UNIVERSITY OF SOUTH FLORIDA

NASA Student Launch 2017

Preliminary Design Review Report

November 4th, 2016

SOCIETY OF AERONAUTICS AND ROCKETRY

14247 Les Palms Circle, Apt. 102

Tampa, Florida 33613

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1 Summary of PDR Report

1.1 Team Summary

1.1.1 Team Name & Mailing Address

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

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

1.1.2 Team Mentor, NAR/TRA number and certification level

Team mentor: Jim West

Jim West is an experienced member of the hobby rocketry community and local Tampa TRA. He oversees launches at Varn Ranch on Tripoli launch days and has acted as a mentor in terms of design and manufacturing of our rockets, particularly high powered designs.

TRA number: Jim West Tripoli 0706, Tripoli advisory panel member

Certification level: 3

1.2 Launch Vehicle Summary

Table 1: Dimensions and mass of assembled launch vehicle.

Property	Quantity
Diameter (in)	6
Length (in)	133
Projected unloaded weight (lb.)	39.38
Projected loaded weight (lb.)	51.44

The diameter of our rocket is 6 in. to allow more room for our recovery and payload systems onboard. This will ensure that there is no tangling of the parachutes and allow for successful deployment of any other systems. The length of the rocket was critically analyzed to ensure enough room onboard for the multiple parachutes and any other onboard systems.

1.2.2 Motor Selection

The motor we have selected at this time is the L1090 from Cesaroni Technology. This motor was selected because of its high specific impulse, giving our rocket the best chance of obtaining an apogee of 5280 ft. This big of an L-Class motor is important relative to our rocket, due to the size of our launch vehicle enough thrust will need to be provided to not only get our vehicle of the pad, but so that it also reached its appropriate apogee.

Table 2: Properties of the selected motor (L1090).

Property	Quantity
Total Impulse (Ns)	4687
Burn Time (s)	4.35
Diameter (mm)	75
Length (mm)	665
Propellant Weight (g)	3491

1.2.3 Recovery System

The launch vehicle will be comprised of a total of four parachutes: one for the nose cone, one for the payload, one for the main airframe, and one for the booster. When the rocket reaches apogee, the booster's drogue parachute will deploy while being tethered to the rest of the launch vehicle by shock cord. At another point in flight, the black powder charges will go off for the upper section of the rocket. This will result in the nose cone coming off with its own parachute, the payload coming out with its own parachute, and then the main parachute for the rocket body. All parachutes will be in deployment bags to ensure the parachutes will not get stuck or tangled. A GPS will be in the nose cone, payload section, and altimeter bay for safe retrieval of all components.

1.2.4 Milestone Review Flysheet

The Milestone Review Flysheet can be found on the Society of Aeronautics and Rocketry at the University of South Florida Website on the NSL 2016-17 page under Current Projects, or at the following link: http://www.usfsoar.com/wp-content/uploads/2016/11/Flysheet-2017.pdf

1.3 Landing Module Summary

1.3.1 Landing Module Experiment Procedures

Two experimental tests will be conducted to ensure proper functionality of the landing module. These tests will be performed independently because they are not reliant on one another.

The first of these two tests will be examining the capability of the mounted motors to produce counterspin. Doing so will require a model of actual size of just the inner landing module. This model will be a simplified prototype of the final system with no moving arms, springs, or supplementary systems. It will simply be composed of a phenolic tube with a dowel inserted across its diameter. The only important dimension of this dowel is the overall length from the center to the end on each side. A motor will then be mounted on either end of the dowel resembling the full-scale rocket with all of the necessary electronics. With this prototype constructed, it will be hung from a stand to suspend it in the air, mimicking free fall. Various amounts of spin will then be induced and the ability of the system to make corrections will be assessed. If the response time is too high, then a new program will be written, or larger motors will be implemented to create more thrust. This data is qualitative in nature.

Next, the landing gear is to be tested. Similar to the first test, a full-scale model will be built in a simplified manner. Rather than placing any electronics in the landing module, masses will be used to simulate the additional weight of the electronics and mechanical components. This model will then be dropped from several measured heights and dropped with a deployed parachute to predict the behavior of the landing gear system. Doing so will allow for the predicted applied stresses to be compared to what the system will actually be subjected to in a realistic landing. It will also give a prediction as to what spring and hinge angle setting combinations will work best.

2 Changes Made Since Proposal

2.1 Vehicle Criteria Changes

The design has changed to a four-parachute system since the payload was moved from the fin can of the rocket to the upper section. The fin can will now deploy a drogue parachute at apogee while being connected by shock cord to the main body. Sometime later the upper section will deploy. The nose cone will be on a parachute, followed by the payload on a parachute, and then another parachute that is connected to the main body of the rocket.

2.2 Landing Module Changes

2.2.1 Steering System

The original design for the steering system used 4 vertical flaps orthogonal to each other on the body of the rocket that would be controlled by an onboard computer to steer the rocket. The flaps were rectangular and convex so as to be flush with the body of the rocket. The flaps were hinged at the top so that when extended outward they would provide a drag force to steer the rocket laterally. This design was changed to a more active steering system that uses propellers and brushless motors for steering. This decision was after a meeting with our advisor, who raised concerns about the spin of the rocket on descent. This spin would not only nullify the steering effect of the flaps but also make it harder for the camera to perform its vision analysis. The current active steering system utilizes two brushless motors mounted on folding arms that extend from the body of the landing module. The blades of the propellers are oriented perpendicular to the ground so they can be used for lateral movement as well as eliminated the spinning problem.

2.2.2 Vision System

Based off of original estimates of processing power needed for the real-time vision analysis, the Odroid XU4 computer was chosen for the vision system. This was chosen over the Raspberry Pi 3b because of its superior processing power which would allow us to capture and analyze more images per second. After clarification of the vision requirements and redesigning the system to include GPS integration, the Raspberry Pi 3b was reconsidered as our processing needs significantly dropped and the Raspberry Pi 3b would consume less power during use.

2.2.3 Landing Gear

The original design consists of legs actuated by four motors and had a max extension of 12”. The original design also did not have any absorption system to absorb the impact force of the landing module on the ground. This led to the creation of the newest design, which consists of spring loaded hinges that are actuated when the landing module jettisons from the rocket. The hinges allow a max leg extension of 18”. Extension springs connected between legs will allow for a set descent diameter and absorb the impact force on the ground.

2.3 Project Plan Changes

A more detailed schedule was created to make sure the team always remained on track. Each task has a description and expected deliverables. A major change in the schedule was to build the full-scale rocket earlier than expected in order to perform multiple 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 Vehicle Criteria

3.1 Selection, Design, and Rationale

3.1.1 Mission Statement

The mission is to build a rocket that will launch to an altitude of 5,280 feet and will land a portion of the rocket, containing a camera, upright after identifying a designated tarp. At apogee, the booster to the rocket will be released but will still be tethered to the rest of the rocket. Following soon after is the release of the nosecone and the landing system containing the camera and navigation system for the upright landing. To find everything quickly after the launch, GPS systems will be placed in the nosecone, the landing system, and the electronics bay.

From this mission, SOAR will be able to further expand on the knowledge of engineering and rocketry in order to successfully launch the vehicle and land it upright using many different methods and techniques.

3.1.2 Mission Requirements

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

Table 3: Detailed mission requirements and confirmation methods.

Requirement	Method	Verification
Launch the rocket 5,280 ft.	The rocket will be built with a motor designed to get the vehicle to 5,280 ft. at apogee	Subscale and Full-scale testing
The vehicle shall carry one barometric altimeter for recording the official altitude used in determining the altitude award winner.	The altimeter in the electronics bay will be able to record the altitude of the rocket throughout the whole flight.	NSL Inspection as well as inspected and approved by the safety officer.

Requirement	Method	Verification
All recovery electronics shall be powered by commercially available batteries and an electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver	The altimeter and GPS system will be powered by a 9V battery that it available commercially. There will also be a GPS in every independent section of the launch vehicle.	NSL Inspection as well as inspected and approved by the safety officer.
The launch vehicle shall be designed to be recoverable and reusable.	The launch vehicle will contain parachutes on every separate or tethered part of the rocket that will be released at apogee and an altitude that will allow it time to open up properly and safely.	Subscale and Full-scale testing.
The launch vehicle shall have a maximum of four (4) independent sections.	The rocket will be broken up into four sections: the nosecone, 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 inspected and approved by the safety officer.
The launch vehicle shall be limited to a single stage.	The launch vehicle will only contain one booster that will light to start the flight.	NSL Inspection as well as inspected and approved by the safety officer.

Requirement	Method	Verification
The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal Aviation Administration flight waiver opens.	There will be a Final Assembly and Launch Procedure checklist that will ensure that the launch vehicle will be safely prepared and ready to launch within the 4 hours.	There will be Final Assembly and Launch Procedure Checklist before the test flights of the Subscale rocket and the Full-scale rocket and will be time ourselves to ensure we completed the list safely and within the time of 4 hours.
The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	The launch vehicle and the electronic components within will be properly 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 be at the launch pad for an hour without losing any power.	Full-scale and Subscale testing. It will also be timed in order to make sure the battery life last, at minimum, an hour.
The launch vehicle shall be capable of being launched by a standard 12-volt direct current firing system.	The ignitor used it the rocket will be able to withstand a 12-volt 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 12-volt direct current firing system that is compatible with the ignitor in the launch vehicle.	NSL Inspection as well as inspected and approved by the safety officer.

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 L1100 from Animal Motor Works which is certified by the National Association of Rocketry and it made up of ammonium perchlorate.	NSL Inspection as well as inspected and approved by the safety officer.
Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria.	Our design did not contain a pressure vessel.	NSL Inspection as well as inspected and approved by the safety officer.
The total impulse provided by a University launch vehicle shall not exceed 5,120 N·s.	The motor chosen is not bigger than an L motor and has a total impulse of 2600 N·s.	NSL Inspection as well as inspected and approved by the safety officer.
The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	The center of pressure and the center of gravity in comparison to the diameter of the body tube will have a minimum stability margin of 2.0.	Full-scale and Subscale testing as well as simulations of our rocket in the simulation programs.
. 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 will have a subscale model ready and launched prior to CDR.	Evidence of subscale testing.
All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day.	The full-scale rocket will be built and launched as well as recovered prior to the FRR and it will be a replica of the rocket flown on launch day.	Evidence of full-scale testing as well as NSL inspection.
Any structural protuberance on the rocket shall be located aft of the burnout center of gravity	The launch vehicle is designed to ensure all structural protuberances are aft the burnout center of gravity.	NSL Inspection as well as inspected and approved by safety officer.

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 inspected and approved by 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 inspected and approved by 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 inspected and approved by the safety officer.
At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft·lbf	The correct and appropriate parachute size will be chosen in order to slow the launch vehicle down enough to ensure a kinetic energy of less than 75 ft·lbf. Multiple tests will be simulated.	Full-scale and Subscale testing.
The recovery system electrical circuits shall be completely independent of any payload electrical circuits. The recovery system 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 inspected and approved by 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 inspected and approved by safety officer.

Requirement	Method	Verification
Teams shall design an onboard camera system capable of identifying and differentiating between 3 randomly placed targets	The launch vehicle will contain a landing system that has a camera and navigation system that it 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 inspected and approved by safety officer.

3.1.3 Mission Success Criteria

The following criteria needs to be met to consider the launch a success.

1. The launch vehicle leaves the rail cleanly with minimal interference.
2. The launch vehicle has a stability margin of at least 2.0 for the duration of the flight.
3. The launch vehicle reaches an altitude of 5,280 feet with a margin of error of +/- 50 feet.
4. The parachutes deploy successful and slow the components to a safe speed
5. All components are recovered without damage
6. Sub-scale launch vehicle launched by CDR
7. Full-scale launch vehicle launched by FRR

3.1.4 Vehicle Design Summary

3.1.4.1 Airframe

The airframe of the launch vehicle was selected as 6 in. diameter, G10 fiberglass tubing. A 4-in. diameter airframe was initially considered, but was decided to be too small to fit the proper shock cord and parachutes for each of landing sections. An 8-in. diameter launch vehicle was considered as well, but was quickly concluded to be too large. The 8-in. airframe would have much more mass, resulting in a launch vehicle unable to reach a mile altitude within the range of an L-Class motor. G10 fiberglass was the selected material based on its availability and its superior strength to phenolic tubing. The launch vehicle needs to be as reliable as possible throughout the scope of the competition, as well as after the competition to be utilized for further research.

3.1.4.2 Fins

The launch vehicle will include a three-fin design, composed of three carbon fiber fins. Compared to four fins, the three-fin design reduces drag, allowing the launch vehicle to achieve an optimal apogee. The fins have a height of 15.7 cm and a thickness of 0.476 cm, providing a strong level of stability. The material selection of carbon fiber was due to the its reduced weight, higher rigidity, and higher strength compared to G10 and G12 fiberglass. The lightweight capabilities of the carbon fiber fins keep the launch vehicle in range of reaching the desired apogee, and the high strength and rigidity of the fins ensure that the launch vehicle can withstand any impact.

3.1.4.3 Nosecone

The selected nosecone is a fiberglass ogive nosecone from Public Missiles Ltd, with a diameter of 6 in. The fiberglass nose cone provides higher strength than a plastic nose cone. The ogive design is standard with high-powered model rocketry, which is the most commonly used within the organization.

3.1.4.4 Internal Couplers, Bulkheads, and Centering Rings

The internal couplers will be composed of G10 fiberglass, just like the airframe tubing. Fiberglass was considered over phenolic tubing since it is stronger and lighter, which is more optimal for the launch vehicle design. All the bulkheads are made of 0.5 in thick birch plywood since it is cost efficient and simple to use, and the bulkheads located on the altimeter bay are reinforced with carbon fiber. The centering rings are also composed of 0.5 in thick birch plywood, located on the top and bottom of the booster.

3.1.4.5 Altimeter Bay

The tubing of the altimeter bay is made of G10 fiberglass, providing a snug fit to secure the position of the altimeter bay, but not too snug to allow proper removal. The altimeters and batteries will be secured to a board of 0.5 in thick birch plywood, however, a 3D printed sled, made of PLA plastic, is also being considered. Using a 3D printed sled will provide an easy means of production and optimal use of space in the altimeter bay.

3.1.4.6 Motor Selection

During our motor selection process, we narrowed down the possible motors to the Cesaroni L1090, the Aerotech L1365, and the Aerotech L1390. Through multiple simulations in different environments, we found that the Cesaroni L1090 was simply the best fit for our design. At a projected altitude of 4,954 feet, this motor gave us the optimal amount of margin of error when it came to approaching our target of 5,280 feet, as we are purposely overestimating the mass of the rocket. The Aerotech L1365 was too high for what we were comfortable with at 5,231 feet, and the Aerotech L1390 just could not get the job done with a low 4064 feet.

3.1.5 Evaluation and Verification Plan

Table 4: 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 and/or visual 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	Open Rocket Simulations with the motor loaded
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	The launch vehicle will be seen as it lands safely

3.1.6 Manufacturing, Verification, Integration, and Operations Planning

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

Table 5: Pre-mission tests and purposes.

Name	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 see 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.

3.1.7 Progression and Current Status of Design

The launch vehicle has gone through two design changes. The initial design of our launch vehicle involved landing the aft section of our rocket. This incorporates the motor mount, fins, motor retainer, and quadcopter assembly with parachute for recovery. The second design separated the quadcopter assembly from that of the aft section of our launch vehicle, placing it a little more than mid-way up the rocket.

The positives that arose from a bottom housed bi-propeller system were, to put modestly, 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 quadcopter assembly and the drogue attached to the rest. The drawbacks of this design came from the heavy weight of the aft bay. This weight decreases the stability of our rocket and thus and us rethink our initial design.

As stated above, the alternative, with the quadcopter assembly about midway of the rocket, should be chosen mostly because of the decreased weight of the quadcopter assembly and the increased stability of our rocket. Research shows that the better stabilized a rocket is, the better its flight path can be predicted. Though the rockets stability is now within a reasonably sound range, predicting a rocket's flight path is still extremely difficult, but apogee predictions get closer to reality.

The current rocket design is based around increasing the stability of our rocket. The quadcopter 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 3 calipers and makes it safer to launch. Another positive reason of separating the camera housing from the aft is that this section is now much lighter than that of its original position. The quadcopter assembly will now only need to move itself through the ambient atmosphere and not any other payloads or weight. The disadvantages come from the complicated arrangement of 4 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.

3.1.8 Dimensional Drawing of Assembly

The launch vehicle body is comprised of several different sections. The nose cone is 2 feet tall. There is a body tube below the nose cone that is 5 feet long housing 3 parachutes and the lander system. Below this is the altimeter bay which is a 1 inch band on the outside attached to a 13-in. coupler housing the altimeters. There is a 4-foot-long section below the altimeters that house the motor mount, one parachute, and the fins.

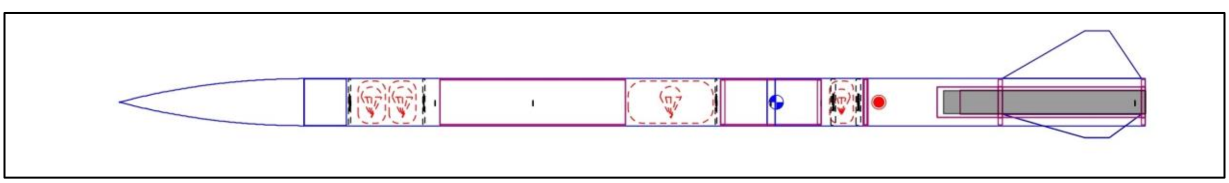


Figure 1: Overview drawing of launch vehicle assembly.

3.1.9 Mass Statement

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

3.1.9.1 Nose Cone

Table 6: Nose Cone mass statement.

Brand	**Model**	**Material**
Public Missiles	FNC-6.00	Fiberglass
Properties		
Nose Shape	Hollow Ogive	
Length (in)	24.0000	
Diameter (in)	6.1000	
Wall Thickness (in)	0.1250	
Body Insert Properties		
OD (in)	5.9700	
Length (in)	5.5000	
Calculations		
CG (in)	14.5000	
Mass (oz.)	28.000	
Radius of Gyration (m, cm)	0.200442, 20.0442	
Moment of Inertia ($kg \cdot m^2$, $g \cdot cm^2$)	0.0318919, 318919	
RockSim XN (in)	11.1411	
CNa	2	

3.1.9.2 Eye Bolt (×5)

Table 7: 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 8: 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 9: 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·m^2, g·cm^2)	0.614155, 6.14155·10^6
RockSim XN (in)	0.0000
CNa	0

3.1.9.5 Nose Cone Parachute

Table 10: 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·m^2, g·cm^2)	0.000279377, 2793.77	

3.1.9.6 Main Parachute

Table 11: 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·m^2, g·cm^2)	0.00141534, 14153.4

3.1.9.7 Lander

Table 12: 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.)	10.9010	
Radius of Gyration (m, cm)	0.183949, 18.2949	
Moment of Inertia (kg·m^2, g·cm^2)	0.0200497, 200497	

3.1.9.8 Lander Electronics

Table 13: 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·m^2, g·cm^2)	0, 0	

3.1.9.9 Lander Parachute

Table 14: 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 Altimeter Bay

Table 15: 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

3.1.9.11 Inner Bay

Table 16: Inner Bay mass statement.

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

3.1.9.12 Altimeter Caps (×2)

Table 17: Altimeter Caps mass statement.

Brand	Model	Material
Public Missiles	--	Carbon Fiber
Properties		
OD (in)	5.8000	
Length (in)	0.5000	
Location (in, from front of Inner Bay)	0.0000	
Calculations		
CG (in)	0.3500	
Mass (oz.)	12.7692	
Radius of Gyration (m, cm)	0.0370537, 3.70537	
Moment of Inertia ($kg{\cdot}m^2$, $g{\cdot}cm^2$)	0.000497018, 4970.18	

3.1.9.13 RRC3 Altimeter, Sled, and Batteries

Table 18: Altimeter, Sled, and Batteries mass statement.

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

3.1.9.14 Booster Section

Table 19: Booster Section mass statement.

Brand	**Model**	**Material**
Custom	--	G10 Fiberglass
Properties		
OD (in)	6.1000	
ID (in)	6.0000	
Length (in)	48.0000	
Calculations		
CG (in)	24.0000	
Mass (oz.)	50.2368	
Radius of Gyration (m, cm)	0.356523, 35.6523	
Moment of Inertia ($kg\cdot m^2$, $g\cdot cm^2$)	0.181026, $1.81026\cdot 10^6$	
RockSim XN (in)	0.0000	
CNa	0	

3.1.9.15 Fin Set

Table 20: 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

3.1.9.16 Outer Motor Mount

Table 21: Outer Motor Mount mass statement.

Brand	**Model**	**Material**
Custom	--	Kraft Phenolic
Properties		
OD (in)	4.0000	
ID (in)	3.9000	
Length (in)	24.0000	
Location (in, from base of Booster Section)	0.0000	
Calculations		
CG (in)	12.0000	
Mass (oz.)	21.6229	
Radius of Gyration (m, cm)	0.179718, 17.9718	
Moment of Inertia (kg·m^2, g·cm^2)	0.0187881, 197991	

3.1.9.17 Centering Ring (×2)

Table 22: Centering Ring mass statement.

Brand	**Model**	**Material**
Public Missiles	CCR-6.0-3.9 (was PML CCR-18)	Aircraft Plywood (Birch)
Properties		
OD (in)	5.9300	
ID (in)	4.0200	
Length (in)	0.5000	
Location (in, from base of Booster Section)	First: 0.0000 Second: 18.5500	

Calculations	
CG (in)	0.5000
Mass (oz.)	2.7161
Radius of Gyration (m, cm)	0.0456913, 4.56913
Moment of Inertia (kg·m^2, g·cm^2)	0.000160753, 1607.53

3.1.9.18 Main Parachute

Table 23: Main Parachute mass statement.

Brand	Model	Material
b2 Rocketry	CERT-3 XLarge - SkyAngle	1.9 oz. Ripstop Nylon
Properties		
Shape	Round	
Diameter (in)	60.0000	
Spill Hole (in)	0.0000	
Calculations		
CG (in)	0.0000	
Mass (oz.)	45.0000	
Radius of Gyration (m, cm)	0.0794957, 7.94957	
Moment of Inertia (kg·m^2, g·cm^2)	0.00806205, 80620.5	

3.1.9.19 Shock Cord (×2)

Table 24: 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

3.1.9.20 Bulkhead

Table 25: 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 ($kg \cdot m^2$, $g \cdot cm^2$)	0.000231581, 2315.81	

3.1.9.21 Motor Adapter

Table 26: 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

3.1.9.22 Motor Mount

Table 27: 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	

3.2 Recovery Subsystem

- Review the design at a component level, going through each components' alternative designs, and evaluating the pros and cons of each alternative.
- For each alternative, present research on why that alternative should or should not be chosen.
- Using the estimated mass of the launch vehicle, perform a preliminary analysis on parachute sizing, and what size is required for a safe descent.
- Choose leading components amongst the alternatives, present them, and explain why they are the current leaders.
- Prove that redundancy exists within the system.

3.2.1 Determination of Launch Vehicle Mass and Analysis of Recovery System

Table 28: Weight of launch vehicle sections.

Section	**Approximate weight** (lb.)
Nose Cone	3
Upper section with lander	16.5
Altimeter Bay	6
Booster section	14.5

Each section of the launch vehicle will be connected to a parachute to allow for a successful landing. The nose cone will have a small parachute attached to it. The lander will have a small parachute attached to it. The upper section of the launch vehicle will have a large parachute on it since it is a large heavier section of the launch vehicle. There will be a drogue parachute attached to the booster section of the rocket to slow descent. There will be shock cord attached to each parachute to reduce the stress on the parachute cords. The parachutes will be in deployment bags to ensure safe separation. U-bolts will be used on each side of the bulkheads to divide the forces across the entire bulkhead.

3.2.2 Description and Analysis of Major Recovery System Components

The recovery system is comprised of several different items to ensure the separation happens cleanly and the section makes a safe landing.

Table 29: Primary recovery system components.

Component Name	**Purpose**
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.

Deployment Bag	Holds the shock cord and parachute to make sure the system can come out of the launch vehicle easily and more organized.
U-bolts	Divide the stress to the entire surface of the bulkhead instead of eyebolts where it is all in the center.
Bulkheads	Holds the U-bolts to the body of the launch vehicle

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 deployment bags will ensure all parts of the recovery system come out successfully. All products will be purchased from trusted vendors.

3.2.3 Recovery System Electronics Schematic

It is a redundant system where each altimeter is connected to a battery, a switch, and the main and drogue charges. Below is the schematic of the current design for the altimeter bay.

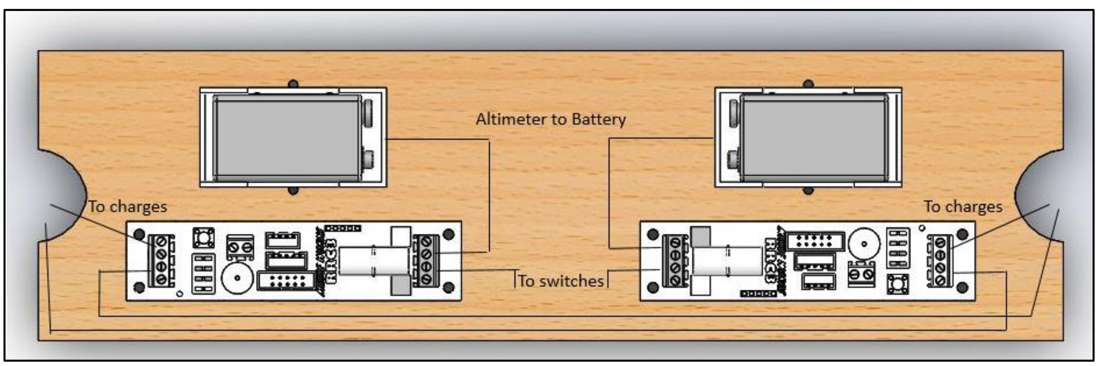


Figure 2: Schematic of recovery system electronics.

3.3 Mission Performance Predictions

3.3.1 Mission Performance Criteria

The criteria that the mission's performance will be based on is shown below.

Table 30: Criteria to be used for evaluating mission performance.

Characteristic	Description	Goal
Apogee	Max height of the launch vehicle's flight path	Reach 5,280 feet
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 will return to the ground with parachutes inflated	The launch vehicle sustains no damages
Drift	The distance the launch vehicle moves away from the rail	The launch vehicle is easily recoverable

3.3.2 Mission Analysis

The launch vehicle was simulated on a L1090 manufactured by Cesaroni. The thrust curve of the motor is shown below.

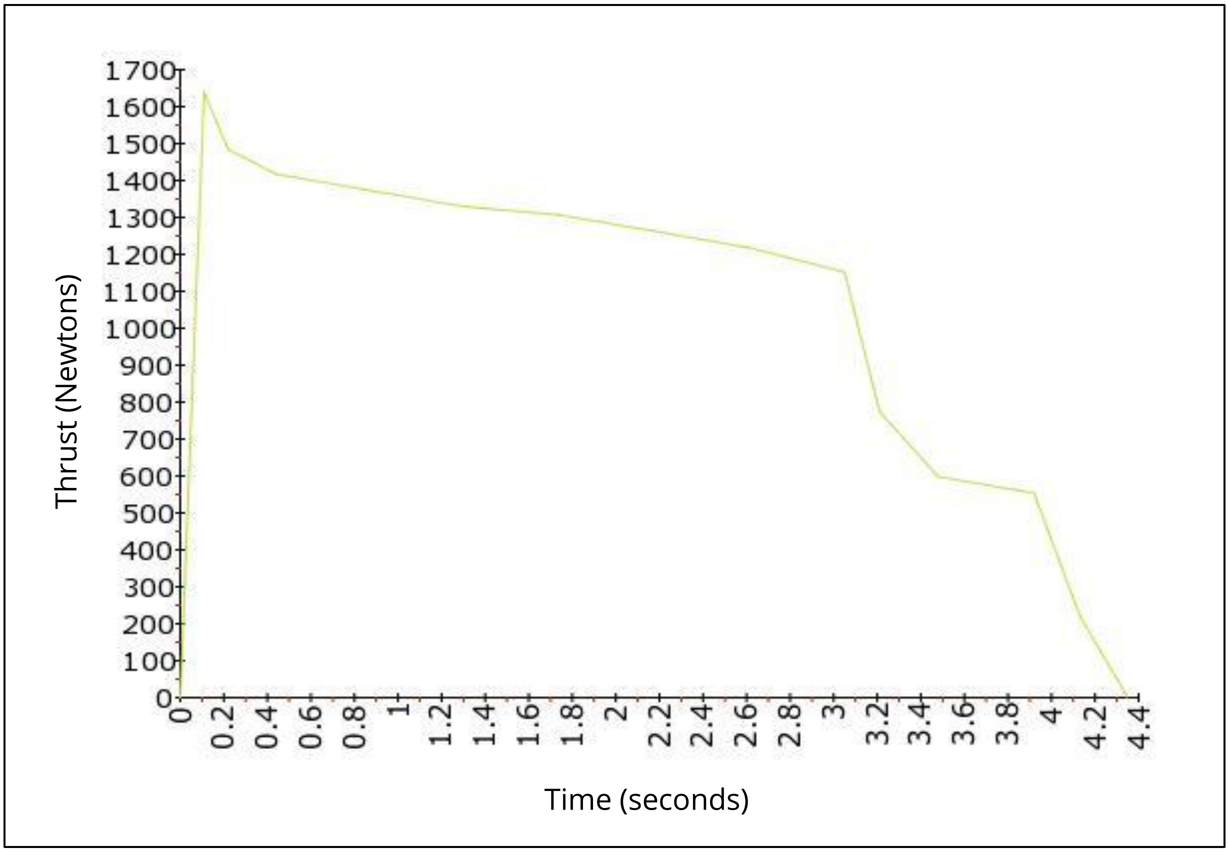


Figure 3: Chart of the thrust curve of an L1090 motor.

The effect of the wind speed on the launch vehicle was tested in the simulations with the collected data below.

Table 31: Effects of various simulated wind speeds on the launch vehicle.

Wind Speed (mph)	**Data**	
0	**Apogee** (ft.)	4958
	Time to Apogee (s)	18.6
	Max Velocity (ft./s^2)	542
	Max Acceleration (ft./s)	198

Wind Speed (mph)	**Data**	
10	**Apogee** (ft.)	4924
	Time to Apogee (s)	18.6
	Max Velocity (ft./s^2)	541
	Max Acceleration (ft./s)	198
15	**Apogee** (ft.)	4902
	Time to Apogee (s)	18.6
	Max Velocity (ft./s^2)	540
	Max Acceleration (ft./s)	198

The launch conditions were set to parameters that simulated the expected conditions of launch date. The relative humidity was set to 80%, 60 degrees Fahrenheit, with no cloud coverage. The launch vehicle was launched at 5 degrees from vertical. All simulation showed a successful landing.

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

The center of gravity of the full-scale launch vehicle is 74.66 in from the nose cone unloaded and 85.25in from the nose cone loaded. The center of pressure is 98 in from the top of the nose cone and this gives the launch vehicle a stability margin of 2.1 calipers. The Barrowman equations were used for calculation of center of pressure. The diagram of the launch vehicle is shown below in figure.

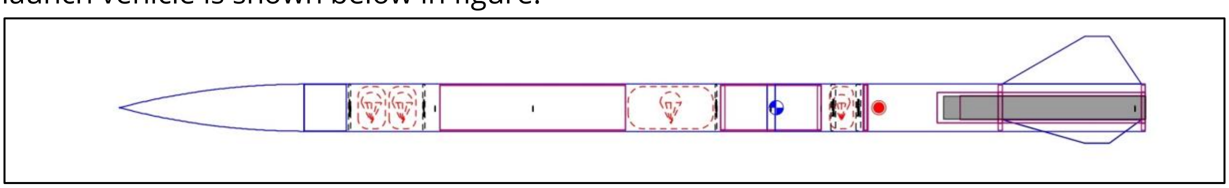


Figure 4: Drawing of launch vehicle with centers of gravity and pressure shown.

3.3.4 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 32: Expected velocity and kinetic energy values for launch vehicle sections.

Section	**Descent Velocity with L Cert-3** (ft./s)	**Descent Velocity with XL Cert-3** (ft./s)	**Kinetic Energy with L Cert-3** (ft·lbf)	**Kinetic Energy with XL Cert-3** (ft·lbf)
Nosecone	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

3.3.5 Drift Analysis

The drift of the launch vehicle is calculated by multiplying the velocity of the wind by the time after apogee to the ground. This time would be the time that the launch vehicle is being controlled by the parachute. Since it is launched vertically, it is assumed there is no drift until after apogee. The time to apogee is 75.9 seconds.

Table 33: Drift analysis values at various wind speeds.

Wind Speed (mph)	**Wind Speed** (ft./s)	**Drift** (ft.)
0	0	0
5	7.33	556.35
10	14.66	1,112.70

15	23.46	1780.60
20	29.33	2226.15

4 Safety

4.1 Final Assembly and Launch Procedure Checklists

Table 34: Assembly and launch procedure checklist

Prior to Departure	Completed(Y/N)?
1. Check to make sure all tools and materials needed for launch are available.	
2. Make sure everyone is present to walk out to launch site.	
3. Make sure the proper size parachutes and shock cords are present for assembly of rocket.	
4. Prepare new batteries for the recovery systems.	
5. Ensure batteries for SOAR Lander are charged. Test with Voltmeter.	
Recovery System Setup	**Complete(Y/N)?**
1. Inspect the electronics bay and confirm that all wires are secure and correctly fastened.	
2. Install the new, 9V batteries for the altimeters and GPS system.	
3. Check to make sure the altimeters are programmed to release parachutes at the correct altitude.	

4. Measure the length and cut the proper size e-match to insert into the rocket.	
5. Connect the e-matches to the electronics bay and confirm that they are secure.	
6. Calculate how much black powder is needed and pour the needed amount into the charge canisters. Then, pack with nonflammable insulation.	
7. Seal the charge canister with masking tape or caps.	
8. Connect the correct shock cords to the appropriate section of the rocket.	
9. Seal the parachutes in the parachute bags and put them in the correct portions on the rocket. Then, wrap them in Nomex protection cloths.	
10. Test to make sure the parachutes slide in and out of the rocket easily and will not get stuck in the rocket during flight.	
Launch Vehicle Assembly	**Completed(Y/N)?**
1. Slide the electronics bay into the bottom airframe and confirm that the bottom airframe does not slide off.	
2. Slide the top airframe onto the electronics bay and confirm that it is snug.	

3. Slide the SOAR landing system into the airframe and then the confirm that it is not too tight and is able to slide out during flight.	
4. Slide the nose cone into the top of the airframe and check to make sure it is snug.	
Flight Inspection	**Completed(Y/N)?**
1. Place the launch vehicle in a way that it is balanced and mark where the center of gravity is located to ensure it is appropriate for the rocket.	
2. Make sure the approval for launch from the RSO is received.	
Launch Procedure	**Completed(Y/N)?**
1. Be sure power is turned off from launch control.	
2. Slide the launch vehicle onto the launch rail.	
3. Orient rail to 5 degrees from vertical.	
4. Turn on all electronics onboard and listen to the altimeters to ensure no problems are detected.	
5. Ensure that the igniter is inserted up the motor until it reaches a dead-end and then pull back about 1-2 inches.	
6. Tape or clip the e-match cord to the motor retainer to secure it in place.	
7. Conduct one final inspection to ensure the connection to launch control is proper.	
Post Launch Assessment	**Completed(Y/N)?**

1. Retrieve the launch vehicle once it has come down safely and permission from the RSO is received.	
2. Bring the SOAR landing system, proof of navigation detection, and the altimeter bay to the judges to be scored.	
3. Deactivate all electronics on the launch vehicle.	

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 to ensure the individual knows the process of building a rocket

4.3 Hazard Analysis

Careful observation regarding the team members, rockets, payload components, and work and launch environment has been done and any hazards observed have been addressed. Each potential hazard has received a risk assessment level using the risk assessment matrix found on page 56 of the NASA Student Launch Handbook. Risk levels are determined by the severity of the potential situations and the probability the hazards will occur.

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 below in Table 35.

Table 35: Risk severity levels and definitions.

Description	Personnel Safety and Health	Facility / Equipment	Range Safety	Project Plan	Environ-mental
– 1 – Catastrophic	Loss of life or a permanent disabling injury.	Loss of facility, systems or associated hardware that result in being unable to complete all mission objectives.	Operations not permitted by the RSO and NFPA 1127 prior to launch. Mission unable to proceed.	Delay of mission critical components or budget overruns that result in project termination.	Irreversible severe environment al damage that violates law and regulation.
– 2 – Critical	Severe injury or occupation al related illness.	Major damage to facilities, systems, or equipment that result in partial mission failure.	Operations not permitted by the RSO and NFPA 1127 occur during launch. Mission suspended or laws and regulations are violated.	Delay of mission critical components or budget overruns that compromise mission scope.	Reversible environment al damage causing a violation of law or regulation.

Description	Personnel Safety and Health	Facility / Equipment	Range Safety	Project Plan	Environ-mental
– 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 36 depicts the levels of probability for each risk.

Table 36: 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 37). These levels range from high (red) to minimal (white) and are defined in Table 38.

Table 37: Overall risk assessment level assignment criteria.

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

Table 38: 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.

Level of Risk	Definition
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.

4.3.1 Launch Vehicle Hazard Analysis

Table 39: Hazard/risk analysis for the launch vehicle.

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
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/ personal injury/ disqualification.	1D	Redundancies will be implemented to ensure the igniter safety system performs as expected.	1E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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, work their way into humans, causing illness.	2E	Batteries and other chemicals should be disposed of properly in accordance with the MSDS sheets. Should a spill occur, proper measures are to be taken in accordance with the MSDS sheets and any EHS standards.	2E
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 air.	3E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Environmental	Plastic waste material.	Plastic using in the production of electrical components and wiring.	Sharp plastic material produced when shaving down plastic 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.	3E
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.	3E
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.	3D

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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	Use shared calendar to keep all personnel apprised of deadlines. Send reminder notifications to technical leads well in advance of deadlines. When possible, maintain suitable substitute parts on hand.	2E
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Pad	Unstable launch platform.	Un-level ground or loose bolts.	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.	2E
Pad	Unleveled launch platform.	Un-level ground 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. Payload door jams. 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. A spare piece of airframe will run through the launch pad. If any resistance is noted, the joints of the tower can be moved to improve the alignment of the tower, allowing the rocket to freely move through the tower. Also, talcum powder will be applied to each beam in order to reduce any frictional forces on the rocket.	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 should be filed down and de-burred.	3E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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
Payload	Altimeter failure.	Failure in electronics. Failure in programming.	Parachutes will fail to deploy. Sections will fail to separate. No data collection.	2D	Checking and testing of altimeter programming before days of flight. Two altimeters are used to provide redundancy in the case one fails.	2E
Payload	Failure of onboard electronics (altimeters, tracking devices, etc.)	Generation of electromagnetic field from onboard devices	Parachute deployment failure. Sections fail to separate. Damage to the launch vehicle.	1D	No devices that generate a significant electromagnetic field will be used.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Payload	GPS tracking malfunction.	Low battery. Signal interference at ground station.	Launch vehicle not found. Harm to environment, launch vehicle parts will be left in the field where wildlife may interact with it.	3D	GPS batteries will be charged the night before launch. The tracking system will be tested on full scale flight. A radio tracking system will also be included on the launch vehicle.	3E
Recovery	Parachute deployment failure.	Altimeter failure. Electronics failure. Parachutes snag on shock cord.	Launch vehicle will not lose enough speed as it descends and will strike the ground at a high velocity.	2D	Careful measurement of shroud lines and shock cord for appropriate lengths. Utilize checklist in packaging of parachutes. Ground testing will be done on the full scale. Altimeter and electronics check 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. Launch vehicle becomes ballistic.	2D	Calculate the correct amount of black powder needed for each blast charge. Measure black powder using scale. Ground tests will confirm that the amount of black powder is adequate. Altimeter and electronics check conducted with checklist several hours prior to launch. Inside of rocket body 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 into 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	Parachute does not open.	Parachute gets stuck in the deployment bag. Parachute lines become tangled.	Rocket follows ballistic path, becoming unsafe.	2E	Deployment bags have been specially made for the parachutes. This will allow for an organized packing that can reduce the chance of the parachute becoming stuck or the lines becoming tangled. Parachute deployment has been both ground tested and flight tested verifying that the setup results in repeatable successful results. Should the rocket become ballistic, 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 components of the rocket to be damaged.	2E	The parachutes have each been carefully selected and designed to	2E
Recovery	Rocket descends too slowly.	Parachute is improperly sized.	The rocket will drift farther than intended, potentially facing damaging environmental obstacles.	3E	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Extensive ground testing was performed to verify the coefficient of drag is approximately that which was used during analysis.	3E

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 custom deployment bag will be used and tested for the parachute to ensure that the lines do not tangle during deployment. 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 training on power tools and other lab equipment.	Mild to severe cuts or burns to personnel. Damage to rocket or components of the rocket. Damage to equipment	3C	Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them. Proper PPE must be worn at all times. Sweep or vacuum up shavings to avoid cuts from debris.	3D
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 must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them.	3E

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 to inhalation.	2C	MSDS documents will be readily available at all times and will be thoroughly reviewed prior to working with any chemical. All chemical containers will be marked to identify appropriate precautions that need to be taken. Chemicals will be maintained in a designated area. Proper PPE will be worn at all times when handling chemicals.	2E
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 get 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.	3D

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.	3E
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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.	3E
Shop	Metal shards.	Using equipment to machine metal parts.	Metal splinters in skin or eyes.	1D	Team members must wear long sleeves and safety glasses whenever working with metal parts. Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them.	3D

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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
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

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Stability	Loss of stability during flight.	Damage to fins or launch vehicle body, poor construction.	Failure to reach target altitude, destruction of vehicle.	1D	Measure the CG of the vehicle prior to launch. Use checklists 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. Use inspection to make sure parachutes and shock cord do not move freely in the airframe.	2E
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 assure proper dimensions. Robust material such as aluminum will be used to assure the integrity of the design. Ground Testing will be used to make sure an ejection charge does not push the motor out.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Stability	Mass increase during constructio n.	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	Maintain record of mass changes. Repeat launch vehicle simulations for each mass change. Perform subscale and full scale launches 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	Follow NAR safety code and wait a minimum of 60 before approaching the rocket to ensure that the motor is not simply delayed in launching. If there is no activity after 60 seconds, have the safety officer check the ignition system for a lost connection or a bad igniter. If this does not fix the failure mode, be prepared to remove the ignition system from the rocket motor, retrieve the motor from the launch pad and replace the motor with a spare. Igniters have been securely installed throughout the season, having a 100% success rate.	1E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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 are run to verify the motor selection provides the necessary exit velocity. The launch pad will be coated in talcum powder prior to each launch in order to minimize friction. Full scale test launches have verified that the launch rocket will exit the launch pad at a safe velocity. 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 components supported by the bulkheads will no longer be secure. Parachutes attached to bulkheads will be left ineffective.	2E	The bulkheads have been designed to withstand the force from takeoff with an acceptable factor of safety. Electrical components are mounted using fasteners that will not shear under the forces seen during the course of the flight. A catastrophic failure is likely. A portion of the rocket or the cache capsule would become ballistic. Calculations have been made to ensure that the bulkheads can withstand all forces that will be seen during flight. Flight tests have verified such calculations.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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	This system has been tested during full scale flights without any signs of failure. Analysis has been completed to validate that the current design is strong enough to withstand forces seen during flight.	2E

4.3.2 Landing Module Hazard Analysis

Table 40: Hazard/risk analysis for the landing module.

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Landing	Landing gear fails to extend.	Springs in landing gear fail to extend.	Lander does not land upright. Failure to meet objective.	2D	Ground and flight testing of launcher will be conducted. Separate checklist will be created to inspect lander prior to launch.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
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 identification.	2E	Ground and 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
Landing	Parachute cord tangles in propellers.	Lander component must change orientation after exiting launch vehicle with parachute initially on bottom side.	If drift is sufficient, failure to meet objectives for tarp identification.	2D	Ground and flight testing of launcher will be conducted. Deployment bags will be used and properly packed in accordance with instructions prior to launch.	2E

Area	Hazard	Cause	Effect	Pre RAC	Mitigation	Post RAC
Landing	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 identification.	2E	Ground and flight testing of launcher will be conducted. GPS and electronics test will be conducted prior to launch. Deployment bags will be used and 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. Deployment bags will be used and properly packed in accordance with instructions prior to launch.	1E

4.4 Environmental Concerns

The main concern for the launch vehicle 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 cancelled until the winds calm. The rain can affect how the launch vehicle flies. Since the vehicle will be moving at high speeds, the rain can hinder the apogee of the vehicle and drive it off course. The rain also makes it possible for the launch to be cancelled as well.

5 Selection, Design, and Rationale of Payload

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 needs to be met to consider the success of the landing module:

1. The landing module with a drogue parachute is 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 guides it within 2500 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 Design Comparison

5.2.1 Steering System

Grade Scale (1 - 5): 1 - Minimal chance for Success -- 5 - Greatest Chance for Success

Requirements taken into account when designing the system and their weight factors of importance:

- **Steering** - Ability for the design to effectively steer the system as intended.
  - 5x weight factor
- **Spin** - Ability for the design to effectively eliminate the spin of system.
  - 2x weight factor
- **Reliability** - Ability for the design to work repeatedly without failure.
  - 4x weight factor
- **Weight** - Weight of design per Rocketry for optimal flight conditions.
  - 2x weight factor

Table 41: Comparison of steering system designs.

Steering System Design	Steering	Spin	Reliability	Weight	Total Score
Opening Flaps Design	Design intentions are to have flaps come out that would rotate and use the force of the wind to steer the system in the intended direction. **1** This score is given based on the inability to accurately steer using outside (air) force without causing unintended yaw and pitch of system.	Design intentions are to have the flaps act as rudders counteracting the force responsible for rotation of steering system. **4** This score is given due to rudders proven track record with controlling spin however only a 4 due to upward force on flaps may cause inadvertent yaw and pitch possibly disturbing system.	Design intentions called for 4 motors for 4 flaps which give more room for mechanical failure. **3** This score is given based on its level of mechanical components to work.	Design calls for higher weight with multiple motors for actuation. **2** This score is given based on its overall weight requirements from Rocketry in ability of Rocket to achieve mile.	**7.25**

Steering System Design	Steering	Spin	Reliability	Weight	Total Score
Quad-Prop Design	Design intentions are to have 4 motors with two blade props 90˚ apart around the system. Each pair of motors 180˚ apart would be facing the same way so that they can laterally steer the system in its intended direction without inducing spin. **5** This score is given based on the ability of the design to laterally steer the system with 4 motors.	Design intentions are to have the motors for the props work independently and run when necessary to counteract the spin. **5** This score is given based on the independent ability of the motors with the accelerometer to eliminate the spin.	Design intentions have 4 independent motors and springs to push out the arms so the blades clear the system and magnetic latches to latch them in place. **3** This score is given based on the level of mechanical components required for the system to work.	Design calls for higher weight with multiple motors for actuation along with arms. **1** This score is given based on its overall weight requirements from Rocketry in ability of Rocket to achieve mile.	**12.25**

Steering System Design	Steering	Spin	Reliability	Weight	Total Score
Bi-Prop Design	Design intentions are to have 2 motors with two blades 180˚ apart around the system. Each pair of motors would be facing the same way so that they can laterally steer the system its intended direction without inducing spin. **4** This score is given based on the ability of to laterally steer the system with 4 motors.	Design intentions are to have the motors for the props work independently and run when necessary to counteract the spin. With controlled induced spin to get into position to laterally steer where necessary. **4** This score is given based on the independent ability of the motors with the accelerometer to eliminate the spin. Also because of induced spin required for steering it does not get a 5.	Design intentions have 2 independent motors and springs to push out the arms so the blades clear the system and magnetic latches to latch them in place. **4** This score is given based on the minimized level of mechanical components required for the system to work compared with the Quad-Prop design.	Design calls for lighter weight with only two motors for actuation along with arms. **3** This score is given based on its minimal weight compared to the overall weight requirements from Rocketry in ability of Rocket to achieve mile.	**12.5**

5.2.2 Landing Gear

Grade Scale (1 - 5): 1 - Minimal chance for Success -- 5 - Greatest Chance for Success

Requirements taken into account when designing the system and their weight factors of importance:

- **Compact** - Ability for the design to fit within the allowed dimensions from Rocketry.
  - 1x weight factor
- **Expansion** - Ability for the design to provide the maximum amount of leg width to reduce tipping.
  - 5x weight factor
- **Force Absorption** - Ability for the design to absorb the force of landing.
  - 3x weight factor
- **Reliability** - Ability for the design to work repeatedly without failure.
  - 4x weight factor

Table 42: Comparison of landing gear designs.

Landing Gear Design	Compact	Optimal Expansion	Force Absorption	Reliability	Total Score
Spring Cylinder Legs Design	Design intentions are to have the same diameter cylinder cut into 4 equal pieces so that they can easily fit within the outer rocket and fold out into position. **5** This score is given based on the ability for the landing gear to easily fit within the outer shell of the rocket in the allowed space from Rocketry group.	Design allows a total expansion of 18in with a system height of 18.5in changing proportionally with angle of legs as they adjust. **4** This score is given based on the 1 to 1 ratio of height to base width at full expansion. It will change closer to 2 to 1 at rest.	Design has springs on the outer edges of the legs that counteract the hinge spring thus upon landing will act like a shock and absorb the force. **3** This score is given based on ability to provide a force absorbed fall but the design does allow for a possibility of having bounce back from the spring force.	Design only has springs that are counteracting each other with compression and extension. No electrically controlled components. **5** This score is given based on its simplicity and lack of complex components to achieve desired intent.	**19.7**

Landing Gear Design	Compact	Optimal Expansion	Force Absorption	Reliability	Total Score
Mechanically Actuated Legs Design	Design intentions are to have four 3in legs that are actuated perpendicular from the system with 3in feet **5** This score is given based on the ability for the landing gear to easily fit within the outer shell of the rocket in the allowed space from Rocketry group.	Design allows a total expansion of 12in with a system height of 21.5in changing **3** This score is based on the designs max leg width of 12 inches with respect to overall height.	Design does not have any absorption components built in. **1** This score is given based on the design lacking any force absorption components	Design has 4 actuating motors to push out the legs that are electrically controlled **4** This score is given based on its simplicity and lack of complex components to achieve desired intent.	**14.7**

5.2.3 Electronics Bay

Grade Scale (1 - 5): 1 - Minimal chance for Success -- 5 - Greatest Chance for Success

Requirements taken into account when designing the system and their weight factors of importance:

- **PROCESSING SPEED** - Ability for the system to process data in order to provide a minimal response time.
    - 5x weight factor
- **EASE OF INTERFACE** - Ability for simplistic and common interface of single board computer.
    - 3x weight factor

- **COST EFFICIENCY** - Ability for the system to meet performance requirements while minimizing overall cost.
    - 1x weight factor
- **RELIABILITY** - Ability for the system to consistently satisfy our requirements without failure.
    - 4x weight factor

Table 43: Comparison of electronics designs.

Electronics Bay Design	Processing Speed	Ease of Interface	Cost Efficiency	Reliability	Total Score
ODROID XU4 System	System utilizes a 2GHz quad-core and 1.5GHz quad-core processor, 2GB of RAM, and Mali T628 GPU **5** This score was given due to the very high processing speeds and RAM size in comparison to competitor boards	Lack of popularity of this single board computer leads to minimal reference material and models to compare to, as well as a small selection of supported peripherals **2** This score is based on the minimal documentation that we would have to guide us with configuration and programming	The high-level performance and small selection of easily compatible peripherals leads to high component prices. **2** This score is given due to its significantly higher prices compared to other options that would also satisfy our objectives	High processing speeds ensure image processing capabilities as well as sensor interpretation, lack of examples to model after might not reveal limitations **3** This scored is given based off its high-performance levels however configuration errors could occur due to lack of documentation	**11.25**

Electronics Bay Design	Processing Speed	Ease of Interface	Cost Efficiency	Reliability	Total Score
Raspberry Pi 3 System	System utilizes a 1.2GHz quad-core processor, 1GB of RAM, and VideoCore IV GPU **3** This score was given due to its processing speeds and capabilities being average when compared to other single board computers.	The design of this system allows for the use of common components with many examples and tutorials relating to our goals **5** This score was given based on the availability of documents and resources for the Raspberry Pi 3	Due to the popularity and mid-level performance of this system, component costs are reduced **4** This score was given because of this system's ability to achieve our goals while costing much less than our other design	Sufficient processing speeds coupled with high precision sensors allows for quick and accurate responses **4** This score is based off the use of high quality components and documented experiments verifying similar goals	**12.5**

5.2.4 Final Decision

For the Steering system based on the grading table our final choice will be the bi-prop design to steer the system towards the desired direction and minimize the spin. This system will land on the Spring Cylinder Leg design as that is our final choice for the landing gear based on the grading table. The electronics bay system will utilize a Raspberry Pi 3 as the primary computer to execute image and sensor processing based off the grading table above.

5.3 Design Overview

5.3.1 Overall Assembly

The overall assembly 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 communicates with 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

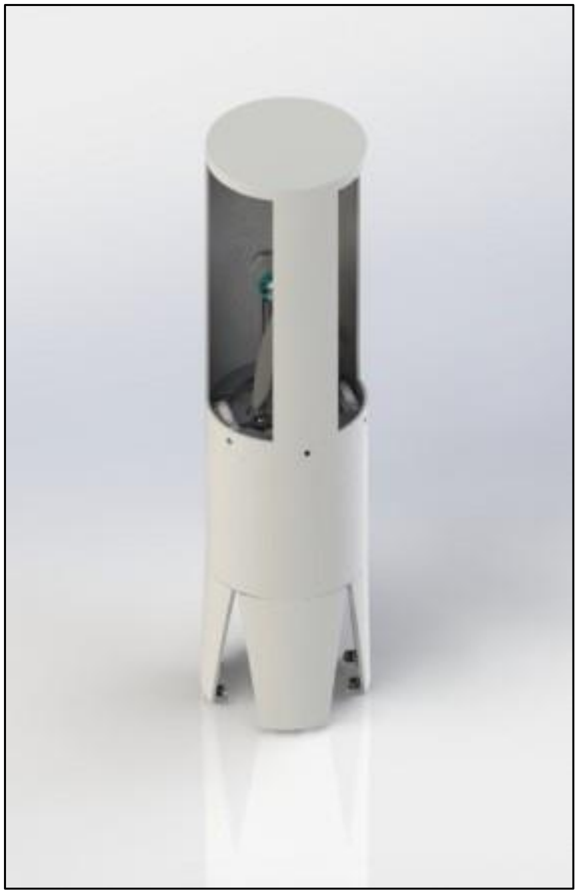


Figure 5: Rendering of overall assembly in stowed position.

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.

Figure 6: Rendering of overall assembly in expanded position.

5.3.2 Subsystems

5.3.2.1 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" Unistrut channels, channel nuts with springs, and mounting brackets. The motor arms are pressed against the channel nut with spring when stowed (Figure 5). 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 6).

Figure 7 Isolated rendering of steering mechanism.

5.3.2.2 Electronics

The electronics bay control system is comprised of a Raspberry Pi 3, Raspberry Pi Camera board v2, Adafruit Ultimate GPS Module, and Adafruit 10-DOF Breakout board. The Raspberry Pi 3 is the primary computer that will be used for image processing and controlling the steering system. In order to output multiple hardware PWM signals to the electronic speed controllers for the steering system the use of a PWM Driver board connected to the Raspberry Pi will be required. The Raspberry Pi Camera board v2 directly connects to the Camera Serial Interface port on the Raspberry Pi, this connection leads directly to the onboard GPU so there is minimal processing demand from the CPU. The Ultimate GPS Module and 10-DOF Breakout board connect to the Raspberry Pi via USB and I2C interfaces respectively for high speed data transfer rates.

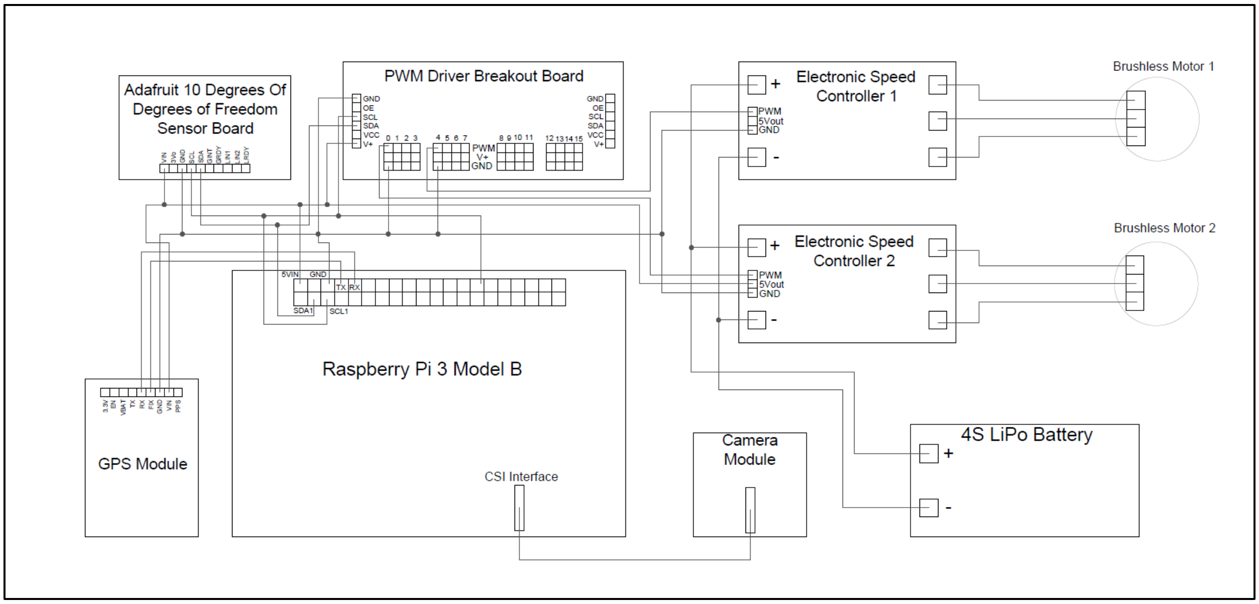


Figure 8: Electrical schematic of the primary control/computer system.

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 9: Rendering of the bottom of the landing gear system.

5.3.3 Guidance

The guidance control system is operated by the Raspberry Pi 3 computer board. It will be running a custom python software package to optimize processing speed and power consumption. Through the use of the Adafruit Ultimate GPS module the electronics bay control system will be able to acquire a GPS coordinate lock at its launch site. The software program will then compute a 300' and 2500' radius to account for the location of the targets and the allotted drift distance respectively. The Adafruit Ultimate GPS module has a standard 3-meter position accuracy and a 10 Hz update frequency for rapid position tracking. The Adafruit 10-DOF Breakout board will transmit data concurrently with the Ultimate GPS module to improve position and orientation sensory. The 10-DOF board is comprised of a STMicroelectronics L3DG20H gyroscope, LSM303DLHC accelerometer and compass, and Bosch BMP180 digital pressure sensor. These are some of the highest quality consumer level sensors due to their cost and reliable readings. The Raspberry Pi will be able to process the data from the 10-DOF board and calculate the orientation and rotation of the rocket. Upon descent, the Raspberry Pi can interpret these readings and send a proper PWM signal to the electronic speed controllers for the brushless motor in order to counter the spin of the rocket. This counter spin will be used to stabilize the rocket so the onboard camera can accurately view and identify the 3 different targets on the ground. While the targets are being identified the guidance control system will ensure the landing module remains stabilized and does not drift out of the allotted range. Upon further testing, if the Raspberry Pi is not able to process our custom software package quickly enough then an additional microcontroller may be incorporated to assist in sensory data processing.

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 ENG4, 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 tabs. These tabs will be made of phenolic as well, and attached to the encapsulation using resin. A hole will be drilled in these tabs so that members can be bolted down.

5.6 Integration

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. 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.

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” phenolic tube will be used for the construction of the electronics bay and landing gear system. The tube is cut into two 6” 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” 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” 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. 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.

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.

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 Requirements Compliance

Table 44: Competition requirements and methods of meeting/testing such.

Requirement	Method of Meeting Requirement	Verification
Onboard camera system shall be capable of identifying and differentiating between 3 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 Open CV 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 hour.	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.

Requirement	Method of Meeting Requirement	Verification
The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The launch vehicle will be designed to separate into 4 separate sections. Each section with its own recovery parachute to ensure the rocket body stays intact. The motor can be replaced within 1-2 hours 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.

6.2 Budgeting and Timeline

6.2.1 Budget Plan

Table 45: Current budget overview for project duration.

Budget Item	Projected Cost	Current Budget
Rocket	$3,000	$2,460.10
Payload	$2,000	$1,558.00
Travel	$4,500	N/A

Table 46: Detailed budget breakdown with previous and projected costs.

Projected Expenses	**Vendor**	**Cost** ($)
Landing System		
Lightweight Self-Closing Spring Hinge	McMaster-Carr	15.24
Roller Ball Bearing	Amazon	12.49
Clevis Pin	McMaster-Carr	7.28
Strut Channel Spring	Fastenal	18.20
Magnetic Catch	McMaster-Carr	17.52
13/16 in. x 16 in. Galvanized Strut Channel	Home Depot	9.68
Phenolic Coupler Tube for 6" Diameter	Public Missiles	44.99
10cm Male to Male Servo Connectors	Amazon	8.99
15cm Male to Male Servo Connectors	Amazon	9.99
XT60 to 5.5mm 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
32gb eMMC Module Linux for ODROID	Ameridroid	45.95
Arduino UNO R3	Amazon	23.99
Adafruit 1604 10DOF Sensor Board	Amazon	30.99
Adafruit 1141 Data Logging Shield for Arduino	Amazon	18.93

Projected Expenses	Vendor	Cost ($)
SanDisk Extreme 32gb SD Card	Amazon	16.95
Arduino Stackable Header Pins	Amazon	4.75
Gens Ace 11.1v 1300 mAh LiPo Battery	Amazon	16.99
10 Pair Deans Style Battery Connectors	Amazon	7.59
5.5mm x 2.1mm Arduino Power Plug	Amazon	5.68
	Spent	442.00
	Total Projected	2,000.00
Rocket		
Mobius Video Camera Shroud	Additive Aerospace	39.90
	Spent	39.90
	Total Projected	3,000.00
Travel		
	Total	4,500.00
	Total Budget	7,942.00

6.2.2 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.

6.2.3 Project Timeline

Table 47: 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

Due Date	Tasks/Event	Description	Deliverables
10/20/2016	Begin Subscale Fabrication	Begin initial stages of subscale fabrication	Prepared airframe
10/28/2016	PDR Rough Draft Due	Prepare PDR report for final review	PDR Rough Draft
10/30/2016	PDR Review Session	Review the PDR draft and prepare the report for the final review	Revised PDR report
11/2/2016	PDR Final Review Session	Final review of the PDR report before the submission	Final PDR report
11/4/2016	PDR Submission	Submit PDR to NASA	PDR report
11/6/2016	PDR Presentation Practice	Rehearse speaking roles of PDR presentation with team members	Prepared PDR Presentation
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

Due Date	Tasks/Event	Description	Deliverables
11/27/2016	Revise Full-scale Design	Consider any necessary changes to design based on subscale launch data	Revised full-scale design
11/27/2016	Revise Landing System Design	Consider any necessary changes to design based on prototype testing	Revised landing system design
12/2/2016	CDR Q&A Session	Ask NASA employees specific questions pertaining to the designs of the landing system and launch vehicle	All questions answered
12/10/2016	Begin Full-scale Fabrication	Begin initial stages of full-scale fabrication	Prepared airframe
12/13/2016	Assign CDR Sections	Assign sections of the CDR report to team members involved	Team members know CDR sections they are responsible for
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

Due Date	Tasks/Event	Description	Deliverables
1/7/2017	CDR Review Session	Review the CDR draft and prepare the report for the final review	Revised CDR report
1/9/2017	CDR Final Review Session	Final review of the CDR report before the submission	Final CDR report
1/13/2017	CDR Submission	Submit CDR to NASA	CDR report
1/16/2017	CDR Presentation Practice	Rehearse speaking roles of CDR presentation with team members	Prepared CDR Presentation
1/17/2017	Complete Full-scale Fabrication	Launch vehicle and recovery system ready for testing	Prepared full-scale
1/17/2017	Complete Landing System Fabrication	Initial landing system prepared for testing	Prepared landing system
1/21/2017	Varn Ranch Launch	Launch full-scale with initial landing system and record any valuable data	Launched full-scale and recovered landing system
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

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

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

Due Date	Tasks/Event	Description	Deliverables
4/17/2017	PLAR Rough Draft Due	Prepare PLAR report for final review	PLAR Rough Draft
4/19/2017	PLAR Review Session	Review the PLAR draft and prepare the report for the final review	Revised PLAR report
4/22/2017	PLAR Final Review Session	Final review of the PLAR report before the submission	Final PLAR report
4/24/2017	PLAR Submission	Submit PLAR to NASA	PLAR report

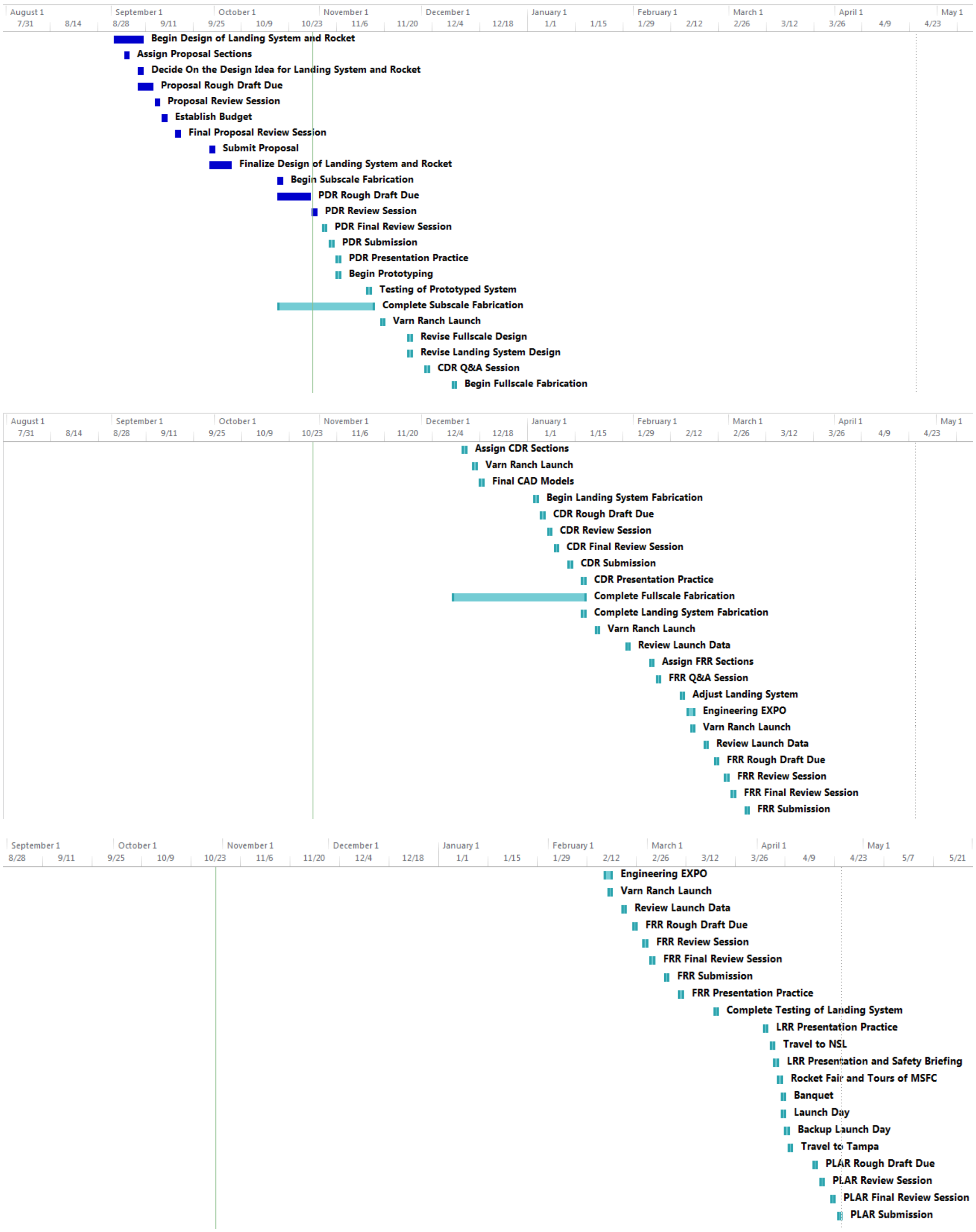


Figure 10: GANTT chart of project timeline

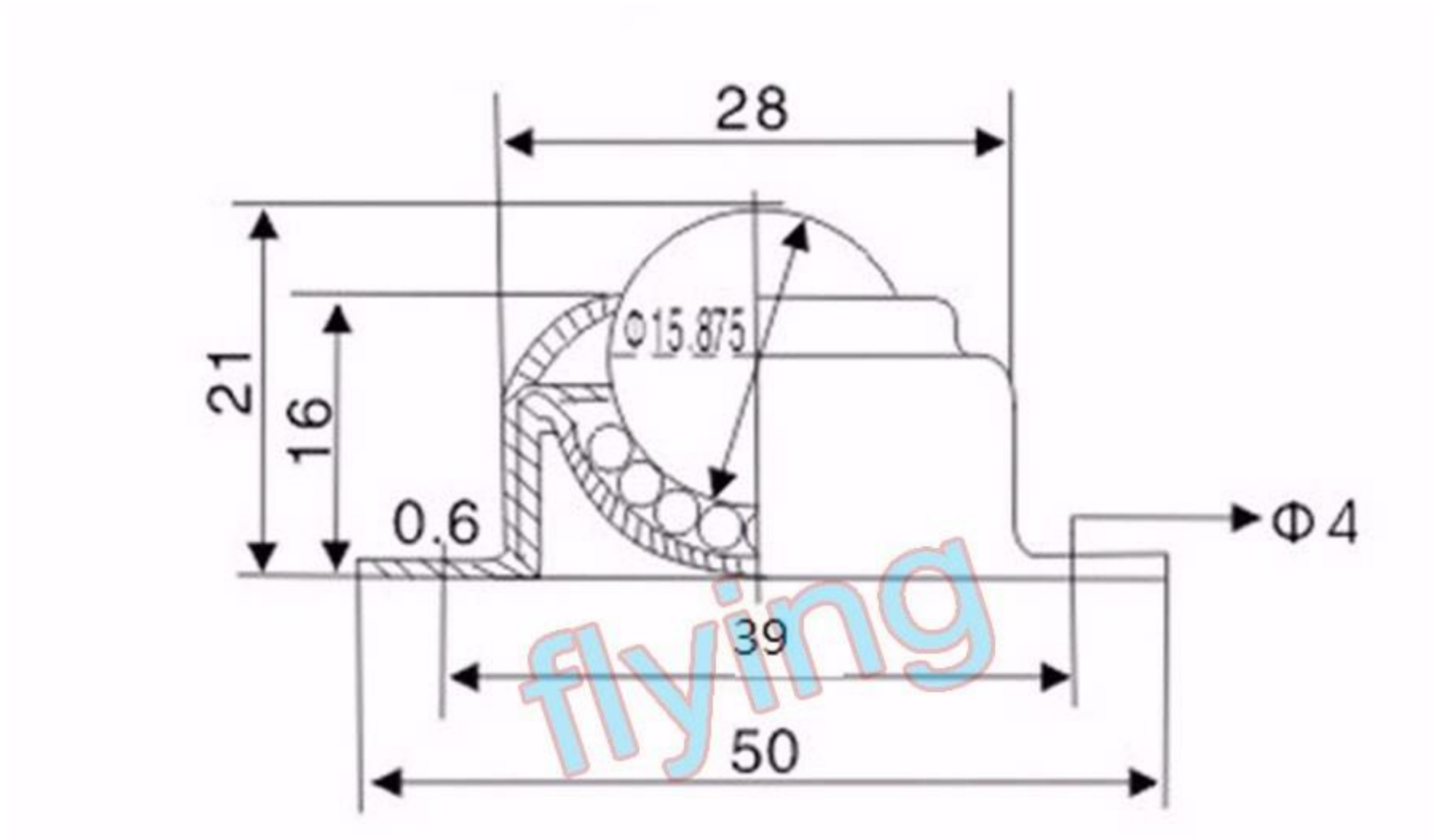
7 Appendix

7.1 Contributors

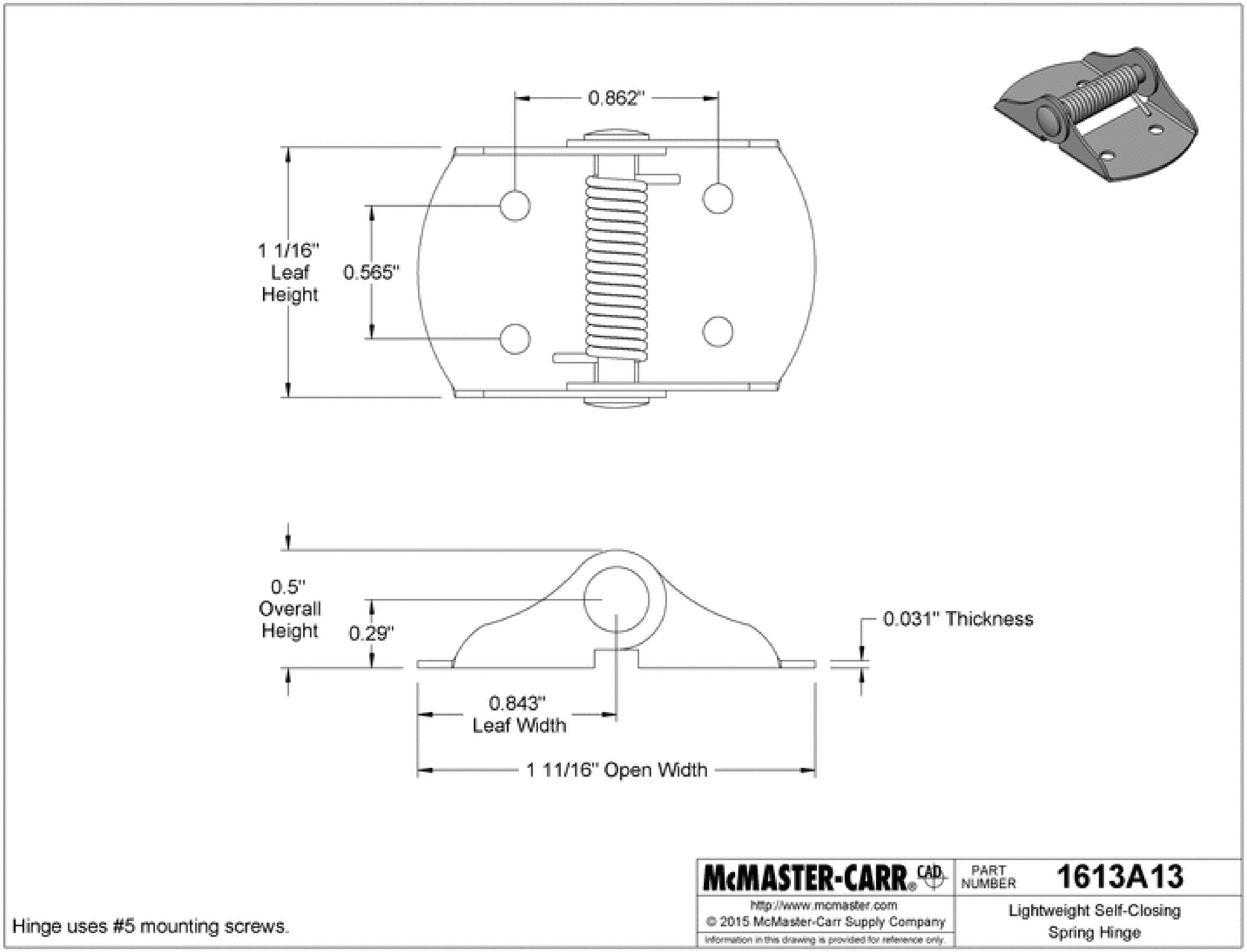
- **Project Management**:
  - Kateryna Turchenko
  - Danielle Petterson
  - Andrew Huff
- **Launch Vehicle**:
  - Jamie Waters
  - Brooke Salas
  - Frankie Camargo
  - Logan Sveum
  - Andrew Huff
- **Landing Module**:
  - Jaime Gomez
  - Simon Wilson
  - James Pierce
  - Nicholas Abate
  - Tanner Diberardino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

7.2 Drawings

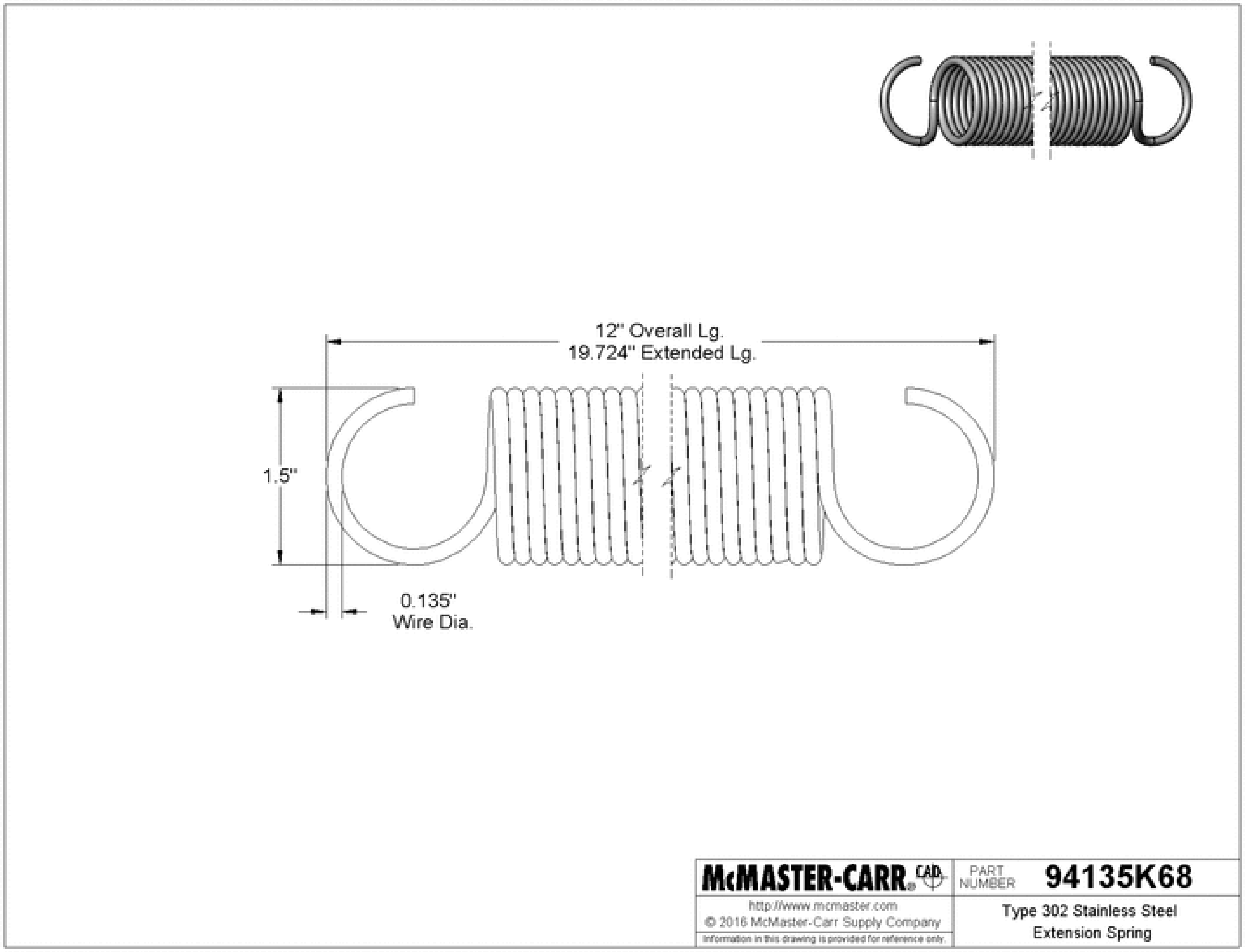
See the following pages for SolidWorks drawings of purchased (McMaster-Carr branded drawings) and fabricated (SOAR branded drawings) parts.

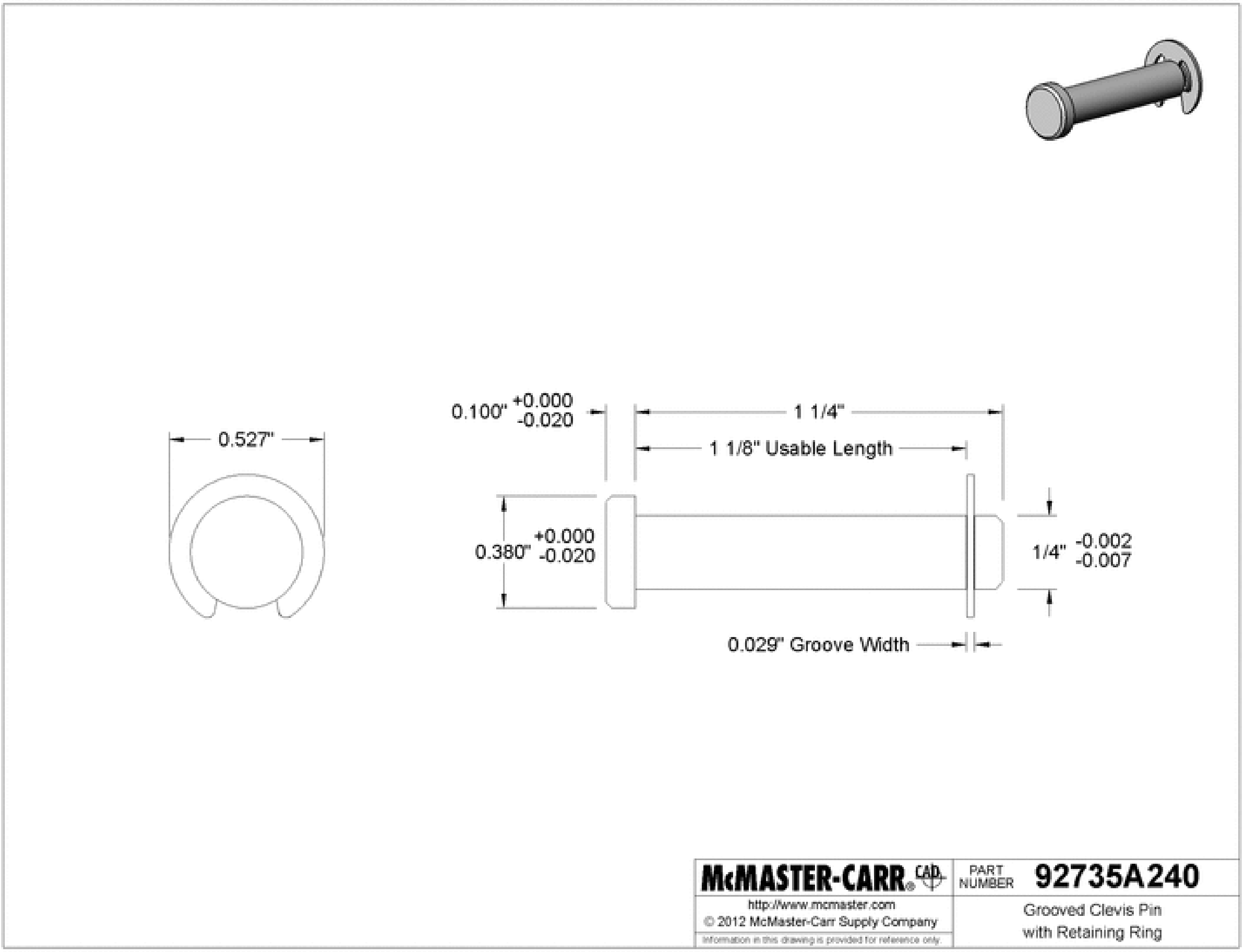


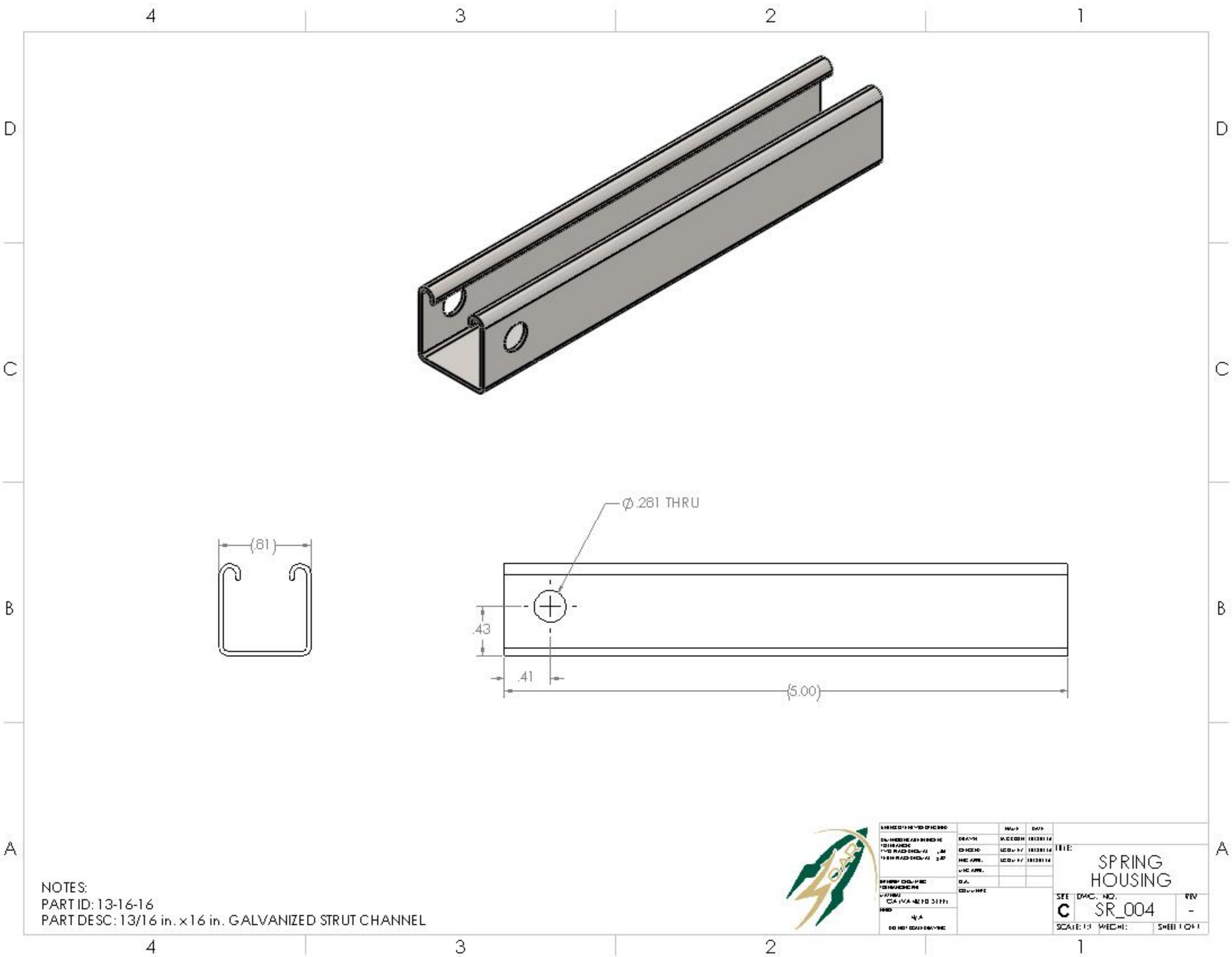
Landing gear wheel section.



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
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
http://www.mcmaster.com
© 2012 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
92735A240
Grooved Clevis Pin
with Retaining Ring



Ø.281 THRU
(.81)
.43
.41
(5.00)
NOTES:
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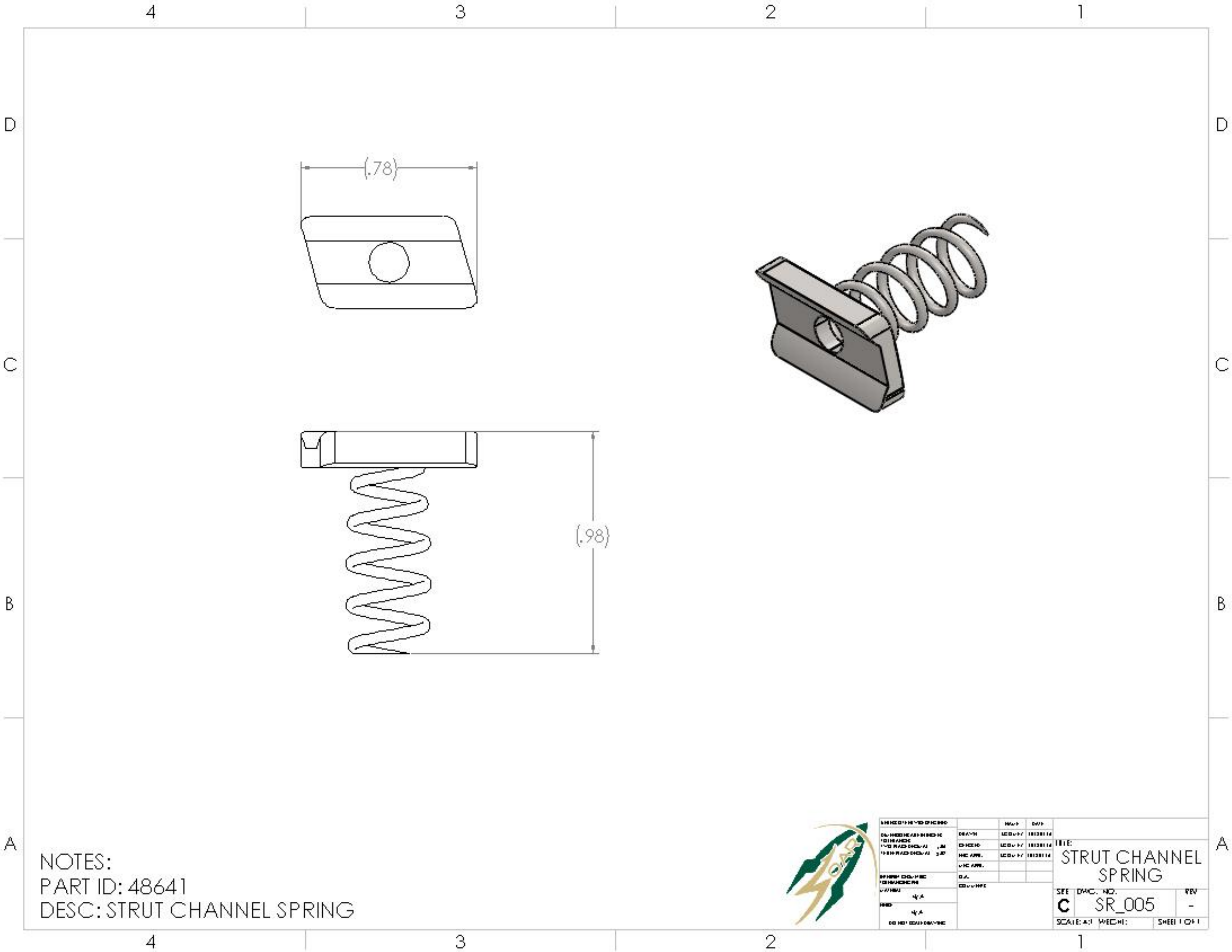
PART DESC: 13/16 in. x 16 in. GALVANIZED STRUT CHANNEL
SPRING HOUSING
C
SR_004
-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(.98)
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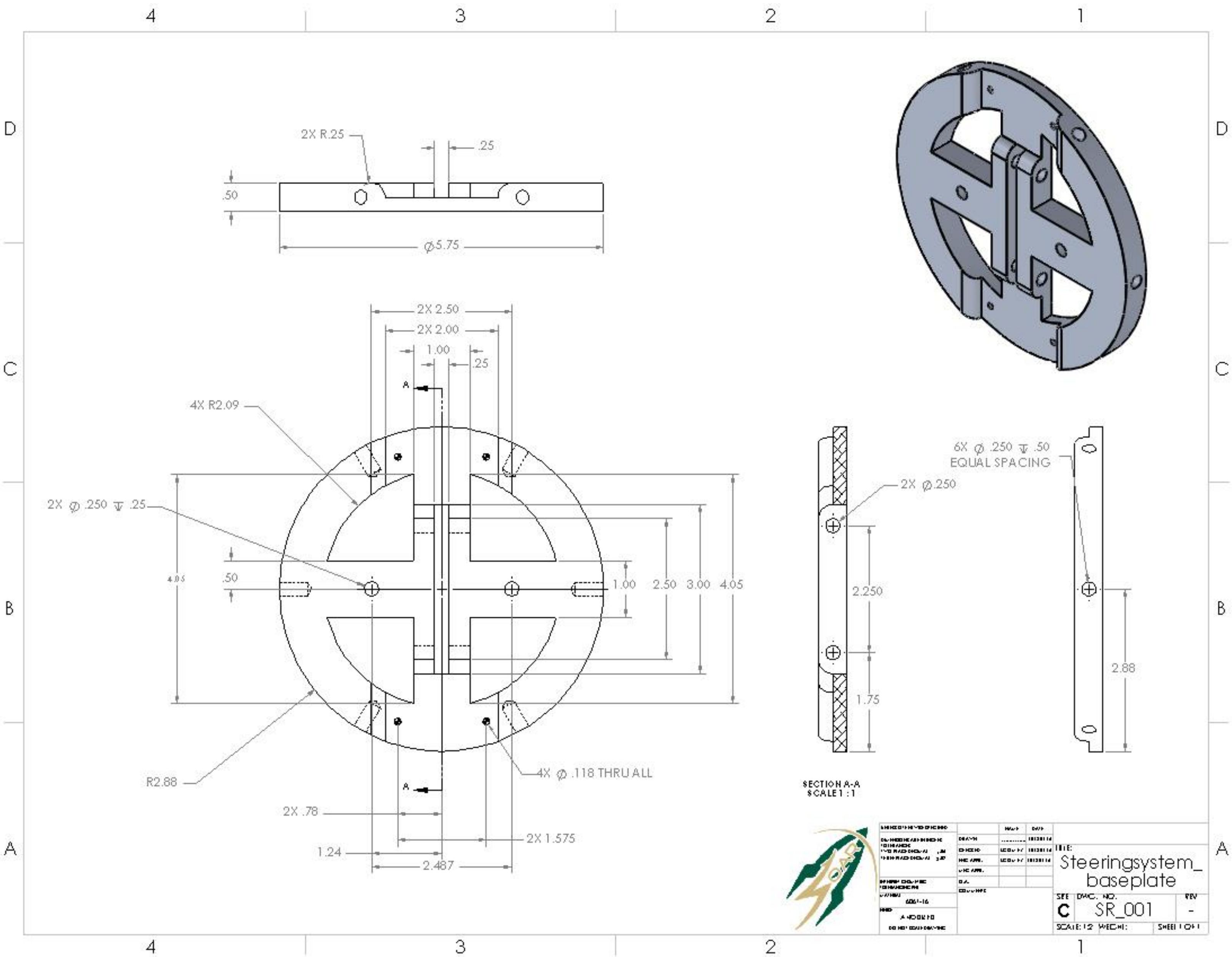
STRUT CHANNEL SPRING
C
SR_005
-



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
2.487
2X 1.575
2X ⌀.250
2.250
1.75
6X ⌀ .250 ↧ .50
EQUAL SPACING
2.88
SECTION A-A
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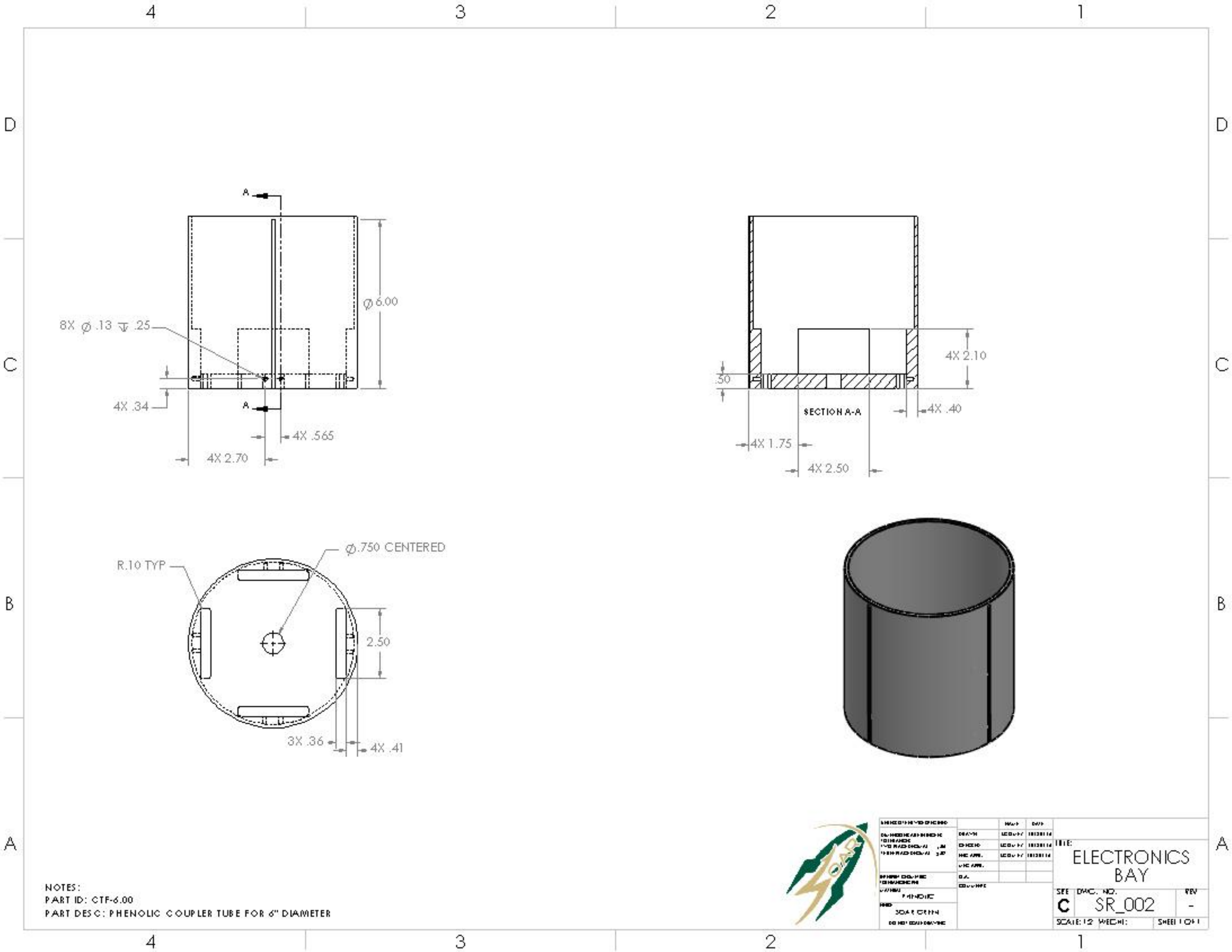
Steeringsystem_
baseplate
C
SR_001
-


A
A
8X ⌀ .13 ↧ .25
4X .34
4X .565
4X 2.70
⌀ 6.00
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
ELECTRONICS BAY
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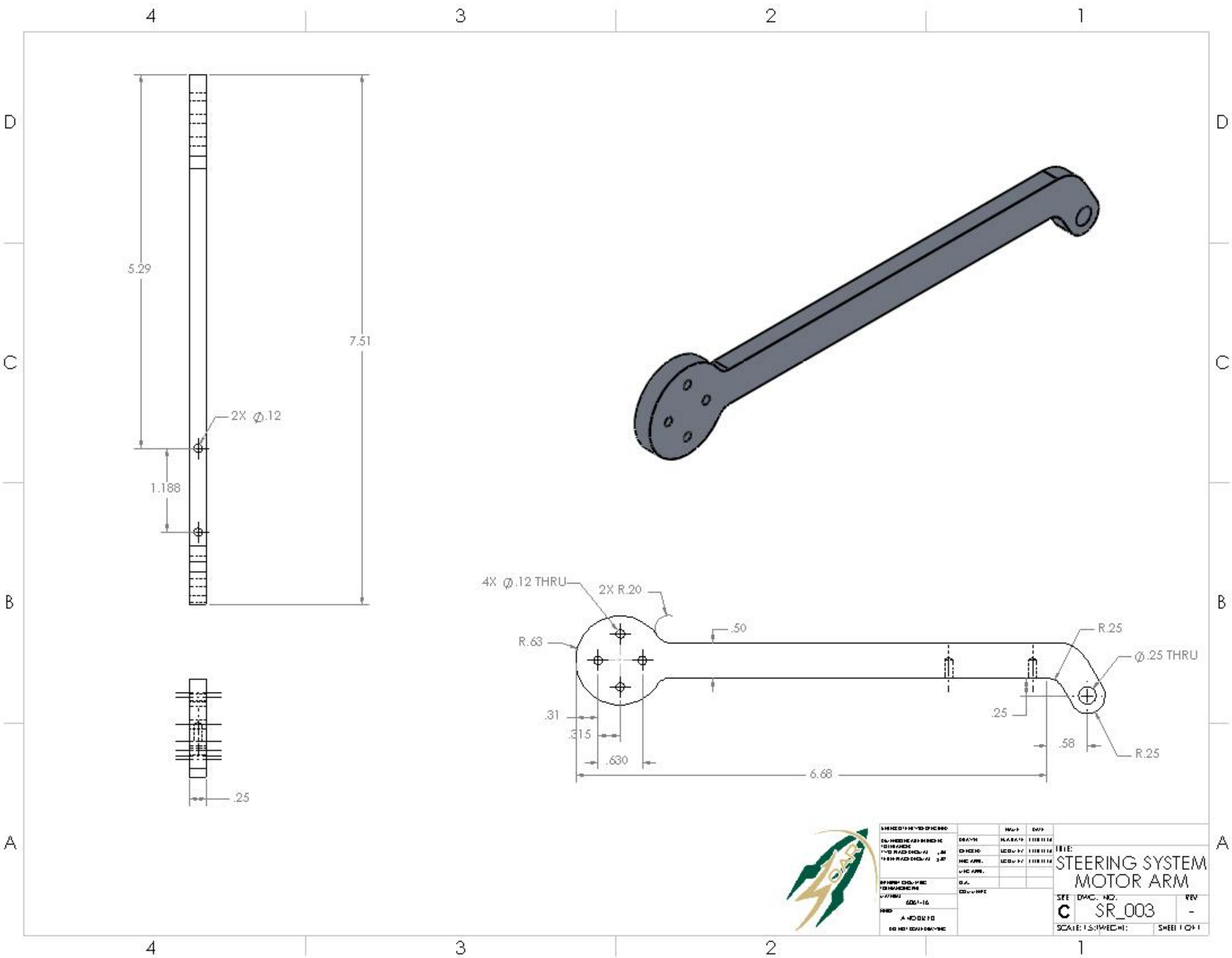
PART DESC: PHENOLIC COUPLER TUBE FOR 6" DIAMETER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7.51
2X ⌀.12
1.188
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4X ⌀.12 THRU
2X R.20
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R.63
R.25
⌀.25 THRU
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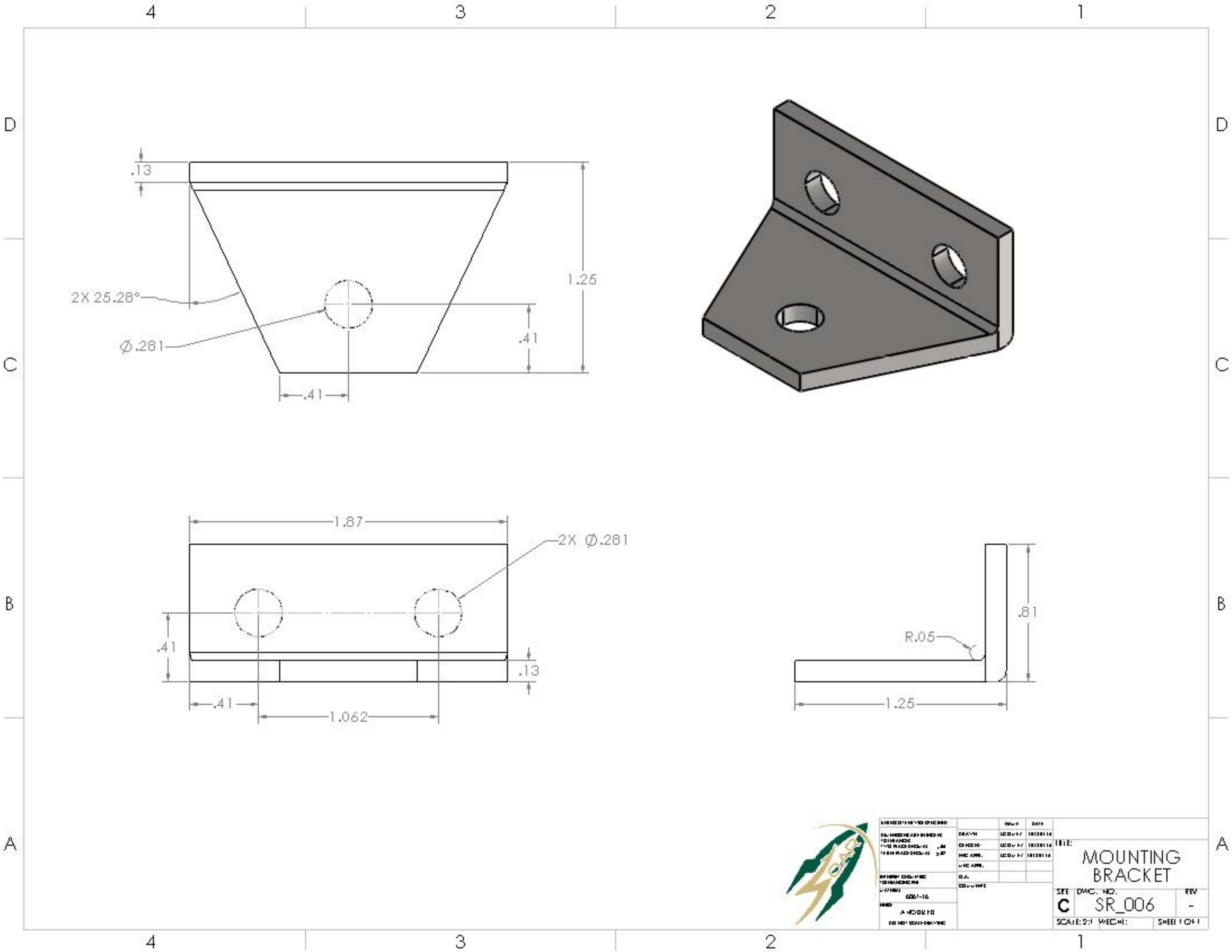
.630
.25
.58
R.25
6.68
STEERING SYSTEM MOTOR ARM
SIZE DWG. NO. REV
C SR_003 -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⌀.281
1.25
.41
.41
1.87
2X ⌀.281
.41
.13
.41
1.062
R.05
.81
1.25
MOUNTING BRACKET
DWG. NO.
C
SR_006
REV
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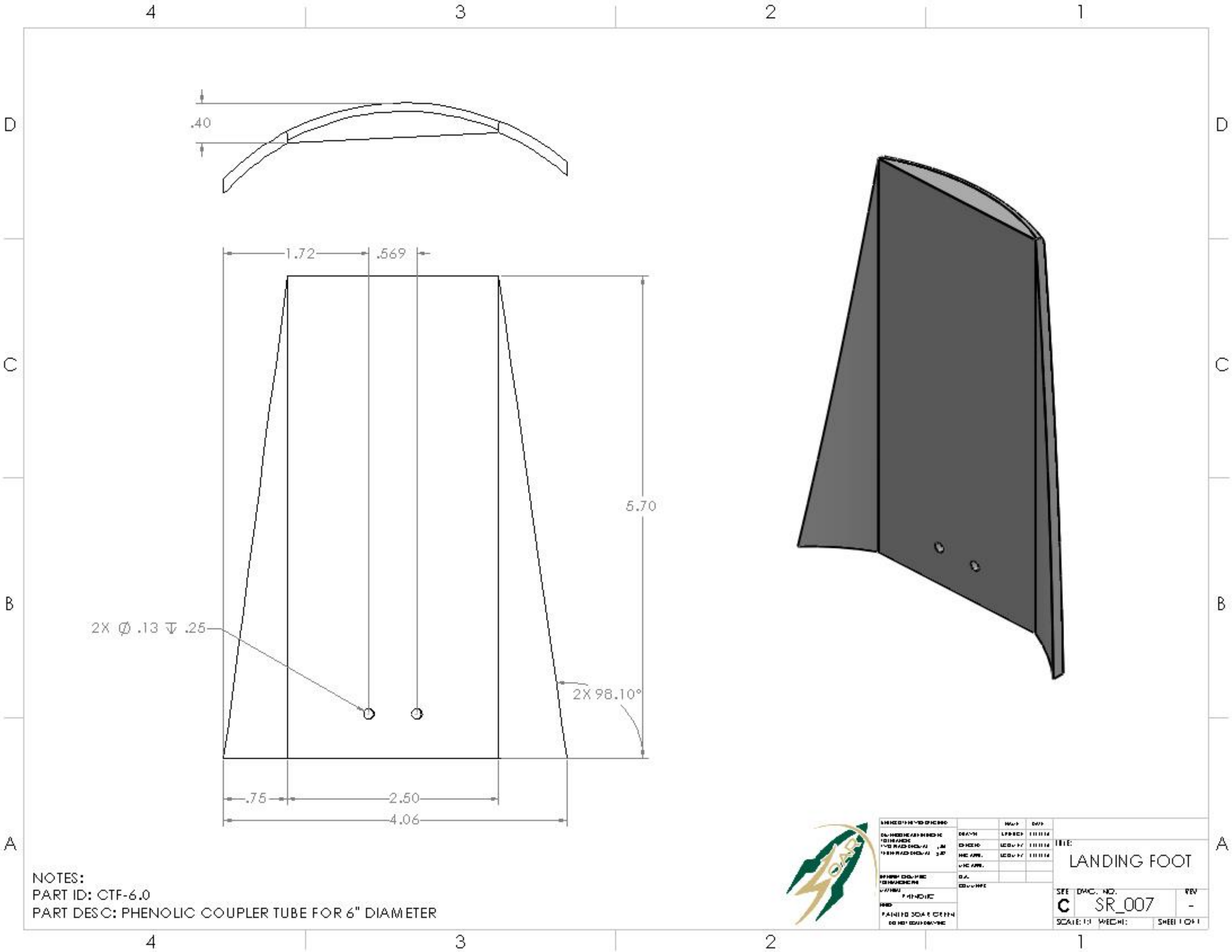
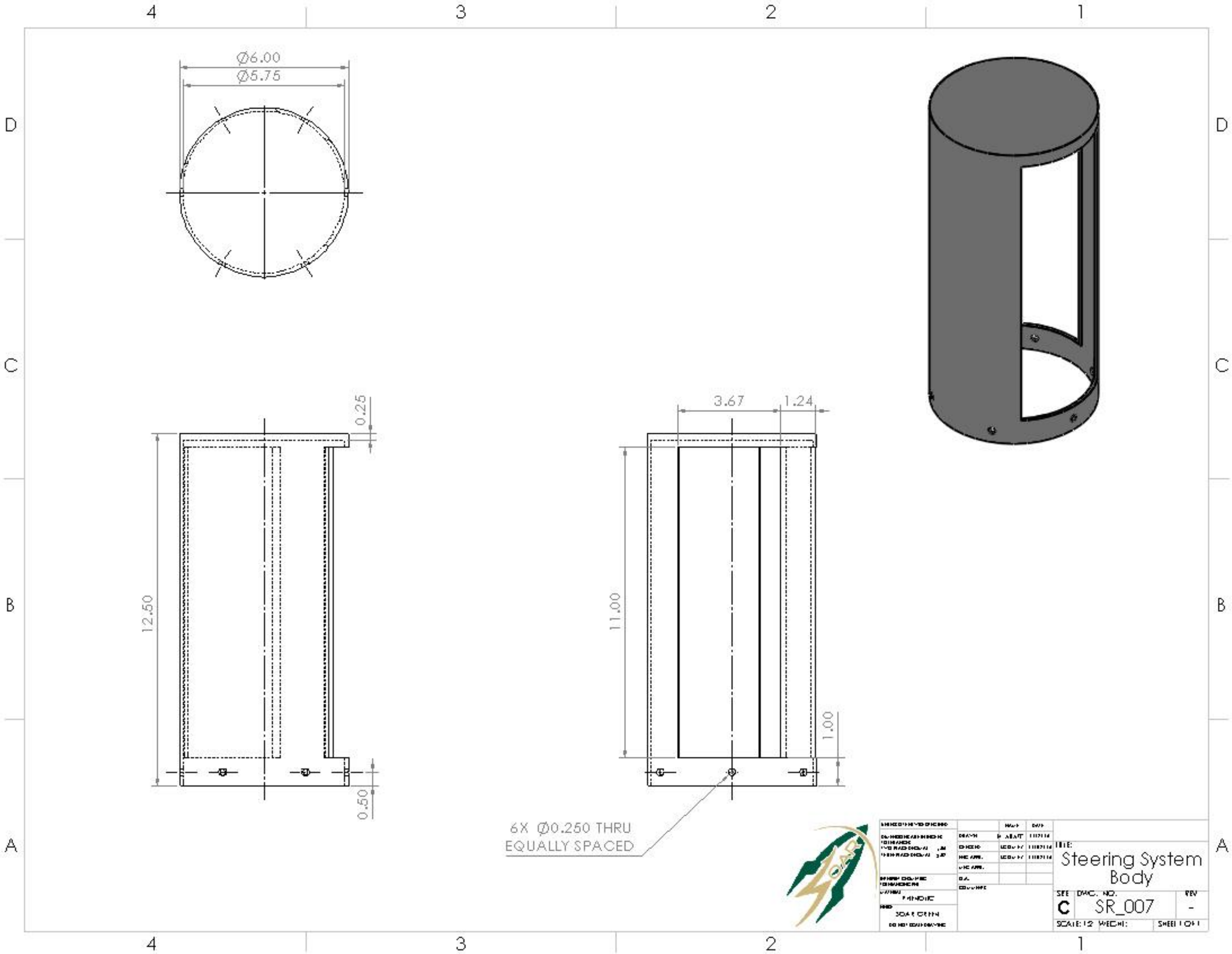
6061-T6
SCALE: 2:1


.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
TITLE:
LANDING FOOT
SIZE
C
DWG. NO.
SR_007
REV
-
PHENOLIC


Ø6.00
Ø5.75
0.25
12.50
0.50
3.67
1.24
11.00
1.00
6X Ø0.250 THRU
EQUALLY SPACED
Steering System
Body
C
SR_007
-