



NASA STUDENT LAUNCH 2019

PRELIMINARY DESIGN REVIEW REPORT

11/2/2019



SOCIETY OF AERONAUTICS AND ROCKETRY

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1 SUMMARY OF PDR REPORT

1.1 TEAM SUMMARY

1.1.1 NAME AND ADDRESS

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1.1.2 TRA AFFILIATION

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1.1.3 TEAM MENTOR

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1.2 LAUNCH VEHICLE SUMMARY

SAOR will build and launch a large 6" diameter carbon fiber filament-wound high-powered rocket with two untethered sections, a fully redundant recovery system, and three parachutes (two SkyAngle CERT-3 XLs and one SkyAngle Classic 20"). The rocket's title will be *Apis III*, in keeping with SOAR's tradition of naming NSL rockets after the Egyptian bull god Apis. The preliminary vehicle design prescribes a 134" long rocket that weighs 35.2 lb. without its 11 lb. motor installed. This vehicle will carry the payload to 5,000 ft. apogee, and will have onboard three innovative subsystems: the Recovery Leveling Subsystem, the Airbrakes Subsystem, and the Adjustable Ballast Subsystem.

1.3 PAYLOAD SUMMARY

1.3.1 PAYLOAD TITLE

A deployable rover payload has been chosen and will be referred to as the *Phoenix* rover throughout the prototyping phase.

1.3.2 ROVER DESIGN SUMMARY

The *Phoenix* rover concept was inspired by a reversed snowmobile, with drive wheels pulling along the rest of the body. The rover will contain an Arduino, batteries, soil recovery module, and all guidance sensors. The projected diameter is 5.67"; the internal diameter of the rocket body. The rover will be seated inside a reserved section alongside the leveling system that will prevent deployment issues. The rover will roll out of the vehicle and complete the mission objective after an initiating signal has been received.



2 CHANGES MADE SINCE PROPOSAL

2.1 CHANGES TO VEHICLE CRITERIA

Table 1: Changes to vehicle criteria.

Change Summary	Reason for Change	Section Reference
An airbrakes subsystem was added to vehicle	There was a lack of confidence that the rocket would be able to closely approach the target altitude based solely on calculations because simulations cannot take into account every factor that could influence the altitude	4.1.4.2.1 Airbrakes
A payload leveling subsystem was added to the vehicle	The payload in the previous year's competition did not deploy, partially due to debris entering the body tube	4.1.4.2.3 Payload Leveling System
Switched to SkyAngle parachutes	Fruity Chutes parachutes are fragile and expensive	4.2.2.1.2 Main Booster and Payload Parachutes
Exact body tube length and fin shape were adjusted	Necessary modifications to accommodate for subsystem changes	4.1.4.1 Launch Vehicle Structure
Selected motor was changed to Cesaroni L1410	The added mass of the airbrakes and payload levelling system and the decreased risk of overshooting the target altitude due to the airbrakes system, make it necessary to use a more powerful motor	4.1.5 Motor Selection



2.2 CHANGES TO PAYLOAD CRITERIA

Table 2: Changes to payload criteria.

Change Summary	Reason for Change	Section Reference
Exploring the possibility of removing the deployment system (pending future testing)	Less points of failure, especially if our rover is able to drive out of the rocket autonomously	6.1.5.2.2 Deployment System:
Considering having independently-powered drive wheels, as opposed to powering both wheels with a single DC motor	Would allow for the rover to be steered to some extent by varying the voltage to the two motors, as opposed to having no steering capabilities if a single source of power was used	6.1.5.2.3 Steering/driving system
Prototyping an electromagnetic steering system as a potential option to replace a servo-powered arm	More space-efficient and avoids the challenge of mounting a motor directly to the pivoting arm	6.1.5.2.3 Steering/driving system

2.3 CHANGES TO PROJECT PLAN

Table 3: Changes to project plan.

Change Summary	Reason for Change	Section Reference
Vehicle team project timeline has been updated.	Incorporate latest updates and air brakes system development	8.2.3 Vehicle Fabrication Timeline
More derived requirements to vehicle and payload team have been added	This is to account for the new subsystems added	7.1 Required and Derived Requirements
Budget had been updated	This is to readjust previous budget estimations	8.1 Budget



3 TEAM PERSONNEL

3.1 PRIMARY LEADERSHIP

3.1.1 USF FACULTY ADVISOR

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3.1.2 TEAM MENTOR

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3.1.3 TEAM ADVISOR & POINT OF CONTACT

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

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3.1.4 PROJECT MANAGER

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

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3.2 TEAM MEMBERS

3.2.1 TEAM MEMBERS

SOAR's 2019 NASA Student Launch Initiative Team consists of 26 currently active student members. Team managers and leaders take attendance at each team meeting to ensure team members are engaged throughout the academic year. Attendance records are kept on BullSync, USF's distribution of the OrgSync student organization management software.

Table 4: Complete roster of project team members, sorted alphabetically.

Name	Position
Adheesh Shenoy	Payload Test Engineer
Arnold Perez	Payload Computer Engineer I
Ashleigh Stevenson	Project Advisor
Ashley De Kort	Safety Officer
Ben Bortz	Rocket Production Lead
Brian Alvarez	Payload Electrical Engineer II
Chance Belloise	Payload Team Member I
Clinton Lancaster	Technical Writer I
Cole Hill	Senior Payload Electrical Engineer
Dhairya Soni	Vehicle Electrical Engineer I



Name	Position
Didier Rusangiza	Project Scheduler
Evan Williams	Project Manager
Ian Sanders	Vehicle Team Lead
James Waits	Payload Team Lead
Javian Hernandez	Airbrakes Subteam Member II
John Russell	Payload Team Engineer I
Madison Kozee	Outreach Coordinator
Matthew Miller	Vehicle Team Engineer I
Mrudit Trivedi	Vehicle Team Engineer II
Naveen Kumare	Airbrakes Subteam Lead
Pankti Mehta	Vehicle Team Member I
Phuc Nguyen	Airbrakes Subteam Engineer
Ryan Carlomany	Payload Electrical Engineer I
Sara Vlhova	Operations Manager
Tepie Meng	Airbrakes Subteam Member I
Thomas Hall	Senior Payload Computer Engineer

3.2.1.1 FOREIGN NATIONAL TEAM MEMBERS

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



3.2.1.2 TRAVEL TEAM MEMBERS

The list of travel team members has not yet been finalized, however, names and required information for team members traveling to competition week in Huntsville, AL will be submitted to NASA no later than submission of the Critical Design Review Report.



4 VEHICLE CRITERIA

4.1 SELECTION, DESIGN, AND RATIONALE OF LAUNCH VEHICLE

4.1.1 MISSION STATEMENT

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

4.1.2 MISSION SUCCESS CRITERIA

In order for the vehicle mission to be considered a success, the following criteria must be met. These criteria are derived from the requirements and derived requirements located in 7.1.2 Vehicle Requirements.

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

4.1.3 VEHICLE MATERIAL & DESIGN RESEARCH

For all significant vehicle design decisions, the impact and requirements of the decision were considered and the pros / cons of each alternative choice weighed. The results of this research are presented in this section. Any alternative option that would be banned under the competition rules is not presented here, as the overall project mission is to meet the requirements of the NASA Student Launch competition.

In the tables in this section, the selected choice is formatted in *italics*. Exact details, drawings, and specifications for each selection are found in 4.1.4 Selected Preliminary Vehicle Design.

4.1.3.1 LAUNCH VEHICLE STRUCTURE

4.1.3.1.1 AIRFRAME

4.1.3.1.1.1 MATERIAL AND CONSTRUCTION

The choice material of the rocket airframe is a significant factor in the overall weight of the launch vehicle. The vehicle must be lightweight, but also able to withstand the rigors of flight and landing. Per the vehicle requirements described in 7.1.2 Vehicle Requirements, metal was not considered as a body material.

The material fabrication method was considered simultaneously, as manufacturing capabilities may prevent the selection of an otherwise ideal option. SOAR recently obtained an X-Winder desktop carbon fiber filament winder, and as such can consider manufacturing composite tubes in-house.

Table 5: Pros and cons of vehicle material and construction method alternatives.

Material	Construction Method	Pros	Cons
Carbon Fiber	Commercially Wound / Laid	Lightweight Extremely strong Consistent and reliable material properties Convenient and fast	Expensive No manufacturing experience gain for members Hard to find in specific parts Blocks radio signals Cannot obtain exact custom diameters Cannot select exact winding parameters
Carbon Fiber	Wound / Laid In-House	Lightweight Strong Very inexpensive Members gain manufacturing experience	Time-consuming winding process Members are inexperienced in filament winding Inconsistent material properties Unknown exact material properties Blocks radio signals



Material	Construction Method	Pros	Cons
Fiberglass	Commercially Wound / Laid	<p>Significant member experience with material</p> <p>Radio-transparent</p> <p>Expensive</p> <p>Widely available for rocketry</p>	<p>Relatively heavy</p> <p>Lower yield strength than carbon fiber</p> <p>Cannot obtain exact custom diameters</p> <p>Cannot select exact winding parameters</p> <p>No manufacturing experience gain for members</p>
Fiberglass	Wound / Laid In-House	<p>Relatively heavy</p> <p>Lower yield strength than carbon fiber</p> <p>Radio-transparent</p> <p>Inexpensive</p>	<p>Time-consuming winding process</p> <p>Members are inexperienced in filament winding</p> <p>Inconsistent material properties</p> <p>Unknown exact material properties</p> <p>Relatively heavy</p> <p>Lower yield strength than carbon fiber</p>
Phenolic (and Blue Tube)	Commercially Manufactured	<p>Lightweight</p> <p>Very inexpensive</p> <p>Easy to work with</p> <p>Easy to paint</p> <p>Widely available</p> <p>Radio-transparent</p>	<p>Low weight to strength ratio</p> <p>No manufacturing experience gain for members</p> <p>Cannot select manufacturing parameters</p>



4.1.3.1.1.2 EPOXY

SOAR uses epoxy extensively throughout the rocket construction process. It is used to secure bulkheads, attach fins, hold the altimeter switch band, create fillets, and harden composite materials. Several epoxy choices have been researched and are presented in Table 6. All of these epoxies cure at room temperature and dry clear.

Table 6: Pros and cons of proposed epoxy alternatives.

Epoxy	Pros	Cons
Aeropoxy Laminating Epoxy¹	Extremely strong Long working time (good for filament winding) High viscosity (forms excellent fin fillets) Extensive prior member experience	Highly viscosity (unusable for filament winding) Long working time (increases build time)
MasterBond EP29LP²	Low viscosity Extremely strong Long working time	Low viscosity Long working time Expensive Unobtainable by non-corporations (disqualifying characteristic)
Soller Composites 820 Epoxy³	Low viscosity Very strong Long working time Intended for filament winding	Low viscosity Long working time Expensive No prior member experience

¹ Information available at: <https://www.aircraftspruce.com/catalog/cmpages/aeropoxy.php>

² Information available at: <https://www.masterbond.com/tds/ep29lp>

³ Information available at: <https://www.sollercomposites.com/Epoxy.html>



Epoxy	Pros	Cons
Bob Smith Slow-Cure 30 Minute Epoxy⁴	Low viscosity Fast cure time (great for rapid prototyping) Easy to work with Inexpensive	Not very strong Very short cure time (unusable for filament winding)

4.1.3.1.1.3 DIAMETER

The diameter of the rocket body sets a crucial limiting control on the size of the payload. A larger diameter allows for a longer and wider payload bay. However, the larger the rocket, the heavier and more expensive it becomes. Only standard diameters were considered, as non-standard choices introduce unnecessary complications and confusion into the building process.

Table 7: Pros and cons of vehicle body diameter alternatives.

Diameter (in)	Pros	Cons
4	Very lightweight Inexpensive Easy to construct	Too small for adequate payload (disqualifying characteristic)
5	Lightweight Same size as SOAR's NSL 2018 rocket (allowing for reuse of designs) Less expensive motors	From NSL 2018 experience, too small for payload Difficult to integrate subsystems besides primary payload due to space

⁴ Information available at: <https://modelmerchants.com/shop/bob-smith-slow-cure-30-minute-epoxy/>



Diameter (in)	Pros	Cons
5.5	Moderately lightweight Increased payload capacity	Relatively uncommon size (difficult to source parts) Small tolerances for payload size (ie, would not allow for significant design changes later on)
6	Significantly increased payload capacity Same size as SOAR's NSL 2017 rocket Requirement of 12" coupler / altimeter bay allows for more complicated subsystems Larger size allows for increased tolerances Significant organizational experience with 6-in. rockets	Difficult to manufacture More expensive due to increased material mass and higher-power motor Heavier (offset somewhat by carbon fiber if selected)
7.5	Very large payload capacity Excessive space for other systems Very large manufacturing tolerances	Uncommon size Very difficult to manufacture Very expensive Likely cannot reach the target altitude with the motor power range allowed by NASA Student Launch (disqualifying characteristic)

4.1.3.1.2 NOSE CONE

The nose cone of the rocket significantly affects the rocket's coefficient of drag, which must be minimized in order to maximize altitude for a given motor thrust (thus maximizing the cost/altitude ratio and allowing for heavier systems). While SOAR does have the capability to manufacture carbon fiber tubes with the aforementioned X-Winder, nose cones present a



significant difficulty as high-performance nose cones must be wound or laid about a machined mandrel, created using an equation-driven curve. SOAR does not have CNC milling capabilities, and thus can only manufacture conic nose cones.

4.1.3.1.2.1 AVAILABLE NOSE CONES

As this research was performed after selecting the body diameter and material, the selection was limited to 6" diameter nose cones in a carbon fiber-compatible material (ideally carbon fiber or a similar composite). All of these options are detailed Table 8.

Table 8: Specifications of commercially available composite 6" nose cones.

Supplier	Model	Material	Weight (lb)	Length (in)	Shape	Cost (\$)
MadCow Rocketry	Fiberglass 6"⁵	Fiberglass	Not Provided	Not Provided	5.5:1 Von Karman	138.95
Apogee Components	6" Fiberglass Ogive 5:1 Nose Cone⁶	Fiberglass	2.29	30.0	5:1 Ogive	101.60
Public Missiles	Fiberglass Nosecone FNC-6.0⁷	Fiberglass	1.79	24.0	Not Provided	104.99
Wildman Rocketry	FNC6.0-5-1VK-FW-MT⁸	Fiberglass	Not Provided	Not Provided	5:1 Von Karman	129.00
Public Missiles	CFNC-6.0-PS⁷	Carbon Fiber	0.79	24.0	4:1 Ogive	219.95

⁵ Information available at: <https://www.madcowrocketry.com/fiberglass-6-filament-wound-metal-tip-select-shape/>

⁶ Information available at: https://www.apogeerockets.com/Building-Supplies/Nose-Cones/Fiberglass-Nose-Cones/6in-Fiberglass-Ogive-5-1-Nose-Cone?cPath=42_47_296&

⁷ Information available at: <https://publicmissiles.com/product/nosecones>

⁸ Information available at: <https://wildmanrocketry.com/collections/nosecone/products/fnc6-0-5-1vk-fw-mt>



4.1.3.1.2.2 NOSE CONE SHAPES

At this point it becomes necessary to compare the available nose cone shapes listing the pros and cons of each alternative.

4.1.3.1.2.2.1 Ogive

The ogive nose cone shape is based upon a circle section. The shape is thus simple to construct, as it can be defined solely by base radius (R) and length (L) (if the shape is constrained to be tangent to the body at the shoulder point, which is common in commercial parts). The radius of the circle that forms the curve is defined by Equation 1

$$r = \frac{R^2 + L^2}{2R}$$

Equation 1: Radius of the circular section that forms a tangent ogive nose cone profile.

This radius is then used to construct a curve defined by Equation 2} (where x ranges from 0 to L), which is rotated about the x-axis to form the final shape.

$$y = \sqrt{r^2 - (L - x)^2} + R - r$$

Equation 2: Curve that defines the shape of a tangent ogive nose cone.

When rotated about the x-axis, this equation yields the shape shown in Figure 1.



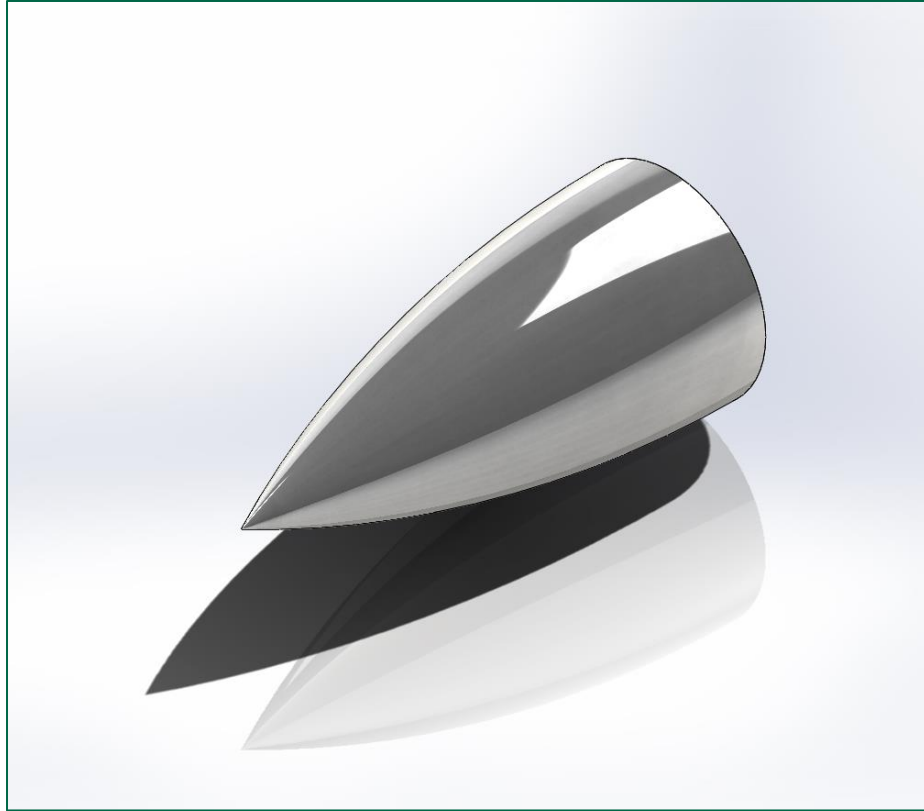


Figure 1: Tangent ogive nose cone render.

The ogive nose cone shape, while cleaner-looking than a conic nose cone, has inferior drag characteristics when compared to almost any other shape (except conic). This is due to the cone being designed for ease of definition, rather than minimum drag.

4.1.3.1.2.2 Von Karman

The Von Karman nose cone is a variant of the Haack series nose cone profile. It is optimized to create the least possible drag for a given diameter and length. The profile is much more complicated to calculate than a comparable ogive nose cone, so it is less common, but yields higher performance for its size.

The Von Kármán shape is defined by Equation 3. The curve is plotted from $x = 0$ to $x = L$ and then rotated about the x -axis to form the final volume, as with the ogive shape.

$$y = \frac{R}{\sqrt{\pi}} \sqrt{\arccos\left(1 - \frac{2x}{L}\right) - \frac{\sin(2\arccos(1 - \frac{2x}{L}))}{2}}$$

Equation 3: Curve that defines the shape of a Von Karman nose cone.

When constructed, the volume is similar to the nose cone shown in Figure 2.



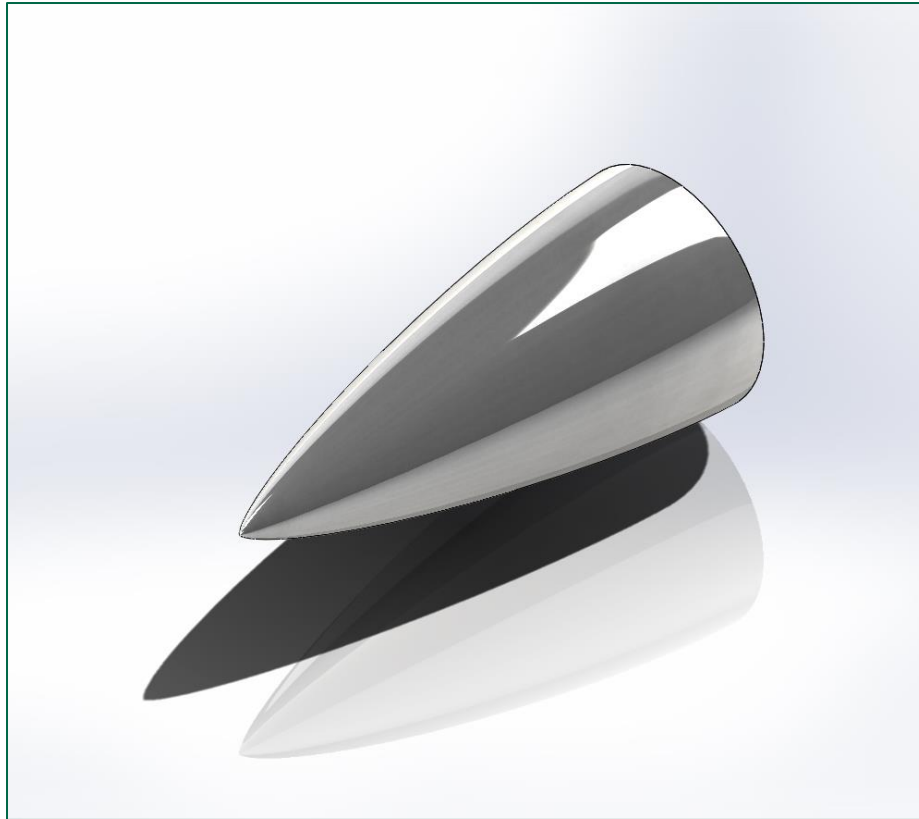


Figure 2: Von Karman nose cone render.

4.1.3.1.2.3 COMPARISON OF ALTERNATIVES

Once the possible options were collected and the nose cone shapes researched, a pros and cons table (Table 9) was constructed for the various nose cone models.

Table 9: Pros and cons of available composite 6" nose cones.

Supplier	Model	Pros	Cons
MadCow Rocketry	Fiberglass 6"	Von Karman shape (less drag)	Little information available High cost
Apogee (MadCow Rocketry)	6" Fiberglass Ogive 5:1 Nose Cone	Inexpensive	Very heavy Ogive shape



Public Missiles	Fiberglass Nosecone FNC-6.0	Inexpensive Lighter weight	Shape not provided
Wildman Rocketry	FNC6.0-5-1VK-FW- MT	Von Karman shape Moderately inexpensive Lighter than the MadCow 6" (shorter due to smaller ratio) SOAR preferred vendor	Little information available
Public Missiles	CFNC-6.0-PS	Carbon fiber (like body) Extremely lightweight	Ogive shape Thin, likely fragile Very expensive

4.1.3.1.3 FINS

4.1.3.1.3.1 MATERIAL AND CONSTRUCTION METHOD

The fins on a rocket are the primary control over the location of the center of pressure. As such, they must be considered a mission-critical component; if the fins fail, the rocket will lose stability and could cause injury or even death to onlookers. However, the fins are also very low in the rocket (by necessity); any increase in fin weight will also bring the center of gravity lower, thus decreasing stability. As such, the fin material must be a balance of weight and strength. Composite materials are especially well-suited for this task, and as such we primarily considered fiberglass and carbon fiber as fin materials. This comparison is detailed in Table 10.

Table 10: Pros and cons of composite sheet materials.

Material	Pros	Cons
Fiberglass	Inexpensive Significant member experience	Heavier Lower strength



Material	Pros	Cons
Carbon Fiber	Lighter Stronger Consistent with body material	Increased learning experience Expensive

As SOAR does not have the capability to create custom composite lay-up sheets, the sheets will be bought commercially and cut using the CNC router available at USF's Design for X makerspace. The exact fin shape will depend on the final location of the center of gravity of the rocket.

4.1.3.1.3.2 NUMBER OF FINS

Another consideration is the number of fins to install. The pros and cons of each potential number of fins are listed in Table 11.

Table 11: Comparison of possible fin counts.

Number of Fins	Pros	Cons
1 or 2		Only provide stability in one direction, creating an inherently unstable rocket (disqualifying characteristic)
3	Minimal fin material Equally stable in all directions	
4+	Equally stable in all directions	Higher drag and weight No increase in stability More expensive



4.1.3.1.4 BULKHEADS & CENTERING RINGS

Nearly every bulkhead on the launch vehicle will be an attachment point for recovery devices, and as such must be able to withstand the significant forces applied when the parachute is deployed. Therefore, the bulkheads must also be extremely strong, while remaining lightweight. These requirements are similar to that of the fin material, so the material comparison shown in Table 10 also applies to the bulkheads.

4.1.3.2 SUBSYSTEMS

4.1.3.2.1 AIRBRAKES

An airbrakes subsystem has been implemented in this vehicle design in order to maximize the vehicle's altitude score. The system's goal and requirements are defined below, with the mission statement left intentionally broad in order to foster creative and innovative ideas.

4.1.3.2.1.1 MISSION STATEMENT OF SUBSYSTEM

The mission of the airbrakes subsystem is to increase accuracy in reaching the target vehicle apogee.

4.1.3.2.1.2 DESIGN PARAMETERS

All proposed alternatives must meet several design constraints in order to be considered. These constraints were defined when the system was initially proposed, in order to ensure that no work is wasted on considering unusable designs.

1. The airbrakes subsystem must be completely isolated from the recovery subsystem in order to prevent interference with vehicle recovery
2. The subsystem must be reliable; use of such a system requires simulating above the target altitude, and as such, if the system fails, the altitude would be less accurate than without any airbrakes system at all
3. The subsystem must fit within the available empty space in the primary altimeter bay / coupler
4. The subsystem must not produce any protrusions from the rocket until after the rocket leaves the launch rail
5. All protrusions and cuts in the rocket body will be located within the range of the altimeter switch band, as this section is the only externally reaching section of the main altimeter bay
6. No more than 50% of the circumference of the altimeter switch band will be cut, and there will be at least three evenly spaced cuts (thus preserving the structural integrity of the altimeter bay)
7. The subsystem must be able to be removed from the launch vehicle for service and configuration



8. The subsystem must be able to be armed and disarmed without disassembling the launch vehicle
9. The subsystem must not exceed the allotted weight (2 lb.) without prior approval from the vehicle team lead
10. The subsystem must be able to be completed and fully usable by the payload test flight in Spring 2019

4.1.3.2.1.3 PROPOSED ALTERNATIVES

4.1.3.2.1.3.1 *Linear Dynamic Fin Deployment*

The linear fin ejection system would implement a linear actuator attached with pins to three bars. Each of these bars would begin in an angled position and would be attached with a pin joint to another bar, this one horizontally constrained. Each horizontal bar would then attach directly to a fin; such that when the linear actuator extends, each angled bar would approach horizontally and thus push the horizontal bars (and therefore the fins) outside the rocket through three equally spaced horizontal cuts.

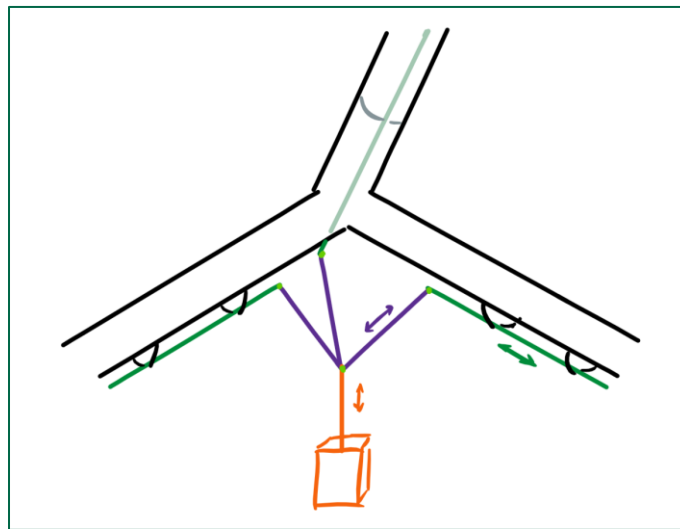


Figure 3: Conceptual 3D sketch of linear fin deployment alternative, with linear actuator shown in orange.

4.1.3.2.1.3.2 *Loaded Spring Drag Fin Deployment*

The loaded spring drag concept utilizes a motor with spring-loaded fins installed on a circular platform. The inner walls of the rocket would hold these fins in a compressed position until deployment. To deploy the fins, a motor would rotate the fin mount platform, causing the spring-loaded fins to deploy through slits in the rocket body. Rotation in the opposite direction would retract the fins.



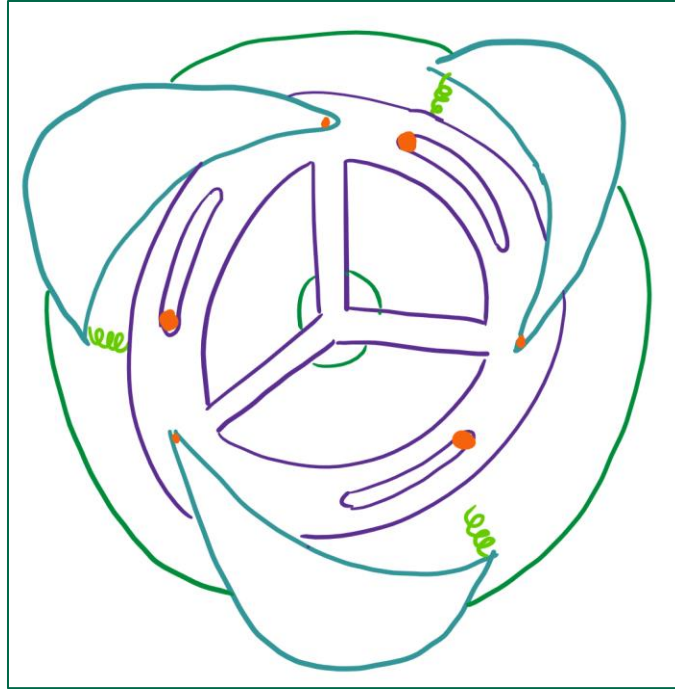


Figure 4: Conceptual sketch of loaded spring drag fin deployment alternative.

4.1.3.2.1.3.3 Dynamic Gear-Actuated Fin Deployment

The dynamic gear-actuated fin deployment design alternative employs the use of a gear system to transmit motor torque from a center shaft to the fins, allowing for dynamic and fine-tuned fin deployment. The system of gears would provide a significant increase in torque, allowing for a lighter battery and servo without sacrificing strength and accuracy. The design consists of a central servo with a spur gear attached, three surrounding compound spur gears, and three pivoting fins with spur gears attached. In Figure 5, spur gears are shown as smooth cylinders with purple arrows.

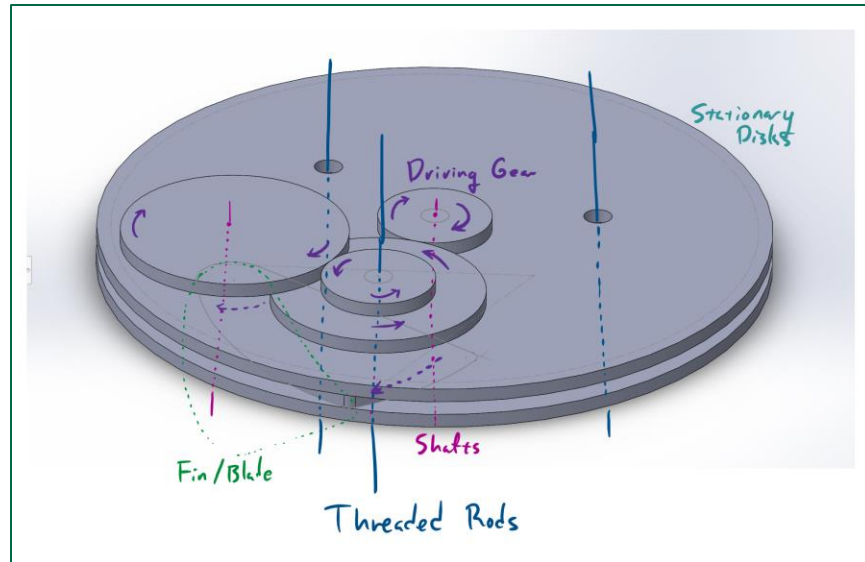


Figure 5: Conceptual 3D sketch of gear actuated fin deployment system.

4.1.3.2.1.4 COMPARISON OF ALTERNATIVES

Table 12: Pros and cons of airbrakes subsystem alternatives.

Alternative	Pros	Cons
Linear Dynamic Fin Deployment	<p>Simple fin shape; easier to design and calculate drag</p> <p>Simple deployment system</p>	<p>Design would not handle drag stresses well</p> <p>Inefficient use of vertical space</p> <p>High stress on diagonal bars</p> <p>Significant possibility of joint misalignment</p> <p>Difficult to assemble / disassemble</p>

Alternative	Pros	Cons
Loaded Spring Fin Drag Deployment	Simple to engineer Few moving parts High reliability	High friction between fins and airframe could damage fins or frame Springs are difficult to align and calibrate with accuracy High torque required to move system from rest (overcome static friction)
Dynamic Gear-Actuated Fin Deployment	Uses commercially available parts Simple design that is easy to build and implement Requires little custom part fabrication Highly variable deployment speed	Gears are heavy and use significant vertical space Gears must be aligned exactly, requiring machines bases Complicated fin shape design due to pivoting form

4.1.3.2.2 ADJUSTABLE BALLAST SYSTEM

SOAR's launch vehicle for the NSL 2018 competition included an adjustable ballast subsystem, which allowed the nose cone weight to be easily adjusted depending on final launch configuration. This system was successfully implemented and resulted in extremely accurate altitudes during some test launches, and thus the team has decided to reuse the concept in this year's vehicle.

4.1.3.2.2.1 MISSION STATEMENT OF SYSTEM

The mission of the adjustable ballast system is to provide a method for rapidly adjusting the static stability margin and expected altitude of the launch vehicle.

4.1.3.2.2.2 DESIGN PARAMETERS

1. The adjustable ballast subsystem must be completely isolated from the recovery subsystem in order to prevent interference with vehicle recovery
2. The subsystem must be easily accessible and configurable at the launch site
3. The subsystem must fit within the allotted space inside the nose cone



4. The subsystem must take advantage of lessons learned from SOAR's previous adjustable ballast subsystem

4.1.3.2.2.3 PROPOSED ALTERNATIVES

This subsystem design will iterate on the successful previous design⁹ in order to prevent an unnecessary repeated design and prototyping process. The only significant flaws from the previous design were the significant weight of the empty system (weight of the ballast container) and inadequate strength of the chosen container material (3D printed PLA plastic). These issues can both be addressed by selecting a better material, while the layout is simply updated from the previous one. The design consists of layers of flat plates, each containing slots for weights, which can be removed or added as necessary. As such, any material that can be cut with a laser cutter or CNC router can be used for the system. Considered container materials include:

- Carbon fiber
- Fiberglass
- Wood
- Acrylic
- Aluminum

4.1.3.2.2.4 COMPARISON OF ALTERNATIVES

Table 13: Pros and cons of potential vehicle material alternatives.

Material	Pros	Cons
Carbon fiber	Very Lightweight Strong	Poor machining quality for non-through slots Very Expensive
Fiberglass	Lightweight Strong	Poor machining quality for non-through slots Expensive
Wood	Somewhat lightweight Very easy to machine Very inexpensive	Does not hold tolerances Degrades under moisture Low strength

⁹ Description available in full at <http://www.usfsoar.com/completed-projects/nsf-2017-2018/>



Material	Pros	Cons
Acrylic	Easy to machine Holds tolerances well Relatively inexpensive	Dense Moderate strength
Aluminum	Very strong Holds tolerances very well	Very dense Difficult to machine Expensive

4.1.3.2.3 PAYLOAD COMPARTMENT LEVELING SYSTEM

The Payload Compartment Leveling System is intended to solve a problem encountered at the 2018 NASA Student Launch Competition in which the body tube where the rover was held impacted the ground end-first and was filled with mud, preventing the rover from deploying from the launch vehicle. This problem is highlighted in Figure 6.



Figure 6: Photo showing how mud can prevent successful payload deployment.

4.1.3.3 PAYLOAD LEVELING

4.1.3.3.1 MISSION STATEMENT OF SUBSYSTEM

The mission of the Payload Compartment Leveling System is to prevent foreign debris from hindering payload deployment upon landing.



4.1.3.3.1.2 PROPOSED ALTERNATIVES

A number of possible solutions were considered for this problem. Not all of them are leveling systems; the name for this subsystem was chosen after selecting a design.

4.1.3.3.1.2.1 Forward Payload Deployment

In the current preliminary vehicle configuration, the payload deploys away from the main parachute. This results in the open end of the payload bay necessarily impacting the ground, as this end is opposite the parachute. A proposed solution to this was to instead deploy the payload towards the parachute, so that the end of the body tube opposite the payload deployment would impact the ground instead. This alternative is sketched in Figure 7.

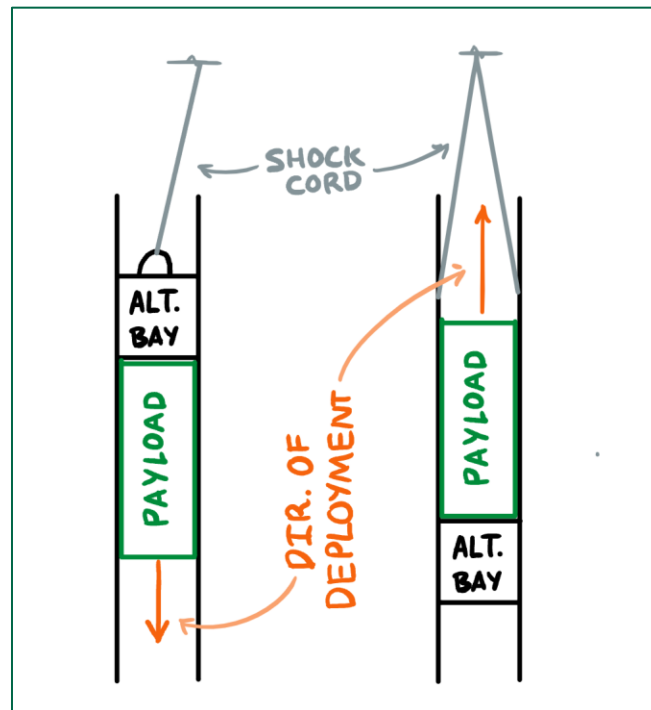


Figure 7: Concept sketch of forward payload deployment alternative. Current layout left, proposed right.

4.1.3.3.1.2.2 High-Torque Deployment

Another proposed alternative was to implement a high-torque deployment system that would deploy the rover upon landing through 'brute force'. As speed of deployment is not an issue, the system could use gears to decrease the speed while increasing torque.

4.1.3.3.1.2.3 Powered Dynamic Leveling

It was noted that if the body tube was to land on its side, little to no debris would enter the open end. This would also have the added benefit of decreased impact stress on the payload retainment system, mitigating any potential damages from landing. Landing a rocket side-wise is quite rare, as it requires two or more parachute attachment points at separate locations along the length of the body.

The dynamic leveling system design proposes that a small-gauge wire be run along the outside of the rocket. This wire would attach at the bottom of the upper altimeter bay, run through a hole at the bottom of the body tube wall, outside the rocket to the top of the body tube, and back into the rocket to attach to the parachute shock cord. A motor would then run to tension the wire and pull the rocket into a horizontal position. This would prevent the wire from needing to survive the full shock of parachute deployment, as it would be slack until the leveling system activates. Therefore, a smaller and lighter wire could be used. The system process is sketched in Figure 8.

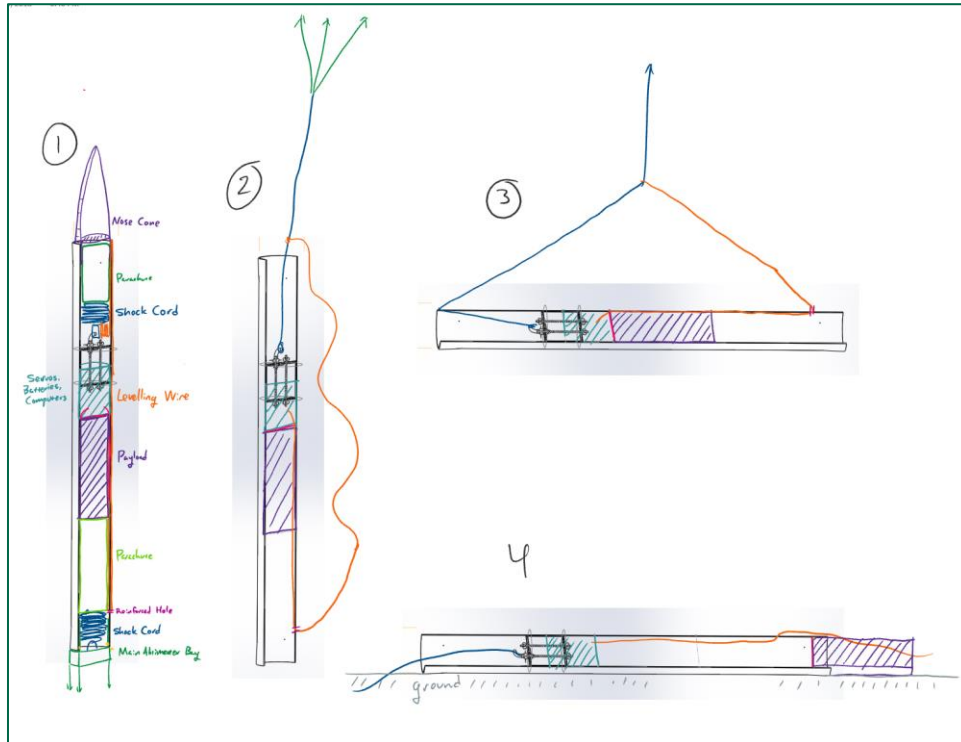


Figure 8: Step-by-step concept sketch of dynamic leveling system design alternative.

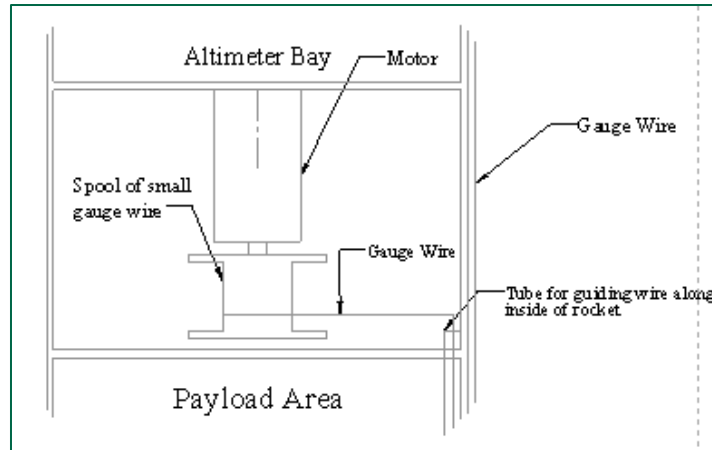


Figure 9: Concept sketch of dynamic leveling system spool area.

4.1.3.3.1.2.4 Mechanical leveling

The proposed mechanical leveling design is similar to the dynamic system described above, except that no motors are required (and thus no batteries or microcontrollers). The mechanical design utilizes a belay device similar to those used by rock climbers. These devices are intended to prevent rock climbers from falling significant distances by allowing them to free-fall just a short distance before catching them and slowly easing them to the ground. This behavior could relieve the wire of the initial stress and then ease the rocket into a horizontal position.

With this design, rather than running through a hole at the bottom of the body tube, the wire could terminate there as it would no longer need to be adjusted. The wire would still run outside the rocket and attach to the shock cord, but at deployment, the belay device would prevent the full force of deployment from acting on the wire. This process is sketched in Figure 10}, and a typical belay device (a figure 8 device, which would be compatible with flat tubular shock cord) is pictured in Figure 11.

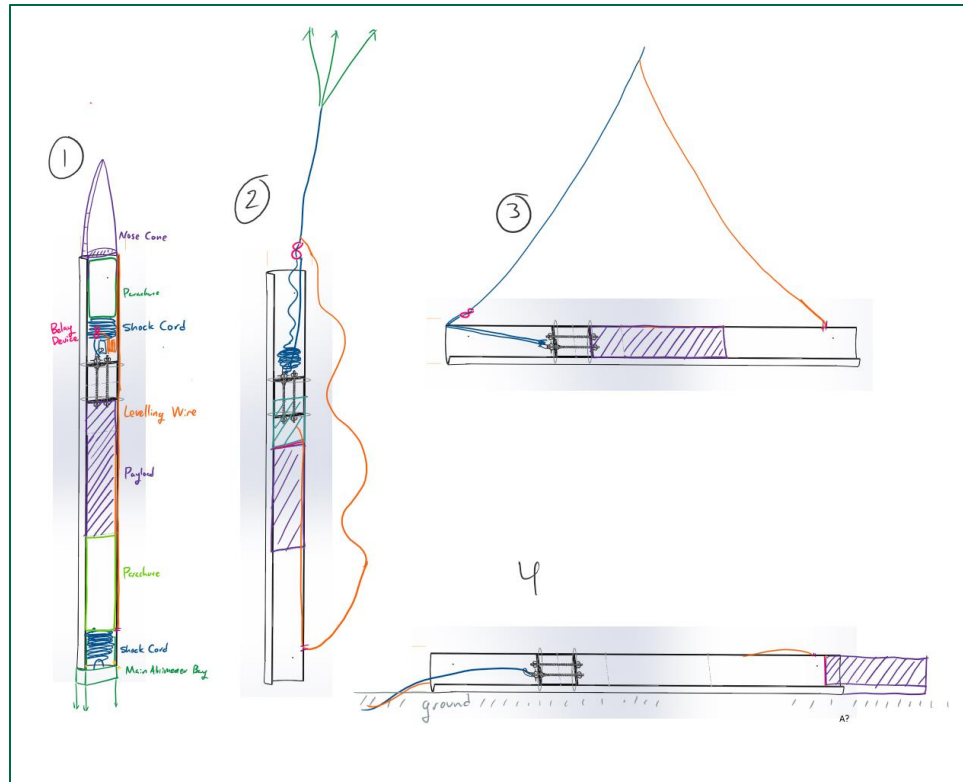


Figure 10: Concept sketch of mechanical leveling system design alternative.



Figure 11: Example of a figure 8 belay device.¹⁰

¹⁰ By Ringomassa at English Wikipedia. - Transferred from en.wikipedia to Commons., CC BY-SA 3.0, <https://commons.wikimedia.org/w/index.php?curid=3029155>

4.1.3.3.1.3 COMPARISON OF ALTERNATIVES

Table 14: Pros and cons of payload leveling subsystem alternatives.

Alternative	Pros	Cons
Forward Payload Deployment	Simple design No extra systems required High reliability	Would require redesign of entire rocket No solid mounting points for forward parachute
Powered Dynamic Levelling	Simple to test on the ground Simple to assemble and program Dynamic control over levelling during flight	Complex Expensive
Mechanical Levelling	Simple design Very high reliability Inexpensive	Chance of parachute shock cord entanglement Difficult to test on the ground

4.1.4 SELECTED PRELIMINARY VEHICLE DESIGN

After researching and examining the proposed design alternatives, a final preliminary vehicle design has been compiled. *Apis III* will be a 6" diameter rocket, with a total length of 134" and an unloaded weight of 40.4 lb. This size provides enough room for all components and systems while leaving some space for flexibility later if necessary later on in the design process.

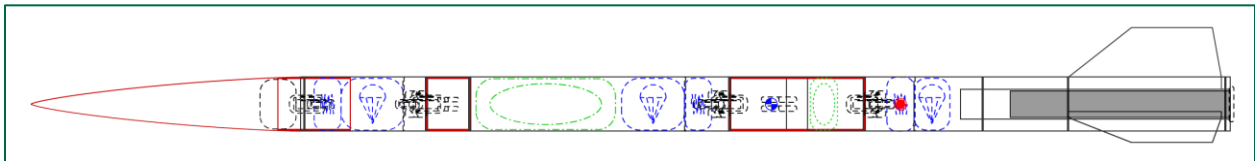


Figure 12: Dimensional drawing of selected launch vehicle design, with CG shown in blue and CP in red.



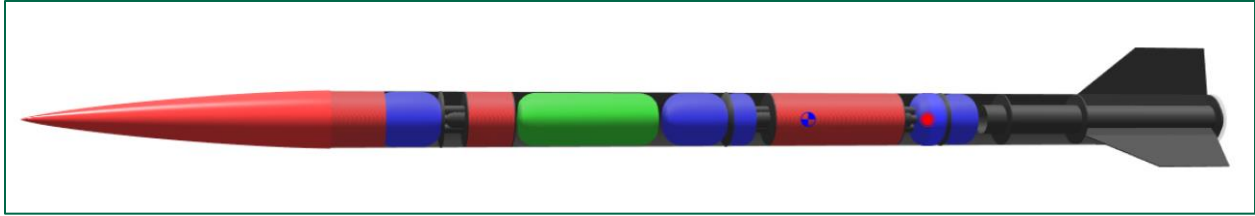


Figure 13: Illustrative 3D render of selected launch vehicle design.

As is visible in the exploded view, the rocket is design with two separate sections. The upper section consists of the following:

1. Nose cone
2. Adjustable ballast subsystem
3. Upper airframe (body tube)
4. Forward altimeter bay
5. Payload bay
6. Payload leveling subsystem
7. Upper section main parachute

And the lower section consists of the following:

1. Main altimeter bay
2. Airbrakes subsystem
3. Lower airframe (body tube)
4. Lower section main parachute
5. Drogue parachute
6. Fins
7. Motor mount

The mass of each component has been sourced from part specifications when possible and OpenRocket simulations when no specifications are available. Components marked “allotted” are allowed maximum masses for teams to design with until specific designs have been finalized.

Table 15: Estimated mass of launch vehicle parts and subsystems.

Vehicle Section	Part / Subsystem	Mass (lb)	Total Section Mass (lb)
Upper	Nose cone (and attached hardware)	3.22	20.6



Vehicle Section	Part / Subsystem	Mass (lb)	Total Section Mass (lb)
	Allotted adjustable ballast subsystem (without ballast)	0.200	
	Upper airframe	5.48	
	Forward altimeter bay (and attached hardware)	1.84	
	Allotted payload	7.00	
	Upper section main parachute	2.81	
Lower	Main altimeter bay (and attached hardware)	5.28	19.2
	Allotted airbrakes subsystem	2.00	
	Lower airframe and centering rings	5.21	
	Lower section main parachute	2.81	
	Drogue parachute	0.312	
	Fins	2.64	
	Motor mount	0.919	
Total mass without motor			39.8



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

4.1.4.1 LAUNCH VEHICLE STRUCTURE

The selected vehicle design prescribes an all-carbon fiber rocket body, with two main sections.

4.1.4.1.1 AIRFRAME

There are two body tubes in the rocket as well as one small altimeter switch band. These body tubes are all carbon fiber cylinders, and are expected to have a 6" outer diameter. The upper body tube is 54" long, while the shorter lower body tube is 47" long. The altimeter switch band is 2.36" in length.

Furthermore, there are 4 internal tubes. Three of these (the 8" long nose cone shoulder, 4.8" long forward altimeter bay, and 15" long main altimeter bay) are coupler sized; their outer diameter must exactly match the inner diameter of the rocket. Finally, the 30" long, 3.3" diameter motor mount tube is sized to fit a 75mm motor casing.

Exact wall thicknesses for the airframe tubes have not yet been determined, as these will largely depend on the number of layers in the filament wound tubes.

4.1.4.1.1.1 MATERIAL AND CONSTRUCTION

4.1.4.1.1.1.1 Body Tubes / Motor Mount

For the primary airframe material of the launch vehicle, SOAR has selected in-house wound epoxy-impregnated carbon fiber. This material presents significant challenges in manufacturing, however these challenges are exciting new learning and development opportunities. Furthermore, the high configurability of this material with this manufacturing choice allows the body tubes to be optimized for this particular application. The use of such a lightweight material allows for much more complicated and innovative systems within the rocket.



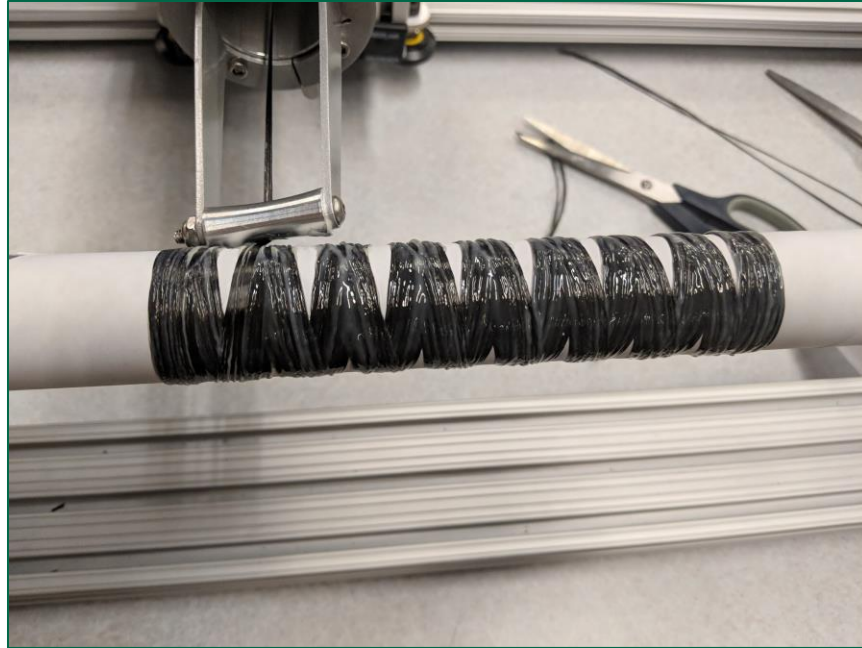


Figure 14: Carbon fiber epoxy-impregnated filament winding example.

4.1.4.1.1.1.1 Testing

Because the carbon fiber body tubes will be manufactured in-house, extensive testing will be performed to ensure that they can withstand the rigors of flight, and to determine the optimal winding characteristics. SOAR will work in collaboration with USF Civil Engineering professors to secure the use of testing equipment. Further research needs to be conducted to compare and select alternatives for:

- Carbon fiber tow K-value (the number of filaments per tow, in thousands)
- Winding angle
- Number of layers
- Winding speed
- Post-winding treatment process
- Pre-winding mandrel treatment process

4.1.4.1.1.1.2 Altimeter Bays / Nose Cone Shoulder

The altimeter bays must be manufactured with an exact outer diameter in order to fit snugly inside the main body tubes. SOAR does not have the capability to wind to exact outer diameters; presently only the inner diameter can be controlled (by the size of the mandrel). Therefore, the altimeter bays and nose cone shoulder will be constructed from commercially manufactured coupler-sized carbon fiber tubing. To ensure proper fit, mandrels with exactly the same outer diameter as the altimeter bays will be selected for filament winding body tubes.



4.1.4.1.1.2 EPOXY

With the selection of filament-wound carbon fiber as the airframe material, epoxies must be selected for both filament winding and structural uses. These require very different properties, and thus different epoxies have been selected.

4.1.4.1.1.2.1 Filament Winding

Filament winding requires an epoxy with low viscosity and high working time to allow the epoxy enough time to fully soak into the carbon fiber. Initial tests with Aeropoxy yielded unsatisfying results, and as such, SOAR will use the Soller Composites 820 epoxy for all filament winding related to this project.

4.1.4.1.1.2.2 Structural Assembly

Aeropoxy will be used for all structural bonds on the rocket. This epoxy has been proven to consistently bond strongly and effectively. Its reliability offsets the disadvantage of its long working time and high viscosity (which actually helps with forming fin reinforcing fillets). 30-Minute Epoxy may be used for some non-critical bonds when rapid cure time is a priority.

4.1.4.1.1.3 DIAMETER

The 6" airframe diameter was selected largely based upon past experiences; in 2018, SOAR launched a smaller rocket and determined that this size was not large enough to meet the requirements of the payload. This year, the SOAR NASA Student Launch Payload Team requested a larger diameter, and 6" was determined to be the maximum feasible size. This is also the largest size the X-Winder can feasibly handle without modifications.

4.1.4.1.2 NOSE CONE

4.1.4.1.2.1 DESIGN AND MATERIAL

The nose cone will be the fiberglass Von Karman-shaped Wildman FNC6.0-5-1VK-FW-MT. While the lightweight carbon fiber ogive nose cone would give an increase in projected apogee over the fiberglass (despite the poor drag characteristics), the carbon fiber cone is prohibitively expensive and very thin, thus it would also likely have to be replaced after several flights.

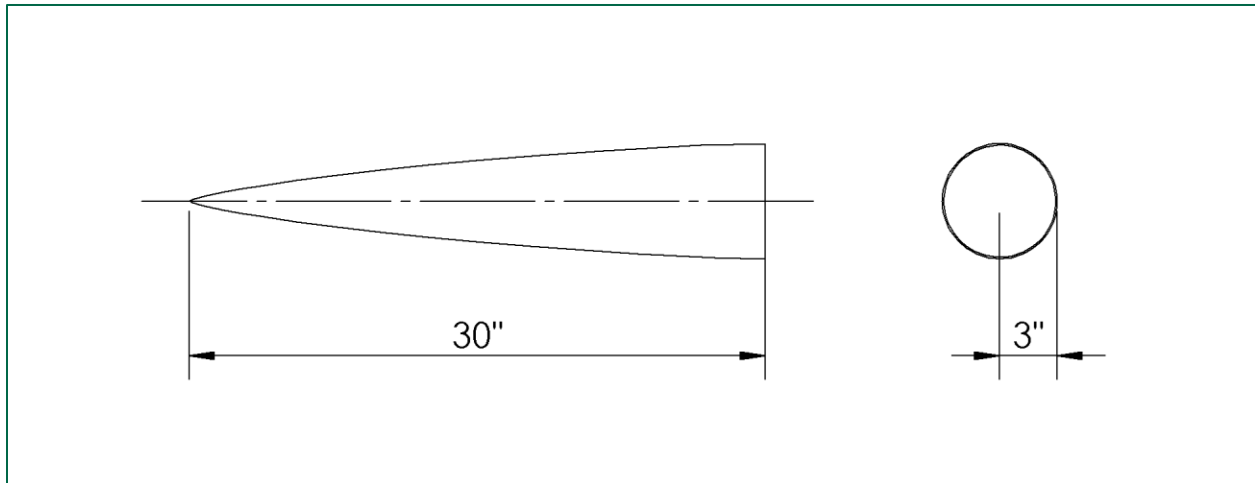


Figure 15: Dimensioned drawing of 6" diameter, 1:5 Von Karman shape nose cone.

4.1.4.1.3 FINS

4.1.4.1.3.1 LOCATION

The three fins will be located such that the bottom of the fins are 1" from the bottom of the lower airframe.

4.1.4.1.3.2 NUMBER OF FINS

When reviewing the pros and cons table, it becomes clear that three is the optimal number of fins. Any less and the rocket cannot be stable; any more is unnecessarily increasing both weight and drag. Therefore, this rocket will have three fins, spaced evenly, or 120°, apart.

4.1.4.1.3.3 DESIGN DETAILS

The exact parameters of these fins are chosen to optimize the static stability margin of the loaded rocket, keeping it greater than 2 but less than 3.5 calipers; therefore these parameters will be adjusted up until the fins are actually cut. The parameters shown in Figure 16 are optimized for the current mass estimates of the launch vehicle as simulated.



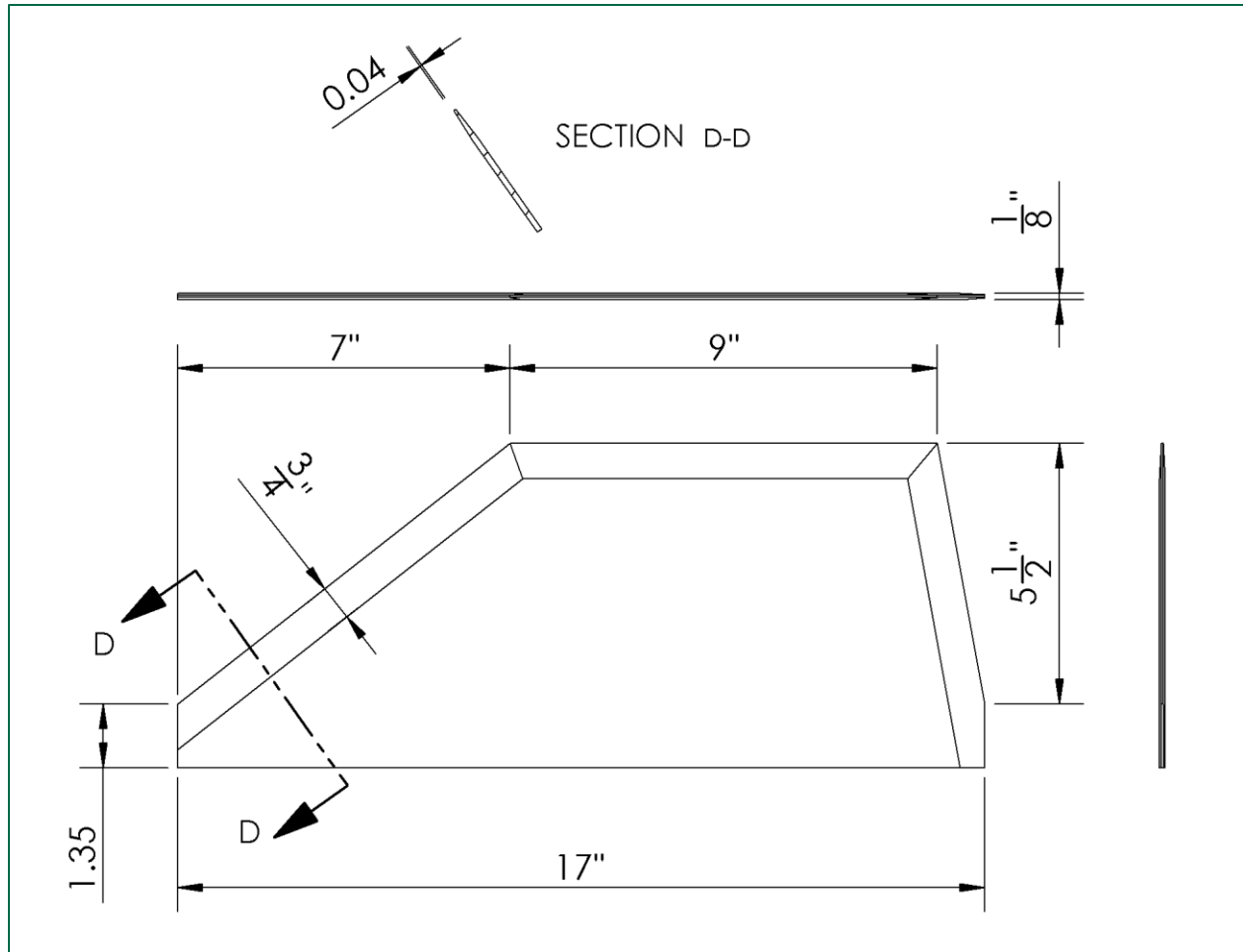


Figure 16: Dimensioned drawing of preliminary trapezoidal $\frac{1}{8}$ " fin shape.

4.1.4.1.3.4 MATERIAL AND CONSTRUCTION

Carbon fiber has been selected for the fin material due to its high rigidity and strength for its weight. In a situation where any sort of flutter could be catastrophic, a rigid material is essential. Furthermore, the fins must be as light as possible in order to prevent bringing the center of gravity down more than necessary. Finally, SOAR is already in possession of several sheets of $\frac{1}{8}$ " carbon fiber, so the decision efficiently uses available resources.

The fins will therefore be cut from $\frac{1}{8}$ "-thick carbon fiber sheets on the USF DFX Lab's CNC router. After cutting, an even chamfer will be sanded into to all exposed edges to decrease drag.

4.1.4.1.4 BULKHEADS & CENTERING RINGS

4.1.4.1.4.1 LOCATION

There are five bulkheads in the preliminary launch vehicle design. Four of these are altimeter bay end caps, while the other is located in the nose cone shoulder. In addition, three centering rings are located in the fin can.



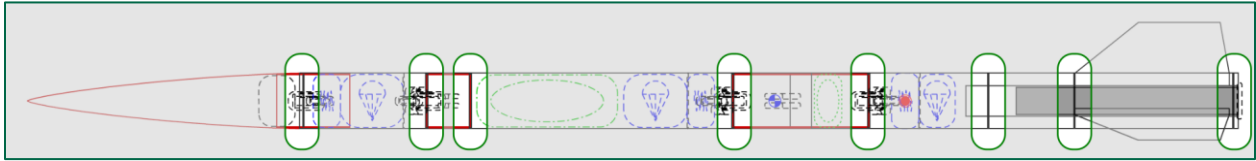


Figure 17: Location of bulkheads and centering rings in the launch vehicle.

4.1.4.1.4.2 DESIGN DETAILS

Three of the altimeter bay end cap bulkheads (shown in Figure 18) are mounting points for black powder deployment charges, and these three bulkheads as well as the nose cone bulkhead are mounting points for U-bolts, used to attach shock cords to the rocket components. The fourth altimeter bay end cap bulkhead is the same as the others except that it does not have the 5/16" or 0.11" holes for U-bolts and separation charges respectively. Circumferences are based upon approximate airframe wall thickness.

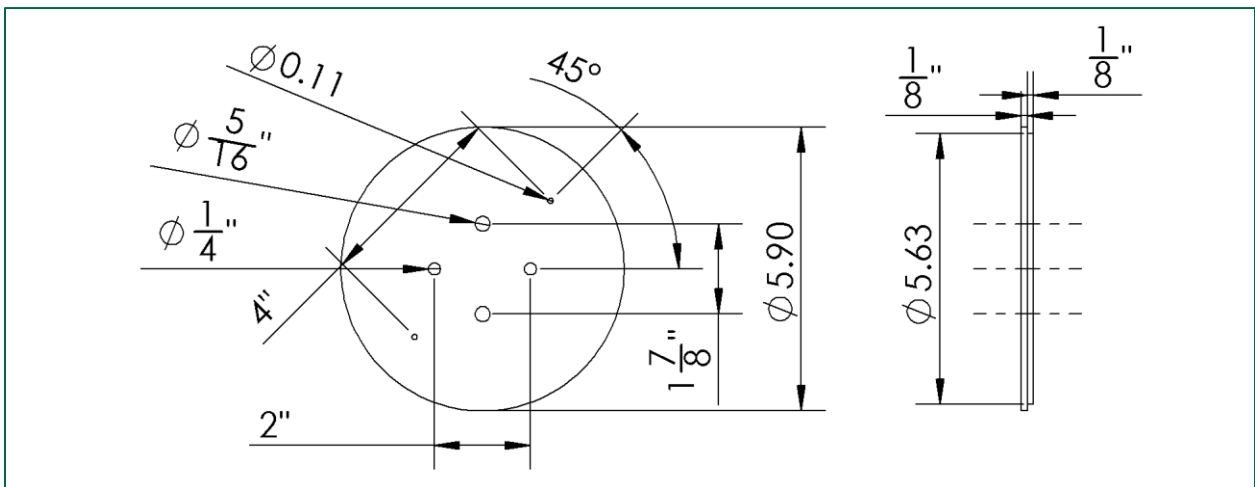


Figure 18: Dimensioned drawing of typical altimeter cap bulkhead.



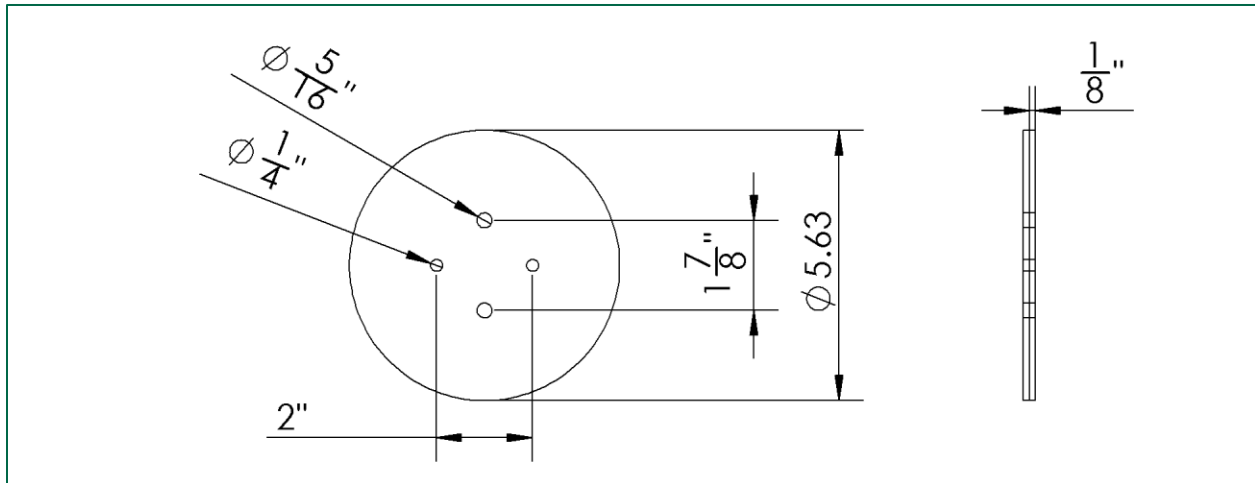


Figure 19: Dimensioned drawing of nose cone bulkhead.

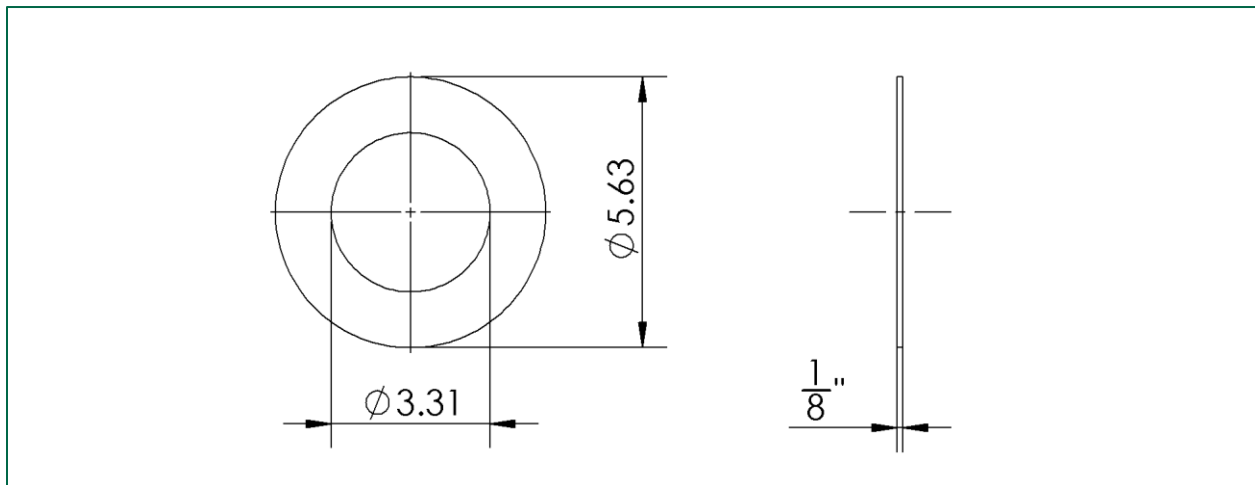


Figure 20: Dimensioned drawing of typical centering ring.

4.1.4.1.4.3 MATERIAL AND CONSTRUCTION

If any of these bulkheads were to yield under load, the results would be potentially catastrophic. The same material has been selected here as for the fins, as the $\frac{1}{8}$ " carbon fiber is lightweight and extremely strong. Each bulkhead will be constructed by epoxying two sheets of this material into a single piece. As with the fins, the bulkheads and centering rings will be cut and drilled with a CNC router, using high-quality HEPA air filters to prevent inhalation of carbon fiber dust.



4.1.4.2 SUBSYSTEMS

4.1.4.2.1 AIRBRAKES

4.1.4.2.1.1 LOCATION

The launch vehicle has been designed with the main altimeter bay also functioning as the coupler for the upper and lower sections. This altimeter bay, therefore, is designed to be 15" long to accommodate the altimeter switch band and 6" coupler depth. As the selected altimeters are just 4" long and the U-bolt attachment point hardware uses about 1" of space at each end, there is approximately 9" of empty usable space in the main altimeter bay. This space is where the Airbrakes system will be located. The Airbrakes system requires access to the external airframe of the rocket, therefore, all airbrakes protrusions will be located within the reinforced switch band.

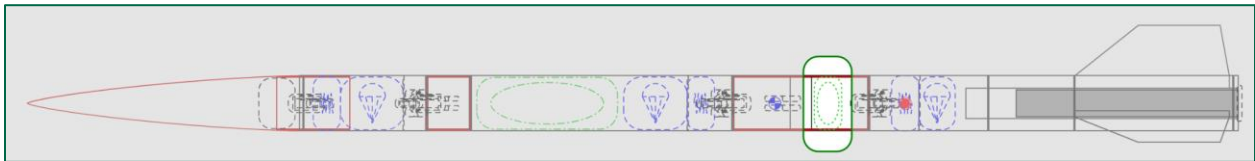


Figure 21: Location of the Airbrakes Subsystem in the launch vehicle.

4.1.4.2.1.2 DESIGN DETAILS

SOAR has selected the dynamic gear-actuated fin deployment subsystems for use on the launch vehicle. This system is accurate, reliable, efficient, and easily reinforced. The majority of the required components are commercially available, making them inexpensive, easy to obtain, and available with very small tolerances.

The exact design for this system has not yet been determined as the concept was only recently selected, but a design concept showing the three fins in various stages of deployment is shown in Figure 22



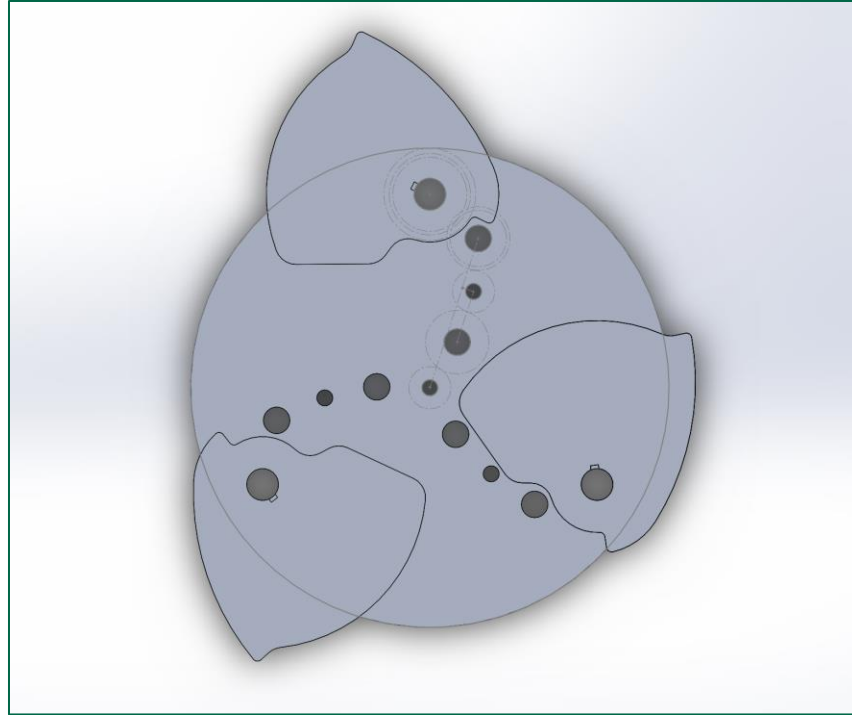


Figure 22: Concept rendering of gear-actuated airbrakes system.

4.1.4.2.1.3 MATERIALS AND CONSTRUCTION

In this application, strength and low mass are of the highest priority. With that in mind, aluminum has been selected as the primary construction material for this system. Aluminum is commonly preferred for use in aircraft and rocketry components because of its high strength-to-weight ratio, and this situation is no exception. These components will be outsourced to a waterjet machine shop once designs are finalized.

4.1.4.2.1.4 ELECTRONICS

This design will require the use of a battery, servo, microcontroller, altitude sensor, and accelerometer. These components have not yet been selected.

4.1.4.2.2 ADJUSTABLE BALLAST SYSTEM

4.1.4.2.2.1 LOCATION

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

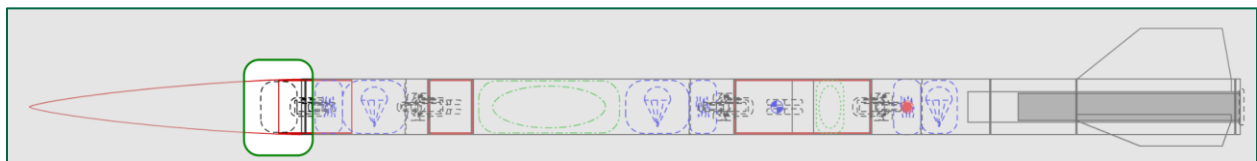


Figure 23: Location of the adjustable ballast subsystem in the launch vehicle.



4.1.4.2.2.2 DESIGN DETAILS

The adjustable ballast system consists of several stackable and removable ballast sleds. Each sled can hold up to 6 oz. of ballast, not including the mass of the sled itself. The ballast is in the form of 1 oz. automotive weights, which can be installed individually, allowing ballast in increments of 1 oz. A typical ballast sled is detailed in Figure 24.

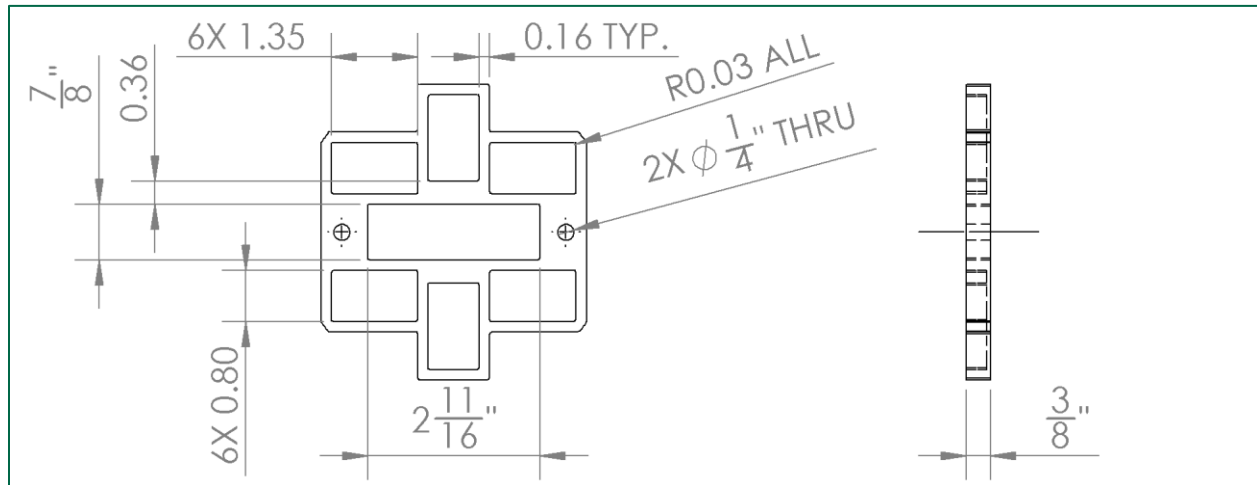


Figure 24: Dimensional drawing of adjustable ballast subsystem.

4.1.4.2.3 PAYLOAD LEVELING SYSTEM

4.1.4.2.3.1 LOCATION

The payload levelling system will consist of a wire that will run from the lower end of the upper airframe to the lower end of the nose cone. This wire will attach to the shock cord located below the nose cone and above the forward altimeter bay.

4.1.4.2.3.2 SELECTED DESIGN

The mechanical levelling alternative has been selected for this design. This system will consist of a small-gauge wire that will run from a static attachment point at the bottom of the upper airframe, up on the outside of the upper airframe to the bottom of the nose cone, between the nose cone shoulder and the upper airframe, and finally to the parachute shock cord. This small-gauge wire will attach to the shock cord at a point that will enable a horizontal landing. The shock cord will be restrained with a mechanical shock-reducing device such as a climber's belay device. This is necessary because the wire must be small enough to fit in a small channel between the nose cone shoulder and airframe tube, therefore, it will not be able to withstand the full shock of parachute deployment.

Instead, the parachute will deploy using a partial length of shock cord, as restrained by the belay device. After the parachute opens fully, the continued force will cause the shock cord to continue to run through the device, but at a slow, controlled speed. As the shock cord continues to ease out, the small levelling wire will eventually come under pressure and begin



to pull the rocket into a horizontal position. Eventually, the shock cord will deploy fully and the tube will be completely level.

As this design selection was made quite recently, a belay device has not been selected and drawings have not been completed. More details on this subsystem will be provided in the CDR report.

4.1.5 MOTOR SELECTION

4.1.5.1 MISSION STATEMENT OF MOTOR

The mission of the vehicle motor is to reliably and predictably power the launch vehicle flight close to (but never below) the target altitude.

4.1.5.2 PROPOSED ALTERNATIVES

Several potential motors were considered for use in the launch vehicle. These motors are detailed in Table 16.

Table 16: Simulated data and specifications of potential motors.

Motor	Simulated Velocity off Rod (ft/s)	Simulated Apogee (ft)
L1420	63.8	4964
L1365	61.8	5117
L2375	82.1	5741
L1410	58.6	5144
L1090	59.6	4839

4.1.5.3 COMPARISON OF ALTERNATIVES

Table 17: Pros and cons of potential motors.

Motor	Pros	Cons
-------	------	------



L1420	Closest to target altitude	Simulates below target altitude (airbrakes would have no effect)
L1365	Simulates above target altitude	Only 100 ft above altitude (could be an issue if mass changes)
L2375	Simulates above target altitude Significant allowance for increased weight	Very expensive Simulates far outside target range
L1410	Simulates above target altitude Some clearance for mass changes	Low velocity off rod
L1090	Launches the rocket up	Simulates below target altitude Simulates far outside target range

4.1.5.4 SELECTED MOTOR

The vehicle team has selected to use the Cesaroni L1410 motor for the preliminary design. With this motor choice, the team can be confident that the vehicle will reach a target altitude of 5,000 ft. or above without the airbrakes subsystem in play. The airbrakes system, in combination with the adjustable ballast system, provide assurance that the rocket will not significantly exceed the target altitude.

4.2 RECOVERY SUBSYSTEM

4.2.1 RECOVERY MATERIAL & DESIGN RESEARCH

4.2.1.1 PARACHUTES

4.2.1.1.1 PROPOSED ALTERNATIVES

The following parachutes were considered when selecting a recovery system for the launch vehicle. All parachute data is based on OpenRocket flight simulations.

4.2.1.1.1.1 FRUITY CHUTES IRIS ULTRA 96"

This parachute has sufficient drag to slow down the launch vehicle sections to below the required 75 ft·lb_F of kinetic energy on impact. However, it also has 12 shroud lines, which can easily become tangled and may also be more difficult and bulky to fold and pack. It would



require more time and precision to obtain very similar results to other commercial parachutes.

Table 18: Fruity Chutes Iris Ultra 96" Compact parachute characteristics.

Property	Value
Material	Rip Stop Nylon (95 psi)
Diameter (in)	96
Drag Coefficient	2.2
Number of Lines	12
Line Length (in)	110
Line Material	Flat Nylon

Table 19: Fruity Chutes Iris Ultra 96" Compact parachute flight data.

Characteristic	Value
Velocity at Deployment (ft/s)	-132
Terminal Velocity (ft/s)	-10.5
Kinetic Energy of Nose-cone and Rover Compartment at Impact (ft·lb _F)	55.28
Kinetic Energy of Booster and Altimeter Bay at Impact	33.58



4.2.1.1.1.2 SKYANGLE CERT-3 XL

The SkyAngle Cert-3 series of parachutes is extremely reliable, easy to fold and pack, and has been extensively tested and reviewed. Further, specific instructions on folding the parachutes are readily available, making it even easier to utilize for the project. This parachute also features 5/8" mil-spec tubular nylon that has a 2,250 lb. shock capacity. No such tests are available for many other commercially available parachutes.

Table 20: SkyAngle Cert-3 XL parachute characteristics.

Property	Value
Material	Zero-Porosity 1.9 oz. Balloon Cloth
Surface Area (ft ²)	89
Drag Coefficient	2.59
Number of Lines	4
Line Length (in)	100
Line Material	5/8" Tubular Nylon

SkyAngle Cert-3 XL parachute flight data.

Characteristic	Value
Velocity at Deployment (ft/s)	-132
Terminal Velocity (ft/s)	-10.5
Kinetic Energy of Nosecone and Rover Compartment at Impact (ft·lb _F)	62.08



Kinetic Energy of Booster and Altimeter Bay at Impact (ft·lb_F)	37.93
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4.2.1.1.1.3 SKYANGLE CERT-3 L

This parachute shares many features with the XL version noted previously. This parachute also features 5/8" mil-spec tubular nylon that has a 2,250 lb shock capacity. This option was discarded after initial simulations, as the kinetic energy for each section was calculated to be above 75 (ft·lb_F).

Table 21: SkyAngle Cert-3 L parachute characteristics.

Property	Value
Material	Zero-Porosity 1.9 oz. Balloon Cloth
Surface Area (ft²)	57
Drag Coefficient	1.26
Number of Lines	4
Line Length (in)	80
Line Material	5/8" Tubular Nylon

Table 22: SkyAngle Cert-3 L parachute flight data.

Characteristic	Value
Velocity at Deployment (ft/s)	-132
Terminal Velocity (ft/s)	-10.5



Characteristic	Value
Kinetic Energy of Nosecone and Rover Compartment at Impact (ft·lb_F)	117.67
Kinetic Energy of Booster and Altimeter Bay at Impact (ft·lb_F)	102.26

4.2.1.1.2 COMPARISON OF ALTERNATIVES

Table 23: Pros and cons of parachute alternatives.

Parachute	Pro	Cons
Fruity Chutes Iris Ultra 96"	<p>Sufficient drag to slow down launch vehicle to desired kinetic energy.</p> <p>Packing size is sufficiently small for application.</p>	<p>Multiple shroud lines may lead to tangling.</p> <p>Twelve-sided design more difficult to pack and install.</p> <p>Past performance proves it to be non-durable for multiple flights.</p>
SkyAngle Cert-3 XL	<p>Sufficient drag to slow down launch vehicle to desired kinetic energy.</p> <p>Fewer shroud lines result in less likelihood of entanglement.</p> <p>Proven design and performance in previous designs.</p>	<p>Large packing size takes up room in launch vehicle.</p> <p>Fewer shroud lines results in each taking increased impact from the shock of deployment.</p>



Parachute	Pro	Cons
SkyAngle Cert-3 L	<p>Fewer shroud lines result in less likelihood of entanglement.</p> <p>Proven design and performance in previous designs.</p>	<p>Drag is insufficient to slow down launch vehicle to desired kinetic energy.</p> <p>Fewer shroud lines results in each taking increased impact from the shock of deployment.</p>

4.2.1.2 SHOCK CORD

Various materials and sizes of shock cords were analyzed for our application. Of which three types of cords are widely available in the market - Tubular Kevlar, Tubular Nylon and Latex rubber elastic cords.

Table 24: Pros and Cons of shock cord alternatives.

Shock Cord	Pros	Cons
Tubular Kevlar	<p>Strong, durable and flexible shock cord that comes in various sizes and braid forms.</p> <p>Heat resistant which make it ideal for rocket recovery applications where high temperatures of ejection blast can degrade the braids and hence the strength.</p>	<p>Higher density compared to other cords, hence increase in weight.</p>
Tubular Nylon	<p>Commonly used</p> <p>Flexible and Lightweight</p>	<p>Less tensile strength than the Kevlar for same size shock cord.</p> <p>Requires a separate flame protection over the cord, or else they may degrade over the long run due to ejection blast and eventually fail.</p>



Shock Cord	Pros	Cons
Latex rubber elastic cords	Nylon or Polyester braided cover for protection Absorbs most of the shock by gradually stretching through its length due to its high elastic nature.	Low tensile strength Stretches to 100% its length, which means their length doubles at full stretch. This could damage the two hanging section of the rocket.

Table 25: Shock cord material and size comparison for tensile strength

Material	Size (in)	Tensile Strength (lb)
Tubular Kevlar	$\frac{1}{8}$	1200
Tubular Kevlar	$\frac{1}{4}$	3600
Tubular Kevlar	$\frac{1}{2}$	7200
Tubular Nylon	1	4000
Nylon braided cover over latex rubber Elastic cord	$\frac{1}{2}$	420

4.2.1.3 AVIONICS

Altimeters are a core part of the rocket system, which measure various crucial parameters of the flight in order to trigger events at the precise time and speed. Therefore the team generally prefers to utilize technology that has been proven in other applications.

4.2.1.3.1 FORWARD ALTIMETERS

These are used at the payload section of the rocket. Due to the space constraint in this section, altimeter size matters significantly along with its speed and accuracy. Some of the options for the forward altimeters are:



4.2.1.3.1.1 MISSILE WORKS RRC2+ ALTIMETER

Table 26: Missile Works RRC2+ altimeter characteristics.

Property	Value
Manufacturer	Missile Works
Weight (oz)	0.35
Length (in)	2.28
Power supply	9V (battery)
Dual Deployment capability	Yes
Max. Altitude (ft)	40,000
Sampling rate (Hz)	20
Time delay for redundancy	Yes
Field locator	Via aux unit
Data options	Peak altitude, peak speed, acceleration, time to apogee, ejection altitudes, flight duration. Beeps available.



4.2.1.3.1.2 ALTUS METRUM EASYMINI ALTIMETER

Table 27: Altus Metrum EasyMini altimeter characteristics

Property	Value
Manufacturer	Altus Metrum
Weight (oz)	0.23
Length (in)	1.5
Power supply	9V battery power
Dual Deployment capability	Yes
Max. Altitude (ft)	100,000
Sampling rate (Hz)	100 ascent, 10 descent
Time delay for redundancy	Yes
Field locator	None
Data options	Peak altitude, peak speed, acceleration, time to apogee, ejection altitudes, flight duration. Beeps available for data output.

4.2.1.3.2 MAIN ALTIMETERS

The main altimeters used at the Main Altimeter Bay needs to be a powerful, dual-deployment capable and high accuracy one. Some of the best available in the market have been tried and tested for the purpose. These are some options researched:



4.2.1.3.2.1 MISSILE WORKS RRC3 ALTIMETER

Table 28: Missile Works RRC3 altimeter characteristics.

Property	Value
Manufacturer	Missile Works
Weight (oz)	0.6
Length (in)	3.92
Power supply	9V (battery)
Dual Deployment capability	Yes
Max. Altitude (ft)	40,000
Sampling rate (Hz)	20
Time delay for redundancy	Yes
Field locator	Via aux unit
Data options	Peak altitude, peak speed, acceleration, time to apogee, ejection altitudes, flight duration. Beeps and LCD screen available



4.2.1.3.2.2 ALTUS METRUM EASYMINI ALTIMETER

Table 29: Altus Metrum EasyMini altimeter characteristics.

Property	Value
Manufacturer	Altus Metrum
Weight (oz)	0.23
Length (in)	1.5
Power supply	9V (battery)
Dual Deployment capability	Yes
Max. Altitude (ft)	100,000
Sampling rate (Hz)	100 ascent, 10 descent
Time delay for redundancy	Yes
Field locator	None
Data options	Peak altitude, peak speed, acceleration, time to apogee, ejection altitudes, flight duration. Beeps available



4.2.1.3.2.3 ALTUS METRUM TELEMETRUM ALTIMETER

Table 30: Altus Metrum Telemetry altimeter characteristics.

Altimeter	Telemetry
Manufacturer	Altus Metrum
Weight (oz)	0.71
Length (in)	1.068
Power supply	9V (battery)
Dual Deployment capability	Yes
Max. Altitude (ft)	100,000
Sampling rate (Hz)	100 ascent, 10 descent
Time delay for redundancy	Yes
Field locator	GPS telemetry
Data options	Peak altitude, peak speed, acceleration, time to apogee, ejection altitudes, flight duration. Beeps and AltOS software available



4.2.2 SELECTED RECOVERY SUBSYSTEM DESIGN

4.2.2.1 SELECTED PARACHUTE PROPERTIES

4.2.2.1.1 DROGUE PARACHUTE

Table 31: SkyAngle Classic 20" parachute properties.

Property	Value
Manufacturer	SkyAngle
Model	Classic 20"
Diameter (in)	20
Drag Coefficient	0.80
Mass (lb)	0.312
Packed Length (in)	4.0

4.2.2.1.2 MAIN BOOSTER AND PAYLOAD PARACHUTES

Table 32: SkyAngle Cert-3 XL parachute properties.

Property	Value
Manufacturer	SkyAngle
Model	Cert-3 XLarge
Diameter (in)	100
Drag Coefficient	2.59



Property	Value
Mass (lb)	2.81
Packed Length (in)	14

4.2.2.2 SELECTED AVIONICS

From previous testing and experience, the Missile Works RRC2+ and RRC3 altimeters were selected due to their reliability, precise values and almost no delay in measurements. 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.

4.2.2.2.1 FORWARD ALTIMETER

Table 33: Missile Works RRC2+ altimeter characteristics.

Property	Value
Altimeter	RRC2+
Manufacturer	Missile Works
Weight (oz)	0.35
Length (in)	2.28
Power supply	9V (battery)
Dual Deployment capability	Yes
Max. Altitude (ft)	40,000



Property	Value
Sampling rate (Hz)	20
Time delay for redundancy	Yes
Field locator	Via aux unit
Data options	Peak altitude, peak speed, acceleration, time to apogee, ejection altitudes, flight duration. Beeps available.

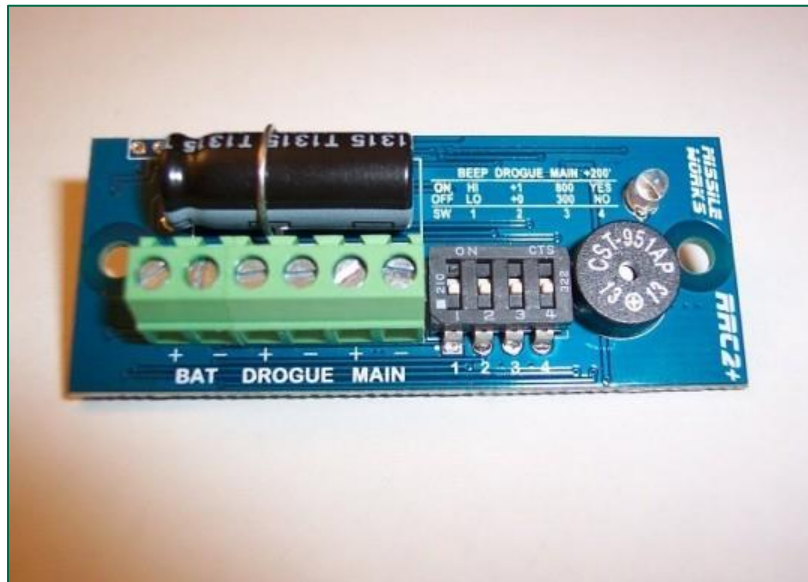


Figure 25: RRC2+ altimeter.

4.2.2.2.2 MAIN ALTIMETER

Table 34: Missile Works RRC3 altimeter characteristics.

Property	Value
Altimeter	RRC3



Property	Value
Manufacturer	Missile Works
Weight (oz)	0.6
Length (in)	3.92
Power supply	9V (battery)
Dual Deployment capability	Yes
Max. Altitude (ft)	40,000
Sampling rate (Hz)	20
Time delay for redundancy	Yes
Field locator	Via aux unit
Data options	Peak altitude, peak speed, acceleration, time to apogee, ejection altitudes, flight duration. Beeps and LCD screen available



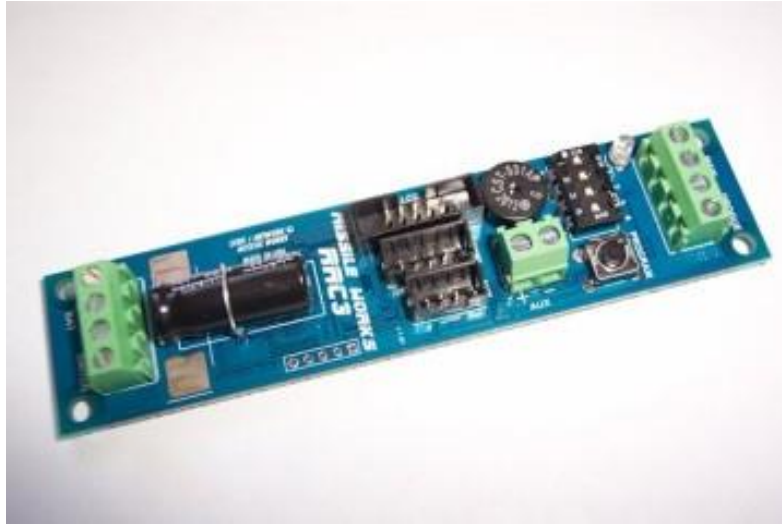


Figure 26: RRC3 altimeter.

4.2.2.2.3 SELECTED SHOCK CORD

The ½" tubular Kevlar shock cord was selected due to reliability, previous testing, sufficient tensile strength, and on the advice of the team mentor.

Table 35: ½" Tubular Kevlar properties.

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

4.3 MISSION PERFORMANCE PREDICTIONS

4.3.1 DECLARATION OF TARGET ALTITUDE

Based on simulations, past performance, and this year's plans, the team has chosen **5,000 ft.** as the target altitude for this competition.



4.3.2 SIMULATION DATA

4.3.2.1 FLIGHT PROFILE

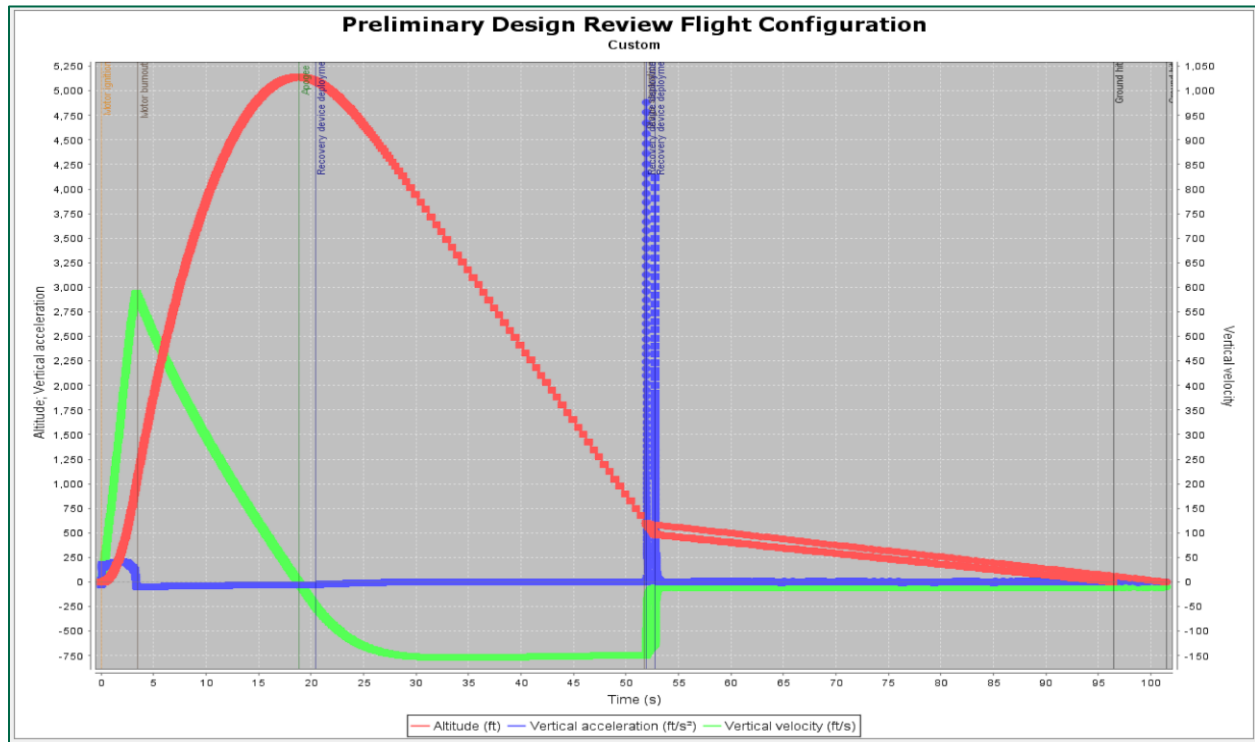


Figure 27: OpenRocket simulation of launch vehicle flight with the selected motor.

4.3.2.2 COMPONENT WEIGHTS

The projected weights of all vehicle parts and subsystems are listed in Table 15. With an unloaded weight of 39.8 lb. and a selected motor with a weight of 11.2 lb., the total weight of the rocket will be 51 lb. The total weight of the upper section will be 20.6 lb., and the total weight of the lower section after burnout will be 19.2 lb.

4.3.2.3 MOTOR THRUST CURVE

The thrust curve of the Cesaroni L1410 motor is shown in Figure 28¹¹.

¹¹ Image provided by ThrustCurve.org



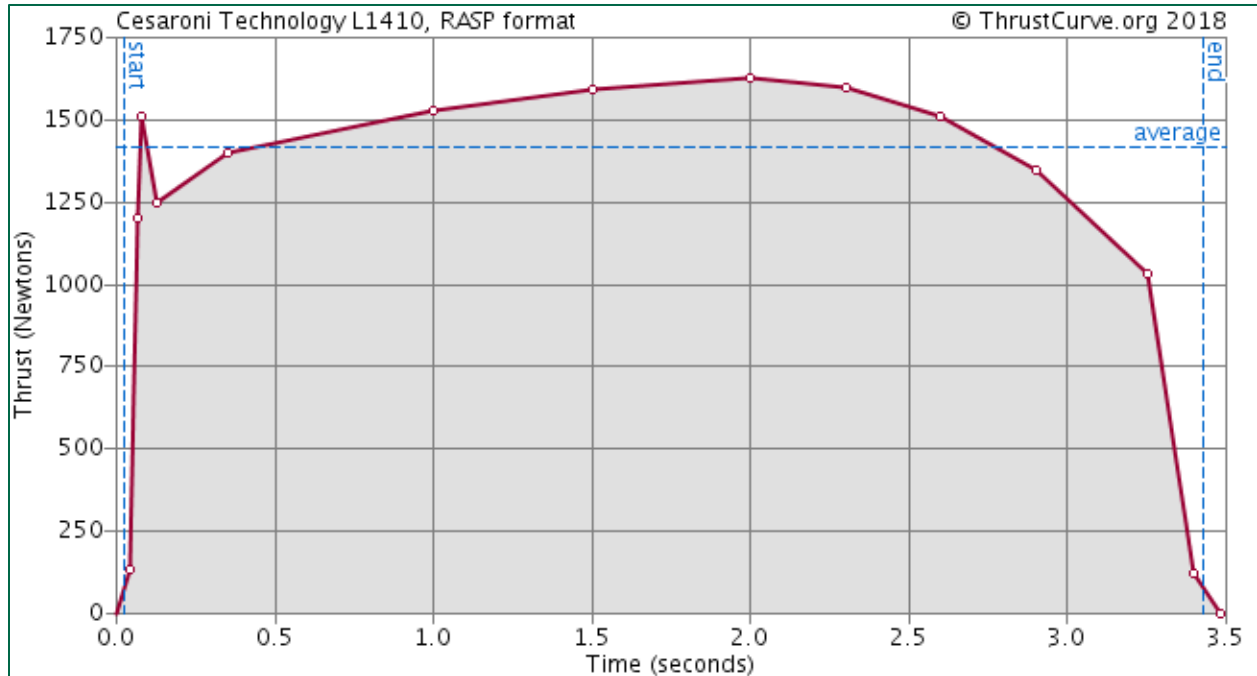


Figure 28: Thrust curve of Cesaroni L1410 motor.

4.3.3 STABILITY

The center of pressure (C_P) and center of gravity (C_g), as well as the static stability margin (M_s) of the selected design (calculated using Equation 4, where d is the diameter of the launch vehicle), are available in Table 36 and shown in Figure 12.

$$M_s = \frac{(C_P - C_g)}{d}$$

Equation 4: Definition of the stability margin property.

Table 36: Stability properties of the selected design.

Property	Value
Center of Pressure (in, from tip)	96.7
Center of Gravity (in, from tip)	82.0
Stability Margin (calipers)	2.45



4.3.4 KINETIC ENERGY AT LANDING

4.3.4.1 PRIMARY CALCULATION METHOD

To ensure the maximum kinetic energy criteria of 75 ft. lb. force at landing, appropriate parachute sizes have to be selected, that maintain a safe descent rate for the two sections. In order to calculate the maximum descent velocities, Equation 5, for the relationship between kinetic energy and velocity was used, where m is the mass of the section.

$$v_{max} = \sqrt{\frac{2E_{max}}{m}}$$

Equation 5: Relationship between energy and velocity.

This velocity was used to determine the parachute drag coefficient (C_D) and canopy area (A) using Equation 6, where g is the acceleration due to gravity and ρ_{air} is the density of air.

$$A \cdot C_D = \frac{2gm}{\rho_{air}v_{max}^2}$$

Equation 6: Parachute descent velocity equation.

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 37: Section and minimum coefficient of drag.

Section	Minimum $A \cdot C_D$ (ft ²)
Nose Cone and Payload	79.16
Booster (with Main Altimeter bay)	48.07

4.3.5 EXPECTED DESCENT TIME

4.3.5.1 PRIMARY CALCULATION METHOD

The descent time t is using the parachute descent velocity formula (Equation 7) solved for V and dividing this by the vertical distance h travelled by the body when the parachute is deployed (Equation 8).

$$V = \sqrt{\frac{2gm}{\rho_{air}(A \cdot C_D)}}$$



Equation 7: Parachute descent velocity equation, solved for V.

$$t = \frac{V}{h}$$

Equation 8: Parachute descent time definition.

This yields the values in Table 38.

Table 38: Descent duration post- deployment of vehicle sections; manual calculation method.

Section	Descent velocity (ft/s)	Descent time (s)
Nose Cone and Payload	11.09	74.83
Booster (with Main Altimeter bay)	10.7	76.47

4.3.5.2 ALTERNATE CALCULATION METHOD

Alternative calculations were performed with OpenRocket, yielding the values in Table 39.

Table 39 Descent duration post- deployment of vehicle sections; OpenRocket simulation method.

Section	Descent velocity (ft/s)	Descent time (s)
Nose Cone and Payload	10.5	79.2
Booster (with Main Altimeter bay)	10.5	81.9

4.3.6 DRIFT

4.3.6.1 PRIMARY CALCULATION METHOD

The drift of the launch vehicle was calculated using OpenRocket simulations while overriding rocket mass.

Table 40: 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	605.46
10	14.66	1210.92
15	23.46	1937.8
20	29.33	2422.66

Table 41: 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	584.2
10	14.66	1168.4
15	23.46	1869.76
20	29.33	2337.6

4.3.6.2 ALTERNATE CALCULATION METHOD

Calculations were then conducted by using the OpenRocket lateral position at main parachute deployment then subtracting the wind velocity times the descent time. All of the drift distances calculated in this manner were consistently slightly larger than those calculated with OpenRocket simulations. This is likely due to the fact that the simple formula does not



take into account the parasite or friction drag on the rocket components and even the parachute itself.

Table 42: 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	698.28
10	14.66	1350.08
15	23.46	1928.22
20	29.33	2296.03

Table 43: 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	667.465
10	14.66	1306.19
15	23.46	1899.53
20	29.33	2337.17



4.3.7 SUBSCALE TEST VEHICLE

SOAR has begun construction on a $\frac{2}{3}$ scale subscale rocket (*Apis III-S*), which is identical to the full scale design in as many ways as possible, albeit with smaller dimensions. The subscale rocket will launch in November with a prototype payload on board.

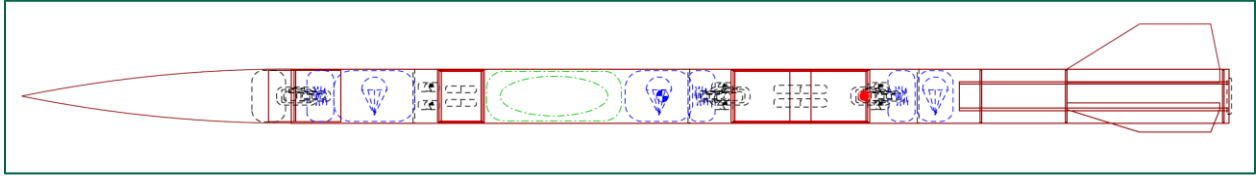


Figure 29: Dimensional diagram of subscale launch vehicle, with centers of pressure and gravity shown.



5 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.

5.1 SAFETY OFFICER INFORMATION

See 3.1.5 Safety Officer for safety officer contact information.

5.2 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.

5.3 NAR/TRA SAFETY

5.3.1 PROCEDURES

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

1. A level II certified member and an NAR/TRA Personnel will oversee any test launch of the vehicle and flight tests of the vehicle.



2. The launch site Range Safety Officer 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.

5.3.2 SAFETY CODES

SOAR conducts launches under both NAR¹² and TRA¹³ codes and will abide by the appropriate High-Power Rocketry Safety Code Requirements during all operations.

5.4 HAZARDOUS MATERIALS

5.4.1 LISTING OF HAZARDOUS MATERIALS

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

5.4.2 LABELS

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

- The name of the hazardous substance(s) in the container

¹² NAR Safety Code available in full at: <http://www.nar.org/safety-information/model-rocket-safety-code/>

¹³ TRA Safety Code available for download at: <http://www.tripoli.org/Portals/1/Documents/Safety%20Code/HighPowerSafetyCode%20-%202017.pdf>



- A hazard warning
- The name and address of the manufacturer or other responsible party

5.4.3 TRAINING

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

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

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

5.4.4 HEALTH AND SAFETY PROCEDURES

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

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

5.5 SAFETY BRIEFING

5.5.1 HAZARD RECOGNITION

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

5.5.2 ACCIDENT AVOIDANCE

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

5.5.3 LAUNCH PROCEDURES

At the team meeting most closely preceding the launch, the Safety Officer will be given time to help the members review launch safety and precautionary measures. Topics discussed at this time include but are not limited to: laws and regulations mandated by the Federal Aviation Administration (FAA), the National Fire Protection Association (NFPA), and Florida State Statutes; prohibited launchpad activities and behaviors; maintaining safe distances; and safety procedures pertaining to any potentially hazardous chemicals which will be present during the launch. All team leaders must 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.

5.6 CAUTION STATEMENTS

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

5.6.1 DEFINITIONS

5.6.1.1 WARNING

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

5.6.1.2 CAUTION

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

5.6.1.3 NOTE

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

5.6.2 SAFETY MANUAL

5.6.2.1 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.

5.6.2.2 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.



5.6.2.3 NOTES

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

5.7 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:

5.7.1 FEDERAL AVIATION REGULATIONS (FARS)

- 14 CFR: Aeronautics and Space, Chapter 1, Subchapter F, Part 101, Subpart C: Amateur Rockets¹⁴
- 27 CFR: Part 55: Commerce in Explosives¹⁵
- NFPA 1127 "Code for High Power Rocket Motors"¹⁶

5.7.2 STATE OF FLORIDA LAWS AND REGULATIONS

- Florida Statute: Title XXV: Aviation, Chapter 331: Aviation and Aerospace Facilities and Commerce¹⁷
- Florida Statute: Title XXXIII: Regulation of Trade, Commerce, Investments, and Solicitations, Chapter 552: Manufacture, Distribution, and Use of Explosives¹⁸

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

¹⁴ Available in full at: <https://www.law.cornell.edu/cfr/text/14/part-101/subpart-C>

¹⁵ Available in full at: <https://www.law.cornell.edu/cfr/text/27/part-555>

¹⁶ Available for download at: <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1127>

¹⁷ Available in full at: <https://www.flsenate.gov/Laws/Statutes/2018/Chapter331>

¹⁸ Available in full at: <https://www.flsenate.gov/Laws/Statutes/2017/Chapter552>



5.9 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.*

5.10 HAZARD ANALYSIS

5.10.1 HAZARD CATEGORIES

5.10.1.1 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.

5.10.1.2 HAZARDS TO ENVIRONMENT RISK ASSESSMENT

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

5.10.1.3 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.

5.10.1.4 LAUNCH PAD FUNCTIONALITY RISK ASSESSMENT

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

5.10.1.5 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.

5.10.1.6 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.

5.10.1.7 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.



5.10.1.8 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.

5.10.2 RISK LEVEL DEFINITIONS

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

Table 44: Risk severity level definitions.

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 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.



Description	Personnel Safety and Health	Facility / Equipment	Range Safety	Project Plan	Environmental
- 3 - Marginal	Minor injury or occupational related illness.	Minor damage to facilities, systems or equipment that will not compromise mission objectives.	Operations are permitted by the RSO and NFPA 1127, but hazards unrelated to flight hardware design occur during launch.	Minor delays of non-critical components or budget increase.	Mitigatable environmental damage without violation of law or regulations where restoration activities can be accomplished.
- 4 - Negligible	First aid injury or occupational-related illness.	Minimal damage to facility, systems, or equipment.	Operations are permitted by the RSO and NFPA 1127, and hazards unrelated to flight hardware design do not during launch.	Minimal or no delays of non-critical components or budget increase.	Minimal environmental damage not violating law or regulation.

5.10.2.2 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 45: Risk probability levels and definitions.

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

5.10.3 RISK ASSESSMENT LEVELS

Each risk is finally assigned a risk level based upon a combination of the risk severity and probability. These levels range from high (red) to minimal (white) and are assigned using Table 46 and Table 47.

Table 46: Risk assessment classification criteria.

Probability	Severity			
	- 1 - Catastrophic	- 2 - Critical	- 3 - Marginal	- 4 - Negligible
- A - Frequent	1A	2A	3A	4A
- B - Probable	1B	2B	3B	4B



Probability	Severity			
	- 1 - Catastrophic	- 2 - Critical	- 3 - Marginal	- 4 - Negligible
- C - Occasional	1C	2C	3C	4C
- D - Remote	1D	2D	3D	4D
- E - Improbable	1E	2E	3E	4E

Table 47: Risk assessment classifications definitions.

Level of Risk	Definition
High Risk	Highly Undesirable. Documented approval from the RSO, NASA SL officials, team faculty adviser, team mentor, team leads, and team safety officer.
Moderate Risk	Undesirable. Documented approval from team faculty adviser, team mentor, team leads, team safety officer, and appropriate sub-team lead.
Low Risk	Acceptable. Documented approval by the team leads and sub-team lead responsible for operating the facility or performing the operation.
Minimal Risk	Acceptable. Documented approval not required, but an informal review by the sub-team lead directly responsible for operating the facility or performing the operation is highly recommended.

5.10.4 CURRENT AND PROBABLE RISK

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



5.10.4.1 PERSONNEL HAZARD ANALYSIS

Table 48: Personnel hazard analysis risk matrix.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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
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



Shop	Working with chemical components resulting in mild to severe chemical burns on skin or eyes, lung damage due to inhalation of toxic fumes, or chemical spills.	Chemical splash. Chemical fumes.	Mild to severe burns on skin or eyes. Lung damage or asthma aggravation due to inhalation.	2C	MSDS documents will be readily available at all times and will be thoroughly reviewed prior to working with any chemical. All chemical containers will be marked to identify appropriate precautions that need to be taken. Chemicals will be maintained in a designated area. Proper PPE will be worn at all times when handling chemicals. Personnel involved in motor making will complete the university's Lab and Research Safety Course. All other individuals will be properly trained on handling common chemicals used in constructing the launch vehicles.	3E
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
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
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



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
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

5.10.4.2 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Table 49: FMEA risk matrix.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Controls	Igniter safety switch fails to activate.	Mechanical failure in switch. Communication failure between switch and controller. Code error.	Vehicle fails to launch.	2D	Safety Officer will double check all connections.	2E	Safety Officer will use launch procedure checklist.



Con- trols	Igniter safety switch ac- tive at power up.	Switch stuck/left in en- abled position. Communica- tion failure be- tween switch and controller. Code error.	Undesired launch se- quence/ per- sonnel injury/ disqualification.	1D	Safety Officer and team member will jointly and au- dibly verify that igniter switch is off.	1E	Safety Officer will use launch procedure checklist.
Pad	Unstable launch plat- form.	Uneven terrain or loose com- ponents.	If the launch pad is unstable while the rocket is leaving the pad, the rocket's path will be unpre- dictable.	2E	Confirm that all personnel are at a distance allowed by the Minimum Distance Ta- ble 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 ve- hicle on launch rail.
Pad	Unleveled launch plat- form.	Uneven terrain or improperly leveled launch tower.	The launch tower could tip over during launch, making the rocket's tra- jectory unpre- dictable.	1E	Inspect launch pad prior to launch to confirm level. Confirm that all personnel are at a distance allowed by the Minimum Distance Ta- ble as established by NAR.	1E	Use the Launch Procedure checklist when placing launch ve- hicle on launch rail.
Pad	Rocket gets caught in launch tower or ex- periences high	Misalignment of launch tower joints. Deflec- tion of launch platform rails. Friction be- tween guide	Rocket may not exit the launch tower with a sufficient exit velocity or may	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 re- sistance is noted, adjust- ments will be made to the	2E	Use the Launch Procedure checklist when placing launch ve- hicle on launch rail.



	friction forces.	rails and rocket.	be damaged on exit.		launch tower, allowing the rocket to freely move through the tower.		
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 deburred 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.
Recovery	Parachute deployment failure.	Altimeter failure. Electronics failure. Parachutes snag on shock cord.	Parachute deployment failure. Sections fail to separate. Damage to the launch vehicle.	2D	Shroud lines and shock cord will be measured for appropriate lengths. Altimeter and electronics check will be conducted with checklist several hours prior to launch. Nomex shields will be secured low on shroud lines to prevent entanglement.	2E	Full scale test launch resulted in all sections separating at planned altitudes. Use Launch Vehicle Assembly and Parachute Folding checklists when assembling launch vehicle.



Re- covery	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	Ground and launch tests verified that the amount of black powder is adequate. In full scale test launch, all sections successfully separated at designated altitudes, including nose cone with shear pins. Use Launch Vehicle Assembly checklist when assembling launch vehicle.
Re- covery	Sections separate prematurely.	Construction error. Premature firing of black powder due to altimeter.	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 test launch, all sections successfully separated at designated altitudes, including nose cone with shear pins. Altimeters performed correctly.



		ter failure or incorrect programming.				
Recovery	Altimeter or e-match failure.	Parachutes will not deploy.	Rocket follows ballistic path, becoming unsafe.	2E	Dual altimeters and e-matches are included in systems for redundancy to eliminate this failure mode. 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 ground testing, e-matches successfully ignited separation charges. In full scale test launch, primary and backup altimeters and black powder charges performed successfully.
Recovery	Rocket descends too quickly.	Parachute is improperly sized.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2E	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Extensive ground testing was performed to verify the coefficient of drag is approximately that which was used during analysis.	2E The website http://descentrate-calculator.onlinetesting.net/ was used to calculate theoretical descent values. Full scale testing resulted in no damage to rocket components.



Recovery	Rocket descends too slowly.	Parachute is improperly sized.	The rocket will drift farther than intended, potentially facing damaging environmental obstacles.	3E	The parachutes have each been carefully selected and designed to safely recover its 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://descentrate-calculator.onlinetesting.net/ was used to calculate theoretical descent values. Full scale testing resulted in no damage to rocket components.
Recovery	Parachute has a tear or ripped seam.	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2E	Through careful inspection prior to packing each parachute, this failure mode will be eliminated. One spare large parachute will be on hand. Ripstop 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	
Recovery	Recovery system separates from the rocket.	Bulkhead becomes dislodged. Parachute disconnects from the U-bolt.	Parachute completely separates from the component, causing the rocket to become ballistic.	1E	The cables and bulkhead connecting the recovery system to each segment of the rocket are designed to withstand expected loads with an acceptable factor of	1E	During full scale test launch, all parachutes remained attached to components and all U-bolts and bulkheads performed sufficiently so that all sections landed safely.



					safety. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.		
Recovery	Lines in parachutes become tangled during deployment.	Parachute becomes unstable or does not open. Parachute cord becomes caught in landing device.	The rocket has a potential to become ballistic, resulting in damage to the rocket upon impact.	1E	A piston recovery system will be utilized to ensure that parachutes are deployed with enough force to ensure separation. Nomex protection cloths will be used between parachutes to avoid entanglement. Ground testing will be performed to ensure that the packing method will prevent tangling during deployment prior to test flights.	1E	Ground and full-scale launch tests verified that the Nomex protection cloths prevented parachutes from becoming entangled with one another or with launch vehicle components. Use Launch Vehicle Assembly and Parachute Folding checklists when assembling launch vehicle.
Recovery	Parachute does not inflate.	Parachute lines become entangled.	Parachute does not generate enough drag.	2E	Parachute lines will be carefully folded in accordance with checklist. Nomex covers will be secured at lower end of shroud lines.	2E	Full scale test launch showed that Nomex covers could interfere with parachute shroud lines opening. Use Launch Vehicle Assembly and Parachute Folding checklists when assembling launch vehicle.



Re- covery	Air Brakes prevent successful recovery deployment.	Mechanical problems, increased pressure, air leaks.	Recovery deployment is unsuccessful.	2E	Ensure system is isolated completely.	2E	Full scale tests to ensure air brakes are working properly and recovery deployment is successful.
Stability	Motor CATO (catastrophic failure) (on launch pad or while in flight).	Improper motor manufacturing. Injury to personnel.	Launch vehicle is destroyed and motor has failed. Moderate explosion.	1D	Ensure nozzle is unimpeded during assembly. Inspect motor for cracks and voids prior to launch. Ensure all team members are a safe distance away from the launch pad upon ignition of the rocket. Wait a specified amount of time before approaching the pad after a catastrophe. All fires will be extinguished before it is safe to approach the pad.	2E	Motor preparation checklist will be utilized to inspect motor prior to launch. Manufacturer's instructions will be followed in assembling the motor.



Stability	Motor Retention Failure.	The drogue parachute ejection charge applied a sufficient force to push the motor out the back of the launch vehicle.	The motor is separated from the launch vehicle without a parachute or any tracking devices.	1D	Ensure that the centering rings have been thoroughly epoxied to both the motor mount and to the inner walls of the airframe. Ensure that motor is properly secured using motor mount adapter and retainer ring.	1E	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.
Stability	Loss of stability during flight.	Damage to fins or launch vehicle body, poor construction.	Failure to reach target altitude, destruction of vehicle.	1D	The CG of the vehicle will be measured prior to launch. Launch vehicle will be inspected prior to launch. Proper storage and transportation procedures will be followed.	2E	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.
Stability	Change in expected mass distribution during flight.	Payload shifts during flight; foreign debris is deposited into the PEM along with the payload.	Decrease in stability of the launch vehicle, failure to reach target altitude, destruction of vehicle.	1D	The payload will be centered inside the launch vehicle and secured. Inspection will be conducted to ensure parachutes and shock cord do not move freely in the airframe.	2E	Final Assembly and Launch Procedure Checklists will be used to assemble launch vehicle and to fold and insert parachutes.



Sta- bility	Motor re- tention fail- ure.	Design of re- tention fails. Retention as- sembly failure.	Motor falls out of booster sec- tion while pro- pelling body forward and launch vehicle fails to achieve 5280 ft altitude.	2D	Retention rings will be ma- chined 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 flight test, motor mount adapter and retainer ring prevented motor from ejecting.
Sta- bility	Mass in- crease dur- ing con- struction.	Unplanned ad- dition of com- ponents or building mate- rials.	Launch vehicle does not fly to correct altitude. All sections land with high kinetic energy. Possible minor damage to rocket body and/or fins.	2C	Record will be maintained of mass changes. Launch vehi- cle simulations will be re- peated for each mass change. Additional launch vehicle simulations will be performed at plus 5% of cal- culated mass. Subscale and full-scale launches will be performed with accurate mass.	3E	During full scale test launch, launch vehicle did not reach planned altitude. Weight reduc- tion of lander is planned. New open rocket simulation indicates 5260 feet at apogee.
Sta- bility	Motor fails to ignite.	Faulty motor. Delayed igni- tion. Faulty e- match. Discon- nected e- match.	Rocket will not launch. Rocket fires at an unex- pected 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 be- fore approaching rocket. If there is no activity after 60 seconds, safety officer will check the ignition system	1E	Igniter Installation checklist will be used when installing igniter. During full scale test launch, ig- niter performed as expected.



					for a lost connection or a bad igniter.	
Stability	Rocket doesn't reach high enough velocity before leaving the launch pad.	Rocket is too heavy. Motor impulse is too low. High friction coefficient between rocket and launch tower.	Unstable launch.	1E	Too low of a velocity will result in an unstable launch. Simulations have been and will continue to be run to verify the motor selection provides the necessary exit velocity. Full 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.



Sta- bility	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 post-flight, it was noted that the two sections of lander bulkhead became separated. This was analyzed and determined to be caused by the ground testing impact with the ground and to be due to the significant weight used for the simulated lander. Despite the damage, the lander remained intact during the full-scale launch and recovery.
Sta- bility	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.



5.10.4.3 ENVIRONMENTAL CONCERNS ANALYSIS

Table 50: Environmental concerns risk matrix.

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 measures 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.	3E	Paint booth will be marked with appropriate signage for hazardous material. Training will be documented for designated individuals.



Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Plastic and fiberglass waste material.	Plastic used in the production of electrical components and wiring and fiberglass used in production of launch vehicle components.	Plastic or fiberglass material produced when shaving down or sanding components could harm animals if ingested by an animal. Plastic could find its way down a drain and into the water system.	3D	All plastic material will be disposed of in proper waste receptacles.	4E	Waste receptacles will be available and properly marked.
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	N/A



Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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	During full scale test launch, the assembled rocket experienced approximately 40 minutes of heavy rain. All components were inspected for water damage prior to launch attempt. Launch was successful with no damage due to water incursion. In addition, all tools and ground station equipment was similarly intact and functional.



Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Envi-ron-men-tal	Thunder-storms.	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	N/A
Envi-ron-men-tal	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	N/A



Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Envi- ron- men- tal	Trees.	N/A	Damage to rocket or para-chutes. 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	N/A
Envi- ron- men- tal	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	N/A



Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Ponds, creeks, and other bodies of water.	N/A	Loss of rocket components. Damaged electronics.	2D	<p>Launching with high winds should be avoided in order to avoid drifting long distances.</p> <p>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.</p>	2E	N/A
Environmental	Extremely cold temperatures.	Batteries discharge quicker than normal. Shrinking of fiberglass.	<p>Completely discharged batteries will cause electrical failures and fail to set off black powder charges, inducing critical events.</p> <p>Rocket will not separate as easily.</p>	3D	<p>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 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.</p>	3E	Use Final Assembly and Launch Procedure Checklists when assembling launch vehicle.



Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Humidity.	N/A	Motors or black powder charges become saturated and don't ignite.	2D	Motors and black powder should be stored in a water-resistant container.	2E	Use Field Packing List when preparing tools, parts, and consumables to go to the field.
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.



6 PAYLOAD CRITERIA

6.1 SELECTION, DESIGN, AND RATIONALE OF PAYLOAD

6.1.1 MISSION STATEMENT

Our Payload, the Phoenix rover, will autonomously drive 10 feet in distance and collect and contain 10 milliliters of soil.

6.1.2 MISSION SUCCESS CRITERIA

The success of the payload's mission will be defined by the following criteria:

1. Deploy from inside the launch vehicle.
2. Autonomously move after initial trigger signal.
3. Sufficient power throughout the entire mission.
4. Ability to traverse terrain during dependent on launch day conditions.
5. Soil sample collection completed.

6.1.3 MATERIAL & DESIGN RESEARCH

6.1.3.1 ROVER BODY

6.1.3.1.1 SIZE

Table 51: Pros and cons of rover body size alternatives.

Size	Pros	Cons
Smaller (12" - 14")	More space for deployment system inside rover compartment. More space for parachute.	Harder to build a smaller, more dense rover May struggle with driving over larger obstacles
Larger (14" - 18")	More space for soil retrieval system. More space for onboard electronics.	Heavier Less space for deployment system & parachutes in rover compartment of the airframe.



6.1.3.1.2 MATERIAL

Table 52: Pros and cons of rover material alternatives.

Material	Pros	Cons
Acrylic	Easier to produce in a laser cutter Better aesthetics	Brittle Can only be manufactured into flat plates
Aluminum	Can be welded to adjust body quickly Can be machined into a 3D form from a block	Harder learning curve in material manufacturing

6.1.3.2 STEERING/DRIVING SYSTEM

Table 53: Pros and cons of payload steering and driving material and shapes.

Design	Pros	Cons
Single-Wheel	Simplistic, so there is less room for error to occur	One wheel makes turning and stability of the rover more difficult Less surface area contacting the ground More difficult to mount a single wheel
Double Wheel - Single Axle	More surface area with traction Easier to mount	More complex of a mechanical system



Design	Pros	Cons
Double Wheel - Individually powered	Steering possible	<p>More points of failure</p> <p>More complex wiring and computing with relays</p> <p>More power required with two motors</p>

6.1.3.3 DISTANCE DETERMINATION

Table 54: Pros and cons of distance determination alternatives.

Alternative	Pros	Cons
Accelerometer	<p>Accurate measurement of acceleration up to +/-16G</p> <p>Can measure acceleration on 3 axes.</p> <p>Low power usage up to 23μA</p>	<p>Acceleration measurement on slopes may affect distance determination</p> <p>Additional programming and calculation to determine distance</p>
Hall Effect Sensor	<p>Every rotation of the wheels will be sensed and counted</p> <p>Saves space and weight due to small size</p>	<p>Have to be installed precisely</p> <p>Can be challenging to implement</p>
Bluetooth Connection (Discontinued)	Wireless Connection	<p>Signal is degraded within rocket and rover</p> <p>Inconsistencies with range may cause an inaccurate reading</p>



Infrared Sensor (Discontinued)	<p>Accurate Distance Measuring</p> <p>Easy to implement with analog signals</p>	<p>Angle of incidence will affect the result of distance measure</p> <p>May not have a line of sight on the rocket</p> <p>Draws more current than other sensors</p> <p>Range won't hold up over the 10m distance</p>
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6.1.3.4 SOIL RETRIEVAL SYSTEM

Table 55: Pros and cons of soil retrieval system designs

Design	Pros	Cons
Auger	Can collect soil over a wide range of soil conditions	<p>Large and complicated deployment mechanism.</p> <p>Could potentially become jammed on a rock</p>
Spinning dirt-throwing arm	Will be able to break up potentially hard dirt	<p>Will require a high RPM motor</p> <p>May not throw dirt given wet or muddy conditions</p>
Wheel Scooper	Able to collect dirt while rover is moving	<p>There will be resistance when driving the vehicle</p> <p>Possible power draw if the drive motors and scooping system end up fighting each other</p>
Sweeper	Could be able to collect 10 mL of dirt without needing to physically penetrate the ground	May not be able to sweep up packed, wet dirt



6.1.3.5 DEPLOYMENT SYSTEM

6.1.3.5.1 OBJECTIVE OF THE DEPLOYMENT SYSTEM

Both options for the deployment system will allow for the rover to successfully leave the vehicle cavity.

Table 56: Pros and cons of deployment system designs.

Design	Pros	Cons
Winch	Reliably operational Already have a successful design from NSL 2017-18 Ability to pull the rover out of rocket body regardless of orientation Can be tested and tweaked to be almost perfect and reliable, with enough work	Heavy weight Takes up valuable space in the vehicle More power required to power deployment system Less room for payload
No Deployment System	Lightweight Saves a lot of space Less power requirements because there will be one less system to power Less points of failure overall	Will require rover modification for self-deployment Will need a specific vehicle body orientation Difficulty in driving rover out if vehicle lands with sideways orientation Will require the installment of a tracked floor for the payload to self-deploy

6.1.4 MATERIAL & DESIGN SELECTION

6.1.4.1 ROVER BODY

The body of the rover will potentially consist of machined aluminum, or possibly acrylic. The design will come down to the workability of both materials, weight, and prototyping capabilities.



6.1.4.2 STEERING/DRIVING SYSTEM

The driving system will consist of a combination of an Arduino, relays, a DC motor, electromagnets and various sensors. Through testing we have confirmed that the motor's direction can be changed using relays and Arduino input. Testing to find the most useful sensors is currently in progress. Ultrasonic sensors and Lidar sensors have been proposed, but may prove to be difficult to use due to a high amount of noise from an unpredictable landing environment. As a result, we are leaning towards collision sensors because it may be more robust in detecting obstacles. We are also working on testing electromagnets for the steering system. The concept for this is to receive analog data from the sensors and then using the Arduino to decide whether the right or left magnet turns on to steer the wheel.

6.1.4.3 DISTANCE DETERMINATION

6.1.4.3.1 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 3.3V 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 rotations over a given period of time, to be calculated by the Arduino. Equation 9, Equation 10, and Equation 11 will be used to calculate the distance, d , given the radius of the wheel r , the change in time Δt , and the revolutions per minute, RPM , of the wheel.

$$v = r\omega$$

Equation 9: Conversion of angular to linear velocity.

$$\omega = RPM * \frac{2\pi}{60}$$

Equation 10: Conversion of RPM to angular velocity.

$$d = V\Delta t$$

Equation 11: Distance traveled over time, given a constant velocity.

6.1.4.3.2 DXL345 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 can also be used to verify the distance traveled by the Equation 12, where a is the acceleration and Δt is the time since last measurement. The sensor will be set to the lowest sensitivity of 2g in order to account for any variation of acceleration from the rover.

$$d = \frac{1}{2}a\Delta t^2$$



Equation 12: Distance traveled over time, given a constant acceleration and starting at rest.

6.1.4.4 SOIL RETRIEVAL SYSTEM

We plan on making the soil retrieval system modular and adaptable to launch day conditions. As seen in Table 55, we have plans to prototype several collection methods under several simulated soil conditions to find which is best under which conditions. From an electrical point of view, all systems will be similar with a singular motor, and then an additional servo for an auger system in order to fully deploy.

6.1.4.5 DEPLOYMENT SYSTEM

There are currently two methods proposed for deploying the rover from the vehicle body. The first method is to use a winch system that will pull the rover out of the vehicle body. This benefit to this design is that the rover will be pulled out of the body of the rocket regardless of orientation and shape of rover. The downside to this method is that extra power is required and there is less space for the rover in the vehicle body. The second deployment method being considered is to have the rover drive itself out of the vehicle body. This will be done by utilizing orientation sensors such as gyroscopes to decide which direction the motor should be driven. The benefits to this method will be that more space is for the payload body and less power consumption will be required. However, more consideration will need to be given for the size and shape of the rover, so that the wheel can have contact with the vehicle body to roll out. For both methods, solenoids will be used to hold the payload in place while in flight and will be set to a fail-safe default¹⁹. This means that the solenoids will have extended arms to secure the payload in the body of the rocket prior to deployment. Upon deployment, power will be supplied to the solenoid and retract the arms, so that the payload can be deployed from the vehicle body.

6.1.4.6 PRELIMINARY TEST DATA

Table 57: Preliminary rover prototype testing results.

Item Tested	Test Result (Pass/Fail)
Feasibility: Do design aspects work as projected?	Pass
Wheel rotation with a brushed DC motor	Pass

¹⁹ Note: This addresses concerns raised by NASA in relation to the retainment system described in the Proposal.



Item Tested	Test Result (Pass/Fail)
Leveling system prototype	Pass
Wheel rotation and second activation using an onboard program	Pass

6.1.5 PRELIMINARY DESIGN

6.1.5.1 ROVER

6.1.5.1.1 BRIEF HISTORY OF DESIGN

As of now we have had 2 official prototypes with sub versions and they follow the main idea of the final design of the rover. The main goal of prototype one, *The Dragon*, was to see if our design would drive. *The Dragon* was composed of a 3D printed wheel, plywood, brushed DC motor, and a 15V battery. Later versions of *The Dragon* (1 Mk2 *Dragon* 2) included a micro-controller brain for more electronic control.



Figure 30: Payload prototype 1 Mk1 Dragon.

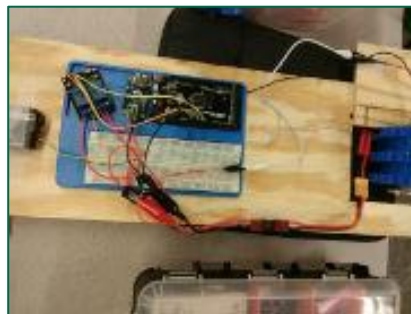


Figure 31: Payload prototype 1 Mk2 Dragon 2.



6.1.5.1.2 EARLY CAD CONCEPTS

From the beginning, the rover was to be designed to operate at any orientation in order to minimize the impact of issues with landing. The design contains a long flat body with one or more drive wheels located in the front of the body in order to pull the rover. Modularity was an important aspect for rover design to improve options once the landing field conditions are known. CAD was used to determine width and height desires for the rover.

We tested what could fit in our 6" Diameter rocket and found that both single and double front driven wheels would fit along with a wire brush sweeper for soil collection, and a 6-link auger deployment mechanism.

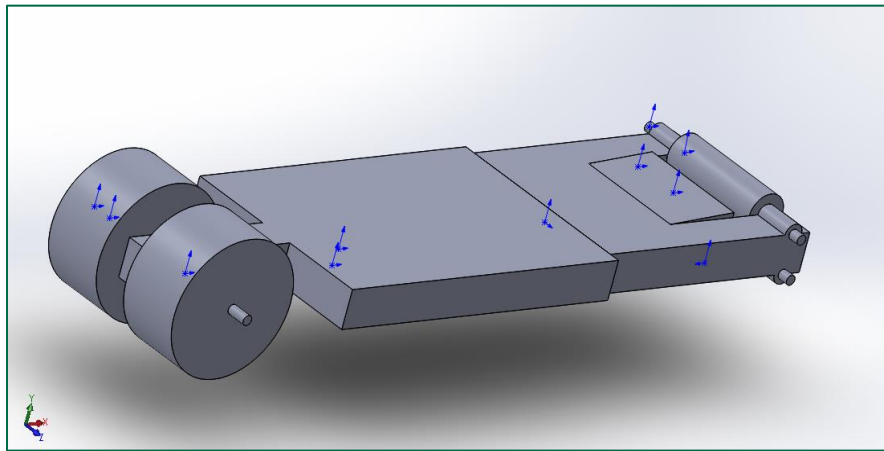


Figure 32: Early rover CAD Concept I.

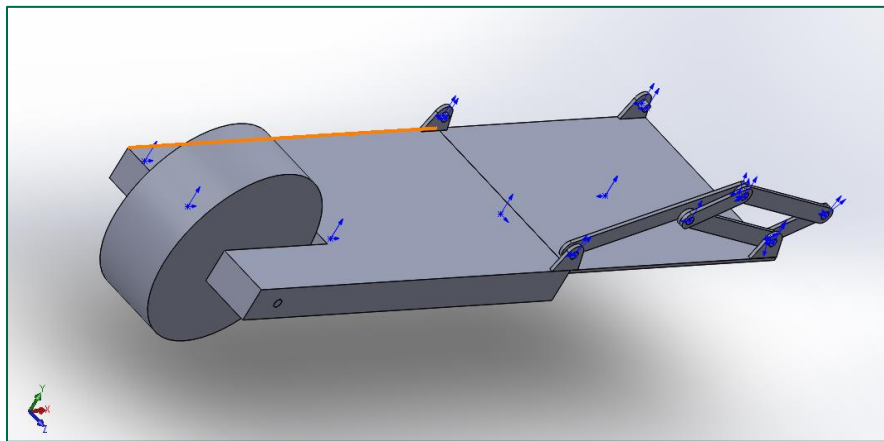


Figure 33: Early rover CAD Concept II.

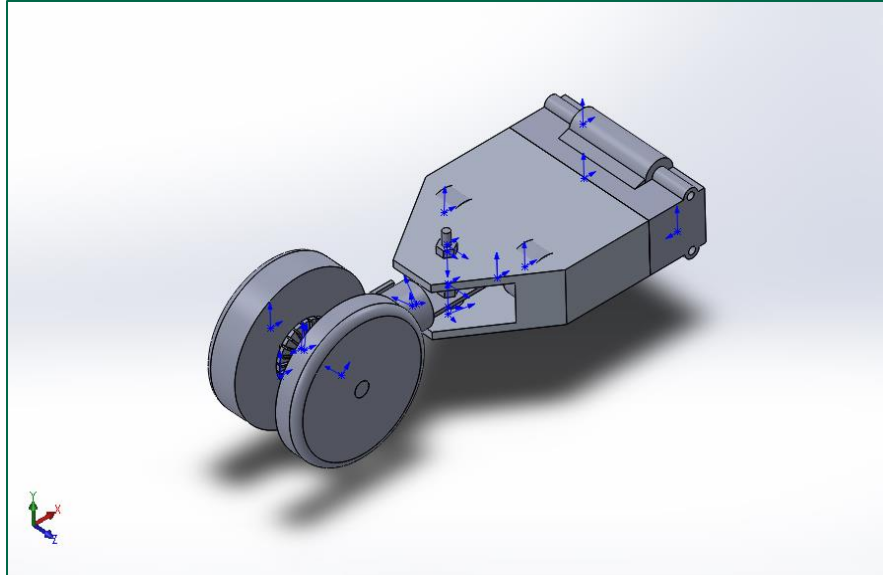


Figure 34: Early rover CAD concept III.

6.1.5.2 SUBSYSTEMS

6.1.5.2.1 SOIL RETRIEVAL SYSTEM

One design has not been chosen as we are still testing the designs listed above in Table 55. Our plan is to have interchangeable designs so that we can choose one based on the conditions of the soil on launch day. There will be mounting holes on the body of the rover giving it the ability to easily change its features.

6.1.5.2.2 DEPLOYMENT SYSTEM:

Our potential deployment system is designed off our version from NSL 2017 - 2018, a winch system that pulls the rover out with help from wires attached to the vehicle body at the open end of the payload section. This year's deployment system will have to be tweaked in order to fit a different size airframe, and may be adapted to hold the motor for the leveling system too, if needed for spacing. We plan on creating it out of 3D printed PLA, and possibly some machined aluminum plating as a secure mounting platform for the motors.

6.1.5.2.3 STEERING/DRIVING SYSTEM

Our rover will have a steering system, which will give us the flexibility to move around obstacles on the ground post deployment, making sure we can still complete the mission. Our steering system will be centralized around moving our main drive shaft, which will be pivot laterally in order to move the drive wheel at the front of the rover. The dimension of the turning mechanism may still vary, as we are still prototyping many different systems in order to optimize the rover. Regardless, we plan to keep the steering mechanism to the front two or three inches of the sled. We plan on making the pivoting arm out of aluminum, and will be mounted to a pivot at the extreme front of the sled, in order to give us as much internal space as possible.



6.1.5.3 ELECTRICAL SCHEMATICS

Figure 35 shows the current travelling through the negative terminal of the DC motor, while Figure 36 shows the current travelling through the positive terminal of the DC motor. This allows for the motor to switch directions. The 5 Volt sources on the side mimic and Arduino I/O pin which outputs a low voltage to switch on a relay. When the switch is open for the 5 Volt loop, no current flows, thus the relay is off as no magnetic field is generated. When the switch is open in the 5 Volt loop, a magnetic field is generated and the switch in the 12 Volt loop is closed. This can be used for moving the rover forward and backwards depending on its orientation upon landing.

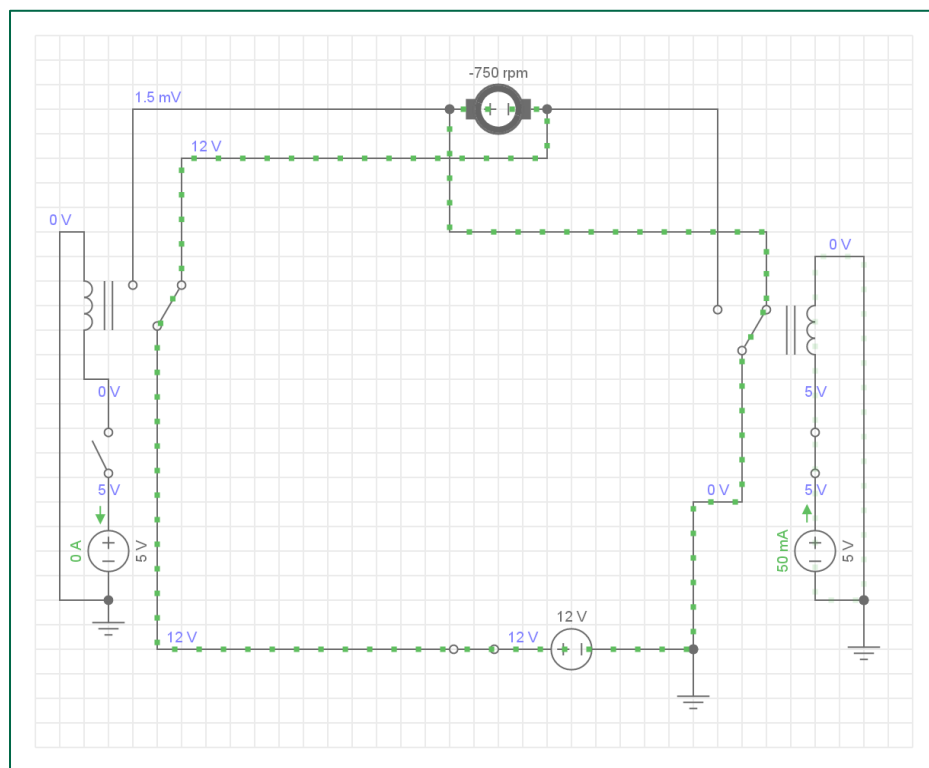


Figure 35: Current travelling through the negative terminal of the DC motor.



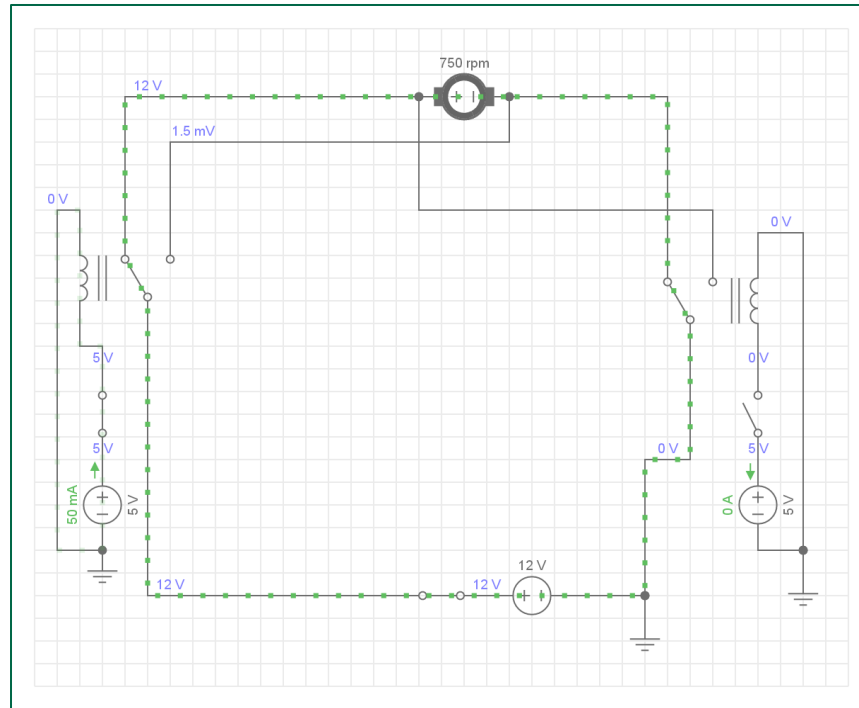


Figure 36: Current travelling through the positive terminal of the DC motor.

6.1.5.3.1 INTERFACES BETWEEN LAUNCH VEHICLE

6.1.5.3.1.1 PAYLOAD LEVELING

The payload leveling subsystem is described in detail in 4.1.4.2.3 Payload Leveling System.

6.1.5.3.1.2 PAYLOAD RETAINMENT

The payload retainment system interfaces directly with the launch vehicle and is described in 6.1.4.5 Deployment System.

7 PROJECT PLAN

7.1 REQUIRED AND DERIVED REQUIREMENTS

7.1.1 GENERAL REQUIREMENTS

Table 58: General requirements and verification of requirements.

Req. Number	Requirement	Method	Verification	Verification Status
1.1	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation 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.



Req. Number	Requirement	Method	Verification	Verification Status
1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	Demonstration	Team leader and project manager will work with 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. Will continue to be verified throughout the course of the project as more documents are submitted.
1.3	Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during certain activities.	Documentation	SOAR will submit information on foreign national students no later than submission of the PDR. A team roster is being kept with information on all Foreign Nationals, this data will be sent to the correct personal no later than the due date of the PDR.	Verified 10/29/18 when email confirmation was received that Frederick Kepner and Zachary Koch received the list of Foreign Nationals.
1.4	The team must identify all team members attending launch week activities by the Critical Design Review (CDR).	Documentation	SOAR will submit information on team member attendees no later than submission of the CDR.	Will be verified with submission of CDR.



Req. Number	Requirement	Method	Verification	Verification Status
1.4.1	Students actively engaged in the project throughout the entire year.	Documentation	SOAR's NSL Team will take attendance at each meeting to track team members who are actively engaged throughout the academic year. A team roster is being kept with information regarding each member's activity level, which will be used to identify team members to travel during competition week.	Will be verified by CDR.
1.4.2	One mentor (see requirement 1.13).	Documentation	SOAR has a designated mentor who meets the requirements of Section 1.13 of the NASA Student Launch 2019 Handbook. The mentor has agreed to travel with the team during launch week.	Verified with project proposal.
1.4.3	No more than two adult educators.	Documentation	SOAR will identify no more than two adult educators who will be attending launch week.	Will be verified by CDR.
1.5	The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. An educational engagement activity report will be completed and submitted within two weeks after completion of an event.	Demonstration	SOAR has designated an Outreach Coordinator to organize and handle all outreach events. Multiple outreach events are scheduled and the Operations Manager has been designated to schedule further events.	Will be verified by submission of Educational Engagement Activity Reports during report submission period.



Req. Number	Requirement	Method	Verification	Verification Status
1.6	The team will establish a social media presence to inform the public about team activities.	Demonstration	SOAR has established social media accounts on Facebook, Twitter, Instagram, and LinkedIn. The NSL team will utilize these established accounts to inform the public about team activities. The Team Lead has access to all of these accounts which she will keep updated with NSL material.	Verified with submission of social media handles to Ryan Connelly on 10/9/18.
1.7	Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient.	Demonstration	The NSL Team Leader will be responsible to send the documentation to NASA project management for each milestone. In addition, each report will be posted on our website to the following page: http://www.usfsoar.com/projects/ns1-2018-2019/	Will be verified upon submission of documents for each milestone.
1.8	All deliverables must be in PDF format.	Inspection	One team member has been designated to format and proofread all documents before submission. They will inspect that each deliverable will be in PDF format.	Will be verified upon submission of documents for each milestone.
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Inspection	One team member has been designated to format and proofread all documents before submission. They will inspect that each report contains a table of contents.	Will be verified upon submission of documents for each milestone.



Req. Number	Requirement	Method	Verification	Verification Status
1.10	In every report, the team will include the page number at the bottom of the page.	Inspection	One team member has been designated to format and proofread all documents before submission. They will inspect that each report has a page number at the bottom of the page.	Will be verified upon submission of documents for each milestone.
1.8, 1.9, 1.10 Derived Requirement	In order to ensure the designated team member has adequate time to format and proofread the document there will be a content deadline one week prior to each submission deadline. This allows for one week of formatting and editing.	Demonstration	The team lead has set deadlines for each milestone report one week prior to the submission date. All document content will be in by these dates to allow for adequate formatting and proofreading.	Will be verified upon completion of each project milestone.
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. Cellular phones can be used for speakerphone capability only as a last resort.	Demonstration	The SOAR team has access to computers, speaker phones, Wi-Fi connection, and a video camera for teleconference purposes. The Team Lead is responsible for booking an adequate conference room and renting all necessary equipment for the presentation.	Will be verified during milestone presentations.



Req. Number	Requirement	Method	Verification	Verification Status
1.12	All teams will be required to use the launch pads provided by Student Launch's launch service provider. No custom pads will be permitted on the launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.	Demonstration	The Launch vehicle will be designed to utilize the standard rails made available on the NSL launch site. Full scale launches will be conducted in a similar way in order to mimic launch day conditions.	Verified with submission of documents which include launch vehicle design.
1.13	Each team must identify a "mentor."	Documentation	SOAR's NSL Team has identified a mentor who meets the qualifications specified in the NASA Student Launch 2019 Handbook.	Verified with submission of project proposal.



7.1.2 VEHICLE REQUIREMENTS

Table 59: Vehicle requirements and verification of requirements.

Requirement Number	Requirement	Method	Verification	Verification Status
2.1	The vehicle will deliver the payload to an apogee altitude between 4,000 and 5,500 feet above ground level (AGL). Teams flying below 3,500 feet or above 6,000 feet on Launch Day will be disqualified and receive zero altitude points towards their overall project score.	Demonstration	We have identified a target apogee of 5,000 feet. Subscale analysis will be conducted to compare the apogee with the respective motor. Calculations will be done to ensure our chosen full scale motor will deliver us to the targeted 5,000 feet.	Will be verified on Launch Day.
<i>Derived Requirement</i> 2.1.1	The team will design an airbrake system in order to control the altitude of the rocket to ensure an apogee within 100 feet of the targeted 5,000 feet.	Demonstration	An airbrake system has been designed to slow down the velocity of the rocket so that it can come close to 5,000 feet.	Will be verified by FRR.
<i>Derived Requirement</i> 2.1.2	The team will construct and launch the airbrake system prior to FRR in order to verify systems functionality.	Demonstration	The team will finalize designs in order to start construction as soon as possible to ensure the system is ready by FRR.	Will be verified by FRR.



Requirement Number	Requirement	Method	Verification	Verification Status
<i>Derived Requirement</i> 2.1.3	The batteries powering the airbrakes subsystem will be brightly colored, clearly marked as a fire hazard, and easily distinguishable.	Inspection	Airbrakes subsystem batteries will be contained in a bright, fireproof container.	Will be verified with construction of airbrake system and full scale vehicle.
2.2	Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score during Launch Week.	Documentation	The target goal will be determined using OpenRocket simulation following any changes to the rocket prior to PDR submission.	Verified with submission of PDR.
2.3	The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner.	Demonstration	The vehicle will feature four altimeters in two separate locations, capable of deploying charges and recording the flight apogee.	Verified with submission of PDR.



Requirement Number	Requirement	Method	Verification	Verification Status
2.4	Each altimeter will be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Inspection	Each altimeter will have an arming switch via an electronic rotary switch. There will be two switches in the switchband of the main altimeter bay, and two switches in the payload altimeter bay. All four switches will be visible and physically accessible.	Will be verified with construction of full scale vehicle.
2.5	Each altimeter will have a dedicated power supply.	Demonstration	One standard 9V Alkaline battery will be configured to each altimeter and be sufficient in supplying power to enable function.	Will be verified with construction of full scale vehicle.
<i>2.5 Derived Requirement</i>	The batteries powering the altimeters will be brightly colored, clearly marked as a fire hazard, and easily distinguishable.	Inspection	Batteries will be colored in bright red or orange.	Will be verified with construction of full scale vehicle.



Requirement Number	Requirement	Method	Verification	Verification Status
2.6	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Inspection	There are two settings to the electronic rotary switch. The switch itself has mechanical components that force it to remain in its set position.	Will be verified with construction of full scale vehicle.
2.7	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Testing/ Inspection	The launch vehicle will contain parachutes on every separate or tethered part of the rocket that will be deployed with sufficient time to slow the rocket adequately. After each launch the Safety officer will inspect the vehicle to identify it as recoverable and reusable.	Will be verified with construction of full scale vehicle.



Requirement Number	Requirement	Method	Verification	Verification Status
2.8	The launch vehicle shall have a maximum of four (4) independent sections.	Demonstration	The launch vehicle will consist four sections: the nose cone, rover compartment, main altimeter bay, and the booster section. The nose cone and rover compartment will be tethered together, as will the altimeter bay and booster, thus resulting in two (2) independent sections.	Verified with submission of Launch Vehicle Design in PDR.
2.8.1	Coupler/ airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.	Demonstration	The main altimeter bay will consist of a switch band and two 6" coupler ends, for a total of 15" or 2.5 times the body diameter.	Verified with submission of Launch Vehicle Design in PDR.
2.8.2	Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	Demonstration	The nose cone shoulder will extend 6", or 1 body diameter, into the upper airframe.	Verified with submission of Launch Vehicle Design in PDR.



Requirement Number	Requirement	Method	Verification	Verification Status
2.9	The launch vehicle shall be limited to a single stage.	Demonstration	Launch vehicle will contain only one motor to light and start the flight.	Verified with submission of Launch Vehicle Design in PDR.
2.10	The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the Federal Aviation Administration flight waiver opens.	Testing	There will be Final Assembly and Launch Procedure Checklist before the test flights of the subscale rocket and the full-scale rocket that will be timed to ensure we complete the list safely and within the time of 2 hours.	Will be verified after full scale launch timing test.
2.11	The launch vehicle will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components.	Testing	The launch vehicle and the electronic components within will be properly connected and sealed to prevent anything from causing it to disconnect or be damaged. The batteries will have a life long enough to be at the launch pad for an hour without losing any power.	Will be verified after full scale launch timing test.



Requirement Number	Requirement	Method	Verification	Verification Status
2.12	The launch vehicle shall be capable of being launched by a standard 12-volt direct current firing system.	Demonstration	The ignitor used in the rocket will be able to fire with a standard 12-volt DC firing system.	Verified with submission of Launch Vehicle Design in PDR.
2.13	The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch.	Demonstration	The only required external circuitry will be the 12-volt direct current firing system that is compatible with the ignitor in the launch vehicle.	Verified with submission of Launch Vehicle Design in PDR
2.14	The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	Demonstration	The motor being used in the launch vehicle will be a Cesaroni L1410, which is certified by the National Association of Rocketry and it made of ammonium perchlorate.	Verified with submission of Launch Vehicle Design in PDR.



Requirement Number	Requirement	Method	Verification	Verification Status
2.14.1	Final motor choices will be declared by the Critical Design Review (CDR) milestone.	Documentation	Preliminary motor has been selected; any changes will be noted and justified in CDR..	Will be verified by CDR.
2.14.2	Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing the safety margin. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.	Documentation	The Cesaroni L1410 motor is currently the motor planned to use for launch and any changes will be documented and submitted through the proper channels.	To be verified with further documents.
2.15	Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria.	Documentation	Our design does not contain a pressure vessel.	Verified with submission of Project Proposal.



Requirement Number	Requirement	Method	Verification	Verification Status
2.15.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.	Documentation	Our design does not contain a pressure vessel.	Verified with submission of Project Proposal.
2.15.2	Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	Documentation	Our design does not contain a pressure vessel.	Verified with submission of Project Proposal.
2.15.3	Full pedigree of the tank will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.	Documentation	Our design does not contain a pressure vessel.	Verified with submission of Project Proposal.



Requirement Number	Requirement	Method	Verification	Verification Status
2.16	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	Analysis	The motor chosen is not bigger than an L class motor and has a total impulse of 4828.3 N-s.	Verified with submission of Launch Vehicle Design in PDR.
2.17	The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	Analysis	The rocket has been simulated in OpenRocket to have a loaded static stability margin greater than 2.5. Will be verified with physical tests.	Verified with submission of Launch Vehicle Design in PDR.
2.18	The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	Analysis	The motor that was chosen for the rocket will allow the rocket to achieve a minimum of 52 fps at rail exit. Current simulations for configurations under consideration place velocity at rail exit at 58.2 fps.	Verified with submission of Launch Vehicle Design in PDR.



Requirement Number	Requirement	Method	Verification	Verification Status
2.19	All teams shall successfully launch and recover a subscale model of their rocket prior to CDR.	Testing	Our team will have a subscale model ready and launched prior to CDR. The subscale information will be documented in the CDR.	Will be verified by CDR.
2.19.1	The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model.	Demonstration	The subscale model will be constructed to resemble the full-scale model as accurately as possible given finances and fabrication techniques. The CDR will provide information regarding the scaling of the fullscale in order to create the subscale rocket.	Will be verified by CDR.
2.19.2.	The subscale model will carry an altimeter capable of recording the model's apogee altitude.	Demonstration	The altimeter bay on the subscale rocket will include an altimeter that will record the subscale's apogee.	Will be verified by CDR.



Requirement Number	Requirement	Method	Verification	Verification Status
2.19.3	The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	Demonstration	The subscale rocket will be newly constructed rocket, designed and build at a scale unique to the full scale rocket.	Will be verified with subscale construction completion, no later than CDR.
2.19.4	Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.	Documentation	An altimeter will be attached to the subscale rocket so that altimeter data can be used to prove a successful launch.	Will be verified by CDR.
2.20	All teams will complete demonstration flights as outlined below.			
2.20.1	All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day.	Testing	The full-scale rocket will be built and launched as well as recovered prior to the FRR and it will be the same rocket flown on launch day.	Will be verified with full scale demonstration flight.



Requirement Number	Requirement	Method	Verification	Verification Status
2.20.1.1	The vehicle and recovery system will have functioned as designed.	Inspection	The vehicle and recovery system will be observed during and after full-scale launch to ensure it functions as designed	Will be verified with full scale demonstration flight.
<i>Derived Requirement</i> 2.20.1.1.1	The vehicle subsystems including the Payload Compartment Leveling System and the Airbrake System will have function as designed.	Inspection	The vehicle and recovery system will be observed during and after full-scale launch to ensure it functions as designed.	Will be verified with full scale demonstration flight.
2.20.1.2	The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	Demonstration	The full scale rocket will be newly constructed rocket, designed and build at a scale unique to the full scale rocket.	Will be verified with full scale demonstration flight.
2.20.1.3	The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:			



Requirement Number	Requirement	Method	Verification	Verification Status
2.20.1.3.1	If the payload is not flown, mass simulators will be used to simulate the payload mass.	Demonstration	If a rover is not ready to fly we will construct a simulated mass in order to act as dead weight in place of the rover.	Will be verified with full scale demonstration flight.
<i>Derived Requirement</i> 2.20.1.3.1.1	If the airbrake system is not flown, mass simulators will be used to simulate the airbrake system mass.	Demonstration	If an airbrake system is not ready to fly we will construct a simulated mass in order to act as dead weight in place of the rover.	Will be verified with full scale demonstration flight.
2.20.1.3.2	The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	Inspection	The mass simulators will be located in the payload compartment of the launch vehicle and will be attached to the payload altimeter bay.	Will be verified with full scale demonstration flight.



Requirement Number	Requirement	Method	Verification	Verification Status
2.20.1.4	If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale demonstration flight.	Documentation	The payload itself does not change the external surface of the rocket.	Verified with submission of Launch Vehicle Design in PDR.
2.20.1.5	Teams shall fly the launch day motor for the Vehicle Demonstration Flight. The RSO may approve use of an alternative motor if the home launch field cannot support the full impulse of the launch day motor or in other extenuating circumstances.	Testing	The launch day motor will be the one declared in the CDR and flown in the vehicle demonstration flight as well as any other full scale launch flights conducted.	Will be verified with full scale demonstration flight.
2.20.1.6	The vehicle must be flown in its fully ballasted configuration during the full-scale test flight.	Inspection	The fully ballasted configuration will be used in the full-scale demonstration flight.	Will be verified with full scale demonstration flight.



Requirement Number	Requirement	Method	Verification	Verification Status
2.20.1.7	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).	Documentation	After completing the full-scale demonstration flight, no components will be changed	Will be verified with full scale demonstration flight.
2.20.1.8	Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement.	Documentation	Complete flight analysis and altimeter data will be included in the FRR report to prove successful flight apogee have been achieved.	Will be verified with submission of FRR.



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



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



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



Requirement Number	Requirement	Method	Verification	Verification Status
2.23	The team's name and launch day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe.	Inspection	The launch team will inspect the rocket airframe and any section that separates to ensure this information will be present.	Will be verified with construction completion of full scale rocket.
2.24	Vehicle Prohibitions			
2.24.1	The launch vehicle will not utilize forward canards. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	Documentation	Our design does not utilize forward canards.	Verified with submission of Launch Vehicle Design in PDR.
2.24.2	The launch vehicle will not utilize forward firing motors.	Documentation	Our design does not utilize forward motors.	Verified with submission of Launch Vehicle Design in PDR.



Requirement Number	Requirement	Method	Verification	Verification Status
2.24.3	The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	Documentation	Our design does not utilize motors that expel titanium sponges.	Verified with submission of Launch Vehicle Design in PDR.
2.24.4	The launch vehicle will not utilize hybrid motors.	Documentation	Our design does not utilize hybrid motors.	Verified with submission of Launch Vehicle Design in PDR.
2.24.5	The launch vehicle will not utilize a cluster of motors.	Documentation	Our design does not utilize cluster of motors.	Verified with submission of Launch Vehicle Design in PDR.
2.24.6	The launch vehicle will not utilize friction fitting for motors.	Documentation	Our design does not utilize friction fitting motors.	Verified with submission of Launch Vehicle Design in PDR.
2.24.7	The launch vehicle will not exceed Mach 1 at any point during flight.	Documentation	Our design does not exceed Mach 1 at any point in flight.	Verified with submission of Launch Vehicle Design in PDR.



Requirement Number	Requirement	Method	Verification	Verification Status
2.24.8	Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with and unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).	Documentation	Any vehicle ballast will not exceed 10% of the total unballasted weight of the rocket.	Verified with submission of Launch Vehicle Design in PDR.
2.24.9	Transmissions from onboard transmitters will not exceed 250 mW of power.	Documentation	Transmission from onboard transmitters do not exceed 250 mW of power.	Verified with submission of Launch Vehicle Design in PDR.
2.24.10	Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of light-weight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	Documentation	The vehicle design will not use excessive or dense metal.	Verified with submission of Launch Vehicle Design in PDR.



7.1.3 RECOVERY SUBSYSTEM REQUIREMENTS

Table 60: Recovery subsystem requirements and verification of requirements.

Re-quire-ment Num-ber	Requirement	Method	Verification	Verification Status
3.1	The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.	Demonstration	Design Parameters: The launch vehicle is designed to deploy the drogue parachute at apogee (around 5,000 ft.) using no delay. The initial main parachute will deploy at 650 ft. with the second main deploying .5-1 s thereafter.	Verified with submission of Launch Vehicle Design in PDR.
3.1.1	The main parachute shall be deployed no lower than 500 feet.	Demonstration	The initial main parachute will deploy at 650 ft with the second main deploying .5-1 s thereafter.	Verified with submission of Launch Vehicle Design in PDR.
3.1.2	The apogee event may contain a delay of no more than 2 seconds.	Demonstration	The apogee event contains no delay.	Verified with submission of Launch Vehicle Design in PDR.
3.2	Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.	Testing	A ground ejection test for the drogue and main parachute will be completed prior to initial subscale and full-scale launches.	Will be verified once testing is conducted.



Re- quire- ment Num- ber	Requirement	Method	Verification	Verification Status
3.3	At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft·lb _F .	Analysis	The correct and appropriate parachute size will be chosen in order to slow the launch vehicle down enough to ensure a kinetic energy of less than 75 ft·lb _F . Multiple tests will be simulated. Calculations in this report detail the descent rate and kinetic energy at impact.	Verified with submission of Launch Vehicle Criteria - Recovery Subsystem in PDR.
3.4	The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	Inspection	Recovery electrical system is connected only to the recovery system altimeters. Payload design incorporates a separate power supply. Inspection will be conducted by the safety officer during construction.	Will be verified once construction is complete.
3.5	All recovery electronics will be powered by commercially available batteries.	Inspection	All recovery electronics will be inspected to ensure they are commercially bought batteries.	Will be verified once construction is complete.
3.6	The recovery system shall contain redundant, commercially available altimeters.	Inspection	The current design includes redundant, commercially available altimeters. The rocket will use a total of four altimeters, each powered by a separate battery that will not power any other equipment.	Verified with submission of Launch Vehicle Criteria - Recovery Subsystem in PDR.



Re-requirement Number	Requirement	Method	Verification	Verification Status
3.7	Motor ejection is not a permissible form of primary or secondary deployment.	Inspection	The launch vehicle design does not include motor ejection as means of deployment.	Verified with submission of Launch Vehicle Criteria - Recovery Subsystem in PDR.
3.8	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Inspection	The launch vehicle has been designed with shear pins at each separation point. Modifications will be made as construction moves along.	Will be verified when construction is complete.
3.9	Recovery area will be limited to a 2500 ft. radius from the launch pads.	Analysis/Testing	Drift calculations will be performed to verify that the rocket will not drift outside the landing zone. Testing will be conducted during subscale and fullscale flights to check accuracy of drift calculations.	Preliminary analysis complete. Verification dependent on testing and analysis of actuals vs theoretical values.
3.10	Descent time will be limited to 90 seconds (apogee to touch down).	Analysis/Testing	Descent time calculations will be performed and compared to actual flight results to check accuracy of calculations.	Preliminary analysis complete. Verification dependent on testing and analysis of actuals vs theoretical values.



Re-requirement Number	Requirement	Method	Verification	Verification Status
3.11	An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	Inspection	A loud audible beacon transmitter will be included in both altimeters bays separate from the recovery electronics. The beacon will produce a high enough decibel that will allow us to locate the separate sections.	Will be verified when construction is complete.
3.11.1	Any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.	Inspection	A loud audible beacon transmitter will be included in both altimeters bays separate from the recovery electronics. The beacon will produce a high enough decibel that will allow us to locate the separate sections.	Will be verified when construction is complete.
3.11.2	The electronic tracking device will be fully functional during the official flight on launch day.	Inspection	The sounding beacons will be installed within the altimeter bays and will be functional on launch day.	Will be verified when construction is complete.
3.12	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Testing	The recovery electronics will be housed in altimeter bays which will contain no other onboard electronics. Testing will be done to ensure no other electronics affect the recovery electronics.	Will be verified when construction and testing is complete.



Re-requirement Number	Requirement	Method	Verification	Verification Status
3.12.1	The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	Inspection	The recovery electronics will be housed in altimeter bays which will contain no other onboard electronics.	Will be verified when construction is complete.
3.12.2	The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	Inspection	The current design includes no other transmitting devices. Safety Officer will monitor updates to design and all payload and launch operations.	Will be verified when construction is complete.
3.12.3	The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	Inspection	The recovery electronics will be housed in altimeter bays which will contain no other onboard electronics. Testing will be done to ensure no other electronics affect the recovery electronics.	Will be verified when construction is complete.
3.12.4	The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Inspection	The airbrakes subsystem and selected payload electronics systems will not interfere or interact in any way with the recovery subsystem.	Will be verified when construction is complete.



7.1.4 PAYLOAD REQUIREMENTS

Table 61: Payload requirements and verification of requirements.

Requirement Number	Requirement	Method	Verification	Verification Status
4.3.1	Teams will design a custom rover that will deploy from the internal structure of the launch vehicle.	Testing	The current design is a sled pulled by a large wheel. We have designed the rover to be deployed from the internal structure of the launch vehicle using a winch system.	Verified with submission of preliminary payload design.
<i>Derived Requirement 4.3.1</i>	In order for the payload to deploy from the launch vehicle we must design a deployment system that will successfully push out the rover from the internal structure.	Testing	The team will develop and test a deployment system that will successfully deploy the rover. The payload team will also work with the vehicle team to ensure the rocket comes down in the best way possible for rover deployment.	Will be verified when testing is conducted.
4.3.2	The rover will be retained within the vehicle utilizing a fail-safe active retention system. The retention system will be robust enough to retain the rover if atypical flight forces are experienced.	Testing	The current design uses a solenoid that will secure the rover in place using magnetic induction. This retaining method was used for our rover last year and was tested during competition week so we know that it is a valuable design. More testing will be done to test the security of this year's rover design. All testing will be recorded and addressed for success and failure which will be inspected and approved by the safety officer.	Will be verified when testing is conducted.



Requirement Number	Requirement	Method	Verification	Verification Status
4.3.3	At landing, and under the supervision of the Remote Deployment Officer, the team will remotely activate a trigger to deploy the rover from the rocket	Testing	Multiple communication systems are being tested and designed. Multiple wireless communications tests will be conducted. All results will be recorded in order to effectively choose the best materials to use.	Will be verified when testing is conducted.
4.3.4	After deployment, the rover will autonomously move at least 10 ft. (in any direction) from the launch vehicle. Once the rover has reached its final destination, it will recover a soil sample.	Testing	Test will be conducted in order to measure the capabilities of the rover. We will perform electrical, obstacle detection, and power consumption tests. Each of these tests will contribute to the rover's capability of moving a successful 10 feet.	Will be verified when testing is conducted.
<i>Derived Requirement 4.3.4</i>	Our team will design and implement an autonomous driving system in order to allow the rover to move in the most efficient way.	Testing	Preliminary prototypes have been made to test electrical and mechanical components to ensure driving and steering capabilities can be achieved.	Will be verified when testing is conducted.
4.3.5	The soil sample will be a minimum of 10 milliliters (mL).	Testing	Tests will be conducted in order to measure the amount of soil that the rover can collect.	Will be verified when testing is conducted.



Requirement Number	Requirement	Method	Verification	Verification Status
<i>Derived Requirement 4.3.5</i>	In order to ensure we obtain a minimum of 10 mL we will design the soil compartment nearly double the size of the needed space so if it fills up we know we got enough soil.	Testing	Tests will be conducted in order to measure the amount of soil that the rover can collect based on the designs tested.	Will be verified when testing is conducted.
4.3.6	The soil sample will be contained in an onboard container or compartment. The container or compartment will be closed or sealed to protect the sample after collection.	Testing	The rover design will include an onboard container in order to protect the soil sample. Testing will be done to test the capabilities of the onboard compartment.	Will be verified when testing is conducted.
4.3.7	Teams will ensure the rover's batteries are sufficiently protected from impact with the ground.	Testing	The rover is designed to protect all electrical components. Stress tests will be conducted to ensure the batteries can withstand impact with the ground. In addition to stress test we will use subscale and full scale flight results to ensure the rover batteries are sufficiently protected and able to survive impact.	To be tested during subscale and full scale launches.



Requirement Number	Requirement	Method	Verification	Verification Status
4.3.8	The batteries powering the rover will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other rover parts.	Inspection	Proper supplies will be used to ensure that the batteries for the rover are secure, safe for transport, and are distinguishable from other rover components. Shipping guidelines and recommendations from IATA and PHMSA will be considered when marking, labeling, and protecting batteries from impact.	Will be verified during construction of the rover.

7.1.5 SAFETY REQUIREMENTS

Table 62: Safety requirements and verification of requirements.

Requirement Number	Requirement	Method	Verification	Verification Status
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	Demonstration	Team will use launch and safety checklists. Subscale launch lists and checklists will be made. Final checklists will be included in FRR report and used during LRR and all launch day operations.	Will be verified by FRR.



Re- quire- ment Num- ber	Requirement	Method	Verification	Verification Status
5.2	Each team must identify a student safety officer who will be responsible for all items in section 5.3.	Demonstration	The Safety Officer has been identified and will ensure safety of participants, spectators and other safety procedures as mentioned in the "Launch Safety" section of NSL Student Handbook. All team activities mentioned in section 5.3 will be supervised to meet specific safety requirements	Verified with submission of Project Proposal
5.3	The role and responsibilities of each safety officer will include, but are not limited to:			
5.3.1	Monitor team activities with an emphasis on Safety during:			
5.3.1.1	Design of vehicle and payload	Demonstration	Safety officer will be present and monitor teams during the design of the vehicle and payload.	Will be verified over the course of the project.
5.3.1.2	Construction of vehicle and payload	Demonstration	Safety officer will be present and monitor teams during the construction of the vehicle and payload.	Will be verified when vehicle and payload construction is complete.



Re- quire- ment Num- ber	Requirement	Method	Verification	Verification Status
5.3.1.3	Assembly of vehicle and payload	Demonstration	Safety officer will be present and monitor teams during the assembly of the vehicle and payload.	Will be verified when vehicle and payload assembly is complete.
5.3.1.4	Ground testing of vehicle and payload	Demonstration	Safety officer will be present and monitor teams during ground testing of the vehicle and payload.	Will be verified during vehicle and payload testing.
5.3.1.5	Subscale launch test(s)	Demonstration	Safety officer will be present and monitor teams during subscale launch tests.	Will be verified during subscale launch tests.
5.3.1.6	Full-scale launch test(s)	Demonstration	Safety officer will be present and monitor teams during fullscale launch tests.	Will be verified during fullscale launch tests.
5.3.1.7	Launch day	Demonstration	Safety officer will be present and monitor teams during Launch Day.	Will be verified on launch day.
5.3.1.8	Recovery activities	Demonstration	Safety officer will be present and monitor teams during all recovery activities.	Will be verified over the course of the project.



Re- quire- ment Num- ber	Requirement	Method	Verification	Verification Status
5.3.1.9	STEM Engagement Activities	Demonstration	Safety officer will be present and monitor teams during STEM Activities.	Will be verified over the course of the project.
5.3.2	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	Demonstration	The most updated checklist will be completed during each and every launch. Safety Officer will supervise all operations using the checklist. All SOAR members will abide by the Safety SOP.	Will be verified in future documents.
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	Demonstration	The Safety Officer will make sure the MSDS/chemical inventory data is up to date and participants are aware of the safety hazards that could occur.	Will be verified throughout completion of project milestones.
5.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Demonstration	Safety Officer will be present throughout the construction of the vehicle and payload which will help guide to write and develop all safety documents and procedures.	Will be verified throughout completion of project milestones.



Re- quire- ment Num- ber	Requirement	Method	Verification	Verification Status
5.4	During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	Demonstration	Safety Officer or designated team lead will supervise all operations to ensure rules and guidance are followed. Before proceeding to test flights, all requirements will be inspected to make sure teams are working accordingly. Effective communication will be taken so the project can run smoothly.	Will be verified throughout the project.
5.5	Teams will abide by all rules set forth by the FAA.	Demonstration	Teams will be knowledgeable of all rules from the FAA. The Safety Officer will ensure these rules are being met throughout the whole timeline of the project. Training records for safety training sessions will be maintained on the SOAR share drive.	Will be verified throughout the project.



8 PROJECT BUDGET AND TIMELINE

8.1 BUDGET

The budget has been created based on material costs, planned test launches, subscale launches, and prior years' expenses. These are projected costs and are subject to change as the need arises.

Table 63: Project budget breakdown.

Category	Budgeted Amount (\$)
Rocket Materials	5400.00
Launch Motors	250.00
Test Launch Motors	750.00
Subscale Materials	850.00
Subscale Motor	350.00
Payload	1200.00
Miscellaneous Hardware	100.00
Travel	1500.00
TOTAL	10400

An overview of the current budget status is shown in Figure 37, while a full itemized list of purchases to date is available in Appendix A: Purchases To Date.



Figure 37: Budget status overview as of November 1, 2018 (from SOAR purchasing database).

8.2.1 GENERAL TIMELINE



Table 64: General project timeline.

Date	Item Due	Team Responsible	Status
August 29th, 2018	NSL General Team Meeting	Payload Team, Vehicle Team	Complete
September 5th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
September 6th, 2018	NSL Handover Meeting	Entire NSL Team	Complete
September 12th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
September 14th, 2018	NSL Proposal Group Writing Session	Entire NSL Team	Complete
September 19th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
September 19th, 2018	NSL Project Proposal Due	Entire NSL Team	Complete
September 26th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
October 3rd, 2018	NSL General Team Meeting	Entire NSL Team	Complete
October 9th, 2018	Outreach Event: Transfer Day	Entire NSL Team	Complete



Date	Item Due	Team Responsible	Status
October 10th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
October 13th, 2018	Outreach Event: Stampede	Entire NSL Team	Complete
October 17th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
October 24th, 2018	NSL General Team Meeting	Entire NSL Team	Complete
October 31st, 2018	NSL General Team Meeting	Entire NSL Team	Complete
November 2nd, 2018	NSL PDR Due Date	Entire NSL Team	Complete
November 7th, 2018	NSL General Team Meeting	Entire NSL Team	
November 9th, 2018	Outreach Event: Manatee County Engineering Day	Entire NSL Team	
November 14th, 2018	Outreach Event: Great American Teach In Pinellas County	Entire NSL Tem	
November 14th, 2018	NSL General Team Meeting	Entire NSL Team	



Date	Item Due	Team Responsible	Status
November 15th, 2018	Outreach Event: Great American Teach In Hillsborough County	Entire NSL Team	
November 16th, 2018	Mount Calvary Junior Academy School Visit	Entire NSL Team	
November 17th, 2018	Outreach Event: Bulls Unite Day	Entire NSL Team	
November 21st, 2018	NSL General Team Meeting	Entire NSL Team	
November 28th, 2018	NSL General Team Meeting	Entire NSL Team	
December 5th, 2018	NSL General Team Meeting	Entire NSL Team	
December 12th, 2018	NSL General Team Meeting	Entire NSL Team	
December 19th, 2018	NSL General Team Meeting	Entire NSL Team	
January 2nd, 2019	NSL General Team Meeting	Entire NSL Team	
January 4th, 2019	NSL CDR Due Date	Entire NSL Team	
January 9th, 2018	NSL General Team Meeting	Entire NSL Team	



Date	Item Due	Team Responsible	Status
January 16th, 2019	NSL General Team Meeting	Entire NSL Team	
January 17th, 2019	Outreach Event: Pinellas County Engineering Day	Entire NSL Team	
January 23rd, 2019	NSL General Team Meeting	Entire NSL Team	
January 30th, 2019	NSL General Team Meeting	Entire NSL Team	
February 2nd, 2019	Outreach Event: Bulls Unite Day	Entire NSL Team	
February 6th, 2019	NSL General Team Meeting	Entire NSL Team	
February 13th, 2019	NSL General Team Meeting	Entire NSL Team	
February 14th, 2019	Outreach Event: Engineering Expo	Entire NSL Team	
February 15th, 2019	Outreach Event: Engineering Expo	Entire NSL Team	
February 20th, 2019	NSL General Team Meeting	Entire NSL Team	



Date	Item Due	Team Responsible	Status
February 27th, 2019	NSL General Team Meeting	Entire NSL Team	
March 4th, 2019	NSL FRR Due Date	Entire NSL Team	
March 6th, 2019	NSL General Team Meeting	Entire NSL Team	
March 13th, 2019	NSL General Team Meeting	Entire NSL Team	
March 20th, 2019	NSL General Team Meeting	Entire NSL Team	
March 27th, 2019	NSL General Team Meeting	Entire NSL Team	
April 3rd, 2019	Team Leaves for Huntsville	Entire NSL Team	
April 6th, 2019	Competition Day	Entire NSL Team	
April 26th, 2019	NSL Post-Launch Assessment Review Due Date	Entire NSL Team	



8.2.2 LAUNCH WEEK TIMELINE

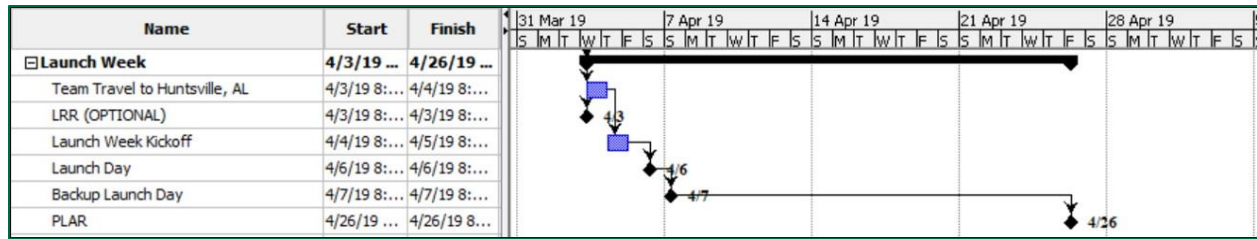


Figure 39: Launch week Gantt chart.

8.2.3 VEHICLE FABRICATION TIMELINE

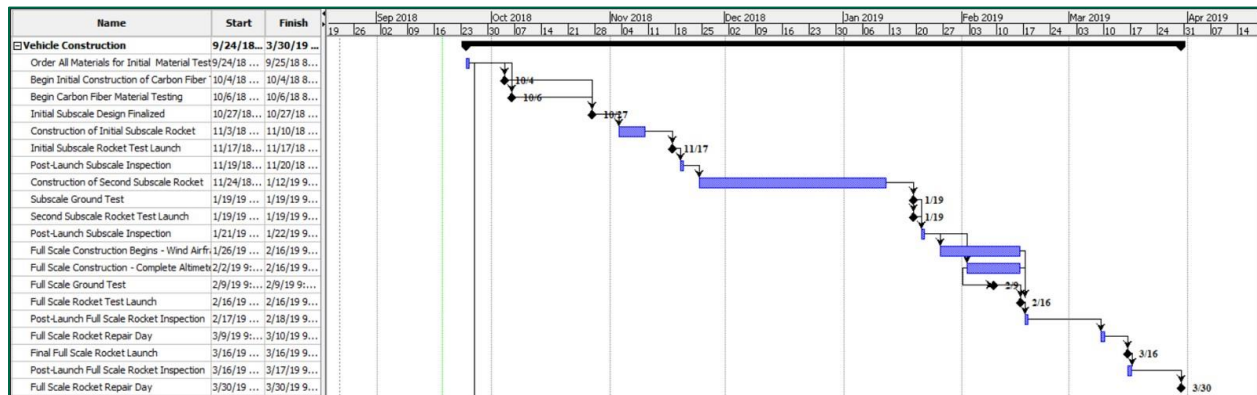


Figure 40: Vehicle fabrication timeline Gantt chart.

Table 65: Vehicle fabrication timeline.

Date	Item Due	Team Responsible	Status
August 31th, 2018	NSL Vehicle Team Meeting	Vehicle Team	Complete
September 10th, 2018	X-Winder Training Session	Vehicle Team	Complete
September 24th, 2018	Order All Materials for Initial Carbon Fiber Testing	Vehicle Team	Complete



Date	Item Due	Team Responsible	Status
September 27th, 2018	Subscale Design Finalized	Vehicle Team	Complete
September 30th, 2018	Order Materials and Hardware for Subscale Launch Vehicle	Vehicle Team	Complete
October 30th, 2018	Order Motors and Parachutes for Subscale Launch Vehicle	Vehicle Team	
November 15th, 2018	Complete Construction of Subscale Launch Vehicle	Vehicle Team	In Progress
November 17th, 2019	Subscale Ground Test	Vehicle Team	
November 17th, 2018	Initial Subscale Test Launch	Vehicle Team, Payload Team	
November 18th, 2018	Begin Initial Construction of Carbon Fiber Tubes for Testing	Vehicle Team	
November 18th, 2018	Post-Launch Subscale Inspection	Vehicle Team	
November 24th, 2018	Begin Construction of Second Subscale Rocket	Vehicle Team	
November 25th, 2018	Begin Carbon Fiber Material Testing	Vehicle Team	



Date	Item Due	Team Responsible	Status
December 20th, 2018	Finalize Full Scale Design (Including Airbrakes)	Vehicle Team, Airbrakes Subteam	
January 1st, 2019	Order All Full Scale Parts and Hardware	Vehicle Team, Airbrakes Subteam	
January 19th, 2019	Second Subscale Test Launch	Vehicle Team, Payload Team	
January 20th, 2019	Post-Launch Subscale Inspection	Vehicle Tea	
February 2nd, 2019	Complete Full Scale Construction, Including All Subsystems	Vehicle Team, Airbrakes Subteam	
February 9th, 2019	Full Scale Ground Test	Vehicle Team	
February 16th, 2019	Full Scale Initial Test Launch	Vehicle Team, Payload Team, Airbrakes Subteam	
February 17th, 2019	Post-Launch Full Scale Rocket Inspection	Vehicle Team, Airbrakes Subteam	
March 9th, 2019	Prepare Full Scale Rocket for Relaunch	Vehicle Team	
March 16th, 2019	Full Scale Payload Test Launch	Vehicle Team, Payload Team, Airbrakes Subteam	



Date	Item Due	Team Responsible	Status
March 17th, 2019	Post-Launch Full Scale Rocket Inspection	Vehicle Team, Airbrakes Subteam	
March 30th, 2019	Prepare Full Scale Rocket for Relaunch	Vehicle Team	

8.2.4 PAYLOAD FABRICATION TIMELINE

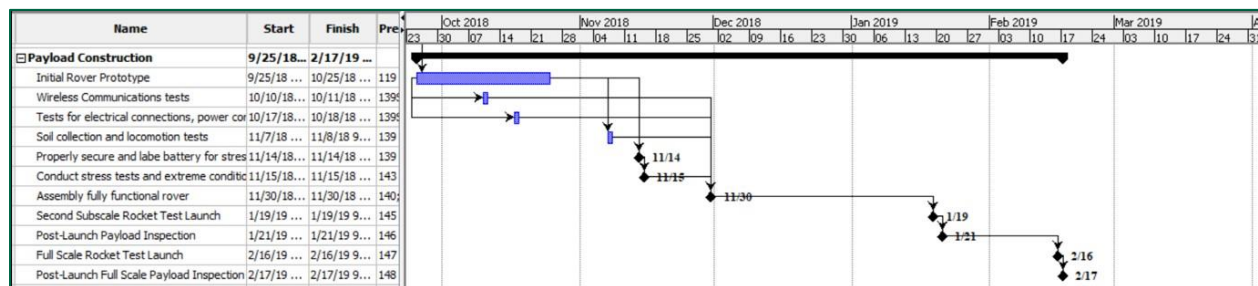


Figure 41: Payload fabrication timeline Gantt chart.

Table 66: Payload fabrication timeline.

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



Date	Item Due	Team Responsible	Status
September 20th, 2018	NSL Payload Team Meeting	Payload Team	Complete
September 20th, 2018	NSL Payload Team Meeting	Payload Team	Complete
October 4th, 2018	NSL Payload Team Meeting	Payload Team	Complete
October 10th, 2018	Wireless Communications tests will be conducted for RF components	Payload Team	Complete
October 11th, 2018	Wireless Communications tests will be conducted for RF components	Payload Team	
October 17th, 2018	Tests for proper electrical connections, power consumption and program debugging will be conducted	Payload Team	
October 18th, 2018	Tests for proper electrical connections, power consumption and program debugging will be conducted	Payload Team	
October 25th, 2018	NSL Payload Team Meeting / complete initial prototype of the rover	Payload Team	
November 7th, 2018	Conduct soil collection and locomotion tests.	Payload Team	
November 8th, 2018	Conduct soil collection and locomotion tests.	Payload Team	



Date	Item Due	Team Respon- sible	Status
November 14th, 2018	Begin properly securing and labeling battery for stress and impact tests.	Vehicle Team, Payload Team	
November 15th, 2018	Conduct stress tests and extreme conditions tests for the battery and electrical components.	Payload Team	
November 29th, 2018	NSL Payload Team Meeting	Payload Team	
November 30th, 2018	Assembly of the fully functional rover completed	Payload team	
December 6th, 2018	NSL Payload Team Meeting	Payload Team	
December 13th, 2018	NSL Payload Team Meeting	Payload Team	
December 20th, 2018	NSL Payload Team Meeting	Payload Team	
January 3rd, 2018	NSL Payload Team Meeting	Payload Team	
January 10th, 2018	NSL Payload Team Meeting	Payload Team	



Date	Item Due	Team Respon- sible	Status
January 17th, 2018	NSL Payload Team Meeting	Payload Team	
January 19th, 2019	Second Subscale Rocket Test Launch/Payload Test	Vehicle Team, Payload Team	
January 21st, 2019	Post-Launch Payload Inspection	Payload Team	
January 24th, 2018	NSL Payload Team Meeting	Payload Team	
January 31st, 2018	NSL Payload Team Meeting	Payload Team	
February 7th, 2018	NSL Payload Team Meeting	Payload Team	
February 14th, 2018	NSL Payload Team Meeting	Payload Team	
February 16th, 2019	Full Scale Rocket Test Launch/Test Payload	Vehicle Team, Payload Team	
February 17th, 2019	Post-Launch Full Scale Payload Inspection	Payload Team	
February 21st, 2018	NSL Payload Team Meeting	Payload Team	



Date	Item Due	Team Responsible	Status
February 28th, 2018	NSL Payload Team Meeting	Payload Team	
March 7th, 2018	NSL Payload Team Meeting	Payload Team	
March 14th, 2018	NSL Payload Team Meeting	Payload Team	
March 21st, 2018	NSL Payload Team Meeting	Payload Team	
March 28th, 2018	NSL Payload Team Meeting	Payload Team	

8.2.5 LAUNCH TIMELINE

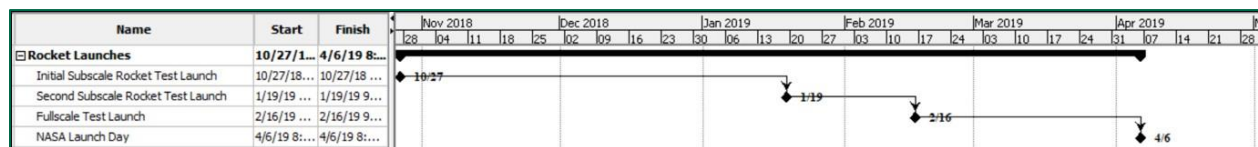


Figure 42: Planned launch Gantt chart.



8.2.6 OUTREACH TIMELINE

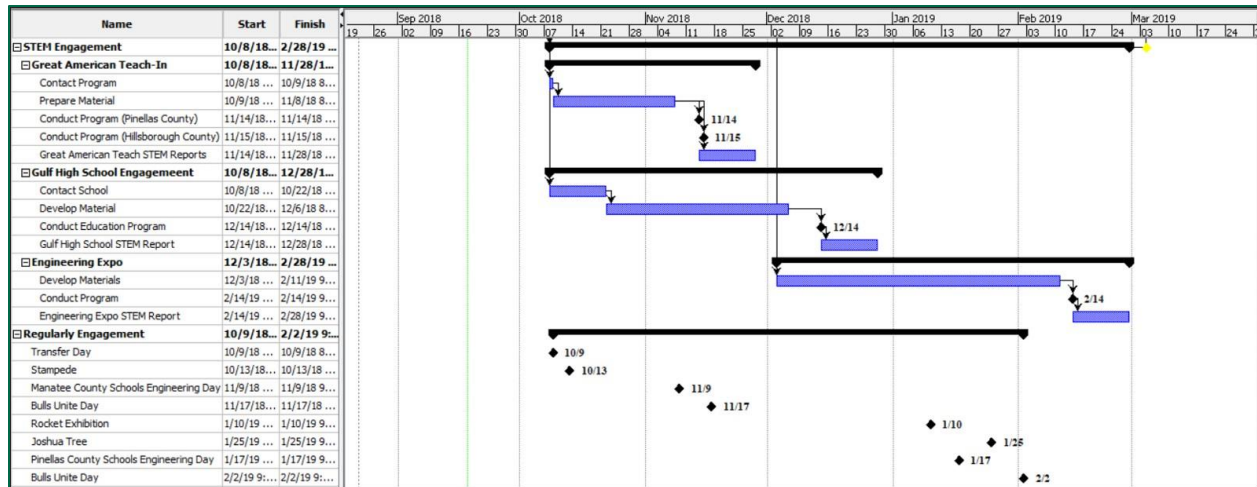


Figure 43: Outreach timeline Gantt chart.

9 EDUCATIONAL ENGAGEMENT

The Society of Aeronautics and Rocketry will work together with local community organizations to provide multiple educational events for our university and surrounding communities. We plan on organizing events with local schools and clubs to inform students on our projects and teach them the importance of STEM Education.

9.1 COMPLETED EVENTS

Table 67: Completed outreach events.

Event	Date	Projected Participants	Description
Stampede	Oct 13, 2018	200	For this event, there was a College Facility Tour with visits to student organization/research tables on the tour. Members of our team set up a booth to talk to local high school students about our organization and the various projects we work on. We brought rockets to display, and 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.



9.2 FUTURE EVENTS

Table 68: Future outreach events.

Event	Date	Projected Participants	Description
Transfer Day	Oct 09, 2018	50	For this event, there will be a College Facility Tour with visits to student organization/research tables on the tour. Members of our team will set up a booth to talk to local high school students about our organization and the various projects we work on. We will bring some of our rockets. We will explain to students how different disciplines and majors are incorporated into our projects in order to fill the engineering, business, and administrative aspects of our teams.
Stampede	Oct 13, 2018	200	For this event, there will be a College Facility Tour with visits to student organization/research tables on the tour. Members of our team will set up a booth to talk to local high school students about our organization and the various projects we work on. We will bring some of our rockets. We will explain to students how different disciplines and majors are incorporated into our projects in order to fill the engineering, business, and administrative aspects of our teams.



Event	Date	Projected Participants	Description
Manatee County Engineering Day	Nov 09, 2018	120	<p>For this event, there will be college lab tours and demonstrations with visits to student organization/research tables. Members of our team will set up a booth to talk to local high school students about our organization and the various projects we work on. We will bring some of our larger rockets that were built for specific competitions and one of our Tripoli Level 1 certification rockets. We will show students the parts of the rockets including their parachutes, fins, and nosecones. We will discuss the specific design of each rocket and what its function was. We want to share with students what possibilities our university and organization can provide for them especially when it comes to valuable hands-on STEM experience. We will explain to students how different disciplines and majors are incorporated into our projects in order to fill the engineering, business, and administrative aspects of our teams.</p>
Great American Teach in Pinellas County	Nov 14, 2018	TBD	<p>For this event, USF SOAR will be going to a school in Pinellas County to demonstrate and engage students in a hands on STEAM activity. SOAR will be partner with a local school to introduce students to career options, hobbies and activity that they may never otherwise experience.</p> <p>This will be demonstrated through a PowerPoint presentation and hands on activities with the students. We will talk about the engineering cycle and how it applies to our rocket building. We will discuss how an idea is developed from the design stages to the building stages.</p> <p>We will stress the process of what it takes to build something along with the safety measures that must be met. We will also stress that because the engineering cycle is in fact a cycle that it takes repetitive testing until you get the final product. We will also talk about STEM education and how all of the disciplines come together to complete a project.</p>



Event	Date	Projected Participants	Description
Great American Teach in Hillsborough County	Nov 15, 2018	TBD	For this event, USF SOAR will be going to a school in Hillsborough County to demonstrate and engage students in a hands on STEAM activity. SOAR will be partner with a local school to introduce students to career options, hobbies and activity that they may never otherwise experience. This will be demonstrated through a PowerPoint presentation and hands on activities with the students. We will talk about the engineering cycle and how it applies to our rocket building. We will discuss how an idea is developed from the design stages to the building stages. We will stress the process of what it takes to build something along with the safety measures that must be met. We will also stress that because the engineering cycle is in fact a cycle that it takes repetitive testing until you get the final product. We will also talk about STEM education and how all of the disciplines come together to complete a project.
Mount Calvary Junior Academy School Visit	Nov 16, 2018	TBD	For this event SOAR will be going to the school Mount Calvary Junior Academy in order to teach them about rocketry and STEM education. We be teaching the students how to make stomp rockets and launching them.
Bulls Unite Day	Nov 17, 2018	150	For this event, there will be a College Facility Tour with visits to student organization/research tables on the tour. Members of our team will set up a booth to talk to local high school students about our organization and the various projects we work on. We will bring some of our rockets. We want to share with students what possibilities our university and organization can provided for them especially when it comes to valuable hands-on STEM experience. We will explain to students how different disciplines and majors are incorporated into our projects in order to fill the engineering, business, and administrative aspects of our teams.



Event	Date	Projected Participants	Description
Pinellas County Engineering Day	Jan 17, 2019	120	For this event, there will be college lab tours and demonstrations with visits to student organization/research tables. Members of our team will set up a booth to talk to local high school students about our organization and the various projects we work on. We will bring some of our rockets. We want to share with students what possibilities our university and organization can provide for them especially when it comes to valuable hands-on STEM experience. We will explain to students how different disciplines and majors are incorporated into our projects in order to fill the engineering, business, and administrative aspects of our teams.
Bulls Unite Day	Feb 02, 2019	150	For this event, there will be a College Facility Tour with visits to student organization/research tables on the tour. Members of our team will set up a booth to talk to local high school students about our organization and the various projects we work on. We will bring some of our rockets. We will explain to students how different disciplines and majors are incorporated into our projects in order to fill the engineering, business, and administrative aspects of our teams.
Engineering Expo	Feb 14-15, 2019	TBD	The Engineering Expo is a two-day event that features hands-on exhibits and shows that help encourage more students to pursue careers in the STEM fields. This event provided us with an opportunity to teach local students about our organization and how the value of a STEM education and experience. We plan to engage these students with an interactive activities that will inspire them to seek a future in STEM and hopefully rocketry.



Event	Date	Projected Participants	Description
Rocket Exhibition	TBD	TBD	<p>This is 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:</p> <p>A showcase of our organization's past rockets with information describing what they were created for and some details about the design.</p> <p>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.</p> <p>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.</p> <p>A presentation about our organization's projects and rocket.</p>
Joshua House	TBD	TBD	<p>Our organization will partner with an organization on campus who embraces education in STEAM.. Members will go to Joshua House, a safe haven for abused, neglected, and abandoned children in the Tampa Bay Area. We will invite any child at the home who wanted to participate to learn how to build water rockets and measure the altitude after launching.</p>
Largo High School Presentation	TBD	60	<p>As part of our educational engagement, we will engage the local high school, Largo High School in the Tampa Bay area. A members is setting up an event with a prior chemistry teacher will organize an event at their prior high school. SOAR will conduct a presentation and some activities with some of the students in the school. We will stay with the chemistry teacher Sommer Paquet the entire day, and speak with each of their classes. We plan to educate the students on our NASA Student Launch rocket and rover design as well as overall basic rocket dynamics. Finally, we're planning to conduct a hands-on activity that involves the students building and testing bottle rockets.</p>



Event	Date	Projected Participants	Description
Girl Scouts of West Central Florida	TBD	TBD	For this event, SOAR will be partnering with some local girl scouts in order to teach them about rocketry and STEM education. We be teaching the students how to make stomp rockets and launching them. We might also be helping the scouts start either a rocketry or a space science badge.



APPENDIX A: PURCHASES TO DATE

Table 69: Itemized list of all project purchases to date (from the SOAR Purchasing Database).

Item Name	Supplier	Product Number	Unit Price	Qty	Total Price	Category	Req. Date	Received Date
Copper Tubing for Drinking Water, 2 feet, 1 1/8" OD, Low Pressure	McMaster Carr	5175K136	9.12	1	9.12	Vehicle Tools	9/16/2018	9/25/2018
Raspberry Pi 3.0 B+	Amazon		39.7	1	39.7	Payload Supplies	9/18/2018	
TB6612 Motor Driver Breakout Board	Amazon		7.49	1	7.49	Payload Supplies	9/18/2018	
DROK Voltage Stepdown Converter	Amazon		11.58	1	11.58	Payload Supplies	9/18/2018	
Raspberry Pi Case	Amazon		5.59	1	5.59	Payload Supplies	9/18/2018	
Grafix R05DC4025 Clear .005 Dura-Lar 40-Inch-by-25-Feet, Roll	Amazon	B004QVIXCG	32.78	1	32.78	Vehicle Supplies	9/27/2018	10/5/2018
CROWN Mold Release and Protector 13 oz. Aerosol Can	Huron Industrial Supply	1-125-3470	5.9	2	11.8	Vehicle Supplies	9/27/2018	10/12/2018



Scotch Heavy Duty Shipping Packaging Tape, 1.88 inches x 800 inches, 6 Rolls with Dispenser, 1.5 inch Core (142-6)	Amazon	B000J07BRQ	11.64	1	11.64	Vehicle Supplies	9/27/2018	10/12/2018
820Resin Gal 824Slow Hardnr 0.2Gal pumps 114.99USD	Soller Composites		114.99	1	114.99	Vehicle Supplies	9/27/2018	10/12/2018
FNC4.0-4.5-1-VK-FW-MT	Wildman Rocketry	FNC4.0-4.5-1-VK-FW-MT	69	1	69	Subscale Supplies	9/24/2018	10/12/2018
G12CT-4.0	Wildman Rocketry	G12CT-4.0	2.6	24	62.4	Subscale Supplies	9/27/2018	10/12/2018
G12-4.0 / 4 Foot Piece	Wildman Rocketry	G12-4.0	93.4	2	186.8	Subscale Supplies	9/27/2018	10/12/2018
Structural Fiberglass Sheet / 24" Wide x 24" Long, 1/8" Thick	McMaster Carr	8537k43	42.49	1	42.49	Subscale Supplies	9/27/2018	10/5/2018
U-Bolt / with Mount Plate, Zinc-Plated Steel, 3/8"-16 Thread Size, 1-1/2" ID	McMaster Carr	3043t78	1.85	4	7.4	Subscale Supplies	9/27/2018	10/5/2018



Oval Shaped Threaded Connecting Link / Zinc-Plated Steel, 5/16" Thickness, 3/8" Opening, Not for Lifting	McMaster Carr	8947t17	2.44	4	9.76	Subscale Supplies	9/27/2018	10/5/2018
RRC2+ Altimeter	Missile Works	RRC2+	44.95	2	89.9	Subscale Supplies	9/27/2018	10/12/2018
RRC3 Sport Altimeter	Missile Works	RRC3	69.95	2	139.9	Subscale Supplies	9/27/2018	10/12/2018
1/4" Tubular Kevlar Shock Cord	Top Flight Recovery	TUK-1/4"	2.5	17	42.5	Subscale Supplies	9/27/2018	10/12/2018
FCP18X18	Wildman Rocketry	FCP18X18	10.95	3	32.85	Subscale Supplies	9/27/2018	10/12/2018
541706M	Wildman Rocketry	541706M	190	1	190	Subscale Supplies	9/24/2018	
2-Pole Rotary Switch	Missile Works	SW-2	4.75	4	19	Subscale Supplies	9/24/2018	10/12/2018
Battery Holder / for 9V Battery, Snap Holder	McMaster Carr	7712K62	2.86	4	11.44	Subscale Supplies	9/24/2018	10/5/2018
Adhesive-Mount Nut / Zinc-Plated Steel, 5/16"-18 Thread Size	McMaster Carr	98007A250	7.46	1	7.46	Subscale Supplies	9/24/2018	10/5/2018



Thread-Locking Button Head Hex Drive Screws / Alloy Steel, 5/16"-18 Thread, 1/2" Long	McMaster Carr	92360a410	3.12	1	3.12	Subscale Supplies	9/24/2018	10/5/2018
RA54	Wildman Rocketry	RA54	38	1	38	Subscale Supplies	9/24/2018	10/12/2018
AeroTech K1103X	Wildman Rocketry	K1103X	114.99	1	114.99	Subscale Supplies	10/5/2018	
G12-2.1 / 2 Foot Piece	Wildman Rocketry	G12-2.1	28.8	1	28.8	Subscale Supplies	9/27/2018	10/12/2018
18-8 Stainless Steel Countersunk Washer / for 5/16" Screw Size, 0.38" ID, 0.891" OD	McMaster Carr	98466A030	7.37	1	7.37	Subscale Supplies	9/30/2018	
Female Threaded Hex Standoff / Zinc-Plated 12L14 Steel, 3/16" Hex, 1/2" Long, 4-40 Thread	McMaster Carr	91920A533	1.5	10	15	Subscale Supplies	9/30/2018	
High-Strength Steel Nylon-Insert Locknut / Grade 8, 3/8"-16 Thread Size	McMaster Carr	90630A121	3.2	1	3.2	Subscale Supplies	9/30/2018	



Cast Wire Rope Clamp - Not for Lifting / Zinc- Plated Iron, for 1/16" Rope Diameter	McMaster Carr	30325T13	0.37	4	1.48	Vehicle Supplies	9/30/201 8	
18-8 Stainless Steel Wire - Not for Lifting / Extra Flexible, 7x19 Construction, 1/16" Diameter	McMaster Carr	3461T96	9.7	1	9.7	Vehicle Supplies	9/30/201 8	
TowerPro MG90S Mirco Servo	Amazon		8.99	1	8.99	Payload Supplies	10/5/201 8	
4 Channel Relay	Amazon		7.59	4	30.36	Payload Supplies	10/5/201 8	
Battery Charger	Amazon		31.44	1	31.44	Payload Supplies	10/5/201 8	
1300 mAh Batteries	Amazon		23.43	3	70.29	Payload Supplies	10/5/201 8	
130 pack jumper wires	Amazon		7.89	1	7.89	Payload Tools	10/5/201 8	
Alligator clips 10 pack	Amazon		6.27	1	6.27	Payload Tools	10/5/201 8	
12V DC 250N Electric Lifting Magnet	Amazon		11.59	3	34.77	Payload Supplies	10/7/201 8	



Hand Vacuum	Amazon		19.99	1	19.99	Payload Supplies	10/9/2018	
Pulley,Gear,belt kit	Amazon		7.99	1	7.99	Payload Supplies	10/9/2018	
IR Remote Control Kit	Amazon		5.58	1	5.58	Payload Supplies	10/10/2018	
L298N Motor Driver 2 pack	Amazon		9.89	1	9.89	Payload Supplies	10/10/2018	
IR Proximity Sensor	Amazon		9.99	1	9.99	Payload Supplies	10/11/2018	
Collision sensor	Amazon		5.16	1	5.16	Payload Supplies	10/11/2018	
PhotoResistors	Amazon		5.35	1	5.35	Payload Supplies	10/11/2018	
Smart Electronics 3pin KEYES KY-017 Mercury Switch Module for Arduino diy Starter Kit KY017	Newegg	9SIADTU5T50155	4.48	1	4.48	Payload Supplies	10/11/2018	
Pressure/Altitude/Temperature Sensor	Amazon		11.99	1	11.99	Payload Supplies	10/11/2018	
1 Kg PLA Spool - Gray	Amazon		19.99	2	39.98	Uncategorized	10/17/2018	



APPENDIX B: MILESTONE REVIEW FLYSHEET

Milestone Review Flysheet 2018-2019

Institution	University of South Florida		Milestone	PDR	
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Vehicle Properties	
Total Length (in)	134
Diameter (in)	6
Gross Lift Off Weight (lb)	46.2
Airframe Material(s)	Carbon Fiber/Fiberglass
Fin Material and Thickness (in)	Carbon Fiber, 1/8
Coupler Length(s)/Shoulder Length(s) (in)	6

Motor Properties	
Motor Brand/Designation	Cesaroni L1410
Max/Average Thrust (lb)	375.3/316.8
Total Impulse (lbf-s)	1085.45
Mass Before/After Burn (lb)	11.3 / 5.3
Liftoff Thrust (lb)	1500
Motor Retention Method	75mm Aerotech Retaining Ring

Stability Analysis	
Center of Pressure (in. from nose)	96.7
Center of Gravity (in. from nose)	82
Static Stability Margin (on pad)	2.45
Static Stability Margin (at rail exit)	2.45
Thrust-to-Weight Ratio	8.13
Rail Size/Type and Length (in)	Type 1515, 144
Rail Exit Velocity (ft/s)	58.2

Ascent Analysis	
Maximum Velocity (ft/s)	594
Maximum Mach Number	0.528
Maximum Acceleration (ft/s ²)	252
Target Apogee (ft)	5000
Predicted Apogee (From Sim.) (ft)	5144

Recovery System Properties - Overall	
Total Descent Time (s)	76.47
Total Drift in 20 mph winds (ft)	2422.66

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

Recovery System Properties - Recovery Electronics				
Primary Altimeter Make/Model		Missile Works RCC2+		
Secondary Altimeter Make/Model		Missile Works RCC3		
Other Altimeters (if applicable)				
Rocket Locator (Make/Model)		Audible Beacon (TBD)		
Additional Locators (if applicable)				
Transmitting Frequencies (all - vehicle and payload)		***Required by CDR*** (Complete on pages 3 and 4)		
Describe Redundancy Plan (batteries, switches, etc.)		All altimeters will have fully redundant backup systems, with completely isolated batteries, switches, wiring, electronic matches, and deployment charges.		
Pad Stay Time (Launch Configuration)		120+ minutes		

Recovery System Properties - Drogue Parachute				
Manufacturer/Model		SkyAngle		
Size or Diameter (in or ft)		20'		
Main Altimeter Deployment Setting		Apogee + 1.5s		
Backup Altimeter Deployment Setting		Apogee + 1.5s		
Velocity at Deployment (ft/s)		50		
Terminal Velocity (ft/s)		132		
Recovery Harness Material, Size, and Type (examples - 1/2 in. tubular Nylon or 1 in. flat Kevlar strap)		1/2" Tubular Kevlar		
Recovery Harness Length (ft)		25		
Harness/Airframe Interfaces		3/16" Quick Links and D-Bolts attached to carbon fiber 1/4" bulkheads.		
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	10800			

Recovery System Properties - Main Parachute				
Manufacturer/Model		SkyAngle Cert 3-XL		
Size or Diameter (in or ft)		89 sq ft		
Main Altimeter Deployment Setting (ft)		650		
Backup Altimeter Deployment Setting (ft)		650		
Velocity at Deployment (ft/s)		132		
Terminal Velocity (ft/s)		10.5		
Recovery Harness Material, Size, and Type (examples - 1/2 in. tubular Nylon or 1 in. flat Kevlar strap)		1/2" tubular kevlar		
Recovery Harness Length (ft)		33.5		
Harness/Airframe Interfaces		3/16" Quick Links and D-Bolts attached to carbon fiber 1/4" bulkheads.		
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	62.08	37.93		



Milestone Review Flysheet 2018-2019

Institution University of South Florida

Milestone PDR

Payload

Payload 1 (official payload)	Overview
	The Phoenix rover concept was inspired by a reversed snowmobile, with drive wheels pulling along the rest of the body. The rover will contain an Arduino, batteries, soil recovery module, and all guidance sensors. The projected diameter is 5.67"; the internal diameter of the rocket body. The rover will be seated inside a reserved section alongside the leveling system that will prevent deployment issues. The rover will roll out of the vehicle and complete the mission objective after an initiating signal has been received.
Payload 2 (non-scored payload)	Overview

Test Plans, Status, and Results

Ejection Charge Tests	Planned, not yet completed. Will be performed the day before launches.
Sub-scale Test Flights	First launch scheduled for November 17, 2018 and second launch for January 19, 2019.
Vehicle Demonstration Flights	Full scale initial test launch scheduled for February 16, 2019.
Payload Demonstration Flights	Full scale demonstration flight with active payload scheduled for March 16, 2019.



Milestone Review Flysheet 2018-2019

Institution University of South Florida

Milestone PDR

Transmitter #1

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

Transmitter #2

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

Transmitter #3

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

Transmitter #4

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



Milestone Review Flysheet 2018-2019

Institution University of South Florida

Milestone PDR

Transmitter #5

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

Transmitter #6

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

Additional Comments

