the center of gravity in comparison to the diameter of the body tube will have a minimum stability margin of 2.0. Current simulations for configurations under consideration place stability margin between 3.55 and 3.86 calibers.	Verified with submission of FRR.
The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	Analysis/ Demonstration	The motor that was chosen for the rocket will allow the rocket to achieve a minimum of 52 fps at rail exit. Current simulations for configurations under consideration place velocity at rail exit at 57.7 fps.	
All teams shall successfully launch and recover a subscale model of their rocket prior to CDR.	Demonstration	SOAR will have a subscale model ready and launched prior to CDR.	Verified during subscale launch test.
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.	Demonstration	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.	Verified on 1/27/18 and 2/17/18 (the dates of the full scale launch tests).

Requirement	Method	Verification	Verification Status
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.	Inspection	There are no external protrusions from the payload.	Verified through design and vehicle constructions.
The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulates, as closely as possible, the predicted maximum velocity and maximum acceleration of the launch day flight.	Demonstration	We have ordered both the Aerotech L1420 which has been used in both test flights. We have two more more motors: one for an additional launch in march and one for competition day. Cesaroni hardware is being used with the Aerotech L1420 motor.	Aerotech L1420R-P motors have been used during both tests flights on 1/27/18 and 2/17/18.
The vehicle must be flown in its fully ballasted configuration during the full-scale test flight.	Inspection	The completed payload or equivalent simulated weight will be used in the full-scale test flight in addition to the adjustable ballast system.	Verified on 2/17/18 when the launch vehicle was flown in its fully ballasted configuration with max ballast inside the launch vehicle.

12.4 Recovery System Requirements

Table 32: Recovery system mission requirements and verification plans.

Requirement	Method	Verification	Verification Status
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	The launch vehicle is designed to deploy the drogue parachute at apogee, with the main Booster section parachute at an altitude of 950ft and the Main Payload section parachute at an altitude of 800ft. During full scale launch testing, the altimeters successfully initiated the separation charges for all of the points of separation at the programmed altitudes.	Verified on 1/27/18 and 2/17/18 the dates of the full scale launch tests.
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 will be completed prior to full-scale launches. Extensive ground testing will be done if any issues are to come forth either during ground testing or full scale flight. During full scale flight, all parachutes deployed as designed and all ejection charges successfully ignited.	Verified on 1/26/18 and 2/9/18, dates of ground testing conducted before each full scale flight .

Requirement	Method	Verification	Verification Status
At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft·lbf	Analysis/ Demonstration	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 on 1/27/18 and 2/17/18, dates of our full scale launches.
The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	Design/ Inspection	NSL Inspection as well as inspected and approved by safety officer. Recovery system electrical system is connected only to the recovery system altimeters. Payload design incorporates a power supply made up of 3V batteries which is integrated into the rover wheels. During operation the 3V batteries will power the rover two motors and all electronics.	Verified with design submission. Safety officer and NSL inspections to be completed.
All recovery electronics will be powered by commercially available batteries.	Design/ Inspection	NSL Inspection as well as inspected and approved by safety officer. Current design incorporates commercially available 9V batteries. During the full-scale launch, all four 9V batteries powering the four altimeters successfully powered the altimeters to initiate all separation charges.	Verified with design submission. Safety officer inspections completed at full scale launches on 1/27/18 and 2/17/18.

Requirement	Method	Verification	Verification Status
The recovery system shall contain redundant, commercially available altimeters.	Design/ Inspection	NSL Inspection as well as inspected and approved by safety officer.	Verified with design submission. Safety officer inspections completed at full scale launches on 1/27/18 and 2/17/18.
Motor ejection is not a permissible form of primary or secondary deployment.	Design/ Inspection	NSL Inspection as well as inspected and approved by safety officer. Launch vehicle design does not include motor motor ejection as means of deployment.	Verified with design submission. Safety officer and NSL inspections to be completed.
Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Design/ Inspection	NSL Inspection as well as inspected and approved by safety officer. Launch vehicle has been designed with shear pins at each separation point: between altimeter bay and booster, between altimeter bay and payload section, and between nose cone and payload section.	Verified with design submission. Safety officer and NSL inspections to be completed.
Recovery area will be limited to a 2500 ft. radius from the launch pads.	Analysis/ Demonstration	Data from simulations. Drift calculated manually. Subscale and full-scale launch data.	Verified on 2/17/18, the date of the full scale flight when the launch vehicle was recovered within a 2500 ft radius from the launch pad.

Requirement	Method	Verification	Verification Status
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.	Design/ Inspection	A loud audible beacon transmitter has been 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.	Verified with design submission. Safety officer and NSL inspections to be completed.
Any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.	Design/ Inspection	A loud audible beacon transmitter has been 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.	Verified with design submission. Safety officer and NSL inspections to be completed.
The electronic tracking device will be fully functional during the official flight on launch day.	Design/ Inspection	The sounding beacons are planned to be installed within the altimeter bays and will be functional on launch day.	Verified with design submission. Safety officer and NSL inspections to be completed.

12.5 Experiment Requirements

Table 33: Experiment mission requirements and verification plans.

Requirement	Method	Verification	Verification Status
Each team will choose one design experiment option from the following list.	Inspection	SOAR has selected Option 2: Deployable Rover as its experimental payload.	Verified with submission of Project Proposal.

Requirement	Method	Verification	Verification Status
Additional experiments (limit of 1) are allowed, and may be flown, but they will not contribute to scoring.	N/A	SOAR has not selected a second experiment.	N/A
If the team chooses to fly additional experiments, they will provide the appropriate documentation in all design reports, so experiments may be reviewed for flight safety.	N/A	SOAR has not selected a second experiment.	N/A
Teams will design a custom rover that will deploy from the internal structure of the launch vehicle.	Demonstration	A winch system will be designed to both secure and deploy the custom rover. The rover will emerge from within and be cleared out of the launch vehicle.	Verified upon submission of CDR when deployment system was redesigned.
At landing, the team will remotely activate a trigger to deploy the rover from the rocket.	Demonstration/ Testing	Rover will utilize a receiver and team will operate a transmitter that will remotely trigger the rover to deploy from the launch vehicle.	Full scale launch in March will test rover's ability to leave the launch vehicle.
After deployment, the rover will autonomously move at least 5 ft. (in any direction) from the launch vehicle.	Demonstration/ Testing	During rover ground testing and full scale launch in March, testing will be conducted to see how far the rover can travel from the launch vehicle.	Full scale launch in March will test rover's ability to leave the launch vehicle.

Requirement	Method	Verification	Verification Status
Once the rover has reached its final destination, it will deploy a set of foldable solar cell panels.	Demonstration/ Testing	Rover will be designed to deploy solar panels once it has reached its destination. Testing will be conducted prior to competition day to ensure solar cells deploy after rover has reached its final destination.	Full scale launch in March will test rover's ability to leave the launch vehicle.

12.6 Safety Requirements

Table 34: Safety requirements and verifications.

Requirement	Verification Method	Verification Plan	Verification Status
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.	Inspection/ Demonstration	Designated Safety Officer will develop launch checklists and ensure that all checklists are used during relevant operations. Final checklists will be included in FRR report and used during LRR and all launch day operations.	Verified on 1/27/18 and 2/17/18 the dates of the full scale launch tests where checklists were used.
Each team must identify a student safety officer who will be responsible for all items in section 10.1.	Demonstration	Kevin Kirkolis has been identified as the team's Safety Officer.	Verified with submission of CDR.
The role and responsibilities of each safety officer will include the items designated in the 2018 NSL Handbook.	Demonstration	SOAR NSL Safety Officer will be assigned the designated duties. Duties are listed and designated in this report and will be so designated in all future reports.	Verified with submission of Project Proposal.

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	SOAR will abide by all rules and guidance of the Tampa Tripoli Rocket Association RSO. Safety Officer or designated team lead will supervise all operations to ensure rules and guidance are followed.	Verified on 1/27/18 and 2/17/18 the dates of the full scale launch tests.Safety Officer will continue to monitor operations.
Teams will abide by all rules set forth by the FAA.	Demonstration	FAA rules are made available on the team share drive, and the safety officer will verify that all rules are followed.	Verified with submission of Project Proposal. Safety Officer will continue to monitor operations.

12.7 Team-Derived Requirements

Table 35: Team-derived requirements and verification plans.

Requirement	Verification Method	Verification Plan	Verification Status
The team will engage 1000 students through education engagement events by the submission of the FRR on 3/5/18.	Demonstration	SOAR has designated an Outreach Coordinator to organize and handle all outreach events.	Verified on 2/23/18 the date of our last outreach event. In total we reached 1653 students over 14 events.
Deployable rover will travel at least 10 ft after departing from launch vehicle.	Testing	Each battery is rechargeable and will be fully charged no later than 24 hours before the launch. Team leads will check the voltage in each battery with a multimeter. Testing will be conducted to test how far the rover can travel.	Rover ground testing done to test ability of movement, we determined the wheels were slippery. A new wheel design is in the works. More testing to be conducted on rover mobility. March 17th launch to test full capability of Rover.
The rover will be under 10 pounds in total weight	Demonstration	Rover body and wheels will be made out of lightweight materials. Rover is design to include only absolutely necessary electronics, sensors, and wires.The rover will be weighed before launch. Any excess weight will be shed from removing some batteries first, then parts of the rover body, then sensors.	Rover will continually be weighed throughout the fabrication process. Simulated weight will be put into the launch vehicle in order to allow for proper weight adjustments of the rover.

Requirement	Verification Method	Verification Plan	Verification Status
The rover will have the capability to distribute power from its solar cells to its batteries	Testing	Rover will have power controllers and distribute power directly to half of its batteries at a time. Team leads will test the voltage output from its solar panels with a multimeter and monitor the changing levels of the voltage from its batteries.	Testing to be completed when final rover is constructed.
Vehicle will have modular capability to adjust to wind conditions to reach 5,280 feet under all conditions.	Design/ Analysis/ Demonstration	Launch vehicle will incorporate adjustable ballast system and calculation sheet will be developed to enable the team to adjust the amount of ballast on the day of the launch.	Design complete. Analysis complete. Fully ballasted launch on 2/17/18 to ensure up to max ballast can be used on competition day.
The launch vehicle will separate into two tethered, deployable parts to satisfy the intended design concept.	Demonstration	Numerous ground tests with specific shear pin configurations will be used to determine the appropriate mass needed for charges and the type and amount of shear pins. During the full scale flight, the rocket will separate, with visual confirmation, into two distinct parts with a safe distance between them; the nose cone and rover compartment, and the main altimeter and booster section.	Verified on 1/27/18 and 2/17/18 the dates of the full scale launch tests.

Requirement	Verification Method	Verification Plan	Verification Status
The launch vehicle will separate as follows: 1. At apogee, the booster section will separate from the main altimeter bay and the drogue parachute will deploy. 2. At 950 feet, the payload section will separate from the main altimeter bay and the first main parachute will deploy. 3. At 800 feet, the nosecone will separate from the payload section and the second main parachute will deploy.	Demonstration	Black powder charges will be used for all launch vehicle section separation. Ground testing and launch testing will be conducted on subscale and full scale rockets to determine the amount of black powder required to successfully and safely separate the designated sections of the launch vehicle. Altimeters will be programmed and programming verified prior to launch. Altimeter batteries will be tested prior to each launch and replaced if voltage is below 9.0V. During subscale launch testing, all altimeters set off black powder charges at the correct altitudes. During full scale ground testing, several of the demonstrations were successful, and amount of black powder and number/size of shear pins was determined by those tests.	Verified on 1/27/18 and 2/17/18 the dates of the full scale launch tests.

Requirement	Verification Method	Verification Plan	Verification Status
Parachutes will deploy safely without shock cord or shroud line entanglement.	Demonstration	Parachutes and shock cords will be packed in such a way as to prevent entanglement of the shock cords. Shock cords will be folded in a Z-type fold, and parachutes will be folded in accordance with the checklist.	Verified on 1/27/18 full scale test launch. During 2/17/18 full scale test launch we had complication with nosecone parachute which was not connected to the nosecone. The nosecone was recovered safely but not ideally.
Drogue parachute will deploy without the load from the shock cord resulting in unintentional separation of either main parachute separation point.	Demonstration	Shear pins will be selected and gauged to prevent early separation of either main parachute separation point. Combinations of 2/56 and 4/40 shear pins will be used appropriately to ensure main parachute separation points remain intact prior to intended separation altitude.	Verified on 1/27/18 and 2/17/18 the dates of the full scale launch tests.

13 Project Budget and Timeline

13.1 Budget

13.1.1 Projected Budget

Table 36 is a projected budget for our project, not including an amount for outreach events as that money is part of our entire organization's budget.

Table 36: Projected project budget.

Material	Expected Cost ($)
Rocket Materials	1,000.00
Launch Motors	400.00
Test Launch Motors	800.00
Subscale Materials	600.00
Subscale Motor	350.00
Payload	800.00
Miscellaneous Hardware	400.00
Travel	1,500.00
Total	**5,850.00**

13.1.2 Current Budget

Table 37: Current project budget.

	Price ($)	**Shipping** ($)	**Total** ($)
Full Scale			
Full-Scale Rocket	3,323.99	213.59	3,537.58
Full Scale Recovery	2,081.37	65.91	2,147.28

	Price ($)	**Shipping** ($)	**Total** ($)
Full Scale Electronics	167.97	16.50	184.47
Subscale			
Subscale Rocket	882.33	54.99	937.32
Subscale Recovery	345.05	19.94	364.99
Subscale Electronics	0.00	0.00	0.00
Rover			
Rover	769.00	43.61	812.61
Supplies			
General Supplies	92.65	19.51	112.16

13.1.3 Line Item Budget

Item Name	**Total Price**	**Project**
5" G12 filament wound fiberglass tube	$ 288.00	NSL Full-scale Rocket
5" G12 filament wound fiberglass tube	$ 34.20	NSL Full-scale Rocket
5 INCH FILAMENT WOUND 5 TO 1 VON KARMAN NOSECONE WITH METAL TIP	$ 94.05	NSL Full-scale Rocket
5.0 INCH G12 COUPLER 12 INCHES LONG	$ 98.24	NSL Full-scale Rocket
Tender Descender Lvl 2	$ 85.00	NSL Full Scale Recovery

Structural Fiberglass Sheet 24" Wide x 24" Long, 1/8" Thick	$	212.45	NSL Subscale Rocket
Birch Plywood (Common: 1/2 in. x 2 ft. x 4 ft.; Actual: 0.476 in. x 23.75 in. x 47.75 in.)	$	39.90	NSL General Supplies
RRC3 "Sport" Altimeter	$	143.90	NSL Full Scale Recovery
KEVLAR SHOCK CORDS Tubular Kevlar 7200 lb test for 5" and larger rockets	$	56.25	NSL Full Scale Recovery
5/16 in. Zinc-Plated Quick Link	$	20.96	NSL General Supplies
EasyMini Altimeter	$	171.20	NSL Full Scale Recovery
EasyMini Altimeter	$	171.20	NSL Subscale Recovery
75mm Flanged Motor Retainer	$	53.50	NSL Full-scale Rocket
75 mm G12 FG tubing (motor mnt)	$	38.96	NSL Full-scale Rocket
Structural Fiberglass Sheet 12" Wide x 12" Long, 1/8" Thick	$	10.17	NSL Subscale Rocket
L293D Dual H-Bridge Motor Control	$	11.80	NSL Rover
4 in. Fiberglass Tomach	$	309.95	NSL Subscale Rocket
3.91" x 4.03" FG Coupler 2 ft. length	$	33.38	NSL Subscale Rocket
ADXL345 Digital Accelerometer	$	35.00	NSL Rover
Hall Effect Board Sensor	$	3.24	NSL Rover
Arduino Mega 2560 Microcontroller Rev3	$	35.00	NSL Rover
4" Phenolic Tube	$	20.99	NSL Subscale Rocket
RRC3 "Sport" Altimeter	$	143.90	NSL Subscale Recovery

1oz, Grey, Adhesive Stick on Wheel Weights, GM, Ford, Automobiles, Trucks,SUVs, 72 oz/box, US Quality, (72pcs).	$ 20.99	NSL Full-scale Rocket
4" X 8" G12 FW FIBERGLASS COUPLER	$ 26.55	NSL Subscale Rocket
Structural Fiberglass Sheet 24" Wide x 24" Long, 1/8" Thick	$ 127.47	NSL Subscale Rocket
Smart Video Car Kit for Raspberry Pi with Android App, Compatible with RPi 3, 2 and RPi 1 Model B+ (Pi Not Included)	$ 89.09	NSL Rover
Rechargeable Batteries 3 Volts, 600 Mah, .66" Diameter x 1.36" High	$ 82.88	NSL Rover
Compression Spring Music-Wire, Closed & Flat Ends, 2" Long, 7/8" OD, 0.635" ID	$ 13.35	NSL Rover
12V 100RPM 583 oz-in Brushed DC Motor	$ 24.68	NSL Rover
AMX3d 5V 30mA Micro Mini Power Solar Cells For Solar Panels, (53X30mm)	$ 22.76	NSL Rover
Cesaroni 75-3G Case	$ 169.95	NSL Full-scale Rocket
4-40 x 1/2" Nylon Shear Pins (Pack of 20)	$ 5.40	NSL General Supplies
2-56 x 1/2" Nylon Shear Pins (Pack of 20)	$ 5.40	NSL General Supplies
Raspberry Pi 3 Model B Motherboard	$ 34.82	NSL Rover
SAMPLE PACK - DRY FABRICS - SELECT FROM 12 DIFFERENT SWATCHES	$ 20.99	NSL General Supplies
RRC3 - 98mm Dual Modular Sled System	$ 29.95	NSL Full Scale Recovery
RRC3 - 98mm Dual Modular Sled System	$ 29.95	NSL Subscale Recovery
ELECTRONICS ROTARY SWITCH	$ 39.72	NSL Full-scale Rocket
ELECTRONICS ROTARY SWITCH	$ 39.72	NSL Subscale Rocket

Pololu Universal Aluminum 6mm Mounting Hubs (4-40)	$ 7.95	NSL Rover
2 PACK OF LARGE RAIL GUIDES	$ 19.00	NSL Full-scale Rocket
KEVLAR SHOCK CORDS Tubular Kevlar 7200 lb test for 5" and larger rockets	$ 112.50	NSL Full Scale Recovery
Cesaroni K 740 C-Star 54mm 4 grain	$ 101.65	NSL Subscale Rocket
Cesaroni 75mm 3grain case only	$ 169.95	NSL Full-scale Rocket
2/56 shear pins	$ 2.00	NSL Full-scale Rocket
4/40 shear pins	$ 2.00	NSL Full-scale Rocket
Bluetooth Module HM-10 for Arduino	$ 33.98	NSL Rover
DFRobot Serial Bluetooth Module	$ 39.98	NSL Rover
G12 5" filament wound fiberglass tube	$ 144.00	NSL Full-scale Rocket
Structural Fiberglass Sheet, 24" Wide x 24" Long, 3/16" Thick	$ 183.28	NSL Full-scale Rocket
SkyAngle Cert 3 Large parachue	$ 278.00	NSL Full Scale Recovery
SkyAngle Cert 3 24" Drogue	$ 27.50	NSL Full Scale Recovery
Smart Electronics 3pin KEYES KY-017 Mercury Switch Module for Arduino diy Starter Kit KY017	$ 13.44	NSL Rover
Nomex Fabric, 24" x 24"	$ 44.85	NSL Full Scale Recovery
9V Battery Box	$ 10.00	NSL Full Scale Electronics
EasyMini Altimeter	$ 171.20	NSL Full Scale Recovery
SparkFun XBee Wireless Kit	$ 95.95	NSL Full Scale Electronics

AMX3d 5V 30mA Micro Mini Power Solar Cells For Solar Panels	$	45.52	NSL Rover
Energizer A23 Battery, 12V (Pack of 4)	$	8.72	NSL Rover
Uxcell Open Frame Push Pull Solenoid, Electromagnet, DC 12V, 0.3A, 3.6W, 3 mm, 35 g	$	17.70	NSL Rover
MagicShield 500M 100LB Super Dyneema Strong Braided Fishing Line	$	10.50	NSL Rover
Smbbit Stainless Steel Shelf Support Corner Brace Angle Bracket Angle Code Right Angle 6 hole, 38mm x30mm x1.3mm(thick) (8Pack)	$	9.99	NSL Rover
5.0 INCH G12 COUPLER 12 INCHES LONG	$	51.72	NSL Full-scale Rocket
SkyAngle Classic II 60" Parachute	$	99.00	NSL Full Scale Recovery
SkyAngle Classic II 20" Parachute	$	22.00	NSL Full Scale Recovery
Iris Ultra 36" HP Compact Chute	$	155.00	NSL Full Scale Recovery
AeroTech 75mm L1420	$	233.10	NSL Full-scale Rocket
AeroTech 75mm L1420	$	701.97	NSL Full-scale Rocket
500# Ball Bearing Swivels	$	22.05	NSL Full Scale Recovery
1/4" Tubular Kevlar Shock Cord	$	62.50	NSL Full Scale Recovery
Transolve BeepX Rocket Locator	$	73.32	NSL Full Scale Recovery
75MM FORWARD SEAL DISK	$	37.45	NSL Full-scale Rocket
LY-01 DC12V Round Tongue Mini Electric Lock	$	15.00	NSL Rover
Electromagnetic Lock	$	20.00	NSL Rover
E-flite Blade EFC-721 720p HD Video Camera - EFLA801	$	44.78	NSL Full-scale Rocket

Adafruit DC & Stepper Motor HAT for Raspberry Pi - Mini Kit	$ 22.50	NSL Rover
6mm Set Screw Hub	$ 37.60	NSL Rover
Uxcell Open Frame Push Pull Solenoid, Electromagnet, DC 12V, 0.3A, 3.6W, 3 mm, 35 g	$ 88.50	NSL Rover
EasyMini Altimeter	$ 171.20	NSL Full Scale Recovery
9V Battery Box	$ 2.50	NSL Full Scale Electronics
ChuteRelease	$ 130.95	NSL Full Scale Recovery
Cesaroni 75mm 3G L1350 motor	$ -	NSL Full-scale Rocket
YXQ DC 12V 40N Electromagnet Drive Lock Solenoid Security System	$ 59.52	NSL Full Scale Electronics
FruityChutes Ultra 60" Iris Parachute	$ 225.00	NSL Full Scale Recovery
LY-01 DC12V Round Tongue Mini Electric Lock	$ 45.00	NSL Rover

Table 38: Project funding plan.

Source	**Amount** ($)
USF Student Government	7,500.00
Total	**7,500.00**

13.2 Timeline

Table 39: Project planning timeline.

Date	Item Due	Team Responsible	Status
November 4th, 2017	Start Subscale Construction	Rocketry Team	Complete
November 5th, 2017	Prototype Rover Parts Purchase Orders Filed	Rover Team, CSCE Team	Complete
November 17, 2017	Begin Rover Construction & Testing	Rover Team	Complete
November 17, 2017	Begin Interactive Subscale Payload Design & Construction	Rover Team, CSCE Team	Complete
November 24th, 2017	Post-Tests Detailed Rover Parts List Filed	Rover Team, CSCE Team	Complete
December 15th, 2017	Interactive Subscale Payload Complete	Rover Team, CSCE Team	Complete
December 15th, 2017	Subscale Construction & Inspection Complete	Rocketry Team	Complete
December 16th, 2017	Conduct CDR/ Subscale Launch	Entire NSL Team	Complete
January 6th, 2018	Initial deployment design finalized	Rover Team	Complete
January 7th, 2018	Action plan due, meeting dates established	Rover Team	Complete

Date	Item Due	Team Responsible	Status
January 7th, 2018	Start full scale construction - Prepare Recovery Hardware	Rocketry Team	Complete
January 12th, 2018	CDR Due	Entire NSL Team	Complete
January 13th, 2018	Prototype rover build starts	Rover Team	Complete
January 13th, 2018	Test box build starts.	Rover Team	In Progress
January 14th, 2018	Full Scale Construction - Cut Airframe/Couplers, cast fins, cut nosecone shoulder	Rocket Team	Complete
January 19th, 2018	Deployment system construction begins,, prototype rover complete.	Rover Team	Complete
January 21th, 2018	Full Scale Construction - Complete Altimeter Bays, Bulkheads, centering rings, and assemble nose cone.	Rocket Team	Complete
January 21th, 2018	Launch analysis completed pending full scale launch day occurs.	Rocket Team	Complete
January 24th, 2018	Full scale rover parts order due.	Rover Team	Complete
January 27th, 2018	Full Scale Launch Day in Bunnell FL	Entire NSL Team	Complete

Date	Item Due	Team Responsible	Status
January 27, 2018	Updates to deployment system and communication systems due.	Rover Team	Complete
February 2nd, 2018	"LAUNCH" programming complete.	CSCE Team	In Progress
February 3rd, 2018	Prototype rover testing	Rover Team	Complete
February 4th, 2018	Action improvement plan completed, design review due.	Rover Team	Complete
February 7th, 2018	FRR Q&A	Entire NSL Team	Complete
February 9th, 2018	Full Scale Ground Testing	Rocket Team	Complete
February 9th, 2018	Outreach planning and paper rocket assembly	Outreach Team	Complete
February 10th, 2018	SASE Workshop Event	Outreach Team	Complete
February 11th, 2018	Full Scale Construction & Launch Prep Day	Rocket Team	Complete
February 11th, 2018	Stomp Rocket Launcher Construction	Outreach Team	Complete
February 16th, 2018	Engineering EXPO Day 1	Outreach Team	Complete

Date	Item Due	Team Responsible	Status
February 16th, 2018	CDR Score Review Meeting	Entire NSL Team	Complete
February 16th, 2018	Programming/rover design edits due, test predictions due. Dummy deployment construction complete	Rover Team, CSCE Team	Complete
February 16th, 2018	Full Scale Vehicle Prep for Launch Day on 2/17/18	Rocketry Team	Complete
February 17th, 2018	Engineering EXPO Day 2	Outreach Team	Complete
February 17th, 2018	Full Scale Launch	Rocket Team	Complete
February 17th, 2018	Prototype deployment system test.	Rover Team	Complete
February 18th, 2018	Action improvement plan update, launch analysis due, rover launch review due	Rover Team	Complete
February 23rd, 2018	Programming edits, update parts list	Rover Team	Complete
February 23, 2018	Northeast High School “Intro To Java” Presentation	Outreach Team	Complete
February 24th, 2018	Prototype rover test and analysis	Rover Team	Complete
February 25th, 2018	Final Rover Construction - Print structural pieces for expanding wheel	Rover Team	Complete

Date	Item Due	Team Responsible	Status
February 28th, 2018	FRR rough draft due to editing team	Entire NSL Team	Complete
March 1st, 2018	Start final rover construction, 3D print expanding wheel legs	Rover Team	In Progress
March 2nd, 2018	Programming edits due	CSCE Team	Complete
March 2nd, 2018	3D print expanding wheel pieces, assemble pieces of expanding wheel	Rover Team	In Progress
March 3rd, 2018	Fit and test expanding wheel, 3D print main body, solar panel configuration	Rover Team	In Progress
March 4th, 2018	Action improvement plan update, design review competed, FRR final edits due	Rover Team	Complete
March 5th, 2018	FRR due	Entire NSL Team	
March 9th, 2018	Final day to order, programming edits due	Rover Team	
March 9th, 2018	Incorporate electronics and coding onto the rover, configure wheel with body	Rover Team, CSCE Team	
March 11th, 2018	Action improvement plan update and final design review	Rover Team	
March 16th, 2018	Final Rover test and analysis	Rover Team	

Date	Item Due	Team Responsible	Status
March 17th, 2018	Final Full Scale launch and Final Rover/deployment system test	Rocket Team, Rover Team, CSCE Team	
March 23rd, 2018	Programming edits due	CSCE Team	
March 24th, 2018	Fully assembled rover test and analysis	Rover Team	
March 25th, 2018	(Small) Action improvement plan completed and rover completed	Rover Team	
March 31st, 2018	Final programming edits due, final rover test	Rover Team, CSCE Team	
April 7th, 2018	Competition day	Entire NSL Team	
April 27th, 2018	PLA due	Entire NSL Team	

14 Educational Engagement

The Society of Aeronautics and Rocketry plans on organizing events with the community and local schools to inform students on our projects and teach them the importance of STEM Education. We will also be engaging in university events that bring in local students to learn about STEM Education, specifically in the engineering field. In addition to these events we will be organizing other events to showcase our current and previous projects to teach fellow students about what we do. We have also developed a questionnaire to give to students after the presentation so that we can gain some insight on whether or not the kids learned anything from our presentation. A detailed description of all of our events is included below along with our presentation surveys.

14.1 Engineering Block Party

On August 24th 2017, members of our organization set up a booth in the main building of the College of Engineering at the University of South Florida. We informed students and educators of the various projects we work on and how these projects provide valuable hands on experience that will allow students to use what they learn in the classroom in the STEM field. We brought some of our rockets and equipment and allowed participants to get up close to examine the different parts and components. We taught participants about the functionality and importance of each piece in order to showcase the ability of our rockets.

14.2 Rocket Exhibition

On August 8th 2017, our organization set up an event in the Marshall Student Center Ballroom at the University of South Florida to showcase our rockets and other various equipment. We set up multiple stations including:

- A showcase of our organization's past rockets with information describing what they were created for and some details about the design.
- A virtual reality launch experience that allowed participants to use a virtual reality headset to view one of our rocket launches as if they were actually there.
- A rocket building/launch station that provided participants with a chance to build their own rocket on the computer and use a simulator to launch it. This station gave participants an idea of how we visualize our designs for the projects we are working on.
- A presentation about our organization's projects to show how much work and research that goes into planning and engineering a rocket.

14.3 E-Council Open House

On August 28th 2017, members from our group set up a booth inside the College of Engineering at The University of South Florida in order to inform students on the projects we are currently working on. We provided participants with a chance to interact with some of our rockets that way they could get a closer look at the various parts and components. We also gave a short presentation to talk about our organization, the various projects that we work on, and our goals for the current school year.

14.4 USF Student Organization Showcase

On August 30th 2017, members of our team set up a booth at the USF Student Organization Showcase in order to provide students with information about our organization and the projects that we are involved in. We showcased our rocket from last year's NASA Student Launch Competition and showed students the opportunities that our organization can help them get connected to. Students were able to see the different components of the rockets and learn about each component's functionality.

14.5 Roboticon

On October 8th 2017, members from our team set up a booth at Roboticon which was held in the Sun Dome at the University of South Florida. We presented to grade school students from the surrounding counties who were attending the event. We informed the students and their parents about the projects we are working on and how we work in teams to achieve multiple goals. We talked about the different teams we have, the importance of setting and meeting goals, and the process of engineering certain rockets. We showed students multiple rockets our organization has built and taught them about each component along with its purpose.

14.6 USF Foundations of Engineering Class Presentation

On October 20th 2017, members from our team gave presentation to two Foundations of Engineering Classes about our organization and the projects we are working on. We showed the students one of our rockets and explained the importance of each section as well as its functionality. We also told the kids about the different projects we are working on and what it means to be a part of that project team. We wanted to show the students how to connect what they learn in the classroom to the STEM field and how gaining engineering experience now can be beneficial for future endeavors.

14.7 Engineering Day at USF

On November 3rd 2017 two 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 two 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 their parachutes, fins, and nosecones. We discussed the specific design of each rocket and what its function was. We wanted 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 explained to students how different disciplines and majors are incorporated into our projects in order to fill the engineering, business, and administrative aspects of our teams.

14.8 Great American Teach in at Palm Harbor Middle School

On November 15th 2017 members from our team presented a PowerPoint presentation about our organization and what we do to middle school students. We talked about the engineering cycle and how it applies to our rocket building. We discussed how an idea is developed from the design stages to the building stages. We stressed the process of what it takes to build something along with the safety measures that must be met. We also stressed that because the engineering cycle is in fact a cycle that it takes repetitive testing until you get the final product. We also talked about STEM education and how all of the disciplines come together to complete a project. Overall, the students were interested in the things we do and how we are able to do them.

14.9 USF Engineering SuperFAM

On December 5th 2017 the Engineering College at USF hosted international recruiters and students in order to increase awareness of the college's programs and benefits available to students. The event was also used for recruiters to gain insight on the type of students to recruit for our university. For this event, we set up a table and several of our rockets in order to demonstrate our capabilities. We also conducted several short explanatory speeches to the groups concerning our past accomplishments and future projects. Our goal was to show that even though the university does not over an aerospace degree there are opportunities in the aerospace field that can be quite beneficial.

14.10 Patio Tuesday Involvement Invasion at USF

Patio Tuesday is an event held by the University on the first Tuesday of every month, this month's theme was called Involvement Invasion and its purpose was to help student organization reach out to the incoming spring students. The Society of Aeronautics and Rocketry set up a stand with a poster board describing our projects along with examples of our rockets. We showcased one of our Level 1 Certification rocket as well as our NSL Subscale. We showed videos of the launch and explained to students how our process works when it comes to a project.

14.11 Joshua House

Members of our organization partnered with an organization on campus who embraces education in STEM and art, ESTEAM. A group of about 10 members went to Joshua House, a safe haven for abused, neglected, and abandoned children in the Tampa Bay Area. We invited any child at the home who wanted to participate to learn how to build water rockets and measure the altitude after launching. We set up stations for fin design, nosecone design, and assembly. Our members helped students understand the different types of fin designs and how they alter the rocket's flight. At the payload station our members discussed why we were attaching a payload and compared it to the payloads we use in our rockets. Once the students assembled the rocket one of our members loaded it onto the launcher and had the student stand 50 feet away in order to measure the altitude of their rocket. Each student used their arm to track how high their rocket went and then another student measured the angle at which their arm was inclined. Once that information was gathered they used trigonometry to find their altitude. Each student launch about once and got to keep their water bottle rockets after as well as one of the launchers we had built so that they could use it in the future.

14.12 SASE Workshop

A few of our members held a workshop for the Society of Asian Scientist and Engineers to teach them about Rocketry. They gave a presentation on the process of building a rocket including: the materials used, the process to calculate stability, and a description of the different components and when they are used. After the presentation we gave a demonstration on how to assemble and prepare one of our rockets for flight. During this demonstration we showed the students how to prep the electronics bay, fold parachutes, and pack parachutes with shock cord inside the separate compartments.

14.13 Engineering Expo at USF

Engineering EXPO is a two-day event put on by the College of Engineering at USF. The event has copious participants including student organizations, local companies, and local schools. These participants set up a booth and activities for local students to learn about STEM education during a seven-hour time frame. At our section we had three main components: a corn-hole game, stomp rockets, and a table setup. The stomp rockets were a lesson plan we got from NASA's website, we made several different kinds of paper rockets to showcase different fin and body designs. During the event we had children choose a rocket that they thought would fly the best, once chosen they loaded the rockets onto the launchers and stomped on a soda bottle to make it fly. The ground was marked with five-foot increments so once the rockets landed the students could retrieve the rockets and their distance; the furthest rocket traveled 90 feet. At the table setup we showcased one of our rockets and gave information about its payload and separate components. We also had a board that had pictures and descriptions of our other projects.

14.14 Northeast High School Presentation

One of our members organized an event at their old high school's IT Academy. SOAR conducted a presentation and some activities with some of the students in the academy. We stayed with one teacher the entire day and talked to each one of his classrooms which consisted of sophomores and juniors. In the beginning of our presentation we discussed our organization briefly and the showed a video of our most recent launch. After we established who we were with the students, one of our Computer Science Members taught the students an introductory lesson on Java. The lesson described the basic syntax and general idea of the object oriented language. The lesson included a couple of activities, one where the students were asked a question during the lesson and another where the students had to code themselves. During the coding activity we asked the student to first guess what the line of code would output, then we had each student write the code in a compiler called Eclipse. These students had never coded before or learned code, so it was a very new thing to them. We walked around the room and explained the code they were writing and helped them if they came across a problem. Once each student had guessed the output and written three lines of code we gave them a different task to try on their own. Each student was tasked with creating some variables, manipulating the variables in some way, and then outputting the value of the variable. About ten minutes before class ended we had students fill out a survey we created in order to get some feedback, the survey has been included below. Data from the surveys conducted is included in the Education Engagement Form submitted for this event.

Table 40: Student outreach count verification.

	NASA Requirement	Team Requirement
Required Amount	200	1,000
Amount Remaining	0	0
Verification Status	Completed	Completed
Total Students Reached	1,653	

Table 41: Student outreach survey data.

Student Survey Data				
	How informational was it?	How were the presenters?	How fun was it?	How was it overall?
Poor	6%	0%	6%	0%
Average	15%	9%	39%	24%
Good	35%	39%	30%	46%
Great	44%	52%	26%	30%

15 Appendices

15.1 Contributors

15.1.1 Project Management/Logistics

- Jackson Stephenson
- Javian Hernandez
- Ashleigh Stevenson
- Andrew Sapashe
- Stephanie Bauman

15.1.2 Launch Vehicle

- Jackson Stephenson
- Kevin Kirkolis
- Stephanie Bauman
- Andrew Sapashe

15.1.3 Editing and Formatting

- Stephanie Bauman
- Ashleigh Stevenson
- Ian Sanders

15.1.4 Presentation

- Ashleigh Stevenson

15.1.5 Electronics/Coding

- Joe Caton
- Tom Hall
- Lott "Kerby" Lalime

15.1.6 Rover

- Javian Hernandez
- Andrew Sapashe
- James Waits
- Chris Purdie
- Jackson Stephenson
- Joe Caton

15.1.7 Educational Engagement

- Jackson Stephenson
- Ashleigh Stevenson

15.1.8 Safety

- Stephanie Bauman
- Kevin Kirkolis

15.2 Milestone Review Flysheet (CDR)

Milestone Review Flysheet 2017-2018

Institution	University of South Florida	Milestone	CDR

Vehicle Properties

Total Length (in)	111
Diameter (in)	5.148
Gross Lift Off Weigh (lb.)	48.7
Airframe Material(s)	G12 Fiberglass
Fin Material and Thickness (in)	FRP Fiberglass at 1/8"
Coupler Length/Shoulder Length(s) (in)	12 / 5

Motor Properties

Motor Brand/Designation	Aerotech
Max/Average Thrust (lb.)	407.8 / 319.2
Total Impulse (lbf-s)	1034.8
Mass Before/After Burn (lb.)	10.1 / 4.4
Liftoff Thrust (lb.)	340
Motor Retention Method	AeroPack 75mm Flanged Motor Retaining Center

Stability Analysis

Center of Pressure (in from nose)	88.3
Center of Gravity (in from nose)	68.34
Static Stability Margin (on pad)	3.88
Static Stability Margin (at rail exit)	3.95
Thrust-to-Weight Ratio	7.07:1
Rail Size/Type and Length (in)	1515 and 96 in
Rail Exit Velocity (ft/s)	57.7

Ascent Analysis

Maximum Velocity (ft/s)	602.89
Maximum Mach Number	0.54
Maximum Acceleration (ft/s^2)	224.28
Predicted Apogee (From Sim.) (ft)	5304

Recovery System Properties

Drogue Parachute

Manufacturer/Model	SkyAngle / Classic II			
Size/Diameter (in or ft)	28			
Altitude at Deployment (ft)	Apogee			
Velocity at Deployment (ft/s)	-3.41			
Terminal Velocity (ft/s)	-69			
Recovery Harness Material	Tubular Kevlar			
Recovery Harness Size/Thickness (in)	1/2 in			
Recovery Harness Length (ft)	30 ft			
Harness/Airframe Interfaces	The 1/2" tubular kevlar shock cord is epoxied and secured to the motor mount. The drogue parachute's shroud lines will be attached to a d-link in a butterfly or another standard loop in the shock cord closer to the booster section			
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	421.39	1168.07	561.86	1449

Recovery System Properties

Main Parachute #1 (p. 4 for #2)

Manufacturer/Model	Fruity Chutes / Iris Ultra			
Size/Diameter (in or ft)	66 in			
Altitude at Deployment (ft)	950			
Velocity at Deployment (ft/s)	-69			
Terminal Velocity (ft/s)	-16.95			
Recovery Harness Material	Tubular Kevlar			
Recovery Harness Size/Thickness (in)	1/4 in			
Recovery Harness Length (ft)	20 ft			
Harness/Airframe Interfaces	*Slowest speed reached before second main parachute deploys. Shroud lines attached to a 500 pound ball bearing swivel. This swivel will be secured to shock cord with d-link, and upper bulkhead of main altimeter bay.			
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	25.43	58.49	33.9	64.44

Recovery Electronics

Altimeter(s)/Timer(s) (Make/Model)	Atlus Metrum / EasyMini
Redundancy Plan and Backup Deployment Settings	Each altimeter will be paired with a spare altimeter set to deploy 50 feet after its parent charge with the same charge mass
Pad Stay Time (Launch Configuration)	8 hours

Recovery Electronics

Rocket Locators (Make/Model)	SB1 Sounding Locator	
Transmitting Frequencies (all - vehicle and payload)	None	
Ejection System Energetics (ex. Black Powder)	Black Powder	
Energetics Mass - Drogue Chute (grams)	Primary	1.5
	Backup	2
Energetics Mass - Main Chute (grams)	Primary	4
	Backup	4.5
Energetics Masses - Other (grams) - If Applicable	Primary	2
	Backup	1.75

Milestone Review Flysheet 2017-2018

Institution	University of South Florida	Milestone	CDR

Payload		
Payload 1 (official payload)	Overview	The Society of Aeronuatics and Rocketry at the University of South Florida are designing, developing and testing a depolyable rover to be their competitive paylaod of choice. The rover is essentially a cylinder in shape, with wheels at the ends and all necessary electrical components in the rover body situated between the two wheels. The rover is expected to be 5 inches wide and 14 inches long, but will continue to be redesigned to have reduced size but perform the same tasks.
Payload 2 (non-scored payload)	Overview	

Test Plans, Status, and Results	
Ejection Charge Tests	The full scale rocket will have three points of separation; the drogue section (booster section and main altimeter bay), the first main (main altimeter bay and rover compartment) and the second main (rover compartment and nosecone). Extensive ground testing at a safe location has been conducted and the following ejection charges and shear pin combinations will be used. 1. Drogue: 1.5 and 2 g black powder; 2 x 2-56 shear pins 2. Main 1: 4 and 4.5 g black powder; 2 x 2-56 and 2 x 4-40 shear pins 3. Main 2: 2 and 1.75 g black powder; 3 x 2-56 shear pins
Sub-scale Test Flights	The subscale test flights were done on December 16th, 2017. The temperature was in the 60s with minimal winds. Pre-launch procedures before first flight included loading and setting the black powder charges, activating altimeters with standard 9V batteries, securing the payload altimeter bay and folding and storing the recover equipment. Saftey officer verified all parts and procedures. First flight used a Cesaroni 54mm 4G K740. Apogee was 3,146 feet and max acceleration of 88 fps^2 and max velocity of 401 fps. Drogue deployed at apogee as expected. The second deployment charge at 1,000 feet, with the first main separating from the rover compartment but the charges did not detach from the main altimeter bay and first main did not deploy. The third deployment charge at 800 feet detached the nosecone and deployed parchute. For the second flight, a Cesaroni 54mm 4G K940 was used was used. This flight reached an apogee of 2,587 feet and max acceleration of 70 fps^2 and max velocity of 362 fps. Deployment and separation at apogee was successful. At 1,000 feet the charges detached the two 4-40 used on this flight for the main alitmeter bay. The shock cord stored in the payload section / rover compartment did not fully extend and detach from the rocket because the parachute was tightly packed. The drogue and first main shock cord became entangled. The rocket safely reached ground without any damage.
Full-scale Test Flights	The ascent of the launch vehicle went well. Given the data received from the EasyMini altimeters on board showed the max acceleration to be 4.12 Gs during the boost phase and the time to apogee at around 28.1 seconds. The drogue chute slowed the launch vehicle to a steady descent rate 77 feet per second until the first main parachute deployment at 950 feet AGL. At this point, the Booster and Main Altimeter Bay separate from the rest of the launch vehicle and descended at an average rate of 28 feet per second for 31 seconds until touchdown. The main parachute responsible for deploying at 800 feet AGL to recover the Nosecone and Rover Compartment airframe was not attached properly, allowing these sections to descend at an unsafe rate. Fortunately, there was no damage to the launch vehicle or electronics stored within the Payload Altimeter Bay.

Milestone Review Flysheet 2017-2018

Institution	University of South Florida	Milestone	CDR

Additional Comments
Note that all calculations were done using the maximum ballast weight of 4.25 lbs.

Recovery System Properties				
Main Parachute #2				
Manufacturer/Model	SkyAngle / Classic II			
Size/Diameter (in or ft)	60 in			
Altitude at Deployment (ft)	800			
Velocity at Deployment (ft/s)	-48.09			
Terminal Velocity (ft/s)	-15.13			
Recovery Harness Material	Tubular Kevlar			
Recovery Harness Size/Thickness (in)	1/2 in			
Recovery Harness Length (ft)	20 ft			
Harness/Airframe Interfaces	The SkyAngle parachute comes equipped with a swivel on the end of its shroud lines, which will be attached via d-link to the 20 feet of 1/2" tubular kevlar shock cord. This shock cord will be stored and attached to the U-bolt			
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	20.26	56.16	27.02	69.67

15.3 Detailed Mass Statement

Parts Detail

Payload

Nose cone	Fiberglass (1.85 g/cm³)	Ogive	Len: 25 in	Mass: 3.5 lb
Bulkhead	Fiberglass (1.85 g/cm³)	Dia$_{out}$ 4.998 in	Len: 0.125 in	Mass: 0 lb
Nosecone Ballast		Dia$_{out}$ 4.65 in		Mass: 2 lb
Rover Compartment	Fiberglass (1.85 g/cm³)	Dia$_{in}$ 5 in Dia$_{out}$ 5.148 in	Len: 47.75 in	Mass: 4.4 lb
800' Nomex		Dia$_{out}$ 4.9 in		Mass: 0.1 lb
Rover		Dia$_{out}$ 5 in		Mass: 7 lb
Payload Altimeter	Fiberglass (1.85 g/cm³)	Dia$_{in}$ 4.753 in Dia$_{out}$ 4.987 in	Len: 4 in	Mass: 2.5 lb
Shock cord	Kevlar (9/16 inch & 2000 lb strength) (7.85 g/m)		Len: 240 in	Mass: 0.9 lb
SkyAngle Classic II 60"	Ripstop nylon (67 g/m²)	Dia$_{out}$ 60 in	Len: 3.5 in	Mass: 0.9 lb
Shroud Lines	Braided nylon (3 mm, 1/8 in) (3.5 g/m)	Lines: 3	Len: 60 in	
Bulkhead	Fiberglass (1.85 g/cm³)	Dia$_{out}$ 4.753 in	Len: 0.125 in	Mass: 0 lb
Bulkhead	Fiberglass (1.85 g/cm³)	Dia$_{out}$ 4.987 in	Len: 0.125 in	Mass: 0 lb
Bulkhead	Fiberglass (1.85 g/cm³)	Dia$_{out}$ 4.987 in	Len: 0.125 in	Mass: 0 lb
Bulkhead	Fiberglass (1.85 g/cm³)	Dia$_{out}$ 4.753 in	Len: 0.125 in	Mass: 0 lb
EasyMini Altimeter		Dia$_{out}$ 0.8 in		Mass: 0 lb
EasyMini Altimeter		Dia$_{out}$ 0.8 in		Mass: 0 lb

Booster stage

Main Altimeter Switchband	Fiberglass (1.85 g/cm³)	Dia$_{in}$ 5 in Dia$_{out}$ 5.148 in	Len: 2 in	Mass: 0 lb
Main Altimeter	Fiberglass (1.85 g/cm³)	Dia$_{in}$ 4.753 in Dia$_{out}$ 4.987 in	Len: 12 in	Mass: 4.1 lb
1/4" Kelvar	Kevlar (9/16 inch & 2000 lb strength) (7.85 g/m)		Len: 240 in	Mass: 0.7 lb
Fruity Chutes Iris Ultra 66"	Ripstop nylon (67 g/m²)	Dia$_{out}$ 60 in	Len: 3.2 in	Mass: 0.425 lb

Shroud Lines	Braided nylon (3 mm, 1/8 in) (3.5 g/m)	Lines: 10	Len: 36 in	
Bulkhead	Fiberglass (1.85 g/cm³)	Dia_{out} 4.753 in	Len: 0.125 in	Mass: 0 lb
Bulkhead	Fiberglass (1.85 g/cm³)	Dia_{out} 4.987 in	Len: 0.125 in	Mass: 0 lb
Bulkhead	Plywood (birch) (0.63 g/cm³)	Dia_{out} 4.753 in	Len: 0.125 in	Mass: 0 lb
Bulkhead	Plywood (birch) (0.63 g/cm³)	Dia_{out} 4.987 in	Len: 0.125 in	Mass: 0 lb
EasyMini Altimeter		Dia_{out} 0.8 in		Mass: 0 lb
EasyMini Altimeter		Dia_{out} 0.8 in		Mass: 0 lb
950' Nomex		Dia_{out} 4.9 in		Mass: 0.127 lb
Main Ballast		Dia_{out} 4.7 in		Mass: 2.25 lb
Booster Section -0.5 for motor weight	Fiberglass (1.85 g/cm³)	Dia_{in} 5 in Dia_{out} 5.148 in	Len: 36 in	Mass: 8.5 lb
Motor Mount	Fiberglass (1.85 g/cm³)	Dia_{in} 2.953 in Dia_{out} 3.071 in	Len: 21 in	Mass: 0 lb
75mm Flanged Motor Retainer		Dia_{out} 3.9 in		Mass: 0 lb
Centering ring	Fiberglass (1.85 g/cm³)	Dia_{in} 3.071 in Dia_{out} 5 in	Len: 0.125 in	Mass: 0 lb
Centering ring	Fiberglass (1.85 g/cm³)	Dia_{in} 3.071 in Dia_{out} 5 in	Len: 0.125 in	Mass: 0 lb
Centering ring	Fiberglass (1.85 g/cm³)	Dia_{in} 3.071 in Dia_{out} 5 in	Len: 0.125 in	Mass: 0 lb
Shock cord	Kevlar (9/16 inch & 2000 lb strength) (7.85 g/m)		Len: 300 in	Mass: 0 lb
Drogue Nomex		Dia_{out} 4.7 in		Mass: 0 lb
Trapezoidal fin set (4)	1/8" McMaster Structural FG (1.85 g/cm³)	Thick: 0.125 in		Mass: 0 lb
SkyAngle 20" Drogue	Ripstop nylon (67 g/m²)	Dia_{out} 20 in	Len: 3.25 in	Mass: 0.2 lb
Shroud Lines	Braided nylon (3 mm, 1/8 in) (3.5 g/m)	Lines: 3	Len: 20 in	
Reinforcement Coupler	Fiberglass (1.85 g/cm³)	Dia_{in} 4.753 in Dia_{out} 4.987 in	Len: 6 in	Mass: 1 lb

15.4 Detailed Drift Analysis Report

Standard Simulated Launch Parameters (Up to date)
696 data points written for 3 variables.
Simulation warnings:
Recovery device deployment at high speed (146 ft/s)
#
Time (s) Altitude (ft Position East of launch (ft)
Event LAUNCH occurred at t=0 seconds
Event IGNITION occurred at t=0 seconds

0	0	0
0.01	0	0
0.02	0.002238	0
0.03	0.011517	0
0.04	0.032945	0
# Event LIFTOFF occurred at t=0.05 seconds		
0.05	0.07015	0
0.06	0.12443	0
0.07	0.19618	0
0.08	0.28584	0
0.09	0.3938	0
0.1	0.52047	0
0.11	0.66629	0
0.12	0.83165	0
0.13	1.0169	0
0.14	1.2223	0
0.15	1.4478	0
0.16	1.6933	0
0.17	1.9589	0
0.18	2.2446	0
0.19	2.5504	0
0.2	2.8762	0
0.21	3.2221	0
0.22	3.5879	0
0.23	3.9739	0
0.24	4.3798	0
0.25	4.8057	0
0.26	5.2516	0
0.27	5.7175	0
0.28	6.2034	0
0.29	6.7093	0
0.3	7.2351	0
0.31	7.7808	0
# Event LAUNCHROD occurred at t=0.32 seconds		
0.32	8.3465	0
0.335	9.2324	-8.44E-07
0.3575	10.645	-5.41E-06
0.39125	12.953	-2.03E-05
0.44125	16.788	-6.16E-05

2.8412	813.03	-0.15045
2.8912	841.77	-0.15966
2.9412	870.92	-0.16924
2.9912	900.45	-0.17915
3.0412	930.31	-0.18939
3.0912	960.35	-0.1999
3.1412	990.42	-0.21064
3.1912	1020.4	-0.22157
# Event BURNOUT occurred at t=3.2412 seconds		
3.2412	1050.3	-0.23268
3.2912	1080.1	-0.24398
3.3412	1109.7	-0.25546
3.3912	1139.2	-0.26711
3.4412	1168.6	-0.27892
3.4912	1197.8	-0.29088
3.5412	1226.9	-0.303
3.5912	1255.8	-0.31528
3.6412	1284.6	-0.32771
3.6912	1313.3	-0.34031
3.7412	1341.9	-0.35308
3.7912	1370.3	-0.36601
3.8412	1398.6	-0.3791
3.8912	1426.8	-0.39235
3.9412	1454.8	-0.40576
3.9912	1482.7	-0.41932
4.0412	1510.5	-0.43304
4.0912	1538.2	-0.44692
4.1412	1565.7	-0.46095
4.1912	1593.1	-0.47513
4.2412	1620.3	-0.48946
4.2912	1647.5	-0.50393
4.3412	1674.5	-0.51856
4.3912	1701.4	-0.53333
4.4412	1728.2	-0.54826
4.4912	1754.8	-0.56333
4.5412	1781.3	-0.57855
4.5912	1807.7	-0.59391
4.6412	1834	-0.60942
4.6912	1860.1	-0.62506
4.7412	1886.2	-0.64084
4.7912	1912.1	-0.65677
4.8412	1937.9	-0.67283
4.8912	1963.5	-0.68904
4.9412	1989.1	-0.70539
4.9912	2014.5	-0.72188
5.0412	2039.8	-0.73852
5.0912	2065	-0.75529

5.1412	2090.1	-0.77219
5.1912	2115	-0.78923
5.2412	2139.8	-0.80639
5.2912	2164.5	-0.82369
5.3412	2189.1	-0.84111
5.3912	2213.6	-0.85867
5.4412	2238	-0.87635
5.4912	2262.2	-0.89417
5.5412	2286.3	-0.91213
5.5912	2310.4	-0.93023
5.6412	2334.3	-0.94845
5.6912	2358	-0.96681
5.7412	2381.7	-0.9853
5.7912	2405.3	-1.0039
5.8412	2428.7	-1.0226
5.8912	2452	-1.0415
5.9412	2475.3	-1.0604
5.9912	2498.4	-1.0795
6.0412	2521.4	-1.0987
6.0912	2544.2	-1.118
6.1412	2567	-1.1375
6.1912	2589.7	-1.157
6.2412	2612.2	-1.1767
6.2912	2634.6	-1.1965
6.3412	2657	-1.2165
6.3912	2679.2	-1.2365
6.4412	2701.3	-1.2567
6.4912	2723.3	-1.277
6.5412	2745.2	-1.2973
6.5912	2766.9	-1.3178
6.6412	2788.6	-1.3384
6.6912	2810.2	-1.3591
6.7412	2831.6	-1.3799
6.7912	2853	-1.4009
6.8412	2874.2	-1.4219
6.8912	2895.3	-1.4431
6.9412	2916.4	-1.4644
6.9912	2937.3	-1.4857
7.0412	2958.1	-1.5072
7.0912	2978.8	-1.5288
7.1412	2999.4	-1.5505
7.1912	3019.9	-1.5723
7.2412	3040.3	-1.5942
7.2912	3060.6	-1.6162
7.3412	3080.8	-1.6383
7.3912	3100.8	-1.6605
7.4412	3120.8	-1.6828

7.4912	3140.7	-1.7052
7.5412	3160.4	-1.7277
7.5912	3180.1	-1.7503
7.6412	3199.7	-1.7731
7.6912	3219.1	-1.7959
7.7412	3238.5	-1.8188
7.7912	3257.7	-1.8418
7.8412	3276.9	-1.8649
7.8912	3295.9	-1.8881
7.9412	3314.9	-1.9114
7.9912	3333.7	-1.9348
8.0412	3352.5	-1.9583
8.0912	3371.1	-1.9819
8.1412	3389.6	-2.0055
8.1912	3408.1	-2.0293
8.2412	3426.4	-2.0531
8.2912	3444.7	-2.0771
8.3412	3462.8	-2.1011
8.3912	3480.9	-2.1253
8.4412	3498.8	-2.1495
8.4912	3516.6	-2.1738
8.5412	3534.4	-2.1982
8.5912	3552	-2.2227
8.6412	3569.6	-2.2473
8.6912	3587	-2.2719
8.7412	3604.4	-2.2966
8.7912	3621.6	-2.3215
8.8412	3638.8	-2.3464
8.8912	3655.9	-2.3714
8.9412	3672.8	-2.3965
8.9912	3689.7	-2.4216
9.0412	3706.5	-2.4469
9.0912	3723.1	-2.4722
9.1412	3739.7	-2.4976
9.1912	3756.2	-2.5231
9.2412	3772.6	-2.5487
9.2912	3788.9	-2.5743
9.3412	3805.1	-2.6
9.3912	3821.1	-2.6259
9.4412	3837.2	-2.6517
9.4913	3853.1	-2.6777
9.5413	3868.9	-2.7037
9.5913	3884.6	-2.7299
9.6413	3900.2	-2.756
9.6913	3915.7	-2.7823
9.7413	3931.2	-2.8087
9.7913	3946.5	-2.8351

9.8413	3961.8	-2.8616
9.8913	3976.9	-2.8881
9.9413	3992	-2.9148
9.9913	4006.9	-2.9415
10.041	4021.8	-2.9682
10.091	4036.6	-2.9951
10.141	4051.3	-3.022
10.191	4065.9	-3.049
10.241	4080.4	-3.0761
10.291	4094.8	-3.1032
10.341	4109.1	-3.1304
10.391	4123.3	-3.1577
10.441	4137.4	-3.185
10.491	4151.5	-3.2124
10.541	4165.4	-3.2399
10.591	4179.3	-3.2674
10.641	4193	-3.295
10.691	4206.7	-3.3227
10.741	4220.3	-3.3504
10.791	4233.8	-3.3782
10.841	4247.2	-3.4061
10.891	4260.5	-3.434
10.941	4273.7	-3.462
10.991	4286.9	-3.4901
11.041	4299.9	-3.5182
11.091	4312.8	-3.5464
11.141	4325.7	-3.5746
11.191	4338.5	-3.6029
11.241	4351.2	-3.6313
11.291	4363.7	-3.6597
11.341	4376.2	-3.6882
11.391	4388.7	-3.7167
11.441	4401	-3.7453
11.491	4413.2	-3.7739
11.541	4425.4	-3.8027
11.591	4437.4	-3.8314
11.641	4449.4	-3.8602
11.691	4461.3	-3.8891
11.741	4473.1	-3.9181
11.791	4484.8	-3.947
11.841	4496.4	-3.9761
11.891	4507.9	-4.0052
11.941	4519.3	-4.0343
11.991	4530.7	-4.0635
12.041	4541.9	-4.0928
12.091	4553.1	-4.1221
12.141	4564.2	-4.1514

12.191	4575.2	-4.1808
12.241	4586.1	-4.2103
12.291	4596.9	-4.2398
12.341	4607.7	-4.2693
12.391	4618.3	-4.2989
12.441	4628.9	-4.3286
12.491	4639.4	-4.3583
12.541	4649.8	-4.388
12.591	4660.1	-4.4178
12.641	4670.3	-4.4476
12.691	4680.4	-4.4775
12.741	4690.5	-4.5074
12.791	4700.4	-4.5374
12.841	4710.3	-4.5674
12.891	4720.1	-4.5975
12.941	4729.8	-4.6276
12.991	4739.4	-4.6578
13.041	4748.9	-4.688
13.091	4758.4	-4.7182
13.141	4767.7	-4.7485
13.191	4777	-4.7788
13.241	4786.2	-4.8092
13.291	4795.3	-4.8396
13.341	4804.3	-4.87
13.391	4813.2	-4.9005
13.441	4822.1	-4.931
13.491	4830.9	-4.9616
13.541	4839.5	-4.9922
13.591	4848.1	-5.0228
13.641	4856.6	-5.0535
13.691	4865.1	-5.0842
13.741	4873.4	-5.1149
13.791	4881.7	-5.1457
13.841	4889.8	-5.1765
13.891	4897.9	-5.2073
13.941	4905.9	-5.2382
13.991	4913.8	-5.2691
14.041	4921.7	-5.3001
14.091	4929.4	-5.3311
14.141	4937.1	-5.3621
14.191	4944.7	-5.3931
14.241	4952.2	-5.4242
14.291	4959.6	-5.4553
14.341	4966.9	-5.4865
14.391	4974.2	-5.5176
14.441	4981.3	-5.5488
14.491	4988.4	-5.5801

14.541	4995.4	-5.6113
14.591	5002.3	-5.6426
14.641	5009.2	-5.6739
14.691	5015.9	-5.7052
14.741	5022.6	-5.7366
14.791	5029.2	-5.768
14.841	5035.7	-5.7994
14.891	5042.1	-5.8309
14.941	5048.4	-5.8623
14.991	5054.7	-5.8938
15.041	5060.9	-5.9253
15.091	5067	-5.9569
15.141	5073	-5.9884
15.191	5078.9	-6.02
15.241	5084.7	-6.0516
15.291	5090.5	-6.0833
15.341	5096.2	-6.1149
15.391	5101.8	-6.1466
15.441	5107.3	-6.1782
15.491	5112.7	-6.2099
15.541	5118	-6.2417
15.591	5123.3	-6.2734
15.641	5128.5	-6.3051
15.691	5133.6	-6.3369
15.741	5138.6	-6.3687
15.791	5143.6	-6.4005
15.841	5148.4	-6.4323
15.891	5153.2	-6.4641
15.941	5157.9	-6.4959
15.991	5162.5	-6.5278
16.041	5167	-6.5596
16.091	5171.5	-6.5915
16.141	5175.8	-6.6234
16.191	5180.1	-6.6553
16.241	5184.3	-6.6872
16.291	5188.4	-6.7191
16.341	5192.5	-6.751
16.391	5196.5	-6.7829
16.441	5200.3	-6.8148
16.491	5204.1	-6.8467
16.541	5207.8	-6.8787
16.591	5211.5	-6.9106
16.641	5215	-6.9425
16.691	5218.5	-6.9745
16.741	5221.9	-7.0064
16.791	5225.2	-7.0384
16.841	5228.4	-7.0703

16.891	5231.6	-7.1022
16.941	5234.7	-7.1342
16.991	5237.6	-7.1661
17.041	5240.6	-7.198
17.091	5243.4	-7.2299
17.141	5246.1	-7.2619
17.191	5248.8	-7.2938
17.241	5251.4	-7.3257
17.291	5253.9	-7.3576
17.341	5256.3	-7.3894
17.391	5258.6	-7.4213
17.441	5260.9	-7.4532
17.491	5263.1	-7.485
17.541	5265.2	-7.5169
17.591	5267.2	-7.5487
17.641	5269.1	-7.5805
17.691	5271	-7.6123
17.741	5272.8	-7.644
17.791	5274.5	-7.6758
17.841	5276.1	-7.7075
17.891	5277.6	-7.7393
17.941	5279.1	-7.771
17.991	5280.5	-7.8027
18.041	5281.8	-7.8343
18.091	5283	-7.866
18.141	5284.1	-7.8976
18.191	5285.2	-7.9292
18.241	5286.1	-7.9608
18.291	5287	-7.9924
18.341	5287.8	-8.0239
18.391	5288.6	-8.0554
18.441	5289.2	-8.0869
18.491	5289.8	-8.1184
18.541	5290.3	-8.1499
18.591	5290.7	-8.1814
18.641	5291	-8.2128
18.691	5291.3	-8.2442
18.741	5291.5	-8.2757
18.791	5291.5	-8.3071
18.841	5291.6	-8.3385
# Event APOGEE occurred at t=18.891 seconds		
18.891	5291.5	-8.3699
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=18.892 seconds		
18.945	5291.3	-8.4036
18.996	5291.1	-8.4357
19.047	5290.8	-8.4678
19.098	5290.3	-8.4999

19.15	5289.8	-8.532
19.201	5289.3	-8.5642
19.252	5288.6	-8.5963
19.304	5287.8	-8.6285
19.355	5287	-8.6608
19.407	5286.1	-8.693
19.459	5285.1	-8.7253
19.511	5284	-8.7576
19.563	5282.8	-8.79
19.615	5281.5	-8.8224
19.668	5280.1	-8.8548
19.72	5278.7	-8.8873
19.773	5277.1	-8.9199
19.826	5275.5	-8.9525
19.88	5273.7	-8.9852
19.933	5271.9	-9.0179
19.987	5270	-9.0507
20.041	5267.9	-9.0836
20.096	5265.8	-9.1166
20.15	5263.6	-9.1496
20.205	5261.2	-9.1827
20.261	5258.8	-9.2159
20.316	5256.2	-9.2492
20.373	5253.6	-9.2826
20.429	5250.8	-9.316
20.486	5247.9	-9.3496
20.543	5244.9	-9.3833
20.601	5241.8	-9.4171
20.66	5238.6	-9.451
20.718	5235.2	-9.4851
20.778	5231.7	-9.5193
20.838	5228.1	-9.5536
20.898	5224.3	-9.588
20.959	5220.4	-9.6226
21.021	5216.4	-9.6573
21.083	5212.2	-9.6922
21.147	5207.9	-9.7273
21.21	5203.4	-9.7625
21.275	5198.7	-9.7979
21.341	5193.9	-9.8335
21.407	5188.9	-9.8693
21.474	5183.7	-9.9052
21.542	5178.4	-9.9414
21.611	5172.8	-9.9778
21.681	5167.1	-10.014
21.753	5161.1	-10.051
21.825	5155	-10.088

21.899	5148.6	-10.126
21.974	5142	-10.163
22.05	5135.1	-10.201
22.128	5128	-10.239
22.207	5120.6	-10.278
22.288	5112.9	-10.317
22.37	5104.9	-10.356
22.454	5096.6	-10.395
22.541	5088	-10.435
22.629	5079.1	-10.475
22.719	5069.7	-10.515
22.812	5060	-10.556
22.907	5049.9	-10.598
23.005	5039.3	-10.64
23.106	5028.2	-10.682
23.21	5016.7	-10.725
23.317	5004.5	-10.768
23.428	4991.8	-10.812
23.543	4978.5	-10.856
23.662	4964.4	-10.901
23.786	4949.6	-10.947
23.915	4933.9	-10.994
24.05	4917.4	-11.041
24.192	4899.8	-11.089
24.34	4881	-11.138
24.496	4861.1	-11.188
24.662	4839.6	-11.238
24.838	4816.6	-11.29
25.026	4791.6	-11.343
25.228	4764.5	-11.398
25.446	4734.8	-11.454
25.684	4702.1	-11.511
25.946	4665.5	-11.57
26.239	4624.3	-11.631
26.57	4577.1	-11.694
26.954	4521.8	-11.76
27.411	4455.1	-11.828
27.911	4381.5	-11.891
28.411	4307.1	-11.943
28.911	4232.3	-11.985
29.411	4157.1	-12.018
29.911	4081.7	-12.043
30.411	4006	-12.06
30.911	3930.2	-12.071
31.411	3854.2	-12.076
31.911	3778.3	-12.075
32.411	3702.3	-12.07

21.899	5148.6	-10.126
21.974	5142	-10.163
22.05	5135.1	-10.201
22.128	5128	-10.239
22.207	5120.6	-10.278
22.288	5112.9	-10.317
22.37	5104.9	-10.356
22.454	5096.6	-10.395
22.541	5088	-10.435
22.629	5079.1	-10.475
22.719	5069.7	-10.515
22.812	5060	-10.556
22.907	5049.9	-10.598
23.005	5039.3	-10.64
23.106	5028.2	-10.682
23.21	5016.7	-10.725
23.317	5004.5	-10.768
23.428	4991.8	-10.812
23.543	4978.5	-10.856
23.662	4964.4	-10.901
23.786	4949.6	-10.947
23.915	4933.9	-10.994
24.05	4917.4	-11.041
24.192	4899.8	-11.089
24.34	4881	-11.138
24.496	4861.1	-11.188
24.662	4839.6	-11.238
24.838	4816.6	-11.29
25.026	4791.6	-11.343
25.228	4764.5	-11.398
25.446	4734.8	-11.454
25.684	4702.1	-11.511
25.946	4665.5	-11.57
26.239	4624.3	-11.631
26.57	4577.1	-11.694
26.954	4521.8	-11.76
27.411	4455.1	-11.828
27.911	4381.5	-11.891
28.411	4307.1	-11.943
28.911	4232.3	-11.985
29.411	4157.1	-12.018
29.911	4081.7	-12.043
30.411	4006	-12.06
30.911	3930.2	-12.071
31.411	3854.2	-12.076
31.911	3778.3	-12.075
32.411	3702.3	-12.07

32.911	3626.2	-12.06
33.411	3550.2	-12.047
33.911	3474.3	-12.03
34.411	3398.4	-12.01
34.911	3322.5	-11.987
35.411	3246.7	-11.962
35.911	3170.9	-11.934
36.411	3095.2	-11.905
36.911	3019.6	-11.874
37.411	2944.1	-11.841
37.911	2868.6	-11.808
38.411	2793.2	-11.773
38.911	2717.9	-11.736
39.411	2642.7	-11.699
39.911	2567.6	-11.662
40.411	2492.5	-11.623
40.911	2417.6	-11.584
41.411	2342.7	-11.544
41.911	2267.9	-11.504
42.411	2193.1	-11.463
42.911	2118.5	-11.422
43.411	2044	-11.381
43.911	1969.5	-11.339
44.411	1895.1	-11.297
44.911	1820.8	-11.255
45.411	1746.6	-11.213
45.911	1672.4	-11.17
46.411	1598.4	-11.128
46.911	1524.4	-11.085
47.411	1450.5	-11.043
47.911	1376.6	-11
48.411	1302.9	-10.957
48.911	1229.3	-10.915
49.411	1155.7	-10.872
49.911	1082.2	-10.829
50.411	1008.8	-10.786
50.911	935.43	-10.744
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=50.912 seconds		
51.411	862.18	-10.701
51.413	861.88	-10.701
51.415	861.58	-10.701
51.417	861.27	-10.701
51.419	860.96	-10.7
51.422	860.65	-10.7
51.424	860.33	-10.7
51.426	860.01	-10.7
51.429	859.69	-10.7

51.431	859.36	-10.699
51.434	859.03	-10.699
51.436	858.69	-10.699
51.439	858.35	-10.699
51.442	858	-10.699
51.445	857.64	-10.698
51.448	857.29	-10.698
51.451	856.92	-10.698
51.454	856.55	-10.698
51.457	856.18	-10.698
51.46	855.8	-10.697
51.464	855.41	-10.697
51.467	855.02	-10.697
51.471	854.62	-10.697
51.474	854.21	-10.696
51.478	853.8	-10.696
51.482	853.38	-10.696
51.486	852.95	-10.696
51.49	852.52	-10.695
51.495	852.07	-10.695
51.499	851.62	-10.695
51.504	851.16	-10.695
51.509	850.69	-10.694
51.514	850.21	-10.694
51.519	849.72	-10.694
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=51.52 seconds		
51.525	849.22	-10.693
51.528	848.95	-10.693
51.531	848.68	-10.693
51.534	848.4	-10.693
51.537	848.12	-10.693
51.541	847.83	-10.693
51.544	847.53	-10.693
51.548	847.23	-10.692
51.552	846.92	-10.692
51.556	846.6	-10.692
51.561	846.28	-10.692
51.565	845.94	-10.692
51.57	845.6	-10.691
51.575	845.25	-10.691
51.58	844.88	-10.691
51.586	844.51	-10.691
51.592	844.13	-10.691
51.598	843.73	-10.69
51.605	843.32	-10.69
51.612	842.9	-10.69
51.619	842.46	-10.69

51.627	842	-10.689
51.636	841.53	-10.689
51.645	841.04	-10.689
51.655	840.53	-10.689
51.665	840	-10.688
51.677	839.44	-10.688
51.689	838.85	-10.688
51.703	838.23	-10.687
51.717	837.58	-10.687
51.734	836.89	-10.687
51.752	836.15	-10.686
51.772	835.36	-10.686
51.795	834.5	-10.685
51.821	833.57	-10.685
51.852	832.54	-10.684
51.887	831.4	-10.684
51.929	830.1	-10.683
51.981	828.6	-10.682
52.046	826.79	-10.682
52.135	824.51	-10.681
52.266	821.33	-10.68
52.505	815.93	-10.678
53.005	805.26	-10.676
53.505	794.67	-10.675
54.005	784.04	-10.674
54.505	773.44	-10.673
55.005	762.82	-10.672
55.505	752.21	-10.671
56.005	741.6	-10.67
56.505	731	-10.669
57.005	720.39	-10.668
57.505	709.79	-10.668
58.005	699.19	-10.667
58.505	688.59	-10.666
59.005	677.99	-10.665
59.505	667.39	-10.664
60.005	656.8	-10.663
60.505	646.21	-10.662
61.005	635.61	-10.661
61.505	625.02	-10.66
62.005	614.44	-10.659
62.505	603.85	-10.659
63.005	593.26	-10.658
63.505	582.68	-10.657
64.005	572.1	-10.656
64.505	561.52	-10.655
65.005	550.94	-10.654

65.505	540.36	-10.653
66.005	529.79	-10.652
66.505	519.21	-10.651
67.005	508.64	-10.651
67.505	498.07	-10.65
68.005	487.5	-10.649
68.505	476.93	-10.648
69.005	466.37	-10.647
69.505	455.8	-10.646
70.005	445.24	-10.645
70.505	434.68	-10.644
71.005	424.12	-10.643
71.505	413.56	-10.643
72.005	403.01	-10.642
72.505	392.45	-10.641
73.005	381.9	-10.64
73.505	371.35	-10.639
74.005	360.8	-10.638
74.505	350.25	-10.637
75.005	339.7	-10.636
75.505	329.16	-10.635
76.005	318.62	-10.635
76.505	308.07	-10.634
77.005	297.53	-10.633
77.505	287	-10.632
78.005	276.46	-10.631
78.505	265.92	-10.63
79.005	255.39	-10.629
79.505	244.86	-10.628
80.005	234.33	-10.627
80.505	223.8	-10.627
81.005	213.27	-10.626
81.505	202.75	-10.625
82.005	192.22	-10.624
82.505	181.7	-10.623
83.005	171.18	-10.622
83.505	160.66	-10.621
84.005	150.14	-10.62
84.505	139.62	-10.62
85.005	129.11	-10.619
85.505	118.6	-10.618
86.005	108.08	-10.617
86.505	97.574	-10.616
87.005	87.065	-10.615
87.505	76.559	-10.614
88.005	66.053	-10.613
88.505	55.549	-10.612

89.005	45.047	-10.612
89.505	34.547	-10.611
90.005	24.048	-10.61
90.505	13.55	-10.609
91.005	3.0541	-10.608

Event GROUND_HIT occurred at t=91.505 seconds
Event SIMULATION_END occurred at t=91.505 seconds

91.505	-7.4403	-10.607

15.5 NAR Safety Code

1. Certification. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.
2. Materials. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
3. Motors. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.
4. Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.
5. Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
6. Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.
7. Launcher. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.
8. Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff

than one-third of the certified average thrust of the high-power rocket motor(s) intended to be ignited at launch.

9. Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.
10. Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).
11. Launcher Location. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.
12. Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.
13. Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

MINIMUM DISTANCE TABLE				
Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 — 320.00	H or smaller	50	100	200
320.01 — 640.00	I	50	100	200
640.01 — 1,280.00	J	50	100	200
1,280.01 — 2,560.00	K	75	200	300
2,560.01 — 5,120.00	L	100	300	500
5,120.01 — 10,240.00	M	125	500	1000
10,240.01 — 20,480.00	N	125	1000	1500
20,480.01 — 40,960.00	O	125	1500	2000

Note: A Complex rocket is one that is multi-staged or that is propelled by two or more rocket motors

15.6 TRA Safety Code

Safety Code for High-Power Rocketry

Tripoli Rocketry Association

This High-Power Rocketry Safety Code is the product of many years of effort on behalf of the hobby by those who care about it and whose prime interest is safety This document sets minimum standards, intended to preserve the hobby in a safe environment. Using this Code as the minimum, it will be your responsibility to regulate your own launches safely for the conditions of each launch site. This Safety Code shall be the standard at all Tripoli Sanctioned Launches.

The Tripoli High-Power Safety Code ***supplements*** **NFPA 1127 Code for High Power Rocketry** with sections that are specific to Tripoli. The foundation of the Tripoli High Power Safety Code is NFPA 1127.

1 General Requirements

1-1 Scope

1-1.1 This code shall set practices for safe operation of High Power rocket launches. It will also address some aspects of safe rocket design, and construction, and limitations of motor power, for use by the certified user for the purposes of education, recreation and sporting use.

1-2 Purpose

1-2.1 The purpose of this code shall be to establish guidelines for reasonably safe operation of rockets at Tripoli Sanctioned Launches.

1-3 Definitions:

For the purposes of this code, the following terms shall be defined as stated in this section. Some of these may be redundant from NFPA 1127.

Insured Flier: A flier that has insurance provided by Tripoli or any rocketry organization that TRA has insurance reciprocity with. At this writing this includes NAR only. Note: some types of TRA membership do not include insurance (e.g. Associate, and Honorary members).

Adult Flier: An *Insured Flier* that is 18 years old or older.

High Power Rocketry Flier (HPR Flier): An *Adult Flier* that is certified to fly High Power rockets at their certification level.

Model Rocket Fliers (MR Flier): An Insured Flier who is not certified to fly High Power rockets.

Invited Guests of Fliers (Guests): A person who is not a member of a recognized rocketry organization/not covered by insurance.

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Launch Director (LD): A Level 2 or Level 3 flier who has overall administrative responsibility for the launch.

Participants. Persons that are either:

- **HPR Fliers**.
- **Model Rocket Fliers**.
- **Invited Guests of Fliers.**

Range Safety Officer (RSO). A Level 2 or Level 3 flier who has the authority to ensure the safe operation of the range.

Sanctioned Launch. A sanctioned launch is a ***Tripoli Insured Launch***. Any *Sanctioned Launch* shall meet ***ALL*** of the following requirements:

- Responsible person of launch shall be member of Tripoli in good standing.
- Follows the appropriate Tripoli Safety Code.
- All AHJ (e.g. FAA waiver) requirements/regulations met and any required permits secured.
- Landowner permission has been formally obtained.

Shall. Indicates a mandatory requirement.

Should. Indicates a recommendation or that which is advised but not required.

Spectator. A nonparticipant whose primary purpose is to view a rocket launch.

Spectator Area. An area designated where spectators view a rocket launch.

Tripoli Mentoring Program (TMP). Program to permit Tripoli Junior members to participate in supervised high power rocketry activities.

Tripoli (TRA). Tripoli Rocketry Association, Inc.

Requirements for High Power Rocket Operation

2 **Operating Clearances.** A person shall fly a high-power rocket only in compliance with:

- This code and NFPA 1127;
- *Federal Aviation Administration Regulations*, Part 101 (Section 307,72 Statute 749, Title 49 United States Code, Section 1348, "Airspace Control and Facilities," Federal Aviation Act of 1958);
- Other applicable federal, state, and local laws, rules, regulations, statutes, and ordinances.
- Landowner permission.

3 Legality

3-1 The Tripoli Rocketry Association does not claim Rocketry to be legal in every municipality, state or political jurisdiction.

4 Insurance

4-1 Tripoli rocketry activities are only insured when the provisions of this code are followed.

4-2 No Tripoli member shall misrepresent to any authority or landowner that Tripoli activities are insured .

5 Participation,

Participation Note: The information provided below identifies the minimum requirements for individuals that participate/attend Tripoli Sanctioned Launches.

A Launch Director has the authority to impose more stringent rules.

Participation and Access at Tripoli Launches shall be limited to the following:

5-1 HPR Fliers may access and conduct flights from the High-Power Launch Area and/or Model Rocket Launch Area.

5-2 Non-Tripoli Members age 18 and over who are students of an accredited educational institution may participate in joint projects with Tripoli members.

5-2.1 These individuals are only allowed in the High-Power Launch Area while supervised by an HPR Flier.

5-2.2 They are only allowed in the Model Rocket Launch Area while supervised by an Adult Flier.

5-2.3 The maximum number of nonmember participants shall not exceed five (5) per supervising flier.

5-3 Tripoli Junior Members who have successfully completed the TMP may access and conduct flights from the High-Power Launch Area while under the direct supervision of a Tripoli HPR Flier in accordance with the rules of the TMP.

5-3.1 The maximum number of TMP participants shall not exceed five (5) per supervising flier.

5-4 Children younger than 18 years of age may conduct flights from the Model Rocket Launch Area under the direction of an Adult Flier.

5-5 An invited guest may be permitted in the Model Rocket Launch Area and preparation areas upon approval of the RSO. Invited guests are not permitted in the High-Power Launch Area.

5-6 Spectators are only permitted in the spectator area(s); they are not permitted in the High-Power Launch Area or Model Rocket Launch Area.

6 Tripoli Launch Operations

6-1 Insured Fliers shall provide proof of membership and certification status upon request.

6-2 All flights and static motor tests conducted by a member shall be within the member's certification level, with the exception of permitted certification attempts.

6-3 When three or more rockets are to be launched simultaneously, the minimum spectator and participant distance shall be the value set forth in the Safe Distance Table for a complex rocket with the same total installed impulse, but not more than 610 m (2000 ft), or 1.5 times the highest altitude expected to be reached by any of the rockets, whichever is less.

6-4 No range activity shall be conducted when a thunderstorm has been reported within ten miles, or less, of the launch site or if thunder or lightning is present.

6-5 No rockets shall be launched when the surface winds exceed 20 MPH (32 KPH)

6-6 The minimum safe standoff distance from the spectator area for the Model Rocket Launch Area shall be 50 feet (15 meters).

6-7 All flights planned to exceed 50,000ft AGL shall be submitted to the Class 3 review Committee for approval.

6-8 Launch Director and Range Safety Officer

6-8.1 The LD or RSO may refuse to allow the launch, or static testing, of any rocket or rocket motor that they deem to be unsafe.

6-8.2 The LD or RSO may require greater Safe Standoff Distances than specified in this code.

6-9 Recovery

6-9.1 **A** rocket shall be launched only if it contains a recovery system that is designed to return all parts of the rocket to the ground safely.

6-9.2 Rockets that employ passive recovery (e.g. tumble recovery, aero-braking) need not employ an active recovery system.

Minimum spectator and Participant Safe Distance Standoffs

Total Installed Impulse, N-s		Motor type	Non-Complex		Complex	
			feet	meters	feet	meters
0.01 to	160	High Power G or smaller	100	30	200	61
160.01	320	H	100	30	200	61
320.01	640	I	100	30	200	61
640.01	1280	J	100	30	200	61
1,280.01 to	2,560	K	200	61	300	91
2,560.01 to	5,120	L	300	92	500	152
5,120.01 to	10,240	M	500	153	1,000	305
10,240.01 to	20,480	N	1,000	305	1,500	457
20,480.01 to	40,960	O	1,500	457	2,000	610

7 Referenced Publications

The following documents or portions thereof are referenced within this code. The edition indicated for each reference is the current edition as of the date of the NFPA issuance of this document.

7-1 NFPA Publications.

National Fire Protection Association, 1 Batterymarch Park, P.O. Box *9101, Quincy, MA 02269-9101*

NFPA 1122, Code for Model Rocketry.

NFPA 1125, Code for the Manufacture of Model Rocket Motors.

NFPA 1127, Code for High Power Rocketry

7-2 Government Publications.

Superintendent of Documents, U.S. Government Printing Office, Washington DC 20402.

Federal Aviation Administration Regulations, from the Code of Federal Regulations. Federal

Hazardous Substances Act, from the United States Code (re. Airspace Control)

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7-3 TRA Publications.

Tripoli Rocketry Association, Inc., P. O. Box 87, Bellevue NE 68005.

Articles of Incorporation and Bylaws

Tripoli Motor Testing Committee (TMT), Testing Policies

Appendix A - Additional Tripoli Rulings

A-1 NFPA 1127 was adopted by the Tripoli Board of Directors as the Tripoli Safety Code. (*Tripoli Report*, April 1994, Tripoli Board Minutes, New Orleans, 21 January 1994, Motion 13.)

A-2 All Tripoli members who participate in Association activities shall follow the Tripoli Certification Standards.

A-3 Any Board action(s) with regard to safety, made previous to or after publication of this document, shall be a part of the Tripoli Safety Code.

A-4 Increased descent rates for rocket activities conducted at the Black Rock Desert venue are acceptable if needed to insure a controlled descent to remain inside the FAA approved Dispersion Area.

A-5 A rocket motor shall not be ignited by using:

a. A switch that uses mercury.
b. "Pressure roller" switches

15.7 Outreach Satisfaction Survey

USF SOCIETY OF AERONAUTICS AND ROCKETRY
THE SKY IS NOT THE LIMIT.

PRESENTATION QUESTIONNAIRE

Name: ______________________________

Date: ______________________________

What was your favorite part of our presentation/workshop today ?

____
____
____
____

What did you learn from today's workshop/presentation?

____
____
____
____

What could we do to improve the presentation/workshop?

____
____
____
____

Please rate our presentation in the following categories (Please Circle):

How Informational was it?	Bad	Poor	Average	Good	Great
How were the presenters?	Bad	Poor	Average	Good	Great
How fun was it?	Bad	Poor	Average	Good	Great
How was it overall?	Bad	Poor	Average	Good	Great

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