



## **NASA Student Launch 2017**

Preliminary Design Review

*November 3, 2017*



**SOCIETY OF AERONAUTICS AND ROCKETRY**

4202 East Fowler Avenue MSC Box 197  
Tampa, Florida 33620

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# 1 Team Summary

## 1.1 Team Name & Mailing Address

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

4202 East Fowler Avenue MSC Box 197

Tampa, Florida 33620

## 1.2 Team Personnel

### 1.2.1 Team Mentor, NAR/TRA Number and Certification Level

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

### 1.2.2 Team Academic Advisor

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

### 1.2.3 Safety Officer

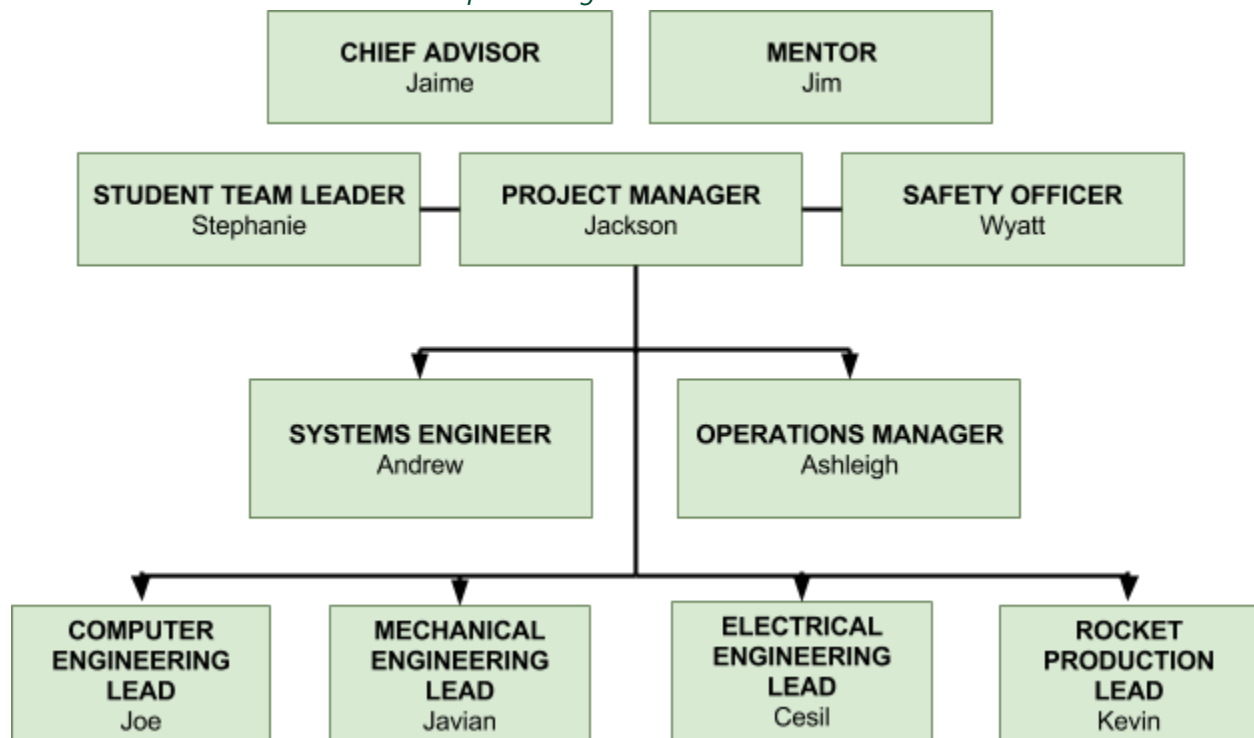
**Team Safety Officer:** Wyatt Boyatt, Sophomore Undergraduate, Mechanical Engineering, 352-874-0193, wyattboyatt@mail.usf.edu

### 1.2.4 Student Team Leader

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

### 1.2.5 Team Structure and Members

#### *1.2.5.1 Team Leadership and Organization Chart*



### 1.2.5.2 Team Members

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

*Table 1: Functional teams and descriptions.*

Functional Team	Team Lead	Description
Rocketry Team	Kevin Kirkolis	Rocketry Team is responsible to design, build, test, and modify launch vehicle and all recovery systems.
Rover Team	Javian Hernandez	Rover Team is responsible to develop, design, test, and prepare the rover payload system, as well as the rover deployment system. The team will implement all mechanical, electrical, and computer engineering designs and systems necessary for a rover that meets all design criteria.
CSCE Team	Joseph Caton	CSCE Team is responsible to design all computer hardware and software needs for the design of the rover and rocket. They will work closely with the electrical engineer lead to ensure system will have continuity. The team lead will remain in close contact with the systems engineer to make sure that all systems function properly.

### 1.2.5.3 Additional Duties

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

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

1.2.5.3.2Outreach Coordinators: Ashleigh Stevenson and Josh Lowenberg. Develops and organizes outreach events.

1.2.5.3.3Computer Science Lead: Linggih Saputro. Primary code developer and computer design expert.



### 1.3 NAR/TRA Affiliates

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

## 2 Launch Vehicle Summary

SOAR's launch vehicle will consist of a 5.148-inch diameter G12 filament wound fiberglass tube with a 5-inch filament wound 5 to 1 von Karman nosecone (metal tip), 5-inch G12 filament wound fiberglass couplers, and  $\frac{1}{8}$ " structural fiberglass trapezoidal swept trailing edge fins. The design will also incorporate a recovery system consisting of two redundant altimeters, a drogue and two XL main parachutes,  $\frac{1}{2}$ " tubular Kevlar shock cord, and a tether release system. The recovery system will be designed to descend in four sections under two parachutes: the nosecone and rover compartment under one parachute, and the altimeter bay and booster section under another. The motor mount is 78 mm, and will be designed for a Cesaroni L995 three-grain solid rocket motor.

### 2.1 Size and Mass

*Table 2: Launch vehicle size and mass.*

Diameter	5.148 in
Length	93 in
Projected Unloaded Weight	22.2 lbs
Projected Loaded Weight	30.2 lbs
Projected Motor	L995
Airframe Material	Fiberglass



Figure 1: Overview drawing of launch vehicle assembly.

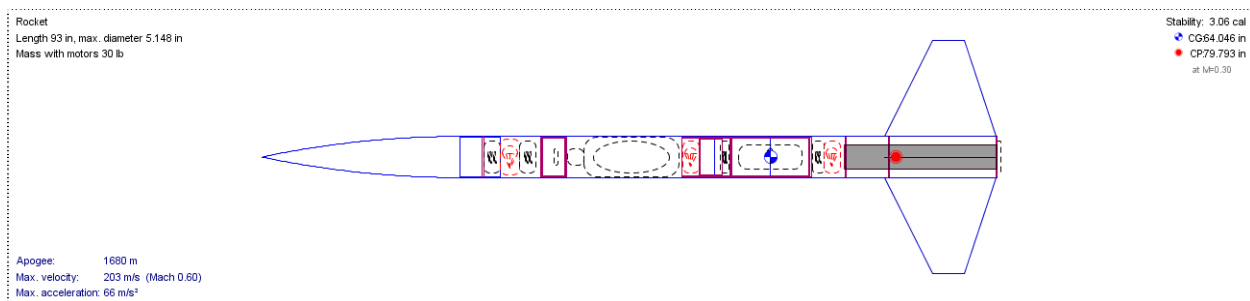


Figure 2: 3D overview of launch vehicle assembly.



## 2.2 Motor Choice

The current motor options for use in the launch vehicle are the Cesaroni L995 75mm motor and the Cesaroni L800 75mm motor with the below specifications. The L995 is the current leading choice. These motors were chosen because the thrust available made reaching an apogee of 5,280 feet possible while allowing for fine adjustment of projected apogee through alteration of fin design, size, sweep angle, and tip and root chord and potentially through removable ballast. Also, these motors, under most configurations slightly exceed the target apogee altitude and, in our previous experience, the constructed rocket is most often somewhat heavier than the simulated weight due to epoxy and parts not accounted for in the simulation software.

Table 3: Cesaroni L995 motor data.

Average Thrust	996.5N
Maximum Thrust	1404.5N
Total Impulse	3618.0Ns
Burn Time	3.6s



Case Info	Pro75-3G
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## 2.3 Recovery System

### 2.3.1 Recovery System Description

A dual deployment system will be sequentially staged from two different recovery bays. This configuration will allow for complete separation of the rover compartment in order to reduce the possibility of entanglement of shock cords and obstruction of the exit area for the rover. The system will consist of one drogue, two main parachutes, a ½" tubular Kevlar shock cord, and a tender descender tether detachment system. The tender descender detachment system will prevent the rover compartment from being dragged along the ground and also prevent the parachute from obstructing the rover's point of exit from the compartment.

## 2.4 Milestone Review Flysheet

Please see Appendix 11.2.

# 3 Payload Summary

## 3.1 Payload Title

Deployable rover payload has been chosen and will be referred to as the Sidewinder Rover throughout.

## 3.2 Rover Design Summary

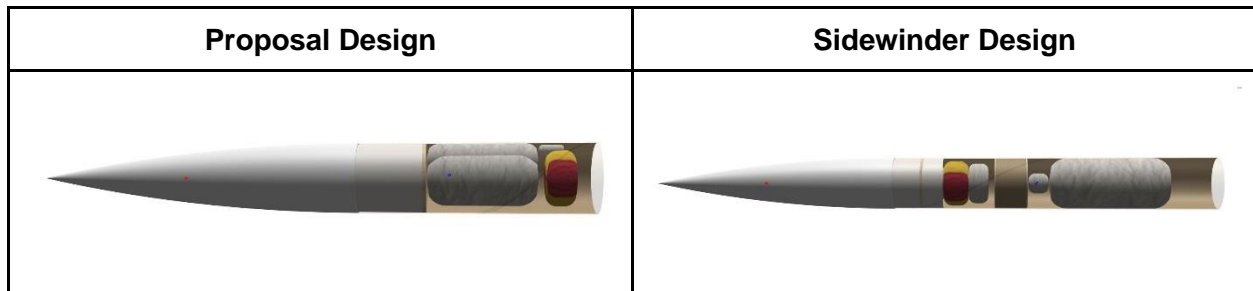
The sidewinder rover concept was born from the idea of maximizing the possible vehicle wheel diameter. This diameter at the time of this writing is the five-inch internal diameter of the rocket body. Rover design as enough room to meet and exceed mission requirements. If this space for instrumentation is not needed design is also easily shortened to reduce space and weight. Design allows for side loading into cargo section. That allows the rover wheels to be maximized to match inner diameter of rocket body. This is the largest solid wheel possible for this system. The design also incorporates Newtonian legs to improve traction of the two-wheeled system.

# 4 Changes Made Since Proposal

## 4.1 Changes Made to Vehicle Criteria

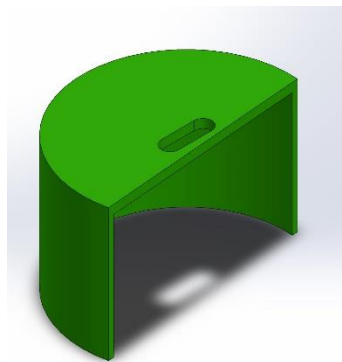
The current and preferred rocket design was heavily influenced by the Sidewinder rover design. The new design adds a second altimeter bay and lessens the chance of parachute obstruction after touchdown. The main feature of the proposal design was the nosecone and rover compartment's permanent attachment throughout flight, with the goal of aiding the rover into proper orientation upon landing. The focused design in the PDR has a second altimeter, separating the nosecone from the rover compartment, thus relocating the recovery hardware from the rover's exit to an area distant from the rover.



*Figure 3: Changes to rover compartment design.*

Notice that the parachute is blocking the rover's exit in the Proposal Design, versus being separate and deployed with a secondary, redundant altimeter.

A piston system, like the one used for the 2017 NSL Launch, was considered and included in this new rocket design. The piston system will likely be made of high-infill 3D printed ABS/PLA plastics or phenolic, and will help aid in the separation of the rover compartment from the internal coupling stage. This is a simple inanimate mechanism that utilizes the forces of black powder charges to eject internal components.

*Figure 4: Cross section of piston system.*

## 4.2 Changes Made to Payload Criteria

The rover has been completely redesigned. The previous design involved a small vehicle on treads. The problem with this design was it failed to maximize the full diameter of the rocket cargo area. The previous rover was able to be loaded into the cargo area facing forward. In this position it had to sacrifice wheel diameter and wheel base. The wheel diameter of previous rover would have been less than three inches. This problem was reduced by loading the rover into the cargo area sideways. In this position the wheel diameter can be the same as the internal diameter of the cargo area. The wheel base is only limited by the length of the cargo area.

*Figure 5: Changes to payload design.*

Previous Design	Current Design
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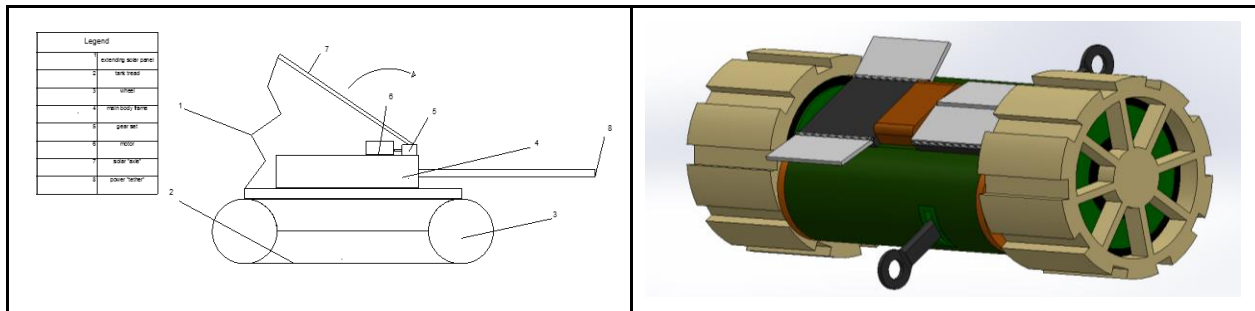


Table 4: Changes to payload design and justification.

Subsystem	Previous design	Current design	Reason for change
Drive	Dual tank tread drive.	Di wheel with five-inch diameter wheels	Previous design despite having tread had small wheel diameter, thereby reducing its ability to climb over obstacles. The side by side di wheel allows for wheel diameter to be maximized to the same diameter as the internal rocket body.
Tether Power Connection	Rover was provided power via a tether to the rocket body segment.	Rover power is provided by onboard battery packs.	The benefit of having external power supplied did not outweigh the risk of entanglement from the tether. It was decided that the rover could carry enough power to exceed mission requirements.
Solar Panels	Single accordion style panel	Four redundant center hinged panels	Additional redundancy





		mounted on top of rover with options to mount second set on bottom for redundancy.	maximizes probability of success.
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### 4.3 Changes Made to Project Plan

Currently, the project plan is on schedule, with supplies and parts for construction of the subscale ordered and the first build day still scheduled for November 4th. This means that major changes are not necessary to the plan at this time. However, a more detailed project plan is laid out in the sections below.

## 5 Vehicle Criteria

### 5.1 Selection, Design, and Rationale

#### 5.1.1 Mission Statement

The University of South Florida Society of Aeronautics and Rocketry will design and build a rocket and payload, guided by the criteria set forth in the 2018 NASA Student Launch Handbook, that will win one or more categories of award for the 2018 NASA Student Launch Competition, while meeting or exceeding all documentation deadlines and requirements. The chosen payload is a rover, which will be designed to deploy from a section of the rocket, autonomously move at least five feet, and deploy solar panels. The project will culminate in a successful rocket launch and payload delivery at the official Launch Day in Huntsville, AL. SOAR's participation and success in this competition will further its goal of becoming the preeminent engineering organization at the University of South Florida, recruiting dedicated and talented members to increase our capabilities, and encouraging the University of South Florida College of Engineering to add an Aerospace Engineering Major to its catalog.

#### 5.1.2 Mission Success Criteria

The following table will show the requirements that need to be met in this mission, how we will meet the requirements, and the verification of meeting them.

*Table 5: Detailed mission requirements and confirmation methods.*

Requirement	Method	Verification
<b>NASA Student Launch Initiative Required Success Criteria</b>		
The vehicle will deliver the payload to an apogee altitude of 5,280 feet above ground level	The rocket will be built with a motor designed to reach an apogee of 5,280 ft. Consideration	OpenRocket simulations, subscale and full-scale testing. Current apogee for chosen motor



(AGL).	will be given to the motor options detailed herein and also to the possibility of removable ballast or fin redesign.	is 5298 feet.
The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner.	The altimeter in the electronics bay will be able to record the altitude of the rocket throughout the whole flight.	NSL Inspection as well as inspected and approved by the safety officer. Full-scale testing, pre-launch checklist.
All recovery electronics shall be powered by commercially available batteries and an electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver	The altimeter and GPS system will be powered by a 9V battery that it available commercially. There will also be a GPS in every independent section of the launch vehicle.	NSL Inspection as well as inspected and approved by the safety officer.
The launch vehicle shall be designed to be recoverable and reusable.	The launch vehicle will contain parachutes on every separate or tethered part of the rocket that will be released at apogee and an altitude that will allow it time to open up properly and safely.	Design, simulations, subscale and full-scale testing.
The launch vehicle shall have a maximum of four (4) independent sections.	The rocket will be broken up into four sections: the nosecone, rover compartment, altimeter bay, and the booster. The nose cone and rover compartment will be tethered together, as will the altimeter bay and booster.	Recovery system and launch vehicle design. NSL Inspection as well as inspected and approved by the safety officer.
The launch vehicle shall be limited to a single stage.	The launch vehicle will only contain one booster that will light to start the flight.	Launch vehicle design. NSL Inspection as well as inspected and approved by the safety officer.
The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal Aviation Administration flight waiver opens.	There will be a Final Assembly and Launch Procedure checklist that will ensure that the launch vehicle will be safely prepared and ready to launch within the 4 hours.	There will be Final Assembly and Launch Procedure Checklist before the test flights of the subscale rocket and the full-scale rocket and will be time ourselves to ensure we completed the list safely and within the time of 4



		hours. Subscale and full-scale test launches.
The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	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.	Full-scale and subscale testing. It will also be timed in order to make sure the battery life last, at minimum, an hour.
The launch vehicle shall be capable of being launched by a standard 12-volt direct current firing system.	The ignitor used in the rocket will be able to withstand a 12-volt DC firing system.	Launch vehicle design, full-scale and subscale testing.
The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch.	The only required external circuitry will be the 12-volt direct current firing system that is compatible with the ignitor in the launch vehicle.	NSL Inspection as well as inspected and approved by the safety officer.
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).	The motor being used in the launch vehicle will be a Cesaroni L995 or L800 from which is certified by the National Association of Rocketry and it made of ammonium perchlorate.	NSL Inspection as well as inspected and approved by the safety officer.
Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria.	Our design did not contain a pressure vessel.	NSL Inspection as well as inspected and approved by the safety officer.
The total impulse provided by a University launch vehicle shall not exceed 5,120 N-s.	The motor chosen is not bigger than an L motor and has a total impulse of 3618 and 3757 N-s, respectively.	NSL Inspection as well as inspected and approved by the safety officer.
The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	The center of pressure and the center of gravity in comparison to the diameter of the body tube	Full-scale and Subscale testing as well as simulations of our rocket in the simulation programs.



	will have a minimum stability margin of 2.0.	Current simulations for configurations under consideration place stability margin at 3.04 and 3.06 calibers.
The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	The motor that was chosen for the rocket will allow the rocket to achieve a minimum of 52 fps at rail exit.	Full-scale and Subscale testing as well as simulations of our rocket in the simulation programs. Current simulations for configurations under consideration place velocity at rail exit at 65 fps.
All teams shall successfully launch and recover a subscale model of their rocket prior to CDR.	SOAR will have a subscale model ready and launched prior to CDR.	Evidence of subscale testing.
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.	The full-scale rocket will be built and launched as well as recovered prior to the FRR and it will be a replica of the rocket flown on launch day.	Evidence of full-scale testing as well as NSL inspection.
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.		
The vehicle must be flown in its fully ballasted configuration during the full-scale test flight.	The completed payload or equivalent simulated weight will be used in the full-scale test flight.	Safety officer inspection. Rover design team verification.
Any structural protuberance on the rocket shall be located aft of the burnout center of gravity	The launch vehicle is designed to ensure all structural protuberances are aft the burnout center of gravity.	NSL Inspection as well as inspected and approved by safety officer.
Vehicle Prohibitions: a) The launch vehicle shall not utilize forward canards. b) The launch vehicle shall not utilize forward firing motors. c) The launch vehicle shall not utilize motors that expel	There are no prohibited items included in the design of the launch vehicle. This includes not exceeding Mach 1 or the vehicle ballast exceeding 10% of the total weight of the rocket.	NSL Inspection as well as inspected and approved by safety officer.



titanium sponges d) The launch vehicle shall not utilize hybrid motors. e) The launch vehicle shall not utilize a cluster of motors. f) The launch vehicle shall not utilize friction fitting for motors. g) The launch vehicle shall not exceed Mach 1 at any point during flight. h) Vehicle ballast shall not exceed 10% of the total weight of the rocket.		
<b>USF SOAR Success Criteria</b>		
Vehicle will have modular capability to adjust to wind conditions to reach 5,280 feet under all conditions.	Launch vehicle will incorporate removable ballast system and calculation sheet will be developed to enable the team to adjust the amount of ballast on the day of the launch.	This system is still under development and not included as a design in this report. Apogee and stability for all conditions will be calculated for all potential ballasted weights using OpenRocket software. Properly ballasted configuration will be tested during full scale and subscale launches.

### 5.1.3 Launch Vehicle Design and Alternatives

#### 5.1.3.1 Airframe

Alternative 1: Fiberglass tubing was the first consideration for airframe design. Wildman Rocketry is a reputable vendor for our organization, and offers a G12 fiberglass airframe (ID: 5" and OD: 5.148") for \$36.00 per foot. We have used fiberglass tubing for multiple projects, and it has been a dependable choice.

*Table 6: Pro and cons of 5" fiberglass tubing.*

Pros	Cons
Widely available	Uncommon size & dimensions
Matching nosecones offered by vendors	Heavier than 4" diameter tubing
Adequate storage volume	More expensive than 4" diameter tubing
Lighter than a 6" airframe	Larger length of coupler joints required
Less expensive than carbon fiber or	



polycarbonate tubing	
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Alternative 2: Four-inch G12 fiberglass tubing was briefly considered in the initial designs. A vendor that supplies 4-inch tubes are Performance Hobbies (\$29.40 per foot) and Hawk Mountain (ID: 3.91" and OD: 4.03", \$16.69 per foot).

*Table 7: Pro and cons of 4" fiberglass tubing.*

Pros	Cons
Comparative lower weight	Limited volume and space
Less expensive than carbon fiber or polycarbonate tubing	Requires new building techniques
Less expensive than 5" tubing	Limited payload considerations
	Lack of matching nosecones; would have to be custom manufactured

Alternative 3: Carbon fiber tubing is an option SOAR has been looking to invest in for recent projects. Carbon fiber tubing is common among popular vendors but ultimately was disregarded due to costs and lack of necessity.

*Table 8: Pro and cons of carbon fiber tubing.*

Pros	Cons
Widely available	More expensive than fiberglass
Superior strength and performance	Unnecessary performance for this project
Lighter than fiberglass tubing	More difficult to work with and customize

#### 5.1.3.2 Fins

Alternative 1: The proposal design called for a three-fin design using fiberglass sheets of 1/4" thickness. SOAR and the team for NSL initially considered using a three-fin design like Apis 1, the rocket used for the NSL Launch in April of 2017. The positive of using a three-fin design is the experience and guaranteed performance. The negative associated with this technique is that is the a three-fin design requires a specific angular separation of 120 degrees between each fin, which is possible to build but is more difficult than 90 degrees with a four-fin design.

*Table 9: Pro and cons of three-fin design.*



Pros	Cons
Proven performance as same configuration as 2016-2017 NSL	Specific angular separation of 120 deg. more difficult to construct
Lower drag component	Considerable fin weight at $\frac{1}{4}$ "
	Lower stability margin
	Less stable flight profile
	High performance via low drag associated with three fins not necessary for mission accomplishment

Alternative 2: One consideration for fin design is to use a four-fin design with  $\frac{1}{8}$ " fiberglass sheets. The generic design does not change from that of Alternative 1, still utilizing a trapezoidal shape. The  $\frac{1}{8}$ " fins are much lighter than  $\frac{1}{4}$ ", allowing for an extra fin for added stability while allowing our selected Cesaroni L995 to perform and deliver the launch vehicle to a mile-high apogee. The positive of this four-fin design is that it will be easier to build and ensure equal angular separation (an even 90 degrees) and the  $\frac{1}{8}$ " thickness will be easier to cut, shape and handle than  $\frac{1}{4}$ " thickness. One of the main negative points of this design is the decrease in thickness from  $\frac{1}{4}$ " to  $\frac{1}{8}$ ", as this will theoretically decrease the structural strength of the fins, and thus the entire fin system of the rocket. However, our mentor ensured our team that the structural integrity of four  $\frac{1}{8}$ " fins will provide enough support and stability while undergoing aerodynamic stress.

*Table 10: Pro and cons of four-fin design.*

Pros	Cons
Increased stability margin	Heavier overall weight
More stable flight profile	Increased drag component
Team has little experience with this design feature	

### 5.1.3.3 Nosecone

Alternative 1: The rocket configuration in the proposal design had the nosecone and rover compartment attached together during descent, and shared a common parachute. The first point of impact for this configuration would have been the nosecone. To reduce the impact and allow the rover compartment to roll into proper orientation for rover deployment, a 5-inch ellipsoid nosecone was considered.



*Table 11: Pro and cons of ellipsoid nosecone.*

Pros	Cons
Reduced Impact	Uncommon Among Vendors
Lessens Chance of Nosecone Spiking	Hard to Self-Manufacture
	Higher Comparative Weight than Ogive or Haack Design

Alternative 2: The current and desired rocket configuration, designed exclusively for the Sidewinder rover design, uses a standard Ogive nosecone. A common and reliable supplier for a nosecone design such as this is available through Wildman Rocketry and has the same outer diameter as the G12 fiberglass airframe, making it compatible with our airframe.

*Table 12: Pro and cons of ogive nosecone.*

Pros	Cons
Common Among Suppliers	Enables Lower Stability Margin than Ellipsoid Nosecone
Less Mass than Ellipsoid Nosecone	

#### *5.1.3.4 Internal Couplers, Bulkheads, and Centering Rings*

##### Bulkheads and Centering Rings

Alternative 1: The original design included ¼" birch plywood bulkheads and centering rings. This is a design that the team is familiar with and has used before on several different rockets. The material is very inexpensive and readily available online and at local stores. Properly installed, it is sufficiently strong to withstand the forces of flight, separation charges, and to retain the motor. However, it was found on previous designs that, over several launches, the plywood deteriorated significantly, especially in the areas of the separation charges. It is also prone to splintering and, because of the thickness required, is more difficult to work with when installing hardware such as U-bolts and all-thread.

*Table 13: Pro and cons of ¼" birch plywood bulkheads and centering rings.*

Pros	Cons
Sufficiently strong for launch applications	Deteriorates over several launches and prone to splintering
Readily available locally	More difficult to work with and customize





Familiar design; team has previous experience with it	Heavier than fiberglass
Inexpensive compared to fiberglass	Requires significant construction time due to epoxy curing time

Alternative 2: The other option for bulkheads and centering rings is  $\frac{1}{8}$ " fiberglass sheeting. This alternative is much lighter and easier to work with. It is, however, more expensive and is not available locally. The shorter construction time, decreased weight, and increased strength more than compensate for these difficulties. It also will not tend to deteriorate over time like the plywood bulkheads and will hold up better under the pressure of separation charges.

*Table 14: Pro and cons of 1/8" fiberglass sheeting bulkheads and centering rings.*

Pros	Cons
Stronger than plywood	More expensive than plywood
Lighter than plywood	Not as widely available
Will not deteriorate as much over time	
Team inexperienced with using fiberglass bulkheads and centering rings	
Less construction time	

### Couplers

Alternative 1: Phenolic tubing couplers are widely used in high power rocketry and are very inexpensive. This was briefly considered, but was discarded as an idea due to strength considerations. In previously built rockets, phenolic components were almost completely destroyed after just two launches, especially if in the area of a separation charge. Due to the requirement that the rocket be able to re-launch the same day, this type of failure would be unacceptable.

*Table 15: Pro and cons of phenolic tubing couplers.*

Pros	Cons
Very inexpensive	Extremely weak structurally and tends to break after a single launch
Easy to work with and cut	Does not contribute to structural stability



Alternative 2: The Sidewinder rocket design includes an internal fiberglass coupler (ID: 4.753" and OD: 4.987") not included in the proposal design. This new coupler connects the airframe of the altimeter bay to the payload airframe, adding to the stability of the rocket during ascension and securing the point of separation until the main deployment charge after apogee. The only negative of this added coupler is the weight, but it estimated to be no greater than 0.75 to 1 pound in weight.

*Table 16: Pro and cons of fiberglass tubing couplers.*

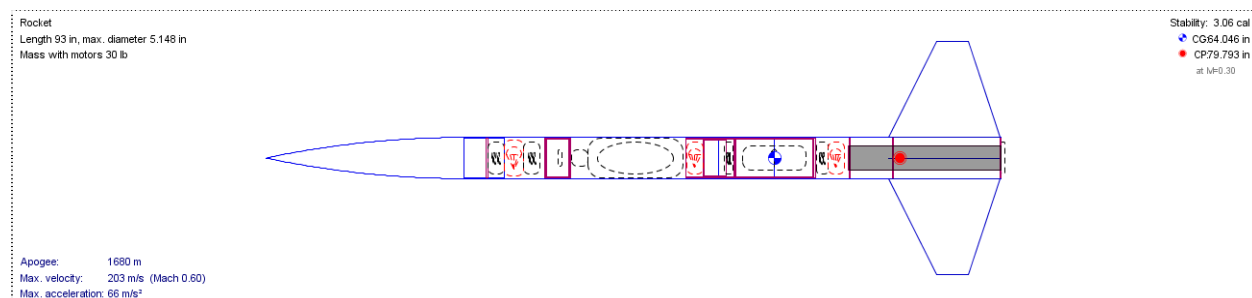
Pros	Cons
Relatively inexpensive	More expensive than phenolic
Contributes to structural stability	More difficult to work with and cut
Much greater structural soundness and unlikely to break even after multiple launches	Heavier than phenolic
Fiberglass on fiberglass contact makes for easy separation due to smooth, non-sticking surfaces	

#### 5.1.4 Selected Design Elements and Justification

There are 5 main subsystems to our rocket design; booster section, main altimeter bay, internal coupling stage, rover, rover compartment and nosecone.

##### 5.1.4.1 Dimensional Drawing

*Figure 6: Dimensional drawing of launch vehicle assembly.*



##### 5.1.4.2 Mass Statement

Please see Appendix 11.3 for detailed mass statement

##### 5.1.4.3 Booster Section

The booster section is composed of the 5" x 5.148" airframe, fins and the 75mm inner motor mount. The motor mount will be secured to the inside of the airframe using the 1/8" fiberglass center rings (approximately 2.95" x 5") with carbon fiber epoxy fillets and joints. The fins will



be  $\frac{1}{8}$ " fiberglass sheets as well, and will be cut with respect to the outer airframe diameter (5.148", or 2.574" from center) in measurements to tip and root chord, sweep length and height. The fins will have a recessed area equivalent to the root chord, and approximately 26 mm (about 1") deep that will be secured to the motor mount with carbon fiber epoxy fillets and the centering rings described above. The booster section is set to be 28.5" long, with the motor mount at 19.25" long. This subsystem is tethered to the main altimeter bay, and deploys a 30" drogue parachute at apogee via a black powder charge from the main altimeter bay.

#### *5.1.4.4 Main Altimeter Bay*

The main altimeter bay houses 1 of 2 on-board altimeters to control deployment and separation, and acts as a critical coupling component to the entire launch vehicle. The main altimeter bay is a 4.753" x 4.987" fiberglass tube, and is set to be 10" long. The bay will be capped with bulkheads composed of two layers (one with 4.987" diameter, the other with 4.753" diameter) of  $\frac{1}{8}$ " fiberglass. The main altimeter bay will use a Missile Works RRC3 "Sport" altimeter, and will detonate black powder charges at apogee and at 800 feet upon descent. The first charge at apogee will disconnect the shear pins securing the booster section to the lower half of the altimeter bay, deploying the drogue parachute. Then at 800 feet during the descent phase, another set of black powder charges will detonate. This detonation interacts with a custom piston system within the Internal Coupling Stage, forcing the piston aft. This disconnects the rover compartment and nosecone from the upper half of the main altimeter bay. During this disconnection, the main parachute is exposed and thus deployed.

#### *5.1.4.5 Internal Coupling Stage*

The internal coupling stage is a subsystem comprised of a fiberglass coupler (4.753" x 4.987"), a 3D printed piston system, the G12 fiberglass airframe and the recovery hardware (shock cord and main parachute). There is a 7" airframe that covers the upper half of the main altimeter bay above the switch band and is secured using standard  $\frac{1}{4}$ -20 screws. This leaves a space of 2" between the end of this airframe and the top bulkhead of the main altimeter bay. In this space is where the 6" long coupler slides in and becomes flush against the top bulkhead of the main altimeter bay, secured by another set of  $\frac{1}{4}$ -20 screws. In this configuration, the internal coupler is protruding 4" from the airframe. This exposed coupler will act as a coupler for the airframe that is the rover compartment. The piston system, designed to capture the force from the black powder charge, will be 3D printed from ABS/PLA plastics and have an approximate diameter of 4.75" and about 3" long. The piston system will be designed to allow a trail of shock cord through it, compacting the recovery hardware to the length of the 7" airframe in this subsystem.

#### *5.1.4.6 Rover*

The rover is based on the Sidewinder design and is detailed in a separate section. The main justification for the design sideways-loading design is to maximize the wheel diameter to be the same as the internal diameter of the cargo area. The wheel base is only limited by the length of the cargo area.



#### 5.1.4.7 Rover Compartment

The rover compartment is the section of airframe that houses the rover, payload altimeter and the recovery hardware used for both this subsystem and the nosecone. This airframe is 32" long and will be secured to the rocket with shear pins to the 4' protruding coupler from the Internal Coupling Stage. The payload altimeter within the rover compartment is located 10 ¼" from the top

#### 5.1.4.8 Airframe

The airframe of the launch vehicle was selected as 5 in. diameter, G12 fiberglass tubing. The 5-in. diameter airframe was selected because it would contain enough room to fit the payload while at the same time help to keep the overall mass as low as possible. Which will allow the launch vehicle to reach the desired altitude of one mile. G12 fiberglass was the selected material based on its availability and superior strength to phenolic tubing. The launch vehicle needs to be as reliable as possible throughout the scope of the competition, as well as after the competition to be utilized for further research.

### 5.1.5 Design Summary

The design of the launch vehicle of 93 inches long and weighs 22.2 pounds with no motor equipped. Below is a detailed depiction of the rocket and its components. See Appendix 11.3 for a detailed mass statement.

*Figure 7: Launch vehicle body components and dimensions.*

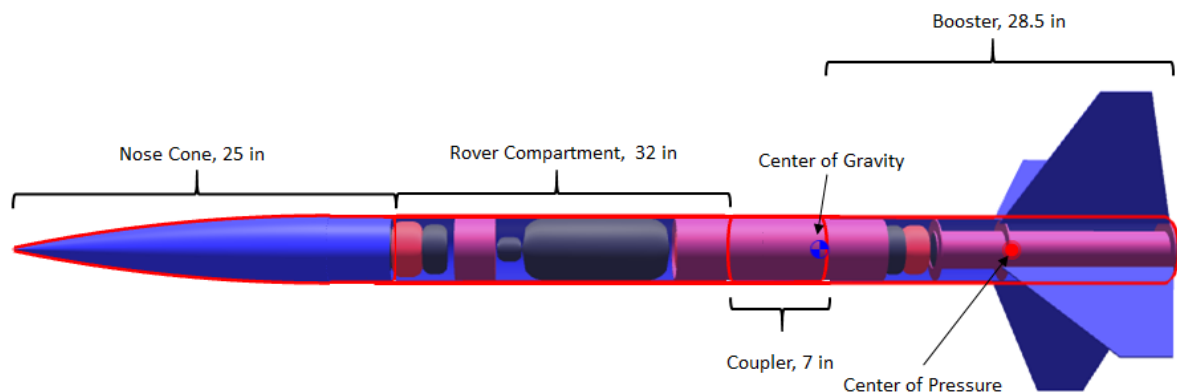
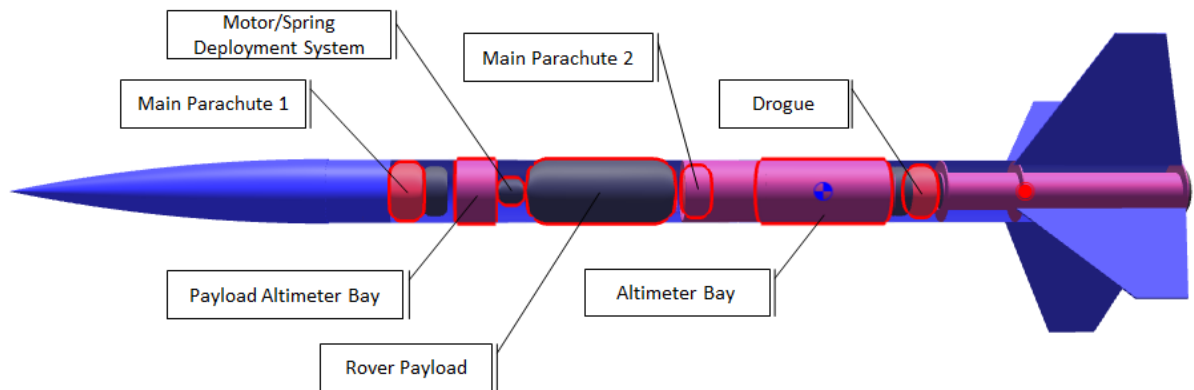


Figure 8: Launch vehicle functional components.



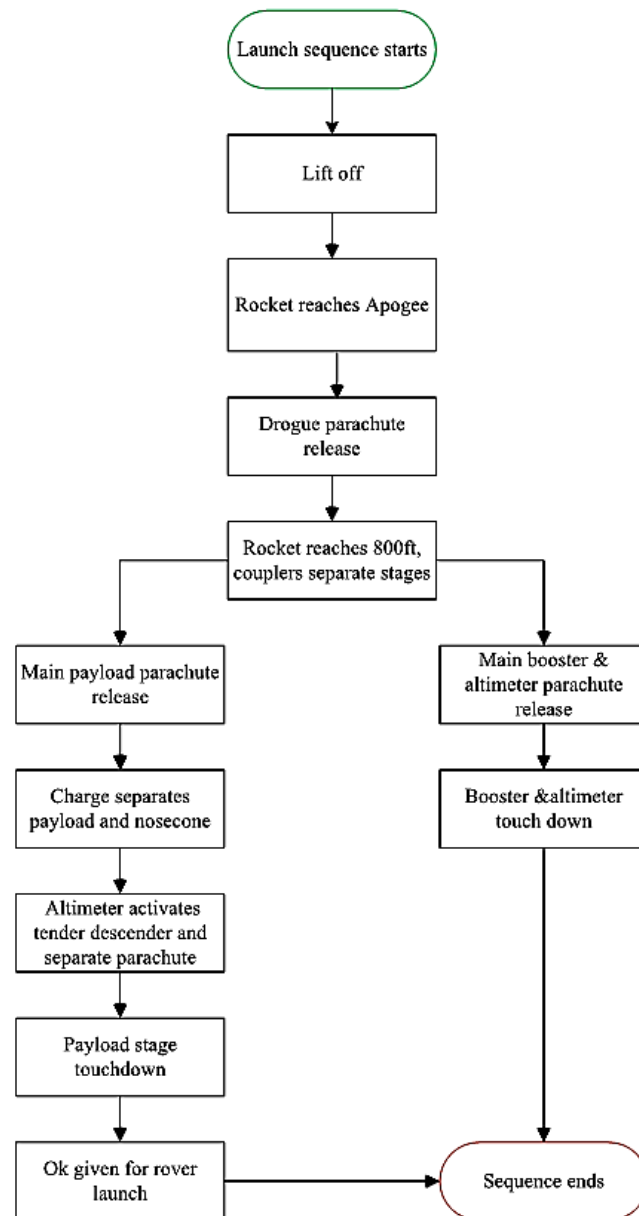
With the L995 or L800 motor installed, the stability variables change very little. Below is a comparison chart of the vital characteristics.

Table 17: Stability variables for motor choices.

Variable	L995 Motor	L800 Motor
Mass with motors	30.2 lbs	30 lbs
Center of Gravity	64.158 in	64.046 in
Center of Pressure	79.793 in	79.793 in
Stability	3.04 cal	3.06 cal



Figure 9 Launch sequence flow chart.



## 5.1.6 Motor Selection and Alternatives

Figure 10: Cesaroni L995 Thrust Curve.

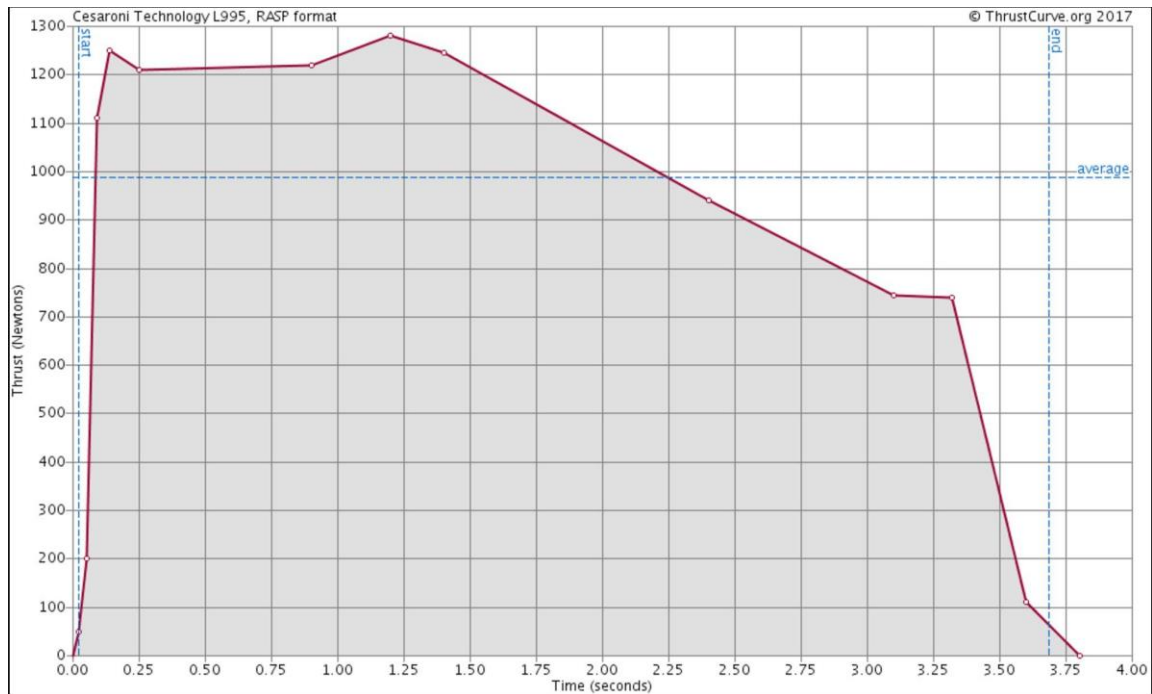


Table 18: Pros and Cons for Cesaroni L995 motor.

Pros	Cons
Fin design can be manipulated to achieve higher apogee.	Motor only reaches 5280 feet in ideal (zero) wind conditions.
Motor has clean, consistent thrust curve with higher average thrust.	Very unlikely to reach 5280 feet in worst wind conditions.
	Will not account for unexpected weight added during construction.

Table 19: Cesaroni L800 motor data.

Average Thrust	804N
Maximum Thrust	1286.1N
Total Impulse	3757.0Ns
Burn Time	4.7s



Case Info	Pro75-3G
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Figure 11: Cesaroni L800 Thrust Curve.

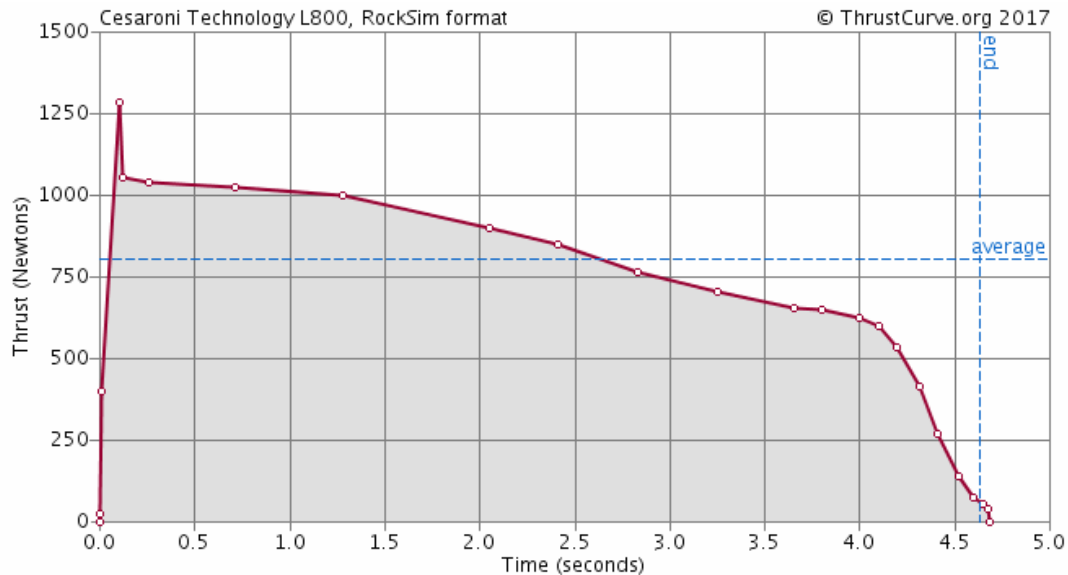


Table 20: Pros and Cons for Cesaroni L800 motor.

Pros	Cons
Motor reaches at least 5280 feet in approximately 50% of all possible launch day wind conditions.	Requires removable ballast design to ensure apogee closest to 5280 feet.
Longer burn time results in better stability off launch rail.	Unlikely to reach 5280 feet in worst wind conditions.

## 5.2 Recovery Subsystem

### 5.2.1 Mission Success Criteria

The following table will show the requirements that need to be met in this mission, how we met the requirements, and the verification of meeting them.

Table 21: Detailed recovery system mission requirements and confirmation methods.

Requirement	Method	Verification
NASA Student Launch Initiative Required Success Criteria		





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.	The launch vehicle is designed to deploy the drogue parachute at apogee and the main parachute at an altitude that is lower than apogee	NSL Inspection as well as inspected and approved by safety officer.
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.	A ground ejection test for the drogue and main parachute will be completed prior to initial subscale and full-scale launches.	Data from the ground ejection test as well as inspected and approved by the safety officer.
At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf	The correct and appropriate parachute size will be chosen in order to slow the launch vehicle down enough to ensure a kinetic energy of less than 75 ft-lbf. Multiple tests will be simulated.	Full-scale and Subscale testing.
The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	The recovery system will be completely independent from the payload circuits.	NSL Inspection as well as inspected and approved by safety officer.
All recovery electronics will be powered by commercially available batteries.	Launch vehicle will be designed with all recovery electronics to be powered by commercially available batteries.	NSL Inspection as well as inspected and approved by safety officer. Current design incorporates commercially available 9V batteries.
The recovery system shall contain redundant, commercially available altimeters.	The recovery system will include a redundant altimeter.	NSL Inspection as well as inspected and approved by safety officer.
Motor ejection is not a permissible form of primary or secondary deployment.	Launch vehicle will not be designed with motor ejection as a form or primary or secondary deployment.	NSL Inspection as well as inspected and approved by safety officer.
Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Launch vehicle will be designed with shear pins for main and drogue parachute compartments.	NSL Inspection as well as inspected and approved by safety officer.
Recovery area will be limited to a 2500 ft. radius from the launch pads.	Launch vehicle recovery system will be designed such that no components under parachute will	Data from simulations. Subscale and full-scale launch data.



	drift farther than 2500 feet from the launch pad.	
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.	Each altimeter will contain its own switch that will be able to be locked in the ON position.	NSL Inspection as well as inspected and approved by safety officer.
Each altimeter will have a dedicated power supply.	Each altimeter will have its own dedicated power supply.	NSL Inspection as well as inspected and approved by safety officer.
Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Each altimeter will contain its own switch that will be able to be locked in the ON position.	NSL Inspection as well as inspected and approved by safety officer.

## 5.2.2 Recovery System Design and Alternatives

### 5.2.2.1 Parachutes

All parachute data is based on L995 motor flight simulation and under conditions detailed previously.

Alternative 1: LOC-Precision LP-78 Rip Stop Nylon Parachute (78.00 in). This parachute has sufficient drag to slow down the launch vehicle sections to below the required 75 ft-lbs of kinetic energy on impact. However, it also has 16 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 22: LOC-Precision LP-78 parachute characteristics.*

Material	Rip Stop Nylon (66.8 t/m <sup>2</sup> )
Diameter	78 in.
Drag Coefficient	1.67
Number of Lines	16
Line Length	68 in.
Line Material	Tubular Nylon



Table 23: LOC-Precision LP-78 parachute flight data.

Velocity at Deployment	- f/s
Terminal Velocity	-f/s
Kinetic Energy of Nosecone and Rover Compartment at Impact	28.3 ft-lbs
Kinetic Energy of Booster and Altimeter Bay at Impact	29.9 ft-lbs
Kinetic Energy of Entire Launch Vehicle at Impact	67.49 ft-lbs

Table 24: Pros and cons of LOC-Precision LP-78 parachute.

Pros	Cons
Sufficient drag to slow down launch vehicle to desired kinetic energy.	Multiple shroud lines may lead to tangling.
Packing size is sufficiently small for application.	Sixteen-sided design more difficult to pack and install.
	Design and performance unfamiliar to team.

Alternative 2: SkyAngle Cert-3 XL parachute. 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 25: SkyAngle Cert-3 XL parachute characteristics.

Material	Zero-porosity 1.9 oz balloon cloth
Surface Area	89 sq. ft.
Drag Coefficient	2.59
Number of Lines	4
Line Length	100 in.
Line Material	5/8" Tubular Nylon



Table 26: SkyAngle Cert-3 XL parachute flight data.

Velocity at Deployment	-78.34 f/s
Terminal Velocity	-10.22 f/s
Kinetic Energy of Nosecone and Rover Compartment at Impact	17.58 ft-lbs
Kinetic Energy of Booster and Altimeter Bay at Impact	18.49 ft-lbs
Kinetic Energy of Entire Launch Vehicle at Impact	42.13 ft-lbs

Table 27: Pros and cons of SkyAngle Cert-3 XL parachute.

Pros	Cons
Sufficient drag to slow down launch vehicle to desired kinetic energy.	Large packing size takes up room in launch vehicle.
Fewer shroud lines result in less likelihood of entanglement.	Fewer shroud lines results in each taking increased impact from the shock of deployment.
Proven design and performance in previous designs.	

Alternative 3: SkyAngle Cert-3 Large Parachute. 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. This option was discarded after initial simulations, as the kinetic energy for the entire rocket was calculated to be 99 ft-lbs.

Table 28: SkyAngle Cert-3 large parachute characteristics.

Material	Zero-porosity 1.9 oz balloon cloth
Surface Area	57 sq. ft.
Drag Coefficient	1.26
Number of Lines	4
Line Length	80 in.



Line Material	5/8" Tubular Nylon
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#### 5.2.2.2 Altimeters

Although there are numerous available types and brands of altimeter available to be purchased, the team generally prefers to utilize technology that has been proven in other applications, especially when there is no compelling reason to choose another option. Additionally, we rely on the advice of our team mentor and his evaluation of components based on his almost 30 years of experience with high powered rockets. Therefore, the Missile Works RRC3 "Sport" altimeter will be used as the primary and alternate means to indicate deployment altitude for separation of components.

#### 5.2.2.3 Shock Cord

As with altimeters, for shock cord, the team prefers to side with proven performance of components unless it is clear that other options need to be considered. Since the team's previous NSL rocket design was nearly twice the weight of this year's design and the design weight is not critical, the ½" tubular Kevlar has once again been chosen as the preferred shock cord for this design. Kevlar tubing is tested for 7200 lb shock, which is more than sufficient for the purposes to which it will be applied.

#### 5.2.2.4 Quick Links and D-Rings

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

### 5.2.3 Selected Recovery Design Elements and Justification

#### 5.2.3.1 Parachutes

The SkyAngle parachutes are clearly the better choice for ease of use, flight characteristics, and performance. They are dependable, well-designed, and have more documentation than most other commercially available high-power rocketry parachutes. For these reasons, this design will incorporate this brand and style parachute.

#### 5.2.3.2 Altimeters

Missile Works RRC3 "Sport" altimeter was selected due to reliability, previous testing, and on the advice of the team mentor.

#### 5.2.3.3 Recovery Shock Cord

The ½" tubular Kevlar was selected due to reliability, previous testing, sufficient weight rating, and on the advice of the team mentor.

#### 5.2.3.4 Quick Links and D-Rings

The 5/16" zinc-plated U-bolts and locking D-rings were selected due to reliability, previous testing, sufficient weight rating, and on the advice of the team mentor.



### 5.2.4 System Redundancy

An RRC3 altimeter will identify the moment of apogee, and a signal will be sent to a charge to eject the booster section from the altimeter section and release the drogue parachute. In the event of a failure in the charge, another signal is also being sent simultaneously from another RRC3 altimeter to a second charge to ensure that the nose cone ejects. The altimeter will then identify the moment when the launch vehicle is 800 feet above ground, and a signal will be sent to the second charge to separate the rover compartment from the altimeter bay, which releases the main parachute for those sections. There is a simultaneous redundant charge to ensure the separation and main parachute deployment. Further, two additional RRC3 altimeters will be installed in the payload altimeter bay for the purpose of separation of the nosecone from the rover compartment. These charges will also be set to 800 feet and will be signaled separately and simultaneously. Each altimeter will be powered by a separate 9-volt battery.

## 5.3 Mission Performance Predictions

### 5.3.1 Flight Profile Simulations

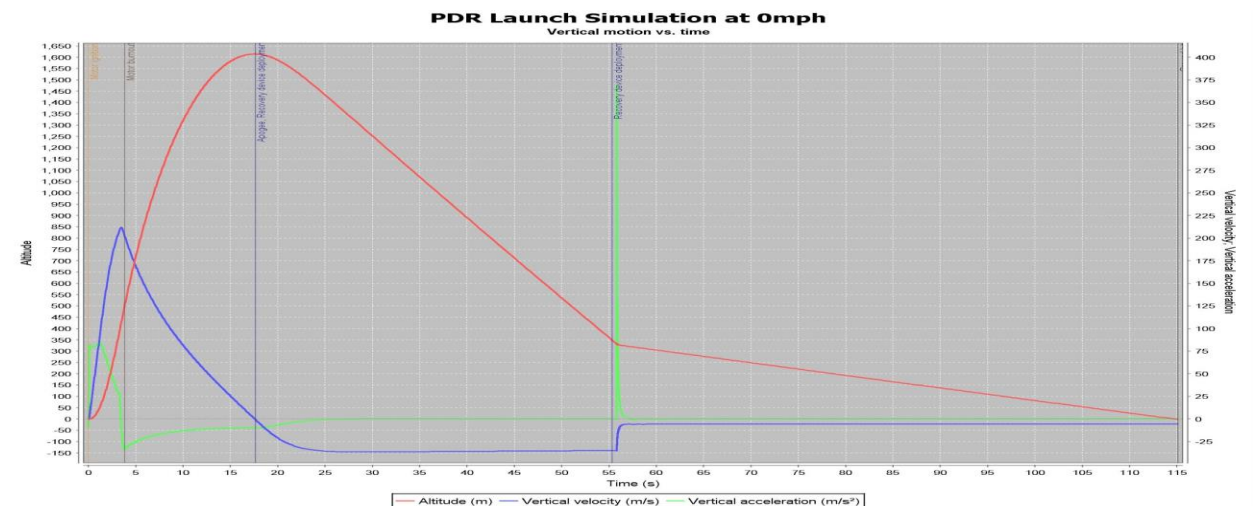
The projected altitude was calculated using OpenRocket using the below parameters.

*Table 29: L995 motor default simulation with zero wind.*

Simulation Parameters	
Average Windspeed	0 mph
Standard Deviation	0.0 m/s
Turbulence Intensity	10% (Medium)
Wind Direction	90 degrees
Launch Rod Length	96 inches
Launch Rail Angle	0 degrees
Atmospheric Conditions	International Standard Atmosphere
Calculation Method	Extended Barrowman
Simulation Method	6-DOF Runge-Kutta 4
Simulation Data	
Apogee	5298 feet



Figure 12: Graph of flight profile under Cesaroni L995 motor.



The projected altitude was 1615 meters, or 5,298 feet. This apogee is very close to the target altitude and may be affected by winds, so several simulations have been conducted. The altitude can be adjusted as necessary by building the rocket and reevaluating CG, CP, and weight given factors unaccounted for in the software. The subtle differences in measurement given the nature of a simulation versus a physical, tangible rocket; we can change and manipulate fin design or add ballast weight to reach our target altitude of 5,280 feet. The proposed motor has considerable thrust and specific impulse for the initial rocket design, and can be controlled accordingly.

### 5.3.2 Alternate Apogees

When calculating alternate apogees, all parameters specified above are identical, except windspeed.

Table 30: L995 motor default simulation showing alternate wind speeds.

Windspeed	Apogee
5 mph	5269 feet
8 mph	5216 feet
10 mph	5157 feet
12 mph	5144 feet
15 mph	5062 feet
18 mph	4997 feet
20 mph	4925 feet

### 5.3.3 Apogees with alternate motor

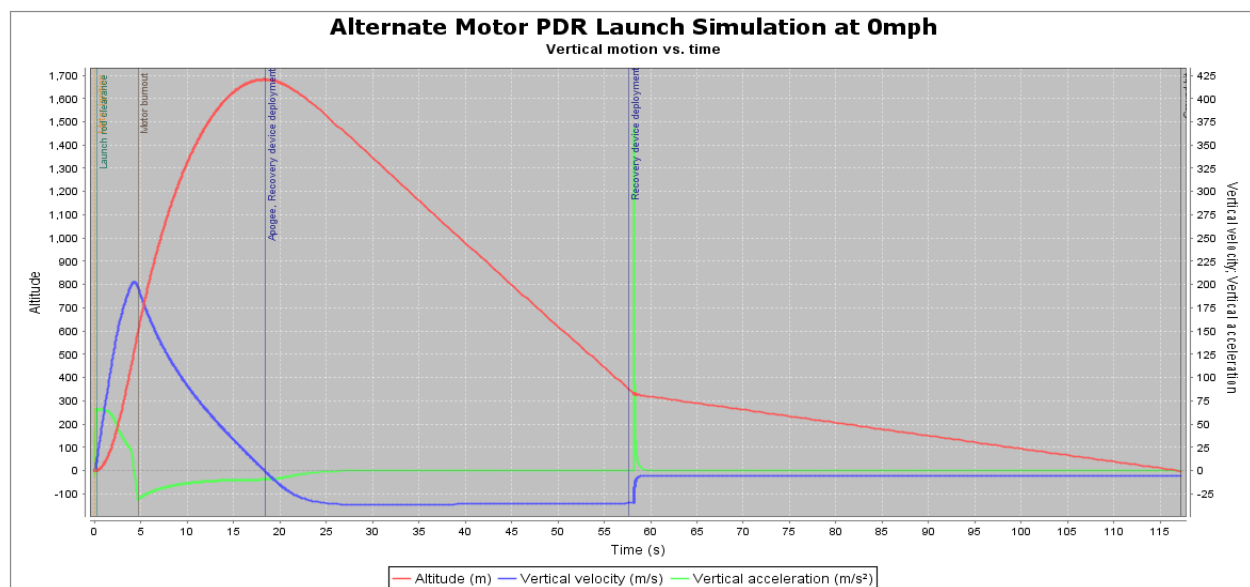


The L800 motor is another option being considered for the launch motor, and is further detailed in the motor selection section.

*Table 31: L800 motor default simulation showing wind speeds and associated apogees.*

Windspeed	Apogee
0 mph	5518 feet
2 mph	5508 feet
5 mph	5479 feet
8 mph	5403 feet
10 mph	5351 feet
12 mph	5266 feet
15 mph	5147 feet
18 mph	5065 feet
20 mph	5036 feet

*Figure 13: Graph of flight profile under Cesaroni L800 motor.*



### 5.3.4 Stability Margin





*Table 32: Stability Margin with L995 Motor.*

Configuration with L995 Motor	
Center of Pressure	79.793 inches
Center of Gravity	64.158 inches
Calibers	3.04

*Table 33: Stability Margin with L800 Motor.*

Configuration with L800 Motor	
Center of Pressure	64.575 inches
Center of Gravity	80.937 inches
Calibers	3.06

### 5.3.5 Kinetic Energy at Landing

OpenRocket has simulation features that display velocities and accelerations of our launch vehicle during ascent and descent procedures. From this information, the kinetic energy at landing can be derived using the below formula. This was calculated for the primary selected parachute, the Sky-Angle Cert-3 XL.

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

For the L995 configuration, the simulation reads out the total velocity of the main launch vehicle at touchdown to be 13.038 ft/s. Using the standard formula for kinetic energy, we can approximate the landing force of the rocket.

*Table 34: Kinetic energy at landing with SkyAngle Cert-3 XL parachute.*

Rocket Component	Kinetic Energy
Entire Rocket	42.13 ft-lbs
Nosecone	3.32 ft-lbs
Rover Compartment	14.26 ft-lbs
Altimeter Bay	2.06 ft-lbs
Booster Section	16.54 ft-lbs



### 5.3.6 Drift

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

*Table 35: 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	483.53
10	14.66	1001.9
15	23.46	1482
20	29.33	2218.1

*Table 36: 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	540.73
10	14.66	1111.8
15	23.46	1746.4
20	29.33	2420.5

### 5.3.1 Alternate Calculation Methods and Discrepancies

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 37: 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 38: 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

## 5.3.2 Simulations

### 5.3.2.1 Flight profile/drift analysis

See Appendix 11.4 for drift analysis exported data.

### 5.3.2.2 Altitude predictions

Figure 14: Graph of flight profile under Cesaroni L800 motor.

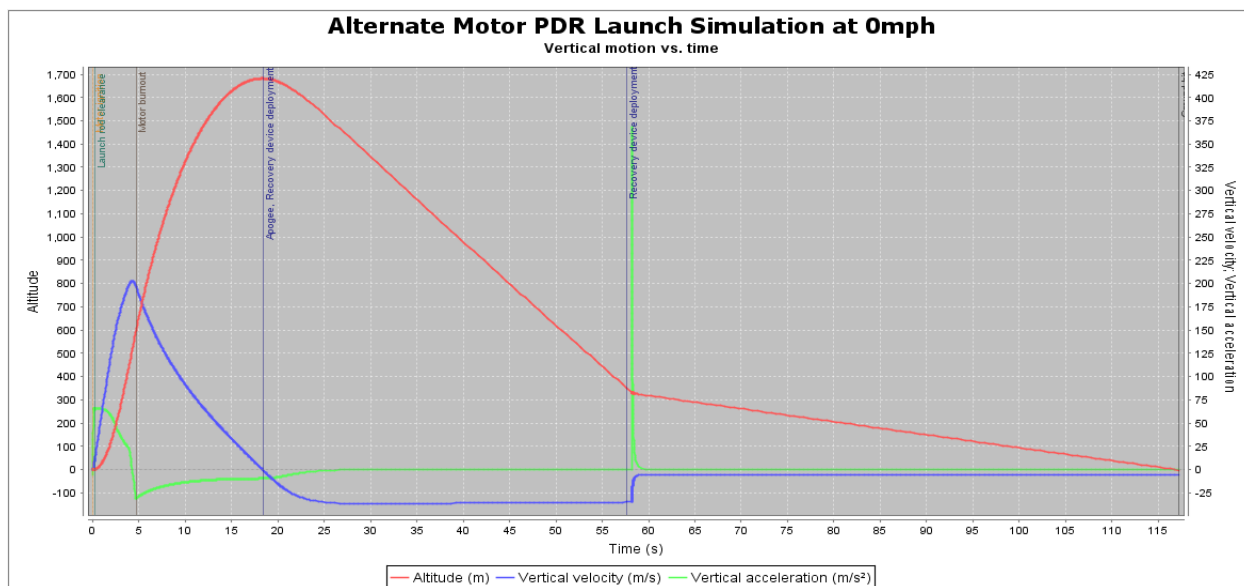
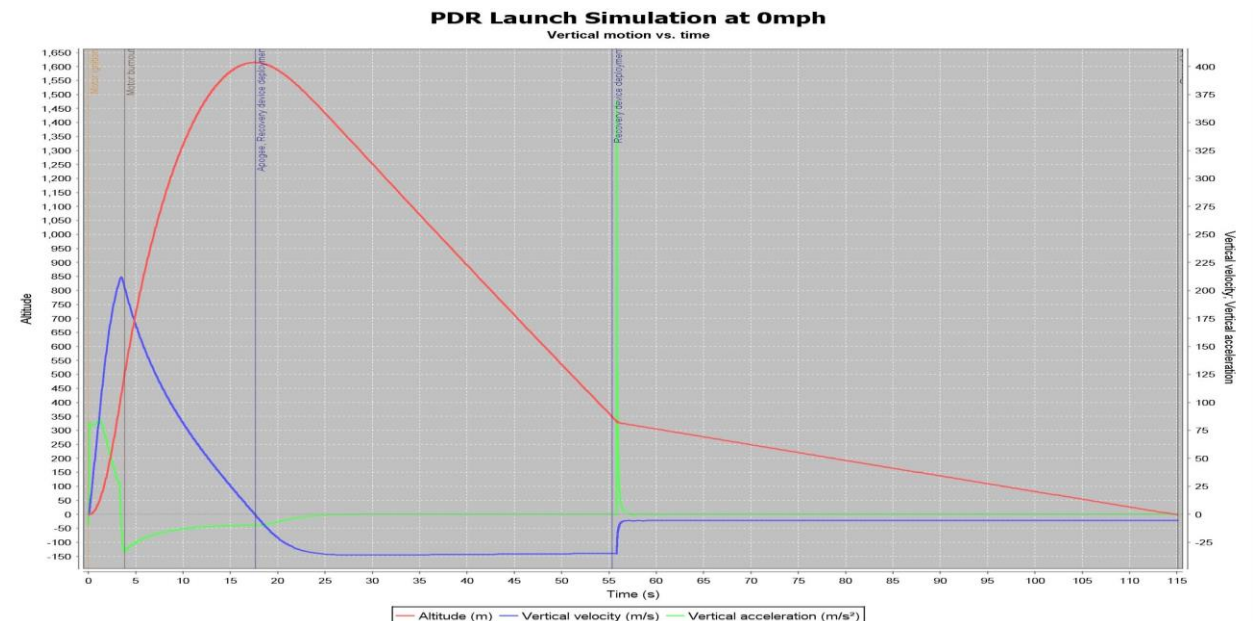


Figure 15: Graph of flight profile under Cesaroni L995 motor.



### 5.3.2.3 Component weights

See Appendix 11.3 for component weights analysis.

### 5.3.2.4 Motor thrust curve

Figure 16: Cesaroni L995 Thrust Curve.

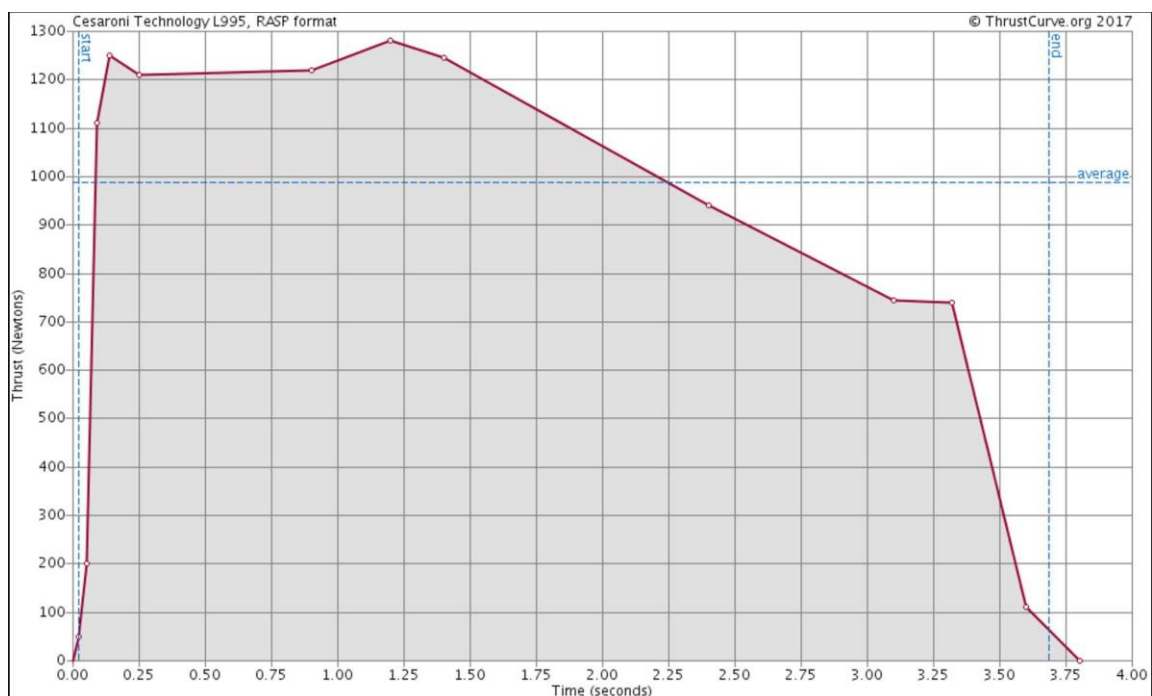
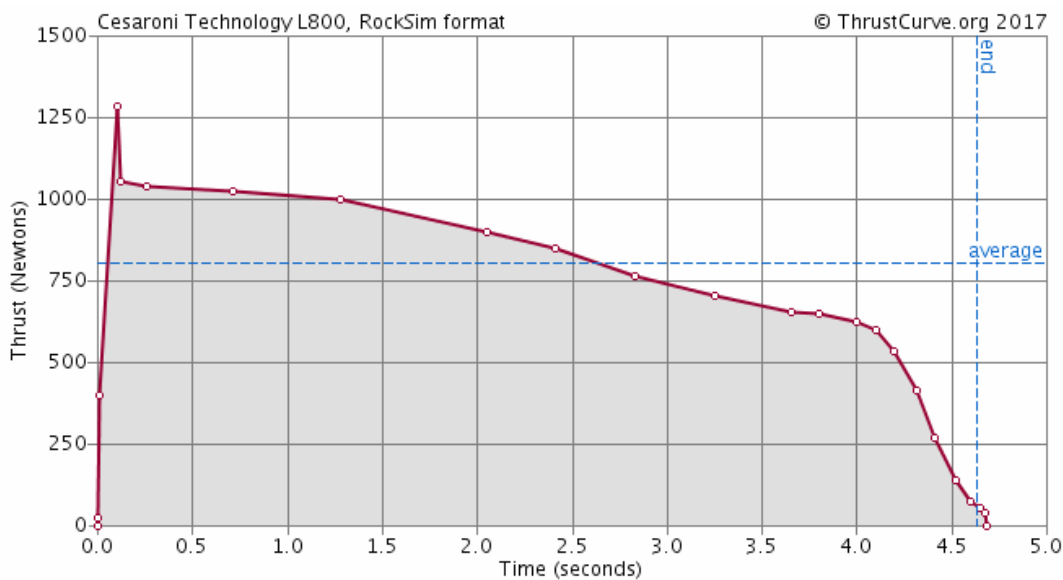
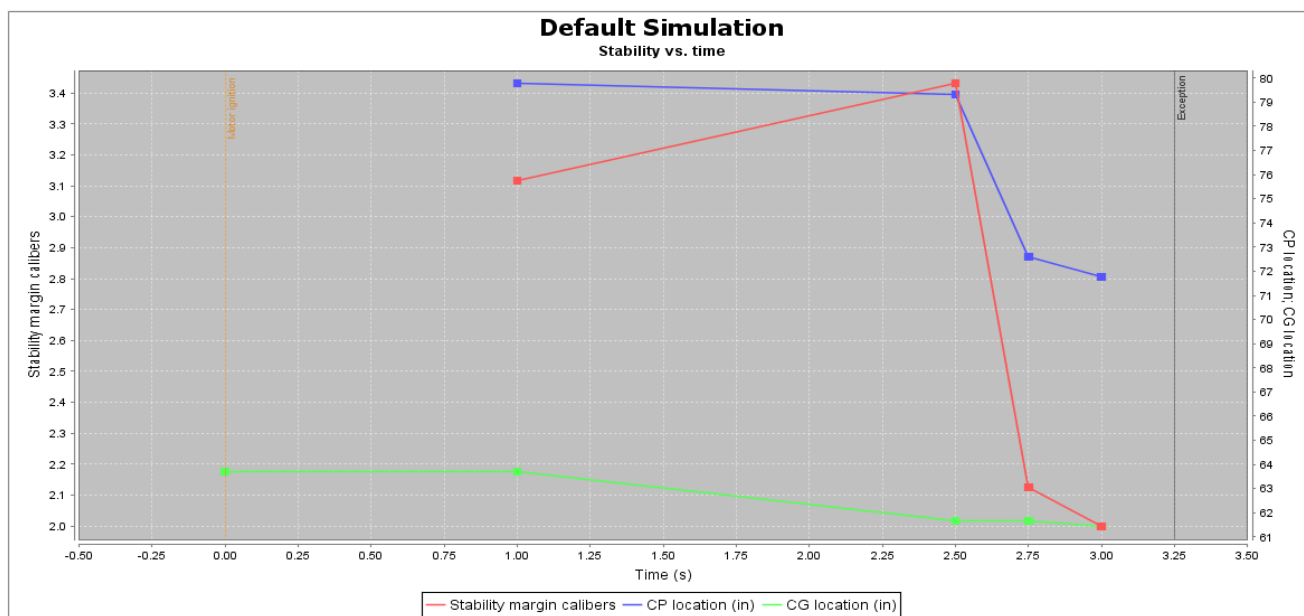


Figure 17: Cesaroni L800 Thrust Curve.



### 5.3.2.5 Stability margin, CP, and CG

Figure 18: Stability vs time graph.



## 6 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.



## 6.1 Safety Officer Duties & Responsibilities

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

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

## 6.2 NAR/TRA Safety

### 6.2.1 Procedures

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

1. A level 2 certified member and an NAR/TRA Personnel will oversee any test launch of the vehicle and flight tests of the vehicle.
2. The launch site Range Safety Officer will be responsible for ensuring proper safety measures are taken and for arming the launch system.
3. If the vehicle does not launch when the ignition button is pressed, then the RSO will remove the key and wait 90 seconds before approaching the rocket to investigate the issue. Only the Project Manager and Safety Officer will be allowed to accompany the RSO in investigating the issue.
4. The RSO will ensure that no one is within 100 ft. of the rocket and the team will be behind the RSO during launch. The RSO will use a 10 second countdown before launch.
5. A certified member will be responsible for ensuring that the rocket is directed no more than 20 degrees from vertical and ensuring that the wind speed is no more than 5 mph. This individual will also ensure proper stand and ground conditions for launch including but not limited to



launch rail length, and cleared ground space. This member will ensure that the rocket is not launched at targets, into clouds, near other aircraft, nor take paths above civilians. Additionally, this individual will ensure that all FAA regulations are abided by.

6. Another certified member will ensure that flight tests are conducted at a certified NAR/TRA launch site.
7. The safety officer will ensure that the rocket is recovered properly according to Tripoli and NAR guidelines.

### 6.2.2 Safety Codes

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

*6.2.2.1 NAR Safety Code (Appendix 11.5)*

*6.2.2.2 TRA Safety Code (Appendix 11.56)*

## 6.3 Hazardous Materials

### 6.3.1 Listing of Hazardous Materials

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

### 6.3.2 Labels

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

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

### 6.3.3 Training

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

- The location and availability of the MSDS 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.

#### 6.3.4 Health, Safety, and Emergency Procedures

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

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

### 6.4 Safety Briefing

#### 6.4.1 Hazard Recognition

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

#### 6.4.2 Accident Avoidance

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

#### 6.4.3 Launch Procedures

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

### 6.5 Caution Statements

#### 6.5.1 Definitions

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





### 6.5.1.1 Warning

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

### 6.5.1.2 Caution

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

### 6.5.1.3 Note

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

## 6.6 Checklists

### 6.6.1 Warnings

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

### 6.6.2 Cautions and Notes

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

### 6.6.3 Field Packing List

- ☐ Tools
  - ☐ Power drill and drill bits
  - ☐ Dremel tool with attachments
  - ☐ Sheet sander
  - ☐ Screwdrivers
  - ☐ Wire cutters/strippers
  - ☐ Scissors
  - ☐ Small funnel
  - ☐ Pliers
  - ☐ Wrenches
  - ☐ PVC Cutters
- ☐ Parts
  - ☐ Rocket components
  - ☐ Quick links
  - ☐ Motor casing
- ☐ Motors (in water resistant container)
- ☐ Parts (cont)
  - ☐ E-matches
  - ☐ Igniter (in water resistant container)
  - ☐ Parachutes
    - ☐ Large × 2
    - ☐ XL × 1
    - ☐ Drogue × 1
  - ☐ Nomex protectors
  - ☐ Spare parts toolkit (nuts, bolts, washers, etc.)
  - ☐ Shear pins
  - ☐ Motor retainer adapter
- ☐ Consumables



- ☐ Charge insulation (in water resistant container)
- ☐ Black powder (in water resistant container)
- ☐ Duct tape
- ☐ Consumables (cont)
  - ☐ Electrical tape
  - ☐ Sandpaper
  - ☐ Electrical wire
- ☐ Silicone
- ☐ Graphite powder
- ☐ Consumables (cont)
  - ☐ White lithium grease
  - ☐ 9V batteries
  - ☐ Rail lubricator
  - ☐ Extra CPVC
  - ☐ Extra launch lugs

### 6.6.4 General Pre-Flight Inspection Checklist

*Table 39: General pre-flight inspection checklist.*

Task	SO Verification
Inspect fins for damage and security	
Inspect rocket body for dents, cracks, or missing parts	
Inspect parachutes for holes and parachutes cords for abrasions or tears	
Inspect shock cords for abrasion or tearing	
Inspect bulkheads and U-bolts for security	
Clean all components of debris and carbon residue	

### 6.6.5 Final Assembly and Launch Procedure Checklist

*Table 40: Final assembly and launch checklist.*

Task	Warning/Caution	SO Verification
<b>1. Prior to Departure</b>		



Task	Warning/Caution	SO Verification
Ensure all tools and materials needed for launch are available.		
Ensure all required personnel are present.		
Prepare new batteries for the recovery systems.	Parachutes may fail to deploy. Mission failure.	
<b>2. Recovery Preparation</b>		
Install new 9V batteries into altimeter bay	Parachutes may fail to deploy. Mission failure.	
Ensure altimeter bay is programmed to deploy at the correct height	Parachutes may fail to deploy. Mission failure.	
Connect e-matches to altimeters	Ensure e-matches are dry. Parachutes may fail to deploy. Mission failure.	

### 6.6.1 Post-Flight Inspection Checklist

Table 41: Post-flight inspection checklist.

Post Flight Inspection	
Task	SO Verification
Listen to record altimeter for apogee altitude.	
Inspect fins for damage and security.	
Inspect rocket body for dents, cracks, or missing parts.	



<b>Post Flight Inspection</b>	
<b>Task</b>	<b>SO Verification</b>
Inspect parachutes for holes and parachutes cords for abrasions or tears.	
Inspect shock cords for abrasion or tearing.	
Check batteries with voltmeter.	
Clean all components of debris and carbon residue.	
Check fit of piston and landing module with launch vehicle body tube; clean and sand as necessary.	
Remove motor from motor casing after it has cooled long enough to be handled but before completely cooled.	
Disassemble motor casing after it has cooled long enough to be handled but before completely cooled.	
Remove all O-rings	
Place components except for motor casing tube into soapy water to remove carbon residue.	
After soaking, clean components with neutral cleaner, dry and reassemble.	

## 6.7 Safety Manual

### 1.1.1 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.

### 6.7.1 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.



### 6.7.2 Notes

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

## 6.8 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:

### 6.8.1 Federal Aviation Regulations (FARs)

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

### 6.8.2 State of Florida Laws and Regulations

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

## 6.9 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 Society of Aeronautics and Rocketry 21 well versed in storage. The propellant will be stored in an off-campus garage, where several other rocket components have been stored carefully. There will be a clear indication that there is propellant in the room, by large lettering on the magazine and yellow/black cautionary 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.

## 6.10 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.



## 6.11 Hazard Analysis

### 6.11.1 Hazard Categories

#### *6.11.1.1 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.

#### *6.11.1.2 Hazards to Environment Risk Assessment*

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

#### *6.11.1.3 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.

#### *6.11.1.4 Launch Pad Functionality Risk Assessment*

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

#### *6.11.1.5 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.

#### *6.11.1.6 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.

#### *6.11.1.7 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.

#### *6.11.1.8 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.

### 6.11.2 Risk Level Definitions

#### *6.11.2.1 Severity*

The severity of each potential risk is determined by comparing the possible outcome to criteria based on human injury, vehicle and payload equipment damage, and damage to environment.



Severity is based on a 1 to 3 scale, 1 being the most severe. The severity criteria are provided below.

Severity Definitions – A condition that can cause:					
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.
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.

#### 6.11.2.2 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.

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
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### 6.11.3 Risk Assessment Levels

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

Probability	Severity			
	1 - Catastrophic	2 - Critical	3 - Marginal	4 - Negligible
<b>A – Frequent</b>	1A	2A	3A	4A
<b>B – Probable</b>	1B	2B	3B	4B
<b>C – Occasional</b>	1C	2C	3C	4C
<b>D – Remote</b>	1D	2D	3D	4D
<b>E - Improbable</b>	1E	2E	3E	4E

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

### 6.11.4 Current and Probable Risk

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





### 6.11.5 Personnel Hazard Analysis

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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	Training will be documented for designated individuals.
Shop	Working with chemical components resulting in mild to severe chemical burns on skin or eyes, lung damage due to inhalation of toxic fumes, or chemical 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	Training will be documented for designated individuals. Certificates will be kept on file for trained individuals until the individuals graduate and leave the organization.

Shop	Damage to equipment while soldering.	Soldering iron is too hot. Prolonged contact with heated iron.	The equipment could become unusable. If parts of the payload circuit become damaged, they could become inoperative.	3C	The temperature on the soldering iron will be controlled and set to a level that will not damage components. For temperature sensitive components sockets will be used to solder ICs to. Only personnel trained to use the soldering iron will operate it.	4D	Training will be documented for designated individuals.
Shop	Dangerous fumes while soldering.	Use of leaded solder can produce toxic fumes.	Team members become sick due to inhalation of toxic fumes. Irritation could also occur.	3D	The team will use well ventilated areas while soldering. Fans will be used during soldering. Team members will be informed of appropriate soldering techniques.	4E	Training will be documented for designated individuals.
Shop	Overcurrent from power source while testing.	Failure to correctly regulate power to circuits during testing.	Team members could suffer electrical shocks which could cause burns or heart arrhythmia.	1D	The circuits will be analyzed before they are powered to ensure they don't pull too much power. Power supplies will also be set to the correct levels. Team members will use documentation and checklists when working with electrical equipment.	2E	When available, an electrical engineering student will supervise electrical operations.
Shop	Use of white lithium grease.	Use in installing motor and on ball screws.	Irritation to skin and eyes. Respiratory irritation.	3D	Nitrile gloves and safety glasses are to be worn when applying grease. When applying grease, it should be done in a well-ventilated area to avoid inhaling fumes. All individuals will be properly trained on handling common chemicals used in constructing the launch vehicles.	4E	Training will be documented for designated individuals.
Shop	Metal shards.	Using equipment to machine metal parts.	Metal splinters in skin or eyes.	1D	Team members will wear long sleeves and safety glasses whenever working with metal parts. Individuals will be trained on the tool being used. Those not trained will not attempt to learn on their own and will find a trained individual to instruct them.	4D	Training on this equipment is provided by the university through the Design for X Labs orientation and safety training program.



## 6.11.6 Failure Modes and Effects Analysis (FMEA) Analysis

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.
Controls	Igniter safety switch active at power up.	Switch stuck/left in enabled position. Communication failure between switch and controller. Code error.	Undesired launch sequence/ personnel injury/ disqualification.	1D	Safety Officer and team member will jointly and audibly verify that igniter switch is off.	1E	Safety Officer will use launch procedure checklist.
Pad	Unstable launch platform.	Uneven terrain or loose components.	If the launch pad is unstable while the rocket is leaving the pad, the rocket's path will be unpredictable.	2E	Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR. Ensure that the launch pad is stable and secure prior to launch.	3E	Use the Launch Procedure checklist when placing launch vehicle on launch rail.
Pad	Unleveled launch platform.	Uneven terrain or improperly leveled launch tower.	The launch tower could tip over during launch, making the rocket's trajectory unpredictable.	1E	Inspect launch pad prior to launch to confirm level. Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR.	1E	Use the Launch Procedure checklist when placing launch vehicle on launch rail.
Pad	Rocket gets caught in launch tower or experiences	Misalignment of launch tower joints. Deflection of launch platform rails. Friction	Rocket may not exit the launch tower with a sufficient exit velocity or may be damaged on exit.	2E	During setup, the launch tower will be inspected for a good fit to the rocket. The launch vehicle will be tested on the launch rail. If any resistance is noted, adjustments will be made to the launch	2E	Use the Launch Procedure checklist when placing launch vehicle on launch rail.



	high friction forces.	between guide rails and rocket.			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 de-burred if possible. If not possible, personnel working with launch tower will be notified of hazards.	4E	Use the Launch Procedure checklist when placing launch vehicle on launch rail.
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.
Recovery	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	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



					does become ballistic, all individuals at the launch field will be notified immediately.		pins. Use Launch Vehicle Assembly checklist when assembling launch vehicle.
Recovery	Sections separate prematurely.	Construction error. Premature firing of black powder due to altimeter failure or incorrect programming.	Structural failure, loss of payload, target altitude not reached.	1D	Use multiple shear pins to prevent drag separation. Verify altimeter altitudes.	1E	In full scale test launch, all sections successfully separated at designated altitudes, including nose cone with shear pins. Altimeters performed correctly.
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 <a href="http://descentratcalculator.online-testing.net/">http://descentratcalculator.online-testing.net/</a> 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 <a href="http://descentratcalculator.online-testing.net/">http://descentratcalculator.online-testing.net/</a> 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. Rip stop nylon was selected for the parachute material. This material prevents tears from propagating easily. In the incident that a small tear occurs during flight, the parachute will not completely fail.	2E	



Recovery	Recovery system separates from the rocket.	Bulkhead becomes dislodged. Parachute disconnects from the U-bolt.	Parachute completely separates from the component, causing the rocket to become ballistic.	1E	The cables and bulkhead connecting the recovery system to each segment of the rocket are designed to withstand expected loads with an acceptable factor of safety. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.	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.
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.
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.
Stability	Motor retention failure.	Design of retention fails. Retention assembly failure.	Motor falls out of booster section while propelling body forward and launch vehicle fails to achieve 5280 ft altitude.	2D	Retention rings will be machined using designs from SolidWorks to ensure proper dimensions. Robust material such as 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.
Stability	Mass increase during construction.	Unplanned addition of components or building materials.	Launch vehicle does not fly to correct altitude. All sections land with high kinetic energy. Possible minor damage to rocket body and/or fins.	2C	Record will be maintained of mass changes. Launch vehicle simulations will be repeated for each mass change. Additional launch vehicle simulations will be performed at plus 5% of calculated mass. Subscale and full-scale launches will be performed with accurate mass.	3E	During full scale test launch, launch vehicle did not reach planned altitude. Weight reduction of lander is planned. New open rocket simulation indicates 5260 feet at apogee.
Stability	Motor fails to ignite.	Faulty motor. Delayed ignition. Faulty e-match. Disconnected e-match.	Rocket will not launch. Rocket fires at an unexpected time.	1D	Checklists and appropriate supervision will be used when assembling. NAR safety code will be followed, and personnel will wait a minimum of 60 seconds before approaching rocket. If there is no activity after 60 seconds, safety officer will check the ignition system for a lost connection or a bad igniter.	1E	Igniter Installation checklist will be used when installing igniter. During full scale test launch, igniter performed as expected.



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.
Stability	Internal bulkheads fail during flight.	Forces encountered are greater than the bulkheads can support.	Internal components supported by the bulkheads will no longer be secure. Parachutes attached to bulkheads will be ineffective.	2E	The bulkheads have been designed to withstand the force from takeoff with an acceptable factor of safety. Additional epoxy will be applied to ensure security and carbon fiber shreds will be added where appropriate. Electrical components will be mounted using fasteners that will not shear under the forces seen during the course of the flight. Full scale testing will be conducted and bulkheads inspected after each flight.	2E	During 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.



Stability	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.
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## 6.11.7 Environmental Concerns Analysis

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Harmful substances permeating into the ground or water.	Improper disposal of batteries or chemicals.	Impure soil and water can have negative effects on the environment that in turn, affect humans and animals, causing illness.	2E	Batteries and other chemicals will be disposed of properly in accordance with the MSDS sheets. Should a spill occur, proper 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.



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



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.
Environmental	Thunderstorms.	N/A	Damage due to electrical shock on system.	2D	When planning test launches, the forecast should be monitored in order to launch on a day where the weather does not prohibit launching or testing the entire system. Should a storm roll in, the entire system should be promptly packed and removed from the premise to avoid having a large metal object exposed during a thunderstorm. In the event that the system cannot be removed, personnel are not to approach the launch pad during a thunderstorm.	2E	N/A



Environmental	High winds.	N/A	Have to launch at high angle, reducing altitude achieved. Increased drifting. Unable to launch.	2D	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. If high winds are present but allowable for launch, the time of launch should be planned for the time of day with the lowest winds.	2E	N/A
Environmental	Trees.	N/A	Damage to rocket or parachutes. Irretrievable rocket components.	2D	Launching with high winds should be avoided in order to avoid drifting long distances. Drift calculations have been computed, so we can estimate how far each component of the rocket will drift with a particular wind velocity. The rocket should not be launched if trees are within the estimated drift radius.	2E	N/A
Environmental	Swampy ground.	N/A	Irretrievable rocket components.	2D	With the potential of the ground being extremely soft at local launch sites and in Huntsville, the rocket should not be launched if there is swampy ground within the predicted drift radius that would prevent the team from retrieving a component of the rocket.	2E	N/A
Environmental	Ponds, creeks, and other bodies of water.	N/A	Loss of rocket components. Damaged electronics.	2D	Launching with high winds should be avoided in order to avoid drifting long distances. The rocket should not be launched if a body of water is within the estimated drift radius. Should the rocket be submerged in water, it should be retrieved immediately and any electrical components salvaged. Electrical components are to be tested for complete functionality prior to reuse.	2E	N/A



Environmental	Extremely cold temperatures.	Batteries discharge quicker than normal. Shrinking of fiberglass.	Completely discharged batteries will cause electrical failures and fail to set off black powder charges, inducing critical events. Rocket will not separate as easily.	3D	Batteries will be checked for charge prior to launch to ensure there is enough charge to power the flight. Should the flight be delayed, batteries will should be rechecked and replaced as necessary. If the temperatures are below normal launch temperature, black powder charges should be tested to ensure that the pressurization is enough to separate the rocket. If this test is successful, the rocket should be safe to launch.	3E	Use Final Assembly and Launch Procedure Checklists when assembling launch vehicle.
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.





## 7 Payload Criteria

### 7.1 Selection, Design, and Rationale of Payload

Deployable rover payload has been chosen. It will be designed according to the following criteria:

1. Teams will design a custom rover that will deploy from the internal structure of the launch vehicle.
2. At landing, the team will remotely activate a trigger to deploy the rover from the rocket.
3. After deployment, the rover will autonomously move at least 5 ft. (in any direction) from the launch vehicle.
4. Once the rover has reached its final destination, it will deploy a set of foldable solar cell panels.

### 7.2 Mission Criteria and Verification

*Table 42: Detailed payload mission requirements and confirmation methods.*

Requirement	Method	Verification
Teams will design a custom rover that will deploy from the internal structure of the launch vehicle.	Custom rover will be designed that will deploy from the internal structure of the launch vehicle.	Current designs include air ejection, rack and piston, and spring-loaded ejection methods.
At landing, the team will remotely activate a trigger to deploy the rover from the rocket.	Rover will utilize a receiver and team will operate a transmitter that will remotely trigger the rover to deploy from the rocket.	Current design criteria include this requirement. Team leads will continue to monitor to ensure continued enforcement of standard.
After deployment, the rover will autonomously move at least 5 ft. (in any direction) from the launch vehicle.	Rover will be designed to move at least 5 ft. from launch vehicle.	Current design criteria include this requirement. Team leads will continue to monitor to ensure continued enforcement of standard.
Once the rover has reached its final destination, it will deploy a set of foldable solar cell panels.	Rover will be designed to deploy solar panels once it has reached its destination.	Current design criteria include this requirement. Team leads will continue to monitor to ensure continued enforcement of standard.

## 7.3 Launch Vehicle Design and Alternatives

### 7.3.1 Main Rover Design: Sidewinder

Figure 19: Sidewinder rover.

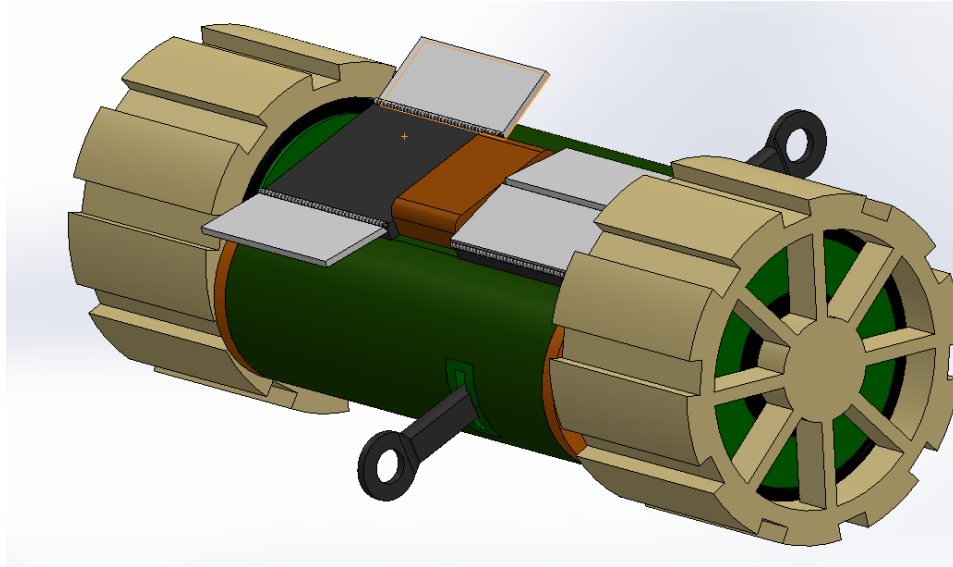


Figure 20: Sidewinder rover views.

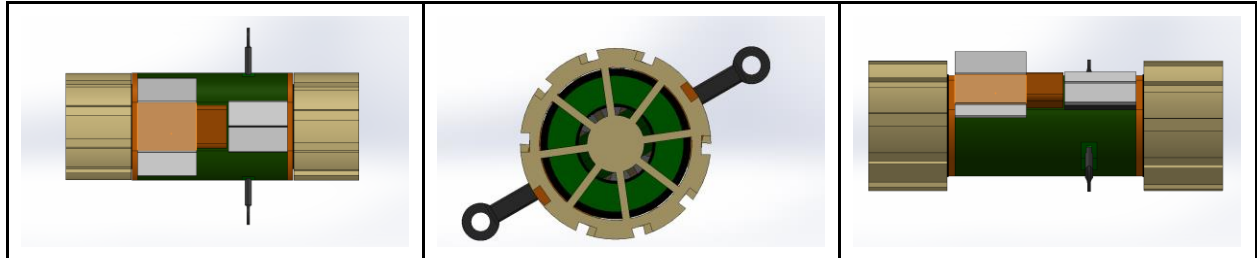


Table 43: Sidewinder rover pros and cons.

Pros	Cons
Takes up the most volume for the payload section, and allows for the largest diameter wheels.	Heavier than some designs
Design is modular. Parts or assemblies can be change quickly. This allow for fast repairs and efficient research and design.	Has the potential to get more easily "stuck" than other designs
Large relative body size makes for easy incorporation of a wide variety of sensor and other electronics.	Will have difficulty going over obstacles than a tank or other wheeled design.



<p>Rover will be able to hold up to 16 AA size batteries plus a 5V battery for the nav system. This allows it to have massive power reserves to accomplish the mission.</p>	
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### 7.3.2 Brief History of Sidewinder Design

The sidewinder rover concept was born from the idea of maximizing the possible vehicle wheel diameter. This diameter at the time of this writing is the five-inch internal diameter of the rocket body. This led to a side by side wheel design also known as di-wheel. The design team was given specifications for weight limit of ten pounds and an overall length of rover and extraction mechanism needed to be no more than 12 inches. The design team placed upon themselves additional restrictions. These restrictions include the ability to achieve mission objectives regardless of orientation, the ability to detect motion or the lack thereof and adjust direction to resolve. The team also wished to give the vehicle flexibility to grow beyond current mission requirements. This flexibility is in the form of vast power reserves, and versatile sensor/equipment compartments.

The first physical concept was built and showed the need of lever legs to push off from. The design team designated these legs as Newtonian legs. This concept model was unpowered and was limited by the construction medium. The strength of this model was it did have five-inch wheels, so it could be built to scale and made foreseeing future design easier. This concept was well received by management and the design team was encouraged to further develop it and told to present their ideas in a week.

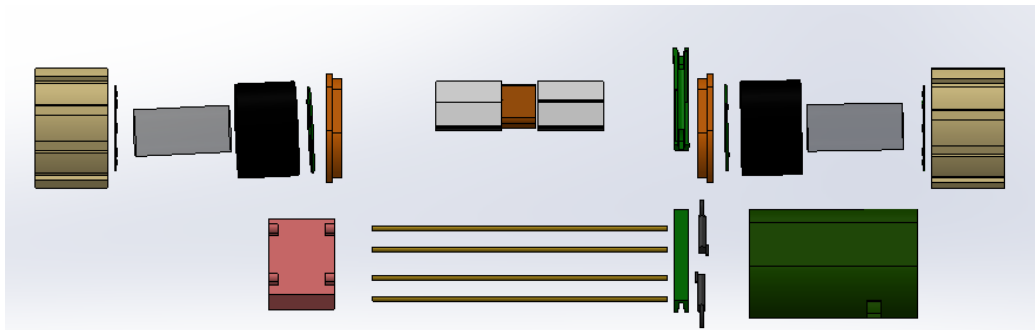
In that design week the sidewinder team developed a powered concept vehicle. The construction material was improved upon by using a combination of 3D printing and PVC pipe. The electric motors and the battery power supply were pulled from small power screwdrivers. This model was powered but was guided by an operator via a tether. This model proved the method of locomotion, it also helped the design team perfect rapid prototyping via 3D printing. When the model was directed to go straight it turned slightly, direction depending on orientation. This turn proved a need for correcting the small differences in motor turning rates.

### 7.3.3 Early CAD concepts

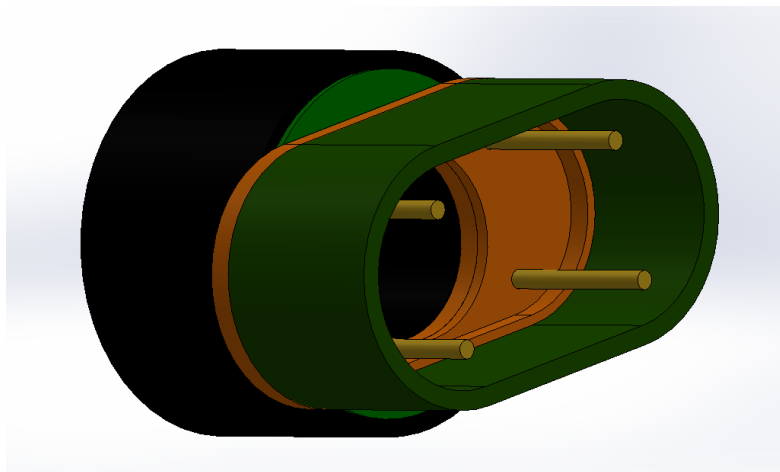
Some design concepts were explored via CAD drawings only. These designs were evaluated and rejected based on the drawings. Fig 3 shows an early concept that had the Newtonian legs as a single bar swinging from the top plane. This concept was rejected due to its failure to meet the design condition of being able to achieve the mission from every orientation.


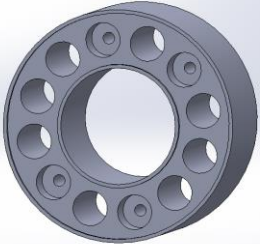
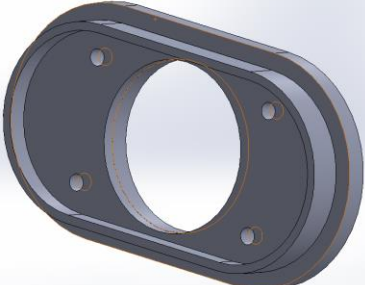
Another idea that was explored in CAD drawings was Newtonian weights. The idea was to use battery weight and possibly ballast weight to shift the center of gravity as low as possible in order to create leverage. This design would have the advantage of not having to deploy leverage legs. This concept was not outright rejected. It was decided that when a powered version of the rover was created an experiment will be conducted to measure this locomotion alternative. This idea loses some of its appeal as a reliable deployment method for Newtonian legs is developed.



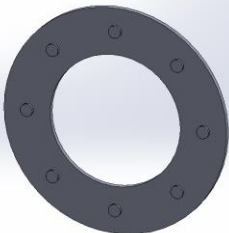

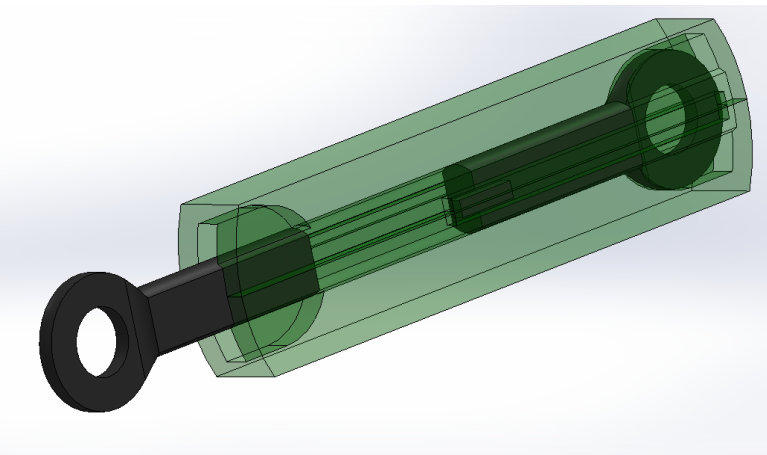
*Figure 21: Sidewinder rover prototypes.**Figure 22: Sidewinder rover components.*

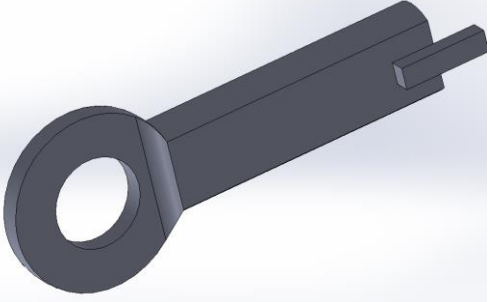
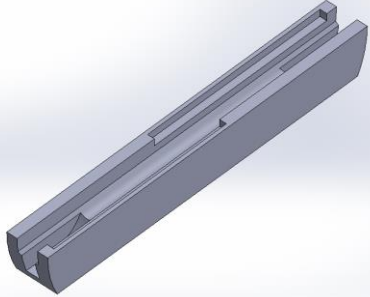
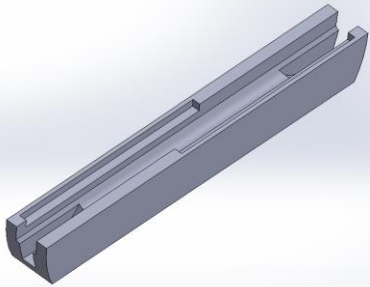
Structural System PN RA100



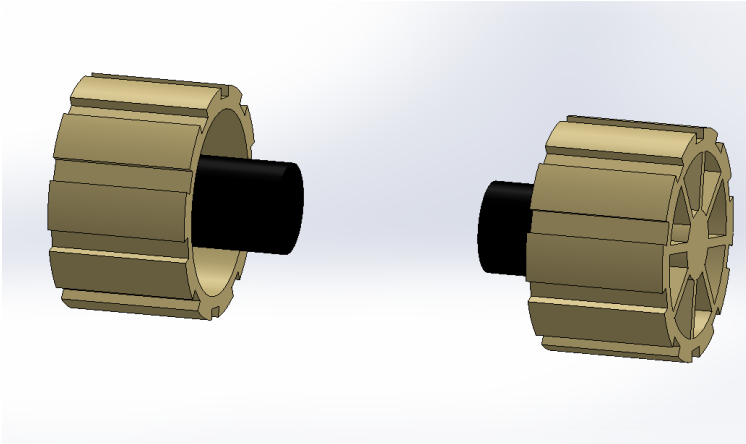
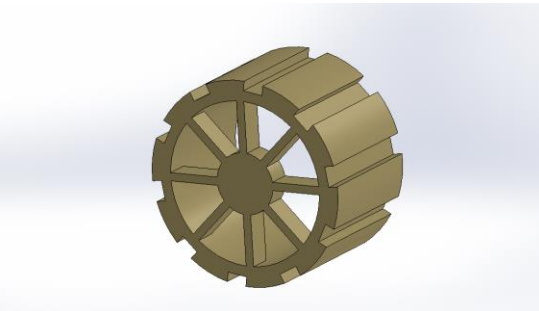
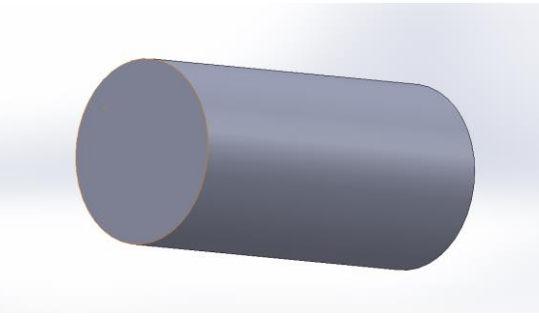
<p>Main Rover Body PN:R101 Quantity: 1</p> <p>This is the outer cover for the main body segment of the rover. It is made to fit the internal diameter of the rocket body wall lengthwise. And it is designed for ground clearance vertically. Ports are cut in the front and back for the Newtonian leg assembly.</p> <p>The dimensions of this part will change to fit rocket body internal diameter. Length of part may change to change length of rover. If current volume is excessive for requirements body will be reduced to save weight and space.</p> <p>Additional ports in body may be cut for sensors. Portions of top and bottom of body may be removed for solar panel assembly installation.</p>	
<p>Side Rover Body Segment PN:R102-R103 Quantity: 2</p> <p>These parts are placed on either side of the main rover body segment. The side body segment houses the batteries and is where the skeletal support rods begin and end. There are eight battery holes in the part, sized to fit the AA battery type. This makes the power system extremely flexible. The system voltage can be changed quickly to a wide spectrum of voltages including 12V, 24V and 48V just by changing to different AA battery voltages and/ or changing the series/parallel connections.</p> <p>Part may change in the future to include an area for a wheel rotation sensor. If wheel diameter or motor area size changes this part will also have to be changed.</p>	
<p>Body Segments Connector PN:R104-R105 Quantity: 2</p> <p>This is the part that joins the main body and the side body segments.</p> <p>It may have ports cut into it for wheel rotation sensors.</p>	



<p>Battery Compartment Cover. PN:R106-R109 Quantity: 4 These parts attach to the side body segments. They allow for quick access to battery compartment. They will cover and hold batteries, terminal boards, terminal springs.</p> <p>These part needs to be updated to become two different parts. One that remains the same the other needs to include holes where the structure rods will pass through.</p>	
<p>Skeletal Support Rods PN:R110-R113 Quantity: 4 These parts are within the rover. They are basic steel threaded rods used to squeeze all body pieces together. They are also used to mount and secure internal components.</p> <p>Rods will have to be cut to specific length and will have to be recut if rover length changes.</p>	
<p>Newtonian Leg Assembly PN RA400</p>	
	

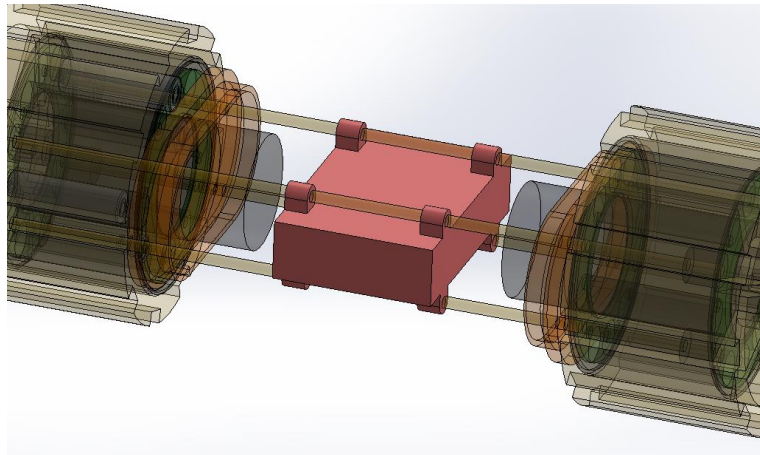
<p>Newtonian Leg PN:R401-R402 Quantity: 2 This part rests within the Newtonian leg assembly and is spring loaded while in the rocket body. The rocket body walls hold the legs back. When the rover is deployed the legs automatically deploy.</p> <p>A rotating wheel may be added to replace the circular ring. The end will need to be hollowed out to make room for the deployment spring.</p>	
<p>Leg Ejector Body Half 1 PN:R404 Quantity: 1 This part houses the Newtonian legs and the leg deployment spring. It prevents the Newtonian legs from rotating. It not the same as the other half. The cutouts for the restraining tabs make them different.</p>	
<p>Leg Ejector Body Half 2 PN:R405 Quantity: 1 This part houses the Newtonian legs and the leg deployment spring. It prevents the Newtonian legs from rotating. It not the same as the other half. The cutouts for the restraining tabs make them different.</p>	
Drive Section PN: RA300	



	
<p>Wheels PN:R306-R307 Quantity: 2 These parts are placed at the ends of the rover covering the side body segments. The wide hollow design allows the wheel to completely cover the side body portion of the rover. this allow for that portion of the body to be maximized without threat of the body portion from hitting ground obstacles.</p> <p>Wheels are currently five inches wide. They need to be redesigned based on the exact internal diameter of the rocket body cargo area. Wheel treads are flexible and will be the subject of future research to determine the best tread pattern for different conditions.</p>	
<p>Motor Assembly PN: Quantity: 2 This object represents the designated space for the motor assemblies. When motors are chosen their exact dimensions will be used instead.</p>	
Control/Sens/Nav/Com PN: RS600	





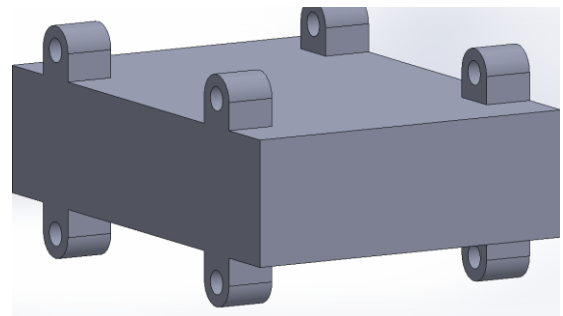
**Controller Housing**

PN:RS602

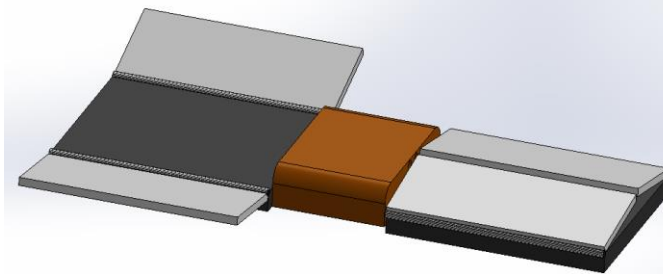
Quantity: 1

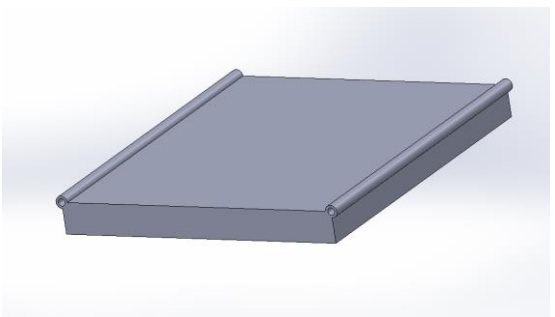

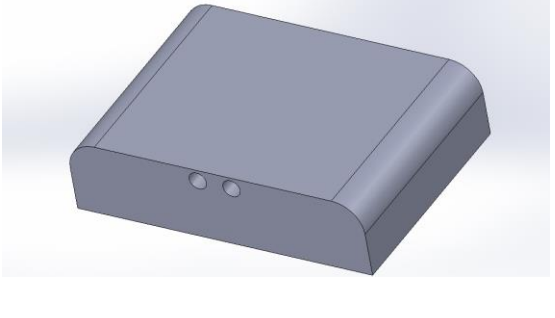
This object represents the designated space for the controller housing. It was based on general dimensions of possible controllers. It is positioned in the center of the rover and is attached to the skeletal support rods.

This part will need to be split into two so that the controller can be sandwiched in between. The ports for connections will have to be cut into it.



Solar Assembly PN: RA500



<p>Solar System Base PN:R501-R502 Quantity: 2 This part is the base piece for the solar system. It mounts to the body of the rover and acts as a pivot point for the solar cell arms. Solar cells will be mounted on the surface.</p> <p>When solar cells are chosen the design of the base will be changed so that the cells are recessed into the plate.</p>	
<p>Solar System Panel PN: R503-R506 Quantity: 4 This part is the rotating piece for the solar system. It mounts to the base of the solar assembly. Solar cells will be mounted on the surface.</p> <p>When solar cells are chosen the design of the panel will be changed so that the cells are recessed into the plate.</p>	
<p>Solar System Deployment Trigger Block PN:R508 Quantity: 1 This part is placed in between the two folding solar cell assemblies. It will house the trigger mechanisms holding the solar panels closed. Four pins holding back the panels can be made to be pulled independently. Thereby making it possible to create redundant deployment systems.</p> <p>This part will be designed with more detail when the trigger mechanisms are developed.</p>	

### 7.3.4 Research

Table 44: Preliminary sidewinder test.

Test Description	Test Result (Y/N)
Feasibility: Do design aspects work as projected	Yes
Mobility on dirt	No Possible ineffective wheel design or under



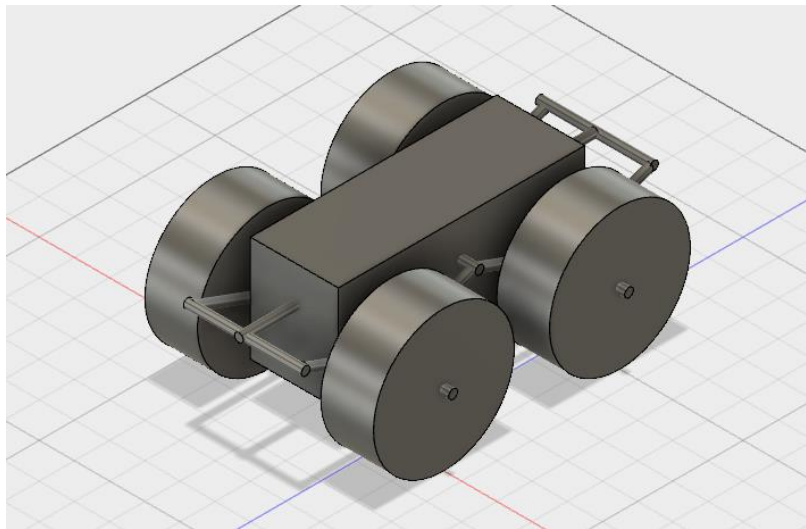
	powered motor.
Mobility on grass	Yes
Wheel rotation with a 4-volt motor	Did not provide enough torque for desired movement.

### 7.3.5 Research Discussion

Rover design has enough room to meet and exceed mission requirements. If this space for instrumentation is not needed design is also easily shortened to reduce space and weight. Design allows for side loading into cargo section. That allows the rover wheels to be maximized to match inner diameter of rocket body. This is the largest solid wheel possible for this system. For these reasons this design has been chosen as our main design for our payload

## 7.4 Alternative 2- Curiosity 2

*Figure 23: Curiosity 2 prototype drawing.*

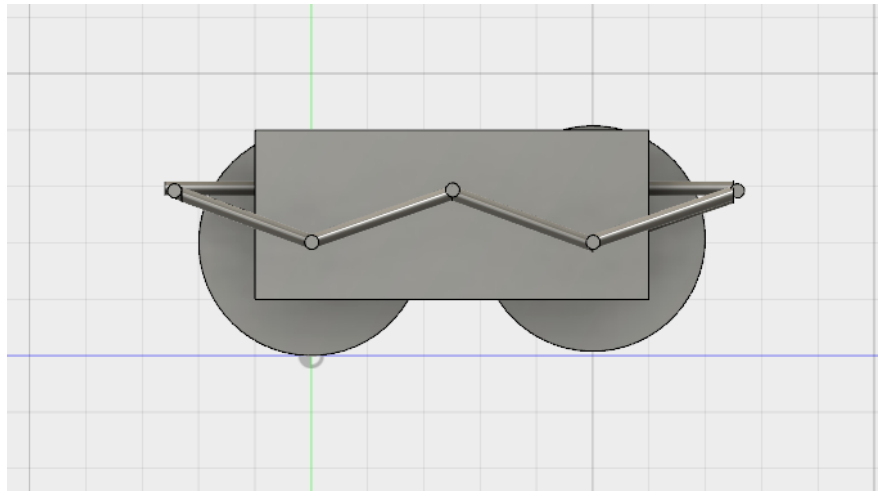
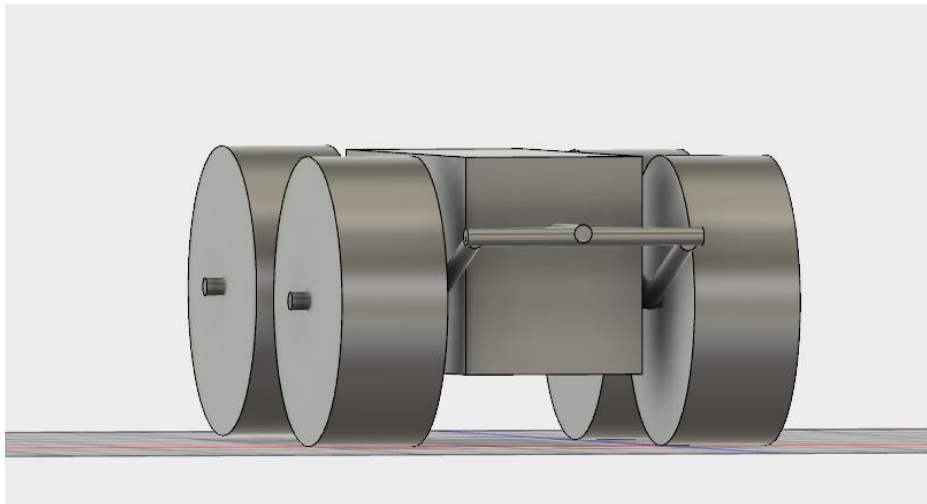


### 7.4.1 Curiosity 2 Description

This design was focused on having a simplistic suspension system to allow for ease of movement over the soft dirt and obstacles at the launch site. The rationale behind this incorporated design for the NASA Curiosity rover and its integrated suspension system. This rover consists of 4 wheels in which the two wheels on the same side of the rover are connected by rods which pivot in the center. Pictured here (without the wheels).

These rods are connected to the front and back of the rover respectively where they pivot as well. The idea is that when the rover approaches an obstacle the pivot arms allow for the wheel to go up and roll over the object. When one wheel goes up the opposite wheel goes down keeping all other wheels to the ground allowing for the most surface area to contact the dirt to allow for the maximum traction of the payload



*Figure 24: Curiosity 2 suspension view.**Figure 25: Curiosity 2 plane view.**Table 45: Pros and cons of Curiosity 2 rover.*

Pros	Cons
Has a suspension system which can be used to go over obstacles	It does not maximize cargo space
Has a large surface to carry solar panels and other electronics	Has to have motors at all wheels therefore requiring more power
	is not omni-directional like other rover designs

Because this design has a high likelihood of flipping and because this design incorporated as much volume in the payload section it was scrapped.

## 7.5 Alternative 3- Tumblr Rover

### 7.5.1 Tumblr Rover Description

The line of reasoning for this design are the advantages of a continuous track system of movement. For this mission, those advantages don't only extend to mobility, but also to the deployment of the rover. The rover (pictured without tread) would be secured inside the rocket, and after descent be unsecured to allow it to simply drive itself out of the exposed end. The half cylinders on the sides of the rover function to roll it back onto an upright position in the case the rover tread is not parallel to the ground after descent.

One of the main drawbacks of this design is the limitations on space for the computer system, batteries, and solar panel system. Inscribing a square in a circle of a diameter of 5 inches (figure 2) yields sides of length around 3.5". Having the rover width and height close to this measurement will allow the tire width to support a track of adequate surface area, while not limiting the space for electronics any further. To increase space and elongate the 7" side of the 7" by 3.4" plane for more room may lead to the track sagging down onto the space, or else require additional support be added to compensate, which would increase the complexity and reduce the reliability of the rover.

*Figure 26: Tumblr rover prototype drawing.*

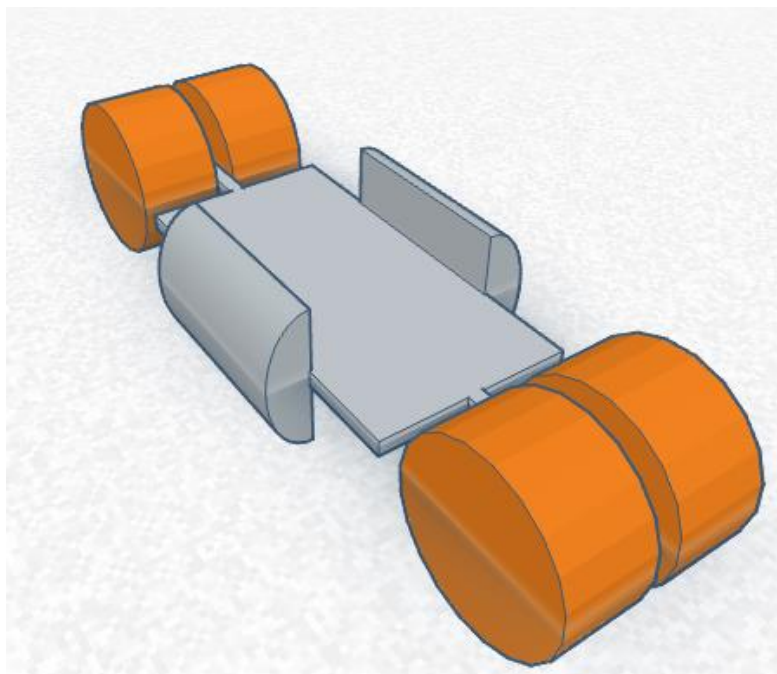


Figure 27: Tumblr rover dimension view.

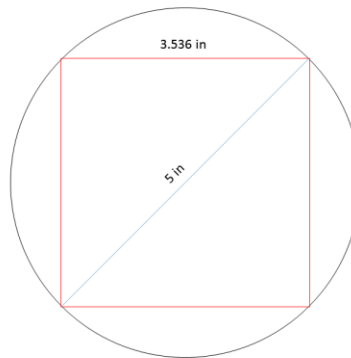


Table 46: Pros and cons of Tumblr rover.

Pro	Con
Mobility - Surface area of movement system in contact with the ground is the most with a continuous track system	Complexity of the continuous track system makes it more difficult to build, and less reliable.
Deployment - The most complex part of the deployment system will be securing and releasing the rover from the rocket. Orientation of the landing will not present an issue either.	Space for the computer, batteries, and solar panel system will be limited  The axle that supports two motors is a fragile point on the frame.

## 7.6 Payload Deployment Method

### 7.6.1 Objective of the Deployment system

- To initiate when commanded by the ground safety officer
- Move a 10 lb payload beyond the exterior of the vehicle
- Secure the payload prior to activation
- Release the payload when beyond the exterior of the vehicle

### 7.6.2 Deployment thought process

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

- The simplicity of the design prevents an over complicated design from failing upon launch. The more simplistic the design, the better. This means relying more on as few electronic components as possible.
- The weight of the deployment system cannot be too large, or the rocket will not reach the desired Apogee. The maximum weight for the rover and deployment system is set at 10lbs. For



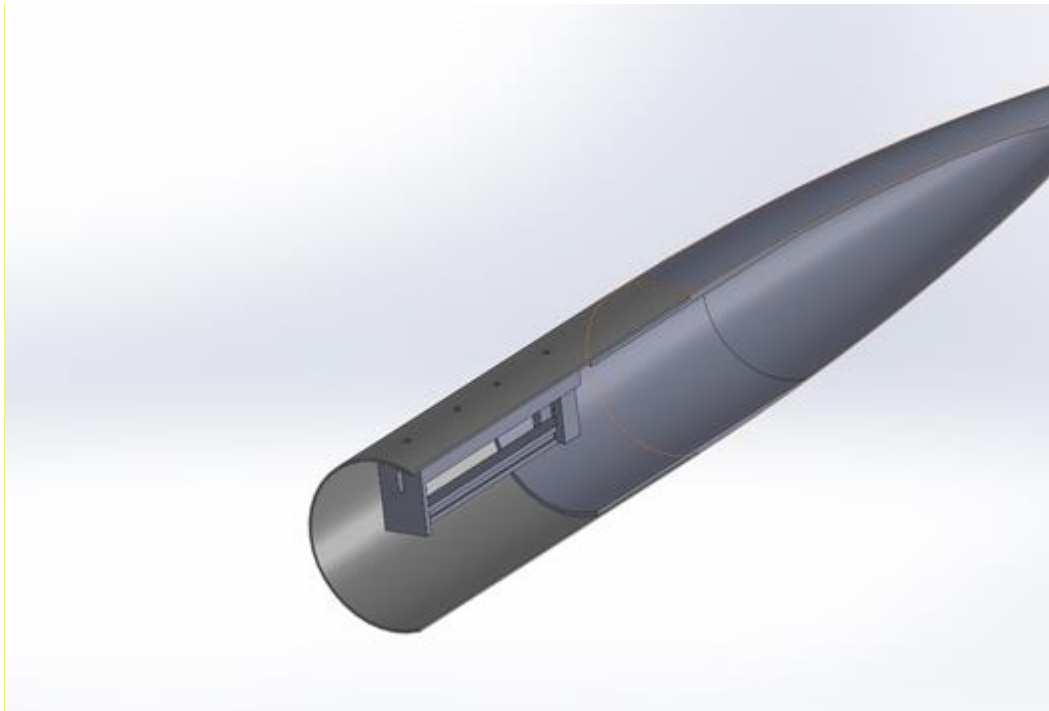
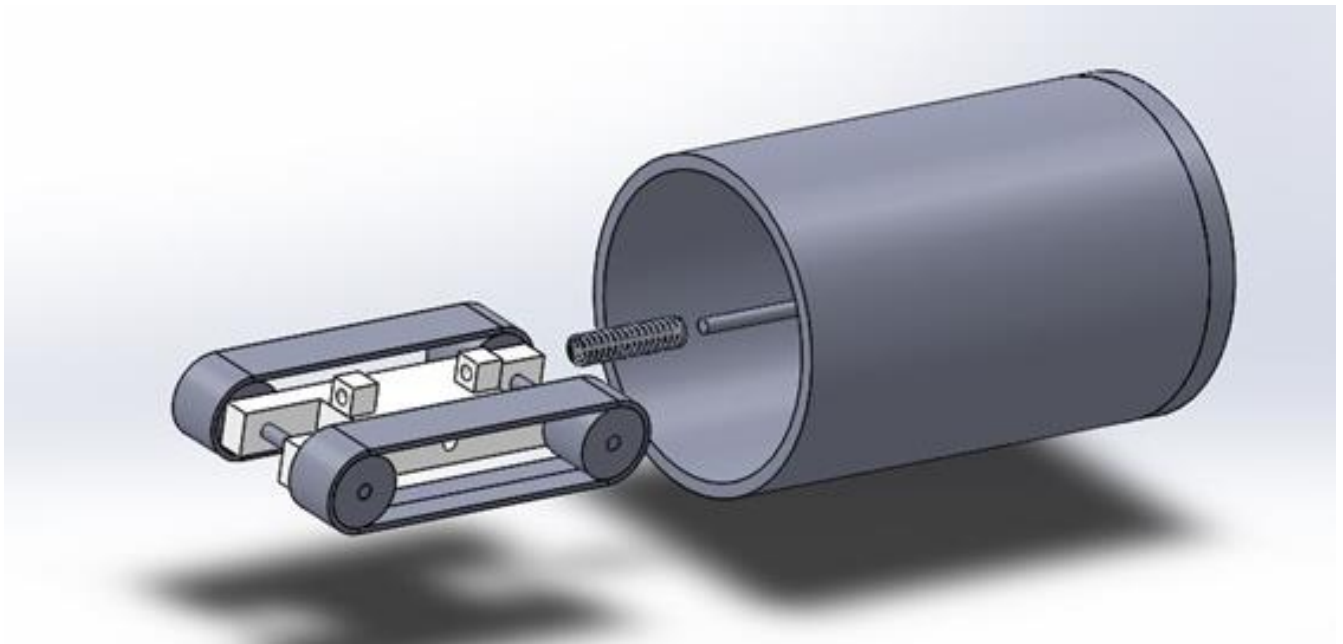
- this reason, alternative materials such as 3D printed parts are preferable to metal as they are lighter and do not have large forces being applied.
- The size is important because it must fit within the frame of the rocket and compress to allow for as large of a rover as possible. This also affects the weight of the system as a larger system tends to be heavier.
  - Ease of loading and unloading the rover into the vehicle. Not only does the system have to deploy the rover, it must be able to load and secure the rover. It must be capable of loading while the rocket is assembled. Taking safety into consideration is very important for this, a sensitive system may launch the rover prior to being set and secured.

### 7.6.3 Review of initial design

In the previously submitted design of the deployment method, the rover will be secured to the rocket by using a series of powered clamps. These clamps will be attached to the guide rail of the rover apparatus, secured in a linear configuration on the inside of the airframe, and be part of the first set of actions upon the deployment trigger. Upon landing, the rover will be triggered remotely by our ground team. With the trigger, the clamps will release tension on the guide rail, allowing the rover the ability to mobilize itself out of the rocket. Once the clamps release and the rover is detached, the next command for the onboard computers will be to move the rover forward towards the opening. This second command of movement will be responsible for delivering the rover out of the launch vehicle and moving at least 5 feet from the point of exit.

Upon review the Cons of this design outweigh the Pros and the system needs to be redesigned. The main factors affecting this are the length of the system being too long for the payload compartment and the biggest reason is that current design of the rover is not equipped to work with this system.



*Figure 28: Initial deployment device rail system.**Figure 29: Initial deployment device system with rover.**Table 47: Pros and cons of Tumbler rover.*

Pros	Cons
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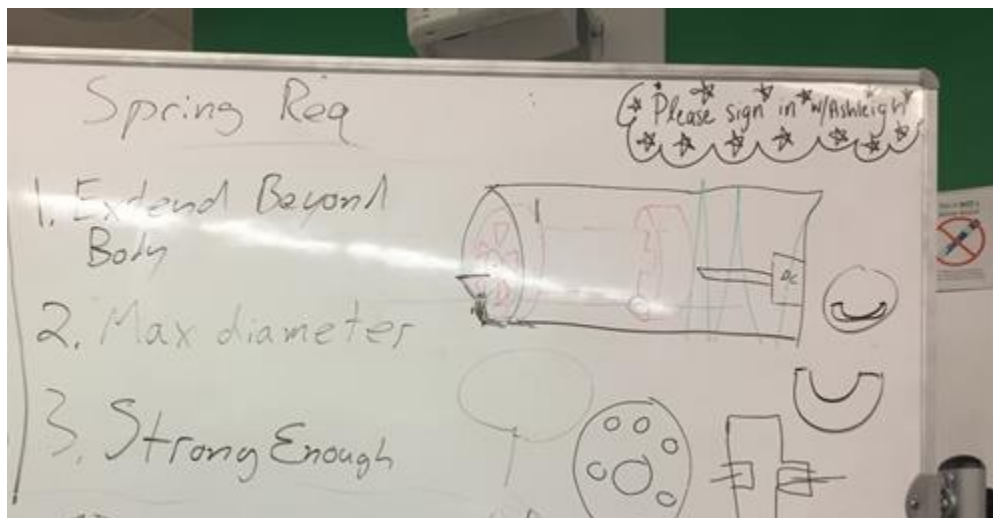
Easy to secure rover	NOT FOR CURRENT ROVER DESIGN
Consistent deployment	Too long to fit in payload area
	Extremely heavy
	Not omni-directional

#### 7.6.4 Alternative design A: Spring Loaded

Upon initiation by the ground team, a 50 lb spring will push on the payload to propel it out of the vehicle frame. An aluminum hub will be attached to the outside of the rear wheel of the payload. This hub will attach to the wheel on one side and will be attached to a threaded rod on the opposite side. This allows the rover to be secured with a threaded rod to prevent the spring from releasing the rover prior to initiation. The threaded rod will be fixed on the rear end and will be powered by a motor to screw into and out of the rover hub. The spring will be the size of the frame to prevent the spring from bending perpendicular to the direction of desired force. It must also be longer than the payload compartment to ensure that the rover is deployed fully. Upon initiation the motor will turn, unscrewing from the hub, and the rover will be forced out of the tube by the compressed spring. As a failsafe, by powering the wheels on the rover, the rover could also be twisted off the threaded rod.

Based on the Pros and Cons of the design, the spring-loaded deployment method was deemed as a usable system. The system will be further developed as an alternative however it will not be the preferred design. This is mainly because the weight and size of the system being on the upper limit of the allowable range.

*Figure 30: Preliminary drawings of spring loaded deployment device.*



*Table 48: Pros and cons of spring loaded deployment device.*

Pros	Cons
Spring is passive	Wheel hub remains on wheel after deployment
Plenty of force to push rover out of the vehicle	Less room for rover design
Easy to load	Hard to find spring with our specific needs
Failsafe if motor fails	More room for error (What is the threaded rod bends?)
	Potential safety hazard

### 7.6.5 Alternative Design B: Air powered

A canister of compressed air is located behind the rover with an inflatable bag. Upon initiation by the ground team, the air canister will open and fill the bag with air. This will result in a force being applied evenly on the rover wheel pushing the rover out of the vehicle frame and allowing the rover to drive away. The canister will be filled with compressed air prior to the flight with enough pressure to expand the bag beyond the end of the vehicle.

This design did not meet all the requirements for the deployment system by not having a method to secure the rover prior to initiation. Also, the potential for error was too large to be launched inside of the rocket.

*Table 49: Pros and cons of air powered deployment device.*

Pros	Cons
Lightweight and compact	Only a one-time use
Minimal electronics	Large potential for misfire
	Large potential for failure to push rover out of vehicle

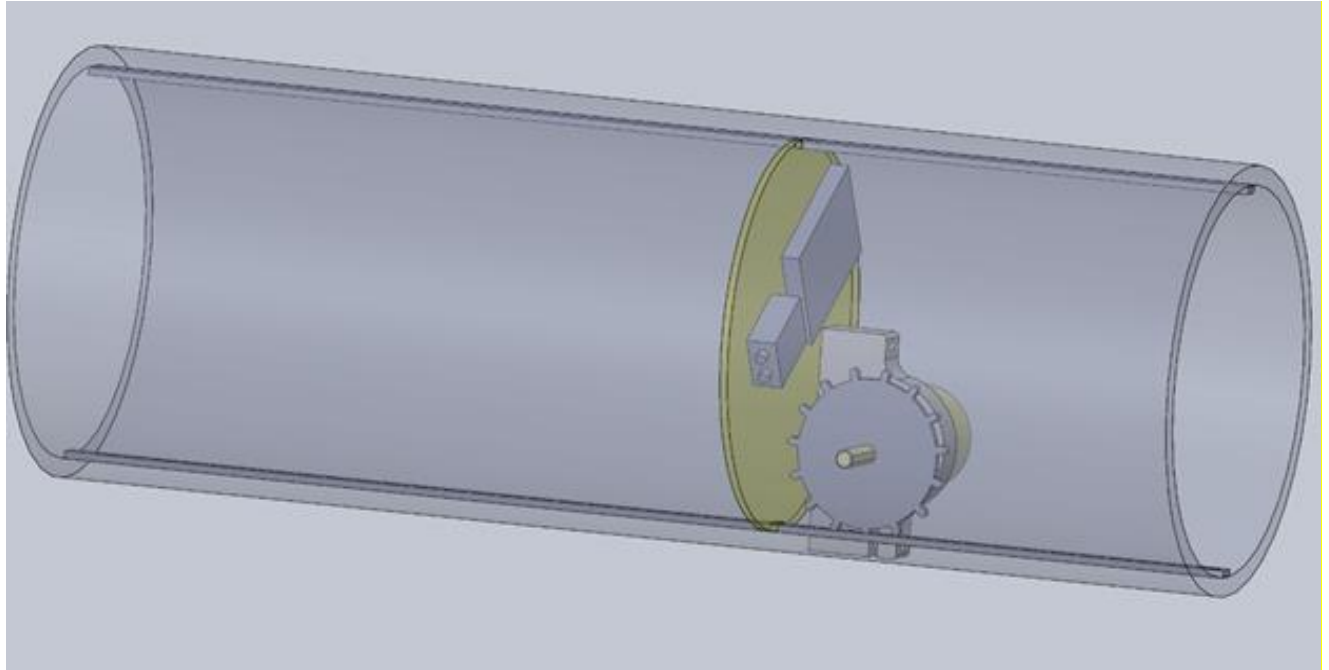
### 7.6.6 Alternative Design C: Rack and pinion

Upon initiation by the ground team, the payload will be moved by a rack and pinion system inside of the vehicle. A powered bike sprocket and bike chain, fixed to the inside of the vehicle, will be used as the rack and pinion as seen below. The motor, battery, and onboard computer will be secured to the back side of the plate. The payload will be secured with a fixed attachment that goes through the tread of the wheel and expands on the other side to secure the payload in



relation to the plate. This allows the payload to move with the rack and pinion while still inside of the vehicle frame. Outside of the vehicle frame, the payload will be able to detach from the plate using its own forward motion.

*Figure 31: Rack and pinion device drawing.*



#### *7.6.6.1 Rack and pinion design*

The bike sprocket and chain combination was chosen as the rack and pinion due to the availability of the parts. These parts are inexpensive and easy to replace if broken. This system will be able to deliver the necessary force to move the payload out of the vehicle frame.

#### *7.6.6.2 Motor*

The motor must be a low speed high torque motor that stays under 500 rpm. This is because we need the motor to have the power to push the payload. This can either be done two ways, having a large motor or by using a faster motor with a gearbox to increase the torque. Due to the size constraint of a 2in body, not including shaft length, the smaller motor with a gearbox was chosen. Inside the gearbox is a planetary gear system that transfers from 6 teeth to 24 teeth to 48 teeth within a small area, as seen in the figure below.

This gearing system gives us a power ratio of, where  $P$  = power ratio,  $N_S$  = number of teeth on the sun gear,  $N_R$  = number of teeth on ring.

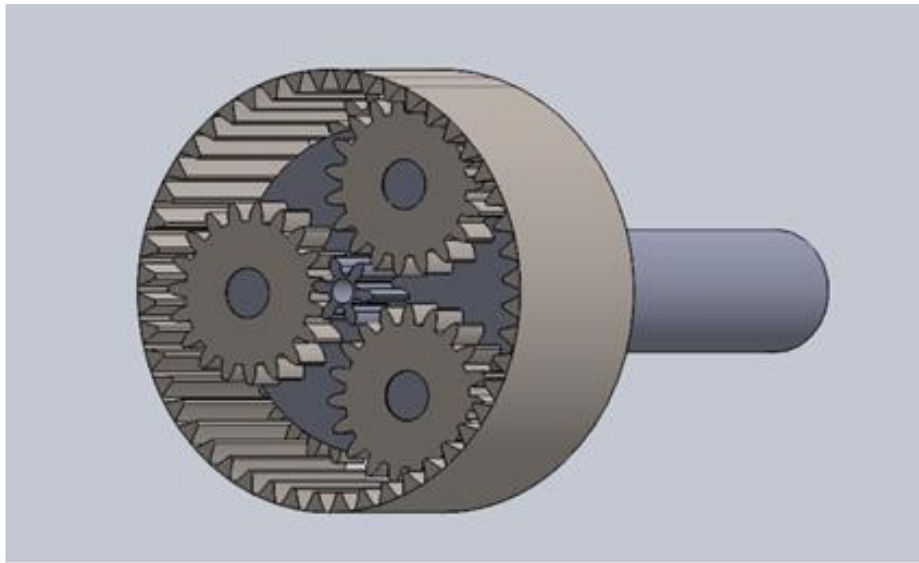
$$P = N_R / N_S$$

$$8 = 48 \text{ teeth} / 6 \text{ teeth}$$

The power ratio of eight will allow a smaller motor to produce eight times as much torque on the shaft that can be used to move the payload.



Figure 32: Rack and pinion planetary gear system.



#### 7.6.6.3 Battery

A small battery will be used that will power the motor and the electronic communications system. The battery will be mounted to the plate to reduce the length of wires and to prevent wires from getting stuck in the bike chain.

#### 7.6.6.4 Electronics

Attached to the plate we are projected to add a sensor to allow for communications outside of the vehicle after landing to initiate the rover to be deployed. There will also be a motor controller to allow for power to be sent to the motor.

Table 50: Pros and cons of rack and pinion deployment device.

Pros	Cons
Consistent	Requires more battery power
Simplistic and easily measurable success	Hard to reload without additional programming
Less chance for failure	
Easy to secure rover	

The rack and pinion deployment method was selected as the main solution for deploying the rover from the vehicle. The main factors leading to this was the size and simplicity of the system. The length of the rack will align with the wheels on the over preventing unwanted rotation. There is no need for a secondary motor to secure the rover. The only motor is situated horizontally which reduces the amount of space taken in the payload compartment. Lastly, it is safe to load the rover prior to launching the rocket.



## 7.6.7 Distance Determination

Table 51: Pros and cons of distance determination options.

	Pros	Cons
Accelerometer(NEW)	<ul style="list-style-type: none"> <li>-Accurate measurement of acceleration up to 16G</li> <li>-Can measure acceleration on 3 axes.</li> <li>-Low power usage up to 23<math>\mu</math>A</li> </ul>	<ul style="list-style-type: none"> <li>-Acceleration measurement on slopes may affect distance determination</li> <li>-Additional programming and calculation to determine distance</li> </ul>
Hall Effect Sensor(NEW)	<ul style="list-style-type: none"> <li>-Every rotation of the wheels will be sensed</li> <li>-Saves space and weight due to small size</li> </ul>	<ul style="list-style-type: none"> <li>-Can be knocked loose</li> <li>-Possible short-circuit and will not work</li> </ul>
Bluetooth Connection(Discontinued)	<ul style="list-style-type: none"> <li>-Wireless Connection</li> </ul>	<ul style="list-style-type: none"> <li>-Signal is degraded within rocket and rover</li> <li>-May send trigger signal too soon due to signal strength</li> <li>-</li> </ul>
Infrared Sensor(Discontinued)	<ul style="list-style-type: none"> <li>- Accurate Distance Measuring</li> <li>- Easy to implement with analog signals</li> </ul>	<ul style="list-style-type: none"> <li>-Angle of incidence will affect the result of distance measure</li> <li>-May not have a line of sight on the rocket</li> <li>-Draws more current than other sensors</li> <li>-Heavier than other methods of measuring</li> </ul>



### 7.6.7.1 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 3.5V which is managed by the Arduino and this operating voltage will also minimize the amount of current leakage from the IC. The sensor will keep track of the amount of rotations over a given period of time. The equations to compute the distance will be the following,  $V = \omega r$   $\omega = (RPM * 2\pi)/60$   $d = V * t$ . V is linear velocity in meters/second,  $\omega$  = angular velocity in radians/second, d = distance in meters.

### 7.6.7.2 ADXL345 Digital Accelerometer

The ADXL345 Accelerometer will be used to verify that the rover is moving. This verification will be used in addition to the hall effect sensor so that way if the rover is moving it will keep the hall effect sensor active and will continue counting. The accelerometer can be used to determine the distance traveled by the equation:  $d = 1/2 * a t^2$  where d: distance in meters, a: acceleration in m/s<sup>2</sup> and t: time in seconds. The sensor will be set to the lowest sensitivity of 2g in order to account for any variation of acceleration from the rover.

## 8 Project Plan

### 8.1 General Requirements

Table 52: General requirements and verifications.

Requirement	Method	Verification
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).	Team project manager and team leaders will supervise all build operations to ensure that all design, construction, flight preparations, reports, and presentations are conducted by USF SOAR student members. However, as detailed in the Safety Plan and to be monitored by the Safety Officer, the team mentor will handle all motor assembly, black powder, explosive ejection charges, and will prepare and install any electric matches or igniters.	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.
The team will provide and	Team leader and project manager	SOAR utilizes an online shared



maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.	will work with 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 personnel assigned.	calendar to track event dates and milestones and an online shared file storage to store information about budget and community support, checklists, personnel assigned, educational engagement events. Safety information about risks and mitigations is posted in the work space and on the shared storage drive. Further, the personnel in designated roles will ensure that all proper coordination is made for the requirements.
Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during these activities.	Students must provide document proof of either U.S. citizenship or foreign nationality. Verify that this information is provided before the PDR.	SOAR has submitted information on foreign national students who are a member of the team as of the date of this report. Team leads will continue to monitor membership and ensure that all foreign national students are recognized.
The team must identify all team members attending launch week activities by the Critical Design Review (CDR).	Students will commit to attend launch and make appropriate notifications to their professors. Mentor will verify intent to attend.	Project manager and team leads will designate potential launch week participants no later than three weeks prior to launch week. Mentor has confirmed intent to participate.
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.	SOAR will participate in USF's Engineering Expo, which draws attendees from multiple local high schools and middle schools, and plan at least two additional engagement activities in local schools. All indirect engagement activities will also be documented and reported.	An Outreach Coordinator has been designated to handle all outreach events. Participation in Engineering Expo will ensure the minimum of 200 participants is reached.



The team will develop and host a Web site for project documentation.	A team member will be designated to update the website on a minimum of a bi-weekly basis. All documentation will be posted to the website in a timely manner.	The SOAR website is currently up and functional, with the current documentation uploaded.
Teams will post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.	All documentation will be posted to the website in a timely manner.	The SOAR website is currently up and functional, with the current documentation uploaded.
All deliverables must be in PDF format.	One team member has been designated to format and submit all documentation and is familiar with the requirement for PDF format.	Documentation to date has been properly submitted, and the designated individual will continue to do so.
In every report, teams will provide a table of contents including major sections and their respective sub-sections.	One team member has been designated to format and submit all documentation and is familiar with the requirement for table of contents, sections, and subsections.	Documentation to date has been properly submitted, and the designated individual will continue to do so.
In every report, the team will include the page number at the bottom of the page.	One team member has been designated to format and submit all documentation and is familiar with the requirement for page numbers.	Documentation to date has been properly submitted, and the designated individual will continue to do so.
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.	The SOAR team has access to computers, speaker phones, Wi-Fi connection, and a video camera for teleconference purposes.	For each meeting, a designated individual will arrive early to set up and verify all electronic components.
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.	SOAR's rocket will utilize standard rails made available on the NSL launch site.	Launch vehicle will be designed to utilize standard rails made available on the NSL launch site.





Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.		
Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194)	Verify that Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards are implemented.	SOAR will thoroughly read and adhere to the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards.
Each team must identify a "mentor."	Qualified mentor will be designated.	Jim West, Tripoli 0706 (Tripoli advisory panel member), Certification Level 3 has been designated as the team mentor.

## 8.2 Vehicle Requirements

Please see requirements Table 5: Detailed mission requirements and confirmation methods.

## 8.3 Recovery System Requirements

Please see requirements Table 21: Detailed recovery system mission requirements and confirmation methods.

## 8.4 Experiment Requirements

Please see requirements Table 42: Detailed payload mission requirements and confirmation methods.

## 8.5 Safety Requirements

*Table 53: Safety requirements and verifications.*

Requirement	Method	Verification
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.	Team will use launch and safety checklists. Final checklists will be included in FRR report and used during LRR and all launch day operations.	Safety officer has been designated and will develop launch checklists. Safety officer will ensure that all checklists are used during relevant operations.
Each team must identify a student safety officer who will be responsible for all items in section 5.3.	SOAR NSL team will designate a Safety Officer.	Wyatt Boyatt has been designated as the Safety Officer.



The role and responsibilities of each safety officer will include the items designated in the 2018 NSL Handbook.	SOAR NSL Safety Officer will be assigned the designated duties.	Duties are listed and designated in this report and will be so designated in all future reports.
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.	SOAR will abide by all rules and guidance of the Tampa Tripoli Rocket Association RSO.	Safety Officer or designated team lead will supervise all operations to ensure rules and guidance are followed.
Teams will abide by all rules set forth by the FAA.	Team will abide by rules set by FAA.	FAA rules are made available on the team share drive, and the safety officer will verify that all rules are followed.

## 9 Project Budget and Timeline

### 9.1 Budget

Rocket Materials	\$1,000
Launch Motors	\$400
Test Launch Motors	\$800
Subscale Materials	\$600
Subscale Motor	\$350
Payload	\$800
Miscellaneous Hardware	\$400
Travel	\$1,500
<b>TOTAL</b>	<b>\$5,850</b>



## 9.2 Timeline

Date	Item Due	Team Responsible
November 4th, 2017	Start Subscale Construction	Rocketry Team
November 5th, 2017	Prototype Rover Parts Purchase Orders Filed	Rover Team, CSCE Team
November 17, 2017	Begin Rover Construction & Testing	Rover Team
November 17, 2017	Begin Interactive Subscale Payload Design & Construction	Rover Team, CSCE Team
November 24th, 2017	Post-Tests Detailed Rover Parts List Filed	Rover Team, CSCE Team
December 15th, 2017	Interactive Subscale Payload Complete	Rover Team, CSCE Team
December 15th, 2017	Subscale Construction & Inspection Complete	Rocketry Team
December 16th, 2017	Conduct CDR/ Subscale Launch	Entire NSL Team
January 12th, 2018	CDR Due	Entire NSL Team
February 7th, 2018	Rover Parts Fabricated & Assembled	Rover Team
February 10th, 2018	Prototype Rover Coding Complete	CSCE Team
February 16th, 2018	Prototype Rover Complete for Full Scale Launch	Rover Team, CSCE Team
February 16th, 2018	Full Scale Construction Complete	Rocketry Team
February 17th, 2018	Conduct FRR/ Full Scale Launch	Entire NSL Team

## 10 Educational Engagement Plan

The Society of Aeronautics and Rocketry along will work together to provide multiple educational events for our university and surrounding communities. We plan on organizing events with local schools to inform students on our projects and teach them the importance of STEM Education. We will also be engaging in university events that bring in local students to learn about STEM Education, specifically in the engineering. In addition to these events we will be organizing other events to showcase our current and previous projects to teach fellow students about what we do. Some of our past activities and upcoming events ones are described below.



## 10.1 Past Events

### 10.1.1 Engineering Block Party

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

### 10.1.2 Rocket Exhibition

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

1. A showcase of our organization's past rockets with information describing what they were created for and some details about the design.
2. 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.
3. 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.
4. A presentation about our organization's projects to show how much work and research that goes into planning and engineering a rocket.

### 10.1.3 E-Council Open House

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

### 10.1.4 USF Student Organization Showcase

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

### 10.1.5 Roboticon

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



### 10.1.6 USF Foundations of Engineering Class Presentation

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

### 10.1.7 Engineering Day at USF

Projected event for November 3rd 2017 where local high school students come and visit the university to view the different student organization in the engineering department. We will provide students with the opportunity to learn about our projects and see one of our rockets.

### 10.1.8 Middle School Presentation

Projected event for November 15th 2017 where a group of our members will speak to middle school students at Palm Harbor Middle School and possibly launch small rockets if an adequate space is found.

### 10.1.9 High School Presentation

Projected event for December where a group of our members will speak to students from the Academy of Information Technology at Northeast High School in Saint Petersburg. Our outreach team leader is working closely with the teachers at the school to come up with a good curriculum plan in order to appeal to a variety of students at different levels within their program.

### 10.1.10 Boy Scout Presentation

Projected event where a group of our members will speak to a boy scout group and hopefully show them how to build a small rocket that they will be able to launch.

### 10.1.11 Engineering Expo at USF

Projected event taking place over two days, February 16th and 17th in 2018 where student grades K-12 will come to the university to understand the importance of STEM education. This event will allow us to connect to students and teach them about our organization and how we are able to gain valuable engineering experience. We will also provide students with a form of active engagement.

*Table ###: Upcoming Educational Engagement events.*

Event	Date
Engineering Day at USF	11/03/2017
Palm Harbor Middle School Presentation	11/15/2017
Northeast High School Academy of IT Presentation	December
Boy Scout Presentation	TBD
Engineering Expo at USF	02/16/2018



# 11 Appendix

## 11.1 Contributors

- **Project Management/Logistics**

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

- **Launch Vehicle**

- Jackson Stephenson
- Kevin Kirkolis
- Stephanie Bauman

- **Editing and Formatting**

- Stephanie Bauman
- Jackson Stephenson

- **Electronics/Coding**

- Joe Caton
- Cesil Alex
- Linggih Saputro

- **Rover**

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

- **Educational Engagement**

- Jackson Stephenson
- Ashleigh Stevenson

- **Safety**

- Stephanie Bauman
- Wyatt Boyatt



## 11.2 Milestone Review Flysheet (PDR)

Milestone Review Flysheet 2017-2018																			
Institution					University of South Florida					Milestone					PDR				
Vehicle Properties										Motor Properties									
Total Length (in)					93					Motor Brand/Designation					Cesaroni/L995				
Diameter (in)					5.148					Max/Average Thrust (lb.)					287.05/214.08				
Gross Lift Off Weight (lb.)					30.2					Total Impulse (lbf-s)					813.36				
Airframe Material(s)					Fiberglass					Mass Before/After Burn (lb.)					7.92/4.22				
Fin Material and Thickness (in)					1/8" Fiberglass					Liftoff Thrust (lb.)					252.69				
Coupler Length/Shoulder Length(s) (in)					12/5					Motor Retention Method					Aeropak Retainer Ring/Front End of Motor				
Stability Analysis										Ascent Analysis									
Center of Pressure (in from nose)					79.793					Maximum Velocity (ft/s)					693.45				
Center of Gravity (in from nose)					64.158					Maximum Mach Number					0.625				
Static Stability Margin (on pad)					3.04					Maximum Acceleration (ft/s <sup>2</sup> )					278.25				
Static Stability Margin (at rail exit)					3.07					Predicted Apogee (From Sim.) (ft)					5298.56				
Thrust-to-Weight Ratio					8.37														
Rail Size/Type and Length (in)					1515/96														
Rail Exit Velocity (ft/s)					65														
Recovery System Properties										Recovery System Properties									
Drogue Parachute										Main Parachute									
Manufacturer/Model					SkyAngle CERT3					Manufacturer/Model					SkyAngle CERT-3				
Size/Diameter (in or ft)					Drogue					Size/Diameter (in or ft)					XL				
Altitude at Deployment (ft)					5298.56					Altitude at Deployment (ft)					1000				
Velocity at Deployment (ft/s)					-3.53					Velocity at Deployment (ft/s)					-78.34				
Terminal Velocity (ft/s)					-82.75					Terminal Velocity (ft/s)					-10.22				
Recovery Harness Material					Tubula Kevlar					Recovery Harness Material					Tubular Kevlar				
Recovery Harness Size/Thickness (in)					1/2"					Recovery Harness Size/Thickness (in)					1/2"				
Recovery Harness Length (ft)					30					Recovery Harness Length (ft)					30				
Harness/Airframe Interfaces					5/16" Zinc-Plated U-bolt, 5/16" locking quick link, parachute swivel					Harness/Airframe Interfaces					5/16" Zinc-Plated U-bolt, 5/16" locking quick link, parachute swivel, Carbon Fiber Strengthened Marine Epoxy				
Kinetic Energy of Each Section (ft-lbs)		Section 1		Section 2		Section 3		Section 4		Kinetic Energy of Each Section (Ft-lbs)		Section 1		Section 2		Section 3		Section 4	
		217.98		934.63		135.04		1084.55				3.32		14.26		2.06		16.54	
Recovery Electronics										Recovery Electronics									
Altimeter(s)/Timer(s) (Make/Model)					Missileworks RRC3					Rocket Locators (Make/Model)									
Redundancy Plan and Backup Deployment Settings					The recovery system electrical circuits shall be completely independent of any payload electrical circuits. The recovery system shall contain redundant altimeters.					Transmitting Frequencies (all - vehicle and payload)					***Required by CDR***				
Pad Stay Time (Launch Configuration)					5-6 hours					Ejection System Energetics (ex. Black Powder)									
										Energetics Mass - Drogue Chute (grams)					Primary				
										Backup									
										Energetics Mass - Main Chute (grams)					Primary				
										Backup									
										Energetics Masses - Other (grams) - If Applicable					Primary				
										Backup									



## Milestone Review Flysheet 2017-2018

<b>Institution</b>	University of South Florida	<b>Milestone</b>	PDR
--------------------	-----------------------------	------------------	-----

Payload	
Payload 1 (official payload)	<div style="text-align: center; border-bottom: 1px solid black; padding-bottom: 5px;">Rover</div> <p>Rover design: The sidewinder rover concept was born from the idea of maximizing the possible vehicle wheel diameter. This diameter at the time of this writing is the five-inch internal diameter of the rocket body. Rover design as enough room to meet and exceed mission requirements. If this space for instrumentation is not needed design is also easily shortened to reduce space and weight. Design allows for side loading into cargo section. That allows the rover wheels to be maximized to match inner diameter of rocket body. This is the largest solid wheel possible for this system. The design also incorporates Newtonian legs to improve traction of the two-wheeled system.</p>
Payload 2 (non scored payload)	<div style="text-align: center; border-bottom: 1px solid black; padding-bottom: 5px;">N/A</div> <div style="text-align: center; padding-top: 50px;">N/A</div>

Test Plans, Status, and Results	
Ejection Charge Tests	Tests have not been run yet
Sub-scale Test Flights	Tests have not been run yet
Full-scale Test Flights	Tests have not been run yet





**Milestone Review Flysheet 2017-2018**

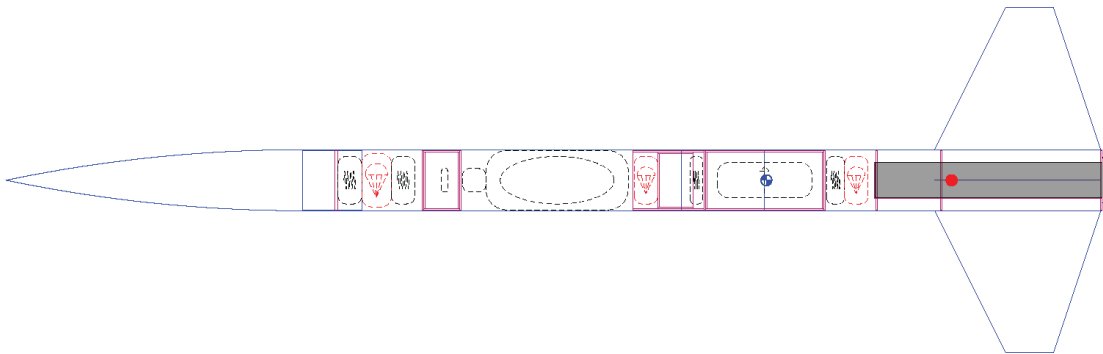
<b>Institution</b>	University of South Florida	<b>Milestone</b>	PDR
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**Additional Comments**



## 11.3 Detailed Mass Statement

### Rocket Design



Rocket  
Stages: 2  
Mass (with motors): 30.2 lb  
Stability: 3.04 cal  
CG: 64.158 in  
CP: 79.793 in

#### None; L995-RL-0

		Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Propellant Wt	Size
Altitude	1615 m	L995-RL	987 N	3.66 s	1280 N	3618 Ns	7.36:1	4.4 lb	75/486 mm
Flight Time	115 s								
Time to Apogee	17.6 s								
Optimum Delay	13.8 s								
Velocity off Pad	13.1 m/s								
Max Velocity	211 m/s								
Velocity at Deployment	34.9 m/s								
Landing Velocity	5.52 m/s								

#### None; L800-0

		Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Propellant Wt	Size
Altitude	1679 m	L800	805 N	4.63 s	1024 N	3731 Ns	6.04:1	3.95 lb	75/486 mm
Flight Time	118 s								
Time to Apogee	18.3 s								
Optimum Delay	13.7 s								
Velocity off Pad	11.8 m/s								
Max Velocity	203 m/s								
Velocity at Deployment	35.1 m/s								
Landing Velocity	5.55 m/s								








## Parts Detail

### Payload

	Nose cone	Fiberglass (1.85 g/cm <sup>3</sup> )	Ogive	Len: 25 in	Mass: 1.31 lb
	Bulkhead	Plywood (birch) (0.63 g/cm <sup>3</sup> )	Diain 4.998 in	Len: 0.25 in	Mass: 0.112 lb
	Shock cord	Kevlar (9/16 inch & 2000 lb strength) (7.65 g/m)		Len: 36 in	Mass: 0.015 lb
	Payload Parachute	Ripstop nylon (67 g/m <sup>2</sup> )	Diain 84 in	Len: 2.5 in	Mass: 0.604 lb
	Shroud Lines	Braided nylon (3 mm, 1/8 in) (3.5 g/m)	Lines: 4	Len: 97 in	
	Payload Tube	Fiberglass (1.85 g/cm <sup>3</sup> )	Diain 5 in Diadout 5.148 in	Len: 32 in	Mass: 2.52 lb
	Rover		Diadout 5 in		Mass: 5 lb
	Payload Altimeter	Fiberglass (1.85 g/cm <sup>3</sup> )	Diain 4.753 in Diadout 4.987 in	Len: 3 in	Mass: 0.359 lb
	Bulkhead	Fiberglass (1.85 g/cm <sup>3</sup> )	Diadout 4.753 in	Len: 0.125 in	Mass: 0.148 lb
	Bulkhead	Fiberglass (1.85 g/cm <sup>3</sup> )	Diadout 4.987 in	Len: 0.125 in	Mass: 0.163 lb
	PerfectFlite Altimeter		Diadout 2 in		Mass: 0.024 lb
	Bulkhead	Fiberglass (1.85 g/cm <sup>3</sup> )	Diadout 4.987 in	Len: 0.125 in	Mass: 0.163 lb
	Bulkhead	Fiberglass (1.85 g/cm <sup>3</sup> )	Diadout 4.753 in	Len: 0.125 in	Mass: 0.148 lb
	Shock cord	Kevlar (9/16 inch & 2000 lb strength) (7.65 g/m)		Len: 36 in	Mass: 0.015 lb
	DC Motor/Spring		Diadout 2 in		Mass: 0.25 lb

### Booster stage

	Separation/Coupler Stage	Fiberglass (1.85 g/cm <sup>3</sup> )	Diain 5 in Diadout 5.148 in	Len: 7 in	Mass: 0.552 lb
	Payload Coupler/Separator	Fiberglass (1.85 g/cm <sup>3</sup> )	Diain 4.753 in Diadout 4.987 in	Len: 6 in	Mass: 0.718 lb
	Booster Section	Fiberglass (1.85 g/cm <sup>3</sup> )	Diain 5 in Diadout 5.148 in	Len: 28.5 in	Mass: 2.25 lb
	Altimeter	Fiberglass (1.85 g/cm <sup>3</sup> )	Diain 4.753 in Diadout 4.987 in	Len: 10 in	Mass: 1.2 lb
	Piston System	PVC (1.39 g/cm <sup>3</sup> )	Diain 4.5 in Diadout 4.753 in	Len: 3 in	Mass: 0.277 lb



	Bulkhead	PVC (1.39 g/cm <sup>3</sup> )	Di <sub>out</sub> 4.5 in	Len: 0.125 in	Mass: 0.1 lb
	Shock cord	Kevlar (9/16 inch & 2000 lb strength) (7.65 g/m)		Len: 60 in	Mass: 0.026 lb
	Main Parachute	Ripstop nylon (67 g/m <sup>2</sup> )	Di <sub>out</sub> 84 in	Len: 2 in	Mass: 0.604 lb
	Shroud Lines	Braided nylon (3 mm, 1/8 in) (3.5 g/m)	Lines: 4	Len: 97 in	
	Bulkhead	Fiberglass (1.85 g/cm <sup>3</sup> )	Di <sub>out</sub> 4.753 in	Len: 0.125 in	Mass: 0.148 lb
	Bulkhead	Fiberglass (1.85 g/cm <sup>3</sup> )	Di <sub>out</sub> 4.987 in	Len: 0.125 in	Mass: 0.163 lb
	Bulkhead	Plywood (birch) (0.63 g/cm <sup>3</sup> )	Di <sub>out</sub> 4.753 in	Len: 0.125 in	Mass: 0.051 lb
	Bulkhead	Plywood (birch) (0.63 g/cm <sup>3</sup> )	Di <sub>out</sub> 4.987 in	Len: 0.125 in	Mass: 0.056 lb
	E-bay		Di <sub>out</sub> 3 in		Mass: 0.25 lb
	Motor Mount	Fiberglass (1.85 g/cm <sup>3</sup> )	Di <sub>in</sub> 2.953 in Di <sub>out</sub> 3.071 in	Len: 19.25 in	Mass: 0.719 lb
	75mm Flanged Motor Retainer		Di <sub>out</sub> 3.9 in		Mass: 0.125 lb
	Shock cord	Kevlar (9/16 inch & 2000 lb strength) (7.65 g/m)		Len: 60 in	Mass: 0.026 lb
	Drogue Chute	Ripstop nylon (67 g/m <sup>2</sup> )	Di <sub>out</sub> 15 in	Len: 2 in	Mass: 0.03 lb
	Shroud Lines	Braided nylon (3 mm, 1/8 in) (3.5 g/m)	Lines: 4	Len: 17 in	
	Trapezoidal fin set (4)	Fiberglass (1.85 g/cm <sup>3</sup> )	Thick: 0.125 in		Mass: 3.82 lb
	Centering ring	Fiberglass (1.85 g/cm <sup>3</sup> )	Di <sub>in</sub> 3.071 in Di <sub>out</sub> 5 in	Len: 0.125 in	Mass: 0.102 lb
	Centering ring	Fiberglass (1.85 g/cm <sup>3</sup> )	Di <sub>in</sub> 3.071 in Di <sub>out</sub> 5 in	Len: 0.125 in	Mass: 0.102 lb
	Centering ring	Fiberglass (1.85 g/cm <sup>3</sup> )	Di <sub>in</sub> 3.071 in Di <sub>out</sub> 5 in	Len: 0.125 in	Mass: 0.102 lb

## 11.4 Detailed Drift Analysis Report

```

5 mph.csv
# Default Simulation (Up to date)
#
# Time (s)           Altitude (ft)           Lateral distance (ft)
# Event BURNOUT occurred at t=3.837 seconds
# Event EJECTION_CHARGE occurred at t=3.837 seconds
      3.987           1980.4           107.2
      4.487           2321.2           128.59
      4.987            2633           148.41
      5.487           2919.5           166.89
      5.987           3183.7           184.22
      6.487           3427.8           200.57
      6.987           3653.7           216.06
      7.487            3863           230.79
      7.987           4056.9           244.85
      8.487           4236.6           258.32
      8.987            4403           271.25
      9.487           4556.9           283.72
      9.987            4699           295.77
     10.487           4829.8           307.43
     10.987           4949.8           318.76
     11.487           5059.6           329.78
     11.987           5159.5           340.53
     12.487           5249.8           351.03
     12.987           5330.8           361.31
     13.487           5402.8           371.38
     13.987            5466           381.28
     14.487           5520.6           391
     14.987           5566.8           400.55
     15.487           5604.6           409.94
     15.987           5634.3           419.14
     16.487           5655.8           428.12
     16.987           5669.5           436.8
     17.487           5675.3           445.13
# Event APOGEE occurred at t=17.687 seconds
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=17.688 seconds
     17.895           5674.4           451.63
     18.425           5665.5           459.7
     18.992           5646.7           467.77
     19.631           5614.9           475.92
     20.41            5563.4           484.24
     21.492           5474.2           492.59
     23.593           5266.4           498.97
     28.466           4732.1           483.26
     33.466            4178           451.26
     38.466           3628.2           415.75
     43.466           3082.8           379.51

```



48.466	2541.9	343.11
53.466	2005.3	306.68
58.466	1472.9	270.24
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=62.967 seconds		
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=62.967 seconds		
63.47	944.36	233.77
63.477	943.79	233.72
63.487	943.08	233.64
63.506	942.12	233.51
63.55	940.66	233.18
63.858	936.21	230.93
67.088	905.21	207.25
70.132	875.9	184.92
73.173	846.63	162.62
76.21	817.39	140.35
79.244	788.19	118.1
82.275	759.02	95.881
85.302	729.88	73.681
88.326	700.76	51.504
91.348	671.67	29.347
94.367	642.61	7.2143
97.383	613.57	14.916
100.4	584.56	37.016
103.41	555.56	59.103
106.42	526.59	81.175
109.43	497.63	103.23
112.43	468.69	125.28
115.44	439.77	147.31
118.44	410.85	169.34
121.44	381.95	191.35
124.45	353.06	213.36
127.45	324.18	235.36
130.44	295.31	257.35
133.44	266.45	279.34
136.44	237.59	301.32
139.44	208.73	323.31
142.44	179.88	345.28
145.43	151.03	367.26
148.43	122.17	389.24
151.43	93.32	411.22
154.43	64.464	433.2
157.42	35.603	455.19
160.42	6.7377	477.18
# Event GROUND_HIT occurred at t=161.29 seconds		
# Event SIMULATION_END occurred at t=161.29 seconds		



```

10 mph.csv
# Default Simulation (Up to date)
#
# Time (s)           Altitude (ft)           Lateral distance (ft)
# Event LAUNCH occurred at t=0 seconds
# Event IGNITION occurred at t=0 seconds
      0.02                0                0
# Event LIFTOFF occurred at t=0.09 seconds
      0.11             0.27346                0
      0.21             2.9732                0
# Event LAUNCHROD occurred at t=0.3 seconds
      0.3              8.0275                0
      0.65496          52.084             0.2438
      0.90646          106.58             2.0312
      1.2219           202.48             9.119
      1.5598           339.69            21.203
      2.0369           587.7             45.873
      2.5369           902.26            79.775
      3.0369           1257             120.05
      3.5369           1636.8            164.78
# Event BURNOUT occurred at t=3.8369 seconds
# Event EJECTION_CHARGE occurred at t=3.8369 seconds
      3.9369           1933.9             200.4
      4.4369           2275.6            241.74
      4.9369            2588            279.98
      5.4369           2874.9            315.63
      5.9369           3139.2            349.05
      6.4369           3383.3            380.54
      6.9369           3609.1            410.36
      7.4369           3818.2            438.71
      7.9369           4011.9            465.76
      8.4369           4191.2            491.65
      8.9369           4357.2            516.52
      9.4369           4510.7            540.47
      9.9369           4652.2            563.6
     10.437            4782.5            585.99
     10.937            4902             607.72
     11.437            5011.2            628.86
     11.937            5110.4            649.46
     12.437            5200.1            669.58
     12.937            5280.5            689.26
     13.437            5351.8            708.55
     13.937            5414.3            727.48
     14.437            5468.2            746.07
     14.937            5513.6            764.35
     15.437            5550.7            782.33
     15.937            5579.7             800

```



16.437	5600.7	817.34
16.937	5613.8	834.36
17.437	5619.3	851.07
# Event APOGEE occurred at t=17.637 seconds		
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=17.638 seconds		
17.844	5618.2	864.41
18.38	5609	880.68
18.961	5589.7	896.49
19.612	5557.5	911.89
20.391	5506.7	926.83
21.418	5423.7	940.72
23.073	5265.3	950.51
27.051	4836.4	931.29
32.051	4282.5	871.02
37.051	3731.8	800.58
42.051	3185.6	728.03
47.051	2643.9	655.04
52.051	2106.5	581.96
57.051	1573.3	508.86
62.051	1044.4	435.75
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=62.552 seconds		
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=62.552 seconds		
63.054	938.78	421.09
63.06	938.23	421
63.07	937.55	420.85
63.086	936.66	420.61
63.122	935.34	420.08
63.275	932.45	417.84
66.064	905.34	376.95
69.097	876.07	332.46
72.127	846.84	288.02
75.155	817.62	243.61
78.18	788.44	199.25
81.202	759.28	154.92
84.223	730.13	110.62
87.241	701.01	66.359
90.257	671.91	22.129
93.271	642.83	22.095
96.284	613.76	66.275
99.295	584.71	110.44
102.3	555.67	154.58
105.31	526.64	198.7
108.32	497.62	242.81
111.33	468.61	286.91
114.33	439.61	330.99
117.34	410.62	375.07
120.34	381.62	419.14





123.35	352.64	463.2
126.35	323.65	507.26
129.36	294.66	551.32
132.36	265.68	595.39
135.37	236.69	639.45
138.37	207.69	683.52
141.38	178.69	727.6
144.38	149.69	771.69
147.39	120.68	815.79
150.4	91.654	859.91
153.41	62.622	904.04
156.42	33.578	948.19
159.43	4.5202	992.36

# Event GROUND\_HIT occurred at t=160.03 seconds

# Event SIMULATION\_END occurred at t=160.03 seconds



```

15 mph.csv
# Default Simulation (Up to date)
#
# Time (s)           Altitude (ft)           Lateral distance (ft)
# Event LAUNCH occurred at t=0 seconds
# Event IGNITION occurred at t=0 seconds
      0.03                0                0
# Event LIFTOFF occurred at t=0.09 seconds
      0.12            0.40539                0
      0.22            3.413                0
# Event LAUNCHROD occurred at t=0.3 seconds
      0.315            9.1093            0.0018652
      0.58592          40.485            0.47223
      0.82235          86.138            0.94032
      1.0477           145.2            6.6022
      1.2663           217.6           14.416
      1.5073           314.52          26.702
      1.902            508.74          53.818
      2.402            807.33          99.395
      2.902           1149.8         154.88
      3.402           1521.2         217.6
# Event BURNOUT occurred at t=3.802 seconds
# Event EJECTION_CHARGE occurred at t=3.802 seconds
      3.802           1821.4         269.52
      4.302           2168.4         330.08
      4.802           2485.1         385.97
      5.302           2775.4         437.93
      5.802           3042.6         486.54
      6.302           3289.1         532.27
      6.802           3516.9         575.49
      7.302           3727.7         616.51
      7.802           3922.8         655.59
      8.302           4103.4         692.95
      8.802           4270.4         728.77
      9.302           4424.7         763.24
      9.802           4566.9         796.47
     10.302           4697.8         828.61
     10.802           4817.7         859.76
     11.302           4927.3         890.02
     11.802           5026.8         919.47
     12.302           5116.7          948.2
     12.802           5197.2         976.28
     13.302           5268.6         1003.8
     13.802           5331.2         1030.7
     14.302            5385         1057.2
     14.802           5430.4         1083.1
     15.302           5467.5         1108.7

```



15.802	5496.4	1133.9
16.302	5517.2	1158.6
16.802	5530.1	1183.1
17.302	5535.2	1207.2
# Event APOGEE occurred at t=17.452 seconds		
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=17.453 seconds		
17.7	5533.7	1225.9
18.226	5524.4	1248
18.803	5505.2	1269
19.451	5473.8	1288.7
20.21	5425.6	1306.7
21.164	5350.9	1322.2
22.53	5225	1331.8
25.149	4951.9	1319.6
30.101	4406.3	1240.4
35.101	3854.8	1136.9
40.101	3307.7	1028.4
45.101	2764.9	918.93
50.101	2226.5	809.21
55.101	1692.5	699.45
60.101	1162.6	589.68
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=62.102 seconds		
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=62.102 seconds		
62.603	899.04	534.76
62.608	898.52	534.64
62.617	897.89	534.45
62.631	897.07	534.15
62.659	895.92	533.54
62.743	893.85	531.67
64.725	873.86	488.08
67.786	843.91	420.74
70.85	813.94	353.34
73.916	783.94	285.88
76.985	753.92	218.37
80.057	723.86	150.78
83.132	693.78	83.136
86.21	663.66	15.428
89.292	633.51	52.393
92.377	603.33	120.27
95.467	573.1	188.23
98.56	542.84	256.28
101.66	512.54	324.42
104.76	482.19	392.66
107.87	451.8	461
110.98	421.36	529.44
114.09	390.88	598
117.21	360.34	666.66



120.34	329.76	735.44
123.47	299.12	804.34
126.61	268.42	873.37
129.75	237.66	942.53
132.9	206.85	1011.8
136.06	175.97	1081.3
139.22	145.03	1150.8
142.39	114.03	1220.6
145.57	82.951	1290.4
148.75	51.806	1360.5
151.94	20.589	1430.7

# Event GROUND\_HIT occurred at t=154.28 seconds

# Event SIMULATION\_END occurred at t=154.28 seconds



```

20 mph.csv
# Default Simulation (Up to date)
#
# Time (s)           Altitude (ft)           Lateral distance (ft)
# Event LAUNCH occurred at t=0 seconds
# Event IGNITION occurred at t=0 seconds
      0.04           3.89E-04           0
# Event LIFTOFF occurred at t=0.09 seconds
      0.13           0.6849           0
      0.23           4.6178           0
# Event LAUNCHROD occurred at t=0.29 seconds
      0.31427        10.736           0.0089196
      0.39176        18.614           0.14474
      0.55158        41.69           0.2265
      0.62042        54.392           0.40799
      0.67316        65.199           1.3656
      0.77118        87.776           4.1972
      0.84782        107.78          7.0274
      0.91418        126.8           9.7203
      1.0145         158.5           14.509
      1.1205         195.82          20.899
      1.2186         233.98          27.659
      1.3536         292.08          38.598
      1.4954         359.93          51.95
      1.7623          505           82.113
      2.255          823.4          152.75
      2.755          1196.2          239.97
      3.2177          1568.9          330.29
      3.5651          1857.4          401.78
# Event BURNOUT occurred at t=3.8165 seconds
# Event EJECTION_CHARGE occurred at t=3.8165 seconds
      3.8882          2114.4          465.99
      4.3664          2461.1          553.06
      4.8664           2787          635.63
      5.3664          3081.5          711.12
      5.8664          3349.3          780.77
      6.3664          3593.6          845.49
      6.8664          3817.2          906.02
      7.3664          4022.3          962.92
      7.8664          4210.6          1016.7
      8.3664          4383.4          1067.7
      8.8664          4542.1          1116.3
      9.3664          4687.4          1162.7
      9.8664          4820.4          1207.3
      10.366          4941.7          1250.1
      10.866          5052           1291.4
      11.366          5151.7          1331.4

```



11.866	5241.2	1370.2
12.366	5321.1	1407.9
12.866	5391.5	1444.6
13.366	5452.8	1480.4
13.866	5505.3	1515.5
14.366	5549.1	1549.8
14.866	5584.4	1583.5
15.366	5611.4	1616.6
15.866	5630.2	1649.2
16.366	5641	1681.3
# Event APOGEE occurred at t=16.866 seconds		
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=16.867 seconds		
17.209	5641	1733
17.694	5631.5	1757.1
18.25	5613.1	1779.6
18.889	5583.2	1799.5
19.647	5537.4	1816.2
20.605	5467	1827.7
21.977	5349.1	1828.9
24.62	5094.5	1796
29.584	4593.1	1676.4
34.584	4088.4	1534.6
39.584	3587.3	1388.9
44.584	3090	1242.6
49.584	2596.4	1096.1
54.584	2106.4	949.68
59.584	1619.9	803.2
64.584	1136.9	656.72
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=66.085 seconds		
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=66.085 seconds		
66.586	944.55	598.08
66.592	944.06	597.9
66.601	943.44	597.62
66.619	942.6	597.1
66.662	941.28	595.83
67.45	933.2	572.71
70.782	902.59	475
74.128	871.84	376.84
77.489	840.95	278.24
80.866	809.91	179.18
84.259	778.73	79.665
87.655	747.53	19.991
91.052	716.35	119.6
94.446	685.19	219.17
97.841	654.04	318.75
101.24	622.91	418.32
104.63	591.81	517.84



108.02	560.71	617.38
111.41	529.64	716.87
114.81	498.58	816.39
118.2	467.54	915.87
121.59	436.53	1015.3
124.98	405.52	1114.8
128.37	374.54	1214.2
131.76	343.58	1313.6
135.14	312.64	1412.9
138.53	281.7	1512.3
141.92	250.79	1611.7
145.31	219.89	1711
148.69	189.01	1810.4
152.08	158.16	1909.6
155.46	127.33	2008.9
158.84	96.501	2108.2
162.23	65.695	2207.4
165.61	34.912	2306.6
168.99	4.1467	2405.8

# Event GROUND\_HIT occurred at t=169.49 seconds

# Event SIMULATION\_END occurred at t=169.49 seconds



```

5 mph nose.csv
# Default Simulation (Up to date)
#
# Time (s)           Altitude (m)           Lateral distance (ft)
# Event APOGEE occurred at t=17.404 seconds
      17.404           1811.2           476.63
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=17.405 seconds
      17.93           1809.5           484.95
      18.488           1804.8           493.19
      19.118           1796.4           501.48
      19.891           1782.3           509.92
      21              1756.4           518.34
      23.448           1687.1           523.41
      28.448           1532.7           502.32
      33.448           1377.9           468.64
      38.448           1224.2           432.67
      43.448           1071.6           396.29
      48.448           920.18           359.84
      53.448           769.87           323.37
      58.448           620.68           286.89
      63.448           472.55           250.41
      68.448           325.47           213.93
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=69.449 seconds
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=69.449 seconds
      69.951           281.49           202.97
      69.957           281.34           202.93
      69.967           281.15           202.85
      69.986           280.88           202.71
      70.035           280.45           202.35
      71.317           276.64           192.95
      74.355           268.22           170.68
      77.4             259.78           148.35
      80.453           251.31           125.96
      83.514           242.83           103.51
      86.584           234.32           81.004
      89.662           225.79           58.434
      92.748           217.23           35.802
      95.843           208.65           13.105
      98.948           200.04           9.6667
      102.06           191.41           32.496
      105.18           182.76           55.397
      108.32           174.07           78.37
      111.46           165.36           101.42
      114.61           156.62           124.54
      117.78           147.85           147.73
      120.95           139.05           171.01
      124.13           130.22           194.36

```





127.33	121.36	217.8
130.54	112.47	241.31
133.76	103.55	264.92
136.99	94.593	288.61
140.23	85.603	312.39
143.49	76.578	336.27
146.75	67.518	360.23
150.04	58.422	384.3
153.33	49.288	408.46
156.64	40.116	432.72
159.96	30.906	457.08
163.3	21.655	481.55
166.65	12.364	506.13
170.02	3.0302	530.82
# Event GROUND_HIT occurred at t=171.37 seconds		
# Event SIMULATION_END occurred at t=171.37 seconds		
171.37	-0.71513	540.73



```

10 mph nose.csv
# Default Simulation (Up to date)
#
# Time (s)           Altitude (m)           Lateral distance (ft)
# Event LAUNCH occurred at t=0 seconds
# Event IGNITION occurred at t=0 seconds
      0.02                0                0
# Event LIFTOFF occurred at t=0.09 seconds
      0.11              0.10192              0
      0.21              1.079              0
# Event LAUNCHROD occurred at t=0.29 seconds
      0.305             3.0294             0.0014875
      0.48157           9.284             0.14703
      0.65275           18.612            0.57073
      0.80812           29.833            3.0665
      0.91597           39.181            5.3667
      1.0712            54.876            9.6194
      1.2621            77.867            16.63
      1.4822            109.38            27.06
      1.8729            177.2            51.273
      2.3729            282.07            91.263
      2.8729            401.25            138.87
      3.2916            507.83            182.73
      3.5066            563.84            206.17
# Event BURNOUT occurred at t=3.8022 seconds
# Event EJECTION_CHARGE occurred at t=3.8022 seconds
      4.252             743.09             281.87
      4.752             847.79             326.52
      5.252             942.36             367.29
      5.752             1028.3            404.87
      6.252             1106.8            439.77
      6.752             1178.8            472.39
      7.252             1244.8            503.07
      7.752             1305.5            532.04
      8.252             1361.4            559.54
      8.752             1412.8            585.74
      9.252             1460.1            610.8
      9.752             1503.5            634.84
     10.252             1543.3            657.99
     10.752             1579.6            680.34
     11.252             1612.6            701.97
     11.752             1642.5            722.97
     12.252             1669.5            743.41
     12.752             1693.5            763.35
     13.252             1714.7            782.85
     13.752             1733.2            801.94
     14.252             1749.1            820.67

```



14.752	1762.3	839.09
15.252	1773	857.2
15.752	1781.2	875.02
16.252	1787	892.57
16.752	1790.3	909.85
17.252	1791.3	926.91
# Event APOGEE occurred at t=17.302 seconds		
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=17.303 seconds		
17.666	1790.3	940.51
18.22	1786.5	956.89
18.835	1779.3	972.67
19.555	1767.5	987.84
20.48	1747.8	1002
21.893	1711.4	1013
25.239	1612	1002.3
30.239	1457.1	944.42
35.239	1302.8	874.01
40.239	1149.6	801.35
45.239	997.65	728.3
50.239	846.77	655.18
55.239	697.01	582.04
60.239	548.34	508.9
65.239	400.73	435.75
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=68.74 seconds		
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=68.74 seconds		
69.239	283.4	377.24
69.244	283.26	377.16
69.252	283.09	377.04
69.266	282.87	376.85
69.294	282.54	376.43
69.404	281.88	374.81
72.061	274.43	335.86
75.222	265.63	289.49
78.394	256.79	242.97
81.577	247.93	196.29
84.771	239.03	149.44
87.976	230.1	102.43
91.193	221.14	55.252
94.422	212.15	7.908
97.663	203.12	39.646
100.92	194.05	87.365
104.18	184.96	135.27
107.46	175.82	183.37
110.76	166.65	231.67
114.06	157.44	280.17
117.38	148.19	328.88
120.72	138.89	377.8



124.07	129.56	426.94
127.44	120.19	476.3
130.82	110.77	525.89
134.21	101.33	575.58
137.59	91.901	625.28
140.98	82.474	674.97
144.37	73.056	724.63
147.75	63.643	774.28
151.14	54.233	823.94
154.52	44.828	873.59
157.91	35.43	923.23
161.29	26.036	972.86
164.68	16.647	1022.5
168.06	7.2624	1072.1
# Event GROUND_HIT occurred at t=170.77 seconds		
# Event SIMULATION_END occurred at t=170.77 seconds		
170.77	-0.23962	1111.8



```

15 mph nose.csv
# Default Simulation (Up to date)
#
# Time (s)           Altitude (m)           Lateral distance (ft)
# Event LAUNCH occurred at t=0 seconds
# Event IGNITION occurred at t=0 seconds
      0.02                0                0
# Event LIFTOFF occurred at t=0.09 seconds
      0.11           0.10192                0
      0.21           1.079                0
# Event LAUNCHROD occurred at t=0.29 seconds
      0.30116          2.9314          0.0013181
      0.40543          6.1659           0.127
      0.58447          14.503          0.035932
      0.65611          18.805          0.82895
      0.74723          25.059           2.702
      0.85703          33.786          5.8175
      0.97525          44.662          9.7754
      1.0601           53.401          13.349
      1.185            67.701          19.66
      1.3508           89.375          29.788
      1.5565           120.31          45.193
      1.9452           189.76          82.183
      2.4452           296.03          142.43
      2.9452           415.52          213.25
      3.2031           480.41          252.68
      3.5536           570.46          308.27
# Event BURNOUT occurred at t=3.8088 seconds
# Event EJECTION_CHARGE occurred at t=3.8088 seconds
      3.8588           645.91          355.26
      4.2095           726.31          405.53
      4.7095           830.67          471.23
      5.2095           924.84          531.15
      5.7095           1010.4          586.32
      6.2095           1088.4          637.51
      6.7095           1159.8          685.32
      7.2095           1225.3          730.23
      7.7095           1285.5          772.61
      8.2095           1340.8          812.81
      8.7095           1391.7          851.07
      9.2095           1438.4          887.63
      9.7095           1481.3          922.69
      10.21            1520.5          956.41
      10.71            1556.2          988.94
      11.21            1588.7          1020.4
      11.71            1618           1050.9
      12.21            1644.4          1080.6

```



12.71	1667.8	1109.5
13.21	1688.4	1137.8
13.71	1706.3	1165.4
14.21	1721.6	1192.5
14.71	1734.2	1219.1
15.21	1744.3	1245.3
15.71	1751.9	1271
16.21	1757	1296.4
16.71	1759.7	1321.4
# Event APOGEE occurred at t=17.11 seconds		
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=17.111 seconds		
17.605	1758.5	1364
18.155	1754.2	1385.4
18.776	1746.6	1405.3
19.5	1734.4	1423.3
20.406	1715.2	1438.6
21.693	1682.5	1448
24.135	1611.7	1436.5
29.045	1460.5	1356.3
34.045	1306.2	1251.7
39.045	1153	1142.8
44.045	1001	1033.2
49.045	850.09	923.38
54.045	700.31	813.57
59.045	551.62	703.77
64.045	403.98	593.95
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=67.546 seconds		
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=67.546 seconds		
68.045	286.64	506.1
68.05	286.5	505.99
68.058	286.33	505.81
68.071	286.11	505.52
68.1	285.78	504.89
68.21	285.12	502.47
70.938	277.44	442.46
74.327	267.94	367.89
77.725	258.41	293.13
81.123	248.89	218.38
84.521	239.37	143.64
87.917	229.86	68.924
91.313	220.35	5.8339
94.709	210.85	80.5
98.103	201.36	155.18
101.5	191.87	229.86
104.89	182.39	304.51
108.28	172.91	379.16
111.68	163.43	453.78



115.07	153.97	528.41
118.46	144.5	603.02
121.85	135.05	677.61
125.24	125.6	752.19
128.63	116.16	826.75
132.02	106.72	901.32
135.41	97.283	975.85
138.8	87.853	1050.4
142.18	78.432	1124.9
145.57	69.014	1199.4
148.96	59.599	1273.9
152.34	50.194	1348.4
155.72	40.792	1422.8
159.11	31.395	1497.3
162.49	22.006	1571.7
165.88	12.62	1646.2
169.26	3.2389	1720.6

# Event GROUND\_HIT occurred at t=170.43 seconds

# Event SIMULATION\_END occurred at t=170.43 seconds



```

20 mph nose.csv
# Default Simulation (Up to date)
# Simulation warnings:
#
# Time (s)           Altitude (ft)           Lateral distance (ft)
# Event LAUNCH occurred at t=0 seconds
# Event IGNITION occurred at t=0 seconds
      0.03              0              0              8              8
# Event LIFTOFF occurred at t=0.09 seconds
      0.12             0.52182              0             10              0
      0.22             4.2827              0             11              1
# Event LAUNCHROD occurred at t=0.28 seconds
      0.3033           10.321           0.0086507           13              3
      0.37765          17.926           0.14107           14              4
      0.52841          39.775           0.26584           15              5
      0.59753          52.606           0.32222           16              6
      0.64818          63.081           1.2102            17              7
      0.7267           81.112           3.3594            18              8
      0.81664          104.55           6.6026            19              9
      0.87583          121.64           8.9789            20              0
      0.97749          154.03          13.739            21              1
      1.0777           189.62          19.689            22              2
      1.1633           223.07          25.484            23              3
      1.291            278.01          35.516            24              4
      1.4325           345.95          48.552            25              5
      1.6792           480.78          75.897            26              6
      2.1573           792.84          143.43            27              7
      2.6573           1172.6          230.2             28              8
      3.0416           1488.4          304.78            29              9
      3.3492           1749.9          367.79            30              0
      3.5664           1935.7          413.11            31              1
      3.7995           2127.8          460.17            32              2
# Event BURNOUT occurred at t=3.8495 seconds
      33              3
# Event EJECTION_CHARGE occurred at t=3.8495 seconds
      34              4
      4.1739           2414           530.44            35              5
      4.6739           2758.8          615.56            36              6
      5.1739           3067.9          692.56            37              7
      5.6739           3347.1          762.98            38              8
      6.1739           3600.7          827.93            39              9
      6.6739           3831.8          888.28            40              0
      7.1739           4043           944.69            41              1
      7.6739           4236.4          997.72            42              2
      8.1739           4413.5          1047.8            43              3
      8.6739           4575.8          1095.3            44              4
      9.1739           4724.3          1140.6            45              5
      9.6739           4860           1183.8            46              6
      10.174           4983.7          1225.3            47              7

```





10.674	5096	1265.2	48	8
11.174	5197.5	1303.7	49	9
11.674	5288.8	1340.9	50	0
12.174	5370.1	1377	51	1
12.674	5442	1412.1	52	2
13.174	5504.6	1446.4	53	3
13.674	5558.3	1479.8	54	4
14.174	5603.3	1512.4	55	5
14.674	5639.8	1544.5	56	6
15.174	5668	1575.9	57	7
15.674	5687.9	1606.8	58	8
16.174	5699.7	1637.2	59	9
16.674	5703.5	1667.2	60	0
# Event APOGEE occurred at t=16.724 seconds			61	1
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=16.725 seconds			62	2
17.024	5701.5	1686.9	63	3
17.506	5692.9	1709.7	64	4
18.059	5675.5	1730.9	65	5
18.697	5646.7	1749.5	66	6
19.458	5601.9	1764.7	67	7
20.429	5531.9	1774.6	68	8
21.855	5411.6	1773.1	69	9
24.829	5130.2	1729.5	70	0
29.829	4638.1	1603.1	71	1
34.829	4147.5	1460	72	2
39.829	3660.4	1314.1	73	3
44.829	3176.8	1167.7	74	4
49.829	2696.7	1021.3	75	5
54.829	2220	874.79	76	6
59.829	1746.7	728.3	77	7
64.829	1276.7	581.81	78	8
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=67.83 seconds			79	9
# Event RECOVERY_DEVICE_DEPLOYMENT occurred at t=67.83 seconds			80	0
68.33	949.54	479.25	81	1
68.335	949.09	479.09	82	2
68.344	948.53	478.85	83	3
68.359	947.78	478.4	84	4
68.394	946.63	477.37	85	5
68.617	943.45	470.82	86	6
71.384	919.27	389.66	87	7
74.154	895.06	308.42	88	8
76.926	870.83	227.1	89	9
79.701	846.57	145.69	90	0
82.48	822.29	64.193	91	1
85.261	797.98	17.423	92	2
88.046	773.64	99.088	93	3
90.834	749.27	180.87	94	4



93.625	724.87	262.74	95	5
96.42	700.44	344.72	96	6
99.218	675.98	426.8	97	7
102.02	651.49	508.99	98	8
104.83	626.97	591.29	99	9
107.64	602.41	673.71	100	0
110.45	577.82	756.23	101	1
113.27	553.19	838.88	102	2
116.09	528.53	921.64	103	3
118.91	503.83	1004.5	104	4
121.74	479.1	1087.5	105	5
124.58	454.32	1170.7	106	6
127.42	429.5	1254	107	7
130.26	404.65	1337.4	108	8
133.11	379.75	1420.9	109	9
135.96	354.81	1504.6	110	0
138.82	329.83	1588.5	111	1
141.68	304.8	1672.5	112	2
144.55	279.73	1756.6	113	3
147.43	254.62	1840.9	114	4
150.31	229.45	1925.3	115	5
153.19	204.24	2010	116	6
156.08	178.98	2094.7	117	7
158.98	153.67	2179.7	118	8
161.88	128.3	2264.8	119	9
164.79	102.89	2350.1	120	0
167.7	77.422	2435.5	121	1
170.62	51.9	2521.2	122	2
173.55	26.322	2607	123	3
176.48	0.68839	2693.1	124	4
# Event GROUND_HIT occurred at t=176.67 seconds			125	5
# Event SIMULATION_END occurred at t=176.67 seconds			126	6



## 11.5 NAR Safety Code

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



will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

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

MINIMUM DISTANCE TABLE

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

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



## 11.6 TRA Safety Code

### Safety Code for High-Power Rocketry Tripoli Rocketry Association

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

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

#### 1 General Requirements

##### 1-1 Scope

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

##### 1-2 Purpose

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

##### 1-3 Definitions:

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

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

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

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

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

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



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

**Participants.** Persons that are either:

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

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

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

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

**Shall.** Indicates a mandatory requirement.

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

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

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

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

**Tripoli (TRA).** Tripoli Rocketry Association, Inc.

#### Requirements for High Power Rocket Operation

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

- This code and NFPA 1127;
- *Federal Aviation Administration Regulations*, Part 101 (Section 307.72 Statute 749, Title 49 United States Code, Section 1348, "Airspace Control and Facilities," Federal Aviation Act of 1958);
- Other applicable federal, state, and local laws, rules, regulations, statutes, and ordinances.
- Landowner permission.



**3 Legality**

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

**4 Insurance**

- 4-1** Tripoli rocketry activities are only insured when the provisions of this code are followed.
- 4-2** No Tripoli member shall misrepresent to any authority or landowner that Tripoli activities are insured .

**5 Participation,**

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

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

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

- 5-1** HPR Fliers may access and conduct flights from the High-Power Launch Area and/or Model Rocket Launch Area.
- 5-2** Non-Tripoli Members age 18 and over who are students of an accredited educational institution may participate in joint projects with Tripoli members.
- 5-2.1** These individuals are only allowed in the High-Power Launch Area while supervised by an HPR Flier.
- 5-2.2** They are only allowed in the Model Rocket Launch Area while supervised by an Adult Flier.
- 5-2.3** The maximum number of nonmember participants shall not exceed five (5) per supervising flier.
- 5-3** Tripoli Junior Members who have successfully completed the TMP may access and conduct flights from the High-Power Launch Area while under the direct supervision of a Tripoli HPR Flier in accordance with the rules of the TMP.
- 5-3.1** The maximum number of TMP participants shall not exceed five (5) per supervising flier.
- 5-4** Children younger than 18 years of age may conduct flights from the Model Rocket Launch Area under the direction of an Adult Flier.
- 5-5** An invited guest may be permitted in the Model Rocket Launch Area and preparation areas upon approval of the RSO. Invited guests are not permitted in the High-Power Launch Area.
- 5-6** Spectators are only permitted in the spectator area(s); they are not permitted in the High-Power Launch Area or Model Rocket Launch Area.



## **6 Tripoli Launch Operations**

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

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

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

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

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

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

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

### **6-8 Launch Director and Range Safety Officer**

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

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

### **6-9 Recovery**

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

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





### Minimum spectator and Participant Safe Distance Standoffs

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

## 7 Referenced Publications

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

### 7-1 NFPA Publications.

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

NFPA 1122, Code for Model Rocketry.

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

NFPA 1127, Code for High Power Rocketry

### 7-2 Government Publications.

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

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

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



**7-3 TRA Publications.**

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

Articles of Incorporation and Bylaws

Tripoli Motor Testing Committee (TMT), Testing Policies

**Appendix A - Additional Tripoli Rulings**

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

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

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

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

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

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

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