NASA Student Launch 2017

Critical Design Review Report

January 13, 2016

SOCIETY OF AERONAUTICS AND ROCKETRY

14247 Les Palms Circle, Apt. 102
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: 40.06 lb

Projected Loaded Weight: 49.81 lb

1.2.2 Final Motor Choice

L1115 from Cesaroni Technology:

Total Impulse: 5015 Ns

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 Landing Module Summary

Length: 24 in.

Est. Weight: 9.38 lb

Const. Material: Phenolic & Aluminum

Processor: Raspberry Pi 3B, Arduino

Parachute: SkyAngle Large

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/2017/01/CDR-Flysheet-2017.pdf.

2. Changes Made Since PDR Report

2.1 Vehicle Criteria Changes

The selected motor has been changed since the Preliminary Design Review Report (PDR) was completed. The L1115 is the motor that will be launched in the full-scale launch vehicle. The higher amount of thrust will allow us to ensure the launch vehicle can reach the goal of 5,280 ft. and reach 52 fps off the rail. The test launches will be used to confirm this. The launch vehicle will now be using a piston system and no deployment bags will be used. The nose cone is 3 ft. long. This will ensure the gases from the black powder will not go around the parachutes and make sure that everything in the launch vehicle is ejected.

2.2 Landing Module Changes

2.2.1 Steering System

The only alteration made to the steering system design since the PDR is the mounting location of the motors. Rather than mounting the motors on the front face of the unistrut, the motors will be mounted at the ends.

2.2.2 Steering Control System

In the PDR, the Raspberry Pi was planned to be used for the vision system as well as the steering control system. An Arduino based microcontroller will instead control the steering control system due to the ease of interfacing brushless motors, a GPS module, and required sensors. Separating the work between the two systems helps ensure there will be enough processing power to navigate the lander module within a specified range of the targets while simultaneously being able to identify and differentiate the three targets. This also assist in mitigating problems; if one system were to experience failures, the other system could continue normal operation.

2.2.3 Vision System

The Raspberry Pi 3B will still be used as the computer for the vision system. The camera module for the vision system has been narrowed down to either the oCam USB 3.0 camera or the Raspberry Pi Camera Module v2. Further testing will need to be conducted in order to determine which camera has the field of view and resolution necessary to identify the targets.

2.2.4 Landing Gear

The design from the PDR was chosen for the landing gear setup, but with the addition of wheels installed at the bottom of each leg. Implementing special wheels will allow the module to accommodate rough terrain, helping to ensure that it remains vertical upon landing.

2.3 Project Plan Changes

A more detailed schedule was created to ensure the team remains on track. Each task has a description and expected deliverables. A major change in the schedule was to move the full-scale rocket build dates up in order to perform more launches and testing prior to the contest. In addition to the new schedule, a spreadsheet was created to help the team keep track of expenditures and plan for future purchases.

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 push 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, the landing system, and the 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 different design and fabrication methods.

3.1.2 Mission Requirements

The following table will show the requirements that need to be met in this mission as well as how we ensured that we met those requirement:

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.

Requirement	Method	Verification
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.
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 a 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.	The full-scale rocket will be built and launched as well as recovered prior to the FRR and it will be the same rocket flown on launch day.	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 randomly placed targets.	The launch vehicle will contain a landing system that has a camera and navigation system that is able to identify the random 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 system.	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 by on December 17th.

9. Full-scale launch vehicle launched by FRR.

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. In the main body tube, going from the nose cone down, there is a small parachute for the nose cone, a parachute for the landing module, the landing module, a parachute for the main body of the launch vehicle, and a piston system. All of these parts will deploy at an altitude of between 800 and 1,000 ft. Below the altimeter bay in the design is the drogue section with a parachute that will deploy at apogee. The piston system will prevent the gases from going around the parachutes and ensure all stages and parachutes are pushed out of the launch vehicle. The landing module was chosen to be inside the launch vehicle because it will provide consistent stability when compared to locating it near the motor mount. It also keeps the rocket free of structural protuberances from our propeller design.

3.1.5 Evaluation and Verification Plan

Table 2: Goals and verification of goals for specific flight characteristics.

Characteristic	Description	Goal	Verification
Apogee	Max 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.

Characteristic	Description	Goal	Verification
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% - 25% probability), so all Level D hazards are 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.

3.1.7.2 Proper Use of Materials

The fins are to be made of fiberglass to ensure that they can withstand impact when landing. The bulkheads will be thick and epoxied in between two wooden plates, and then epoxy will be applied all around the bulkhead to ensure no fire damage and breakage. In order to prevent the nose cone from being pushed out before 1,000 ft, shear pins are to be placed 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 placed to fasten together the main airframe and the altimeter bay because the airframe will not be its own separate component, but rather just space for the landing module and main parachute to be held. The shock cords will be attached to a U-bolt that will be securely fastened with a nut.

3.1.7.3 Sufficient Motor Mounting and Retention

The motor mounting will be secured with a motor casing along with a bulkhead on top to prevent the motor from moving up. In order to prevent the motor from falling out of the rocket, a motor retainer will be installed.

3.1.7.4 Final Weight of Launch Vehicle

Table 3: Estimated weight of components and entire rocket.

Component	**Weight** (lb)
Nose Cone & Parachute	2.14
Landing Module & Parachute	9.38
Altimeter Bay with Main Airframe, Parachute, Shock Cords, & Piston	15.0
Booster & Shock Cords	12.69
Total Estimated Weight	49.81

3.1.8 Manufacturing, Verification, Integration, and Operations Planning

The launch vehicle components will be purchased from a vendor early enough to ensure there is enough time to test all systems and get several launches on the full-scale rocket to reach the 5,280 ft. goal. The epoxy that we use on the launch vehicle will be mixed with carbon fibers for added strength. The fins will be epoxied directly to the motor mount with reinforcing fillets from the fin to the motor mount. When the fins are added to the outer body tube, more fillets will be applied to ensure the fins will not be damaged upon impact with the ground.

Table 4: Pre-mission tests and purposes.

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

The subscale test launch and recovery was successfully completed on December 17th, as shown in Figure 1.

Figure 1: Successful recovery system ejection test.

3.1.9 Progression and Current Status of Design

The launch vehicle has gone through two major design changes since proposal. The initial design of our launch vehicle involved landing the aft section of our rocket. This incorporates 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 has been 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 current rocket design is 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 makes it safer to launch. Another positive reason for separating the camera housing from the aft is that this section is now much lighter than that of its original position. The bi-prop assembly will now 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 the subscale launch.

3.1.10 Dimensional Drawing of Assembly

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

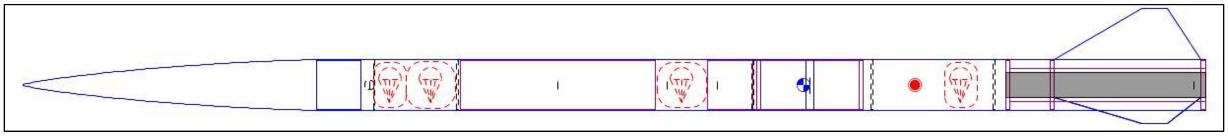


Figure 2: Overview drawing of launch vehicle assembly.

3.1.11 Mass Statement

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

3.1.9.1 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·m^2, g·cm^2)	0.0318919, 318919	

RockSim XN (in)	11.1411
CNa	2

3.1.9.2 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	

3.1.9.3 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	

3.1.9.4 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	

3.1.9.5 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

3.1.9.6 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	

3.1.9.7 Lander

Table 11: Lander mass statement.

Brand	**Model**	**Material**
Custom	--	Kraft Phenolic
Properties		
OD (in)	5.9700	
ID (in)	5.8000	
Length (in)	24.0000	
Location (in, from front of Main Section)	17.6250	

Calculations	
CG (in)	12.0000
Mass (oz)	20.9010
Radius of Gyration (m, cm)	0.183949, 18.3949
Moment of Inertia ($kg \cdot m^2$, $g \cdot cm^2$)	0.0200497, 200497

3.1.9.8 Lander Electronics

Table 12: Lander Electronics mass statement.

Brand	Model	Material
Public Missiles	--	3/8" Tubular Nylon (SkyAngle)
Calculations		
CG (in)	0.0000	
Mass (oz)	176.0000	
Radius of Gyration (m, cm)	0, 0	
Moment of Inertia ($kg \cdot m^2$, $g \cdot cm^2$)	0, 0	

3.1.9.9 Lander Parachute

Table 13: Lander 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

3.1.9.10 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	

3.1.9.11 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

3.1.9.12 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	

3.1.9.13 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·m^2, g·cm^2)	0.00952508, 95250.8	

3.1.9.14 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·m^2, g·cm^2)	0.000497018, 4970.18

3.1.9.15 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·m^2, g·cm^2)	0, 0	

3.1.9.16 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·m^2, g·cm^2)	0.181026, 1.81026·10^6	

RockSim XN (in)	0.0000
CNa	0

3.1.9.17 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	

3.1.9.18 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 ($kg \cdot m^2$, $g \cdot cm^2$)	0.0187881, 197991

3.1.9.19 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 ($kg \cdot m^2$, $g \cdot cm^2$)	0.000160753, 1607.53	

3.1.9.20 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 ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0.00806205, 80620.5

3.1.9.21 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 ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0, 0	

3.1.9.22 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

3.1.9.23 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	

3.1.9.24 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·m^2, g·cm^2)	0.0194813, 194813

3.3 Subscale Flight Results

The subscale prototype was successfully launched on December 17th, 2016. A video of this launch can be found at http://www.usfsoar.com/subscale-launch-day/.

3.2.1 Flight Data

Table 29: Flight data from subscale test, gathered by an RRC3 Missile Works Altimeter.

Flight Property	Value
Maximum Altitude (Apogee) (ft)	1,899
Maximum Velocity (fps)	321
Ascent Time (s)	11.15
Descent Time (s)	46.75
Drogue Rate (fps)	71
Main Rate (fps)	30

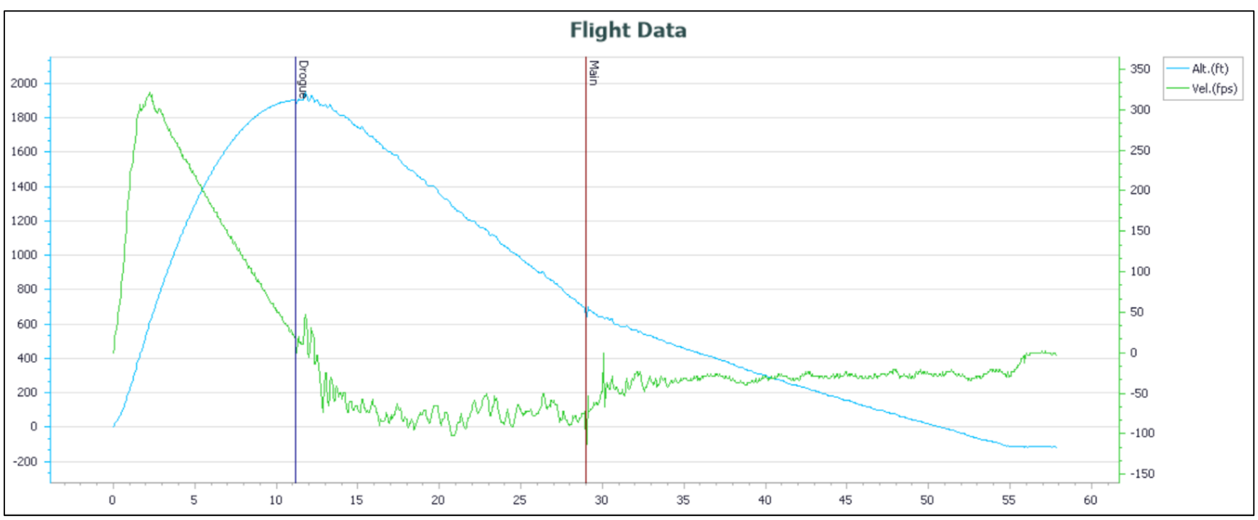


Figure 3: Graph of data from subscale test, with parachute release times marked.

3.2.2 Scaling Factors

The subscale rocket was two-thirds the size of the full-scale. Every portion of the rocket was scaled down in order to fully created a two-thirds model of the full-scale rocket. This includes the overall length, fin area, and body tube diameter.

3.2.3 Launch Day Conditions Simulation

The launch took place on December 17th at the local Tripoli flight location in Plant City. The simulations are shown in the Mission Analysis section. Below is the summary of the launch day conditions.

Table 30: Summary of launch day conditions.

Condition	Value
Weather	Sunny
Temperature (°F)	78
Humidity (%)	75
Wind (mph)	4

3.2.4 Analysis of Subscale Flight

Based upon the conditions of the day, a detailed simulation was created. The simulated model of the subscale flight predicted an expected apogee of 2,180 ft. and a maximum velocity of 356 fps. In the simulation, the rocket hits the ground at a velocity of 28.8 fps, and the velocity off the launch rail is 43 fps.

When comparing flight data to the simulated data, we found that both the apogee and maximum velocity of the rocket in the actual subscale test were significantly lower than expected, with differences of 281 ft. and 35 fps, respectively. Finally, during the flight estimated average drag coefficient during the duration of the flight was 0.43.

3.2.5 Impact of Full-Scale Design

During the subscale launch, there was an issue in which the landing module and the nose cone had gotten wrapped up and tangled during descent. That helped shape a new method for packing the parachute and nose cone with the landing module to prevent further entanglement. Also, we were able to determine how much black powder is needed in the full-scale. We confirmed that the design works and full-scale production will continue.

3.3 Recovery Subsystem

3.3.1 Chosen Design Alternatives from the PDR

The alternative for the recovery system shown in the PDR will be used with the addition of the piston system. 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 will be used to ensure the gases from the black powder will not go 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	Secures 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. Swivels 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 hooked up. This setup has been used before by the organization and has proven effective. Since it is a 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 4 shows the diagram of how the altimeters will be wired. The two systems are redundant and independent of each other.

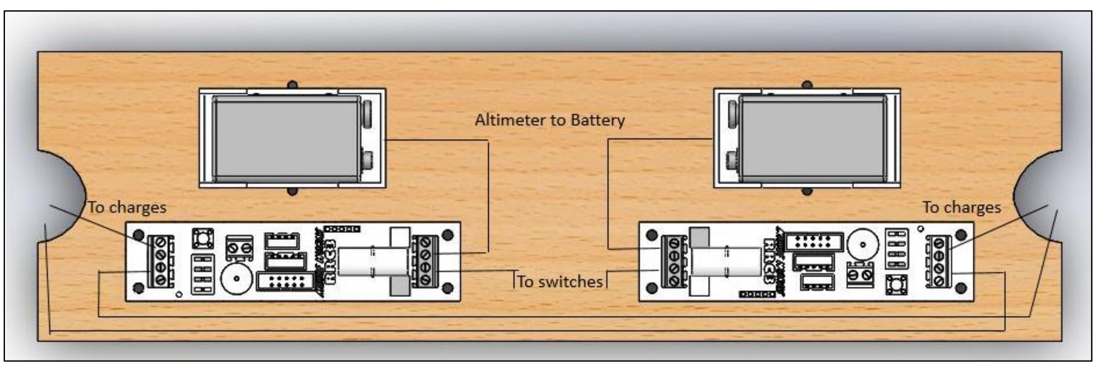


Figure 4: Schematic of recovery system electronics.

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 up to nine miles. 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 5.

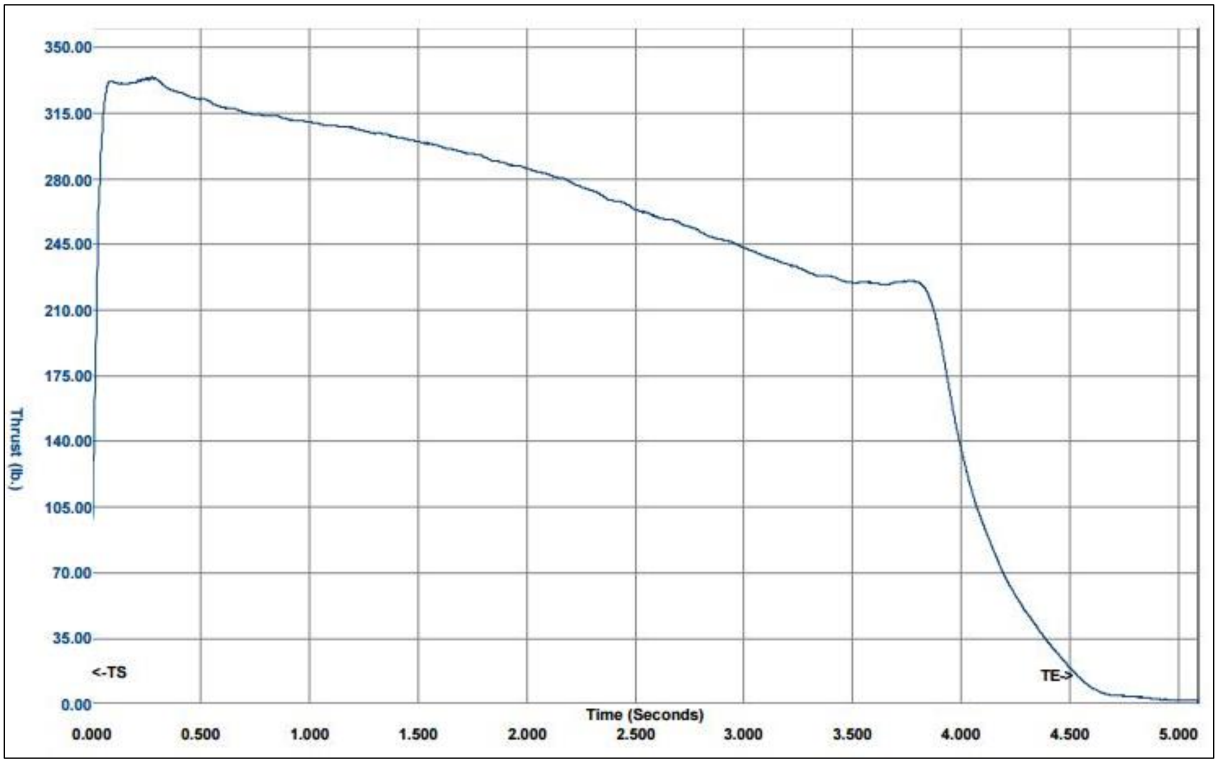


Figure 5: Chart of the thrust curve of the L1115 motor.

The effect of the wind speed on the launch vehicle was tested in the 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)	5594
	Time to Apogee (s)	19.6
	Max Velocity (fps)	583
	Max Acceleration (fps^2)	216
10	**Apogee** (ft)	5565
	Time to Apogee (s)	19.7

Wind Speed (mph)	**Data**	
	Max Velocity (fps)	583
	Max Acceleration (fps^2)	216
15	**Apogee** (ft)	5550
	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° Fahrenheit, 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 86.737 in. from the nose cone unloaded and 95.717 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 2.24 calipers. The Barrowman equations were used for calculation of center of pressure. The diagram of the launch vehicle is shown in Figure 6.

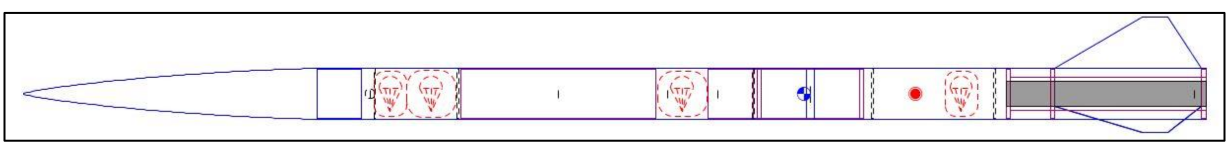


Figure 6: Drawing of launch vehicle with centers of gravity and pressure shown.

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 Lander	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 and 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 apogee is 78.5 s.

Table 35: Calculated drift analysis values.

Wind Speed (mph)	**Wind Speed** (fps)	**Drift** (ft)
0	0	0
5	7.33	575.41
10	14.66	1,150.81
15	21.99	1,726.22
20	29.32	2301.63

4 Safety

4.1 Safety Checklists

4.1.1 Final Assembly and Launch Procedure Checklist

Table 36: Checklist to be followed for final assembly and launch.

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.		
Make sure the proper size parachutes and shock cords are present for assembly of rocket.	Kinetic energy will exceed limitations. Damage to launch vehicle.	
Prepare new batteries for the recovery systems.	Parachutes may fail to deploy. Mission failure.	
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	Parachutes may fail to deploy. Mission failure.	
Warning: Keep away from flames. **PPE Required**: Eye protection, gloves.		

Task	Warning/Caution	SO Verification
Load the altimeter bay with charges and insulation	Failure of landing system to eject will result in mission objective failure.	
Slide piston into launch vehicle	Failure of landing system to eject will result in mission objective failure.	
Ensure all parachutes are attached correctly to their section	Parachutes may become entangled. Sections become ballistic.	
Pack parachutes neatly. Ensure parachutes slide in and out of the rocket easily.	Parachutes may become entangled. Sections become ballistic. Ensure parachutes will not shift during flight.	
3. Launch Vehicle Assembly		
Slide the electronics bay into the bottom airframe.	Ensure all fittings are snug but not tight.	
Slide the top airframe onto the electronics bay.	Ensure all fittings are snug but not tight.	
Slide the SOAR landing system into the airframe	Ensure all fittings are snug but not tight. Failure of landing system to eject will result in mission objective failure.	
Slide the nose cone into the top of the airframe.	Ensure all fittings are snug but not tight.	
4. Motor Preparation		

Task	Warning/Caution	SO Verification
Warning: Keep away from flames. Inspect motor for cracks and voids. Refer to MSDS for white lithium grease. **PPE Required**: Eye protection, gloves.		
Have motor assembled and inserted into the launch vehicle	Ensure motor retainer is secure.	
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.	
Place the launch vehicle on the rail.	Test launch vehicle on launch rail for resistance or friction. Adjust as necessary. Inspect bearings for debris.	
Turn on altimeters and get 3 distinct beeps	Parachutes may fail to deploy. Mission failure.	
6. Igniter Installation		
Insert ignitor into the launch vehicle	Ensure that the igniter is inserted up the motor until it reaches a dead-end and then pull back about 1-2 in. Failed or delayed ignition possible.	
Tape or clip the e-match cord to the motor retainer to secure it in place.	Conduct final check to ensure security of e-match.	

Task	Warning/Caution	SO Verification
7. Post Launch Procedure		
Monitor drift and locate launch vehicle after flight	Ensure launch vehicle is recovered in a timely manner.	
Recover launch vehicle, determine altitude, and deactivate altimeters		
Deactivate all electronics.		

Table 37: 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.

4.1.2 Landing Module Pre-Flight Checklist

Table 38: 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 or navigation meaning that mission objectives could not be accomplished.	
Test all batteries with voltmeter.	Vision or navigation system may fail. Mission objective failure.	
Check spring loaded motor arm mechanisms for proper operation.	Navigation and stabilization of spin unavailable. Failure to identify tarp.	
Check prop assembly pin system for free rotation of motor arms.	Navigation and stabilization of spin unavailable. Failure to identify tarp.	
Check props for free rotation.	Navigation and stabilization of spin unavailable. Failure to identify tarp.	
Check magnetic catch system for secure attachment between motor arms and base plate.	Navigation and stabilization of spin unavailable. Failure to identify tarp.	
Check landing gear wheels for free rotation.	Lander 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.	

Task	Warning/Caution	Engineering Lead Verification
Ensure GPS operational.	Navigation unavailable. Failure to identify tarp.	
Ensure vision camera operational.	Failure to identify tarp.	
Ensure all wires, parachute, and other components do not interfere with motor arm deployment.	Possible damage to components and or failure of motor to properly deploy.	

4.1.3 Post-Flight Inspection Checklist

Table 39: Post-flight inspection checklist.

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

4.2 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.

4.3 Hazard Analysis

4.3.1 Risk Level Definitions

4.3.1.1 Severity

The severity of each potential risk is determined by comparing the possible outcome to criteria based on human injury, vehicle and payload equipment damage, and damage to environment. Severity is based on a 1 to 3 scale, 1 being the most severe. The severity criteria are provided in Table 40.

Table 40: 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 environmental damage that violates law and regulation.
– 2 – Critical	Severe injury or occupational related illness.	Major damage to facilities, systems, or equipment that result in partial mission failure.	Operations not permitted by the RSO and NFPA 1127 occur during launch. Mission suspended or laws and regulations are violated.	Delay of mission critical components or budget overruns that compromise mission scope.	Reversible environmental damage causing a violation of law or regulation.
– 3 – Marginal	Minor injury or occupational related illness.	Minor damage to facilities, systems or equipment that will not compromise mission objectives.	Operations are permitted by the RSO and NFPA 1127, but hazards unrelated to flight hardware design occur during launch.	Minor delays of non-critical components or budget increase.	Mitigatable environmental damage without violation of law or regulations where restoration activities can be accomplished.

4.3.1.2 Probability

The probability of each potential risk has been assigned a level between A and E, A being the most certain. The scale of probabilities is determined by analyzing the risks and estimating the possibility of the accident to occur. Table 41 depicts the levels of probability for each risk.

Table 41: 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

4.3.1.3 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 42). These levels range from high (red) to minimal (white) and are defined in Table 43.

Table 42: 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

Probability	Severity			
	1 - Catastrophic	2 - Critical	3 - Marginal	4 - Negligible
E - Improbable	1E	2E	3E	4E

Table 43: 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.

4.3.3 Hazard Analysis Matrix

Table 44: Hazard/risk analysis for the launch vehicle and landing module.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Controls	Igniter safety switch fails to activate.	Mechanical failure in switch. Communication failure between switch and controller. Code error.	Vehicle fails to launch.	2D	Redundancies will be implemented to ensure the igniter safety system performs as expected.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Controls	Igniter safety switch active at power up.	Switch stuck/left in enabled position. Communication failure between switch and controller. Code error.	Undesired launch sequence/ personnel injury/ disqualification.	1D	Redundancies will be implemented to ensure the igniter safety system performs as expected.	1E
Environmental	Harmful substances permeating into the ground or water.	Improper disposal of batteries or chemicals.	Impure soil and water can have negative effects on the environment that in turn, affect humans and animals, causing illness.	2E	Batteries and other chemicals will be disposed of properly in accordance with the MSDS sheets. Should a spill occur, proper measure are to be followed in accordance with the MSDS sheets and any EHS standards.	2E
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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. Use checklist when assembling launch vehicle. Ensure technical lead supervision in handling of parts.	2E
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
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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
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
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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
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 electromagneti c field will be used.	4E
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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. Checklist will be utilized in packaging of parachutes. Ground testing will be done on the full scale. Altimeter and electronics check will be conducted with checklist several hours prior to launch.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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. Ground tests will be performed to confirm that the amount of black powder is adequate. Altimeter and electronics check will be conducted with checklist several hours prior to launch. Inside of rocket body will be greased 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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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. If a section is loose, then tape will be wrapped around a coupler until the connection is sufficiently tight. Check black powder firing circuits for correctness and verify altimeter altitudes.	1E
Recovery	Altimeter or e-match failure.	Parachutes will not deploy.	Rocket follows ballistic path, becoming unsafe.	2E	Multiple 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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Recovery	Rocket descends too quickly.	Parachute is improperly sized.	The rocket falls with a greater kinetic energy than designed for, causing component s 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
Recovery	Rocket descends too slowly.	Parachute is improperly sized.	The rocket will drift farther than intended, potentially facing damaging environmen tal 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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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. Rip stop nylon was selected for the parachute material. This material prevents tears from propagating easily. In the incident that a small tear occurs during flight, the parachute will not completely fail.	2E
Recovery	Recovery system separates from the rocket.	Bulkhead becomes dislodged. Parachute disconnects from the U-bolt.	Parachute completely separates from the component, causing the rocket to become ballistic.	1E	The cables and bulkhead connecting the recovery system to each segment of the rocket are designed to withstand expected loads with an acceptable factor of safety. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.	1E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Recovery	Lines in parachutes parachute 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
Recovery	Parachute does not inflate.	Improperly sized lines.	Parachute does not generate enough drag.	2E	A subscale parachute was constructed and tested to verify the design of the vortex ring. All full-scale parachutes have been ground tested to ensure that the parachute will properly inflate during flight.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Shop	Using power tools and hand tools such as blades, saws, drills, etc.	Improper use of PPE. Improper training on the use of equipment.	Mild to severe cuts or burns to personnel. Damage to rocket or component s of the rocket. Damage to equipment	3C	Individuals will be trained on the tool being used. Those not trained will not attempt to learn on their own and will find a trained individual to instruct them. Proper PPE must be worn at all times. Shavings and debris will be swept or vacuumed up to avoid cuts from debris.	4D
Shop	Sanding or grinding materials.	Improper use of PPE. Improper training on the use of equipment.	Mild to severe rash. Irritated eyes, nose or throat with the potential to aggravate asthma. Mild to severe cuts or burns from a Dremel tool and sanding wheel.	2C	Long sleeves will be worn at all times when sanding or grinding materials. Proper PPE will be utilized such as safety glasses and dust masks with the appropriate filtration required. Individuals will be trained on the tool being used. Those not trained will not attempt to learn on their own and will find a trained individual to instruct them.	4E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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.	3E
Shop	Damage to equipment while soldering.	Soldering iron is too hot. Prolonged contact with heated iron.	The equipment could become unusable. If parts of the payload circuit become damaged, they could become inoperative.	3C	The temperature on the soldering iron will be controlled and set to a level that will not damage components. For temperature-sensitive components sockets will be used to solder ICs to. Only personnel trained to use the soldering iron will operate it.	4D

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Shop	Dangerous fumes while soldering.	Use of leaded solder can produce toxic fumes.	Team members become sick due to inhalation of toxic fumes. Irritation could also occur.	3D	The team will use well ventilated areas while soldering. Fans will be used during soldering. Team members will be informed of appropriate soldering techniques.	4E
Shop	Overcurrent from power source while testing.	Failure to correctly regulate power to circuits during testing.	Team members could suffer electrical shocks which could cause burns or heart arrhythmia.	1D	The circuits will be analyzed before they are powered to ensure they don't pull too much power. Power supplies will also be set to the correct levels. Team members will use documentation and checklists when working with electrical equipment.	2E
Shop	Use of white lithium grease.	Use in installing motor and on ball screws.	Irritation to skin and eyes. Respiratory irritation.	3D	Nitrile gloves and safety glasses are to be worn when applying grease. When applying grease, it should be done in a well ventilated area to avoid inhaling fumes.	4E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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. Ground Testing will be conducted to ensure that the ejection charge does not blow out the motor.	1E
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. Checklists and appropriate supervision will be used when assembling.	2E
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 by the PEM. Inspection will be conducted to ensure parachutes and shock cord do not move freely in the airframe.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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. Ground testing will be used to make sure an ejection charge does not push the motor out.	2E
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

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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Stability	Internal bulkheads fail during flight.	Forces encountered are greater than the bulkheads can support.	Internal component s 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
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Stability	Piston system becomes jammed.	Temperature variations cause contraction/expansion between piston and launch vehicle frame. Dirt or residue collects inside airframe.	Lander 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
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.	Lander 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 lander and nosecone.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Controls	LiPo battery catches fire.	Battery overcharged or short in electrical system.	Lander module / rocket catches fire.	1E	Lipo batteries will be encases in fire retardant bags and electrical connections will be insulated properly also battery voltage will be measured before flight to ensure its not overcharged.	1E
Landing	Landing gear fails to extend.	Springs in landing gear fail to extend.	Lander does not land upright. Failure to meet objective.	2D	Ground testing of lander has been conducted successfully. Flight testing of lander will be conducted. Separate checklist will be created to inspect lander prior to launch.	2E
Landing	Magnets to retain propellers fails to engage.	Propellers will not be available for directional control.	If drift is sufficient, failure to meet objectives for tarp identificatio n.	2E	Ground testing of lander has been conducted successfully. Flight testing of launcher will be conducted. If possible, simulations will be conducted to measure the wind speed on descent and appropriate magnet strength will be selected. Separate checklist will be created to inspect lander prior to launch.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Landing	Parachute cord tangles in propellers.	Lander component must change orientation after exiting launch vehicle with parachute initially on bottom side.	Lander does not land upright. Lander becomes ballistic. Damage to lander. Failure to meet objective.	2D	Ground testing of lander has been conducted successfully. Flight testing of launcher will be conducted. Parachutes will be properly packed in accordance with instructions prior to launch.	2E
Landing	Lander fails to jettison from launch vehicle body.	Insufficient black powder to ensure jettison. Parachutes become entangled together.	Lander 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
Navigation / Guidance	GPS guidance malfunction.	General malfunction. Coding error. GPS battery failure.	Lander will not return to origin, which is within 300 feet of the tarps. If drift is sufficient, failure to meet objectives for tarp identificatio n.	2E	Ground and flight testing of launcher will be conducted. GPS and electronics test will be conducted prior to launch. Batteries will be tested prior to launch. Parachutes will be properly packed with appropriate supervision in accordance with instructions prior to launch.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Navigation / Guidance	Lander hovers over civilians while propellers spinning.	Lander navigated itself to wrong location/ wind took it to bad location.	Could cause injury or property damage.	3D	Lander module will cutoff power to motors while the altitude is less than ~ 100 feet.	3E
Navigation / Guidance	Lander unable to navigate to target / goes wrong way.	Potentially started too far away /wind is stronger than motors.	Lander drifts past 2500ft limit.	2D	If lander drifts out of boundary, cutoff power so it doesn't keep going further away due to steering system.	2E
Recovery	Danger to ground crew from spinning propellers.	When attempting recovery, spinning props may cut or injure personnel.	Abrasions, cuts, bruises to personnel.	3B	Once the navigation gets the lander to within the specified distance of the launch site/tarps, the motors will shut off. There will also be a failsafe to shut the motors off once the lander is under 300ft from the ground.	4D

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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. Counter spin from electronic speed controllers for rotor systems will be used to stabilize the lander.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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	To check for the first possibility, the system will recheck the GPS location in relation to the launch pad and make any necessary corrections. 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

4.3.5 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.
    - Lander 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.
    - Lander 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 lander 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 (future) launch testing of:
    - Parachute and recover system to include parachute inflation.
    - Launch vehicle stability, including mass changes, apogee altitude, drift, and kinetic energy.
    - Lander module to include GPS tracking system, vision system, rotor functionality, counter spin capability, and power cutoff at 100 ft.

4.4 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.

5 Landing Module Criteria

5.1 General Overview

5.1.1 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'X40' 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.

5.1.2 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.

5.1.3 Team Criteria

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

1. The landing module with a drogue parachute separates from the body of the rocket following the initial parachute at apogee.
2. The mechanical arms with propellers to steer the landing module extend and lock into place.
3. The landing module's GPS and steering systems guide it within 2,500 ft. of the launch site.

4. The on-board camera is able to see and identify the different colored tarps.
5. The landing module lands upright in the same orientation in which it was launched.

5.2 Chosen Design Alternatives

The payload will consist of three sections: the steering system, the electronics bay, and the landing gear system. The steering system will be used to navigate the landing module and prevent excessive spinning to allow the vision system to capture the specified targets. The electronics bay controls the motors to create horizontal thrust and houses the vision system. Also, the landing gear system allows for a successful controlled landing. The overall system will be housed as an internal stage of the rocket and will jettison from the rocket at apogee. All subsystems will be spring loaded and actuated upon release from the rocket. Once the overall system jettisons from the rocket, the system will act as a single unit to reach the team's objective.

5.3 Design Overview

5.3.1 Steering

The steering system is made up of a spring-loaded system, bi-prop assembly, magnetic catch, and pin system. A spring-loaded system is required to actuate the arms that are stowed inside of the lander's housing once the system is jettisoned from the rocket. The spring-loaded system consists of $^{13}/_{16}$-in. Unistrut channels, channel nuts with springs, and mounting brackets. The motor arms are pressed against the channel nut with spring when stowed (Figure 7). This places the springs in compression and allows the arms to extend once jettisoned from the rocket. A magnetic catch system is used to secure the motor arms onto the baseplate. This allows the bi-prop assembly to only provide a horizontal thrust and eliminate a vertical thrust. A pin system is used to allow rotation of motor arms to vertically stow and horizontally expand (Figure 8).

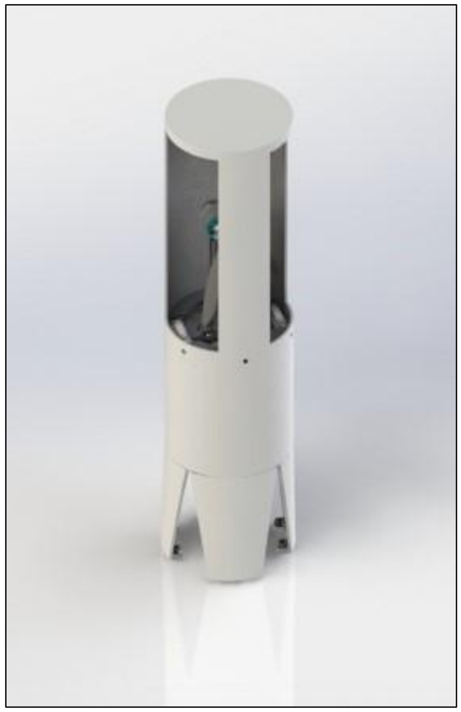


Figure 7: Rendering of landing module prior to deployment.

Figure 8: Rendering of deployed landing module.

Figure 9: Isolated rendering of the steering mechanism.

5.3.2 Payload Electronics Bay

The payload electronics bay is comprised of two subsystems: the vision system and the steering control system. The main components for both of these subsystems include the Raspberry Pi 3B, an Arduino based microcontroller, an Adafruit Ultimate GPS Breakout board, and various sensors. The electronics bay is located in the bottom section of the lander body and will house a custom designed mounting bracket for the various electronic components. A hole will be drilled through the bottom mounting plate of the lander module for the vision system camera to view through. Wires for the brushless motors will run up into the steering system section and fasten to the arms securely to remain clear of the propellers and spring loaded hinges. Due to the large current draw from the brushless motors, the payload electronics may need shielding from electromagnetic interference to avoid sensor errors. Further testing will be conducted to determine if the motors are far enough away to affect the steering control system.

5.3.3 Landing Gear

The landing gear system consists of self-closing spring hinges, extension springs and wheels. 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. The wheels will be used to maneuver the system on any terrain to prevent tipping.

Figure 10: Rendering of the bottom half of he landing gear system.

5.4 Mechanical Component Selection

5.4.1 Materials

Considerable thought was placed in selecting the materials for the mechanical subsystems. The physical structure encapsulating the steering system, along with the bulkhead to house the camera and the landing gear arms seen in Figure 10, 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 slightly smaller diameter compared to the rocket's inner diameter, which allows for a tight and smooth fit. Most other components, like the arms that the motors are mounted on, the locking mechanism, and the base that attaches all of these components together will be constructed of 6061 aluminum. These parts were chosen to be made of a high-grade aluminum primarily for its high strength-to-weight ratio. Maximizing this property reduces the overall weight of the system. Other mechanical properties such as good machinability and relatively high stiffness, in conjunction with moderately low cost contributed to the final decision to use aluminum.

5.4.2 Connection Types

Various methods of connections were used between members in order to achieve the desired motion. The most important connection types are the ones associated with the arms that extend out upon separation. These arms are pin connected at the lower end, and are held in place with a spring mechanism pushing it away from the center of the rocket prior to separation. This spring aids in extending the arm, and these arms remain in their horizontal position through the use of magnets once separation occurs. One magnet is placed on the arm, and another at the aluminum base. When they come in contact, the arms will be locked into position for the duration of the descent.

Additionally, the landing gear system employs some unique methods of connections. At the top of the landing gear arms, there are spring loaded hinges that act to pull each arm away from the center of the rocket. To ensure that these arms are not completely extended, an elastic line, similar to a bungee cord, will be attached in a triangular fashion to each arm. The length of the cord will determine how far the arms will be extended, and can be adjusted if the need arises by using a cord either longer or shorter. As well, at the bottom of each of the landing gear arms are small wheels. These wheels will prevent the rocket from tipping by allowing it to roll easily.

All of these systems will then be attached to the phenolic body rigidly through the use of phenolic tabs, attached to the encapsulation with resin a hole will be drilled in these tabs so that members can be bolted down.

5.5 Payload Electronics

5.5.1 Overview

The electronics system of the payload (Figure 11) is split into two subsections: a vision system and a steering control system. The vision system is controlled by a Raspberry Pi 3B and the steering 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 steering control system will ensure the lander module remains within the 2,500 ft. drift limit and is close enough to the targets for the vision system to operate successfully.

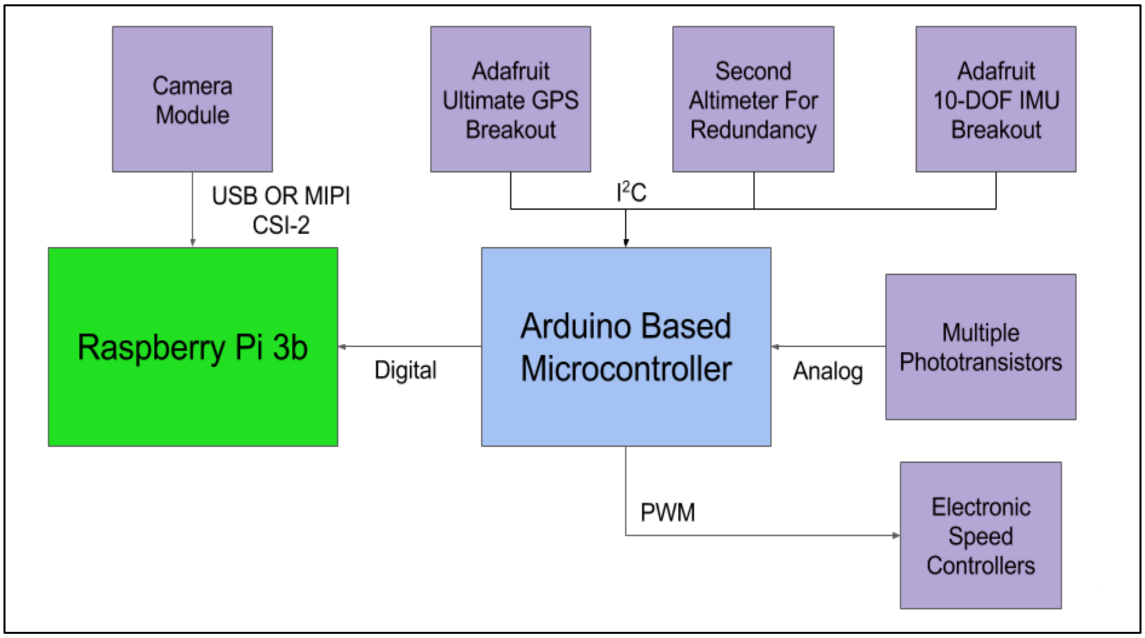


Figure 11: Payload electronics wiring block diagram.

5.5.2 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 down between one of two cameras. The first is the oCam camera module by Hardkernel, it 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. The other camera option is the Raspberry Pi Camera Module v2. It has an 8 MP sensor with a 62.2° (horizontal) × 48.8° (vertical) angle of view. This camera module uses the MIPI CSI-2 interface which is connected directly to the GPU on the Raspberry Pi. Bypassing the CPU initially via the MIPI CSI-2 interface might improve the processing speed of our software package and result in an increased chance of successful target identification. To this point, only very small scale vision tests have been conducted using a simple USB 2.0 webcam.

These tests have been successful, however, larger scale testing using both cameras will be necessary to determine if their resolution and angle of view will be sufficient from long distances. Once testing is complete we will be able to decide which camera to integrate into the lander module.

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 will be calculated. 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.

5.5.3 Steering Control System

An Arduino based microcontroller will be responsible for controlling the steering system on the lander module. Tests have begun 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 steering 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 45: 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 the steering control 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 navigate the lander module to during its 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 its flight path to its destination.

Altitude, angular velocity, and navigational bearings are three very important measurements for the success of the lander 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 a safe and successful landing attempt. The BMP180 barometer / temperature sensor has an acceptable 25 cm resolution when calculating the altitude of the lander. Multiple safety features will be included in the software package to ensure the lander 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 motors to receive power. A second separate barometer / temperature sensor will also be incorporated in the steering control system for added safety and redundancy. If either of the two altitude readings are lower than the minimum specification, the lander module will turn off both motors.

Phototransistors will be mounted on various locations of the lander module to measure the level of light from its surroundings. These will be used as a start trigger for the lander module to begin its onboard software package. While the lander module is within the rocket body it will be very dark and the phototransistors will measure a very minimal amount of light. Once the lander 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 steering control system program. This requirement will serve multiple purposes: it will greatly reduce the steering control systems power consumption while waiting on the launch pad and during the rocket's ascent, and it will also prevent the lander module from accidentally powering the motors on while inside the rocket. When the phototransistors receive the predefined level of light indicating the lander 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 lander module.

The majority of the power consumer by the payload electronics will be from the two brushless motors. The motors will be powered from a Turnigy 4S 5,000 mAh LiPo battery, step down voltage regulators will also be connected to the LiPo battery in order to power all other electronics on the lander module. 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 72,000 mWh of power for our payload electronics. Based off the data in Table 46 and the calculations in Equation 1, this battery would be able to provide power to all components for approximately 35 min. This approximation assumes the use of the components listed in the table below, excluding the Arduino Zero and Raspberry Pi Camera Module v2 due to their similar alternate option.

Table 46: Payload electronics power consumption data.

Part	Voltage (V)	Current (mA)	Power (mW)	Measured or Estimate
Raspberry Pi 3b	5.0	750	3750	Estimate
Teensy 3.5	5.0	100	500	Estimate
Arduino Zero	5.0	60	300	Estimate
oCam Camera	5.0	280	1,400	Estimate
Raspberry Pi Camera Module v2	5.0	250	1,250	Estimate
Adafruit Ultimate GPS Breakout	5.0	20	100	Measured
Adafruit 10-DOF IMU Breakout (Quantity 2)	5.0	40	200	Measured
Phototransistor (Quantity 4)	5.0	80	400	Estimate
SunnySky X2212-9 KV1400 Brushless Motor (Quantity 2)	14.8	8,000	118,400	Estimate

$$3{,}750 + 500 + 1{,}400 + 100 + 200 + 400 + 118{,}400 = 124750 \text{ mW}$$

$$\frac{72{,}000\ mW}{124{,}750\ mW} = 0.57715$$

$$60 \text{ min} \times 0.57715 = \mathbf{34.63\ min}$$

Equation 1: Battery life calculations for payload electronics.

$$1{,}000 + 500 + 100 + 200 = 1{,}800 \text{ mW}$$

$$\frac{72{,}000 \text{ mW}}{1{,}800 \text{ mW}} = 40$$

$$1 \text{ hr} \times 40 = \mathbf{40\ hr}$$

Equation 2: Battery life calculations for payload electronics in low power mode.

While this 35-minute calculation seems low it should be plenty of time for the descent of the lander module. During the time that the lander 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 steering control system. Estimated calculations (Equation 2) show that in this low power mode the system should only draw approximately 1,800 mW of power. This results in the payload electronics system being able to remain in low power mode for 40 hours.

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 lander 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 lander module begins its software package reduces the chance of any mishap occurring from a single switch accidentally being turned on. The switches will be located on the underside of the lander 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.

Figure 12 describes the sequence of events for the steering control system software package:

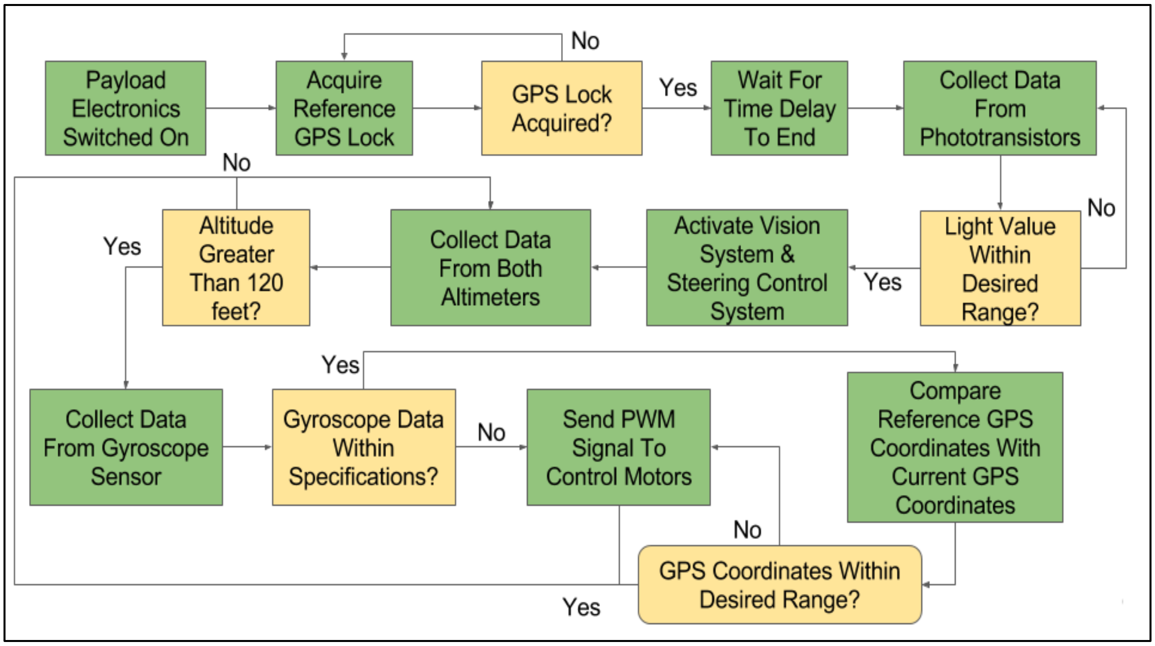


Figure 12: Steering control system flowchart.

5.6 Integration

This housing will slide out of the lower stage when the bottom separates from the nose cone removing any dimensional constraints. Without the constraints from the outer rocket tube, the spring-loaded mechanisms will force the arms with the mounted motors to be in a horizontal orientation, and the landing gear in a tripod configuration for landing.

In order for this design to function as intended, the different subsystems are required to have synchronized motion. Below is a discussion as to what motion is coupled, and how the system is oriented prior to deployment, as well as after deployment.

5.6.1 Subassembly Interactions

As mentioned above, a significant amount of motion is required for the steering system to function. This is all initiated by the black powder charges blowing to separate the rocket into its stages. Upon separating, the encapsulation with all of the mechanical systems gets pulled out of the main body of the rocket. At this time the steering system will deploy along with the landing gear.

5.6.2 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 three stages, one of them being the inner phenolic tube housing. Simple processes are used to make this transition occur, which will be explained in subsequent sections.

5.6.2.1 Pre-Deployment

Prior to separating, the rocket is one solid piece, with the encapsulation inside the lower stage. In this configuration, the arms with the mounted motors are oriented vertically, and the landing gear arms are tightly compressed to resemble a cylindrical shape. The landing gear and motor arms are held in this position due to the constraints placed by the outer rocket tube diameter.

5.6.2.2 Post-Deployment

Once the rocket begins to descend, it will separate into three stages, one of them being the inner phenolic tube housing.

5.7 Prototyping

Prototyping will be done to ensure that the final system design is achievable and the objective is complete. This prototype will be identical to the final system design, but will use purchased materials in the early stage. In the final stages of prototyping the design will integrate machined and fabricated parts to complete the final system design. Each system will be tested individually to make sure each works properly, then they will all be assembled to ensure that the integrated systems achieve the desired result. All of this will only be performed once a thoroughly developed model is constructed in SolidWorks to accurately depict the rocket in its entirety.

5.7.1 Construction

A 12 in. phenolic tube will be used for the construction of the electronics bay and landing gear system. The tube is cut into two 6 in. pieces using a hand saw. One piece will be used to form the housing of the electronics bay and the other will be used to form the landing gear system. A laser cutter is operated to cut the 6 in. tube into three equal legs. The legs will also be tapered with the application of the laser cutter. Makeshift wheels are mounted to each leg and spring loaded hinges connect each leg to the electronics bay. Bungee cords are used in place of the extension springs in early prototyping stages. The electronics bay will only be a housing formation and will not contain any electronics until all stages are integrated. Another 12 in. phenolic tube will be used for the construction of the steering system. Two static aluminum square tubes will take the place of the motor arms and mount to the phenolic tube. Motors are attached to the square tubes in order to test maneuverability of the system. Once each system is complete the two sections will mount together using an internal bracket. The construction of the prototype can be used to integrate the final parts and form the overall final assembly.

5.7.2 Testing

Independent tests will be conducted for the two primary subsystems that comprise the small third stage that will land vertically.

5.7.2.1 Steering System Test

The first test to be conducted will be for the steering mechanism. To ensure the chosen design can generate enough torque to induce sufficient counter rotation, a simplified model of the third inner small stage will be constructed. This model will have all of the same dimensions as the full-scale rocket. The arms for mounting the motors will not be pin actuated, so they will be locked in the horizontal position as if the stage is in the post-deployment orientation. These arms will be made using aluminum square bar stock to maintain a low cost and to allow for easy machining. The model will then be assembled with all of the motors, mounts, batteries, and other components necessary to steer the rocket. With all of these components assembled in the phenolic tube, it will be hung by a wire and the motors will be turned on. Doing so will allow the amount of thrust produced by the motors to be demonstrated and calculated given the moment arm, power input, and other parameters of the system.

5.7.2.2 Impact Test

The second test will be an impact test to examine the strength of the landing gear. To do so will require another phenolic tube with dimensions equivalent to those of the full-scale model, including the landing gear section. No additional components will be assembled other than those required for full functionality of the landing gear. Masses will be inserted into the phenolic tube to account for the lack of internal components. This setup will then be dropped from successively increasing heights with a parachute attached. Once impacted, visual observations will be made to check for failure. Calculations will also be made to find the impulse caused by impact given the drop height.

5.7.2.3 Simulated Tests

Finite Element Analysis tests will also be performed on the SolidWorks model to ensure all structures have a safety factor greater than one and are structurally stable.

6 Project Plan

6.1 Testing

6.1.1 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 Landing Module Test

The ability of the motors to induce counterspin and provide lateral movement was tested through the use of a working prototype (shown in Figure 13). This prototype was of roughly the same size and weight as the final module. With the model constructed, it was hung several feet off the ground in a fixture to simulate descent. The motors were set to various power settings with 10 in. propellers mounted. Motor power was gradually increased until sufficient thrust was generated by the motors. It was deemed that 15% power worked best in combination with the aforementioned propeller size. A video of this test is available online at http://www.usfsoar.com/2nd-prototyping-meeting/.

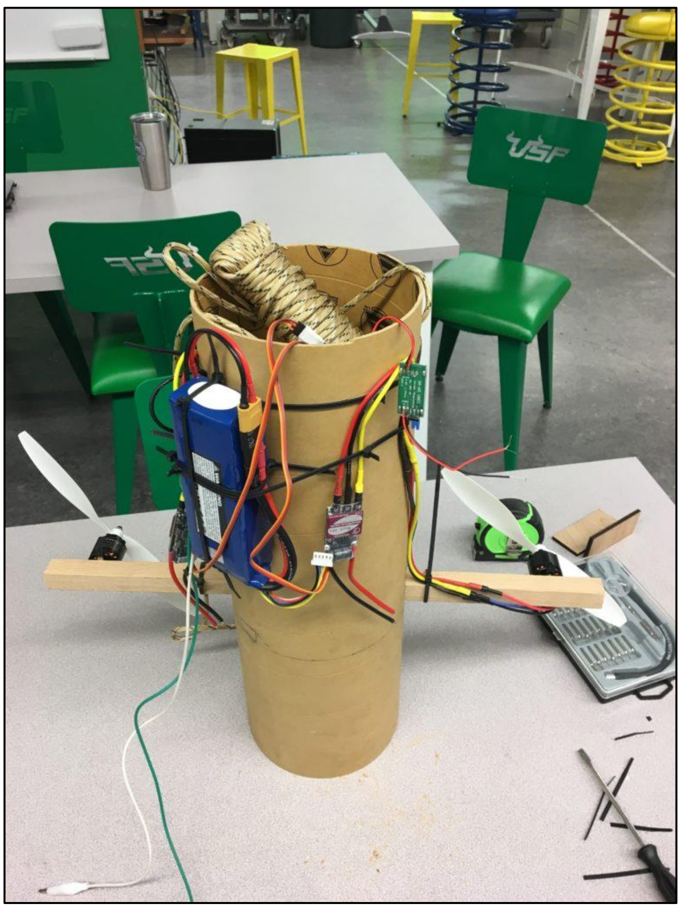


Figure 13: Early landing module prototype, used for testing.

6.1.3 Subscale Launch Test

The subscale testing was performed on December 17th, 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 we will fix it.

6.1.4 Full-Scale Launch Test

The full-scale test is scheduled for February 2017. Multiple test flights will be done to ensure all systems are working correctly and the launch vehicle reaches as close to 5,280 ft. as possible. This test will be considered a success if all systems deploy correctly, the launch vehicle reaches apogee near 5,280 ft, no damage is sustained, and all subsystems are recovered.

6.2 Requirements Compliance

Table 47: List of competition requirements and methods used to meet them.

Requirement	Method of Meeting Requirement	Verification
Onboard camera system shall be capable of identifying and differentiating between three randomly placed targets.	The downward facing camera will connect to the onboard computer (Raspberry Pi 3B) which will be processing the images captured of the targets.	For verification, review data captured and analyzed by system once recovered after launch.
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.

Requirement	Method of Meeting Requirement	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 task 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 four 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 48: Current budget overview for project duration.

Budget Item	**Projected Cost** ($)	**Amount Spent** ($)	**Remaining Budget** ($)
Rocket	3,000	263.90	2,736.10
Payload	2,000	1,074.29	925.71
Travel	2,857.08	N/A	N/A

Table 49: Detailed expense breakdown for the lander 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

Projected Expenses	**Vendor**	**Cost ($)**
SanDisk Extreme 32 GB SD Card	Amazon	16.95
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

Projected Expenses	Vendor	Cost ($)
SunnySky X2212-9 KV1400 Brushless Motor	Buddy RC	30.60
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

Projected Expenses	**Vendor**	**Cost** ($)
Male Header Pins	Amazon	8.99
10 DOF Sensor Board	Amazon	23.99
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
Rocket		
Mobius Video Camera Shroud	Additive Aerospace	39.90
6 in. G12 Color Airframe	Madcow rocketry	224.00
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 50: 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
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

Due Date	Tasks/Event	Description	Deliverables
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
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

Due Date	Tasks/Event	Description	Deliverables
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
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

Due Date	Tasks/Event	Description	Deliverables
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
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

Due Date	Tasks/Event	Description	Deliverables
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
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

Due Date	Tasks/Event	Description	Deliverables
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		
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

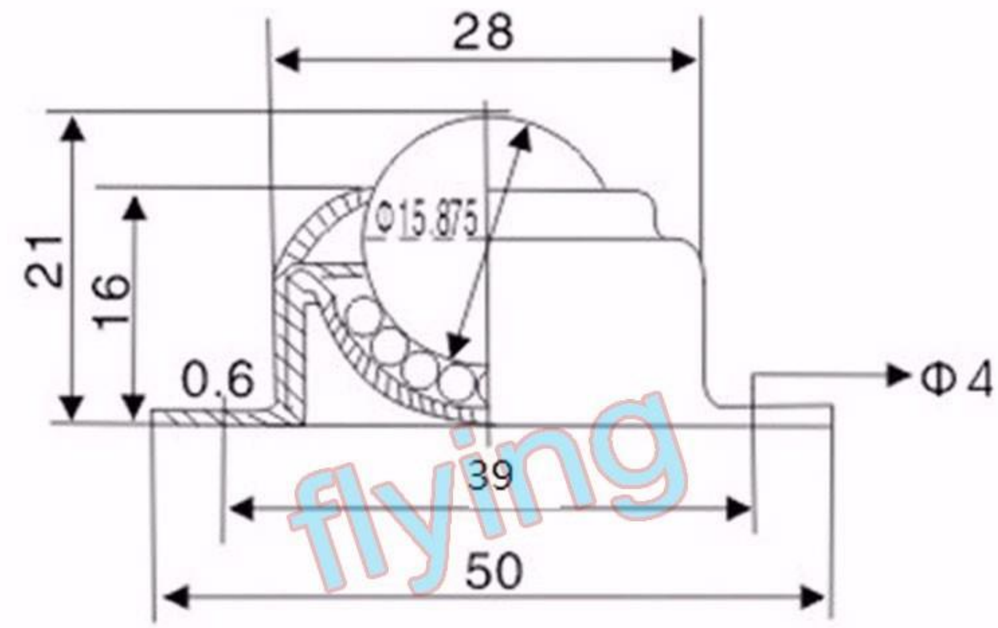
Due Date	Tasks/Event	Description	Deliverables
4/24/2017	PLAR Submission	Submit PLAR to NASA	PLAR report

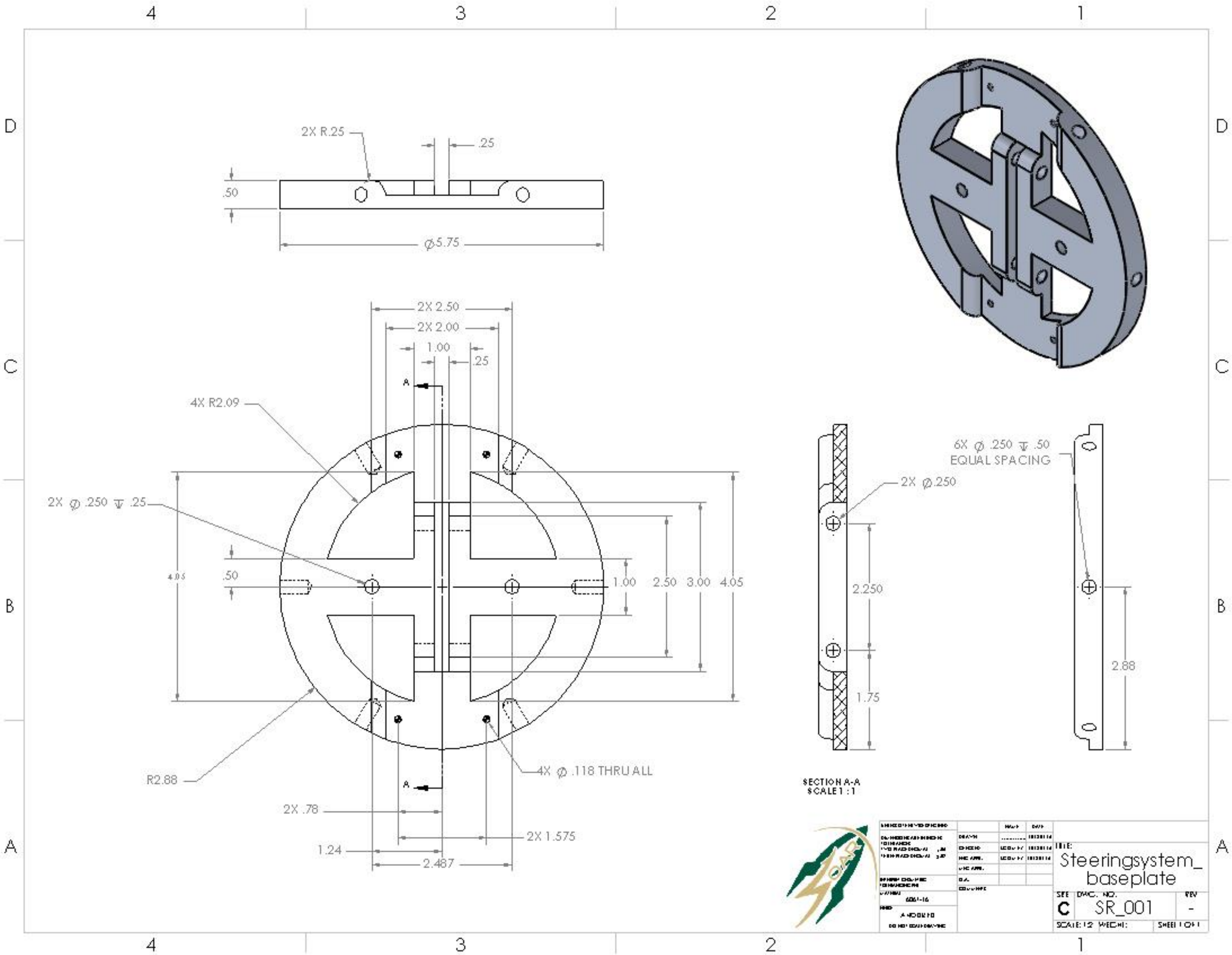
7 Appendix

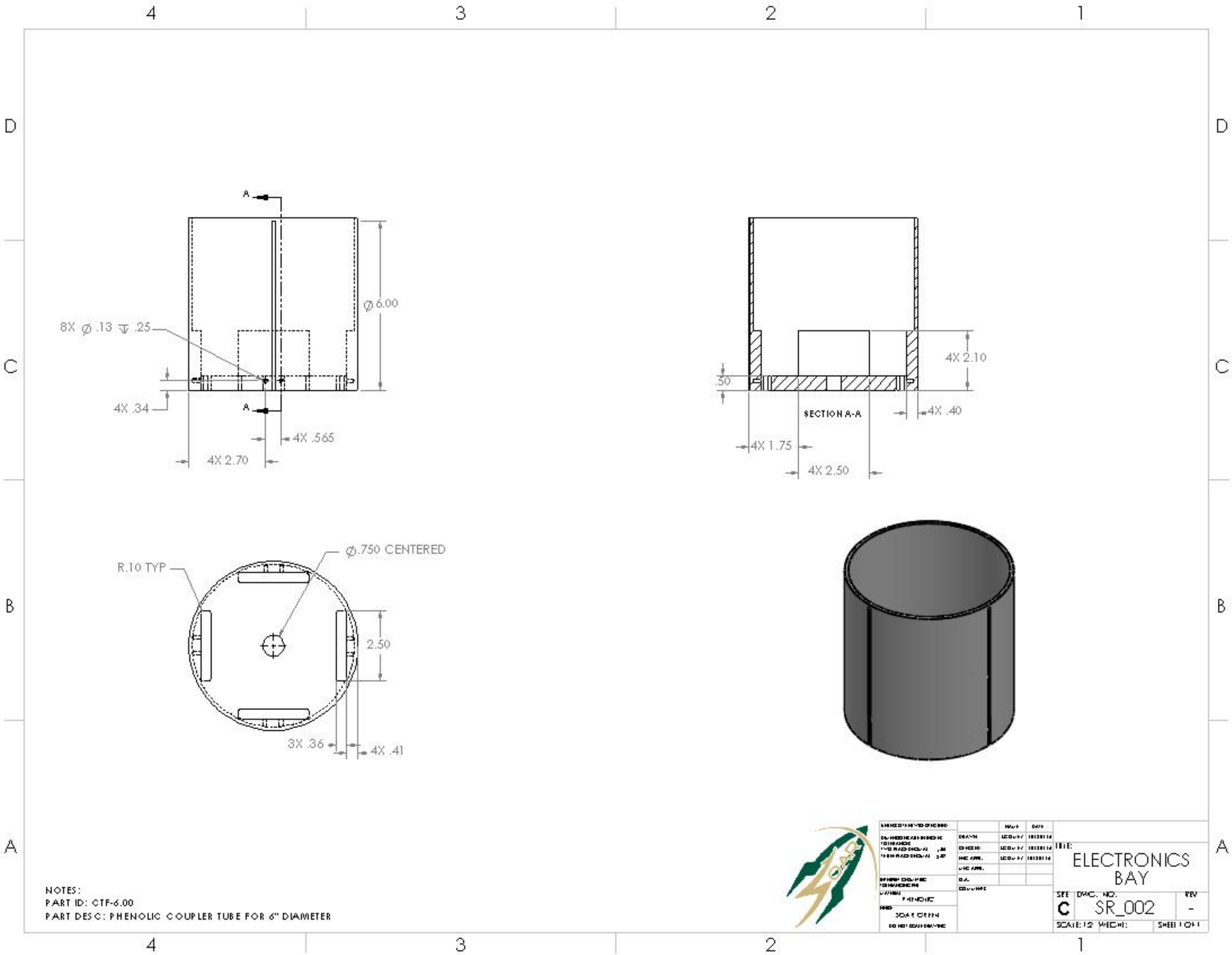
7.1 Contributors

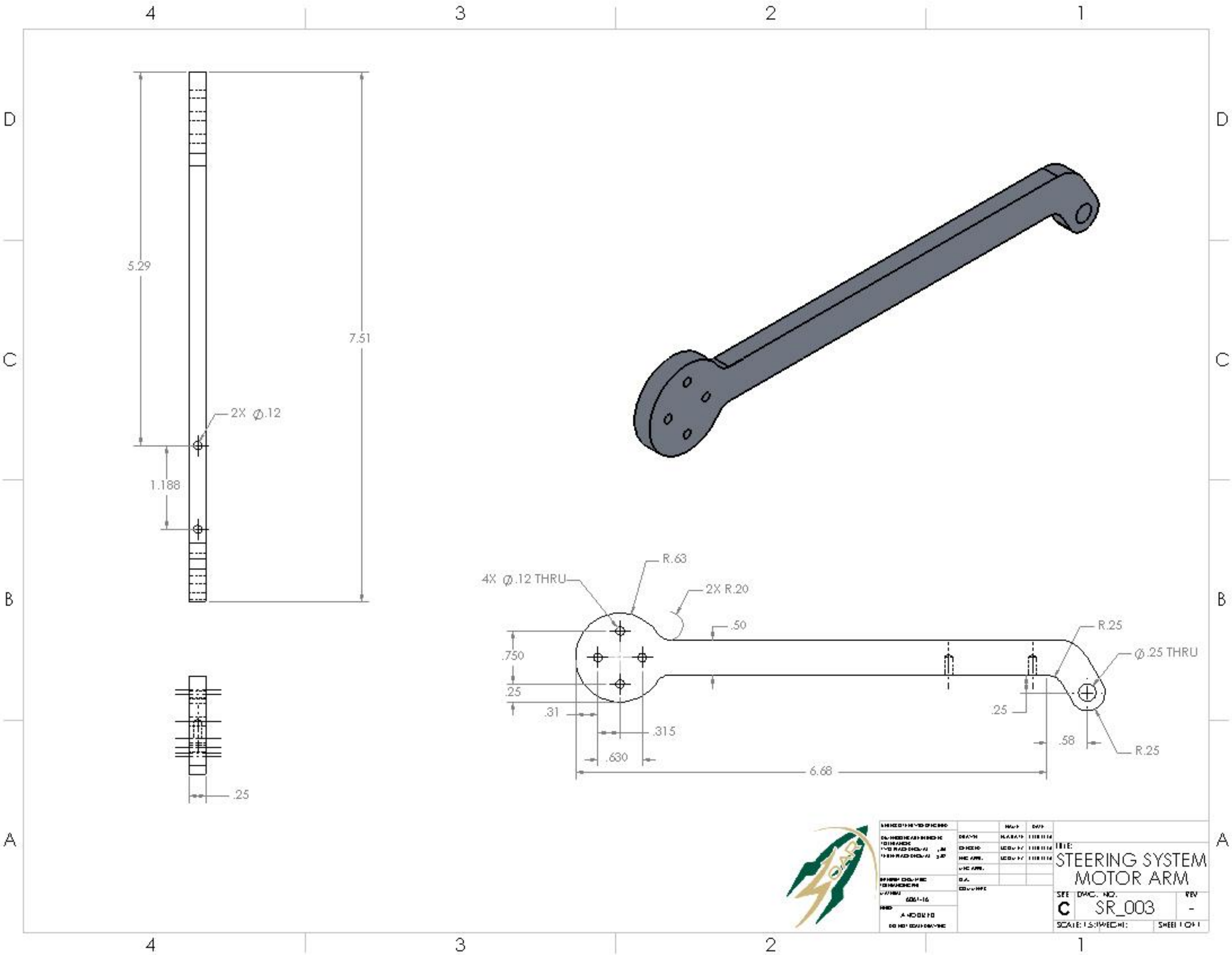
- **Project Management:**
    - Kateryna Turchenko
    - Danielle Petterson
    - Andrew Huff
- **Launch Vehicle:**
    - Jamie Waters
    - Brooke Salas
    - Frankie Camargo
    - Logan Sveum
    - Andrew Huff
- **Landing Module:**
    - Jaime Gomez
    - Simon Wilson
    - James Pierce
    - Nicholas Abate
    - Tanner Diberardino
- **Safety:**
    - Stephanie Bauman
- **Editing and Formatting:**
    - Ian Sanders

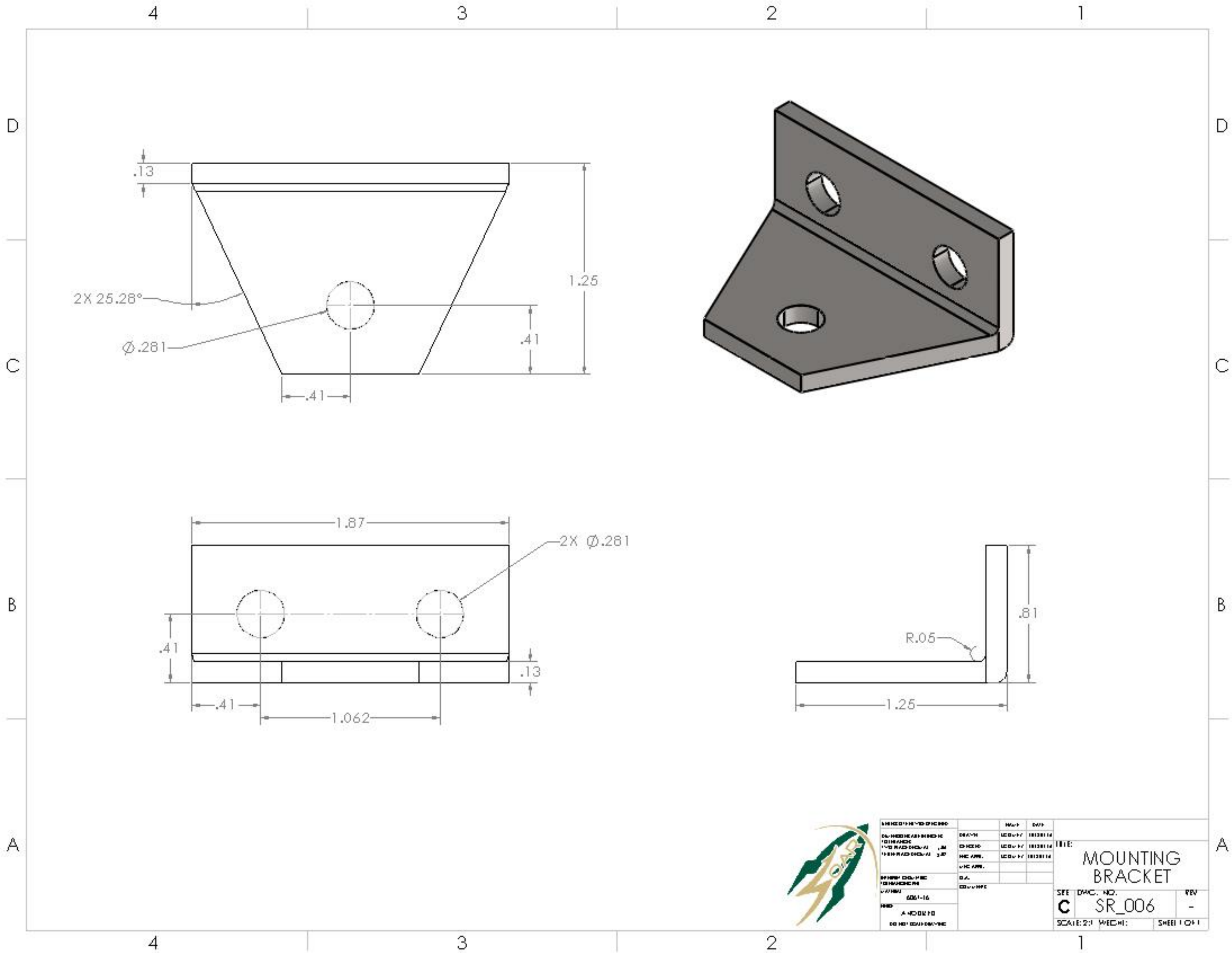
7.2 SolidWorks Drawings



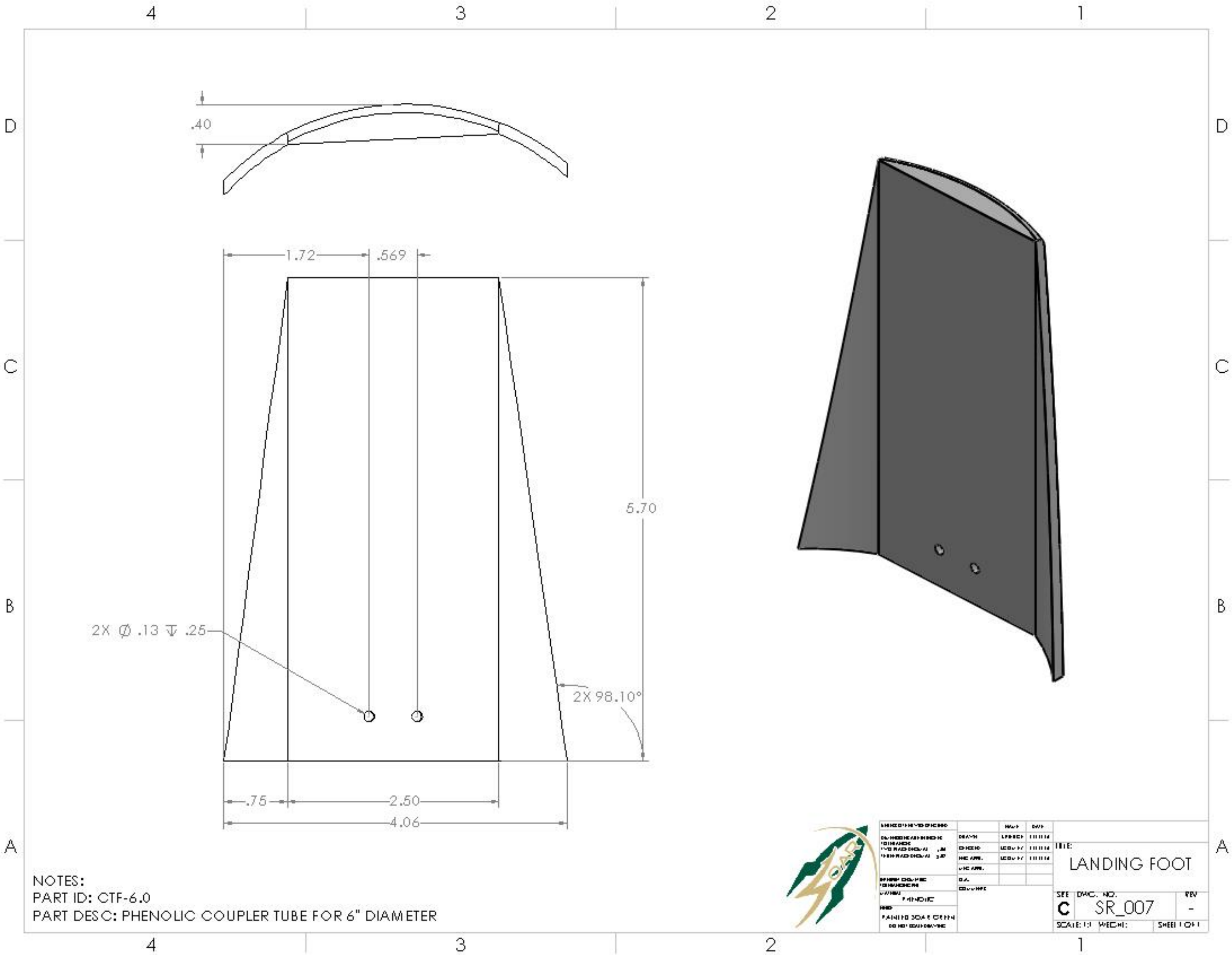

2X R.25
.25
.50
⌀5.75
2X 2.50
2X 2.00
1.00
.25
4X R2.09
2X ⌀ .250 ↧ .25
.50
1.00
2.50
3.00
4.05
R2.88
4X ⌀ .118 THRU ALL
2X .78
1.24
2X 1.575
2.487
2X ⌀ .250
2.250
1.75
SECTION A-A
SCALE 1 : 1
6X ⌀ .250 ↧ .50
EQUAL SPACING
2.88
Steeringsystem_
baseplate
SIZE C
DWG. NO. SR_001
REV -

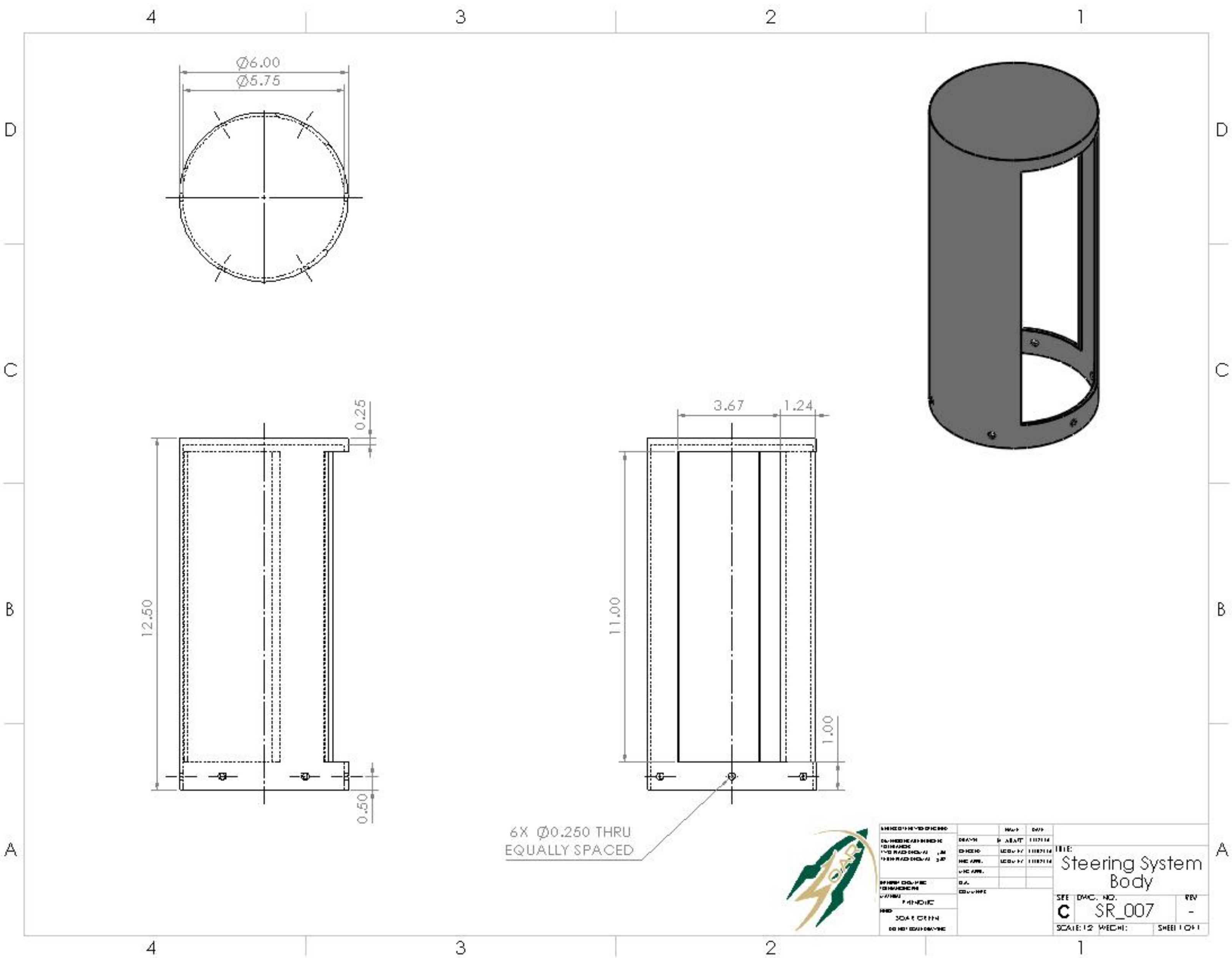

8X ⌀ .13 ↧ .25
⌀ 6.00
4X .34
4X .565
4X 2.70
4X 2.10
.50
SECTION A-A
4X .40
4X 1.75
4X 2.50
R.10 TYP
⌀.750 CENTERED
2.50
3X .36
4X .41
NOTES:
PART ID: CTF-6.00
PART DESC: PHENOLIC COUPLER TUBE FOR 6" DIAMETER
ELECTRONICS BAY
SR_002


5.29
7.51
2X ∅.12
1.188
.25
4X ∅.12 THRU
R.63
2X R.20
.50
R.25
∅.25 THRU
.750
.25
.31
.315
.630
6.68
.25
.58
R.25
STEERING SYSTEM MOTOR ARM
C
SR_003

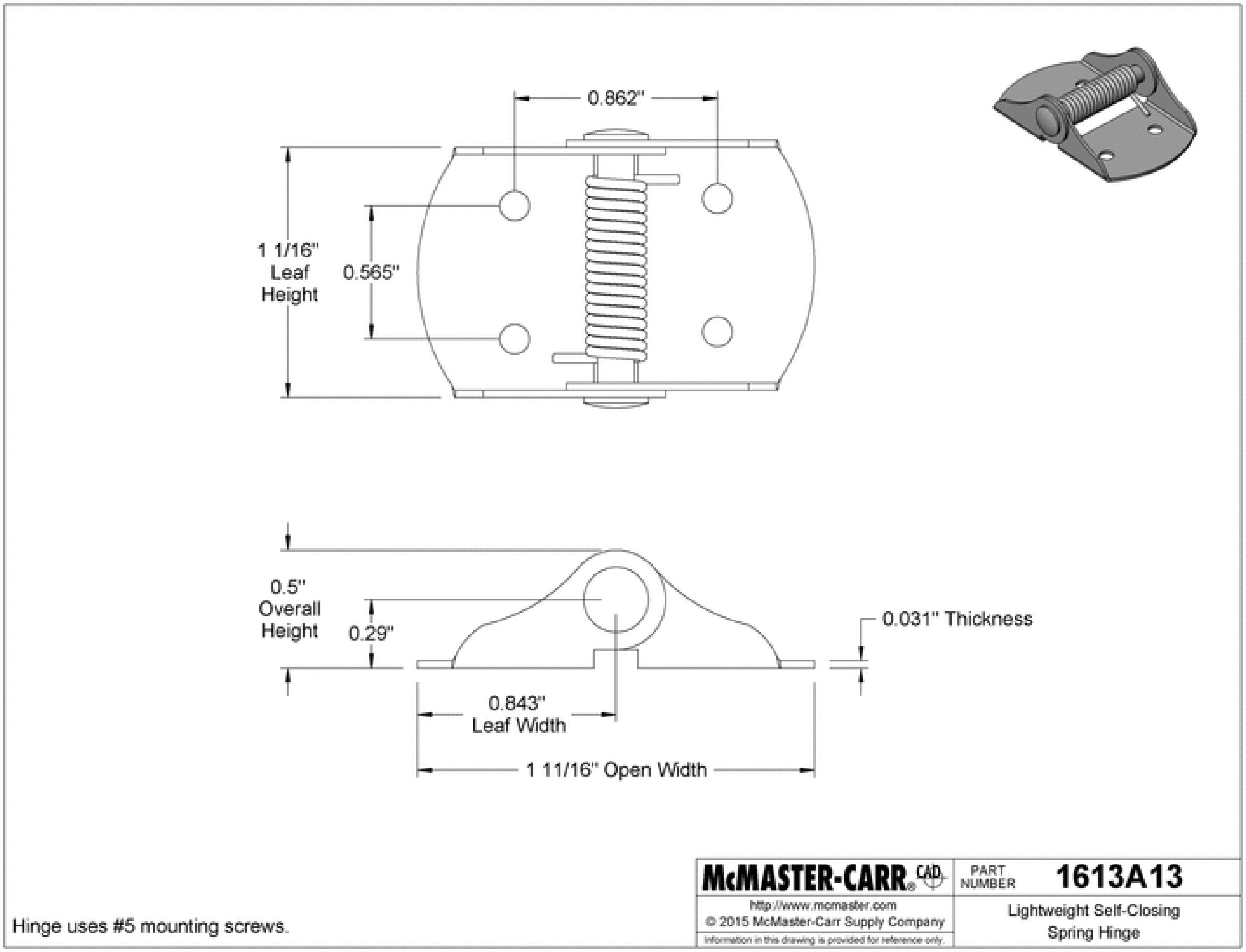


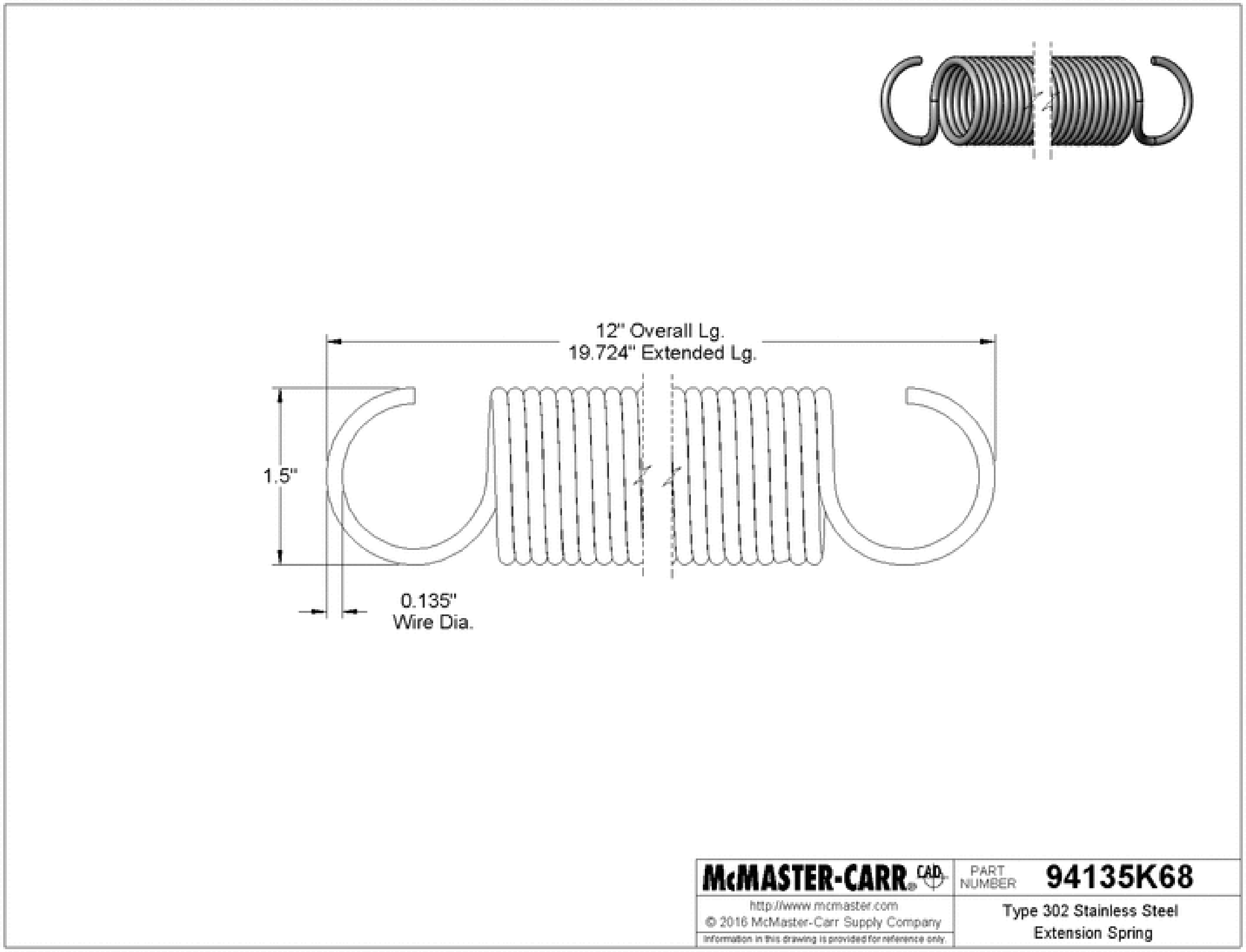
.13
1.25
2X 25.28°
Ø.281
.41
.41
1.87
2X Ø.281
.41
.13
.41
1.062
.81
R.05
1.25
MOUNTING BRACKET
SIZE C
DWG. NO. SR_006
REV -
SCALE: 2:1

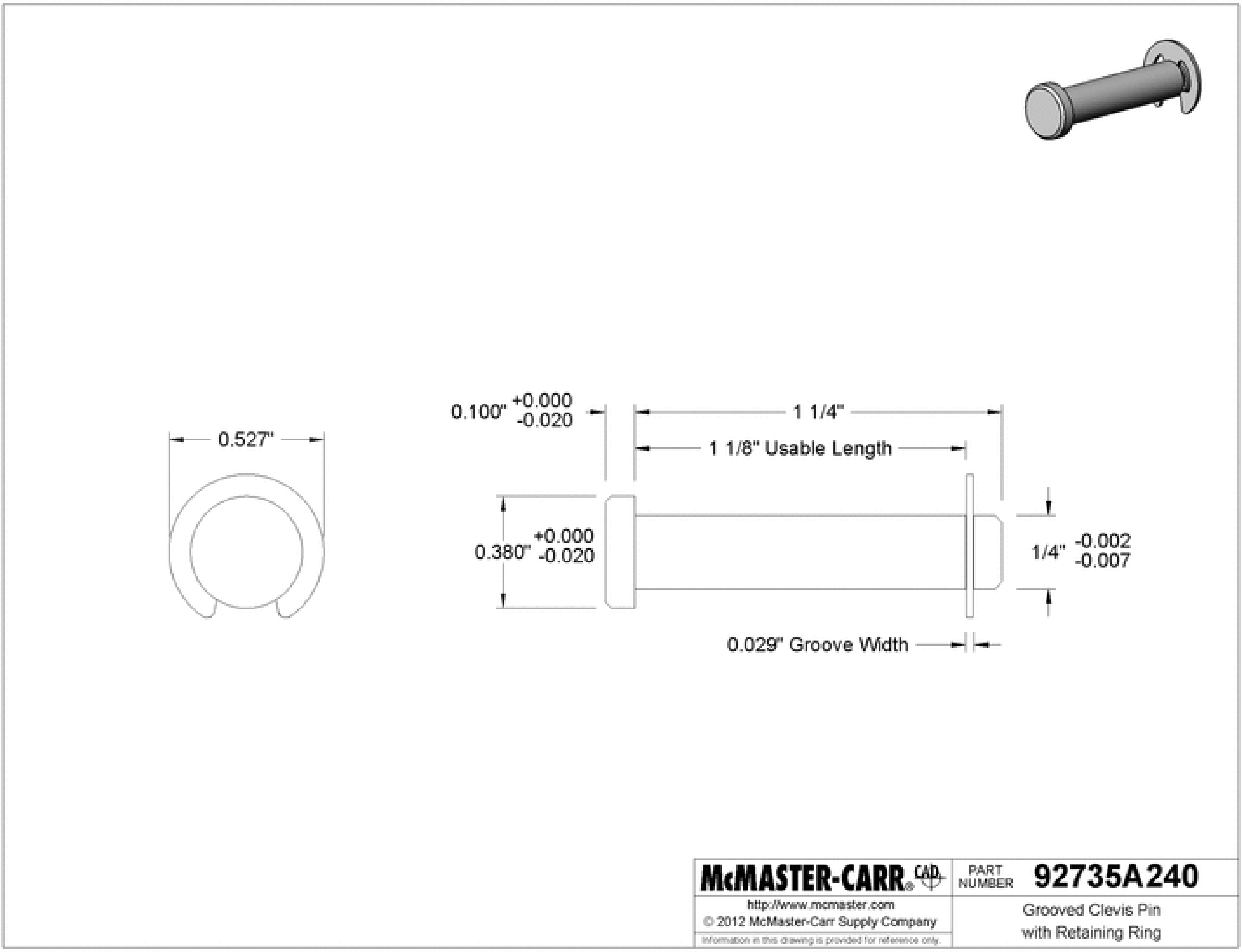

.40
1.72
.569
5.70
2X Ø .13 ⊽ .25
2X 98.10°
.75
2.50
4.06
NOTES:
PART ID: CTF-6.0
PART DESC: PHENOLIC COUPLER TUBE FOR 6" DIAMETER
PHENOLIC
LANDING FOOT
C
SR_007
-

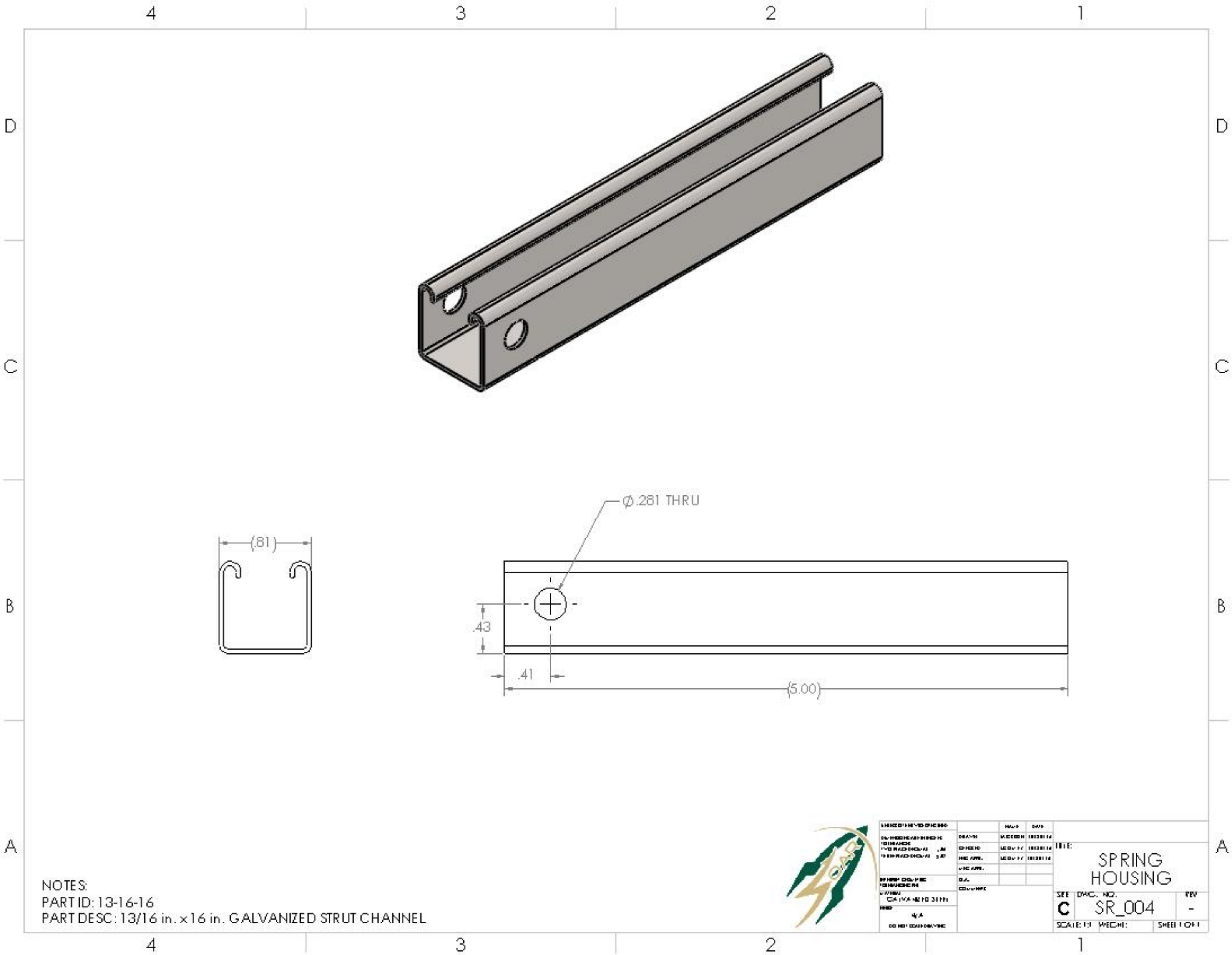


Ø6.00
Ø5.75
0.25
12.50
0.50
3.67
1.24
11.00
1.00
6X Ø0.250 THRU EQUALLY SPACED
TITLE:
Steering System Body
SIZE C
DWG. NO. SR_007
REV -

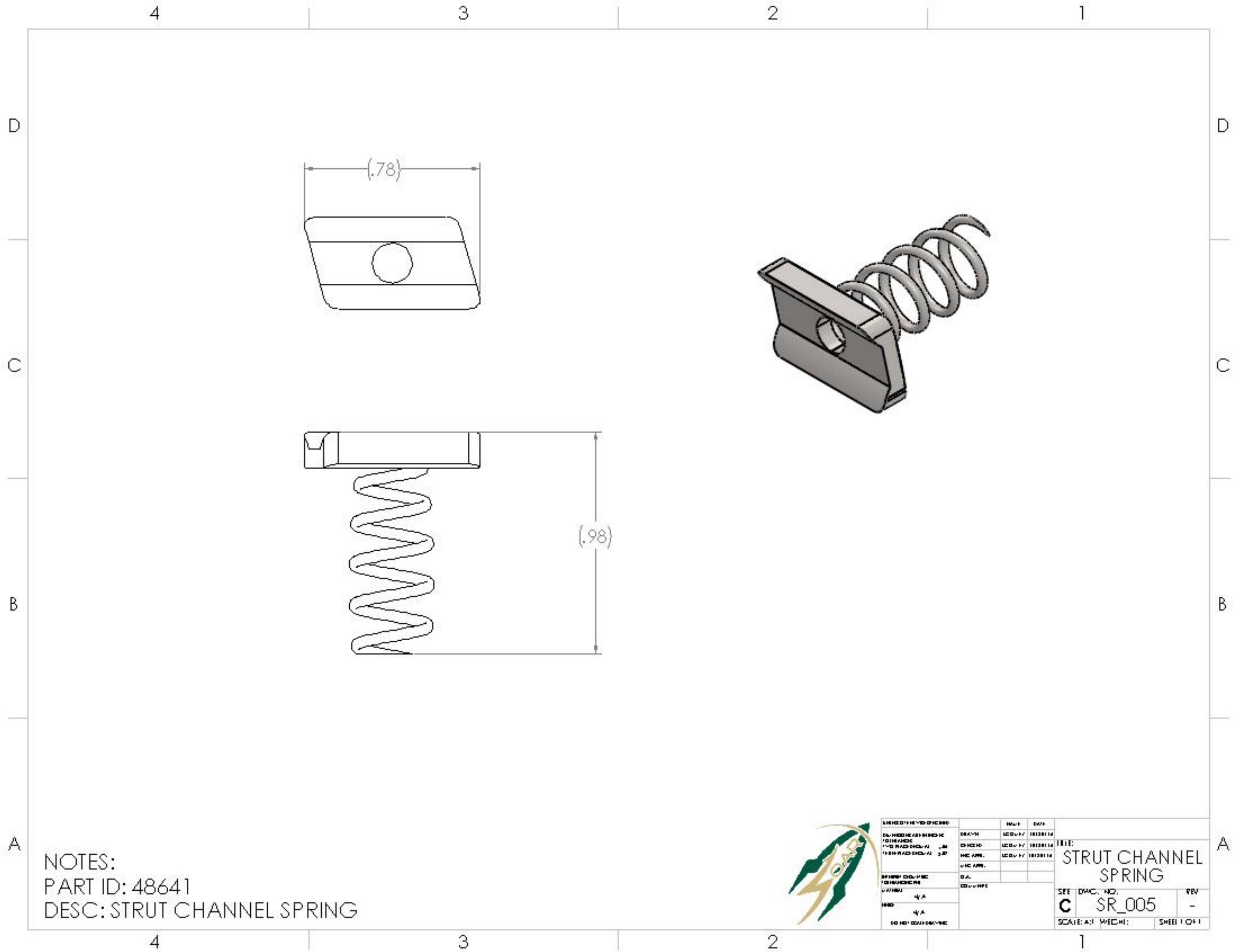

0.862"
1 1/16" Leaf Height
0.565"
0.5" Overall Height
0.29"
0.031" Thickness
0.843" Leaf Width
1 11/16" Open Width
Hinge uses #5 mounting screws.
McMASTER-CARR CAD
PART NUMBER 1613A13
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Lightweight Self-Closing Spring Hinge


12" Overall Lg.
19.724" Extended Lg.
1.5"
0.135"
Wire Dia.
McMASTER-CARR CAD
PART NUMBER
94135K68
http://www.mcmaster.com
© 2016 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Type 302 Stainless Steel
Extension Spring


0.527"
0.100" +0.000 -0.020
1 1/4"
1 1/8" Usable Length
0.380" +0.000 -0.020
1/4" -0.002 -0.007
0.029" Groove Width
McMASTER-CARR
PART NUMBER 92735A240
http://www.mcmaster.com
© 2012 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Grooved Clevis Pin with Retaining Ring



Ø.281 THRU
(.81)
.43
.41
(5.00)
NOTES:
PART ID: 13-16-16
PART DESC: 13/16 in. x 16 in. GALVANIZED STRUT CHANNEL
TITLE:
SPRING HOUSING
SIZE
C
DWG. NO.
SR_004
REV
-
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1



NOTES:
PART ID: 48641
DESC: STRUT CHANNEL SPRING