NASA Student Launch 2017

Flight Readiness Review Report

March 6, 2017

SOCIETY OF AERONAUTICS AND ROCKETRY

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Tampa, Florida 33613

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1 Summary of CDR Report

1.1 Team Summary

1.1.1 Team Name & Mailing Address

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

14247 Les Palms Circle, Apt. 102
Tampa, Florida 33613

1.1.2 Team Mentor, NAR/TRA Number and Certification Level

Team mentor: Jim West, Tripoli 0706 (Tripoli advisory panel member), Certification Level 3

1.2 Launch Vehicle Summary

1.2.1 Size and Mass

Diameter: 6 in.

Length: 145 in.

Projected Unloaded Weight: 39.7 lb.

Projected Loaded Weight: 47.5 lb.

1.2.2 Final Motor Choice

L1115 from Cesaroni Technology:

Total Impulse: 5015 N·s

Burn Time: 4.5 s

Diameter: 75 mm

Length: 621 mm

Propellant Weight: 2394 g

1.2.3 Recovery System

The launch vehicle will be comprised of a piston system and four parachutes for each the nose cone, landing module, main airframe, and booster. GPS devices will be installed in the nose cone, payload section, and altimeter bay for safe retrieval of components.

1.2.4 Rail Size

The launch vehicle will be equipped with rail guides that fit a 12 ft. tall 1515 rail.

1.2.5 Milestone Review Flysheet

The Milestone Review Flysheet can be found on the SOAR website or by following the link: http://www.usfsoar.com/wp-content/uploads/2017/03/FRR-Flysheet-2017.pdf.

1.3 Landing Module Summary

A landing module will deploy from the main body of the rocket upon separation at an altitude of 1,000 ft. on descent. This landing module will house an electronics bay and camera aiming system to locate and identify the tarps. At the bottom of the landing module are 4 cylindrical spring-loaded legs designed to ensure that the module lands vertically.

2 Changes Made Since CDR Report

2.1 Vehicle Criteria Changes

There have been no changes to the launch vehicle since the Critical Design Review (CDR) report. The full-scale launch showed that the L1115 did give the amount of thrust necessary to approach the altitude goal. The launch also showed that the launch vehicle works in full-scale and can safely deploy the components and recovery mechanisms. Any changes since the CDR took place in the landing module, as described in 2.2 Landing Module Changes.

2.2 Landing Module Changes

2.2.1 Steering System

Extensive free-fall testing made it evident that the steering system was incapable of guiding the landing module. In the trials conducted, the module was strongly affected by even slight winds, causing it to not only veer off course, but also spin significantly. It was deemed that the issue was with the physical setup of the system (motors, blades, and shape), and not with the steering control system (programming), so the entire steering system was removed from our design. The new design replaces this steering system with a camera aiming system, which points the camera at the target using a dual-servo mount (see 4.5.3 Camera Aiming System for more details). Figure 1 and Figure 2 illustrate the previous design with an implemented steering system, whereas Figure 3 and Figure 4 display the pre- and post-deployed states of the new landing module design.

Figure 1: Prior landing module design in pre-deployed state.

Figure 2: Prior landing module design in deployed state.

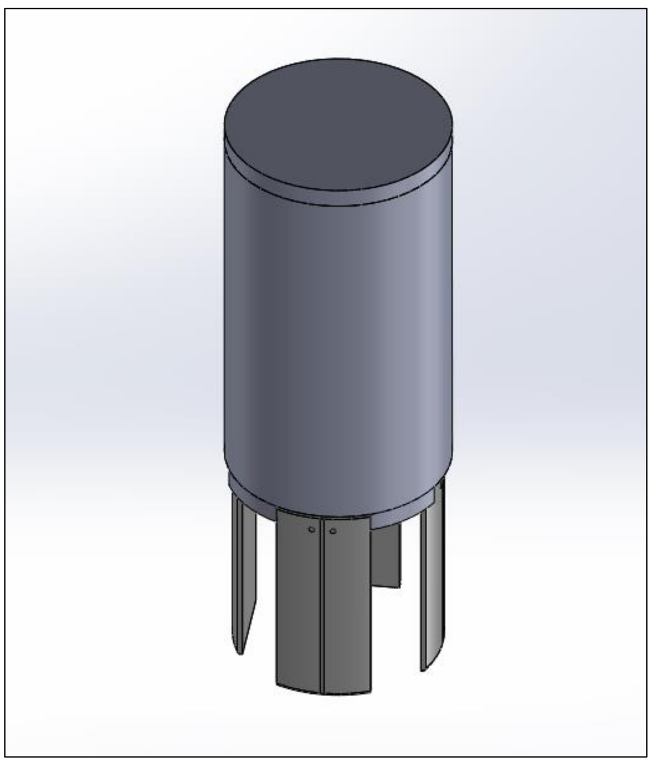


Figure 3: Current landing module design in pre-deployed state.

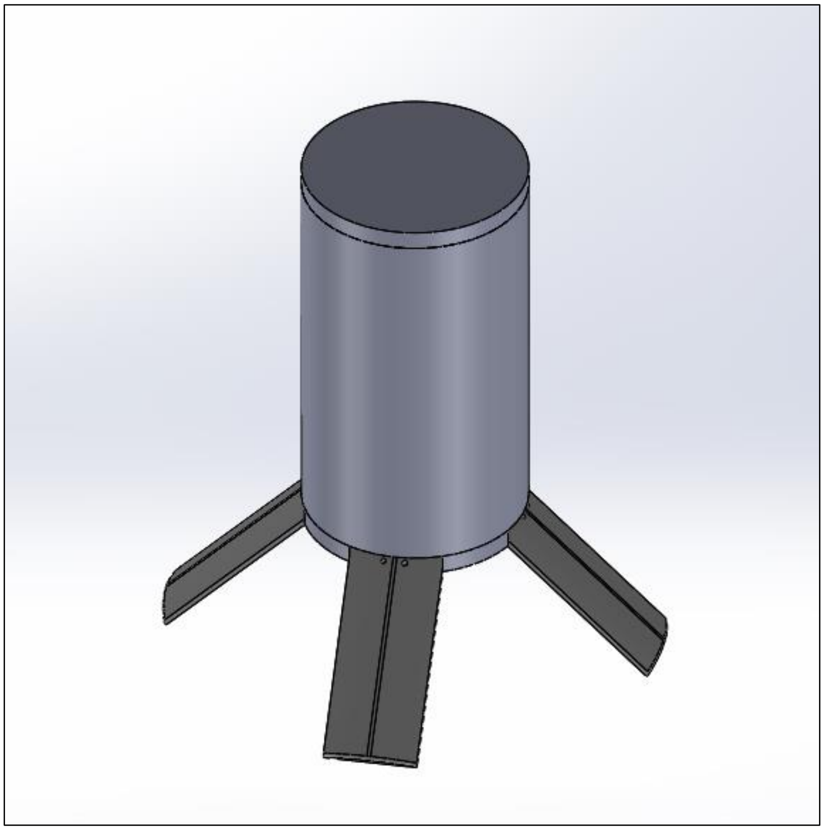


Figure 4: Current landing module design in deployed state.

2.2.2 Steering Control System

Because the steering control system will no longer control steering, it has become the camera aiming system, and will use the same sensors and similar code to calculate pan and tilt and run the servos. This system will still be run on an Arduino based microcontroller.

2.2.3 Vision System

The Raspberry Pi 3B will be used along with the oCam USB 3.0 camera to identify the targets on the ground. Testing has been performed to determine the field of view and size of the tarps in pixels, so that the computer can better identify the tarps.

2.2.4 Landing Gear

No changes were made to the landing gear during this stage of the project.

2.3 Project Plan Changes

No changes were made to the project plan since the Critical Design Review report. New expenditures have been added and accounted for in 6.3.1 Budget Plan. The previously established project plan has been progressing smoothly, so no adjustments have been made.

3 Launch Vehicle Criteria

3.1 Design & Verification of Launch Vehicle

3.1.1 Mission Statement

The mission is to build a rocket that will launch to an altitude of 5,280 ft. and will land a portion of the rocket, containing a camera, upright after identifying colored tarps on the ground. At apogee, the booster to the rocket will be released but will still be tethered to the rest of the rocket. Between 800 and 1,000 ft, the black powder charges will eject the piston system resulting in the release of the nose cone and the landing module (which contains the camera and navigation system). In order to find everything quickly after the launch, GPS systems will be placed in the nose cone, landing module, and electronics bay.

This mission will enable SOAR to further expand on the knowledge of engineering and rocketry in order to successfully launch the vehicle and land it upright utilizing many unique and innovative design and fabrication methods.

3.1.2 Mission Requirements

Table 1 shows the requirements that need to be met in this mission as well as how it can be ensured that we met those requirements.

Table 1: Detailed mission requirements and verification methods.

Requirement	Method	Verification
Launch the rocket 5,280 ft.	The rocket will be built with a motor designed to get the vehicle to 5,280 ft. at apogee.	Subscale and full-scale testing.
The vehicle shall carry one 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 entire flight.	NSL inspection as well as inspection and approval by the safety officer.

Requirement	Method	Verification
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 device in every independent section of the launch vehicle.	NSL inspection as well as inspection and approval 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.	Subscale and full-scale testing.
The launch vehicle shall have a maximum of four independent sections.	The rocket will be broken up into four sections: the nose cone, the electronics bay, the landing system, and the booster. The nose cone and the landing system will be the only parts that will not be tethered to the rocket.	NSL inspection as well as inspection and approval 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.	NSL inspection as well as inspection and approval by the safety officer.

Requirement	Method	Verification
The launch vehicle shall be capable of being prepared for flight at the launch site within four hours, from the time the Federal Aviation Administration flight waiver opens.	There will be Final Assembly and Launch Procedure checklists that will ensure that the launch vehicle will be safely prepared and ready to launch within the four hours.	The checklists will be completed before the test flights of the subscale and the full-scale rockets and we will time ourselves to ensure we completed the list safely and within the time of four hours.
The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of one hour without losing the functionality of any critical on-board component.	The launch vehicle and the electronic components within will be properly hooked up and sealed to prevent anything from causing it to disconnect or be damaged. The batteries will also have a life long enough to sit at the launch pad for at least an hour.	Full-scale and subscale testing. Battery testing to ensure the battery life lasts, at minimum, an hour.
The launch vehicle shall be capable of being launched by a standard 12V direct current firing system.	The ignitor used in the rocket will be able to withstand a 12V DC firing system.	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 12V 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.

Requirement	Method	Verification
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 is a L1115 from Animal Motor Works which is certified by the National Association of Rocketry and uses ammonium perchlorate.	NSL inspection as well as inspection and approval by the safety officer.
Pressure vessels on the vehicle shall be approved by the RSO and shall meet the criteria.	Our design does not contain a pressure vessel.	NSL inspection as well as inspection and approval 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 5015 N·s.	NSL inspection as well as inspection and approval 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 will have a minimum stability margin of 2.0.	Full-scale and subscale testing as well as computer simulations.
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. The altimeters will be able to record the acceleration of the launch vehicle.

Requirement	Method	Verification
All teams shall successfully launch and recover a subscale model of their rocket prior to CDR.	SOAR launched a subscale model on December 17, 2016.	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.	SOAR launched the full-scale rocket on February 18, 2017	Evidence of full-scale testing as well as NSL inspection.
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 of the burnout center of gravity.	NSL inspection as well as inspection and approval by the safety officer.

Requirement	Method	Verification
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 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.	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 inspection and approval by the safety officer.
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 inspection and approval by the safety officer.

Requirement	Method	Verification
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 inspection and approval 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 shall contain redundant, commercially available altimeters.	The recovery system will be completely independent from the payload circuits and there will be a redundant altimeter.	NSL inspection as well as inspection and approval by the safety officer.
Each altimeter shall 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 shall have a dedicated power supply. Each arming switch shall be capable of being locked in the 'ON' position for launch.	Each altimeter will contain its own switch that will be able to be locked in the 'ON' position. As well as having its own switch, each altimeter will have its own dedicated power supply.	NSL inspection as well as inspection and approval by the safety officer.

Requirement	Method	Verification
Teams shall design an onboard camera system capable of identifying and differentiating between three adjacently placed targets.	The launch vehicle will contain a landing system that has a camera aiming system that is capable of identify the targets by color.	Full-scale and subscale testing as well as proof from the camera.
After identifying and differentiating between the three targets, the launch vehicle section housing the cameras shall land upright, and provide proof of a successful controlled landing.	Based on the design of the landing system, it will land upright safely and will be recorded through the entire flight.	Full-scale and subscale testing as well as proof from the camera.
Data from the camera system shall be analyzed in real time by a custom designed on-board software package that shall identify and differentiate between the three targets.	The camera system will be able to identify and differentiate the targets using a software package integrated into the landing module.	Full-scale and subscale testing as well as proof from the camera. Also, NSL inspection as well as inspection and approval by the safety officer.

3.1.3 Mission Success Criteria

The following criteria must be met to consider the launch a success:

1. The launch vehicle leaves the rail cleanly with minimal interference.
2. The launch vehicle leaves the rail at a speed of at least 52 fps.
3. The launch vehicle has a stability margin of at least 2.0 for the duration of the flight.
4. The launch vehicle reaches an altitude of 5,280 ft. with a margin of error of ±50 ft.
5. The piston comes completely out of the launch vehicle.
6. The parachutes deploy successfully and slow the components to a safe speed.
7. All components are recovered without damage.
8. Subscale launch vehicle was launched on December 17, 2016.
9. Full-scale launch vehicle was launched on February 18, 2017.

3.1.4 Vehicle Design Summary

The design alternative that houses the landing module in the main section of the rocket is what will be built for the full-scale launch vehicle. This alternative consists of a 3 ft. nose cone, a 5 ft. main body tube, an altimeter bay, and a 4 ft. drogue section. Figure 5 shows the layout of launch vehicle subsections. The magenta markings indicate a connection, either a line (shock cord and/or quick links) or asterisk (bolts). Separation points are indicated by red lines.

The airframe is constructed primarily of fiberglass tubing with a fixed fin system. Beginning from the nose cone, inside the upper airframe, there is a large parachute for the nose cone, connected to the nose cone directly via a quick link. Below that is a large parachute for the landing module, then the landing module, which are connected directly via a quick link. Below the landing module, is the main parachute connected via quick link and shock cord to the upper airframe (main body), through an opening in the piston system, and to the altimeter bay with another quick link. The altimeter bay is connected to the drogue parachute and to the lower airframe (booster) shock cord by another quick link. The shock cord is secured to the motor mount in the booster system via a combination of fiberglass and epoxy. Nomex protectors are inserted between each parachute and the respective charges to prevent damage and between the two large parachutes to prevent entanglement.

The drogue parachute will deploy at apogee at separation point 1 to slow the kinetic energy of the system. The remainder of the components stowed in the upper airframe will deploy at an altitude of 1,000 ft. and exit through separation point 2. The piston system is designed to prevent the gases from the separation charge from escaping around the parachutes and will ensure all stages and parachutes are pushed out of the launch vehicle. The landing module was designed to be inside the launch vehicle body to avoid a design with structural protuberances and was placed in the upper airframe to maintain center of gravity.

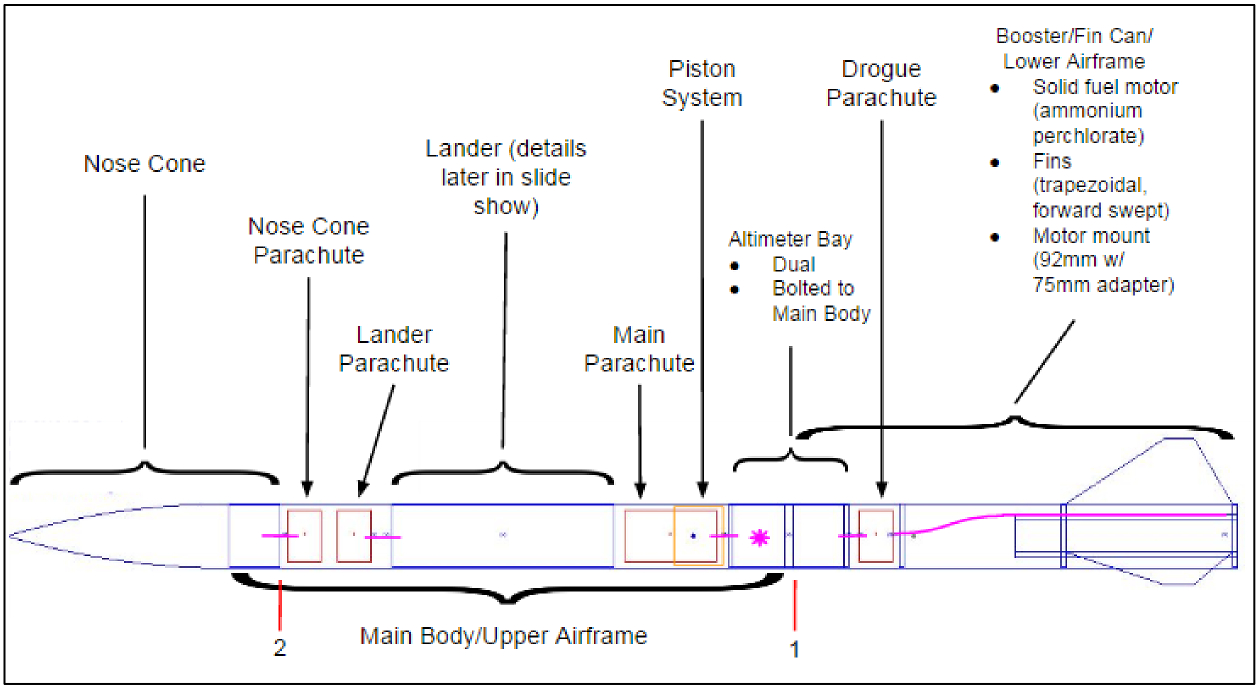


Figure 5: Annotated launch vehicle layout diagram.

3.1.4.1 Final Weight of Launch Vehicle

Table 2: Estimated unloaded weight of components and entire rocket.

Component	Weight (lb)
Nose Cone & Parachute	4.00
Landing Module & Parachute	7.98
Altimeter Bay with Main Airframe, Parachute, Shock Cords, & Piston	15.00
Booster & Shock Cords	12.69
Total Estimated Weight	39.67

3.1.5 Evaluation and Verification Plan

Table 3: Goals and verification of goals for specific flight characteristics.

Characteristic	Description	Goal	Verification
Apogee	Maximum height of the launch vehicle's flight path.	Launch to a height of 5,280 ft.	On-board altimeters will provide audio output of recorded altitude.
Stability	The distance between the center of pressure and center of gravity must be at least one diameter of the launch vehicle.	Have a stability margin of at least 2.0.	OpenRocket simulations with the motor loaded.
Rail velocity	The velocity that the launch vehicle has leaving the rail.	Leave the rail at a speed of at least 52 fps.	OpenRocket simulations will show the velocity and altimeter on test launches will verify.
Landing	The launch vehicle will return to the ground with parachutes inflated.	The launch vehicle and payload will not sustain damage.	The team and RSO will review the launch vehicle after landing.
Drift	The distance the launch vehicle moves away from the rail.	The parachutes will be of correct size so the drift is minimized to less than 2,500 ft.	The launch vehicle will be seen as it lands safely.

3.1.6 Level of Risk Assessment

Based on the hazard analysis, the highest level of severity of any single risk or hazard is Level 1 (Catastrophic), thus all Level 1 hazards are associated with Level E frequency (Improbable – less than 1% probability). The highest level of frequency of any single hazard or risk is Level D (Remote – 1% to 25% probability), so all Level D hazards must be associated with Level 4 severity (Negligible). The highest risk or hazard associated with full functionality and completion of all mission objectives is Low.

3.1.7 Integrity of Design

3.1.7.1 Suitability of Shape and Fin Style

The goal of selecting a suitable planform fin shape is to balance the effect of the restoring force around the center of pressure with the disturbance forces around the center of gravity. The semi-span of the fins must also be sufficiently large to operate outside of the turbulent air near the rocket body. Several shapes and sizes of fin would be suitable for the rocket and were considered. However, the trapezoidal shape was chosen for its drag reduction as opposed to a simple rectangle or parallelogram. Also, the forward swept trailing edge minimizes damage to the trailing edge of the fins upon landing to maximize potential for recovery and reuse.

The fins were epoxied directly to the motor mount with reinforcing fillets from the fin to the motor mount. When the fins were added to the outer body tube, more fillets were applied to ensure the fins will not be damaged upon impact with the ground.

3.1.7.2 Proper Use of Materials

The fins are made of fiberglass to ensure that they can withstand impact when landing. The bulkheads are thick and epoxied in between two wooden plates, and epoxy was applied all around the bulkhead to ensure no fire damage and/or breakage occurs. The epoxy that we used on the launch vehicle was mixed with carbon fibers for added strength. In order to prevent the nose cone from being pushed out before 1,000 ft, shear pins are to be placed on launch day to withstand the weight on the nose cone but still remain breakable when the thrust is applied. Along with the shear pins, bolts will be installed to fasten together the main airframe and the altimeter bay, because the airframe will not function as its own separate component, but rather as space for the landing module and main parachute to be held. The shock cords will be attached to a securely fastened U-bolt.

3.1.7.3 Sufficient Motor Mounting and Retention

The motor mounting is secured with a motor casing along with a bulkhead on top to prevent the motor from shifting upwards. In order to prevent the motor from falling out of the rocket, a motor retainer was installed.

3.1.8 Manufacturing, Verification, Integration, and Operations Planning

The launch vehicle components were purchased from a vendor early enough to ensure there was enough time to test all systems and get multiple launches on the full-scale rocket to reach the 5,280 ft. goal.

3.1.8.1 Pre-Mission Tests Overview

The tests in Table 4 have all been completed successfully over the development of the rocket, and the full-scale test launch will be repeated with an active landing module in March.

Table 4: Pre-mission test descriptions.

Testing	Purpose
Black Powder Test	This showed that the recovery system can come out of the launch vehicle with the correct amount of black powder.
Recovery System Ejection Test	This showed how the recovery system leaves the launch vehicle when a force is applied similar to the black powder charges. It proved the systems do not get tangled when leaving the launch vehicle.
Deployment Test	This showed how the parachutes and shock cord come out of the deployment bags. It proved the recovery system is safe to us.
Subscale and Full-Scale Test Launches	These showed that all the systems will work together to ensure the deployment happens correctly and there is a safe landing.

3.1.9 Recovery System Ejection Test

This test was conducted on February 18, prior to the full-scale launch test, to ensure that a sufficient amount of black powder charges was used for a successful separation of the nose cone, and the simulated landing module from the body tube attached to its consequent altimeter bay. The simulated landing module does not have the landing gear nor steering system, but is a single, 18 in. long phenolic tube with two bulkheads (including one bulkhead with a U-bolt for attaching a shock cord to its parachute), and a 10 lb. dumbbell wrapped in memory foam. The total weight of the simulated landing module was approximately 11 lb. Three separate tests were conducted at a distance with the rocket attached to a safe and secure, holding apparatus. The apparatus allowed the rocket to be set at an upward angle while being secured at the sides. The tests would be controlled with a wired detonator linking to the altimeter bay.

The first test used 8 g of black powder to ignite the ejection canisters (PVC pipes filled with the desired amount of black powder, and a paper, biodegradable filling). The ejection of the nose cone was successful, but the simulated landing module did not eject far enough as predicted and the main parachute did not fully open nor separated an appropriate distance from the body tube. Deductive reasoning led to believe that the main parachute did not fully separate and open due to the body tube being dragged forward as a result of the friction caused by the landing module leaving said tube.

The second test used 9 g of black powder for separation. During this test, the nose cone ejected in the same manner as the first test. The simulated landing module however, did not eject fully from the body tube, and the parachute never emerged due to the fact that it was behind the landing module. The landing module rested in the body tube with about half of the module able to appear out. It was speculated that the ejection of the simulated landing module and main parachute was inadequate due to the loading inside the body tube. The simulated landing module was, in fact, not in contact with the piston during detonation in the ejection canisters. This allowed a loss of kinetic energy during the transfer when the piston hit the landing module while inside the body tube.

The third test was reduced to 8 g of black powder like the first test. The inside of the body tube was wiped down to remove any residue from detonation and all components were loaded properly, with the simulated landing module resting inside the body tube in contact with the piston. This would allow optimal transfer of kinetic energy. The result was a complete separation of all components, including nose cone, simulated landing module, and main parachute, as shown in Figure 6. The ejection with 8 g of black powder and proper packing of components helped the landing module reach a lateral distance of 45 ft. from the body tube.

Figure 6: Successful full-scale recovery system ejection test.

3.1.10 Progression and Current Status of Design

3.1.10.1 Past Progression of Design

The launch vehicle has gone through three major design changes since the initial proposal. The initial design of our launch vehicle involved landing the aft section of our rocket. This incorporated the motor mount, fins, motor retainer, and bi-propeller assembly with parachute for recovery. The second design separated the bi-prop assembly from that of the aft section of our launch vehicle, placing it a little more than mid-way up the rocket. Since the Preliminary Design Report, a piston system was added for successful parachute deployment.

The positives that arose from a bottom housed bi-prop system were related to the increased simplicity. This would allow for an almost typical rocket design with a main parachute and a drogue parachute. Though of course, the main parachute would have to be tied to the aft of our rocket that is housing the bi-prop assembly and the drogue attached to the rest. The drawbacks of this design came from the heavy weight of the aft bay. This weight decreased the stability of our rocket and thus made us rethink our initial design.

As stated above, the alternative, with the bi-prop assembly about midway up the rocket, was chosen because of the decreased weight of the bi-prop assembly and the increased stability of our rocket. Research shows that the better stabilized a rocket is, the more accurately its flight path can be predicted. Though the rocket's stability is now within a reasonably sound range, predicting a rocket's flight path is still extremely difficult sue to the large number of variables, however apogee predictions are at least closer to reality.

The rocket design as of the Critical Design Review Report was focused around increasing the stability of our rocket. The bi-prop assembly housing the camera was moved just past the most central part of our rocket's axial length. This increased the stability of our rocket well above three calipers and made it safer to launch. Another positive reason for separating the camera housing from the aft is that this section would be much lighter than that of its original position. The bi-prop assembly would only need to move itself through the ambient atmosphere and not any other payloads or weight. The disadvantages stem from the complicated arrangement of four parachutes now within the rocket. These parachutes are laid out this way because every section of the rocket needs to have its own parachute to land safely, including the payload, nose cone, and aft of our rocket. The piston system has been added to ensure the parachutes deploy successfully. This system was tested successfully during and prior to the subscale launch.

3.1.10.2 Current Design Status

The changes in the current rocket design are meant to improve the design of the landing module. In the most recent design change, the bi-prop system was totally removed, as the propellers proved unable to move the landing module with even moderate wind conditions. The launch vehicle itself remains the same with the only change being to the landing module. The piston system will still be used and was further tested at the full-scale launch.

3.1.11 Dimensional Drawing of Assembly

The launch vehicle body is comprised of several different sections. The nose cone is 3 ft. tall. There is a body tube below the nose cone that is 5 ft. long, housing three parachutes, the landing module system, and the piston system. Below this is the altimeter bay which is a 1 in. band on the outside attached to a 13 in. coupler/altimeter bay. There is a 4 ft. long section below the altimeters that houses the motor mount, one parachute, and the fins.

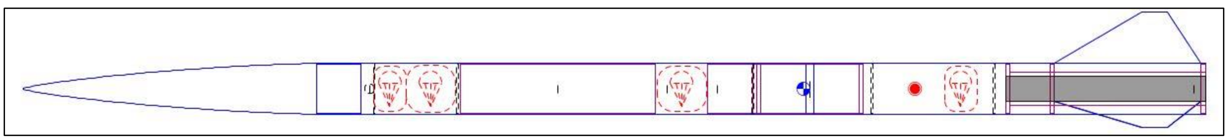


Figure 7: Overview drawing of launch vehicle assembly.

3.1.12 Mass Statement

The following is the parts list for the full-scale launch vehicle showing the mass of each component:

3.1.12.1 Nose Cone

Table 5: Nose Cone mass statement.

Brand	**Model**	**Material**
Public Missiles	FNC-6.00	Fiberglass
Properties		
Nose Shape	Hollow Ogive	
Length (in)	24.0000	
Diameter (in)	6.1000	
Wall Thickness (in)	0.1250	
Body Insert Properties		

OD (in)	5.9700
Length (in)	5.5000
Calculations	
CG (in)	14.5000
Mass (oz)	28.000
Radius of Gyration (m, cm)	0.200442, 20.0442
Moment of Inertia ($kg \cdot m^2$, $g \cdot cm^2$)	0.0318919, 318919
RockSim XN (in)	11.1411
CNa	2

3.1.12.2 Eye Bolt (×5)

Table 6: Eye Bolt mass statement.

Brand	**Model**	**Material**
Public Missiles	HDWE-EYE-1/8	Steel
Calculations		
CG (in)	0.0000	
Mass (oz)	0.2000	
Radius of Gyration (m, cm)	0, 0	
Moment of Inertia ($kg \cdot m^2$, $g \cdot cm^2$)	0, 0	

3.1.12.3 Shock Cord (×4)

Table 7: Shock Cord mass statement.

Brand	**Model**	**Material**
Public Missiles	--	3/8” Tubular Nylon (SkyAngle)
Calculations		
CG (in)	0.0000	

Mass (oz)	4.0000
Radius of Gyration (m, cm)	0, 0
Moment of Inertia ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0, 0

3.1.12.4 Main Section

Table 8: Main Section mass statement.

Brand	**Model**	**Material**
Custom	--	G10 Fiberglass
Properties		
OD (in)	6.1000	
ID (in)	6.0000	
Length (in)	60.0000	
Calculations		
CG (in)	30.0000	
Mass (oz)	110.0001	
Radius of Gyration (m, cm)	0.443782, 44.3782	
Moment of Inertia ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0.614155, $6.14155{\cdot}10^6$	
RockSim XN (in)	0.0000	
CNa	0	

3.1.12.5 Nose Cone Parachute

Table 9: Nose Cone Parachute mass statement.

Brand	**Model**	**Material**
b2 Rocketry	CERT-3 Drogue	1.9 oz Ripstop Nylon (SkyAngle)
Properties		
Shape	Round	

Diameter (in)	21.8000
Spill Hole (in)	0.0000
Calculations	
CG (in)	0.0000
Mass (oz)	6.0000
Radius of Gyration (m, cm)	0.0405272, 4.05272
Moment of Inertia ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0.000279377, 2793.77

3.1.12.6 Main Parachute

Table 10: Main Parachute mass statement.

Brand	Model	Material
Public Missiles	PAR-60R	Ripstop Nylon
Properties		
Shape	Round	
Diameter (in)	60.0000	
Spill Hole (in)	9.5000	
Calculations		
CG (in)	0.0000	
Mass (oz)	7.9000	
Radius of Gyration (m, cm)	0.0794957, 7.94957	
Moment of Inertia ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0.00141534, 14153.4	

3.1.12.7 Landing Module

Table 11: Landing Module mass statement.

Brand	Model	Material
Custom	--	Kraft Phenolic
Properties		

OD (in)	5.9700
ID (in)	5.8000
Length (in)	18.0000
Location (in, from front of Main Section)	17.6250
Calculations	
CG (in)	12.2500
Mass (oz)	102.080
Radius of Gyration (m, cm)	0.069676, 6.9676
Moment of Inertia ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0.0140493, 140493

3.1.12.8 Landing Module Electronics

Table 12: Landing Module Electronics mass statement.

Brand	Model	Material
Custom	--	--
Calculations		
CG (in)	0.0000	
Mass (oz)	82.0000	
Radius of Gyration (m, cm)	0, 0	
Moment of Inertia ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0, 0	

3.1.12.9 Landing Module Parachute

Table 13: Landing Module Parachute mass statement.

Brand	Model	Material
b2 Rocketry	CERT-3 Drogue - SkyAngle	1.9 oz Ripstop Nylon
Properties		
Shape	Round	
Diameter (in)	21.800	

Spill Hole (in)	0.0000
Calculations	
CG (in)	0.0000
Mass (oz)	6.0000
Radius of Gyration (m, cm)	0.0405272, 4.05272
Moment of Inertia (kg·m^2, g·cm^2)	0.000279377, 2793.77

3.1.12.10 Bulkhead (×2)

Table 14: Bulkhead mass statement.

Brand	Model	Material
Public Missiles	CBP-6.0 (was CBP-15)	Birch
Properties		
OD (in)	6.0000	
Length (in)	0.5000	
Location (in, from base of Booster Section)	24.0000	
Calculations		
CG (in)	0.2500	
Mass (oz)	5.5632	
Radius of Gyration (m, cm)	0.0383191, 3.83191	
Moment of Inertia (kg·m^2, g·cm^2)	0.000231581, 2315.81	

3.1.12.11 Piston

Table 15: Piston mass statement.

Brand	Model	Material
Custom	--	Kraft Phenolic
Properties		

OD (in)	5.9700
ID (in)	5.8000
Length (in)	6.0000
Location (in, from front of Main Section)	47.7500
Calculations	
CG (in)	3.0000
Mass (oz)	5.2300
Radius of Gyration (m, cm)	0.183949, 18.3949
Moment of Inertia ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0.0200497, 200497

3.1.12.12 Altimeter Bay

Table 16: Altimeter Bay mass statement.

Brand	Model	Material
Custom	--	Fiberglass
Properties		
OD (in)	6.1000	
ID (in)	6.0000	
Length (in)	1.0000	
Calculations		
CG (in)	0.5000	
Mass (oz)	1.0466	
Radius of Gyration (m, cm)	0.0548866, 5.48866	
Moment of Inertia ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	$8.93839{\cdot}10^{-5}$, 893.839	
RockSim XN (in)	0.0000	
CNa	0	

3.1.12.13 Inner Bay

Table 17: Inner Bay mass statement.

Brand	Model	Material
Custom	--	G10 Fiberglass
Properties		
OD (in)	5.9700	
ID (in)	5.8000	
Length (in)	13.0000	
Location (in, from base of Altimeter Bay)	-6.0000	
Calculations		
CG (in)	7.5000	
Mass (oz)	28.2192	
Radius of Gyration (m, cm)	0.109116, 10.9116	
Moment of Inertia ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0.00952508, 95250.8	

3.1.12.14 Altimeter Caps (×2)

Table 18: Altimeter Caps mass statement.

Brand	Model	Material
Public Missiles	--	Carbon Fiber
Properties		
OD (in)	5.8000	
Length (in)	0.5000	
Location (in, from front of Inner Bay)	0.0000	
Calculations		
CG (in)	0.3500	
Mass (oz)	12.7692	

Radius of Gyration (m, cm)	0.0370537, 3.70537
Moment of Inertia ($kg \cdot m^2$, $g \cdot cm^2$)	0.000497018, 4970.18

3.1.12.15 RRC3 Altimeter, Sled, and Batteries

Table 19: Altimeter, Sled, and Batteries mass statement.

Brand	Model	Material
Public Missiles	--	3/8” Tubular Nylon (SkyAngle)
Calculations		
CG (in)	0.0000	
Mass (oz)	5.2911	
Radius of Gyration (m, cm)	0, 0	
Moment of Inertia ($kg \cdot m^2$, $g \cdot cm^2$)	0, 0	

3.1.12.16 Booster Section

Table 20: Booster Section mass statement.

Brand	Model	Material
Custom	--	G10 Fiberglass
Properties		
OD (in)	6.1000	
ID (in)	6.0000	
Length (in)	48.0000	
Calculations		
CG (in)	24.0000	
Mass (oz)	50.2368	
Radius of Gyration (m, cm)	0.356523, 35.6523	
Moment of Inertia ($kg \cdot m^2$, $g \cdot cm^2$)	0.181026, $1.81026 \cdot 10^6$	

RockSim XN (in)	0.0000
CNa	0

3.1.12.17 Fin Set

Table 21: Fin Set mass statement.

Brand	Model	Material
Custom	--	Carbon Fiber
Calculations		
CG (in)	10.2600	
Mass (oz)	54.0750	
Radius of Gyration (m, cm)	0.105775, 10.5775	
Moment of Inertia ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0.0171516, 171516	
RockSim XN (in)	122.4138	
CNa	11.7792	

3.1.12.18 Outer Motor Mount

Table 22: Outer Motor Mount mass statement.

Brand	Model	Material
Custom	--	Kraft Phenolic
Properties		
OD (in)	4.0000	
ID (in)	3.9000	
Length (in)	24.0000	
Location (in, from base of Booster Section)	0.0000	
Calculations		
CG (in)	12.0000	
Mass (oz)	21.6229	

Radius of Gyration (m, cm)	0.179718, 17.9718
Moment of Inertia (kg·m^2, g·cm^2)	0.0187881, 197991

3.1.12.19 Centering Ring (×2)

Table 23: Centering Ring mass statement.

Brand	**Model**	**Material**
Public Missiles	CCR-6.0-3.9 (was PML CCR-18)	Aircraft Plywood (Birch)
Properties		
OD (in)	5.9300	
ID (in)	4.0200	
Length (in)	0.5000	
Location (in, from base of Booster Section)	First: 0.0000 Second: 18.5500	
Calculations		
CG (in)	0.5000	
Mass (oz)	2.7161	
Radius of Gyration (m, cm)	0.0456913, 4.56913	
Moment of Inertia (kg·m^2, g·cm^2)	0.000160753, 1607.53	

3.1.12.20 Main Parachute

Table 24: Main Parachute mass statement.

Brand	**Model**	**Material**
b2 Rocketry	CERT-3 XLarge - SkyAngle	1.9 oz Ripstop Nylon
Properties		
Shape	Round	
Diameter (in)	60.0000	
Spill Hole (in)	0.0000	

Calculations	
CG (in)	0.0000
Mass (oz)	45.0000
Radius of Gyration (m, cm)	0.0794957, 7.94957
Moment of Inertia (kg·m^2, g·cm^2)	0.00806205, 80620.5

3.1.12.21 Shock Cord (×2)

Table 25: Large Shock Cord mass statement.

Brand	Model	Material
Public Missiles	--	3/8" Tubular Nylon (SkyAngle)
Calculations		
CG (in)	0.0000	
Mass (oz)	10.0000	
Radius of Gyration (m, cm)	0, 0	
Moment of Inertia (kg·m^2, g·cm^2)	0, 0	

3.1.12.22 Bulkhead

Table 26: Bulkhead mass statement.

Brand	Model	Material
Public Missiles	CBP-6.0 (was CBP-15)	Birch
Properties		
OD (in)	6.0000	
Length (in)	0.5000	
Location (in, from base of Booster Section)	36.0000	
Calculations		
CG (in)	0.2500	

Mass (oz)	5.5632
Radius of Gyration (m, cm)	0.0383191, 3.83191
Moment of Inertia (kg·m^2, g·cm^2)	0.000231581, 2315.81

3.1.12.23 Motor Adapter

Table 27: Motor Adapter mass statement.

Brand	Model	Material
Giant Leap	SLIM98-76 SlimLine 98-76mm Adapter	
Calculations		
CG (in)	0.0000	
Mass (oz)	18.3000	
Radius of Gyration (m, cm)	0, 0	
Moment of Inertia (kg·m^2, g·cm^2)	0, 0	

3.1.12.24 Motor Mount

Table 28: Motor Mount mass statement.

Brand	Model	Material
Custom	--	Kraft Phenolic
Properties		
OD (in)	3.0709	
ID (in)	2.9921	
Length (in)	24.0000	
Location (in, from base of Booster Section)	0.0000	
Calculations		
CG (in)	12.0000	
Mass (oz)	21.6229	

Radius of Gyration (m, cm)	0.17827, 17.827
Moment of Inertia ($kg \cdot m^2$, $g \cdot cm^2$)	0.0194813, 194813

3.2 Full-Scale Flight Results

The full-scale rocket was successfully launched on February 18, 2017. A video of this launch can be found at http://www.usfsoar.com/full-scale-launch-day/.

3.2.1 Flight Data

Table 29: Flight data from subscale test, collected with an RRC3 Missile Works Altimeter.

Flight Property	Value
Maximum Altitude (Apogee) (ft)	3,574
Maximum Velocity (fps)	425
Ascent Time (s)	15.73
Descent Time (s)	80.48
Drogue Rate (fps)	120
Main Rate (fps)	21

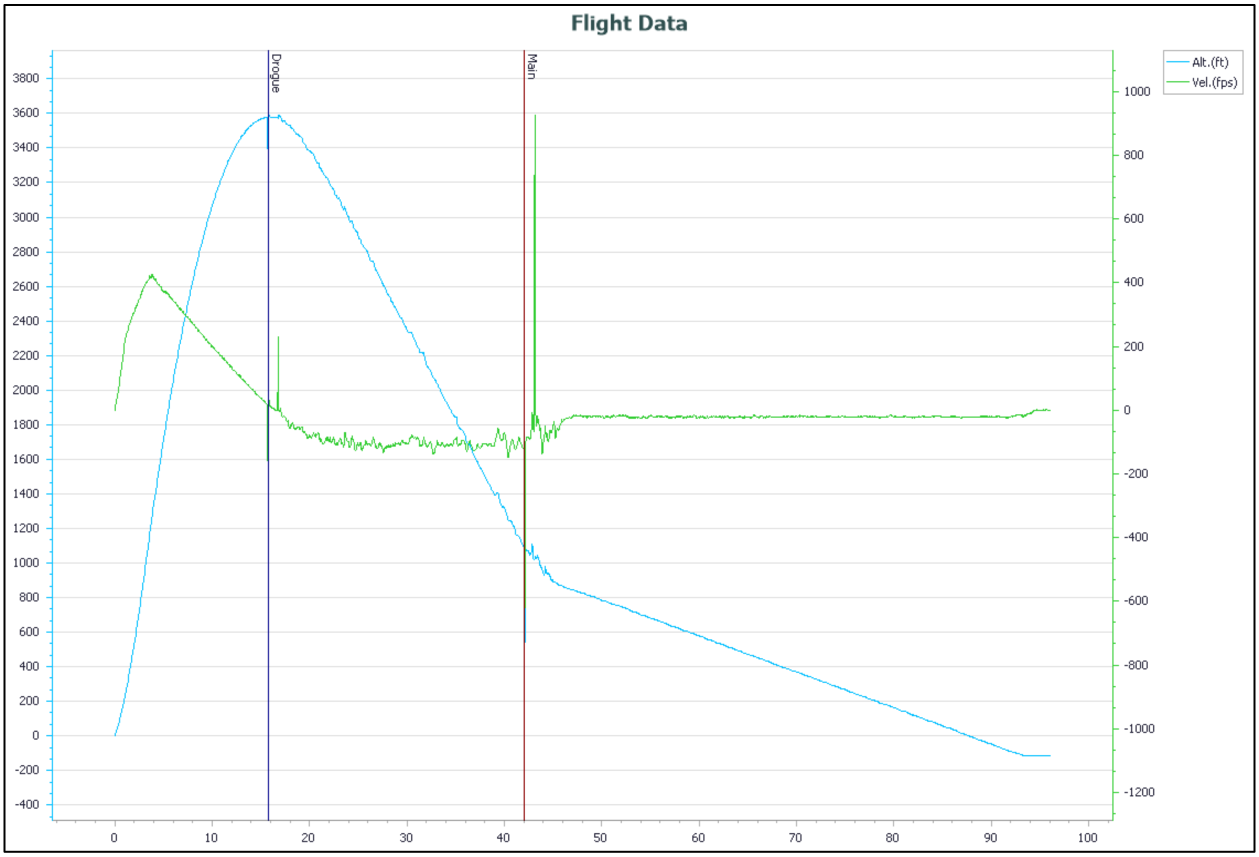


Figure 8: Chart of data from full-scale launch, with parachute release times marked.

3.2.2 Launch Day Conditions Simulation

The launch took place on February 18, 2017 at Varn Ranch, the local Tripoli flight location in Plant City. The simulations are shown in the Mission Analysis section. A summary of the launch conditions is available in Table 30.

Based upon the conditions of the day, a detailed simulation was created. The simulated model of the full-scale flight predicted an expected apogee of 5,731 ft and a maximum velocity of 613 fps. This is significantly higher than the actual full-scale launch altitude. As discussed in 3.2.4 Analysis of Full-Scale Flight, the most likely source of this error is the high weight of the simulated landing module. In the simulation, the rocket hits the ground at a velocity of 24.3 fps, and the velocity off the launch rail is 58.3 fps.

Table 30: Summary of launch day conditions.

Condition	Value
Weather	Overcast/Rainy

Condition	Value
Temperature (°F)	77
Humidity (%)	78
Wind (mph)	4

3.2.4 Analysis of Full-Scale Flight

The full-scale test was completed on February 18, 2017. After ground testing of the piston ejection system was completed (see 3.1.9 Recovery System Ejection Test), the launch vehicle was assembled in accordance with the checklist and the motor assembled in accordance with manufacturer's instructions. There were no major issues encountered with assembling the launch vehicle or preparing the ignition system for launch. However, the first launch attempt failed. After troubleshooting was completed, it was determined that the power supply to the launch pad was insufficient to detonate the igniter. The power supply battery was replaced and the second launch attempt was successful.

The winds were minimal, and the trajectory of the launch vehicle appeared to be stable and almost perfectly vertical. The drogue parachute successfully deployed at apogee and the remainder of the systems ejected at 1,000 ft. as planned. However, the nose cone parachute failed to completely open, resulting in the section becoming nearly ballistic. This resulted in no damage to the nose cone, as it landed point first and was embedded into the ground, which had been rather significantly softened by the rain. Analysis revealed that the Nomex protector used between the ejection charge and the parachute had slid up the shroud lines and prevented them from opening. This fault is addressed in the safety hazard section.

The launch vehicle reached an apogee of just 3,574 ft, which is below the target altitude. Analysis reveals that this was likely due to some excess weight in epoxy or other unpredicted mass; however, it was significantly due to the weight of the simulated landing module, which was somewhat heavier than the actual landing module was predicted to be. This discrepancy was intentional, as it was desirable to test for the worst-case scenario. With the redesign of the landing module, the weight of the launch vehicle will be decreased significantly and simulation analysis shows that the new apogee to be at or around 5,260 ft.

All subsystems were recovered intact and no damage was sustained to major components.

3.3 Recovery Subsystem

3.3.1 Chosen Design Alternatives from the PDR

The alternative for the recovery system shown in the Preliminary Design Review Report (PDR) will be used with the addition of the piston system, as shown in the CDR. The recovery system is comprised of several different items to ensure the separation happens cleanly and the section makes a safe landing. The bulkheads will be epoxied to the body of the launch vehicle with anchor bond to ensure it can handle the forces during flight. The U-bolts will be screwed into the bulkheads. The piston system ensures that the gases from the black powder will not escape around the parachutes.

Table 31: Primary recovery subsystem components.

Main Recovery System Components	Component Purpose
Piston	Contain the expanding gases and push the parachutes out of the launch vehicle.
Parachute	Slow the descent of each section of the launch vehicle.
Shock Cord	Reduces the amount of stress on the cords of the parachute to ensure the parachute is undamaged.
U-Bolts	Divide the stress to the entire surface of the bulkhead instead of eyebolts where it is all in the center.
Bulkheads	Secure the U-bolts to the body of the launch vehicle.

3.3.2 Parachutes, Harnesses, Bulkheads, and Attachment Hardware

The current parachutes used for the full-scale launch vehicle are shown below. The drogue parachute will be attached to a U-bolt by shock cord. Parachute and shock cord protectors will be used to ensure the system does not sustain damages from the black powder charges. The U-bolt is screwed into bulkheads that are epoxied into the corresponding section of the launch vehicle. Swivel connectors will be used for the parachutes to limit the amount of tangling.

Table 32: Chosen parachute sizes for each section.

Parachute Name	Parachute Size
Nose Cone Parachute	SkyAngle Drogue
Landing Module Parachute	SkyAngle Large
Main Body Parachute	SkyAngle Large
Drogue Parachute	SkyAngle Drogue

3.3.3 Electrical Components & Redundancies

In our rocket is a redundant system where each altimeter is connected to a battery, a switch, and the main and drogue charges. The altimeters used are Missile Works RRC3 altimeters. The battery and switch will be connected to one side of each altimeter. On the other side of the altimeter is where the charges will be wired. This setup has been used before by the organization and has proven effective. Because it is a fully redundant system, if one altimeter does not work, the remaining altimeter will still function and provide measurements to deploy the parachutes. The charges will be slightly offset to ensure the launch vehicle does not sustain too much force from the deployment.

3.3.4 Drawings, Diagrams, and Schematics

Figure 9 shows the diagram of how the altimeters will be wired. The two systems are redundant and independent of each other.

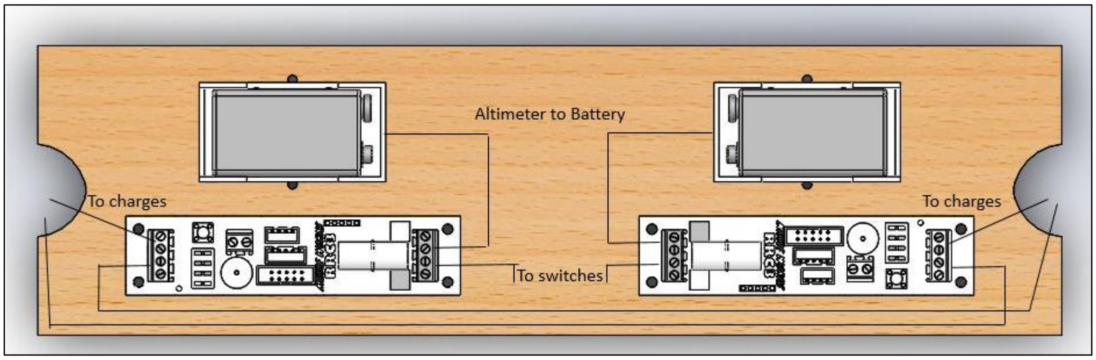


Figure 9: Schematic of recovery system electronics.

3.3.5 Operating Frequencies of the Locating Trackers

The trackers that will be used at the Missile Works RTx system. This system operates between 902 and 928 MHz with a range of up to 9 mi. The Missile Works RTx system was chosen for its reliability and dependency.

3.4 Mission Performance Predictions

3.4.1 Mission Performance Criteria

Characteristic	Description	Goal
Apogee	Max height of the launch vehicle's flight path.	Reach 5,280 ft.
Rail Speed	Velocity of the launch vehicle when it leaves the rail.	Minimum 52 fps.
Stability	The distance between the center of pressure and center of gravity must be at least one diameter of the launch vehicle.	Have a stability margin of 2.0.
Landing	The launch vehicle must return to the ground with parachutes inflated.	The launch vehicle sustains no damages.
Drift	The distance the launch vehicle moves away from the rail shall be minimized.	The launch vehicle lands within 2,500 ft. of the launch site.

3.4.2 Mission Analysis

The launch vehicle was simulated on a L1115 manufactured by Cesaroni. The thrust curve of the motor is shown in Figure 10.

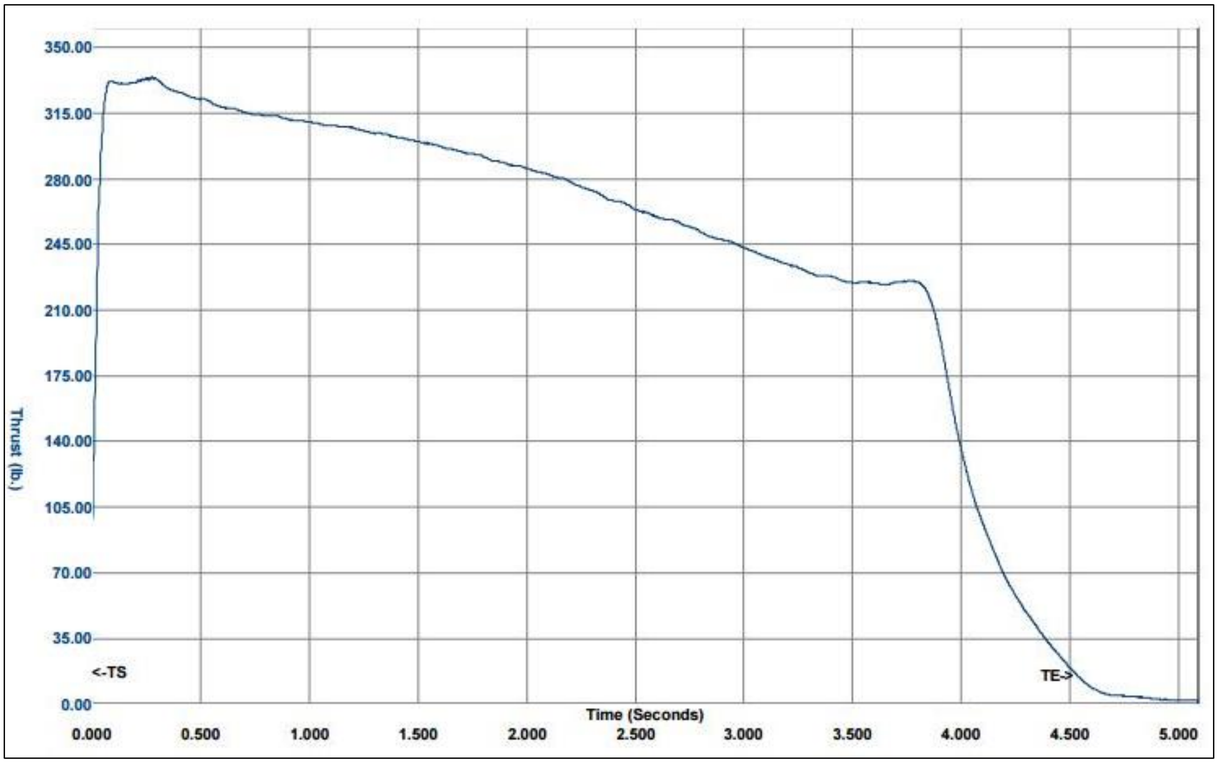


Figure 10: Chart of the thrust curve of the L1115 motor.

The effect of the wind speed on the launch vehicle was tested in simulations, with the collected data shown in Table 33.

Table 33: Effects of various simulated wind speeds on the launch vehicle.

Wind Speed (mph)	**Data**	
0	**Apogee** (ft)	5,594
	Time to Apogee (s)	19.6
	Max Velocity (fps)	583
	Max Acceleration (fps^2)	216
10	**Apogee** (ft)	5,565
	Time to Apogee (s)	19.7

Wind Speed (mph)	**Data**	
	Max Velocity (fps)	583
	Max Acceleration (fps^2)	216
15	**Apogee** (ft)	5,550
	Time to Apogee (s)	19.7
	Max Velocity (fps)	582
	Max Acceleration (fps^2)	216

The launch conditions were set to parameters that simulated the expected conditions of launch date. The relative humidity was set to 8%, 60°F, with no cloud coverage. The launch vehicle was launched at 5° from vertical. All simulation showed a successful landing.

3.4.3 Stability Margin, Center of Pressure, and Center of Gravity Analysis

The center of gravity of the full-scale launch vehicle is 80.081 in. from the nose cone unloaded and 90.861 in. from the nose cone loaded. The center of pressure is 109 in. from the top of the nose cone and this gives the launch vehicle a stability margin of 3.04 calipers. The Barrowman equations were used for calculation of center of pressure. The diagram of the launch vehicle is shown below in Figure 11.

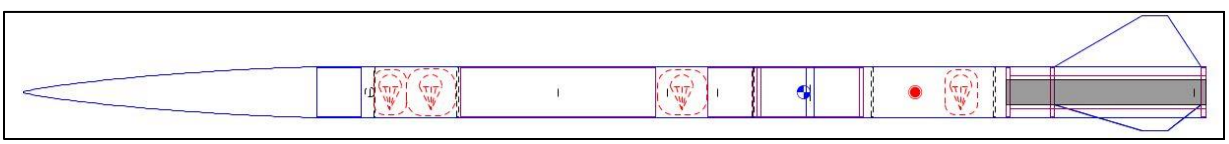


Figure 11: Drawing of launch vehicle with centers of gravity and pressure shown.

3.4.4 Kinetic Energy Analysis

The kinetic energy calculations were completed using the mass approximations and the SkyAngle Descent Velocity Calculator as well as our own descent velocity readings from onboard altimeters during testing. Kinetic energies were calculated based on two parachutes, the Large and XL SkyAngle CERT-3. The calculations concluded that all sections of the launch vehicle will be below the maximum 75 ft·lbf.

Table 34: Expected velocity and kinetic energy values for launch vehicle sections.

Section	**Descent Velocity with L CERT-3** (fps)	**Descent Velocity with XL CERT-3** (fps)	**Kinetic Energy with L CERT-3** (ft·lbf)	**Kinetic Energy with XL CERT-3** (ft·lbf)
Nose cone	16.09	11.33	12.06	5.98
Upper Section with Landing Module	16.09	11.33	66.33	32.89
Altimeter Bay	16.09	11.33	24.12	11.96
Booster Section	16.09	11.33	58.29	28.90

3.4.5 Drift Analysis

The drift of the launch vehicle is calculated by multiplying the velocity of the wind by the time after apogee to the ground. This time would be the time that the launch vehicle is being controlled by the parachute. Since it is launched vertically, it is assumed there is no drift until after apogee. The time to ground from apogee is 83.3 s.

Table 35: Calculated drift analysis values.

Wind Speed (mph)	**Wind Speed** (fps)	**Drift** (ft)
0	0.00	0.00
5	7.33	610.589
10	14.66	1,221.178
15	21.99	1,831.767
20	29.32	2,442.356

4 Landing Module Criteria

4.1 General Overview

4.1.1 Experimental Specifications

Target detection and upright landing:

- *Teams shall design an onboard camera system capable of identifying and differentiating between 3 randomly placed targets.*
- *Each target shall be represented by a different colored ground tarp located on the field.*
- *All targets shall be approximately 40’×40’ in size.*
- *The three targets will be adjacent to each other, and that group shall be within 300 ft. of the launch pads.*
- *After identifying and differentiating between the three targets, the launch vehicle section housing the cameras shall land upright, and provide proof of a successful controlled landing.*
- *Data from the camera system shall be analyzed in real time by a custom designed on-board software package that shall identify and differentiate between the three targets.*

Source: *2017 NASA Student Launch Handbook*, pg. 9.

4.1.2 Objective

The objective of our system is to provide adequate stability for our vision system to acquire focused and clear imagery while also keeping the module within the specified range of the launch pad and performing a controlled landing.

4.1.3 Success Criteria

The following criteria need to be met to consider the success of the landing module:

1. Landing module properly deploys at an altitude of 1,000 ft. on its descent
2. The drogue parachute for the landing module opens to effectively slow descent
3. The on-board vision system identifies and locates the three colored 40ft. × 40 ft. tarps
4. No damage is incurred upon the landing module settling to the ground in an upright, vertical position

4.2 Chosen Design Alternatives

The final landing module design will be composed of two separate sections: the vision system and landing system. The vision system will be used to locate and identify the three different colored tarps, by aiming the camera at the targets and using a computer to process the image. In order to allow the module to land upright, four spring-loaded cylindrical legs will be used as landing gear. These four legs will deploy upon separation of the landing module from the main rocket, and will be kept in tension using two extension springs. The extension springs act as a way to adjust the orientation of the landing gear and optimize the kinetic energy absorption by the spring-loaded hinges.

4.3 Design Overview

4.3.1 Overall Assembly

As mentioned previously, the entire landing module is only composed of two separate systems. Inside of the phenolic body will be the necessary electronics for the vision system. The camera used to locate and identify the tarps will be protruding through the bulkhead at the bottom of the module in order to obtain a view with minimal obstructions. Attached to the bottom bulkhead will be the four individual legs of the landing gear system with their affixed extension springs. This entire module will be fit snugly into the main body of the rocket just below the nose cone. The tight fit of landing module in the rocket will create a geometric constraint to keep the landing gear in its pre-deployed, or loaded state.

4.3.2 Payload Electronics

The payload electronics bay houses the electronics for the vision system. This includes the Raspberry Pi 3b, an Arduino microcontroller, an Adafruit Ultimate GPS Breakout board, and various sensors. The Raspberry Pi will be used for processing the camera input and identifying targets, while the Arduino will be used to aim the camera based upon altimeter, gyroscopic, GPS, and compass data. The camera will be mounted to a Lynxmotion Pan and Tilt Kit along with two servos, to allow for a full 360° panning range and 180° tilt range, enabling the landing module to see the tarps even with significant drift.

4.3.3 Landing Gear

The landing gear system consists of self-closing spring hinge and extension springs. The self-closing spring hinges are in tension when the system is stowed inside of the rocket. Once the system jettisons from the rocket, the spring hinges will compress to extend the legs radially. The extension springs will be connected at the corners of each leg to set the descent angle. Extension springs will also be used to absorb the compressive force of the system impact upon touchdown.

4.4 Mechanical Component Selection

4.4.1 Materials

Considerable thought was placed in selecting the materials for the landing module body and landing gear. The physical structure encapsulating the steering system, as well as the landing gear will be constructed of phenolic. Phenolic was chosen due to its lightweight, low cost, the ease with which it can be manufactured, and mechanical properties such as strength, stiffness, and toughness to resist a high-velocity impact. Phenolic was also chosen due to its standard sizes, allowing proper tolerances between the inner diameter of the rocket body and the outer diameter of the module, not to mention the low frictional properties resulting from phenolic on phenolic abrasive contact.

Several components are employed in the mechanical subsystems of the landing module that are not constructed of phenolic, including the brackets mounted to the landing gear, the spring-loaded hinges, and the servo mount. The hinges are made from steel and the servo mount from aluminum for strength purposes, While the brackets used to mount the landing gear legs to the hinges are made from polylactic acid (PLA). PLA was used not for its mechanical properties, but rather for its ability to be formed to complex shapes by being 3D printed.

4.4.2 Connection Types

Regarding mechanical components, the hinges used for the landing gear will be rigidly connected to the bottom bulkhead of the landing module, and also to the top portion of each landing gear through the use of threaded fasteners. Eye hooks will be incorporated to attach the extension springs to the landing gear. The servo mount will be firmly attached to the bottom bulkhead using stainless steel bolts.

All hardware needed for the electronics bay will be rigidly secured to structural brackets located inside of the landing module to ensure there is no movement of any kind, and vibration is minimized.

4.5 Payload Electronics

5.5.1 Overview

The electronics system of the payload (Figure 12) is split into two subsections: a vision system and a camera aiming system. The vision processing system is controlled by a Raspberry Pi 3B and the camera aiming system by an Arduino based microcontroller. The vision system will be responsible for identifying the three different colored targets and differentiate between them by overlaying graphics on the image it captures and saves to a microSD card. The camera aiming system will ensure that the tarps are always visible within the range of the camera by pointing the camera towards the GPS coordinate of the tarps.

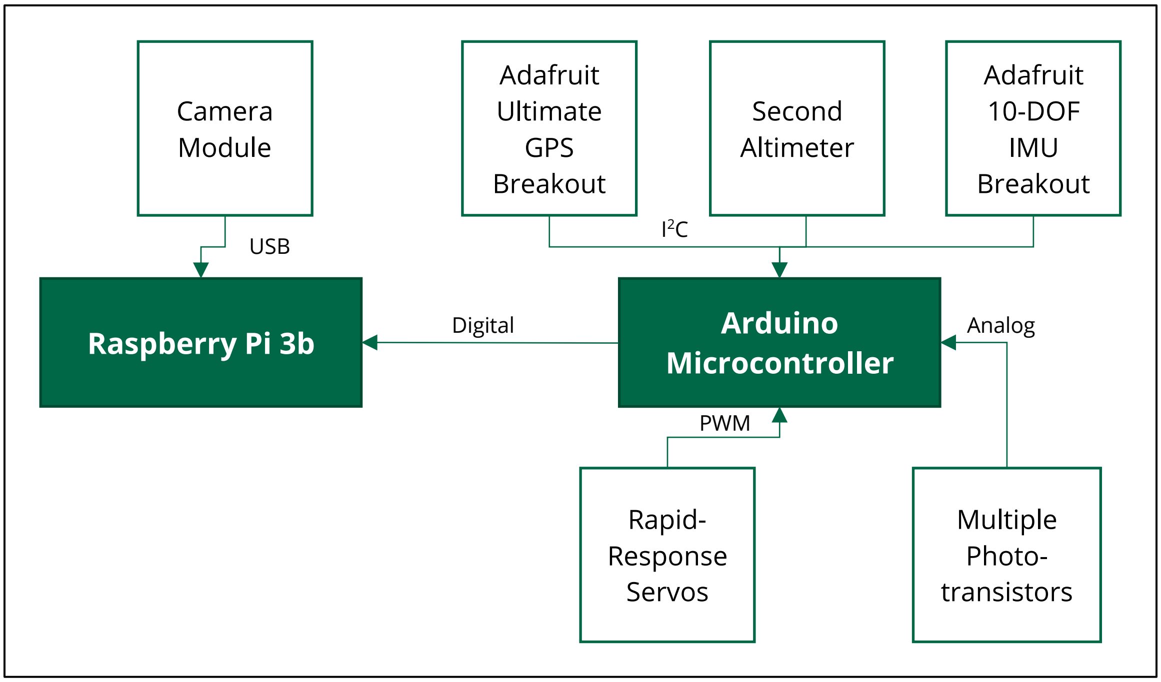


Figure 12: Payload electronics wiring block diagram.

4.5.2 Vision System

The Raspberry Pi 3B was chosen as the computer module for the vision system due to its large collection of supporting documents and price-to-performance ratio. It hosts a 1.2 GHz 64-bit quad-core processor and 1 GB of RAM which together provide plenty of processing power to run our custom software package. A VideoCore IV 300 MHz GPU is built into the Raspberry Pi which will assist in the image processing and reduce the load on the CPU. The onboard USB 2.0 ports, microSD card slot, and MIPI CSI-2 interface (Mobile Industry Processor Interface Camera Serial Interface Type 2) allow direct connection of the required peripherals for our vision system. The camera that will be used for identifying the targets has been narrowed to the oCam camera module by Hardkernel, which features a 5 MP sensor with a 65° angle of view. It is USB 2.0 and Linux compatible so it will integrate smoothly with our Raspberry Pi. Extensive testing was performed to choose this camera over the Raspberry Pi Camera Module v2, which, while it has a higher resolution, has a lower-quality sensor that has less chance of achieving a clear picture of the tarps.

The process of determining which color the three tarps are and subsequently labeling them will be done through a multi-step process. First, using the known hue, saturation, and lightness value (HSV) values, three separate masks will be created. Next, using a combination of thresholding and contouring, the approximate size and shape of all corresponding matches will be determined. Using the onboard altimeter and the known focal length of the camera, the proper size of the tarps in pixels will be calculated (see 4.5.2.1 Tarp Size Approximation for the method used). Using this calculated value, the previously created contours will be filtered, ensuring only matches of the correct size are found. If three separate contours are matches, the HSV values will be used to determine which tarp is which color and a square will be drawn around each, with a corresponding label. If less than three tarps are found, but at least one is found, the HSV range will be expanded, and the next search will be focused around the found tarp(s). If no tarps are found, then "canny" edge detection will be used to locate the proper shapes. Using the aforementioned calculation, the needed size of the tarps will be calculated and compared with the masks created from the edge detection. Using those matches the HSV values will be compared to find the proper tarps and then they be labeled as previously described.

4.5.2.1 Tarp Size Approximation

In order to approximate a function relating the tarp size in pixels to the tarps' distance from the camera lens, we took pictures of a known distance (45 ft.) at 50 ft. intervals over a large range (159 ft. to 709 ft.). We then measured the size of the known distance using photo editing software. By analyzing this data (Table 36) and performing a power regression (Figure 13), we were able to closely approximate a function (Equation 1) for the size of the tarp in pixels.

Table 36: Data from tarp size measurement test.

Distance (ft)	**Measured Size** (px)	**Actual Size** (ft)	**Proportion** (px/ft)	**Tarp Size** (ft)	**Tarp Size** (px)
709	166	45	3.70	40	148
659	182	45	4.03	40	161
609	197	45	4.37	40	175
559	214	45	4.76	40	190
509	241	45	5.36	40	214
459	269	45	5.98	40	239
409	293	45	6.52	40	261
359	351	45	7.79	40	312
309	408	45	9.07	40	363
259	487	45	10.81	40	432

Distance (ft)	**Measured Size** (px)	**Actual Size** (ft)	**Proportion** (px/ft)	**Tarp Size** (ft)	**Tarp Size** (px)
209	608	45	13.52	40	541
159	955	45	21.18	40	847

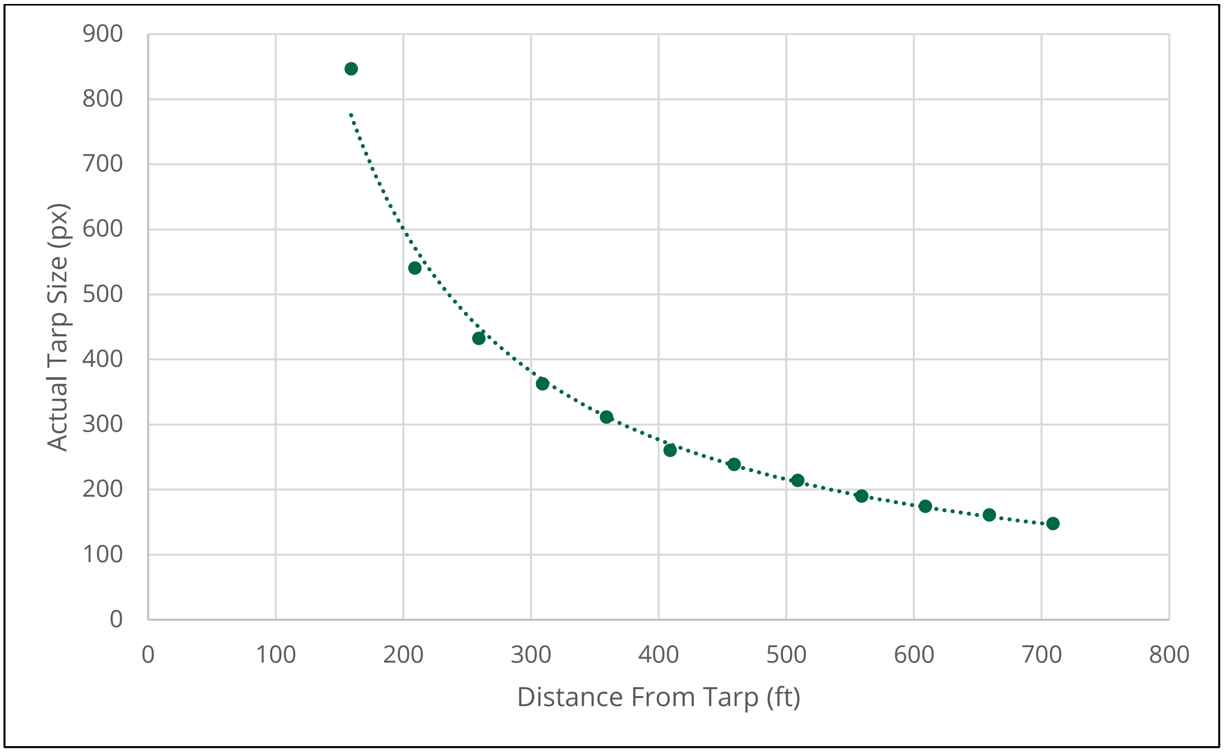


Figure 13: Chart of tarp size data with power regression shown.

$$f(w) = 223208d^{-1.117}$$

Equation 1: Function relating tarp size in pixels (w) to distance from the tarp in feet (d).

4.5.3 Camera Aiming System

The new camera aiming system will take GPS, altitude, compass, and gyroscope data and calculate the necessary pan and tilt values, adjusting the dual-servo system appropriately. This will keep the camera constantly aimed at the location of the tarps, rather than attempting to navigate the module itself to be over the tarps. We predict a much higher chance of success with this design.

An Arduino based microcontroller will be responsible for controlling the camera aiming system on the landing module. Tests have been performed with various microcontrollers to determine whether they have enough RAM and flash memory to run our custom software package. We first tested an Arduino Uno with most of the code for the aiming control system completed and this used 81% of the memory on the Arduino Uno, which could lead to stability issues. Optimizing the code helped reduce the memory usage to 68%, despite that memory reduction we are still unsure how much more memory will be required for the completed software package. Researching other options has led us to choose between the Arduino Zero and the Teensy 3.5 by PJRC. The table below compares the specifications of the microcontrollers in consideration.

Table 37: Comparison of the capabilities of possible microcontrollers.

Microcontroller	**Arduino Uno**	**Arduino Zero**	**Teensy 3.5**
CPU Speed (Mhz)	16	48	120
RAM (kB)	2	32	192
Flash Memory (kB)	32	256	512

Both the Arduino Zero and Teensy 3.5 will greatly outperform the Arduino Uno and are capable of running our software package. The Teensy 3.5 is lighter, smaller, and has substantially better specifications than that of the Arduino Zero. However not 100% of Arduino related accessories and peripherals are compatible with the Teensy 3.5 while they are all compatible with the Arduino Zero. Ideally the Teensy 3.5 will be the microcontroller used for aiming system but compatibility with all other components must be verified first.

Other components that will be incorporated into this system are an Adafruit Ultimate GPS Breakout board, Adafruit 10-DOF IMU Breakout board, and multiple phototransistor light sensors. Upon assembly of the launch vehicle at the launch site the GPS module will acquire a GPS lock as a reference location and will transmit its data to the microcontroller. The microcontroller will have a fixed coordinate destination that it will be attempting to point the camera at during the descent. The Adafruit Ultimate GPS Breakout was selected due to its 10 Hz location update frequency and low current consumption of 20 mA. A GPS update of 10 Hz should be more than sufficient for the steering control system to recalculate the compass heading to the tarps.

Altitude, compass heading, and navigational bearings are three very important measurements for the success of the landing module. The Adafruit 10-DOF IMU Breakout allows us to acquire this data in one low power compact board that also consumes about

20 mA. It is composed of three different sensors, an LSM303DLHC accelerometer and compass, an L3DG20H gyroscope, and a BMP180 barometer / temperature sensor. The Adafruit 10-DOF IMU Breakout connects to the microcontroller via I2C interface, allowing as few wires connected as possible which reduces the chance for errors from loose or improper connections. All 3 sensors provide a 16-bit data output for high resolution of their measurements. Acquiring an accurate altitude throughout the entire flight will be crucial for calculating the camera pitch angle. The BMP180 barometer / temperature sensor has an acceptable 25 cm resolution when calculating the altitude of the landing module. Multiple safety features will be included in the software package to ensure the landing module remains under control and does not cause safety related issues during its flight. The microcontroller will require a minimum altitude reading of 120 ft. AGL in order for the camera to operate.

Phototransistors will be mounted on various locations of the landing module to measure the level of light from its surroundings. These will be used as a start trigger for the landing module to begin its onboard software package. While the landing module is within the rocket body it will be very dark and the phototransistors will measure a very minimal amount of light. Once the landing module is jettisoned from the rocket the sensors will begin to measure light from the outside environment. The phototransistors will have to receive a predefined level of light before the microcontroller initiates the camera control system program. This requirement will serve the purpose of greatly reducing the systems' power consumption while waiting on the launch pad and during the rocket's ascent. When the phototransistors receive the predefined level of light indicating the landing module has been jettisoned, the microcontroller will also send a signal to the Raspberry Pi 3B to begin the vision system software. This also will reduce unnecessary power consumption until the descent of the landing module.

4.5.4 Payload Power Consumption

The majority of the power consumer by the payload electronics will be from the 2 servos. All payload electronics will be powered using a Turnigy 3S 2,200 mAh Li-Poly battery, and step down voltage regulators will be implemented in order to power the electronics properly. An estimated power consumption analysis has been conducted for a majority of the payload electronics. Some values were measured from various test while others are estimated based off datasheets and additional research. The selected LiPo battery is able to provide 24,420 mWh of power for our payload electronics. Based off current measurements and estimates (shown in Table 38 and Equation 2) this battery would be able to provide power to all components for approximately 124 min. This approximation assumes the use of the components listed in the table below.

Table 38: Payload electronics power consumption data.

Part	Voltage (V)	Current (mA)	Power (mW)	Measured or Estimate
Raspberry Pi 3b	5.0	750	3750	Estimate
oCam Camera	5.0	280	1400	Estimate
Atmega328p	5.0	16	80	Estimate
Adafruit Ultimate GPS Breakout	5.0	20	100	Measured
Adafruit 10-DOF IMU Breakout	5.0	20	100	Measured
BMP180 Barometer	5.0	1	5	Estimate
Phototransistor (Quantity 4)	5.0	80	400	Estimate
Hitec RCD HS-5625MG Servo (Quantity 2)	6	1000	6000	Estimate

$$3750 + 1400 + 80 + 100 + 100 + 5 + 400 + 6000 = 11835 \text{ mW}$$

$$\frac{244200\ mW}{11835\ mW} = 2.06337$$

$$60 \text{ min} \times 2.06337 = \mathbf{123.80\ min}$$

Equation 2: Battery life calculations for payload electronics.

$$1000 + 500 + 80 + 100 + 100 + 5 + 200 = 1985 \text{ mW}$$

$$\frac{24{,}420 \text{ mW}}{1{,}985 \text{ mW}} = 12.30227$$

$$1 \text{ hr} \times 12.30227 = \mathbf{12.30\ hr}$$

Equation 3: Battery life calculations for payload electronics in low power mode.

At full load power consumption, the landing module can operate for 124 min. which ensures that the batteries will not drain before the launch is complete. During the time that the landing module is powered on and waiting inside the rocket body it will be in a low power mode waiting for the phototransistors to trigger the start of the vision system and camera aiming system. Estimated calculations (Equation 3) show that in this low power mode the system should only draw approximately 1,985 mW of power. This results in the payload electronics system being able to remain in low power mode for 12.30 hrs.

A programmable low voltage tester will be connected to the LiPo battery at all times to indicate by beeping loudly if the voltage drops below a desired threshold. For added safety the LiPo battery will be contained inside of a fire-retardant safety bag within the landing module to mitigate any hazards if an error were to occur. Two safety switches will be wired in series from the battery to a power distribution board. All components of the payload electronics will then be wired to this power distribution board. Requiring two switches in the 'ON' position before the landing module begins its software package reduces the chance the system wasting power before it is ejected from the rocket body. The switches will be located on the underside of the landing module body for relatively easy access and outside shielding from the four legs. Panel mount slide switches were chosen for their smaller size and usual stiffness which both minimize the chance of the switches accidentally activating.

4.6 Integration

One motion is required for the landing module to properly deploy from the main rocket body at the 1,000 ft. altitude mark on descent. At this altitude, a black powder charge will blow, forcing the landing module to be ejected and allowing the landing gear to spring open. The drogue parachute will eject from the rocket along with the landing module.

4.6.1 Subassembly Interactions

As the landing module slides out from the rocket, the geometric constraints placed on the spring-loaded landing gear are removed, allowing each leg to deploy. The level of deployment, or angle at which the landing gear open to will be set through the use of the aforementioned extension springs.

4.6.2 System Orientation

The structure of the rocket prior to separation is significantly different than after separation. Prior to deployment, the rocket is completely intact. Post-deployment, the rocket is in four stages, one of them being the landing module, which requires its own deployment process. The transition from pre- to post-deployment is described in 4.6.2.1 Pre-Deployment and 4.6.2.2 Post-Deployment.

4.6.2.1 Pre-Deployment

When inside the rocket prior to ejection, the landing module is in its pre-deployed state, as shown in Figure 3. From launch until the rocket reaches an altitude of 1,000 ft. on descent, the landing module is encapsulated inside the rocket body. During this portion of flight, the rocket body imposes geometric constraints on the landing gear to keep the spring-loaded hinges compressed and in a position so that the four legs are in a vertical position taking on the same diameter as the phenolic body of the landing module.

4.6.2.2 Post-Deployment

Once the rocket begins to descend, it will separate into its respective stages, one of them being the landing module. When the landing module is ejected, the geometric constraints are removed and the landing gear deploy to the angle set by the attached extension springs (Figure 4).

4.7 Prototyping

Prototyping was done to determine whether the final system design was achievable and that the team objectives could be met. The prototype was constructed of inexpensive materials to avoid high costs and a long build process. It was made based off of the SolidWorks model shown in Figure 1, using the same dimensions as the final system design. This model was then changed after testing due to the reasons described in 2.2 Landing Module Changes.

4.7.1 Construction

The prototype used for testing was made from a 2 ft. section of phenolic cut by hand using a hacksaw. Two holes were then drilled in the phenolic across its diameter to pass a wooden dowel through, which was of the same length as the designed motor arms. The motors were then mounted to this dowel. One circular bulkhead was then cut to fit over the top of the landing module to mount all of the electronics. This bulkhead was held on by two zip ties that ran through two separate series of holes so that the zip tie ran through the phenolic and then through the bulkhead on each side.

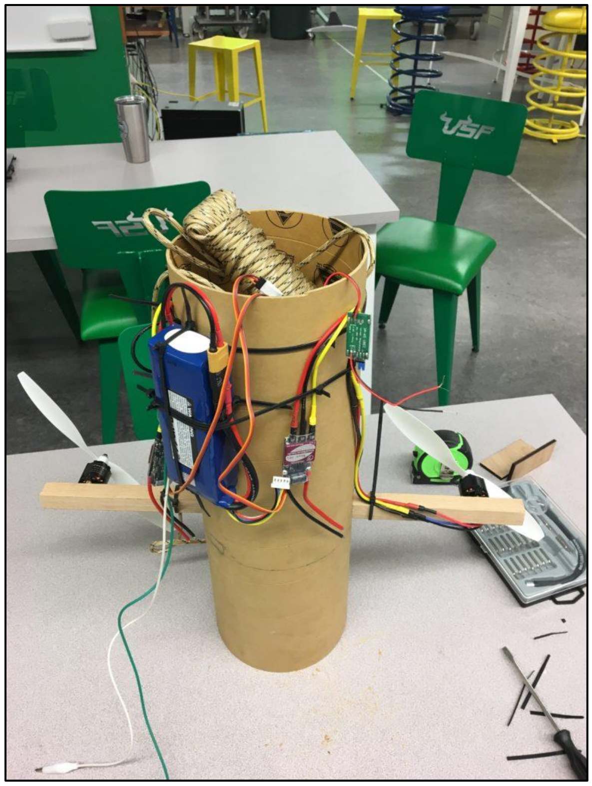


Figure 14: Early landing module prototype.

4.7.2 Testing

Several independent tests were conducted to determine the validity of the design, each of which used the prototype discussed previously. The first test was a static one in which the landing module was hung from a fixture to mimic free fall. Various amounts of spin were induced, and the ability of the motors to counteract this spin to maintain a constant heading was observed. Based on the outcome of each trial, adjustments were made to the motor controllers to achieve better performance. By the end of this series of tests, the motors were able to successfully stabilize the landing module and point it toward a desired compass heading. A video of the initial hanging test is available online at http://www.usfsoar.com/2nd-prototyping-meeting/, and a video of the final successful hanging test is available at http://www.usfsoar.com/2nd-january-build-day/.

With the adjustments made from the first test, the landing module was then prepped to be dropped from an eight-story building to simulate an actual free fall. A parachute was attached to the landing module, which was then dropped in a manner that would allow the parachute to open properly given the limited free fall height. Several additional trials were conducted to further fine tune the camera aiming system.

In conducting the first test, it was deemed that the steering system was capable of performing the tasks that were required of it, but the second free fall test proved otherwise. Dropping the landing module from just eight stories showed that the motors could not generate the thrust necessary to guide the landing module in any sort of wind speed, as it was not capable of handling the upward apparent wind caused by falling rapidly. At this point, several design alterations were made to address these issues, such as the implementation of the camera aiming system described in 4.5.3 Camera Aiming System.

5 Safety

5.1 Safety Checklists

5.1.1 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

5.1.2 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	

5.1.3 Landing Module Pre-Flight Checklist

Table 40: Pre-flight checklist for landing module.

Task	Warning/Caution	Engineering Lead Verification
Make certain that all electrical components are securely fastened to structural members.	Loss of vision system results in mission objective failure.	

Task	Warning/Caution	Engineering Lead Verification
Test all batteries with voltmeter.	Vision system may fail. Mission objective failure.	
Check landing gear wheels for free rotation.	Landing module does not land upright. Failure to meet objective.	
Ensure extension springs are securely fastened to landing gear.	Extension spring detachment would make landing vertical less likely.	
Ensure vision camera operational.	Failure to identify tarp.	
Ensure all electronic equipment is in 'ON' configuration.		

5.1.4 Final Assembly and Launch Procedure Checklist

Table 41: Final assembly and launch checklist.

Task	Warning/Caution	SO Verification
1. Prior to Departure		
Ensure all tools and materials needed for launch are available.		
Ensure all required personnel are present.		
Prepare new batteries for the recovery systems.	Parachutes may fail to deploy. Mission failure.	

Task	Warning/Caution	SO Verification
2. Recovery Preparation		
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.	
Warning: Keep away from flames. **PPE Required**: Eye protection, gloves.		
Measure two portions of 3 g black powder and deposit in each of the CPVC tubes on side of altimeter bay to be inserted into lower airframe.	Ensure black powder is dry. Insufficient charge will result in failure of separation or ejection. Parachutes may fail to deploy. Mission failure.	
Pack insulation tightly on top of black powder and secure with pressure-sensitive tape.	Pack insulation tightly on top of black powder and secure with pressure-sensitive tape.	
Measure two portions of eight grams of black powder and deposit in each of the CPVC tubes on side of altimeter bay to be inserted into upper airframe.	Ensure black powder is dry. Insufficient charge will result in failure of separation or ejection. Parachutes may fail to deploy. Mission failure.	

Task	Warning/Caution	SO Verification
Pack insulation tightly on top of black powder and secure with pressure-sensitive tape.	Ensure insulation is dry. Packing too loosely may result in insufficient force to separate or eject. Parachutes may fail to deploy. Mission failure.	
3. Launch Vehicle Assembly		
Caution: During assembly, ensure that all launch vehicle body sections fit snugly but not tightly. If fit is too tight, sand with fine grit sandpaper until fit is properly adjusted and apply a small amount of graphite powder if necessary.		
Inspect all parachutes for abrasions, rips, tears, or frayed shroud lines.	Parachute may not create enough drag. Launch vehicle section lands with excessive kinetic energy. Damage to launch vehicle.	
3.1. Lower Airframe		
Activate lower airframe GPS tracking system.		
Inspect lower airframe shock cord for damage or fraying.		
Inspect lower airframe shock cord quick link attachment knot and tape for security and condition.		
Inspect quick link for corrosion and clean or replace if necessary.		
Attach quick link to lower		

Task	Warning/Caution	SO Verification
airframe shock cord.		
Fold lower airframe shock cord in Z-type fashion approximately 10 in. in length.		
Insert lower airframe shock cord part way into the lower airframe and attach quick link to drogue parachute swivel.	Ensure parachute remains properly folded during this process.	
Attach quick link to U-bolt on lower airframe side of altimeter bay.		
Close quick link locking gate securely.		
Completely insert lower airframe shock cord into lower airframe.		
Insert the drogue parachute into the lower airframe.	Ensure that Nomex protector completely covers parachute.	
Slide altimeter bay into lower airframe.		
3.2. Upper Airframe		
Activate upper airframe GPS tracking system.		
Inspect upper airframe shock cord for damage or		

Task	Warning/Caution	SO Verification
fraying.		
Inspect upper airframe shock cord quick link attachment knots and tape for security and condition.		
Inspect quick links for corrosion and clean or replace if necessary.		
Attach quick links to both ends of upper airframe shock cord.		
Secure quick link on eyebolt side of piston to U-bolt on upper airframe side of altimeter.		
Close quick link locking gate securely.		
Thread shock cord with piston through bottom of upper airframe and slide upper airframe side of altimeter into the upper airframe, ensuring that alignment indicator marks are lined up.		
Insert machine screws into four designated holes to secure altimeter bay to upper airframe.		
Use shock cord to pull		

Task	Warning/Caution	SO Verification
piston completely through upper airframe and ensure that piston clears the upper airframe by at least 6 in.		
Insert piston partially back into upper airframe.		
Coil shock cord neatly into open end of piston until it is full.		
Fold any remaining shock cord using Z-type fold approximately 6 in. in length.	Ensure quick link is accessible.	
Slide piston into launch vehicle approximately 6 inches.		
Secure quick link to swivel of main (XL) parachute.		
Close quick link locking gate securely.		
Slide piston and main parachute into upper body airframe until parachute is flush with opening.	Ensure parachute remains properly folded and shroud lines are unencumbered. Ensure Nomex protector completely covers parachute.	
3.3. Landing Module		
Activate landing module GPS tracking system.		

Task	Warning/Caution	SO Verification
Perform Landing Module Pre-Flight Checklist.	See Table 40.	
Inspect quick link for corrosion and clean or replace if necessary.		
Attach quick link to U-bolt on landing module.		
Attach quick link to swivel of landing module (large) parachute.		
Close quick link locking gate securely.		
Dust landing module with light coating of graphite powder.		
Slide the landing system and into the airframe.		
Slide landing module parachute into upper airframe.	Ensure all fittings are snug but not tight. Ensure landing module, main parachute, and piston are securely seated against each other and against altimeter bay.	
3.4. Nose Cone		
Activate nose cone GPS tracking system.		
Inspect quick link for		

Task	Warning/Caution	SO Verification
corrosion and clean or replace if necessary.		
Attach quick link to U-bolt on nose cone.		
Attach quick link to swivel of nose cone (large) parachute		
Close quick link locking gate securely.		
Slide the nose cone parachute into the upper airframe.	Ensure parachute remains properly folded and shroud lines are unencumbered. Ensure Nomex protector completely covers parachute to prevent entanglement with landing module parachute. Ensure shear pin holes are aligned.	
Properly fold all parachutes.	See parachute folding instructions below.	
4. Motor Preparation		
Warning: Keep away from flames. Inspect motor for cracks and voids. Refer to MSDS for white lithium grease. **PPE Required**: Eye protection, gloves.		
Assemble the motor in accordance with manufacturer's instructions below.		

Task	Warning/Caution	SO Verification
Install 75 mm motor adapter rings approximately 4 in. from each end of motor casing.	Ensure rings are tightly secured.	
Insert completed motor assembly into the lower airframe.		
Place motor adapter insert over end of motor retainer receiver.		
Securely screw on motor retainer ring.		
5. Launch Procedure		
Have the launch vehicle inspected by the RSO		
Be sure power is turned off from launch control.	Motor may ignite prematurely causing critical injury to personnel and equipment damage.	
Inspect launch pad and rail for debris, corrosion, and stability.	Adjust as necessary. Lubricate as necessary.	
Place the launch vehicle on the rail.	Test launch vehicle on launch rail for resistance or friction. Adjust as necessary. Lubricate as necessary.	
Turn on altimeters and get 3 distinct beeps	Parachutes may fail to deploy. Mission failure.	

Task	Warning/Caution	SO Verification
6. Igniter Installation		
Insert ignitor into the launch vehicle	Ensure that the igniter is inserted up the motor until it reaches a dead-end and then pull back about 1-2 in. Failed or delayed ignition possible.	
Use the manufacturer cap to secure the e-match cord to the motor retainer.	Conduct final check to ensure security of e-match.	
Ensure igniter wires attached to power source.		
Arrange wires carefully to ensure continued attachment to igniter throughout launch sequence.		
7. Launch Sequence		
Ensure ignitor power switch is on at launch control.		
8. Post Launch Procedure		
Monitor drift and locate launch vehicle after flight.	Ensure launch vehicle is recovered in a timely manner.	
Measure drift from launch pad.		

Task	Warning/Caution	SO Verification
Recover launch vehicle, determine altitude, and deactivate altimeters		
Deactivate all electronics.		

Table 42: Final assembly and launch troubleshooting issues and solutions.

Troubleshooting	
Issue	**Solution**
Launch vehicle sections fit too tightly into launch vehicle body.	Lightly sand launch vehicle sections. Apply small amount of white lithium grease.
Batteries not fully charged.	Replace or recharge batteries as necessary.
Excessive friction between launch vehicle and launch rail.	Check launch lugs for damage. Inspect launch rail for debris.
Igniter does not fire.	Check for security of igniter and is in contact with motor.

5.1.5 Post-Flight Inspection Checklist

Table 43: Post-flight inspection checklist.

Post Flight Inspection	
Task	**SO Verification**
Listen to record altimeter for apogee altitude.	
Inspect fins for damage and security.	

Post Flight Inspection	
Task	**SO Verification**
Inspect rocket body for dents, cracks, or missing parts.	
Inspect parachutes for holes and parachutes cords for abrasions or tears.	
Inspect shock cords for abrasion or tearing.	
Check batteries with voltmeter.	
Clean all components of debris and carbon residue.	
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.	

5.1.6 Parachute Folding Instructions

Table 44: Parachute folding instructions and figures.

Instructions	Figure
1. Lay parachute out neatly on the long axis and pull taut.	
2. Inspect parachute for rips, tears, or abrasions.	
3. Arrange the canopy so it lays flat on the floor. Then line up suspension line seams of parachute and stack neatly lengthwise.	
4. Compress parachute to ensure air pockets are removed.	
5. Fold along the long axis using Z-type fold of approximately 6 in. width, beginning with the side opposite the suspension line seams.	
6. Compress parachute to ensure air pockets are removed.	

Instructions	Figure
7. Fold along the length of the parachute using Z-type fold of approximately the below lengths, depending on the parachute size, beginning with the top of the parachute. XL – 8 in. to 10 in. Large – 6 in. to 8 in. Drogue – 6 in. or less	
8. Continue folding in this fashion up to the point where the shroud lines connect to the parachute.	
9. Ensure shroud lines are untangled. Pull the shroud lines taut while maintaining the parachute fully folded.	
10. Fold the shroud lines, using Z-type fold on top of the folded parachute until only about 4 to 6 in. remain extended beyond the folded parachute.	
11. Attach appropriately sized Nomex protector to end of shroud line near swivel. Wrap electrical tape around shroud line above Nomex protector to ensure Nomex protector does not slip during flight or ejection.	
12. When inserting the parachute into the respective launch vehicle section, roll the folded parachute slightly upward around the shroud lines to ensure security.	

5.1.7 Motor Assembly Instructions

Pro75® High-Power Reloadable Rocket Motor Systems

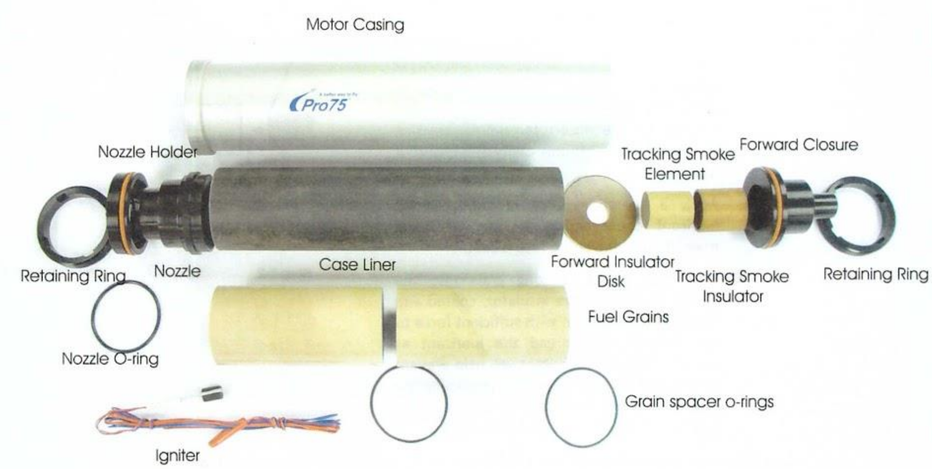
<u>**FOR USE ONLY BY CERTIFIED HIGH-POWER ROCKETRY USERS 18 YEARS OF AGE OR OLDER**</u>

FLAMMABLE MATERIAL – KEEP AWAY FROM OPEN FLAME, CIGARETTES OR OTHER HEAT SOURCES AT ALL TIMES

USE WITHIN 1 YEAR OF MANUFACTURING DATE **TEMPERATURE RANGE: -5 to 30°C**

<u>**Read this BEFORE you start assembly:**</u>

- If you have any questions or require assistance, please contact your dealer. If you are unable to resolve your questions or problems then please contact the manufacturer directly. Assistance is available Mon – Fri. 9am – 4:30pm at (905) 887-2370. Ask for ProXX motor products technical support.
- Read all instructions carefully and be sure you fully understand each step before proceeding with motor assembly.
- **Make sure to also read the Pro75 Product Notes for reload specific instructions. Your reload may require bonding of grains into the case liner. For moonburner reloads there are also separate moonburner instructions for gluing the grains.**
- Inspect the components of your reload kit carefully before you start assembly. DO NOT use any parts that appear damaged or faulty in any way.
- Do not tamper with or modify the hardware or reload kit components in any way. Not only will this void all product warranty, it could cause catastrophic failure of your motor system and result in damage to your rocket vehicle, launch equipment and create a hazard to persons or property.
- Reload kit components are designed for ONE USE ONLY, and may not be reused. Reuse of any of these components could result in motor failure and will void product warranty.
- Follow the safety code and all rules and regulations of your sport rocketry association. Also ensure that you are in compliance with all local, state/provincial, and Federal laws in all activities involving high power rockets and rocket motors.
- Parts checklist:



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Pro75® hardware components (if used):

- ✓ Appropriate size of motor case
- ✓ Forward closure
- ✓ Nozzle holder
- ✓ Threaded retaining rings (2)

Reload kit components:

- ✓ Case liner (phenolic tube)
- ✓ Nozzle
- ✓ Forward insulator disk
- ✓ P75-ORK (o-ring kit)
- ✓ P75-TSI-KIT (smoke tracking grain/insulator & igniter kit)
- ✓ Propellant grains (check reload kit package for number and type required for your motor)

Assembly instructions

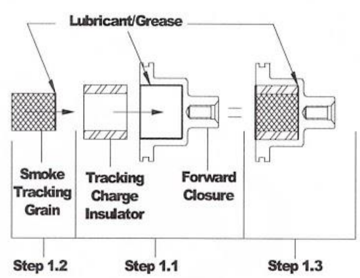
- Be sure to follow the correct instructions for the brand of motor hardware you are using!
- Step 1 is the same for both brands of hardware.
- All o-rings are pre-lubricated at the factory where required.
- Three o-rings are supplied in the P75-ORK o-ring kits. The two larger o-rings are used with both Pro75® and RMS™ hardware. The smaller o-ring is only used with Pro75® hardware.
- Do not apply lubricant to the grain spacer o-rings, they are for spacing only.
- Phenolic and phenolic/paper components such as the nozzle and case liner tube are brittle and can be cracked, broken or otherwise damaged by excessive force or impact. Please be careful during handling and assembly. If you suspect a part has been damaged in any way, STOP and do not proceed with assembly and especially firing until inspected and replaced if necessary.

1. Forward Closure Assembly

1.1. Apply a light coating of o-ring lubricant or grease to the inside of the cavity in the forward closure. Insert the smoke tracking charge insulator into this cavity and ensure it is seated fully.

1.2. Apply a liberal layer of grease or o-ring lubricant to one end of the smoke tracking grain. Be sure the entire face is coated.

1.3. Insert the smoke tracking grain into the smoke tracking charge insulator, coated end first. Push the grain in with sufficient force to fully seat it and spread the lubricant as shown. The excess lubricant will help prevent gas leakage forward as well as protecting the forward closure from heat and combustion products from the smoke tracking charge.



You may now proceed to the remainder of the instructions for your brand of motor hardware.

Step 2 is for Pro75® hardware users.

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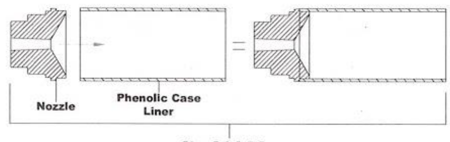
Step 3 is for RMS™ hardware users.

2. Motor Assembly: Pro75® Hardware.

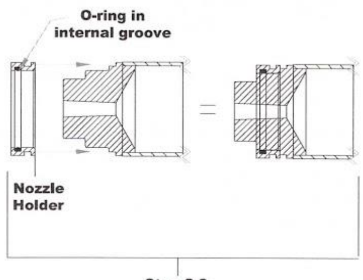
Before proceeding, inspect the external o-ring grooves on the forward closure and nozzle holder, as well as the internal groove on the nozzle holder. Clean thoroughly if necessary to remove ALL combustion residue and debris. Also ensure that the inside of the motor case has been thoroughly cleaned.

2.1. Check both ends of the phenolic case liner to ensure that the inside ends have been chamfered or deburred. If not, use a hobby knife or coarse sandpaper to remove the sharp inner edge to allow components to be inserted easily.



Step 2.1 & 2.2

2.2. Fit the nozzle to one end of the paper/phenolic case liner tube. It may be a snug fit. Push it carefully but with sufficient force to seat the shoulder on the nozzle all the way into the insulator tube.

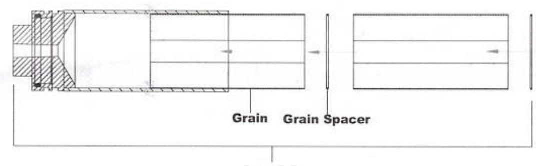


Step 2.3

2.3. Locate the smaller o-ring in the P75-ORK o-ring kit. Fit the o-ring to the internal groove of the nozzle holder. Push the nozzle holder over the nozzle until fully seated. Apply additional lubricant to the nozzle exit section if necessary to facilitate assembly.

2.4. For steps 2.5 – 2.6 work with the nozzle/case liner assembly and motor case horizontally on your work surface.

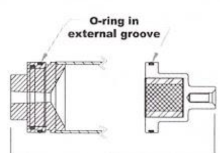
2.5. Insert one propellant grain into the forward end of the case liner and push it a short way into the tube. Fit one grain spacer o-ring to the top face of the grain, ensuring it sits flat on the end of the grain. Insert the second grain, push it in a short ways, then add another grain spacer, and so on until you have loaded all propellant grains into the case liner.



Step 2.5

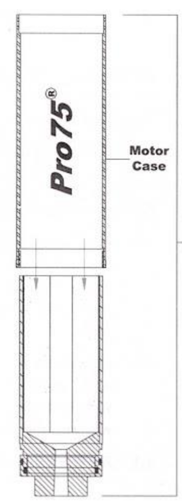
2.5.1. There should be sufficient space after the last grain is inserted to fit the last spacer in place so that it is flush or extends only slightly from the end of the tube. If it extends out by more than 1/3 of its own thickness, remove it and do not use. Only this spacer may be omitted and only if necessary to fit.

2.6. Carefully install the two larger o-rings into the external grooves of the nozzle holder and forward closure. Handle these components with care from this point on so as not to damage or contaminate the o-rings.



Step 2.6

2.7. Place the case liner/nozzle assembly on your work surface with the nozzle end down, and slide the motor case down rear end first (end with thrust ring) over the top of the liner towards the nozzle. **Note:** a light coat of grease on the liner exterior will aid assembly, disassembly and cleanup!



Step 2.7

2.8. Lay the motor case assembly down horizontally, and push on the nozzle ring until the assembly is far enough inside the case that the threads are partly exposed and the screw ring can be threaded into the rear of the case. Don't push on the nozzle itself as you will push it out of the nozzle holder.

2.9. Screw in the nozzle retaining ring using the supplied wrench, pushing the nozzle/nozzle ring/case liner assembly forward as you proceed. Screw it in *only until the retaining ring is*

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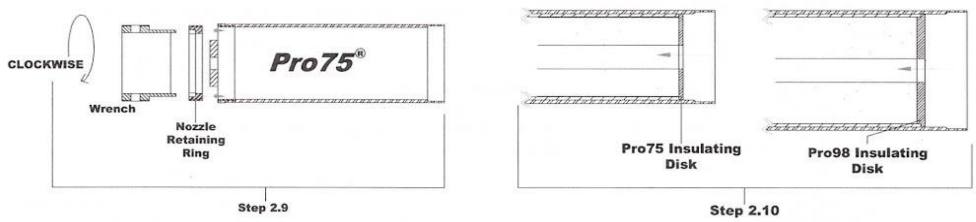
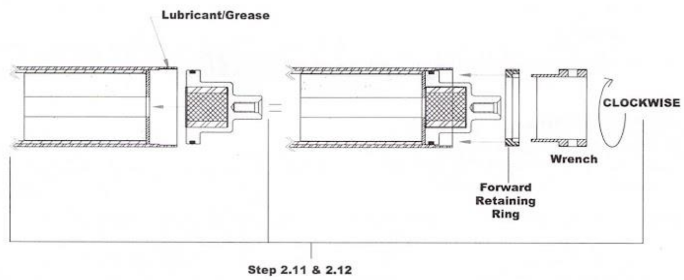
exactly even with the end of the motor case - do not thread it in as far as it will go. Then, back the retaining ring out one half of a turn.

2.10. Fit the forward insulating disk to the top of the case liner, checking that the top grain spacer (if used) is still properly in place.



2.11. Verify that the inside of the motor case is clean ahead of the liner assembly before proceeding. Wipe with a clean rag, tissue or wet-wipe if required. Apply a light coat of silicone o-ring lubricant onto this area after cleaning.

2.12. Insert the assembled forward closure into the top of the motor case, pushing it down carefully with your fingers until you can thread in the retaining ring. Thread in the forward retaining ring using the wrench, until you feel it take up a load against the top of the case liner. At this point the ring should be approximately flush with the end of the motor case, or slightly submerged. If it extends out the case at this point by more than about one half a turn, check the nozzle end to make sure the ring is not screwed in too far forward. If so, unscrew the nozzle retaining ring another half turn and screw the forward closure retainer in further.



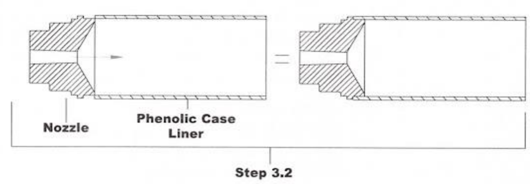
NOTE: it is best to have the forward closure retaining ring flush or slightly submerged and the nozzle retaining ring protruding by a half turn or so, than vice versa. There is more tolerance for o-ring location at the nozzle end. There will always be some minor variation in the length of internal components due to manufacturing tolerances.

2.13. Skip ahead to Section 4, Preflight preparation.

3. **Motor Assembly, RMS™ Hardware.**

3.1. Check both ends of the phenolic case liner to ensure that the inside ends have been chamfered or deburred. If not, use a hobby knife or coarse sandpaper to remove the sharp inner edge to allow components to be inserted easily.

3.2. Fit the nozzle to one end of the paper/phenolic case liner tube. It may be a snug fit. Push it carefully but with sufficient force to seat the shoulder on the nozzle all the way into the insulator tube.



3.3. For steps 3.4 – 3.8 work with the nozzle/case liner assembly and motor case horizontally on your work surface.

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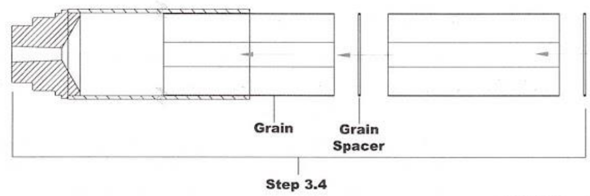
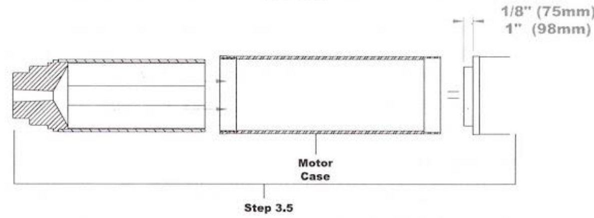
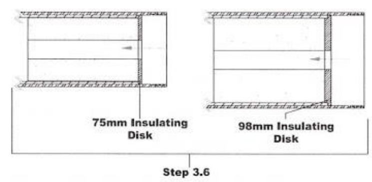
3.4. Insert one propellant grain into the forward end of the case liner and push it a short way into the tube. Fit one grain spacer o-ring to the top face of the grain, ensuring it sits flat on the end of the grain. Insert the second grain, push it in a short ways, then add another grain spacer, and so on until you have loaded all propellant grains into the case liner.



3.4.1. There should be sufficient space after the last grain is inserted to fit the last spacer in place so that it is flush or extends only slightly from the end of the tube. If it extends out by more than 1/3 of its own thickness, remove it and do not use. Only this spacer may be omitted and only if necessary to fit.



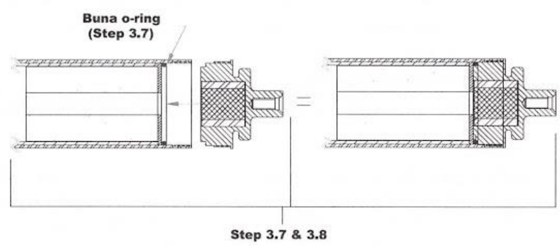
3.5. Slide the completed liner/nozzle/grain assembly into the motor case until the nozzle protrudes about 1/8" from the end of the case. **Note:** a light coat of grease on the liner exterior will aid assembly, disassembly and cleanup!



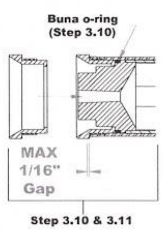
3.6. Fit the forward insulating disk to the top of the case liner, checking that the top grain spacer (if used) is still properly in place.

3.7. Place one of the larger pre-lubricated o-rings from the P75-ORK kit into the forward end of the case until it is seated against the forward insulator.

3.8. Thread the completed forward closure into the forward end of the motor case by hand until it is seated against the case. NOTE: There will be considerable resistance to threading in the closure in the last 1/8" to 3/16" of travel, due to compression of the o-ring.



3.9. Hold the motor vertically on your work surface with the forward closure downwards, and push down on the nozzle to ensure the liner/nozzle assembly is seated fully forward.



3.10. Place the other identical o-ring into the groove in the nozzle.

3.11. Thread the aft closure into the motor case until it is seated. It is normal for a small gap (up to about 1/16") to remain between the closure and the end of the case, due to manufacturing tolerances on internal components. Note: There will be considerable resistance to threading in the closure in the last 1/8" to 3/16" of travel, due to compression of the o-ring.

3.12. Proceed to Section 4, Preflight preparation.

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4. **Preflight Preparation.**

4.1. Prepare the rocket's recovery system, before motor installation if possible.

4.2. Install the motor in your rocket, ensuring that it is securely mounted with a positive means of retention to prevent it from being ejected during any phase of the rocket's flight.

4.3. IMPORTANT: **DO NOT INSTALL THE IGNITER IN THE MOTOR UNTIL YOU HAVE THE ROCKET ON THE LAUNCH PAD, OR IN A SAFE AREA DESIGNATED BY THE RANGE SAFETY OFFICER**. Follow all rules and regulations of your rocketry association, and/or the National Fire Protection Association (NFPA) Code 1127 where applicable.

4.4. Install the supplied igniter, ensuring that it travels forward until it is in contact with the forward closure. Securely retain the igniter to the motor nozzle with tape, or (if supplied) the plastic cap, routing the wires through one of the vent holes. Ensure that whatever means you use provides a vent for igniter gases to prevent premature igniter ejection.

4.5. Launch the rocket in accordance with all Federal, State/Provincial, and municipal laws as well as the Safety Code of your rocketry association, as well as NFPA Code 1127 where applicable.

5. **Post Flight Cleanup.**

Do not try to dismount or disassemble your motor until it has thoroughly cooled down after firing. Some components such as the nozzle may be extremely hot for some time after firing.

Perform motor cleanup as soon as possible after firing, however, as combustion residues are corrosive to motor components, and become very difficult to remove after several hours.

5.1. Unthread and remove the forward and rear closures. Remove the nozzle holder from the nozzle.

5.2. Remove the phenolic tracking smoke charge insulator from the forward closure.

5.3. Remove all o-rings.

5.4. Discard all reload kit components with regular household waste, after they have completely cooled down.

5.5. Use wet wipes, or paper towels or rags dampened with water or vinegar to thoroughly clean all residue, grease etc. off all hardware components. Pay close attention to internal and external o-ring grooves. A cotton swab or small stick of balsa is an excellent tool for cleaning these grooves.

5.6. Apply a light coat of grease or o-ring lubricant to all threaded sections and reassemble threaded components for storage.

MEANS OF DISPOSAL: The propellant grains, smoke tracking charge, and the igniter are extremely flammable and burn with an intense, hot flame. The remainder of the components are inert and may be disposed of with household trash. To destroy the flammable components, dig a shallow hole in the ground in a remote area, away from any buildings, trees, people, or any other combustibles. Place the propellant grains and smoke tracking module in the hole. Install the igniter into the core of one of the propellant grains and secure with tape. Ignite electrically from a minimum distance of 15 meters. Douse any smoldering paper residue and discard. Ensure that you are not in violation of any local or state regulations for this procedure. If in doubt, contact your local fire department. Please direct any questions regarding safe disposal to our technical support number on page one of this document.

First Aid: If ingested, induce vomiting. Burns from flames are to be treated as regular burns with normal first aid procedures. In either case, seek medical attention.

⇒ Check out our web site at http://www.Pro-X.ca for tech tips, FAQ's, user feedback and photos, or e-mail us at ProX@cesaroni.net

⇒ For technical and warranty inquiries, please contact your Pro75® dealer.

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Pro75® Product Notes

Special instructions (supplements standard Pro75® instruction sheets)

Scope

These notes supplement the standard Pro75® instructions for the following motors: K2000, L995, L1355, L1685, L3200, M1300, M1545, M1675, M2020, M2075, M2080, M2245, M2250, M3100, M3700

This note also explains the proper use of the Pro75® casing spacer.

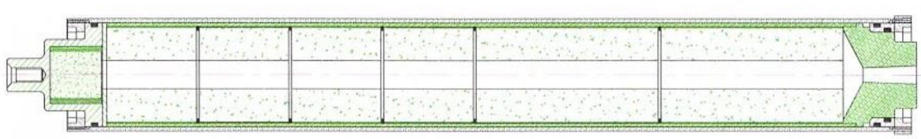
Pro75® motors using 'half' grains: L995, L1355, L1685, M2075

The L995, L1355 and L1685 Pro75® motors use 'half' grains. These grains are half-length of the regular grain length of Pro75® motors. The purpose of these grains is to improve the shape of the thrust curve and maximize the thrust at lift-off. Two 'half' grains with two spacer o-rings (stacked alternately) occupy the same length inside the motor as a single normal grain with its o-ring spacer.

When assembling motors with 'half' grains ensure that the short grains are loaded closest to the forward closure of the motor. All regular grains will be at the nozzle end. As with the regular grains, an o-ring spacer is placed between each grain.

The table below summarizes the number of regular and 'half' grains in the affected Pro75® motors:

L995: 2 regular grains, 2 'half' grains
L1355: 2 regular grains, 4 'half' grains
L1685: 2 regular grains, 6 'half' grains
M2075: 3 regular grains, 6 'half' grains

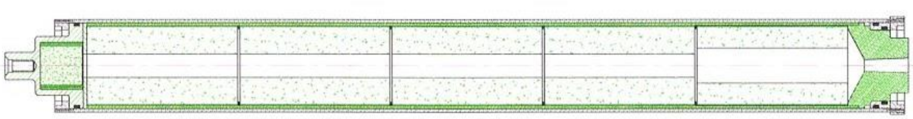


Assembled Pro75®-4G motor with four 'half' grains.

Pro75® motors with stepped grains: M1300 Dual Thrust™ and M2250 C-Star

Dual Thrust™ motors use two different propellant types: a fast burning single grain that creates the extra boost at lift-off and slower burning grains that burn during the sustain phase. The fast burning propellant grain can be recognized by its red color and large port diameter. The M2250 C-Star motor has the same propellant formulation for all grains, but uses a bottom (base) grain with a larger bore.

When assembling motors with a stepped core, ensure that the base grain (with the larger center perforation – bore) is located at the nozzle end of the motor. It is required to bond the grains in the liner (see instructions in next section).



Assembled Pro75®-5G Dual Thrust™ motor.

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Pro75® motors requiring grain bonding:

K2000, L3200, M1300, M1545, M1675, M2020, M2080, M2245, M2250, M3100, M3700

The following motors require bonding of the grains in the liner: K2000/L3200 Vmax™, M1300 Imax™ Dual Thrust, M2250 C-Star™, M3100/M3700 White Thunder™, M2020/M2245 Imax™, M2080 Skidmark™, M1545 Green[3]™, and M1675 Pink™. Bonding the grains in the liner prevents premature blowout of the grains under high acceleration loads or by high core mass flows. **DO NOT USE EPOXY FOR BONDING.**

The process for this is as follows:

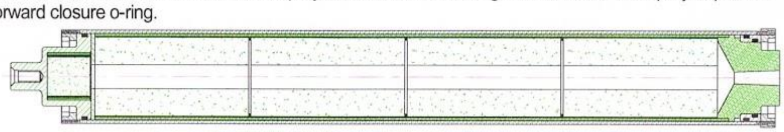
1. The preferred adhesive is Gorilla Polyurethane Glue or Elmer's Glue-All Max (not the white Glue Max!). A 2-oz bottle (e.g. Lowes SKU #: 152243, or Home Depot SKU # 837667) is sufficient for all Pro75 motors.
2. Apply adhesive on the outside (paper liner) of the first grain and use a small brush to spread it evenly. Ensure no adhesive is applied on the grain faces or bore of the propellant.
3. Push the grain in the liner **from the nozzle end** while twisting it. Twisting the grain while inserting it will properly distribute the adhesive. Push it about 1" into the liner.
4. Install a grain spacer o-ring.
5. Repeat steps 2-4 for all grains. Excess adhesive might be scraped off around the end of the liner. This can simply be wiped off.
6. Do not install a spacer o-ring between the bottom grain and the nozzle.
7. Re-install the nozzle and wipe off any excess adhesive.
8. Set the liner/grain assembly upright with the nozzle facing down.
9. Push the top grain down gently through the hole in the forward insulator plate.
10. Let the liner/grain assembly cure in an upright position
11. Continue with the regular assembly process as outlined in the instructions.

Notes:

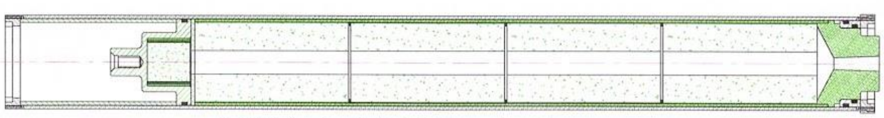
1. Do not insert the bottom grain from the forward closure end of the liner. Most adhesive will have been scraped off when the grain is pushed through all the way and it reaches the end of the liner.
2. For the Pink™ M1675 reload the red grain should be located at the nozzle end. (All other motors use identical grains.)
3. The M2245 Imax™ and M3700 White Thunder™ motor have four (4) longer grains and are bonded like any of the other motors listed above.

Pro75® casing spacers

Pro75® casing spacers allow the use of a reload kit intended for a smaller casing size to be used in the next casing size up. For example, a 3-grain reload kit can be used in a 4-grain casing.[i] When assembling a Pro75® motor with a casing spacer, follow the regular instructions provided with the reload kit, and install the casing spacer between the forward closure and forward closure retaining ring as shown in the example below. Do not slide the forward closure all the way from the nozzle end. It is recommended to spray the inside of the casing with some silicone spray to prevent rolling of the forward closure o-ring.



Pro75®-4G reload in Pro75®-4G casing.



Pro75®-4G reload in Pro75®-5G casing using case spacer.

[i] A 6GXL case can be spaced to a 6G case with a regular spacer. Up to two spacers can be used.

Source: *Pro38.com Pro75 instructions*.

5.2 Safety Officer Responsibilities and Duties

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:

- Ensure all team members have read and understand the NAR and TRA safety regulations
- 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.
- Compile a binder that will have all safety related documents and other manuals about the launch vehicle.
- Ensure compliance with all local, state, and federal laws.
- Oversee the testing of all related subsystems.
- Ensure proper purchase, transportation, and handling of launch vehicle components.
- Identify and mitigate any possible safety violations.
- Become at least Level 1 certified with Tripoli Rocket Association (TRA) to ensure the individual knows the process of building a rocket.

5.3 Hazard Analysis

5.3.1 Hazard Categories

5.3.1.1 Controls Risk Assessment

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

5.3.1.2 Hazards to Environment Risk Assessment

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

5.3.1.3 Logistics Risk Assessment

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

5.3.1.4 Launch Pad Functionality Risk Assessment

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

5.3.1.5 Payload Capture Device Risk Assessment

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

5.3.1.6 Recovery Risk Assessment

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

5.3.1.7 Shop Risk Assessment

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

5.3.1.8 Stability and Propulsion Risk Assessment

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

5.3.1.9 Vision

The hazards included in this category are associated with the vision system of the landing module.

5.3.2 Risk Level Definitions

5.3.2.1 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 in Table 45.

Table 45: Risk severity levels and definitions.

Description	Personnel Safety and Health	Facility / Equipment	Range Safety	Project Plan	Environ-mental
– 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 environment al 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 environment al 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 environment al damage without violation of law or regulations where restoration activities can be accomplishe d.

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

5.3.2.2 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 46 depicts the levels of probability for each risk.

Table 46: Risk probability levels and definitions.

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

5.3.2.3 Risk Assessment Levels

Each risk is finally assigned a risk level based upon a combination of the risk's severity and probability (as shown in Table 47). These levels range from high (red) to minimal (white) and are defined in Table 48.

Table 47: Overall risk assessment level assignment criteria.

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

Table 48: Overall risk assessment levels and definitions.

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

5.3.3 Hazard Analysis Matrix

Table 49: Hazard/risk analysis for the launch vehicle and landing module.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Controls	Igniter safety switch fails to activate.	Mechanical failure in switch. Communicatio n 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 (Table 41).
Controls	Igniter safety switch active at power up.	Switch stuck/left in enabled position. Communicatio n 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 (Table 41).

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 taken in accordance with the MSDS sheets and any EHS standards.	2E	MSDS sheets will be kept on hand in the shop and at the launch field.
Environmental	Spray painting.	The rocket will be painted.	Water contamination. Emissions to environment.	3D	All spray painting operations will be performed in a paint booth by trained individuals. This prevents any overspray from entering into the water system or the air.	3E	Paint booth will be marked with appropriate signage for hazardous material. Training will be documented for designated individuals.

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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Logistic	Not enough time for adequate testing.	Failure to create a precise timeline.	Imprecision in the launch vehicle design and less verification of design.	3C	Create a rigorous timeline and ensure everyone stays on schedule. Make due dates at least three days in advance for deliverables. Use shared calendar to keep all personnel apprised of deadlines. A more detailed schedule was created to make sure the team remains on track. Each task has a description and expected deliverables. Full-scale completion date moved earlier in the schedule to allow more testing.	3E	Subscale and full-scale testing completed on schedule, including ground testing of separation charges. Time remains for second full-scale test launch.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Logistic	Parts ordered late or delayed in shipping.	Long shipping times and delays, failure to order parts in timely fashion.	Project schedule delayed. Selected functions unavailable.	2C	Shared calendar will be used to keep all personnel apprised of deadlines. Reminder notifications will be sent to technical leads well in advance of deadlines. When possible, suitable substitute parts will be maintained on hand. Finance managers will be recruited and trained.	2E	Full-scale launch vehicle completed according to schedule. Minimal delays due to parts ordering.
Logistic	Parts fail or break.	Normal wear and tear. Improper installation. Improper handling.	Project delay. Damage to launch vehicle.	2C	When practicable, maintain suitable replacement parts on hand.	2E	Use checklist when assembling launch vehicle. Ensure technical lead supervision in handling of parts.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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 (Table 41) 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 (Table 41) when placing launch vehicle on launch rail.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Pad	Rocket gets caught in launch tower or experiences high friction forces.	Misalignment of launch tower joints. Deflection of launch platform rails. Friction between guide rails and rocket.	Rocket may not exit the launch tower with a sufficient exit velocity or may be damaged on exit.	2E	During setup, the launch tower will be inspected for a good fit to the rocket. The launch vehicle will be tested on the launch rail. If any resistance is noted, adjustments will be made to the launch tower, allowing the rocket to freely move through the tower.	2E	Use the Launch Procedure checklist (Table 41) when placing launch vehicle on launch rail.
Pad	Sharp edges on the launch pad.	Manufacturing processes.	Minor cuts or scrapes to personnel working with, around, and transporting the launch tower.	3D	Sharp edges of the launch pad will be filed down and de-burred if possible. If not possible, personnel working with launch tower will be notified of hazards.	4E	Use the Launch Procedure checklist (Table 41) when placing launch vehicle on launch rail.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Pad	Pivot point bearings seize.	Load is larger than specifications. Debris enters bearings.	Launch platform will experience higher resistance to motion causing a potential hindrance the vehicle raising.	2D	Bearings will be sized based on expected loads with a minimum factor of safety. The launch platform will be cleaned following each launch and will be cleaned prior to each launch. Proper lubrication will be applied to any point expected to receive friction.	2E	Use the Launch Procedure checklist (Table 41) when placing launch vehicle on launch rail.
Payload	Altimeter failure.	Failure in electronics. Failure in programming. Battery failure.	Parachutes will fail to deploy. Sections will fail to separate. No data collection. Damage to the launch vehicle.	2D	Altimeter programming will be tested several days before flight. Two altimeters will be used to provide redundancy. Fresh batteries will be installed just prior to launch in accordance with launch procedure checklist. Altimeters will be checked via audible beeps just prior to launch.	2E	Altimeters functional during full-scale test launch. Use recovery preparation checklist (Table 41) when preparing launch vehicle.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Payload	Failure of onboard electronics (altimeters, tracking devices, etc.)	Generation of electromagnetic field from onboard devices. Battery failure.	Parachute deployment failure. Sections fail to separate. No data collection. Damage to the launch vehicle.	1D	No devices that generate a significant electromagnetic field will be used.	4E	Devices detailed in FRR sections 3.3.3 Electrical Components & Redundancies, and 4.5 Payload Electronics.
Payload	GPS tracking malfunction.	Low battery. Signal interference at ground station.	Failure to recover launch vehicle. Failure to complete mission.	1D	GPS batteries will be charged the night before launch. The tracking system will be tested on full-scale flight.	3E	Use Prior to Departure checklist (Table 41) when departing for launch field.
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 (Table 41) and Parachute Folding (Table 44) checklists when assembling launch vehicle.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Recovery	Sections fail to separate at apogee or at 500 feet.	Black powder charges fail or are inadequate. Shear pins stick. Launcher mechanics obstruct separation.	Parachute deployment failure. Sections fail to separate. Damage to the launch vehicle.	2D	Correct amount of black powder needed for each blast charge will be calculated. Black powder will be measured using scale. Altimeter and electronics check will be conducted with checklist several hours prior to launch. Inside of rocket body will be coated with graphite powder in areas of launcher mechanics. Couplings between components will be sanded to prevent components from sticking together. Fittings will be tested prior to launch to ensure that no components are sticking together. In the event that the rocket does become ballistic, all individuals at the launch field will be notified immediately.	2E	Ground and launch tests verified that the amount of black powder is adequate. In full-scale test launch, all sections successfully separated at designated altitudes, including nose cone with shear pins. Use Launch Vehicle Assembly checklist (Table 41) 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.

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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Recovery	Rocket descends too slowly.	Parachute is improperly sized.	The rocket will drift farther than intended, potentially facing damaging environmental obstacles.	3E	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Extensive ground testing was performed to verify the coefficient of drag is approximately that which was used during analysis.	3E	The website http://descentratecalculator.onlinetesting.net/ was used to calculate theoretical descent values. Full-scale testing resulted in no damage to rocket components.
Recovery	Parachute has a tear or ripped seam.	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2E	Through careful inspection prior to packing each parachute, this failure mode will be eliminated. One spare large parachute will be on hand. 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	Use Launch Vehicle Assembly (Table 41) and Parachute Folding (Table 44) checklists when assembling launch vehicle.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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 (Table 41: Final assembly and launch checklist.Table 41 and Parachute Folding checklists when assembling launch vehicle.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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 (Table 41) and Parachute Folding (Table 44) checklists when assembling launch vehicle.
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	

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Shop	Sanding or grinding materials.	Improper use of PPE. Improper training on the use of equipment.	Mild to severe rash. Irritated eyes, nose or throat with the potential to aggravate asthma. Mild to severe cuts or burns from a Dremel tool and sanding wheel.	2C	Long sleeves will be worn at all times when sanding or grinding materials. Proper PPE will be utilized such as safety glasses and dust masks with the appropriate filtration required. Individuals will be trained on the tool being used. Those not trained will not attempt to learn on their own and will find a trained individual to instruct them.	4E	Training will be 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 ot inhalation.	2C	MSDS documents will be readily available at all times and will be thoroughly reviewed prior to working with any chemical. All chemical containers will be marked to identify appropriate precautions that need to be taken. Chemicals will be maintained in a designated area. Proper PPE will be worn at all times when handling chemicals. Personnel involved in motor making will complete the university's Lab and Research Safety Course. All other individuals will be properly trained on handling common chemicals used in constructing the launch vehicles.	3E	Training will be documented for designated individuals. Certificates will be kept on file for trained individuals until the individuals graduate and leave the organization.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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.
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.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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 (Table 39) will be conducted prior to launch. Final Assembly and Launch Procedures Checklists (Table 41) will be used during assembly and launch. Launch vehicle will be cleaned and inspected in accordance with Post-Flight Checklist (Table 43).

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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 (Table 41) 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.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Stability	Mass increase during construction.	Unplanned addition of components or building materials.	Launch vehicle does not fly to correct altitude. All sections land with high kinetic energy. Possible minor damage to rocket body and/or fins.	2C	Record will be maintained of mass changes. Launch vehicle simulations will be repeated for each mass change. Additional launch vehicle simulations will be performed at plus 5% of calculated mass. Subscale and full-scale launches will be performed with accurate mass.	3E	During full-scale test launch, launch vehicle did not reach planned altitude. Weight reduction of landing module is planned.
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.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Stability	Rocket doesn't reach high enough velocity before leaving the launch pad.	Rocket is too heavy. Motor impulse is too low. High friction coefficient between rocket and launch tower.	Unstable launch.	1E	Too low of a velocity will result in an unstable launch. Simulations have been and will continue to be run to verify the motor selection provides the necessary exit velocity. Ful scale testing will be conducted to ensure launch stability. Should the failure mode still occur, the issue should be further examined to determine if the cause was due to a faulty motor or in the booster needs to be redesigned.	1E	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 landing module 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 landing module. Despite the damage, the landing module remained intact during the full-scale launch and recovery.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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 (Table 41) will be utilized to inspect motor prior to launch. Manufacturer's instructions will be followed in assembling the motor.
Stability	Piston system becomes jammed.	Temperature variations cause contraction/expansion between piston and launch vehicle frame. Dirt or residue collects inside airframe.	Landing module fails to land separately. Potential for nosecone section to fail to separate properly. Parachutes do not deploy properly.	2D	Fittings will be tested prior to launch to ensure that no components are sticking together. Inside of launch vehicle frame and surface of piston will be thoroughly cleaned after every test launch. In the event that the rocket does become ballistic, all individuals at the launch field will be notified immediately.	2E	During ground testing, it was found that during launch the piston and the landing module may have become slightly distorted or accumulated debris that caused excessive friction with the launch vehicle body. Post flight Inspection checklist updated to include fit check and cleaning/sanding of components as necessary. During full-scale test flight, piston and landing module ejected successfully.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Stability	Piston becomes unstable.	Direction of the force provided by black powder is not in line with the center of gravity causing Piston to rotate around its center of gravity until it hits the side of the launch vehicle frame and becomes stuck.	Landing module fails to land separately. Potential for nosecone section to fail to separate properly. Parachutes do not deploy properly.	2D	Center of gravity of piston will be placed toward the ejection charge. Ground and flight testing will be conducted to ensure piston stability and ejection of landing module and nosecone.	2E	During ground testing and full-scale test launch, piston, landing module, and nose cone ejected successfully.
Environmental	Low cloud cover.	N/A	Unable to test entire system.	3C	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system.	3E	N/A

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Rain.	N/A	Unable to launch. Damage electrical components and systems in the rocket.	3C	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. Have a plan to place electrical components in water tight bags. Have a location prepared to store the entire rocket to prevent water damage. Electronics on the ground station are all stored in water tight control boxes to seal out any moisture.	3E	During full-scale test launch, the assembled rocket experienced approximately 40 min. of heavy rain. All components were inspected for water damage prior to launch attempt. Launch was successful with no damage due to water incursion. In addition, all tools and ground station equipment was similarly intact and functional.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Ponds, creeks, and other bodies of water.	N/A	Loss of rocket components. Damaged electronics.	2D	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 (Table 41) when assembling launch vehicle.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Environmental	Humidity.	N/A	Motors or black powder charges become saturated and don't ignite.	2D	Motors and black powder should be stored in a water resistant container.	2E	Use 5.1.1 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.
Controls	LiPo battery catches fire.	Battery overcharged or short in electrical system.	Landing module module / rocket catches fire.	1E	Lipo batteries electrical connections will be insulated properly also battery voltage will be measured before flight to ensure its not overcharged.	1E	The configuration uses one lithium polymer battery in the landing module. Use Landing Module Pre-Flight Checklist (Table 40) when preparing landing module for flight.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Landing	Landing gear fails to extend.	Springs in landing gear fail to extend.	Landing module does not land upright. Failure to meet objective.	2D	Ground testing of landing module has been conducted successfully. Flight testing of landing module will be conducted. Separate checklist will be created to inspect landing module prior to launch.	2E	Use Landing Module Pre-Flight Checklist (Table 40) when preparing landing module for flight.
Landing	Landing module fails to jettison from launch vehicle body.	Insufficient black powder to ensure jettison. Parachutes become entangled together.	Landing module fails to land separately. Failure to meet objective to land launch vehicle section upright.	1D	Multiple ground and flight testing of launcher will be conducted to determine amount of black powder required. Parachutes will be properly packed in accordance with instructions prior to launch. Piston recovery system will be utilized to ensure pressurization.	1E	During ground and flight tests, landing module ejected successfully using 8 g black powder. Use Final Assembly and Launch Procedure Checklists (Table 41) when assembling launch vehicle.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC	Verification
Vision	No matches for a specific tarp is found.	Coding error. Camera obstructed. Spin too substantial to obtain image.	Unable to meet objectives for tarp identification.	2C	Since a match for at least one has already been made, the system will be designed to search again using a broader range of HSV values, focusing the location near the tarp already found. Computer will run a custom python program utilizing the Open CV computer vision library to differentiate between the three targets.	2E	
Vision	No matches for any tarps found.	Rocket is not close enough to the tarps. Color ranges are not correct for the current cloud conditions.	Unable to meet objectives for tarp identification.	2C	Once the correct location is assured, the system will use Canny edge detection, attempting to locate the tarps using feature matching and not color. Once the edges are found, the colors from inside the shapes will be cross checked to find the most likely matched color.	2E	

5.3.4 Verification of Mitigation of Risks

We have implemented numerous tests to verify that all risks are minimized, including:

- Simulation testing of:
    - Launch vehicle stability, including mass changes, apogee altitude, drift, and kinetic energy.
    - Landing module to include wind speed on descent.
- Ground testing of:
    - Piston ejection system.
    - Parachute and recovery system to include parachute packing methods, black powder charges, shear pins.
    - Landing module to include the steering system, the electronics bay, and the landing gear system. Testing will measure thrust produced by the motors to be demonstrated and calculated given the moment arm, power input, and other parameters of the system.
    - Launch vehicle stability to include drag coefficient, motor ejection charge, and launch vehicle section fittings.
    - Altimeters and electronics, to include record altimeter, backup altimeter, main and landing module GPS systems.
- Subscale launch testing of:
    - Parachute and recover system to include parachute inflation.
    - Launch vehicle stability, including mass changes, apogee altitude, drift, and kinetic energy.
- Full-scale launch testing of:
    - Parachute and recovery system to include parachute inflation.
    - Launch vehicle stability, including mass changes, apogee altitude, drift, and kinetic energy.
    - Landing module to include GPS tracking system, vision system, camera aiming system, and landing gear stability.

5.4 Environmental Concerns

The primary concern for the launch affecting the environment is from the flame of the motor ignition. This heat source can damage the surrounding land beneath the launch area. This will be diminished by having a launch area that is resistant to damage from this flame. The launch area will be on dirt that is not flammable.

The main concerns for the environment affecting the launch vehicle is the wind and rain. The wind will increase the drift that the launch vehicle has from the launch area. If the wind is above 20 mph, it is possible that the launch will be postponed until the winds calm. The rain can also affect how the launch vehicle flies; since the vehicle will be moving at extremely high speeds, the rain can hinder the apogee of the vehicle and drive it off course. Thus, the launch will also be postponed in the event of heavy rain.

6 Project Plan

6.1 Testing

6.1.1 Subscale Ground Test

This test was completed to ensure that there was enough black powder packed into the rocket to separate and push the nose cone, landing module, and main parachute from the altimeter bay. The altimeter bay and the main airframe containing the main parachute, the nose cone, and the landing module were placed on the ground in an area that was a safe distance away. The altimeter bay was packed with black powder and then was matched to see if it pushed all the components out. The first test was done with 1.5 g of black powder. We continued to test with different amounts of black powder until we reached 3 g and a successful ground test.

6.1.2 Subscale Launch Test

The subscale testing was performed on December 17, 2016. We tested to make sure that the landing module would successfully be launched out of the main airframe during flight at 800 ft. Although the nose cone parachute and the landing module parachute became entangled during descent, the test was a success because we were able to determine what would have gone wrong and how to fix it. The data from this launch is available in the Critical Design Review report.

6.1.3 Landing Module Test

A landing module prototype was constructed to test the initial steering design in both an indoor hanging test and an outdoor drop test. These tests enabled us to determine that the navigation design was not feasible and thus caused us to switch to the simpler and more effective system described in 4.5.3 Camera Aiming System. For the full previous landing module testing process, see 4.7 Prototyping.

A real-world flight test for the landing module is scheduled for March 2017, where we will be able to launch with the completed camera aiming system and test all subsystems.

6.1.4 Full-Scale Ground Test

The full-scale ground test was completed on February 18, 2017 in order to ensure that the black powder charges would successfully separate all sections and deploy recovery systems. This was successfully completed after two failures with the simulated landing module (a weighted tube, rather than an active module). This series of tests allowed us to determine the optimal conditions for deployment as well as the necessary amount of black powder (8 g). More information on this test can be found in 3.1.9 Recovery System Ejection Test.

6.1.5 Full-Scale Launch Test

The full-scale rocket was launched with an inactive weighted payload on February 18, 2017. As mentioned previously, another test flight is scheduled for March, which will allow for testing of the actual active landing module in a launch situation. In the February test, all components separated properly, however the nose cone parachute did not deploy successfully. This was due to the Nomex cloth sliding up too far on the parachute cords and preventing deployment. No damage was sustained due to the soft ground and durable nature of the nose cone. More information and analysis of this test is found in 3.2 Full-Scale Flight Results.

6.2 Requirements Compliance

Table 50: List of competition requirements and methods used to meet them.

Requirement	Method of Meeting Requirement	Verification
Section housing the cameras shall land upright and provide proof of a successful controlled landing.	An upright landing of the landing module will be made possible by using a landing gear system that will absorb the impact force of the overall system on touchdown and land on any terrain.	Angle of rocket upon landing will be captured and stored within onboard software for later verification.

Data from the camera system shall be analyzed in real time by a custom designed onboard software package that shall identify and differentiate between the three targets.	An onboard computer (Raspberry Pi 3b) housed in the electronics bay of the landing module will process the captured images in real time. The computer will run a custom python program utilizing the OpenCV computer vision library to differentiate between the three targets.	For verification, review data captured and analyzed by system once recovered after launch.
The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hr.	Power consumption calculations will be assessed and an appropriately rated battery will be selected to ensure the electronics system remains in nominal condition. Onboard sensors will keep the main processing computer in a low power mode until specific tasks are requested.	Computer System with onboard real time clock will log elapsed time of events from the moment it's turned on until the end of the flight.
The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The launch vehicle will be designed to separate into 4 separate sections. Each section with its own recovery parachute to ensure the rocket body stays intact. The motor can be replaced within 1-2 hr. after the casing has cooled. The landing module can be reset quickly by changing out or charging the battery, and relocking the motor arms in their upright positions.	Proper launch procedures and proper handling of the launch vehicles and its components will be followed. All vehicle preparations and launches will be overseen by a certified TRA member.

6.3 Budgeting & Timeline

6.3.1 Budget Plan

Table 51: Current budget overview for project duration.

Budget Item	**Projected Cost** ($)	**Amount Spent** ($)	**Remaining Budget** ($)
Rocket	3,000	1,207.40	1,792.60
Payload	2,000	1,486.40	513.63
Travel	2,857.08	N/A	N/A

Table 52: Detailed expense breakdown for the landing module and rocket.

Projected Expenses	**Vendor**	**Cost** ($)
Landing Module		
10 cm Male to Male Servo Connectors	Amazon	8.99
15 cm Male to Male Servo Connectors	Amazon	9.99
XT60 to 5.5 mm Battery Connector	Amazon	15.95
ODROID XU4 Development Board	ameriDroid	76.95
USB to Serial UART Module	ameriDroid	12.95
ODROID Shifter Shield	ameriDroid	19.95
32 GB eMMC Module Linux for ODROID	ameriDroid	45.95
Arduino UNO R3	Amazon	23.99
Adafruit 1141 Data Logging Shield for Arduino	Amazon	18.93
SanDisk Extreme 32 GB SD Card	Amazon	16.95

Projected Expenses	**Vendor**	**Cost** ($)
Arduino Stackable Header Pins	Amazon	4.75
Gens Ace 11.1 V, 1300 mAh LiPo Battery	Amazon	16.99
10 Pair Deans Style Battery Connectors	Amazon	7.59
5.5 mm × 2.1 mm Arduino Power Plug	Amazon	5.68
Lightweight Self-Closing Spring Hinge	McMaster-Carr	15.24
Roller Ball Bearing	Amazon	12.49
Clevis Pin	McMaster-Carr	7.28
Magnetic Catch	McMaster-Carr	17.52
13/16 in. × 16 in. Galvanized Strut Channel	Home Depot	9.68
Strut Channel Spring	Fastenal	18.20
Phenolic Coupler Tube for 6 in. Diameter	Public Missiles	44.99
Raspberry Pi 3	Amazon	35.70
Raspberry Pi Camera Module v2	Amazon	24.99
10 × 4.5 Propellers, 8 pieces	Amazon	9.89
oCam 5MP USB 3.0 Camera	ameriDroid	99.95
Raspberry Pi Power Supply	Amazon	9.99
Samsung Evo+ Micro SD Card	Amazon	13.75
Adafruit 16 channel PWM Driver	Amazon	16.97
SunnySky X2212-9 KV1400 Brushless Motor	Buddy RC	30.60

Projected Expenses	**Vendor**	**Cost** ($)
Velotech 30A ESC	Buddy RC	16.00
3.5mm Bullet Connector Extension Wires	Hobby King	7.80
5v 3A UBEC Power Regulator	Amazon	10.90
Aluminum 6061-T6 Bare Extruded Angle Structural 1.25 in. × 1.25 in. × 0.125 in. Cut to: 12 in.	Online Metal	4.00
0.25" Aluminum Plate 6061-T651 Plate 0.25" Cut to: 12 in. × 12 in.	Online Metal	85.68
Aluminum 6061-T651 Bare Plate 0.5" Cut to: 8 in. × 8 in.	Online Metal	64.14
12.5 in. 34-Compartment Double-Sided Organizer	Home Depot	17.94
XT60 to 6 × 3.5 mm bullet Multistar ESC Power Breakout Cable	Hobby King	4.54
Fire Retardant LiPoly Battery Bag (170 mm × 45 mm × 50 mm)	Hobby King	6.78
HXT 4mm to 6 × 3.5 mm bullet Multistar ESC Power Breakout Cable	Hobby King	5.05
HXT 4 mm to XT-60 Battery Adapter	Hobby King	3.80
Turnigy 5000 mAh 4S 25C Lipo Pack	Hobby King	33.84
DC Buck Converter 5 V USB Output	Amazon	14.40
Male Header Pins	Amazon	8.99
10 DOF Sensor Board	Amazon	23.99

Projected Expenses	**Vendor**	**Cost** ($)
GPS Module	Amazon	37.89
Lipo Low Voltage Alarm	Amazon	12.98
3.5 mm Bullet Connector	Amazon	7.99
9 in. Propellers	Amazon	12.69
8 in. Propellers	Amazon	10.99
Adafruit 10DOF Board	Amazon	31.05
Phenolic Coupler Tube for 6 in. Diameter	Public Missiles	44.99
18 AWG Silicon Wire	Amazon	10.98
20 AWG Silicon Wire	Amazon	14.98
Flexible Jumper Wire	Amazon	4.79
USB Arduino Cable	Amazon	4.99
Pack of 3 Atmega328p-pu	Amazon	13.44
3 × Mini Solderless Breadboards	Amazon	8.99
Barometer	Amazon	13.98
Piezo buzzers	Amazon	6.82
GPS Module	Amazon	11.80
5V Regulators	Amazon	5.95
Speed Controllers	Amazon	35.99
RF Transceiver	Adafruit	79.80
SMA Antenna Mount	Adafruit	2.50
GPS	DX Soul	49.53
8-bit Microcontrollers	Mouser	6.42

Projected Expenses	**Vendor**	**Cost** ($)
	Electronics	
2 × Digital High Speed Servos	Amazon	86.18
Pan/Tilt Kit	Robot Shop	9.95
Rocket		
Mobius Video Camera Shroud	Additive Aerospace	39.90
6 in G12 Color Airframe	Madcow rocketry	224.00
75 mm flange mount quick-change retainer	Wildman Rocketry	$50.00
Cert 3 Large	Wildman Rocketry	$250.20
Cert 3 Extra large	Wildman Rocketry	$170.10
Recon Recovery 30 in. Chute	Wildman Rocketry	$34.15
Recon Recovery 60 in. Chute	Wildman Rocketry	$87.35
Recon Recovery 50 in. Chute	Wildman Rocketry	$75.95
Aeropoxy	Aircraft Spruce & Specialty Co.	$53.75
98mm Flange-Mount Quick-Change Retainer	Wildman Rocketry	$62.00
75mm/98mm Quick-Change Motor Adapters	Wildman Rocketry	$44.00
Model: E-Match // Product Name: J-TEK3	Off We Go Rocketry	$80.00

Projected Expenses	Vendor	Cost ($)
1 m 100 pcs Electric Igniters E-match 0.45 mm Copper Wire Fireworks Firing System	EBay (ZiyanFireworks)	$36.00
Travel		
N/A	N/A	0.00
Total		**1,338.19**

7.3.2 Funding Plan

To complete this project our organization shall rely primarily on funding allocated to us through the University of South Florida Student Government and fundraising activities completed throughout the year. Out of all money received from the Student Government and through fundraising activities, $5,000 have been allocated to our participation in NASA Student Launch. Any travel expenses will be covered through the travel grant received from the Student Government after completing necessary paperwork.

7.3.3 Project Timeline

Table 53: Project timeline with dates and details.

Due Date	Tasks/Event	Description	Deliverables
9/2/2016	Begin Design of Landing System and Rocket	Brainstorm ideas of the design of landing system and rocket	A list of possible design options
9/5/2016	Assign Proposal Sections	Assign sections of the proposal to corresponding teams	Team members know which sections of the proposal they are responsible for
9/9/2016	Decide on the Design Idea for Landing System and Rocket	Choose landing system and rocket design idea	Finalized idea for rocket and landing system design
9/12/2016	Proposal Rough Draft Due	Prepare Proposal for final review	Proposal rough draft

Due Date	Tasks/Event	Description	Deliverables
9/14/2016	Proposal Review Session	Review proposal rough draft and prepare for the final review	Revised proposal
9/16/2016	Establish Budget	Create budget plan	Budget Plan
9/20/2016	Final Proposal Review Session	Finalize proposal and prepare for submission	Finalized proposal
9/30/2016	Submit Proposal	Proposal submission	Submitted proposal
10/5/2016	Finalize Design of Landing System and Rocket	Decide on the final idea of the design of landing system and rocket	Final design of landing system and rocket
10/20/2016	Begin Subscale Fabrication	Begin initial stages of subscale fabrication	Prepared airframe
10/28/2016	PDR Rough Draft Due	Prepare PDR report for final review	PDR Rough Draft
10/30/2016	PDR Review Session	Review the PDR draft and prepare the report for the final review	Revised PDR report
11/2/2016	PDR Final Review Session	Final review of the PDR report before the submission	Final PDR report
11/4/2016	PDR Submission	Submit PDR to NASA	PDR report
11/6/2016	PDR Presentation Practice	Rehearse speaking roles of PDR presentation with team members	Prepared PDR Presentation

Due Date	Tasks/Event	Description	Deliverables
11/6/2016	Begin Prototyping	Prototyping components of landing system	Components of landing system
11/15/2016	Testing of Prototyped System	Test all components of landing system and record any valuable data	Tested components of landing system
11/16/2016	Complete Subscale Fabrication	Launch vehicle and recovery system ready for testing	Prepared subscale
11/19/2016	Varn Ranch Launch	Launch subscale with simulated mass	Launched subscale
11/27/2016	Revise Full-scale Design	Consider any necessary changes to design based on subscale launch data	Revised full-scale design
11/27/2016	Revise Landing System Design	Consider any necessary changes to design based on prototype testing	Revised landing system design
12/2/2016	CDR Q&A Session	Ask NASA employees specific questions pertaining to the designs of the landing system and launch vehicle	All questions answered
12/10/2016	Begin Full-scale Fabrication	Begin initial stages of full-scale fabrication	Prepared airframe
12/13/2016	Assign CDR Sections	Assign sections of the CDR report to team members involved	Team members know CDR sections they are responsible for

Due Date	Tasks/Event	Description	Deliverables
12/16/2016	Varn Ranch Launch	Second subscale launch	Launched subscale
12/18/2016	Final CAD Models	Full CAD models for all components and assemblies	Finalized CAD models
1/3/2017	Begin Landing System Fabrication	Begin initial fabrication of landing system	Components of landing system
1/5/2017	CDR Rough Draft Due	Prepare CDR report for final review	CDR Rough Draft
1/7/2017	CDR Review Session	Review the CDR draft and prepare the report for the final review	Revised CDR report
1/9/2017	CDR Final Review Session	Final review of the CDR report before the submission	Final CDR report
1/13/2017	CDR Submission	Submit CDR to NASA	CDR report
1/16/2017	CDR Presentation Practice	Rehearse speaking roles of CDR presentation with team members	Prepared CDR Presentation
1/17/2017	Complete Full-scale Fabrication	Launch vehicle and recovery system ready for testing	Prepared full-scale
1/17/2017	Complete Landing System Fabrication	Initial landing system prepared for testing	Prepared landing system
1/21/2017	Varn Ranch Launch	Launch full-scale with initial landing system and record any valuable data	Launched full-scale and recovered landing system

Due Date	Tasks/Event	Description	Deliverables
1/30/2017	Review Launch Data	Review launch data and consider any changes to motor selection and landing system design	Revised motor selection and landing system design
2/6/2017	Assign FRR Sections	Assign sections of the FRR report to team members involved	Team members know FRR sections they are responsible for
2/8/2017	FRR Q&A Session	Ask NASA employees specific questions pertaining to the designs and data of the landing system and launch vehicle	All questions answered
2/15/2017	Adjust Landing System	Adjustments made to landing system before second test launch	Prepared landing system
2/17/2017	Engineering EXPO	Team members interact with K-12 students	Education engagement
2/18/2017	Engineering EXPO	Team members interact with K-12 students	Education engagement
2/18/2017	Varn Ranch Launch	Second full-scale launch with revised landing	Launched full-scale and recovered landing system
2/22/2017	Review Launch Data	Review launch data and consider any changes to rocket and landing system design	Revised motor selection and landing system design
2/25/2017	FRR Rough Draft Due	Prepare FRR report for final review	FRR Rough Draft

Due Date	Tasks/Event	Description	Deliverables
2/28/2017	FRR Review Session	Review the FRR draft and prepare the report for the final review	Revised FRR report
3/2/2017	FRR Final Review Session	Final review of the FRR report before the submission	Final FRR report
3/6/2017	FRR Submission	Submit FRR to NASA	FRR report
3/10/2017	FRR Presentation Practice	Rehearse speaking roles of FRR presentation with team members	Prepared FRR Presentation
3/20/2017	Complete Testing of Landing System	All necessary adjustments made to landing system	Landing system ready for competition
4/3/2017	LRR Presentation Practice	Rehearse speaking roles of LRR presentation with team members	Prepared LRR Presentation
4/5/2017	Travel to NSL	Team members drive to Huntsville, AL	Arrive in Huntsville, AL
4/6/2017	LRR Presentation and Safety Briefing	Present LRR to NASA employees and team members review safety procedures	LRR Presentation and Safety Briefing
4/7/2017	Rocket Fair and Tours of MSFC		
4/8/2017	Banquet		

Due Date	Tasks/Event	Description	Deliverables
4/8/2017	Launch Day	Team will launch full-scale with landing system	Successful launch and landing
4/9/2017	Backup Launch Day		
4/10/2017	Travel to Tampa	Team members drive to Tampa, FL	Arrive in Tampa, FL
4/17/2017	PLAR Rough Draft Due	Prepare PLAR report for final review	PLAR Rough Draft
4/19/2017	PLAR Review Session	Review the PLAR draft and prepare the report for the final review	Revised PLAR report
4/22/2017	PLAR Final Review Session	Final review of the PLAR report before the submission	Final PLAR report
4/24/2017	PLAR Submission	Submit PLAR to NASA	PLAR report

7 Appendix

7.1 Contributors

- **Project Management:**
  - Andrew Huff
  - Danielle Petterson
  - Kateryna Turchenko
- **Launch Vehicle:**
  - Brooke Salas
  - Frankie Camargo
  - Jamie Waters
  - Stephanie Bauman
- **Editing and Formatting:**
  - Ian Sanders
- **Landing Module:**
  - Ian Sanders
  - Jackson Stephenson
  - Jaime Gomez
  - Kyle Hunter
  - Nicholas Abate
  - Simon Wilson
- **Safety:**
  - Stephanie Bauman

7.2 SolidWorks Drawings

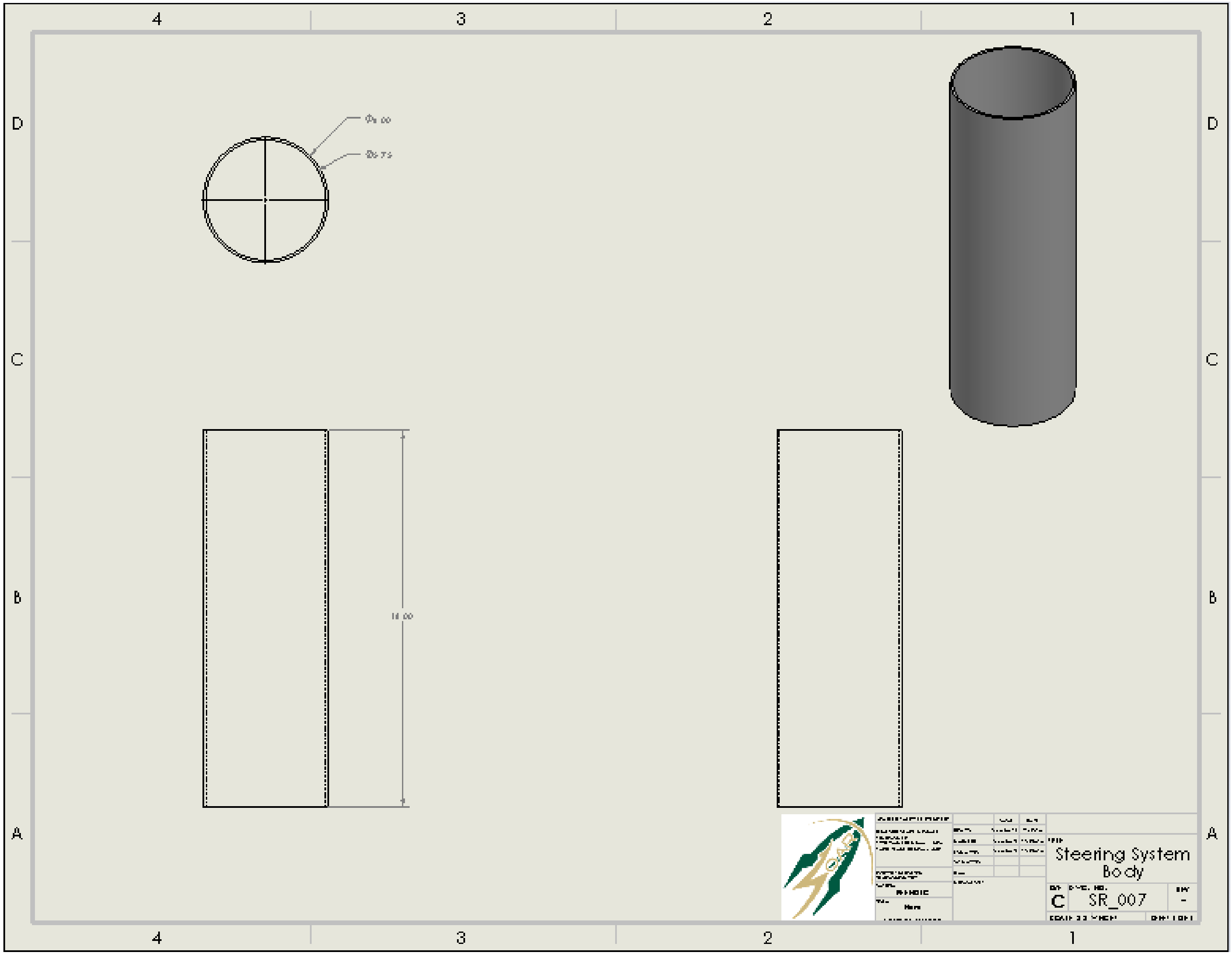


Figure 15: Steering system body drawing.

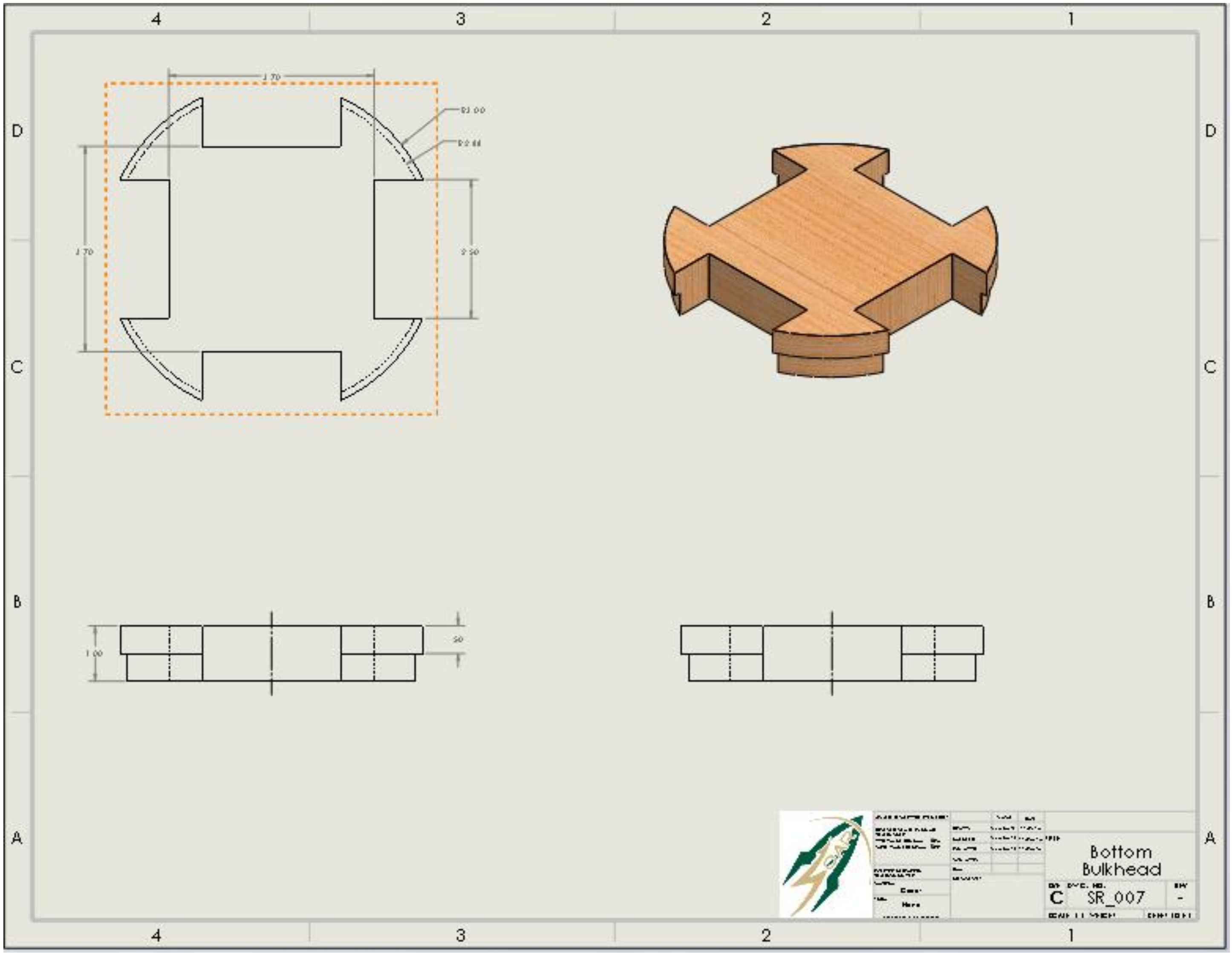


Figure 16: Landing module bottom bulkhead drawing.

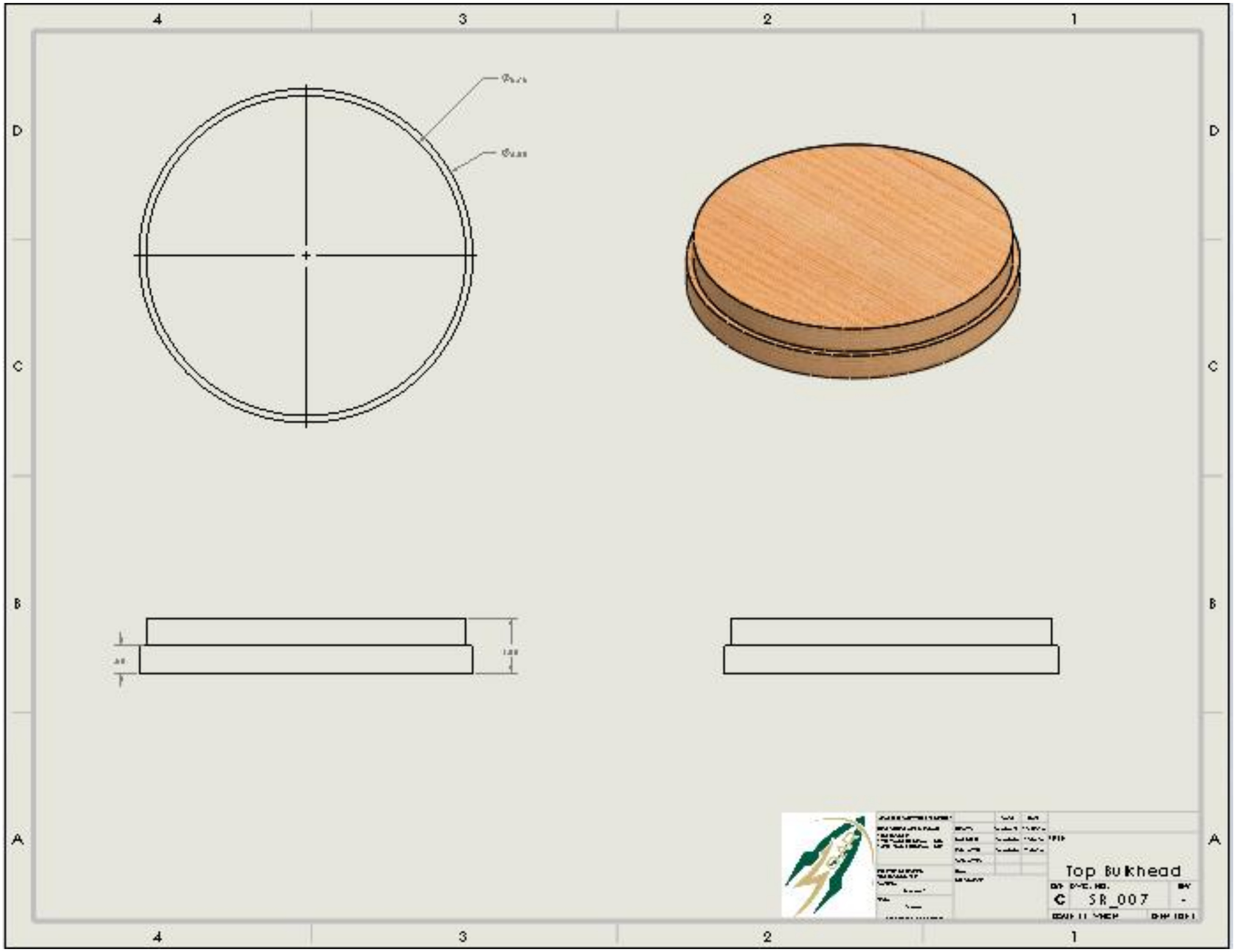


Figure 17: Top landing module bulkhead drawing.

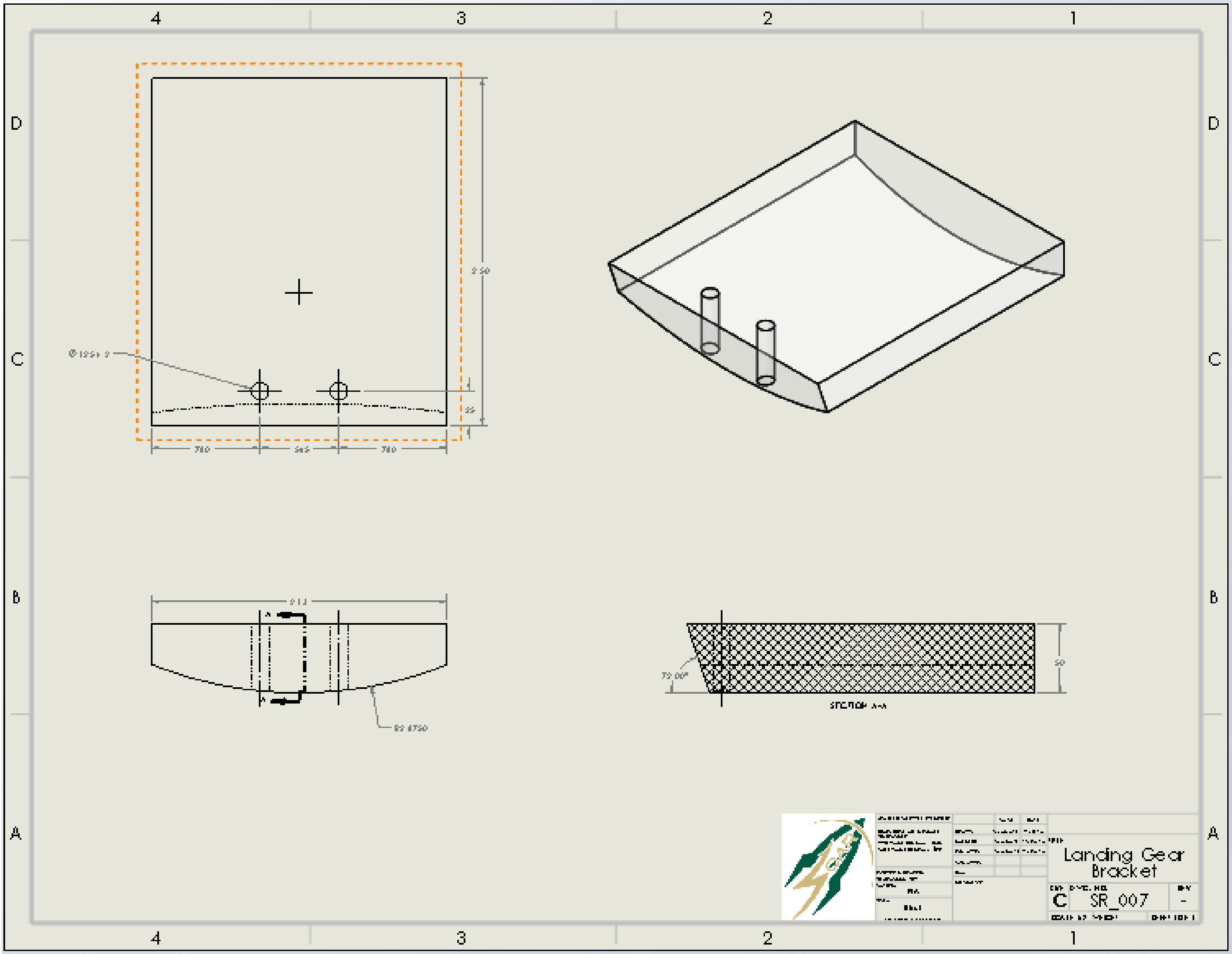


Figure 18: Landing module landing gear bracket drawing.

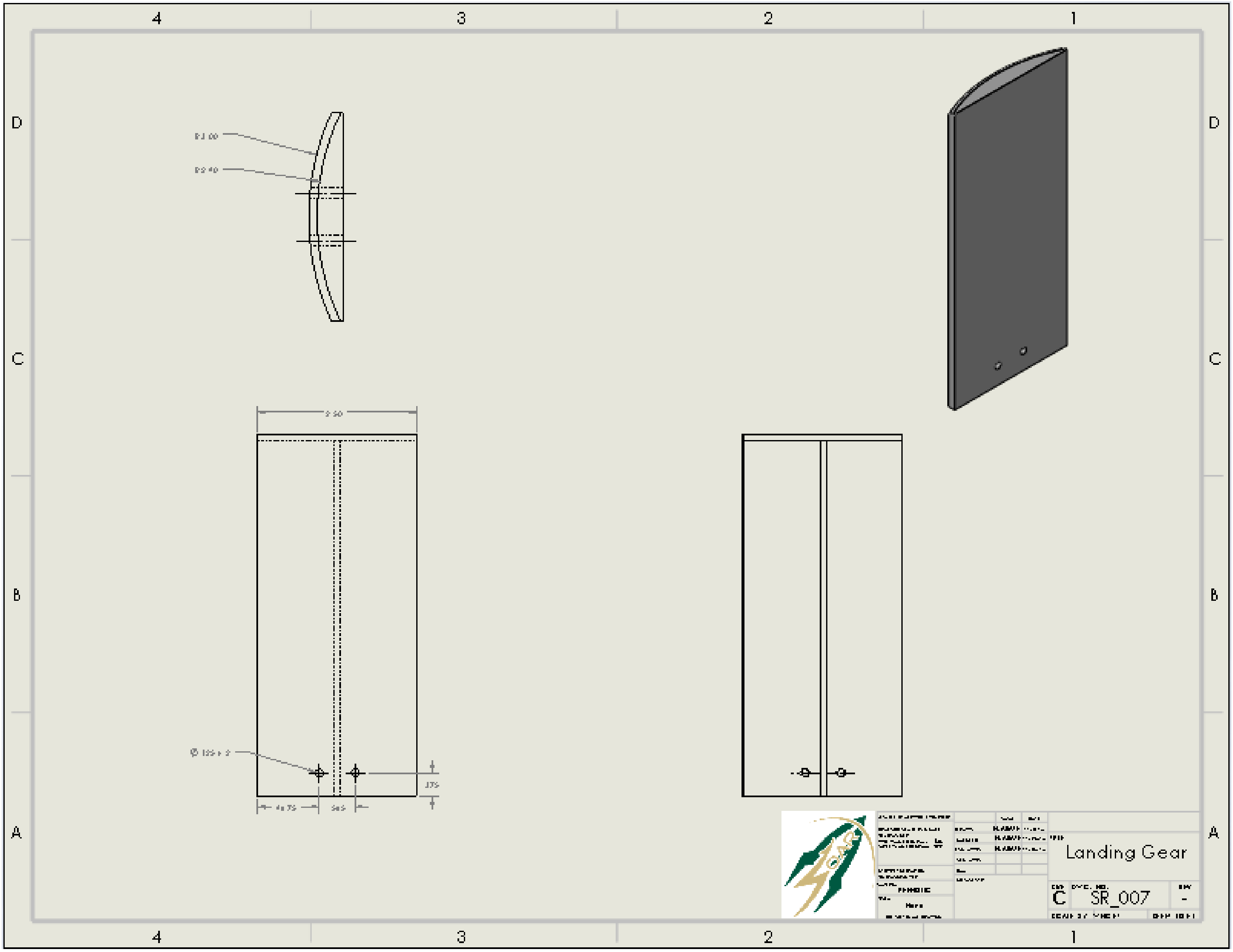


Figure 19: Landing module landing gear leg drawing.

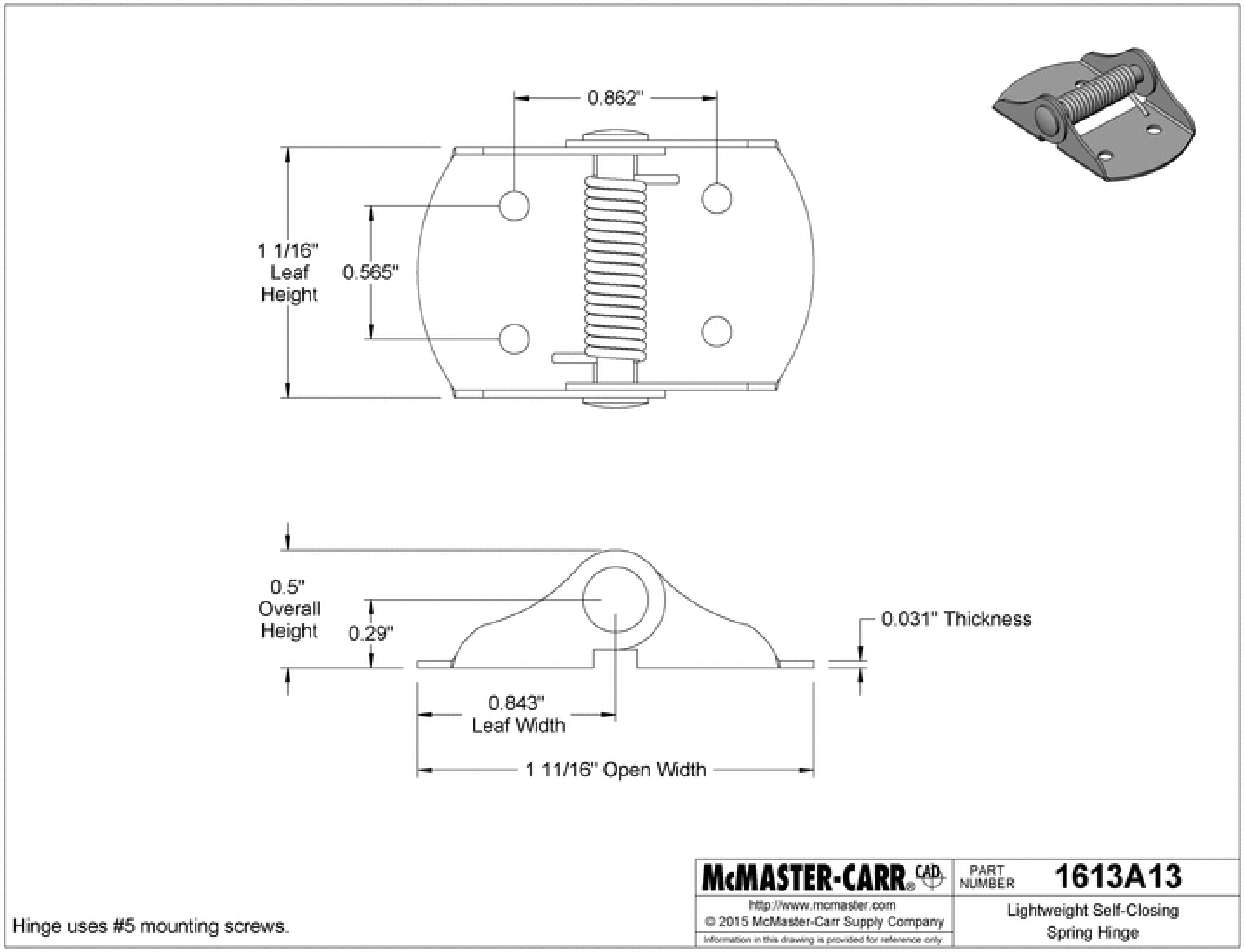


Figure 20: Landing module landing gear hinge drawing.