University of South Florida

NASA Student Launch

Centennial Challenge MAV Project

Flight Readiness Report

14 March 2016

Society of Aeronautics and Rocketry

15219 Plantation Oaks Drive, Apt 4.
Tampa, FL, 33647

Table of Contents

1) Summary of CDR Report

1.1 Team Summary

Institution: *The University of South Florida*
Organization: *USF Society of Aeronautics and Rocketry (SOAR)*
Location: 15219 Plantation Oaks Drive, Apt 4.
Tampa, FL, 33647
Mentor: Rick Waters
Launch Certification: Level 3 Certified TRA #: 8543

1.2 Launch Vehicle Summary

The launch vehicle has been designed in order to fit the criteria as set forth by the competition guidelines in terms of design specifications, manufacturing techniques, and performance testing. The vehicle is constructed of G-12 fiberglass, baltic birch plywood, and a majority adhesive fastener of 30 minute slow cure epoxy. The main focus of the design has been to allow for a safe recovery, repeatability, and confidence in performance. Table 1.2.1 gives a general overview of our launch vehicle attributes.

Table 1.2.1 List of launch vehicle attributions

Vehicle Overall Mass (lbs)	22.82
Vehicle Length (in)	138.6
Vehicle Diameter (in)	4.00
Recovery System	Dual deployment (RRC3 altimeter)
Vehicle Motor Selected	CS L910s

2) Changes Made Since PDR

2.1 Vehicle Criteria

In accordance with the scope and manufacturing time commitment needed for the fabrication of the full scale launch vehicle we have largely constrained our design to what was presented within the Critical Design Review. Since the CDR the team has been working on fabrication of the full scale, as well as developing appropriate tests to confirm design restrictions and tolerances in manufacturing. There have been some minor changes made to the launch vehicle design in order to ensure a successful full scale flight.

In terms of overall structure we have used expanding foam within our fin can in order to fill the former hollow space therein. By foaming the interior of the fan can we hoped to add a little more mass to our rocket in accordance with our current simulation predictions and to add further rigidity in order to secure our fins with a higher safety factor. Furthermore due to the high fineness ratio with our rocket design we are ensuring that all of our couplers are of adequate length. For our payload coupler we have allowed for a 4 inch shoulder while our altimeter bay has a 6 inch shoulder into the fore airframe and another 6 inches into the aft airframe. To further prevent instability the couplers have been layered with fiberglass in order to ensure appropriate friction hold with their adjoining fiberglass airframes.

After doing a further design analysis of our recovery harness we have determined that the eyebolts would not have sufficient space within our 4” frame. Our alternative solution was to epoxy the shock cord directly to the motor mount, layer the upper two centering rings over the cord and further secure it with a sheet of carbon fiber. Based on our estimations this method of securing the shock cord should be more than sufficient while allowing us to work with the smaller diameter of our launch vehicle.

2.2 AGSE Criteria

Throughout the development of our AGSE project we have continuously adjusted the scope and design in order to fabricate a viable working system. Since the Critical Design Review we have cemented our design choices to develop a system that is viable for fabrication and the requirements of the competition.

The rail system has been updated and expanded in order to allow for a more robust structure in order to facilitate appropriate balance and to appropriately secure fixtures to the AGSE. It is constructed primarily out of 1010 80/20. The primary method of movement has been changed to a linear actuator from a motor, this will allow us to save money and give us a greater safety factor. The robotic arm has been modified to be constructed from birch plywood, in order to cut down on the overall fabrication time and ease of fabrication. The containment system has been modified to ensure that at no point during the process will there be an unaligned separation of components, reducing the risk of misalignment errors.

3) Launch Vehicle Criteria

3.1 Design and Verification of Launch Vehicle

3.1.1 Design Overview

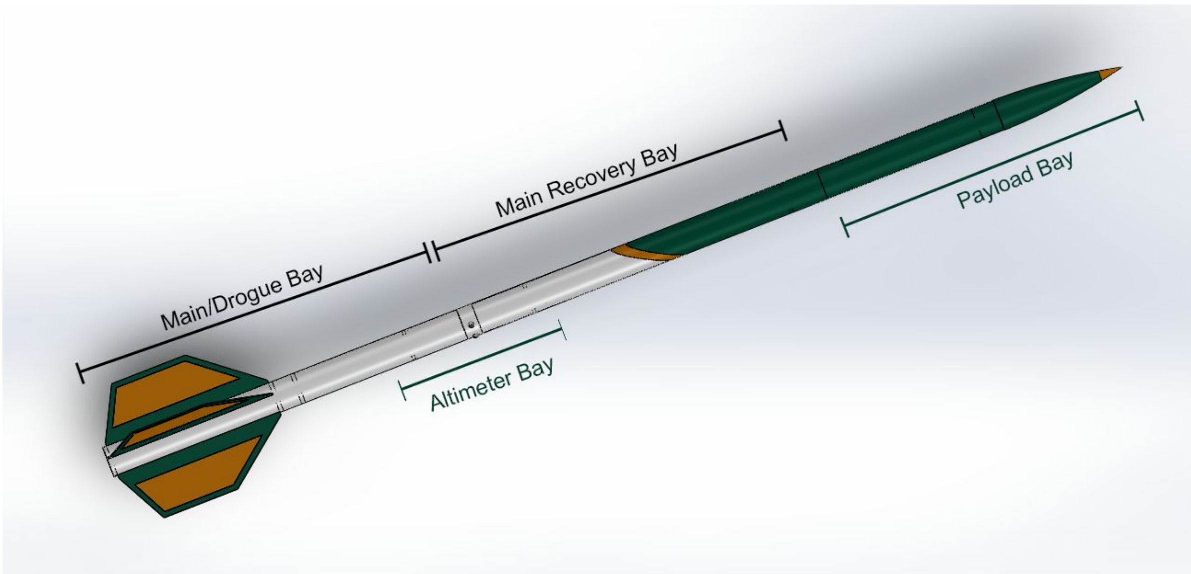


Figure 3.1.1.1: Model of Completed Rocket in Solidworks

The overall launch vehicle design has been an effort to establish a rocket that is first and foremost safe, efficient, and capable of successfully completing its mission criteria. Much of our design has been based on prior projects but because this is our team's first year participating in the NASA Student Launch Initiative we have done our best to develop a novel design that adequately fits the scope of the competition. We have used our collective design and fabrication experience in order to develop a quality vehicle with an emphasis on precision and professionalism in design and fabrication. Figure 1 above gives a general overview of our discrete rocket sections and assembly including: nose cone, payload bay, fore airframe, altimeter bay, and the fin can.

The major airframe structural material of the launch vehicle is G-12 fiberglass from Wildman Rocketry. Our fins are custom G-10 fiberglass fins from Public Missiles, Ltd developed to our design specifications. We will be featuring a sophisticated dual deployment recovery system with a redundant altimeter system with its own associated charges, power supply, and switch.

During the launch vehicle's flight, several criteria points must be met in order for the launch to be considered successful:

1. The launch vehicle achieves apogee between 5,000 and 5,400 feet.
2. At apogee, the drogue parachute is successfully ejected.
3. Between 500 and 600 feet AGL, the nosecone and payload bay are separated from the rest of the vehicle, and the main parachute and payload parachutes are successfully ejected.
4. No portion of the vehicle or payload sustains any major damage during flight or landing.

3.1.2 Applicable Calculations

"The most important characteristic of a model rocket is its stability" - James and Judith Barrowman, 1966

The Barrowmans submitted two documents, one in 1966 and another in 1967, both of which laid a firm foundation for the calculations of rocket stability, through the relative positions of the Center of Gravity (C_g) and the Center of Pressure (C_p).

3.1.2a Center of Pressure

A model rocket will fly straight into the oncoming airflow, however when there is an imbalance in the forces acting on the rocket the vehicle will have translational motion, similarly an imbalance in the torques, or moments, will cause rotational motion. Given a thrust misalignment, a fin incorrectly placed or a gust of wind, the rocket may tilt from its original orientation. In this event the vehicle will fly at a new angle, changing the aerodynamics of its path. The angle of attack, α, is the angle between the centerline of the launch vehicle and the vertical component of its velocity.

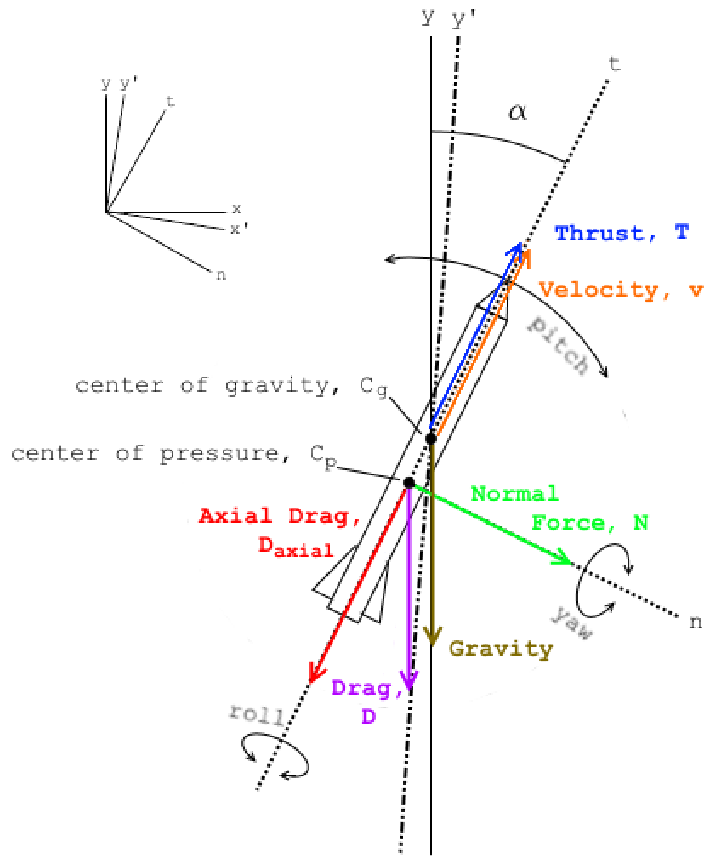


Figure 3.1.2a. 1: Rocket force diagram.

A stable rocket is one which continuously corrects its course to return to $\alpha = 0$ (zero). If the angle of attack increases too much, the C_p will move upwards and potentially overtake the C_g, which will negate the corrective motions of the stable rocket, thus making the rocket unstable.

Each component of the rocket has its own normal forces acting perpendicular the the surface; however, they can be summed up and expressed as acting through the center of pressure, C_p. If the C_p is located one to two calibers (max body diameters) aft of the center of gravity, C_g, the rocket will act to correct its trajectory by producing a moment. The stability margin is the distance between the C_p and C_g in calibers.

The center of pressure, C_p, is the point on the body where the normal force is the only force that produces a pitching moment. It is the point where there is as much normal force ahead as behind; a balancing point separate from the center of gravity. In order to develop the equation for C_p, we must first consider the relevant coefficients. Our plan of derivation:

1. Find Normal Force Coefficient
2. Identify Pitching Moment Coefficient
3. Moving Pitching Moment Coefficient
4. Set to 0 (zero) to find Center of Pressure location, x
5. Use l'Hopital to find Center of Pressure (Barrowman's Method)

The normal force for an axially symmetric body in subsonic flow:

$$N(x) = \rho v_0 \frac{\partial}{\partial x}[A(x)w(x)]$$

Where,

A(x) := cross-sectional area of the body

w(x) := local downwash

ρ := density

v_0 := free airstream velocity

w(x) as a function of α:

$$w(\alpha) = v_0 \sin(\alpha)$$

The normal force N(x) at position x produces a pitching moment at the nose tip:

$$m_{pitch}(x) = xN(x)$$

1. The normal coefficient C_N:

$$C_N(x) = \frac{N(x)}{.5\rho V_0^2 A_{reference}} = \frac{2\sin(\alpha)}{A_{reference}}\frac{dA(x)}{dx}$$

$$C_N = \frac{N}{.5\rho V_0^2 A_{reference}} = \frac{2\sin(\alpha)}{A_{reference}}\int_0^l \frac{dA(x)}{dx}dx = \frac{2\sin(\alpha)}{A_{reference}}[A(l) - A(0)]$$

Where,

l := length of rocket

$A_{reference}$:= area of base of the nose cone

2. Pitch moment coefficient C_m:

$$C_m(x) = \frac{m_{pitch}(x)}{.5\rho V_0^2 A_{reference} d} = \frac{xN(x)}{.5\rho V_0^2 A_{reference} d}$$

$$C_m = \frac{2\sin(\alpha)}{A_{reference} d}\int_0^l x\frac{dA(x)}{dx}dx = \frac{2\sin(\alpha)}{A_{reference} d}[lA(l) - \int_0^l A(x)dx]$$

Where,

d := diameter at a specific point

3. How to move the pitch moment coefficient to another point:

$$C_{m\ new} * d = C_m * d - C_N \Delta x$$

Where,

Δx := distance from nosecone along centerline of vehicle

4. Finding location of C_p by setting $C_{m\ new}$ to 0 (zero), and solving for x:

$$C_{m\ new} * d = C_m * d - C_N \Delta x$$
$$0 = C_m * d - C_N \Delta x$$
$$x = \frac{C_m * d}{C_N}$$

Where,

x := distance of C_p from nosecone tip on centerline

This equation is valid only for when the angle of attack, α, is greater than zero.

$$\lim_{\alpha \to 0} C_m = 0 \text{, and } \lim_{\alpha \to 0} C_N = 0$$

5. Using l'Hopital's Rule and Barrowman's Method to simplify finding C_p:

$$x = \frac{\frac{\partial C_m}{\partial \alpha}}{\frac{\partial C_N}{\partial \alpha}} * d \,|_{\alpha = 0} = \frac{C_{m\alpha}}{C_{N\alpha}} * d$$

Barrowman's method is based on normal force coefficients and is only valid in the linear regime.
At small α, C_N and C_m can be approximated as linear with α, therefore

	For α > 0	For α = 0
Normal force coefficient derivative =	$C_{N\alpha} = \frac{C_N}{\alpha}$	$C_{N\alpha} = \frac{\partial C_N}{\partial \alpha} \,|_{\alpha=0}$
Pitch moment coefficient derivative =	$C_{m\alpha} = \frac{C_m}{\alpha}$	$C_{m\alpha} = \frac{\partial C_m}{\partial \alpha} \,|_{\alpha=0}$

The Barrowman Method uses the coefficient derivatives to determine C_p. The first element in applying this methods is to observe that the normal force contribution of a straight, constant diameter body tube is zero. Only the nose, any body diameter transition sections, and fins contribute to the normal force of the rocket. However, the launch vehicle used in the NSLI has no body transition sections, and thus treatment of such is unnecessary. Calculations are performed with the normal force coefficients. All centers of pressure are referenced to datum zero, which is located at the tip of the nose cone.

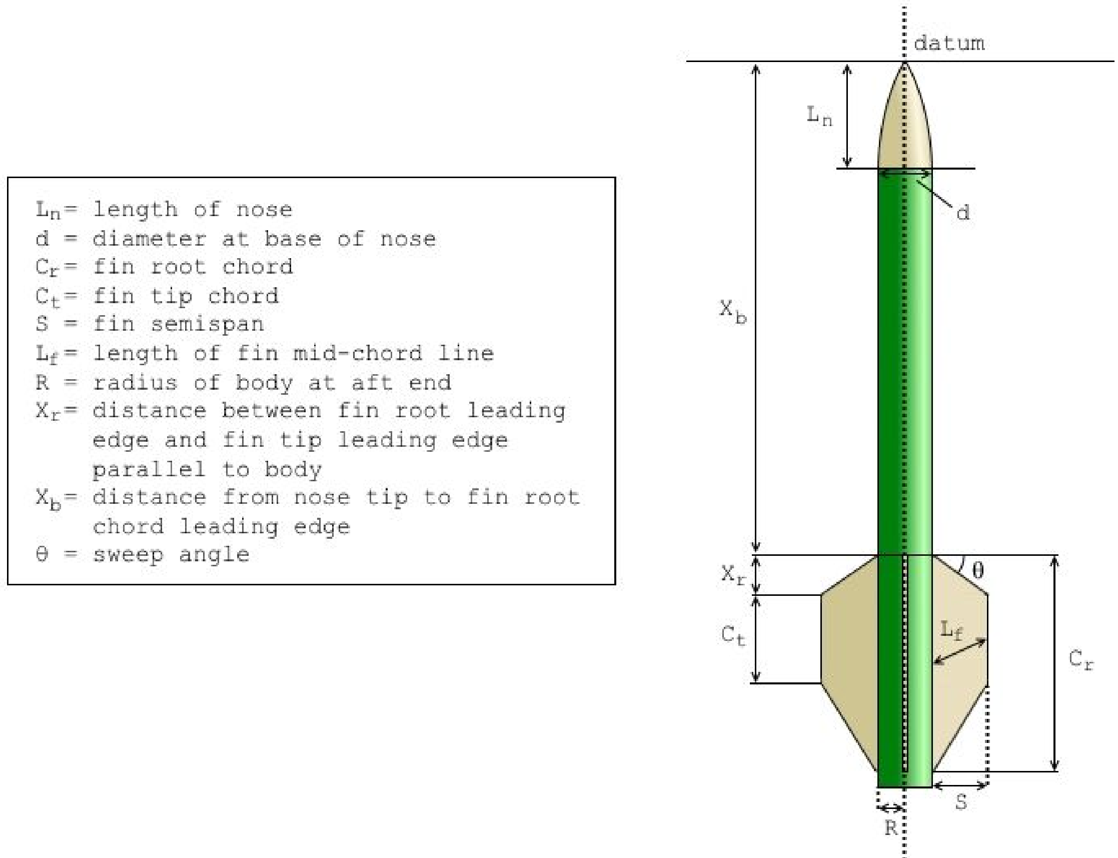


Figure 3.1.2a. 2: Diagram of rocket with legend.

The equations used for calculating the center of pressure of the nose cone depends on the type of curvature the nose cone exhibits. The nose used for this competition has ogive geometry. The shape of an ogive nose cone is formed from a quarter section of a circle with "ogive radius" ρ, like in Figure 4. By rotating the shaded region of the figure about the centerline, the resulting volume of revolution is the nose cone, having a radius of R at its base. The body of the rocket will be tangent to the ogive shape at its base. The distance from the tip of the nose to the center of pressure is X_n. The radius of the nose's base, the ogive radius, and the length L_n of the nose are related in the following way:

$$\rho = \frac{R^2+L_n^2}{2R} .$$

L_n must be less than or equal to ρ. When the two are equal, the nose is a hemisphere. The Barrowmans calculated that the normal force coefficient acting on the center of pressure of the nose is the same, regardless of its shape. So $(C_{N\alpha})_n = 2$.

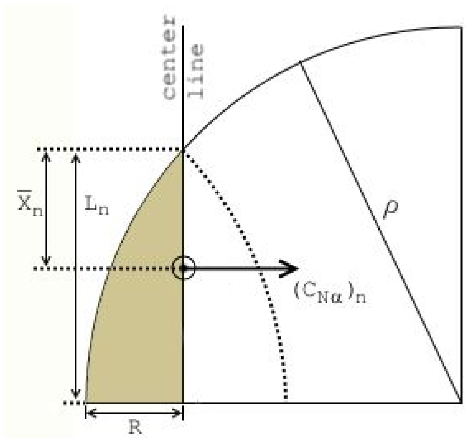


Figure 3.1.2a. 3: Geometry of an ogive nose cone, including location of center of pressure.

The location of the center of pressure, however, depends greatly on the shape of the nose itself. One can calculate the location of the center of pressure of an ogive nose cone by dividing the volume of the nose itself by the area at its base, where the volume is given by the following formula:

$$V = \pi[L_n\rho^2 - \tfrac{L_n^3}{3} - (\rho - R)\rho^2 \arcsin(\tfrac{L_n}{\rho})] .$$

Doing so will yield the distance from the base of the nose to the center of pressure. Subtracting this value from L_n will finally result in X_n, the distance from the tip to the center of pressure. The generic result of this calculation is cited as $0.466L_n$ when $L_n > 6R$.

The normal force coefficient $(C_N)_f$ acting on the center of pressure of the fins is calculated using this formula:

$$(C_N)_f = [1 + \tfrac{R}{S+R}][\frac{4N(\frac{S}{d})^2}{1+\sqrt{1+(\frac{2L_f}{C_r+C_t})^2}}]$$

where the variables involved are the same as those defined in Figure 3, N is the number of fins, and L_f can be calculated using the Pythagorean Theorem:

$$L_f = \sqrt{S^2 + (.5C_t - .5C_r + \tfrac{S}{\tan\theta})^2} .$$

The distance from the tip of the nose cone to the center of pressure of the fins is given by:

$$X_f = X_b + \tfrac{X_r}{3}\tfrac{(C_r+2C_t)}{(C_r+C_t)} + \tfrac{1}{6}[(C_r + C_t) - \tfrac{C_r*C_t}{(C_r+C_t)}] .$$

The normal force coefficient acting on the center of pressure of the entire rocket is simply the summation of the normal force coefficients of the nose, transition sections (of which there are none), and the fins: $(C_N)_{total} = (C_N)_n + (C_N)_f$.

The distance from the tip of the nose cone to the center of pressure of the rocket can be calculated in a way which is analogous to the calculation of center of gravity:

$$X = \frac{(C_N)_n*X_n+(C_N)_f*X_f}{(C_N)_{total}} .$$

In order for this center of pressure calculation to be valid, seven criteria must be satisfied:

1. The angle of attack, α, must be less than 10°.
2. The speed of the rocket's flight must be subsonic.
3. The airflow around the body must be smooth and cannot change rapidly.
4. The rocket must be thin compared to its length.
5. The nose of the rocket must come smoothly to a point.
6. The rocket must be an axially symmetric body.
7. The fins must be thin, flat planes.

Our rocket does satisfy these criteria.

3.1.2b Airflow Considerations

The airflow around the body of a rocket can be approximated as acting in layers, or lamina. These layers each have different velocity. The lamina most adjacent to the surface of the rocket can be said to have zero velocity relative to the rocket and remains with the surface, this lamina is the boundary layer. The boundary layer grows in thickness as the air travels down the length of the launch vehicle. After the boundary layer each new layer has a higher velocity than the last until free stream velocity is reached. This type of orderly airflow is deemed laminar, while disorderly airflow is deemed turbulent.

At some point a transition occurs and the laminae begin to mix. The boundary layer becomes turbulent and grows in thickness rapidly. The skin friction resistance caused by a turbulent boundary layer is much greater than a laminar boundary layer. The point at which the flow becomes turbulent is the point at which there exists a local critical Reynolds number (R_N). The Reynolds number, in our application, denotes a ratios between the inertial (resistant to motion) forces and the viscous (analogous to fluid friction) forces, as such, it is a dimensionless ratio. We shall use the Reynolds number to determine if the airflow is laminar, turbulent, or transitory.

$$R_N = \frac{density*velocity*length}{viscosity}$$

$$R_{N\ critical} = \frac{V_0*x}{\mu}$$

Where,

V_0 := free airstream velocity

x := distance along body from nose to tip

μ (mu) := kinematic viscosity of air (~$1.615*10^{-4}$ ft^2/s)

And,

$R_{N\ critical} = \sim 500{,}000$

Many aerodynamic parameters vary with changing velocity. One important aerodynamic parameter is the Mach number, which is the free airstream velocity divided by the local speed of sound. In subsonic flight all airflow occurs below the speed of sound (M < 0:8). At very low Mach numbers we can treat air as an incompressible fluid ($\nabla \cdot V = 0$) . The SOAR rocket will be safely under the local speed of sound.

$$Mach = M = \frac{V_{stream}}{s}$$

Where,

V_{stream} := free airstream velocity

s := local speed of sound

Recalling that V is representative of the fluid airflow, and that in our model the air is treated as incompressible, we have then that the density can be treated as constant ($\nabla \rho = 0$) and can be accordingly removed from Euler's continuity equation. Taking note that this simplification is not suited for more complex modelling, particularly with rockets travelling near or above the local speed of sound.

Steady Form Continuity

$$\nabla \cdot \rho V = 0$$

Incompressible Form Continuity

$$\nabla \cdot V = 0$$

Accordingly, Euler's Steady Form momentum equations can also be factored and simplified,

Steady Form, Two Dimensional

X - momentum: $\frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} = -\frac{\partial P}{\partial x}$ Y - momentum: $\frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} = -\frac{\partial P}{\partial y}$

Incompressible Form Continuity

X - momentum: $u\frac{\partial(u)}{\partial x} + v\frac{\partial(u)}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x}$ Y - momentum: $u\frac{\partial(v)}{\partial x} + v\frac{\partial(v)}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial y}$

Where, P := Pressure

ρ := Density

u := x-component of velocity

v := y-component of velocity

3.1.2c Center of Gravity

According to Barrowman, we can calculate the Center of Gravity of our vehicle in only five steps,

1. Determine the weight of each individual component.
2. Find the Center of Gravity for each component.
    a. Cylindrical objects (body tubes, engines, couplers, etc.) have C_g at their midpoints.
    b. Nosecones have C_g at one-third their total length, from the wide end.
    c. The parachute, shock cord, and lines have C_g at the middle of their length when packed into the body tube.
3. Measure the distance between the nose tip and the center of gravity of each component.
4. Sum the weights of the individual components to get the total body weight.

$$W_{Body} = \sum_i W_i$$

5. Use the formula: $$X_{CgT} = \frac{\sum_i (W_i (X_{Cg})_i)}{W_{Body}}$$

Where, X_{CgT} := Location of vehicle's Center of Gravity
$(X_{Cg})_i$:= Distance from datum zero to C_g of the i^{th} component
W_i := Weight of the i^{th} component

3.1.2d Drag

Drag resists the motion of the vehicle relative to the air. At subsonic speeds, drag is produced by skin friction, pressure distribution around the components, or parasitic drag from launch lugs on the rocket. Drag increases proportionally to the angle of attack, α, and has a minima when $\alpha = 0$. It is therefore important to use C_p to calculate the stability margin. Having a large enough margin will keep the rocket self-correcting , reducing drag. However, if the margin is too large, on a windy day the rocket will consistently arc overhead instead of flying vertically. This is termed weather-cocking. To avoid it, the standard is to ensure the stability margin is at least equal and preferably a little larger than the greatest diameter of the rocket, or a caliber. "One caliber stability" means that the C_p is one maximum body diameter behind the C_g.

Drag Equation: $D = \frac{1}{2} C_D \rho V_0^{\,2} A_{reference}$

Drag Coefficient: $C_D = \frac{D}{.5\rho V_0^{\,2} A_{reference}}$

And, $C_{D0} = C_{A0}$

Where, $A_{reference}$:= Area of nosecone base
ρ := density

The C_D is used to describe how the shape of the rocket and its angle influence drag. It is a dimensionless quantity and anything that moves in air has a C_D. At $\alpha = 0$, the total drag coefficient (C_D) and axial drag coefficient (C_A) coincide, but at any other angle, they are considered separately. When $C_{D0} = C_{A0}$ it is called Zero Lift Drag Coefficient, and it has several parts. Each rocket component will contribute some drag to the calculation.

- Base Drag, C_{DB}, is only considered in the coasting phase, because at launch the base pressure is equal to the atmospheric, so there is no pressure inequivalence.

$$C_{DB\ booster} = 0$$

$$C_{DB\ coasting} = \frac{0.029}{\sqrt{C_{D\ Nosecone} + C_{D\ Body}}}$$

- Skin friction drag arises from the contact of the body and fins with the airflow. The area in contact is the reference area, and it is called the wetted area.

$$C_{skin\,friction} = \frac{D_{friction}}{.5\rho V_0^{\,2} A_{wetted}}$$

It is a function of the Reynolds number and surface roughness. For a turbulent flow with a smooth surface with a surface roughness completely imbedded in a lamina:

$$R_{N\ critical} = 51\left(\frac{R_S}{L}\right)^{-1.039}$$

Where, R_S := approximate height of the surface in micrometers

If Reynolds number is below 100,000: $C_{skin\,friction} = 0.0148$

If it is above 100,000, but below $R_{N\ critical}$: $C_{skin\,friction} = \frac{1}{1.5 \ln R_N - 5.6}$

If it exceeds the critical value: $C_{skin\,friction} = 0.032(\frac{R_{NS}}{L})^{0.2}$

- Fin drag is a large component of rocket aerodynamics and a full treatment requires many equations, several among them are:

Taper Ratio: $\lambda t = \frac{C_t}{C_r} = \frac{tip\ chord}{root\ chord}$

Aspect Ratio: $AR = \frac{wingspan^2}{surface\ area\ of\ fins\ and\ connection} = \frac{b^2}{S}$

Thickness Ratio: $\frac{t}{c} = \frac{thickness}{chord}$

$$C_{DOFins} = \frac{D_{fins}}{(\frac{1}{2})dv^2 * planform\ area}$$
$$C_{DOFins} = 2 * C_{skin\,friction}(1 + 2(\frac{t}{c}))$$

- Nose cone drag exists, but is much smaller than skin friction drag. For subsonic flights (M < 0.8) we can approximate this coefficient as zero.

$$C_{D\,Nose} + C_{D\,Body} = 1.02C_{skin\,friction}(1 + \frac{1.5}{(\frac{L}{d})^{3/2}})\frac{Wetted\ Surface\ Area}{Area\ of\ Body}$$

- Parasitic drag is what develops from having one or two launch lugs attached to the body of the rocket. It may be modeled as a solid cylinder, instead of a hollow cylinder.

$$C_{D\,Launch\,Lug\,max} = 1.2\frac{Surface\ area\ of\ lug}{Surface\ area\ of\ body\ tube}$$

The Total Drag Coefficient (C_D) is obtained by scaling all of the relevant drag coefficients to a common reference area and making a summation:

$$C_{D0} = \sum_T \frac{A_{Total}}{A_{reference}}(C_D)_{Total}$$
Where, $\alpha = 0$

When $\alpha \neq 0$, $C_{D0} \neq C_{A0}$. More area interacts with the airflow, the pressure gradients change and vortices at the fins develop. The axial drag coefficient (C_A) must be considered separately. All of these are valid for small α, usually less than 10°, but with an upper limit of around 17°.

For, $\alpha = 0^o$ $C_A = 1$

For, $\alpha = 17^{o}$ $C_A = 1.3$

3.1.2e Thrust

The calculation of thrust is a vital step in the understanding of rocketry. As such, it has an important place in the design of SOAR’s launch vehicle. We know,

$$F = ma = m\tfrac{dv}{dt}\,.$$

However, this is relatively general, so we need a more thorough analysis of rocket thrust.

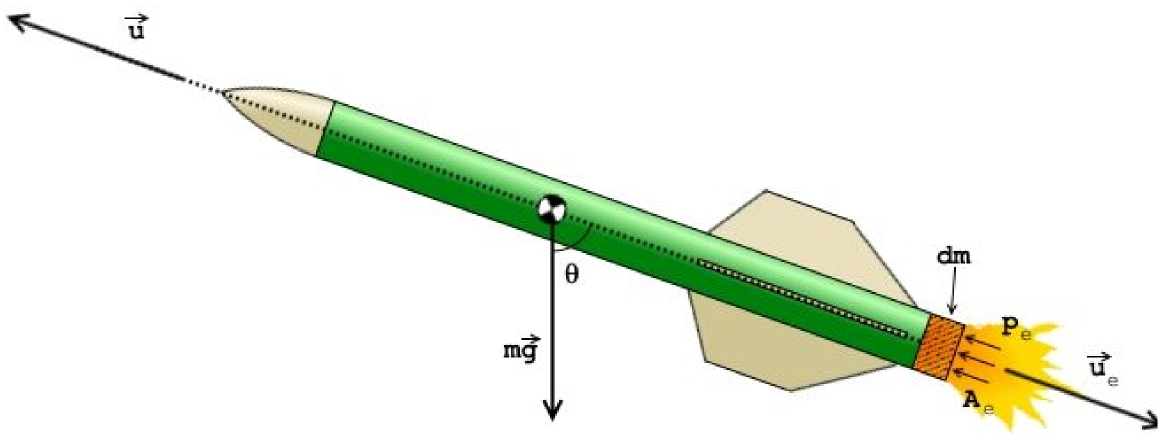


Figure 3.1.2e.1: Diagram of rocket in-flight.

We have

$$\tfrac{d}{dt}(m_b v + \int \rho(u+v)dV) = (P_{out} - P_{atm})A_e + F_{Drag} - F_{Gravity} + \dot{m}(u_e + v)\,,$$

where

$\tfrac{d}{dt}(m_b v + \int \rho(u+v)dV)$:= Rate of change in vehicle momentum

$(P_{out} - P_{atm})A_e + F_{Drag} - F_{Gravity}$:= External forces

$\dot{m}(u_e + v)$:= Momentum flow through outlet

And,

(u + v) := velocity components relative to ground

Treating the mass flow through the outlet,

$$\dot{m} = \frac{d\,(mass\ total)}{dt} = \rho_{exit} u_{exit} A_{exit}$$

Substituting,

$$F_{int} = -\frac{d}{dt}\left(\int \rho(u)\,dV\right)$$

$$F_{thrust} = (P_{out} - P_{atm})A_e + \dot{m}u_e$$

$$\text{Acceleration} = a = \frac{F_{thrust} + F_{drag} + F_{int}}{mass_{total}} - g$$

$$\frac{dv}{dt} = a;\ \frac{d(x,y,z)}{dt} = \text{v},$$

Also, because propellent provides such a large portion of the total mass, the changing mass due to propellant loss must be considered,

Empty Mass = M_{empty} = Payload mass + structural mass
Full Mass = M_{full} = Payload mass + structural mass + propellant mass
= Empty mass + propellant mass

$$\text{Structural Coefficient} = \varepsilon = \frac{structural\ mass}{(propellant\ mass + structural\ mass)}$$

$$\text{Payload Ratio} = \lambda = \frac{payload\ mass}{(full\ mass - empty\ mass)}$$

$$\text{Propellant Mass Ratio} = \text{MR} = \frac{full\ mass}{empty\ mass} = 1 + \frac{propellant\ mass}{empty\ mass} = \frac{1+\lambda}{1+\varepsilon}$$

3.1.2f Kinematics

Now to calculate the burnout altitude and velocity, along with coasting distance and coasting time. It will be helpful to first define a few variables which will keep the calculations more tidy:

$$k = \tfrac{1}{2}\rho C_D A,$$

$$q = \sqrt{\frac{T - mg}{k}},\ \text{and}$$

$$x = \frac{2kq}{m} = 2\frac{\sqrt{(T-mg)\cdot k}}{m},$$

where ρ is the air density, C_D is the drag coefficient calculated in a section above, $m = m_r + m_e - .5m_p$ is the average mass of the rocket during its upward travel, g is the acceleration of gravity, T is the thrust calculated above, and A is the cross-sectional area of the body of the rocket. The amount of time t for which the motor will burn is the motor impulse divided by the thrust:

$$t = \frac{I}{T}.$$

The velocity at burnout is

$$v = q\,\frac{1-\exp(-xt)}{1+\exp(-xt)}.$$

The altitude y_B at burnout is

$$y_B = \frac{-m}{2k}\ln\left(\frac{T-mg-kv^2}{T-mg}\right).$$

The vertical distance y_C for which the rocket will coast after burnout is

$$y_C = \frac{m}{2k}\ln\left(\frac{mg+kv^2}{mg}\right),$$

where m is now equal to $m_r + m_e - m_p$, because all of the propellant has been expelled from the rocket during the coast to apogee. So the altitude at apogee is $y_B + y_C$. The time spent coasting can also be represented neatly by first defining helpful variables:

$$q_a = \sqrt{\frac{mg}{k}}, \text{ and } q_b = \sqrt{\frac{gk}{m}}.$$

Now the coasting time t_C can be found using:

$$t_C = \frac{\arctan(v/q_a)}{q_b}.$$

3.1.3 Stability

Figure 3.1.3.1: Diagram of Rocket showing the Center of Pressure and Center of Gravity

Seen on figure 3.1.2.1 above, our team has determined the center of pressure and gravity of our launch vehicle in order to ensure that our design is stable. The center of gravity is located at 92.512 inches from the nosecone and our center of pressure is located at 114 inches from the nosecone. This gives us a stability of 5.38 calibers, well above the necessary 2 calibers.

Figure 3.1.3.2: Stability, CG, and CP plotted over time

3.1.4 Fabrication

There are numerous aspects and subsystems to be accounted for in fabrication of our launch vehicle. Our primary construction materials are fiberglass and plywood. One of the single most important aspects of fabrication, however, is our method fastening and adhesion. We primarily make use of 30 minute Slow Cure, two part epoxy with a known shear strength of 3500 psi. While Epoxy may yield at a much higher shear strength, 3500 psi is well within the limit of proportionality. In addition, we used shredded carbon fiber to increase the strength of the fillets applied to the fins. All other fasteners are applied as necessary such as plastic rivets in the nose cone, shear pins between sections, and screws in the altimeter bay.

3.1.4a Motor Mount: Centering Rings

The first step in the fabrication of our rocket is to place and then epoxy on the centering rings that will:

1.) Separate the motor mount from the inner diameter of the aft tube.
2.) Secure the motor mount inside of the aft tube
3.) Secure the Fins

In order to properly apply the fillets to the centering rings, we sanded the excess epoxy, then reapplied and smoothed the epoxy with a wooden applicator. Below in Figure 3.1.3a.1 you can clearly see where the three centering rings go on the motor mount. The centering rings we used are made of baltic birch wood, found to have an average density of 0.234 pounds per cubic inch; and we chose to use phenolic tubing for our motor mounts. The bottom most centering ring and the middle centering ring will serve as the borders that will be flush with the fins. In other words, the fins sit comfortably within these two centering rings.

Figure 3.1.4a.1: Motor Mount with Centering Rings

Figure 3.1.4a.1: Motor Mount with Centering Rings

3.1.4b Motor Mount: Fins

The fins are custom made from ⅛” thick G10 fiberglass by Public Missiles Ltd. We went with fiberglass to increase the overall weight of the rocket as well as increase the rigidity of the fins for the higher velocity the rocket will achieve. The fins are cut into a trapezoidal shape to allow the rocket to reach its optimum height as well as minimize the risk of catastrophic damage to the fins upon recovery. As mentioned above the bottom most centering ring and the middle centering ring border the fins as in Figure 3.1.3b.1. If you’ll notice, drawn on the Motor mount is the exact placement the four fins will need to be epoxied in place to ensure a linear assent. These lines are drawn following the arc length formula:

$s = r\theta$

where,

s = arc length
r = radius of the outer diameter of the motor mount
theta = $\pi/2$ (must be in radians)

Thus the distance around the outside diameter of the motor mount that the lines are drawn is 6.236cm from one another.

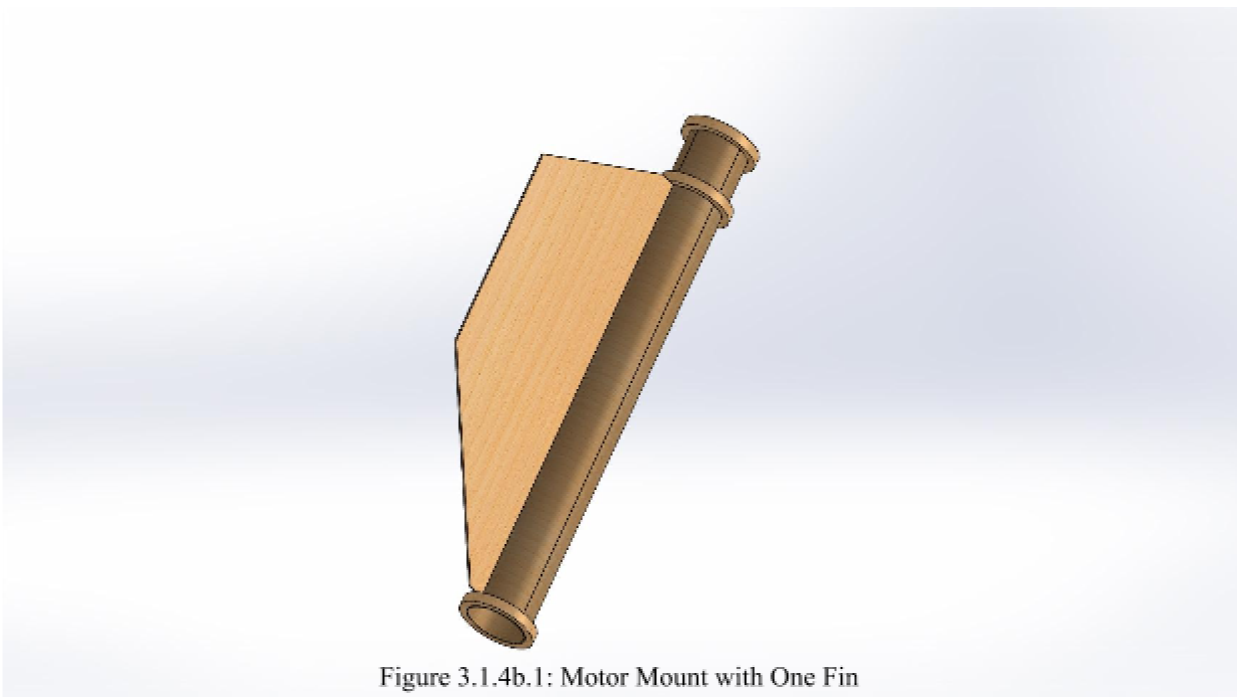


Figure 3.1.4b.1: Motor Mount with One Fin

Once the first fin is placed on the motor mount and epoxied in place, we then proceeded to place the rest of the fins on the motor mount as shown in Figure 3.1.3b.2. After the epoxy dried, we sanded the epoxy where the fins were adhered to the motor mount and created fillets made from a carbon fiber and epoxy mixture.

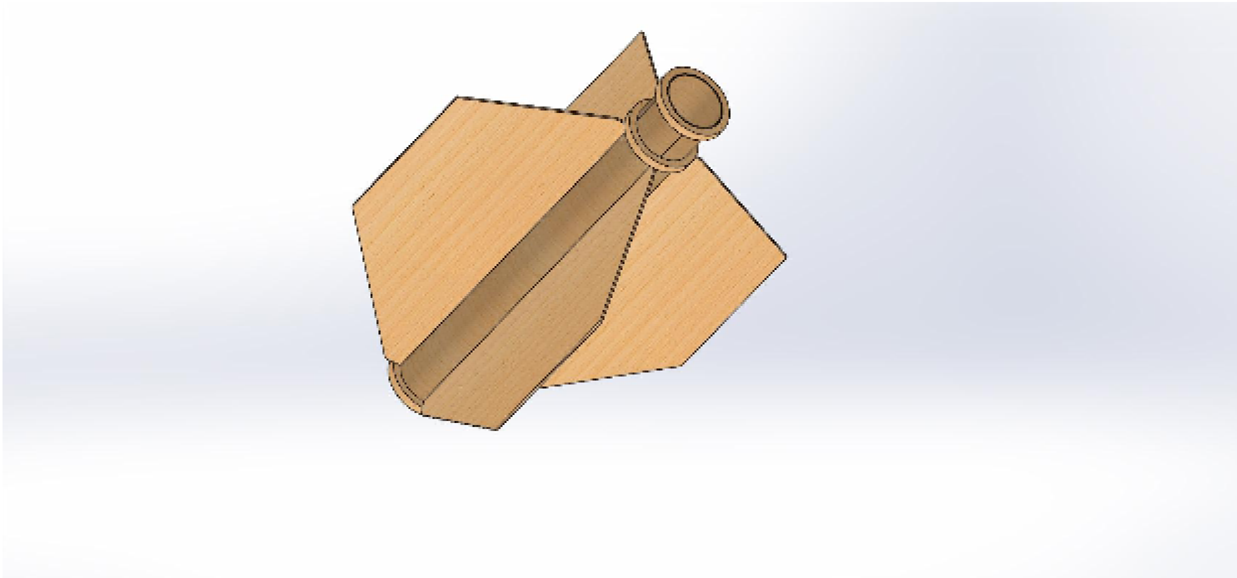


Figure 3.1.4b.2: Completed Motor Can

Figure 3.1.4b.2: Completed Motor Can

3.1.4c Motor Mount: Shock Cord and Motor Retainer

Figure 3.1.4c.1: Shock Cord Attachment

The next step in the fabrication of our rocket is the attachment of the shock cord and the motor retainer. As opposed to the previous eye bolt connection method we have instead decided to attach the shock cord by epoxying it to the motor mount and sealing it with carbon fiber. The motor retainer is attached to the bottom most centering ring which prevents the motor itself from falling out of the bottom of the rocket during ascent. Below in Figures 3.1.3c.1 and 3.1.3c.2 you can see the shock cord and the motor retainer represented respectively.

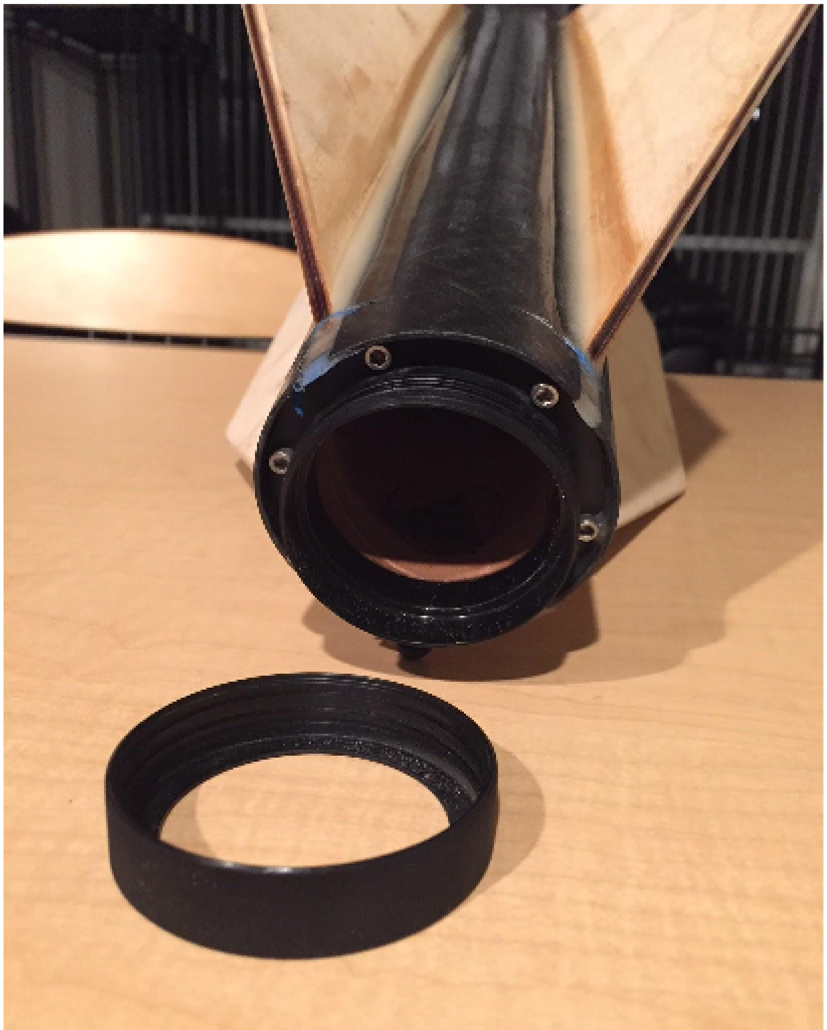


Figure 3.1.4c.2: Motor Retainer (Separated)

Figure 3.1.4c.2: Motor Retainer (Separated)

Below you can see the motor retainer screwed on to the end of the rocket. This, as stated above, is to prevent the motor from dislodging through the rear end of the rocket.

Figure 3.1.4c.3: Motor Retainer

Figure 3.1.4c.3: Motor Retainer

3.1.4d Route the Aft Tube Fin Slots

After the motor mount is completed which includes the fins, shock cord, and motor retainer the next step is to route the aft tubes fin slots. This is done so that we can slide the whole motor mount into the bottom of the aft tube and then secure it in place with epoxy.

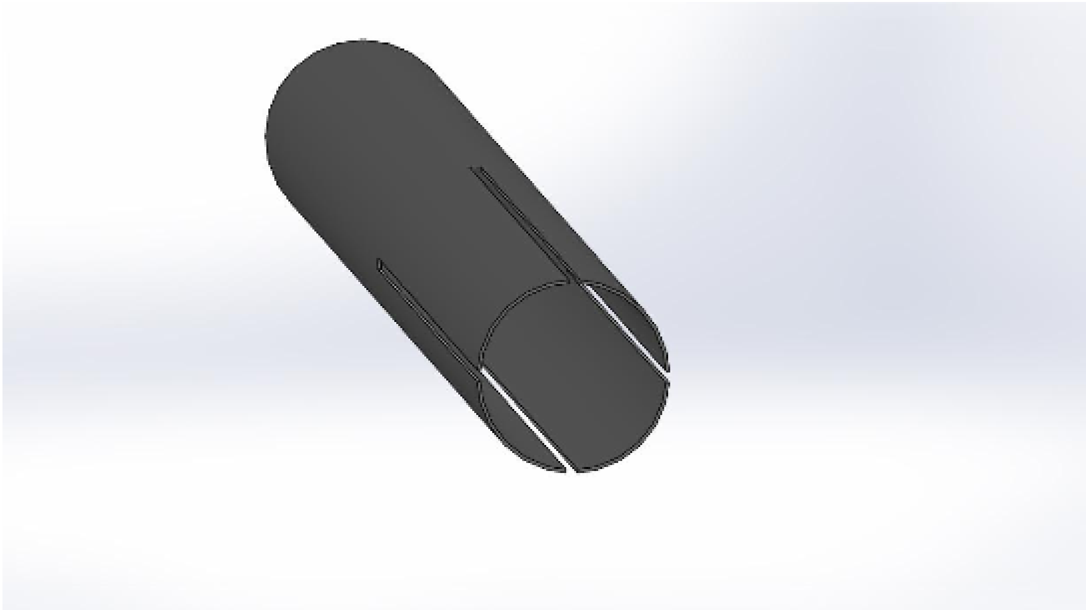


Figure 3.1.4d.1: Routed Aft Tube

Figure 3.1.4d.1: Routed Aft Tube

Once this is complete we can then slide in the finished motor mount and apply slow cure epoxy to hold it in place.

It is pertinent that we assure our fins are secure after sliding the motor mount into the aft airframe. To do this we apply epoxy and carbon fiber fillets for strength and aerodynamics.

Figure 3.1.4d.2: Carbon Fiber Fillets

3.1.4e Altimeter Bay

The Altimeter bay is where the primary sensor of the rocket is housed. In here there will be two altimeters and two batteries as a redundancy. The altimeters are used to sense when the rocket is at apogee, in which case the drogue parachute is deployed, and when the rocket is at approximately 500 feet from the ground, in which case the main parachute is deployed.

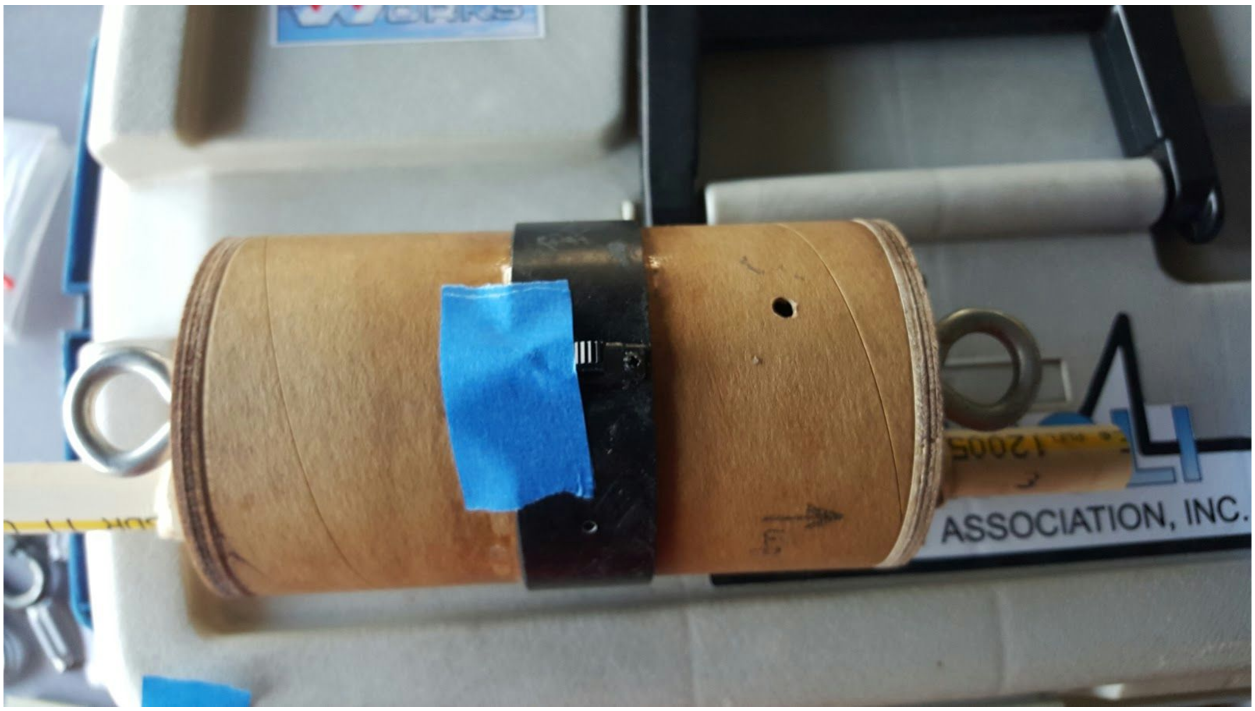


Figure 3.1.4e.1: Side View of Altimeter Bay Assembly

Figure 3.1.4e.2: Altimeter Bay Bulkhead

Here are the following steps in fabricating our altimeter bay:

1. Epoxy one inch fiberglass to center of the 16 inch coupler as shown in Figure 3.1.4e. Drill vent hole into the fiberglass ring, sized in accordance with the final altimeter bay volume.

2. Create two bulkheads with eyebolts, blackpowder tubes, and slots for threaded leads as shown in Figure 3.1.4e.2.

3. Affix altimeters and batteries onto altimeter sled.

4. Affix turn switch (with the on direction being DOWN) to the outside of altimeter bay and then wire the switch to the altimeters and the batteries.

5. Feed eMatches through black powder tubes and wire each to the altimeters.

6. Complete the altimeter bay by attaching bulkheads and securing with wingnuts.

3.1.4f Altimeter Bay Integration

Once the altimeter is completed it can then be placed within the rocket. Though it mostly now becomes part of the rocket.

There are three steps to attaching the altimeter bay to the rocket:

1. Attach paracord to the upper half of the altimeter bay's eyebolt.
2. Pin upper half of the altimeter bay into the lower section of the fore airframe.
3. Attach paracord between the lower half of the altimeter bay and the paracord from the aft bay.

3.1.4g Payload Bay

The payload bay will be where our AGSE system will deposit our sample. We have decided to go with a containment system using a linear actuator so that it will secure around the payload as it is placed inside the launch vehicle. This containment system will prevent the sample from moving freely throughout the payload bay during flight. Once the sample is secured and the rover arm clear, linear actuators will close and lock the payload bay prior to being raised for launch.

The Payload Bay fabrication process is as follows:

1. A trapezoidal prism container will be 3-D printed from ABS plastic to hold the payload.
2. The container will be supported two cylindrical rods that will protrude through the lower bulkhead into the lower coupler assembly housing the linear actuator power source and linear actuator motor.
3. A coupler and a bulkhead will be attached below the payload bay and electronics systems.
4. Paracord will be attached from the bottom of the bulkhead to the fore airframe paracord.

5. The upper payload will contain an empty volume to store the payload and its container

3.1.4h Nose cone

To secure the nose cone to the payload bay we drilled holes in the top most part of the payload bay, while also drilled holes in the nose cone. We then placed the nose cone on top of the payload bay and lined up the holes. Rivets were then placed in the holes to secure the nose cone to the payload bay as shown in Figure 3.1.4h.1.

Figure 3.1.4h.1: Nose Cone with Rivets

3.1.4i Rail Buttons

In regards to rail button placement, we want the upper rail button to rest on our center of gravity and our lower rail button to be attached the lowermost centering ring. This positioning allows us to maintain stability for our rocket on the launch rail and gives us adequate time to have it reach its stable velocity.

Figure 3.1.4i.1: Bottom Most Rail Button

Figure 3.1.4i.2: Top Most Rail Button

3.2 Subsystems

3.2.1 Nosecone

For our final design we have chosen to go with a plastic HDPE (High Density Polyethylene) o-give nosecone style from Public Missiles Ltd. as modeled below in figure 3.2.1.1.

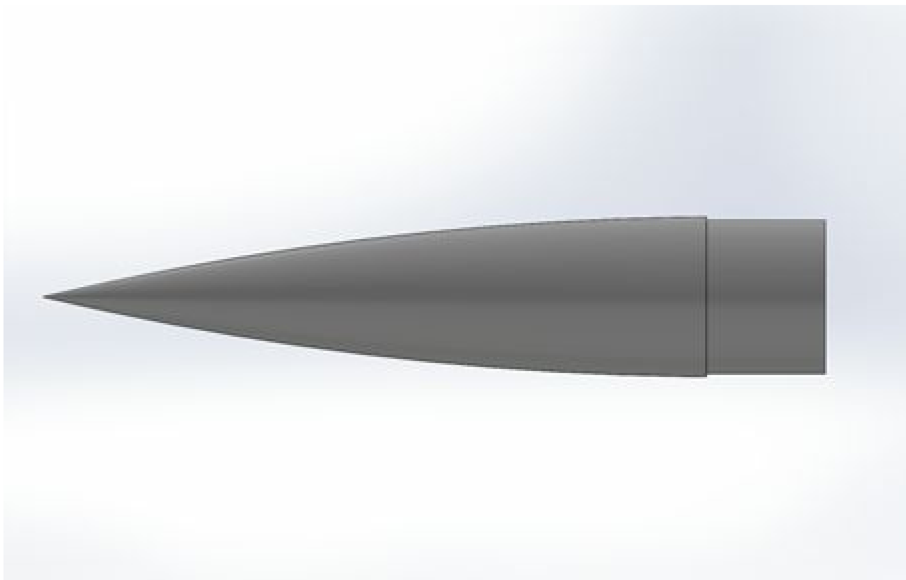


Figure 3.2.1.1: O-GIVE Nosecone Modeled in Solidworks

This particular nosecone model was chosen for several reasons which fit into our greater design scheme. The sandable ridges along the shoulder gave us the flexibility to go with the fiberglass airframe from Wildman Rocketry while still allowing the team to be confident that we could ensure a snug fit between the nosecone and the payload bay. Furthermore the hollow interior of the nosecone is able to have additional mass added and have the interior be foamed for rigidity. This capability of the PML nosecone will also allow us to use the nosecone as a mass ballast in order to bring our center of gravity further towards the nosecone without the need to further complicate our design.

3.2.2 Payload Bay

Figure 3.2.2.1: Closed Payload Bay Modeled in Solidworks

Figure 3.2.2.2: Open Payload Bay Detail Top View Modeled in Solidworks

The payload bay will be located below the nosecone and electronics bay. The bay will be composed of two sections, a lower section housing electronics necessary for the AGSE (see section 4.2), and an upper section housing a payload sled and space for the insertion of the electronics bay or nosecone.

The lower section of the payload bay will be composed of an 16 inch coupler tube, with the 20 inch fiberglass pinned over it.

The upper section of the payload bay will be composed of a section of 4 inch fiberglass airframe, with a bulkplate situated at 5.5 inches inside the tubing. The payload sled will be 3-D printed ABS plastic and will be located within the hollow portion of the payload bay, below the bulk plate. There will be an additional 3 inches above the bulkplate allowing for the insertion of the electronics pay or nosecone.

3.2.3 Motor

The vehicle will use a commercially available solid motor propulsion system. Specifically, the L910s rocket motor from Cesaroni Technology will be used and is certified by the Canadian Association of Rocketry. The vehicle motor is a solid ammonium perchlorate composite propellant that is comprised up of a variety of reactive metals, HTPB binder and also burn rate catalysts. The MSDS forms for each of these chemicals from the motor section can be found in the safety section of the design report. The motor is 75 millimeters in diameter and 14 inches in length. This motor has a total impulse of 2856.1 Newton-seconds, a maximum thrust of 1086.1 Newtons, and a burn time of approximately 3.2 seconds. OpenRocket simulations have been run on this motor to achieve a simulated apogee of approximately 5280 feet and a maximum velocity of approximately 748 feet per second . Table 3.2.4.2 summerizes breifly several of characteristics of the launch vehicle's motor.

The thrust curve shown in figure 3.2.4.1 (thrustcurve.org) has a fairly steady and consistent thrust ending around 3.2 seconds. Around the 2.9 second mark, the thrust decreases exponentially until burnout.

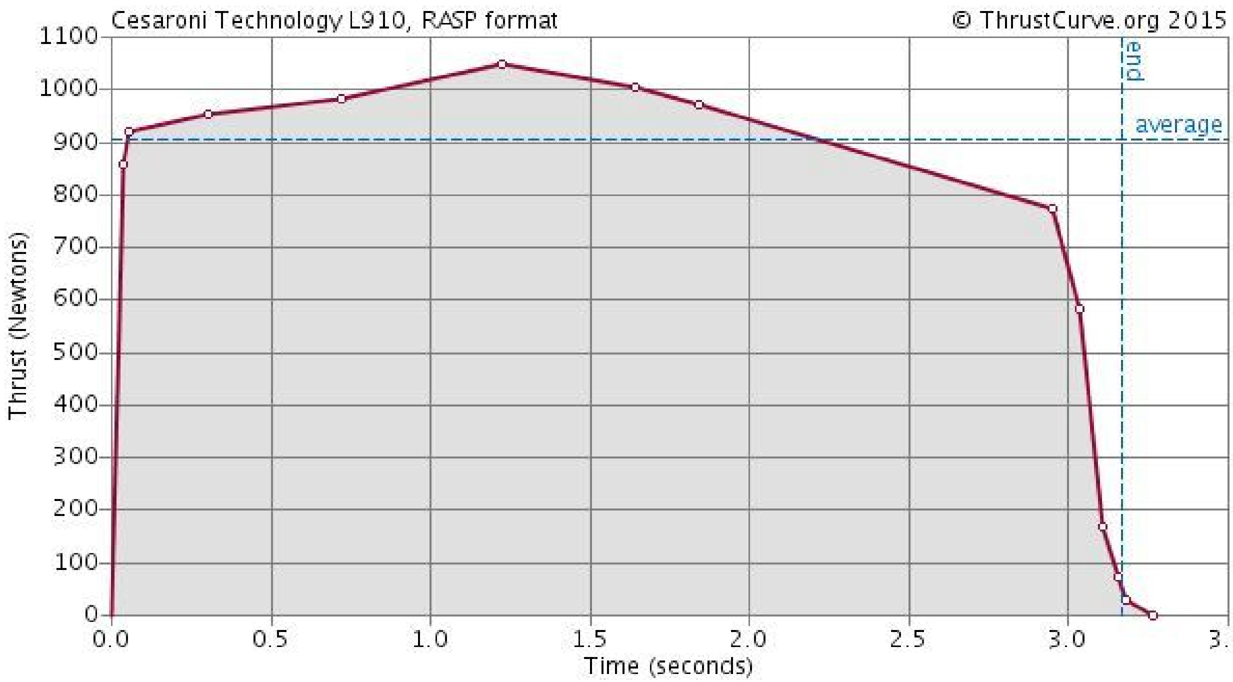


Figure 3.2.4.1 . The thrust curve of an Cesaroni L910 motor

Table 3.2.3.2. List of the full-scale motor specifications

Motor Selected	CS L910s
Maximum Thrust	1086.1 N
Average Thrust	907.10 N
Thrust-to-weight ratio (Total)	8.93
Motor Diameter	75 mm

3.2.4 Fins

Figure 3.2.4.1: 1/8" G10 Fin

1/8" G10 fiberglass has been chosen for the fins for several qualities that it possess. Namely G10 fiberglass is waterproof and stronger than wood. In addition it is less likely to have material flaws that would weaken the overall fin. Due to the higher strength of the fiberglass than wood, the fins can be made thinner reducing overall and drag due to the leading edge thickness. In addition, G10 fiberglass can be readily attached with epoxy if the surface is appropriately roughed beforehand with sandpaper. From an economic standpoint, G10 was readily available for use and we are familiar with fiberglass builds. The relevant properties of the G10 fiberglass have been listed in the table below:

Table 3.2.4.1: G10 Fiberglass Specifications

Density (lb/in^3)	0.065
Length-wise tensile strength (ksi)	43
Cross-wise tensile strength (ksi)	38
Length-wise flexural strength (ksi)	66
Cross-wise flexural strength (ksi)	60
Length-wise flexural modulus (ksi)	2700
Cross-wise flexural modulus (ksi)	2400

Compressive strength (ksi)	44
Max coefficient of linear thermal expansion (in/in/ºF)	0.66×10^{-5}
Max operating temperature (ºF)	284
UL94 Flammability Rating	H-B

The fins are to be attached to the motor can with epoxy resin and carbon fiber. To ensure precise fin attachment we used a fin jig and a laser cut sheet of fiberglass as a guide for a four fin placement. We chose a four fin design as this would allow us to bring the center of pressure further from the nose cone due to the fins have a sizeable surface area. Additionally the four fins will increase the total mass of the rocket, allowing us to achieve our target altitude with a slightly more powerful motor.

3.2.5 Propulsion Bay/ Fin Can

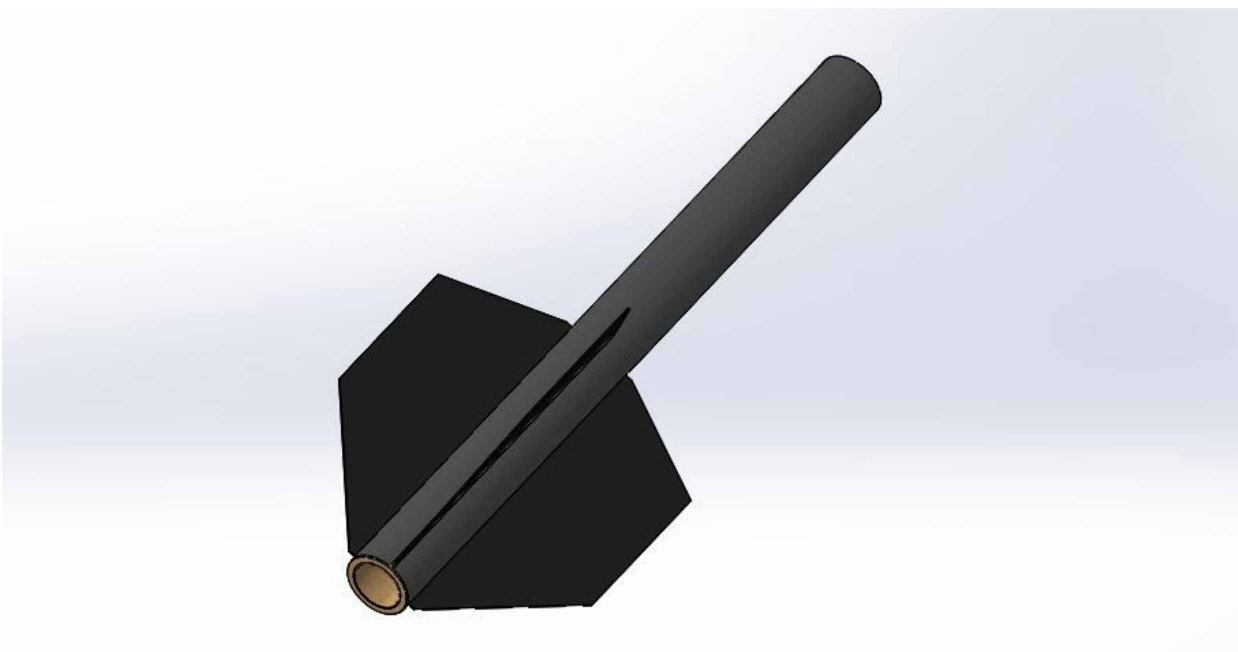


Figure 3.2.5.1 Full-scale propulsion bay/fin can

The launch vehicle propulsion bay will house the solid propulsion system motor mount as well as hold the launch vehicle stabilization fins. The propulsion bay will link with the forward bay through the 16 inch kraft phenolic tube altimeter bay. The propulsion bay will be 48 inches in length and will be fabricated using G-12 fiberglass tubing. The render of the full-scale propulsion bay can be seen in figure 3.2.5.1 above.

3.2.6 Motor Retention

The motor shall be secured in a 36 inch kraft phenolic motor mount. The motor casing will be prevented from moving upwards towards the nose cone via snap ring and it will be further held in retention by a 75 mm aeropack motor retainer to prevent the motor casing from sliding out of the motor mount tube. The motor retainer will be JB welded onto the lowest centering ring and allowed to protrude slightly from the bottom of the rocket. The simple threaded mechanism will allow the motor and casing to be inserted and removed with ease.

Figure 3.2.6.1 . The 75 mm Aeropack motor retainer

The motor mount will be held into place by three birch centering rings purchased from Public Missiles Ltd. They will be epoxied onto the motor mount using 30 minute epoxy, and will in turn be epoxied onto the airframe. Epoxy fillets will be formed along all connected edges in order to increase rigidity and shear strength by filling any remaining voids.

3.2.7 Altimeter and Electronics Bay

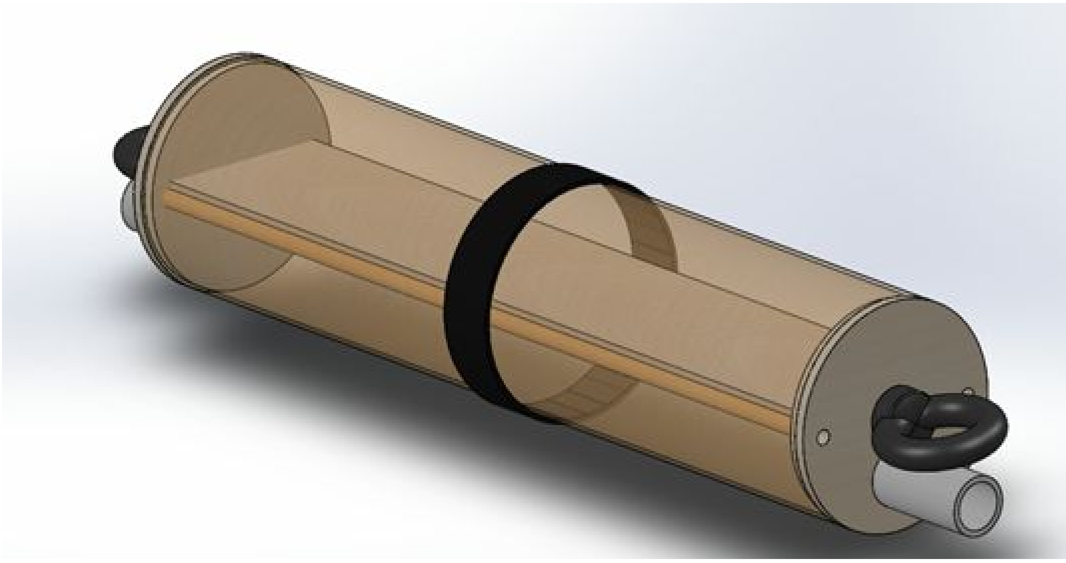


Figure 3.2.7.1 Solidworks Model of Altimeter Bay

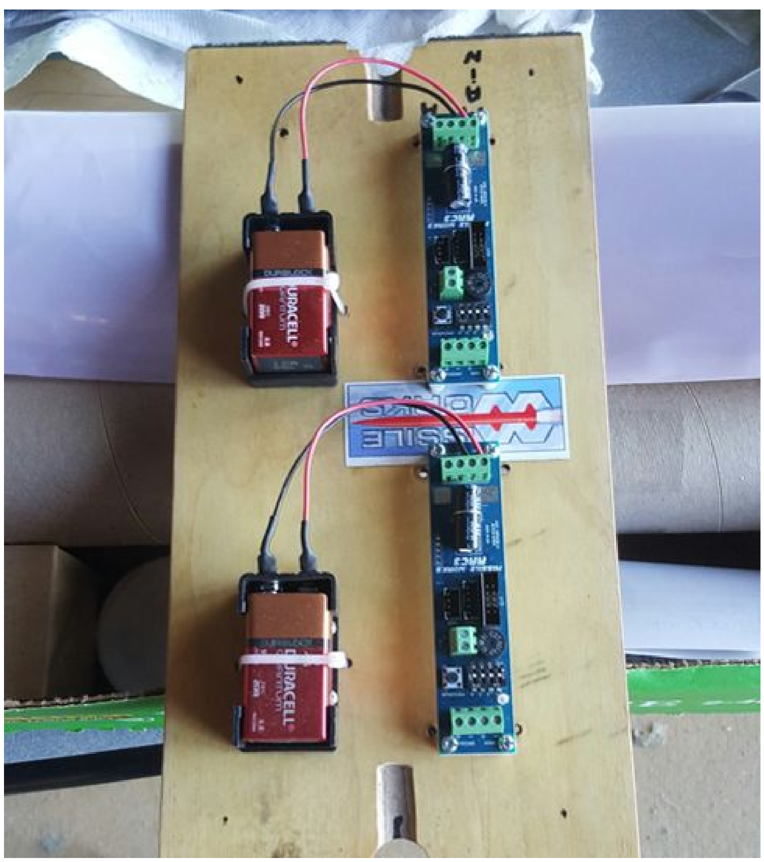


Figure 3.2.7.2 Altimeter Board Setup

Between the fore body tube and the aft body tube lies the altimeter bay. The bay is constructed from a coupler, a 1-inch ring of fiberglass, two wooden bulkheads, and two threaded rods that run the length of the bay. Four segments of 1-inch PVC pipe will protrude from either bulkhead to hold black powder for section separation upon recovery. The pipes will be covered by plastic blast caps. The bay is attached to the fore tube with screws and to the aft tube by couplers. The fasteners present inside of the bay are wingnuts located on threaded bolts and four U-bolts to fasten the parachutes. Because the altimeters used are barometric, it was necessary to drill ports allowing air to flow through the bay. The diameter *D* to be drilled if using a single port depends only on the volume *V* of the bay (which depends on its radius *R* and length *L*).

$$V = \pi R^2 L$$

If the volume is less than 100 cubic inches, then

$$D = \frac{V}{400}$$

$$A = \frac{D^2}{4}\pi$$

are the recommended diameter (in inches) and area *A* (in inches squared) of a single port to be drilled in the bay. It is common to drill multiple holes, instead of a single port. To find the recommended diameter *d* to drill *N* number of ports…

$$d = 2\sqrt{\frac{A}{N\pi}}\,.$$

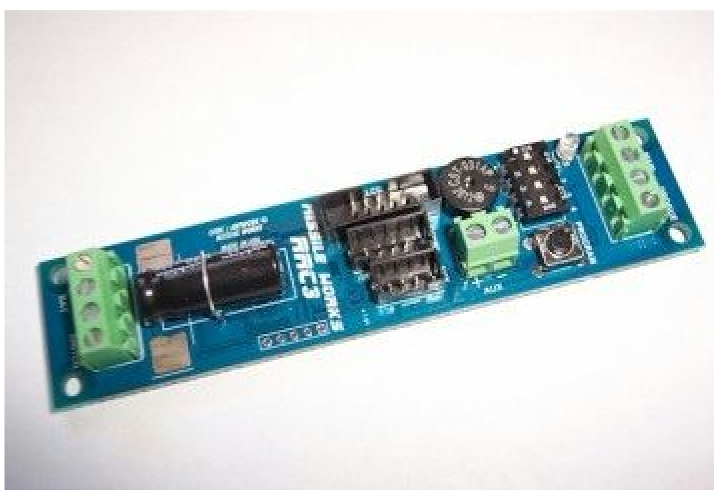


Figure 3.2.7.3 RRC3 Altimeter. Photo taken from Missile Works © website.

The bay is designed to hold two Rocket Recovery Controller 3 (RRC3) altimeters. The RRC3 uses high-resolution barometric pressure sensors to determine the precise altitude of the rocket so as to record the rocket's height at apogee for later reporting, and to deploy the drogue and main parachutes at apogee and at an altitude of 800 feet, respectively. This particular type of altimeter contains a solid dielectric capacitor which, unlike the standard electrolytic capacitor, can withstand virtual vacuum and near-space conditions.

3.3 Recovery

3.3.1 Design Overview

Recovery, although the last phase of the launch, is extremely important because it ensures the safety of the vehicle and observers. The recovery system will use dual-deployment in compliance with the Recovery Subsystem Requirements outlined in the NASA Student Launch handbook. The drogue parachute will be deployed at apogee to minimize drift. After the drogue parachute has been deployed and the rocket has descended to an altitude of 800ft the RRC3 altimeters will deploy the main parachute via an additional ejection charge. The ejection altitude was changed in order to allow more time for the parachute to “catch air” due to our long shock cords we want to ensure that there is enough time for all parts to properly unfurl in the air. The ejection charges will be stored on the end of the altimeter bay, compacted by flame retardant material and covered with a blast cap.

The rocket airframes will be held together by shear pins as is customary to ensure there will be no separation prior to our selected event locations. Blast caps will be placed on both ends of the altimeter bay, they will have black powder charges, flame-retardant wadding, and e-matches which will be connected to the altimeter bay. For the purpose of redundancy we will use two RRC3 altimeters to ensure parachute deployment.

For the recovery system to be considered successful the following criteria must be met:

1. The drogue parachute must deploy at apogee.
2. The main parachute must deploy between 750-850 feet AGL.
3. All independent sections must have a maximum kinetic energy of 75 ft-lb upon impact.

Figure 3.3.1.1 is a graphic representation of our proposed dual-deployment recovery system, with all significant events.

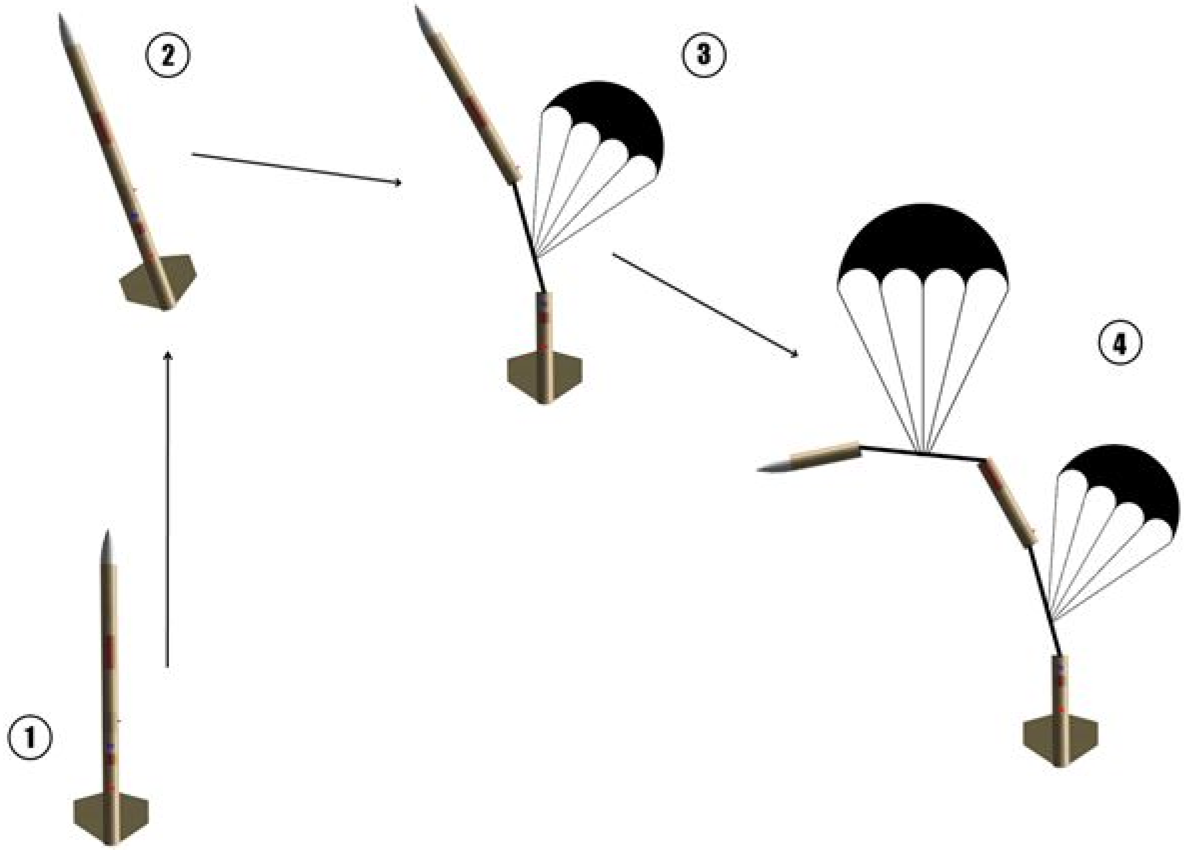


Figure 3.3.1.1: Recovery Sequence of Events

Table 3.3.1.1: Recovery Events and Descriptions

Event	Description
1	Launch (0 feet AGL)
2	Apogee (5280 feet AGL)
3	Drogue Deployment (Apogee)
4	Main Deployment (800 feet AGL)

3.3.2 Parachute Sizing and Selection

In regards to parachute selection we chose to look into companies we were familiar with which could provide consistent quality and compatibility with our design.

Parachutes are sized with the descent velocity of the rocket in mind. For a rocket of weight w (when all fuel has been ejected) and desired descent velocity v, the area A of the parachute can be found by the following equation

$$A = \frac{2w}{\rho C_D v^2} ,$$

where ρ is the density of air and CD is the drag coefficient calculated in section 3.1.1d. The air density in Huntsville, Alabama is recorded by the NOAA to be approximately 105% the standard pressure of air, which is 1.255 kg/m3, so ρ is approximately 1.31775 kg/m3. The empty weight of the rocket is 14.2 lbs. The max descent velocity of the rocket is 27.775 ft/s, a suitable velocity in order to maintain the heaviest separate section of the rocket, the fin can, stays within the required 75 ft-lb kinetic energy on impact. Using the Cert-3 Large parachute drag coefficient of 1.28 we found that the 57 sq. foot parachute would be more than adequate for our purposes.

Our final parachute choices are as follows in the table below.

Table 3.3.2.1: Drogue and Main Parachute Specifications

Parachute	Load Capacity	Surface Area	Drag Coefficient	Suspension Line	Net Weight	Packed Length
Cert-3 Large	16.2 – 35 lbs	57 ft^2	1.26	80 in	34.0 oz	17 in
Cert-3 Drogue	1.0 – 2.2 lbs	6.3 ft^2	1.16	24 in	6.0 oz	<7 in

The Cert-3 parachutes maintain a strong design with 5/8" mil-spec tubular nylon (2,250 lbs.) suspension lines sewn around outside canopy and being composed of zero-porosity 1.9 oz. silicone-coated balloon cloth.

3.3.3 Bulkheads and Connective Elements

With our parachute choices secured and confidence in their capacity to bear the load of our rocket we needed to ensure that all connections made within the recovery system are secure and safely designed.

Figure 3.3.3.1: Rocket Diagram with Parachute Cord Length and Parachute Locations

One potential problem to account for is the issue of discrete rocket parts, connected by parachute cord, colliding with each other upon descent. This is a problem as it can cause serious damage to the rocket structure, preventing reusability, or it can lead to entanglement with the parachutes which could lead to increased velocity descent and higher kinetic energy upon impact. One control for this situation is by including adequate parachute cord length between sections in order to ensure safe distance between separate sections. The rule we follow in design for determining parachute cord length is allowing for at least three times the rocket length in cord to connect each section, meaning for our 138 inch length rocket we allow 414 inches of cord between the payload bay and fore airframe, and an additional 414 inches of cord between the fore airframe and the fin can, leading to a total cord length of 828 inches.

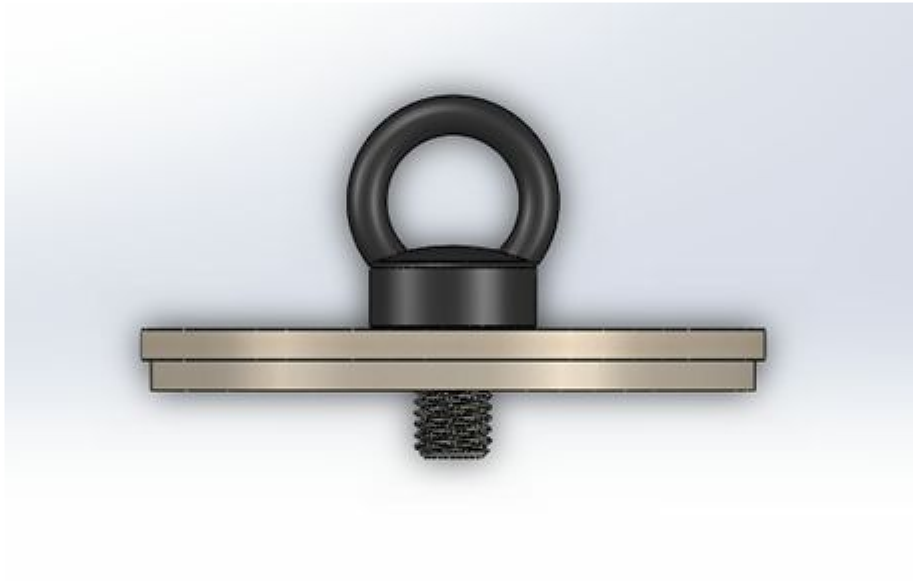


Figure 3.3.3.2: Bulkhead with Eye Bolt

The second vital structure aspect of the recovery system are the bulkhead connective elements which binds the parachute cord to the rocket components. Figure 3.3.3.2 above is a model of the style of bulkhead and eyebolt connection we use to ensure a rigid connection between the cord and rocket sections. This style of bulkhead is used on the rocket payload and both sides of the altimeter bay. The bulkheads are composed of Baltic birch and adhered with 30 minute slow cure epoxy. The eye bolts used are threaded into place with the nut and washer further secured with the slow cure epoxy as well for added strength.

An additional safety precaution used by our attachment scheme will be the use of Nomex parachute protectors being placed on the parachute cord, separating the parachutes from the black powder charges. Though the chutes we are using are durable, the chute protectors will ensure that no undue damage is done to the parachutes on separation.

3.3.4 Altimeter Wiring

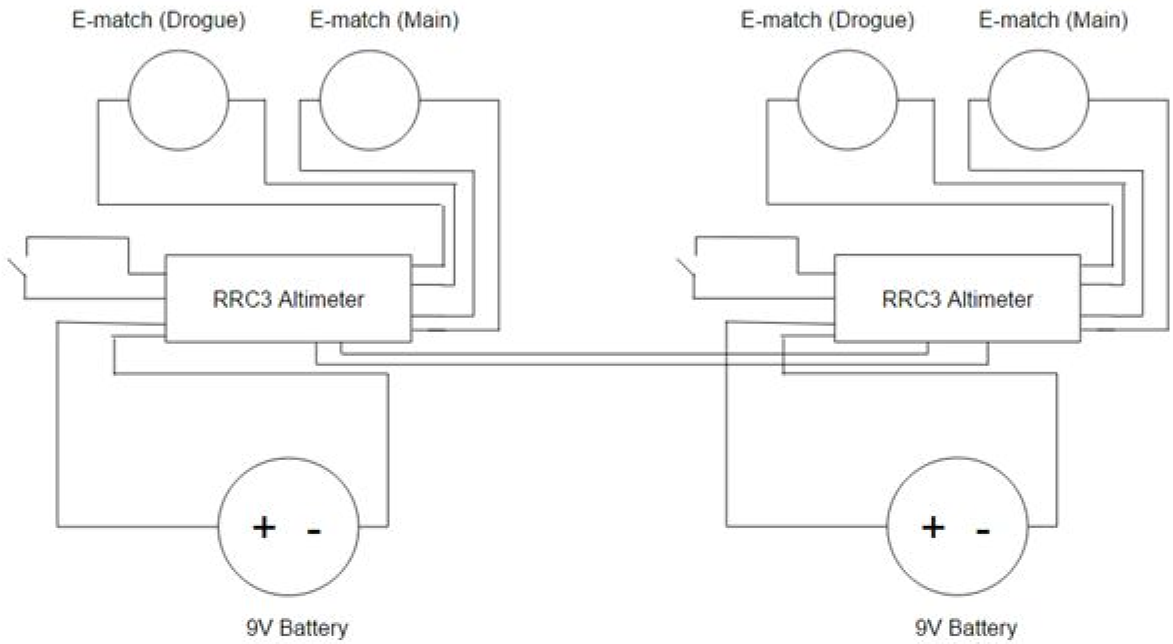


Figure 3.3.4.1: Altimeter Bay Wiring Diagram

3.3.5 Kinetic Energy and Descent Velocities

Table 3.3.5.1: Kinetic Energy and Descent Velocities

Section	Mass (lbf)	Drogue Descent (ft/s)	Main Descent (ft/s)	Kinetic Energy (lbm-ft)
Nosecone/Payload	3.092	63.04	15.93	12.184
Fore Airframe	3.561	63.04	15.93	14.032
Aft Airframe	7.261	63.04	15.93	28.612

Table 3.3.5.1 above details the predicted descent velocities of the different rocket sections and their kinetic energies upon impact. The descent velocities were determined using OpenRocket and confirmed using the SkyAngle Descent Velocity calculator. Ultimately we found that the main descent velocity of 15.93 feet per second was well within the bounds to allow our heaviest section, the aft airframe, to land with a kinetic energy well below the boundary limit.

We have found the above information to be sufficient to call our design suitable for the purposes of providing a safe landing with minimal impact energy.

Additionally, the kinetic energy at burnout is 212741 lb-ft, occurring at an altitude of 1305.77 ft. The rocket will continue to coast for about 17.5 seconds until reaching apogee.

3.3.6 Drift Calculations

Modeling lateral drift of the rocket after chute deployment at apogee is a remarkably complex scenario. The constant variation of wind speed, the changing wind direction against the surface of the rocket, combined with the typical difficulties of rocketry, such as changing air density, changing rates of gravity, and the complications of fluid dynamics sum together to make an incredibly difficult challenge for someone who sets out to make a precise mathematical model of rocket drift caused by wind during recovery. For these reasons it is often acceptable to approximate the drift of the rocket using the simple equation,

$$Distance_{Drift} = Velocity_{wind} * Time_{Descent}$$

Table 3.3.6.1: Drift distances

Wind Speed (mph)	Lateral Drift (ft) 500 ft Deployment	Lateral Drift (ft) 800 ft Deployment
5	786.22	889.43
10	1572.45	1778.86
15	2358.67	2668.29
20	3144.90	3557.72

As opposed to using OpenRocket to calculate drift distances, as we did previously, we have used excel calculations in order to calculate drift distances at original 500 ft deployment altitude and our new 800 foot deployment altitude. These calculations were based on the principle that in 10 mph winds, and a 14.667 ft/sec descent velocity, 1 foot of altitude lost is equivalent to 1 foot of lateral drift due to the resulting velocity vectors. Our own descent rates and variable wind conditions were scaled to these numbers, with separate equations for both drogue and main which were ultimately summed to determine the resulting lateral drift at each wind speed increment.

3.4 Mission Performance Predictions

3.4.1 Performance Criteria

In order to classify the mission as a success the following criteria must be met:

1. The launch vehicle achieves apogee between 5,000 and 5,400 feet.
2. At apogee, the drogue parachute is successfully ejected.
3. Between 750 and 850 feet AGL, the nosecone and payload bay are separated from the rest of the vehicle, and the main parachute and payload parachutes are successfully ejected.
4. No portion of the vehicle or payload sustains any major damage during flight or landing.

3.4.2 Launch Vehicle Characteristics

The program OpenRocket was used to fully design and simulate the flight of our projected launch vehicle. Using this software the following launch vehicle characteristics were ultimately determined as can be seen in Figure X below.

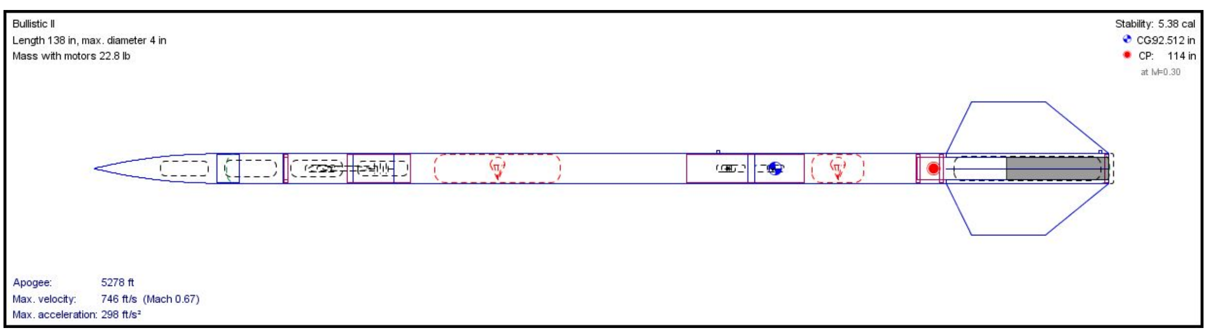


Figure 3.4.2.1: Bullistic II Rocket Model from OpenRocket

- · Length: 138 inches
- · Diameter: 4 inches
- · Max Diameter: 4 inches
- · Empty Mass: 17.1 lbs
- · Loaded Mass: 22.8 lbs
- · Empty Stability Margin (CP/CG): 8.62cal (114in/79.544in)
- · Loaded Stability Margin (CP/CG): 5.38cal (114in/96.891in)

3.4.3 Motor Selection

The full scale launch vehicle will use a Cesaroni Technology L910s solid propulsion unit. The team had used Cesaroni motors in previous competitions, all of which had proven to be reliable and efficient so the manufacturer choice was clear. When selecting the motor, the team had to account for multiple factors such as thrust to weight ratios, specific impulse, motor sizing and also chemical composition. The Cesaroni L910s is an APCP that will have a BATES grain geometry.

The team chose an APCP motor due to the fact that these types of motors tend to be very powerful and compact which results in moderately high specific impulses. A BATES grain configuration was desired by the team because the team preferred a steady thrust through the burn time of the motor. The team's motor has a total impulse of 2856.1 Newton-seconds and a burn time of approximately 3.2 seconds. The motor will have an average thrust of 907.1 Newtons throughout the 3.2 burn time. Conducted OpenRocket simulation data states that the launch vehicle with this L-motor is expected to achieve a apogee of approximately 5280 feet, exactly the desired altitude for the launch competition.

Factors including launch elevation and wind speed were accounted for in the team's OpenRocket launch simulations. These various simulation conditions yielded relatively consistent apogee data values. These simulations will be discussed more in detail in section 3.4.4. Several of the OpenRocket data plots can be seen in the figures illustrated below in section 3.4.4. as well. Table 3.4.3.1 depicts some of the motor characteristics that contributed to the overall selection of the propulsion unit.

Table:3.4.3.1 Table of Launch Motor characteristics

Motor weight	5.760 lbs
Thrust-to-weight ratio	8.930
Average thrust	907.1 N
Specific Impulse	229.0 s
Motor Diameter	75.00 mm
Rail Exit Velocity	43.00 ft/s
Burn time	3.200 s

Maximum acceleration	300.0 ft/s^2

3.4.4 OpenRocket Simulations

In order to fabricate any sort of launch vehicle a plethora of dimension, motor and weather conditions testing and analysis must be conducted to ensure mission success as well as vehicle and pedestrian safety. Programs such as OpenRocket allow the user to conduct theoretical vehicle simulations that do not require the user to expend a pre-set mission budget. The team designed their initial and final launch vehicles using the OpenRocket program. Due to the conglomeration of ideas in the team the vehicle design was constantly being edited and tweaked in an attempt to ensure overall success and safety.

Once a final full-scale OpenRocket design was conceived, numerous flight simulations were implemented. A paramount component of the competition is reaching an apogee of exactly one mile. This factor was tested and simulated by the team through trial and motor research. Different sized and impulse rocket motors were tested on the program until a final CS L190s motor was selected. The graph of the altitude vs time using the CS L190s motor can be observed below in figure 3.4.4.1.

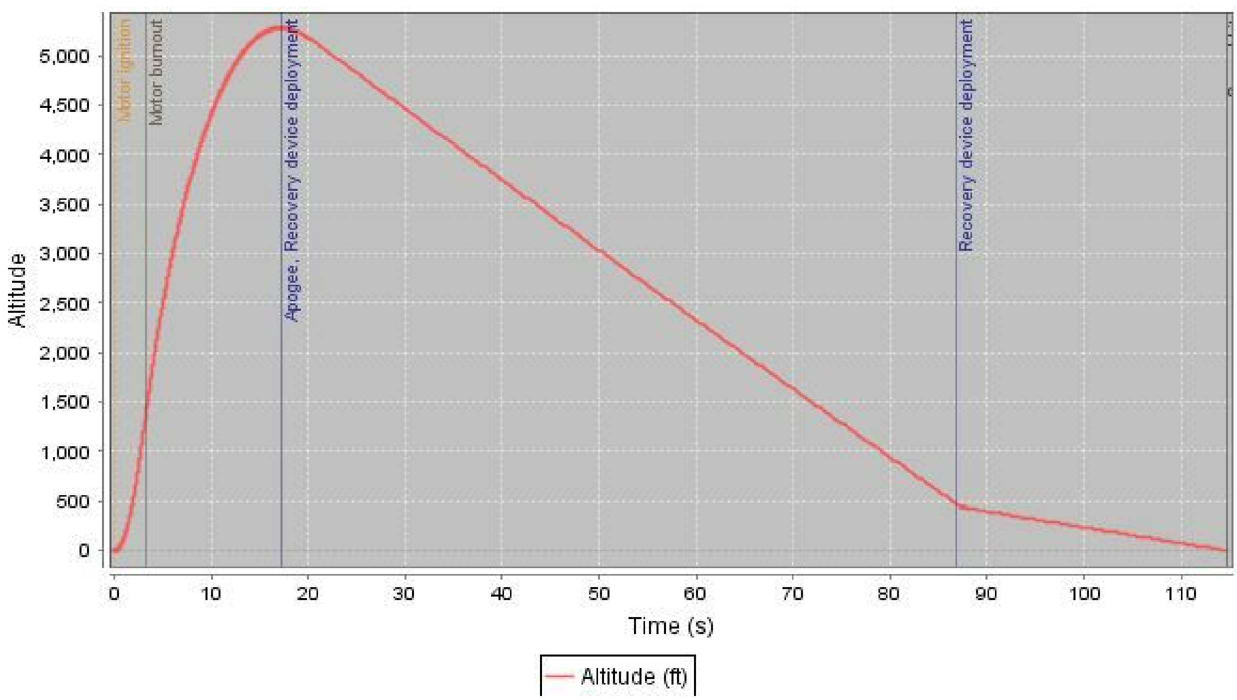


Figure 3.4.4.1 Graph of Altitude vs. Time

The graphs in figures 3.4.4.2 and 3.4.4.3 depict the vertical velocity vs. time and vertical acceleration vs time for the team launch vehicle during its flight. Specific simulation data such as the graphs listed below were crucial to use as a reference when selecting vehicle materials and building the launch vehicle structure.

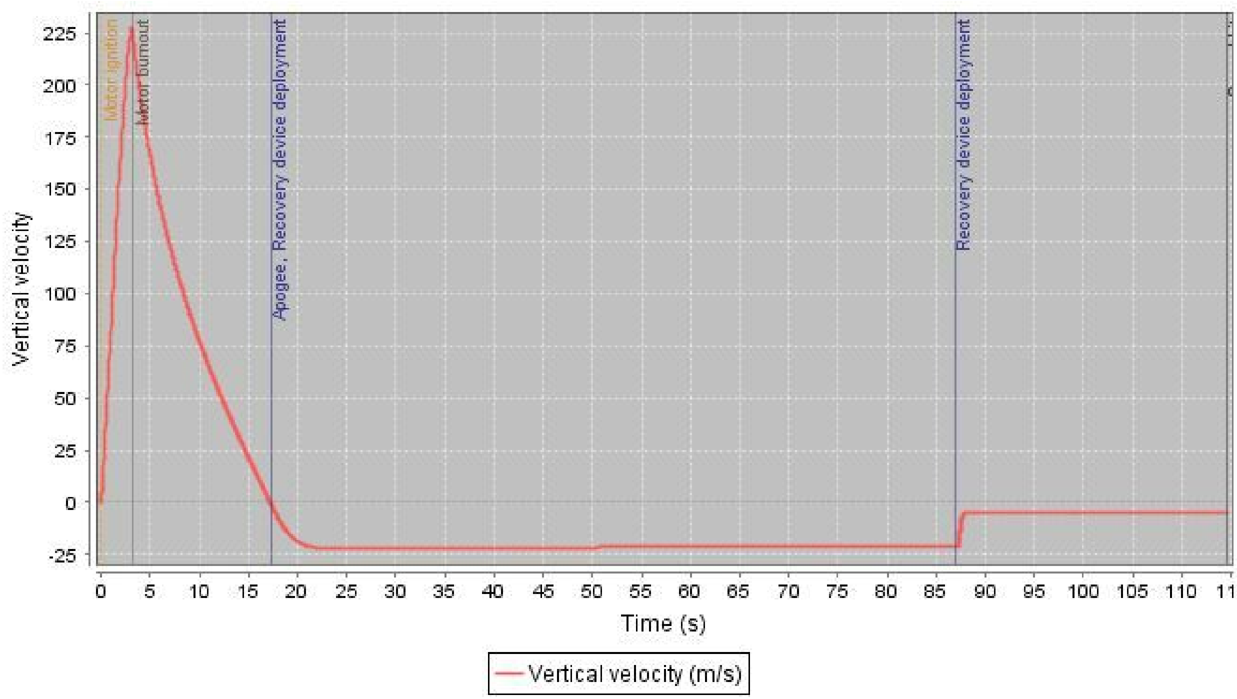


Figure 3.4.4.2 Graph of Vertical velocity vs. Time

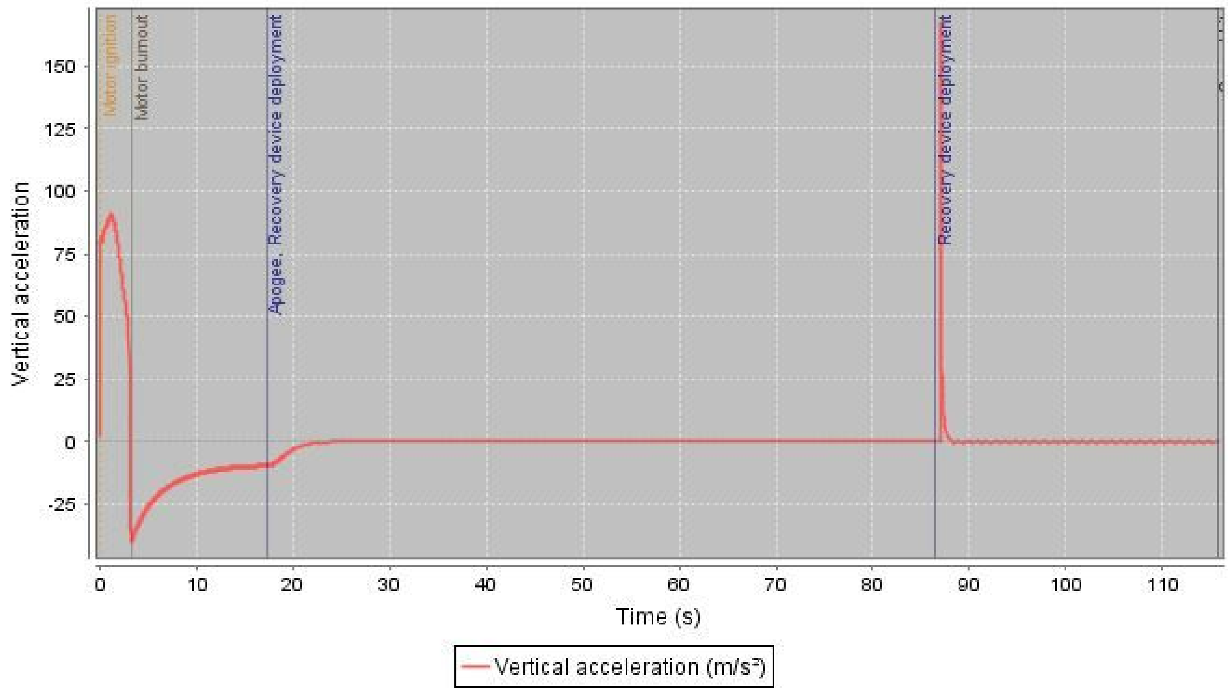


Figure 3.4.4.2 Graph of Vertical acceleration vs. Time

Various weather conditions were also tested on launch vehicle flight simulations in an attempt to prepare the vehicle for a number of conditions. Wind speed and launch elevation were the two main focuses of these weather condition simulations. The team found that launch elevation was directly proportional to flight apogee as previously expected. The launch elevation was set to approximately 620 feet to prepare for the elevation change in Huntsville, Alabama. It was also found that wind speed was inversely proportional to final flight apogee of the vehicle. As wind speed in the simulator increased, the apogee of the launch vehicle decreased.

The team analyzed the data and created vehicle modifications in specified areas in order to accommodate for the possible weather conditions.

3.4.5 Mass Statement

Table 3.4.5.1 Mass Statement of Rocket Sections

Section	Mass (lbs)
Nosecone	1.925
Payload/Electronics	2.59
Fore Airframe	4.445
Fin Can	8.145
Motor	6.1

3.4.6 Launch Requirements and Solutions

Table 3.4.6.1 Launch Vehicle Requirements from Student Launch Handbook

Requirement Number	Description	Design	Verification
1.1	The vehicle shall deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL).	The structural design and motor selection will be determined around the projected altitude.	The design shall be verified via simulation, calculations, and finally testing
1.2	The vehicle shall carry one commercially available, barometric altimeter	The launch vehicle will have two barometric RRC3 altimeters.	The design shall be inspected and tested.
1.3	The launch vehicle shall be designed to be recoverable and reusable.	The launch vehicle will engage a dual stage parachute recovery system that will limit the kinetic energy of all components upon impact.	The recovery system will be analyzed, inspected, simulated, and tested.

1.4	The launch vehicle shall have a maximum of four (4) independent sections.	The launch vehicle will have three independent sections upon recovery after aft bay separation and nosecone/payload separation.	The requirement will be reflected in design.
1.5	The launch vehicle shall be limited to a single stage.	The launch vehicle will have one stage.	The requirement will be reflected in design.
1.6	The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours.	The team will have launch day procedures that will be practiced to ensure launch on schedule.	The requirement will be reflected in design and practice.
1.7	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.	All sensitive equipment will be adequately protected.	The requirement shall be met in design and tested.
1.8	The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system.	The launch vehicle will be developed to work with standard 12 volt ematches.	The requirement shall be met in design and verified in testing.
1.9	The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP)	The team will purchase a commercially available APCP motor.	The requirement will be met in design.
1.10	The total impulse provided by a launch	The team will purchase a commercially available	The requirement will be met in design.

	vehicle shall not exceed 5,120 Newton-seconds (L-class)	L-class motor.	
1.11	Pressure vessels on the vehicle shall be approved by the RSO	No pressure vessels will be used in the launch vehicle.	The requirement will be met in design.
1.12	All teams shall successfully launch and recover a subscale model of their full-scale rocket prior to CDR.	The subscale rocket was launch 12/20/2015 successfully with a follow up launch planned for 1/15/16	The requirement shall be met in testing.
1.13	All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration.	A full-scale launch in its final configuration is scheduled for 2/20/2015.	The requirement shall be met in testing.
1.14	Each team will have a maximum budget of $7,500 they may spend on the rocket and its payload(s).	A detailed budget will be followed to ensure that the project remains under the maximum budget.	The requirement will be verified in inspection.
1.15	Vehicle Prohibitions.	No prohibited items will be used in the launch vehicle	The requirement will be verified in design.
2.1	The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.	The recovery system will deploy a drogue at apogee and a main chute at 500 feet AGL.	The requirement will be verified in design and verified in testing.
2.2	Teams must perform a successful ground ejection test for both the drogue and main	Ejection systems will be tested prior to launch.	The requirement will be met in testing.

	parachutes.		
2.3	At landing, each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	Simulations and hand calculations will be done to ensure a low maximum kinetic energy on impact.	The requirement will be met in calculation, simulation, and testing.
2.4	The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	The recovery system will be managed by the RRC3 altimeters.	The requirement will be met in design.
2.5	The recovery system shall contain redundant, commercially available altimeters.	The recovery system will use two RRC3 altimeters.	The requirement will be met in design.
2.6	Motor ejection is not a permissible form of primary or secondary deployment.	Motor ejection will not be utilized.	The requirement will be met in design.
2.7	A dedicated arming switch shall arm each altimeter, which is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Each altimeter will have a dedicated key switch available on the outside of the rocket.	The requirement will be met in design.
2.8	Each altimeter shall have a dedicated power supply.	Each altimeter will have one dedicated 9 volt battery.	The requirement will be met in design.
2.9	Each arming switch shall be capable of being locked in the ON position for launch.	The key switches used will be able to be locked in an on position.	The requirement will be met in design and verified in testing.

2.10	Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	Shear pins will be used at separation points at the fore and aft bay.	The requirement will be met in design and verified in testing.
2.11	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.	A TeleGPS will be implemented with the altimeter in electronics bay.	The requirement will be met in design and verified in testing.
2.12	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight	All electronic systems will be properly integrated, shielded, and have appropriate cable management.	The requirement will be met in design and verified in testing.

Table 3.4.6.2 Launch Vehicle Requirements as set forward by USF SOAR

Requirement Number	Description	Design	Verification
S1	The payload will be able to seal completely with no protrusions.	The design of the payload will focus on uniform closure with a linear actuator and paired sections.	The requirement shall be met in inspection, analysis, and testing.
S2	The parachutes will not be damaged by the ejection charge.	The chutes will both have Kevlar chute protectors separating them from the black powder charges.	The requirement shall be met in inspection, analysis, and testing.
S3	The parachutes shall not break off from the rocket	Appropriate weighted shock cord will be used	The requirement shall be met in

	after separation.	in addition to checking all fastening systems and associated yield stresses.	inspection, analysis, and testing.
S4	All epoxied sections, including centering rings and bulkheads will be able to withstand max thrust of the motor.	Calculations shall be done to determine the max shear strength of all epoxied sections.	The requirement shall be met in inspection, analysis, and testing.
S5	All components of the rocket will be held together until the time of separation.	Appropriate shear pins will be utilized.	The requirement shall be met in inspection, design, and testing.

3.5 Interfaces and Integration

3.5.1 Payload Bay System

Figure 3.5.1.1 Payload Containment System

The payload bay containment system was designed with integration in mind from the very start, using stock rocket components as a structure and choosing appropriate electronics and custom parts with these parameters. However for the payload bay system integration to be considered a success the following criteria must be met:

1. The system must be able to fit within the traditional volume of a payload bay, i.e 4 inch diameter and 24 inches in length.
2. All components must be capable of access from outside the rocket, or to be manipulated by the AGSE system.
3. The system must be able to function while the rocket is secured on a launch rail.
4. The system cannot adversely affect vital systems such as recovery or the altimeter bay.
5. The system must have it's own power source.
6. The system cannot interfere with vital rocket events such as launch, parachute deployment, or locating the launch vehicle.

With our design criteria in mind our team set out to build the system in a way that best reflected these constraints. The ultimate linear actuator system to detailed in section 4, can be inserted into the fore airframe as with any other payload bay. Furthermore radio control will allow the actuator to interact with the AGSE. Due to the simple design the payload containment system should not interfere with flight nor any other rocket systems.

3.6 Testing and Verification

3.6.1 Ejection Test

Objective

The purpose of the ejection test was to determine that our recovery systems are fully functional and to ensure that our selected main parachute is able to be ejected completely with an appropriate amount of black powder.

Testing Plan

A baseline was calculated to determine the amount of black powder needed for separation. Using a black powder calculator (http://www.rockethead.net/black_powder_calculator.htm) we determined that a minimum of 3.07 grams was neccesary for ejection at 10 psi with an upper boundary of 4.61 grams at 15 psi. We established three different levels of black powder charge to determine the optimal amount necessary for main chute ejection with all other factors remaining consistent.

Results

Table 3.6.1.1: Black Powder Levels and Results

Black Powder (grams)	Success	Comments
3	Partial	Slight catch at the end of the airframe
3.5	Full	Full ejection
4	Full	Full ejection

Conclusion
At the minimum level of black powder we did find that there was ejection, but it did not seem forceful enough to properly clear the airframe without catching. At 3.5 grams we did find that ejection was more successful but ultimately we found that 4 grams was preferable, offering full ejection of the chute and shock cord, with an appropriate safety factor, without being in excess.

3.6.2 Launch Pad Readiness

Objective
Using the second subscale launch on January 20th as a baseline we determined the amount of time required for us to ready our rocket, and that it could withstand conditions for at least two hours.

Testing Plan
The basis of the plan was to assemble the subscale rocket under normal conditions and allow the assembled altimeter bay to withstand conditions for at least 2 hours.

Results/Conclusion
The assembled altimeter sled was prepared the night before, allowing us to leave the altimeters, the most sensitive part of the system, to withstand conditions. After arriving at the field at 10 am, we managed to launch the rocket by 1 am, successfully exhibiting that the altimeter bay is capable of maintaining viability in normal conditions for 2+ hours. In terms of launch vehicle preparation we found that we could adequately prepare the recovery system, propulsion system, and check all systems within thirty minutes.

3.6.3 Subscale Test

Testing Plan

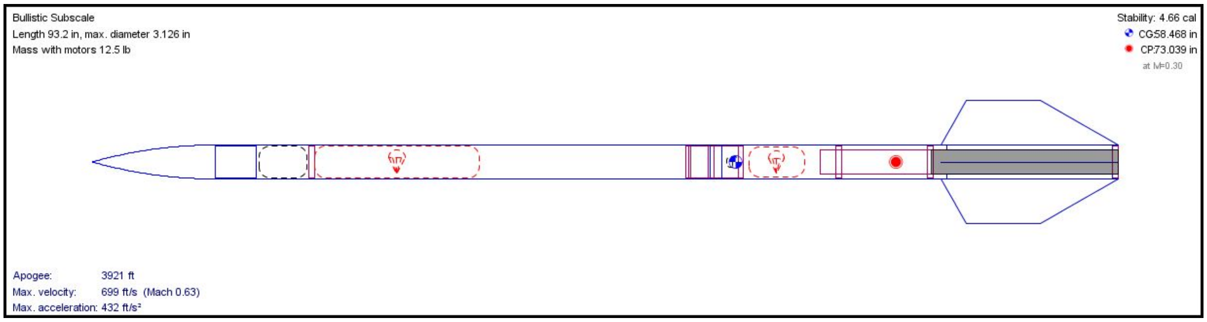


Figure 3.6.3.1: Openrocket Subscale Model

As a major test of our design for our full scale rocket, our team developed a subscale rocket with similar properties in order to validate fabrication techniques and overall stability and performance. Though we had one successful launch in December we conducted another test in January, adding more mass to the payload bay in order to simulate the weight of the AGSE containment bay. The subscale model can be seen in Figure 3.6.3.1.

Table 3.6.3.1: Subscale Launch Vehicle Characteristics

Motor	K630WC
Length (in)	93.2
Mass (Loaded/Empty) (lbs)	12.5/9.27
Projected Altitude (ft)	5026
Projected Max Velocity (ft/s)	734
Stability (cal)	4.66

Results

The subscale rocket was launched to an altitude of 6262 feet with the main parachute deploying at 500 feet. This resulted in a 19% error from our projected altitude which could be attributed to center of drag estimations in OpenRocket and flight conditions. The extended stability margin however made this flight closer to our final full scale design, instilling confidence in our designs stability in flight and soundness of the design.

3.6. Full Scale Launch

At the time of this writing we have not been able to have a launch of our full scale due to budgetary and organizational reasons. Throughout the course of the competition we have adhered strictly to timelines set forward by our gaant chart with several backup plan and dates. We originally had a launch scheduled for February 20th, and received FAA waivers for the weekend of March 5th and 6th. Unfortunately our limitation was in regards to the delivery of our motors. In accordance with our gaant chart we allotted a minimum month waiting period for parts ordered so our motors (4 L910s) were ordered by January 20th in order to ensure timely delivery, followed by 2 smaller impulse motors two weeks later. Due to internal bueracracy we have still not received these motors as of March 14th, though we had been assured several times in the previous weeks we would receive them shortly. As of now we are collecting outside funds in order to purchase a 75 mm motor casing and motors produced locally. Our full scale test will be conducted on the weekend of March 18th and a full report shall accompany our presentation.

3.7 Safety

3.7.1 Safety Officer Responsibilities

Safety is critical at the Society of Aeronautics and Rocketry and the University of South Florida in its entirety. While our Safety Officer actively ensures the well-being of members and property, our entire team is expected to maintain constant awareness of all potential dangers. SOAR members are briefed of the potential hazards in our project and encourage them to voice any concerns.

The roles and responsibilities of the safety officer include, but are not limited to:

A. Monitor all team activities with an emphasis on safety, including:

1) Design of launch vehicle and Autonomous Ground Support Equipment (AGSE)
2) Creation of launch vehicle and AGSE
3) Set-up of launch vehicle and AGSE
4) Exhaustive ground testing of launch vehicle and AGSE
5) Sub-scale launch test(s)
6) Full-scale launch test(s)
7) Competition activities and launch
8) Recovery Activities
9) Educational Engagement Activities

B. Coordinate and implement the safety procedures outlined by the organization for the design, creation, set-up, launch, and recovery of the launch vehicle as well as the design, creation, set-up, and use of the AGSE.

C. Finding the relevant Material Safety Data Sheets (MSDS), sharing them with organization, and maintaining the appropriate folder in the organization's Google Drive, Material Safety Data Sheets. The Safety Officer will also ensure proper and safe conditions of materials during storage, transport, and implementation.

D. Analyze and record the team's hazard analysis tests, failure mode analysis, simulations, experimental data, and other relevant information sources for failures 32 and potentially hazardous trends. As well as coordinating the compliance with safety procedures and improvements to reduce risk.

E. Assist in the management and development of the team's hazard analysis, failure mode analysis, safety simulations, safety procedures, and guidelines.

F. Maintaining responsible and appropriate organizational behavior at all stages of design, development, test, travel, and launch.

G. Finally, the safety officer is expected to become familiar with all TRA, local, state, and federal laws, rules, customs, and regulations which apply to the use and transportation of motors, propellants, and other sources of risk. Based on this familiarity the safety officer is expected to ensure compliance with the aforementioned regulations.

3.7.2 Team Safety Procedures

Team Safety

A team safety meeting will be held before all tests and launches to ensure that all members are aware of all safety regulations. Each member is required to review all safety procedures and each member is responsible for remaining up to date on any updates to safety regulations.

Any member found to be in violation of any safety procedure at any time while working on the project will receive a verbal warning for the first violation. Should a member violate any safety procedures more than once, they will become ineligible to work on the project until their probation is appealed. Continued minor offenses or serious hazardous risks will make a given member ineligible to continue work on projects or participate directly in testing or launches until otherwise noted.

Hazard Recognition

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

NAR/TRA Personnel Duties for Launch

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

1. A level 2+ certified member and an NAR/TRA Personnel will oversee any test launch of the vehicle and flight tests of the vehicle
2. The launch site Range Safety Officer will be responsible for ensuring proper safety measures are taken and for arming the launch system
3. If the vehicle does not launch when the ignition button is pressed then the RSO will remove the key and wait 90 seconds before approaching the rocket to investigate the issue. Only the project lead and safety officer will be allowed to accompany the RSO in investigating the issue
4. The RSO will ensure that no one is within 100 ft of the rocket and the team will be behind the RSO during launch.The RSO will use a 10 second countdown before launch.
5. A certified member will be responsible for ensuring that the rocket is directed no more than 20 degrees from vertical and ensuring that the wind speed is no more than 5 mph. This individual will also ensure proper stand and ground conditions for launch including but not limited to launch rail length, and cleared ground space.This member will ensure that the rocket is not launched at targets, into clouds, near other aircraft, nor taking paths above civilians. As well this individual will ensure that all FAA regulations are abided by.
6. Another certified member will ensure that flight tests are conducted at a certified NAR/TRA launch site.
7. The safety officer will ensure that the rocket is recovered properly according to Tripoli and NAR guidelines.

3.8 Serious Vehicle Safety Hazards

1. **Motor ignition failure**
   Probability: 3, Moderate
   Severity: 1, Catastrophic

   Outcome: Failure of the motor igniting inhibits the rocket from launching, or possibly causes the rocket to fire at an unexpected time. An unexpected launch could potentially harm personnel and spectators.

Mitigation: Proper TRA safety code will be followed by waiting a minimum of 60 seconds before approaching the rocket to ensure that the motor is not just delayed in launching.
If there is no activity after 60 seconds, the safety officer will check the ignition system for a lost connection or a bad igniter. In the event of a faulty ematch, the safety officer or project leader will remove the ignition system from the rocket motor, retrieve the motor from the launch pad and replace the motor with a spare.

2. **Parachute Inflation Failure**
   Probability: 4, Unlikely
   Severity: 1, Catastrophic

   Outcome: Failure of the rocket parachute to inflate after being ejected from the rocket is a huge safety risk. If the parachute does not inflate during descent, the rocket becomes a very heavy and deadly spear that is traveling at a high enough velocity to seriously injure or cause death to another person.

   Mitigation: To ensure that the parachute is deployed at 500 feet above the ground, we ensured that our parachute has ample room to fit inside of the aft bay. As well as choosing the material for the parachute to be silicone coated balloon cloth to reduce the friction between fiberglass and the parachute.

3. **Separation of rocket at apogee and/or 500ft does not occur (Altimeter/Ematch failure)**
   Probability: 3, Moderate
   Severity: 1, Catastrophic

   Outcome: Failure at separation stages will result in the rocket becoming ballistic. A ballistic rocket can potentially endanger personnel and spectators.

   Mitigation: Separation sections of rocket will be designed to ensure that the black powder charges provide enough force to cause the pins to shear. Ground test have been done to ensure the correct amount of black powder is used. 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.

4. **Optimum velocity is not reached upon leaving the launch rail**
   Probability: 3, Moderate
   Severity: 2, Critical

Outcome: If the rocket does not reach optimum velocity after leaving the launch rail, the rocket may take an unpredicted flight path, potentially harming personnel and spectators.

Mitigation: Simulations have been run to confirm that the necessary velocity can be achieved by the motor selected. Motor has been selected based on simulation data to meet lift off and flight requirements. Prior to installation and launch, the launch buttons will be tested for fitting on the launch rail to ensure minimal friction.

5. Internal bulkheads fail during ascent/flight

Probability: 4, Unlikely
Severity: 1, Catastrophic

Outcome: Components inside the rocket being held by the bulkheads will no longer be secure and could cause an anomaly. Parachutes attached to bulkheads will be left ineffective. Rocket may pose a threat to individuals at the field.

Mitigation: All bulkheads will be secured with high strength 30 minute epoxy. Bulkheads that have parachutes attached will have extra epoxy around eyebolts to ensure the bulkhead and eyebolts are secure within the rocket. In the event that the rocket may pose a threat to any individual, all individuals at the launch will be notified immediately

4) AGSE/Payload Criteria

4.1 Systems Overview

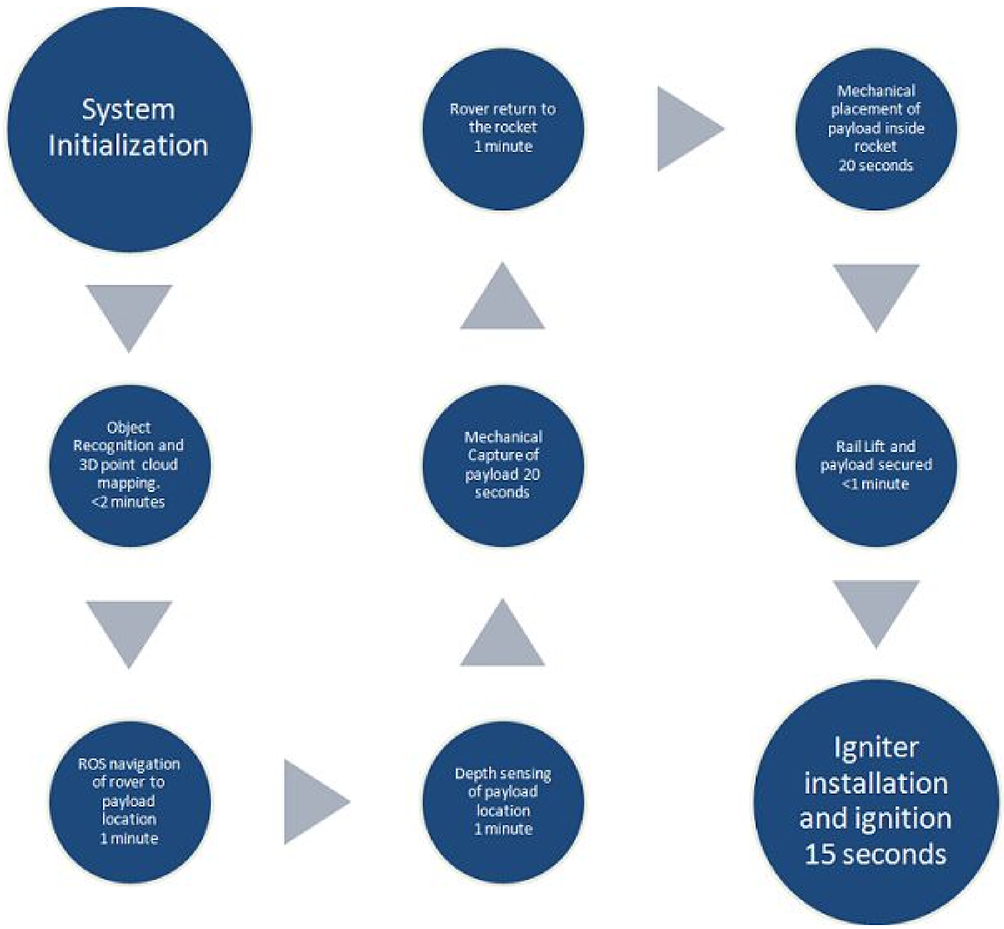
The AGSE must follow these requirements to ensure success

1. Team will place the launch vehicle in the horizontal position on the AGSE.
2. A master switch will be used to power on all autonomous procedures to be carried out.
3. A pause switch will be activated, temporarily halting all AGSE procedures and subroutines.
4. Once the launch vehicle has been inspected by the launch services official and grants permission to launch, a switch will then be activated to enable final launch procedures.
5. The Launch Control Officer will activate a hard switch, then provide a 5-second countdown.
6. At the end of the countdown, the LCO will activate the launch button to initiate the launch.
7. All AGSE systems shall be autonomous.
8. The system must suffer no delays once the launch switch is activated.
9. The system must complete all tasks within 10 minutes.
10. The capture/containment system must be able to retrieve the payload from 12 inches away from the vehicle MOLD line and from the ground.
11. No forbidden technologies will be used, such as
    a. Components that rely on Earth's magnetic field
    b. Sound-based sensors
    c. Earth-based or Earth-orbit based radio aids
    d. Open Circuit pneumatics
    e. Air breathing systems

Along with the requirements above, the following requirements regarding the controls must be met for success.

1. A master switch to power all systems of the AGSE, where the switch must be easily accessible and hardwired into the AGSE.
2. A pause switch to temporarily shut down all actions carried out by the AGSE. The pause switch must be easily accessible and hardwired into the AGSE.
3. A safety light that indicates that the AGSE is powered on.

4.1.1 System Timeline



4.1.1.1 Figure describing the time allocated to each operation throughout the payload capture. The above times are estimations based on research and inspection.

4.2 Payload Capture and Containment

4.2.1 Overview

The objective of this system is to grasp the payload from the required position, raise it up to the launch vehicle's level, and then insert the payload into the specified payload bay of the rocket. For successful payload capture, a mechanical arm was designed to mount to the AGSE or to a possible rover that will retrieve the payload. The arm will start in a retracted position, and when activated, will extend 12 inches to the placed payload. The gripper assembly at the end of the arm will carefully grasp the payload. The arm will then rotate around its base, raise up to the payload bay of the rocket, and then be safely inserted into the payload bay. The payload bay will be directed by the system system to close when the payload is in place.

4.2.2 Design

The design of our payload capture and containment system is simple for the most part. It consists of 5 degrees of freedom and is constructed out of 304 stainless steel. Each component was carefully considered, being designed to ensure stability when arm is in motion. Placement of servo motors was considered, mirroring the mechanics of a human arm. Bottom plate of the base structure is designed to have the capability to be mounted to a rover or another structure.

Height (in)	Length (in)	Width (in)	Mass (lbm)
19.64	15.14	2.18	3.97

Figure 4.2.2.1: General dimensions of payload arm

4.2.2a Base Structure

The Base Structure of our robotic arm is 95mm in diameter with 4 appendages used to secure the structure to another object mobile or static. See figure 4.2.2a.1 below.

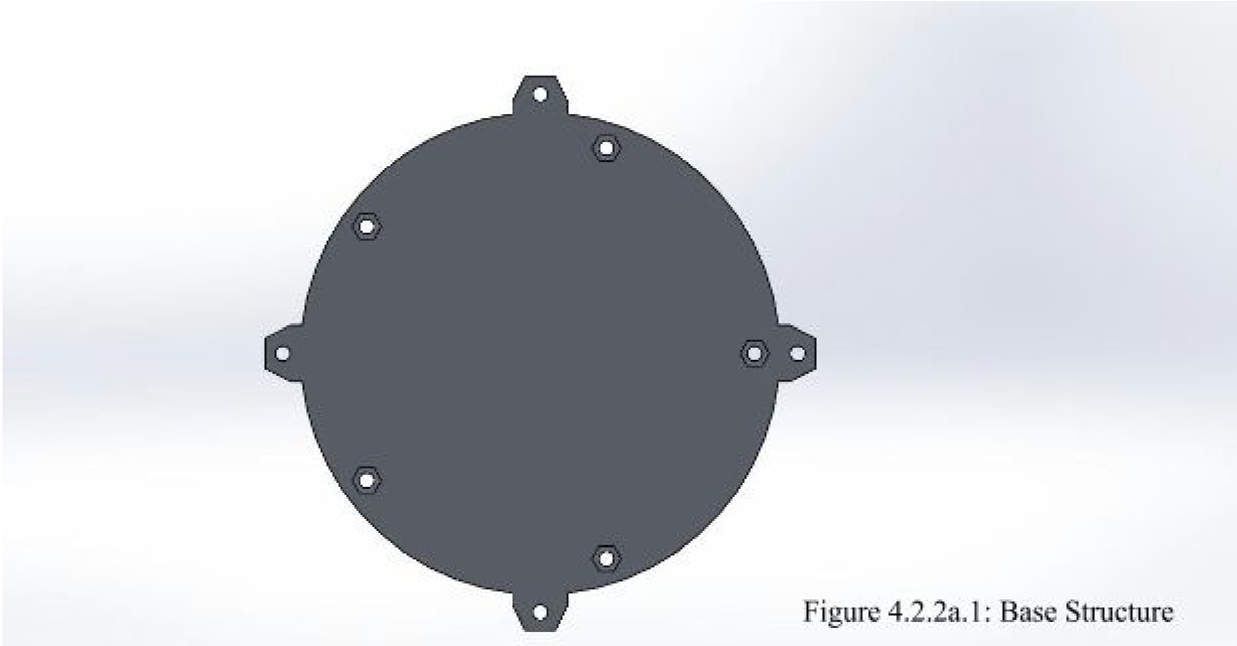


Figure 4.2.2a.1: Base Structure

The completed base structure can be seen below which includes 5 metal pillars which allow for a servo to be placed on the bottom of the top plate. The servo placed here will be used to rotate the entire structure 360 degrees thus giving us the first degree of freedom.

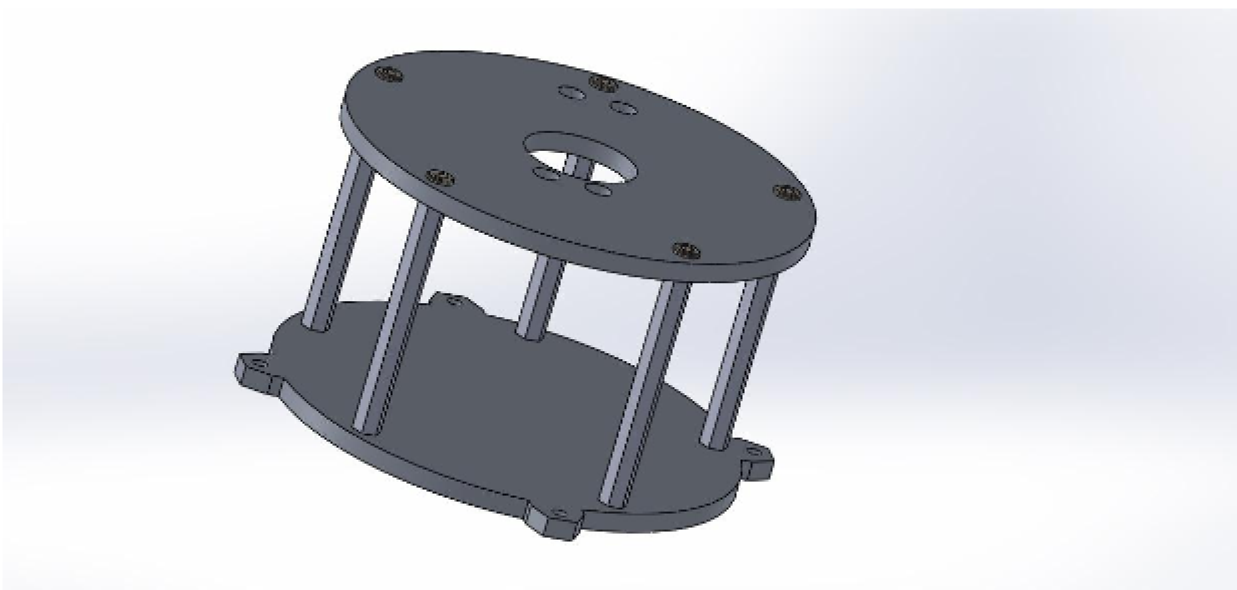


Figure 4.2.2a.2 Completed Base Structure

4.2.2b Shoulder Joint (2nd Degree of freedom)

The shoulder joint is designed on a base plate, which is mounted to the base structure.There are two long plates, each connected to a rotating servo, allowing the plates to swing up and down. This grants the second degree of freedom.

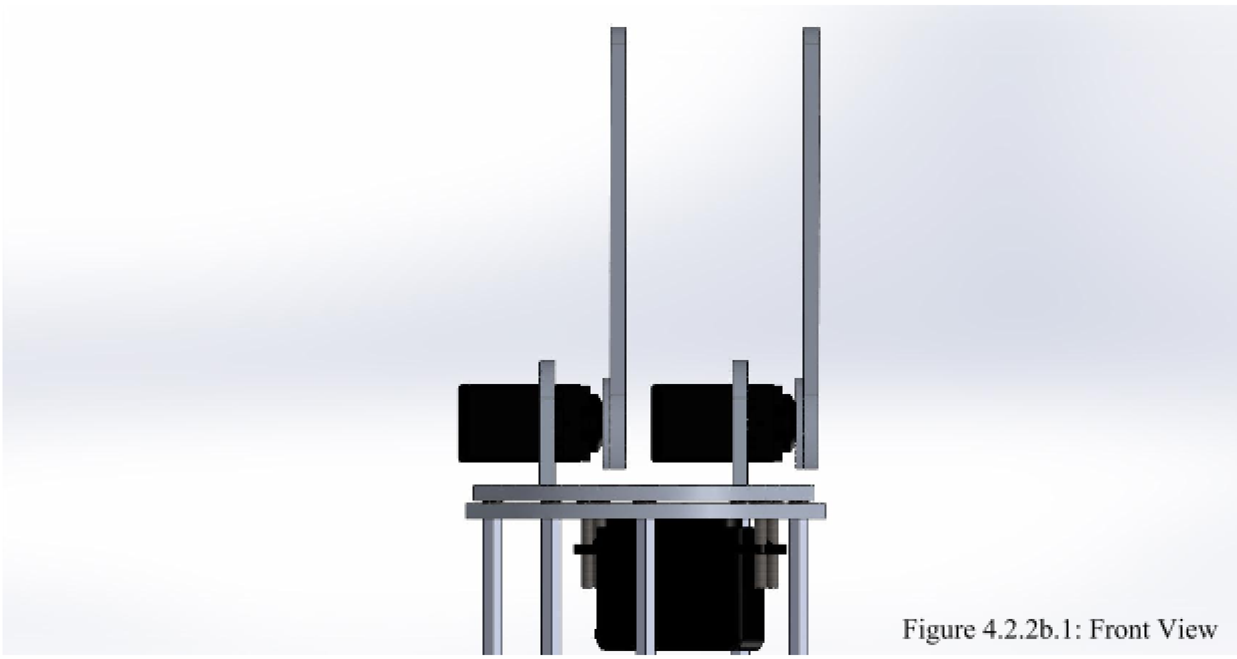


Figure 4.2.2b.1: Front View

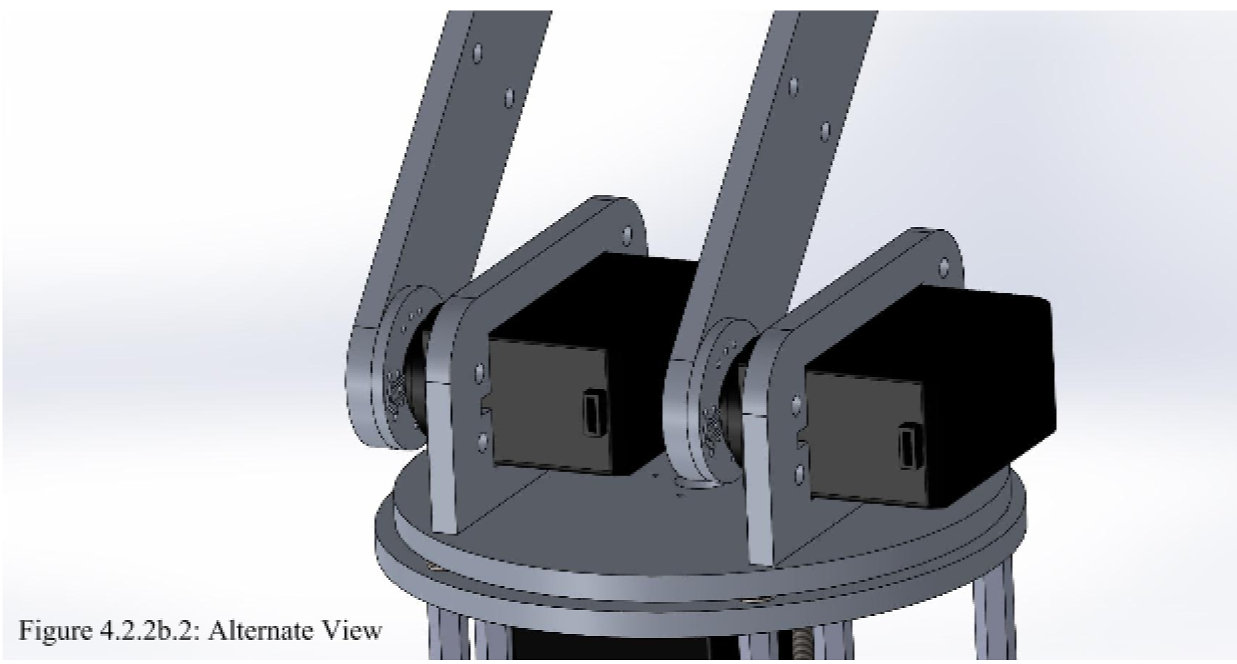


Figure 4.2.2b.2: Alternate View

4.2.2c Elbow Joint (3rd Degree of freedom)

The elbow joint provides the third degree of freedom. Mounted in between the two plates from the shoulder joint, the elbow joint contains one servo, allowing 180 degree rotation. The rotation allows the mechanical arm to extend and retract for proper payload retrieval.

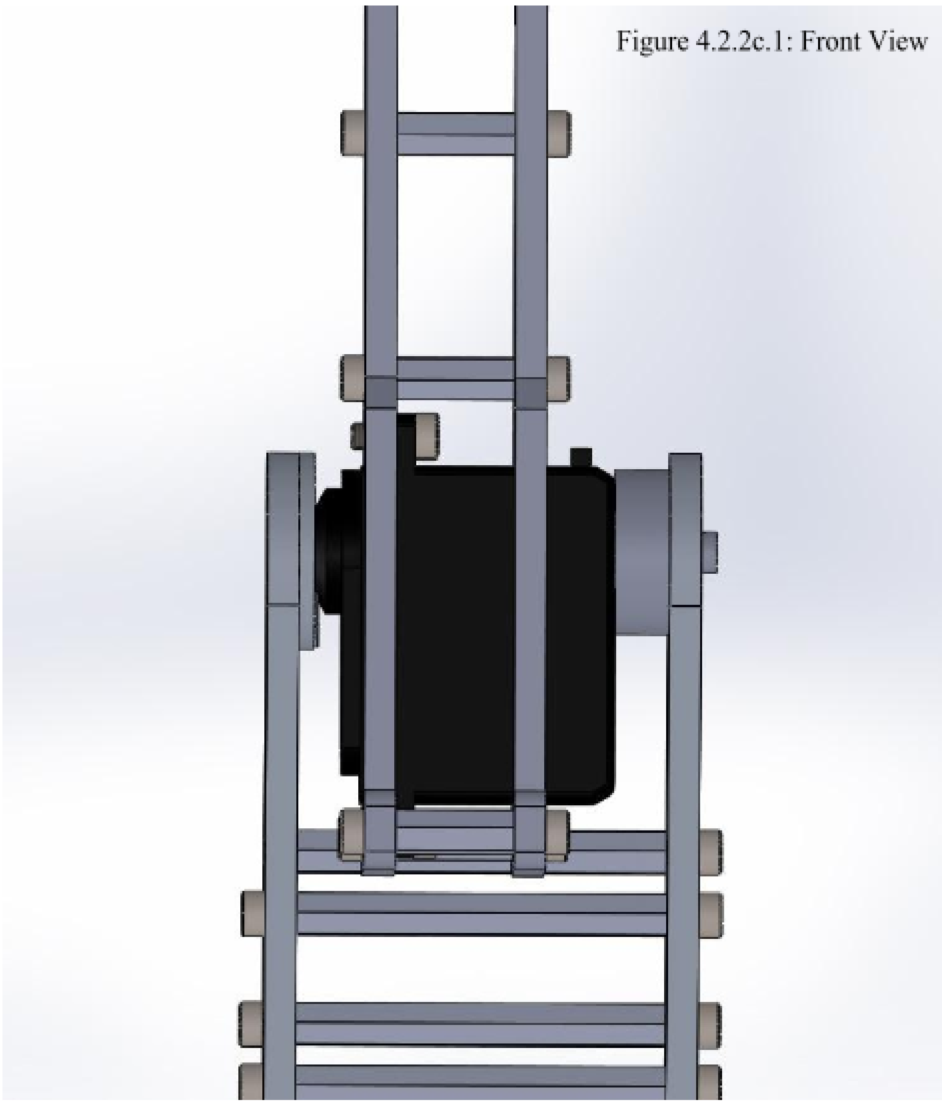
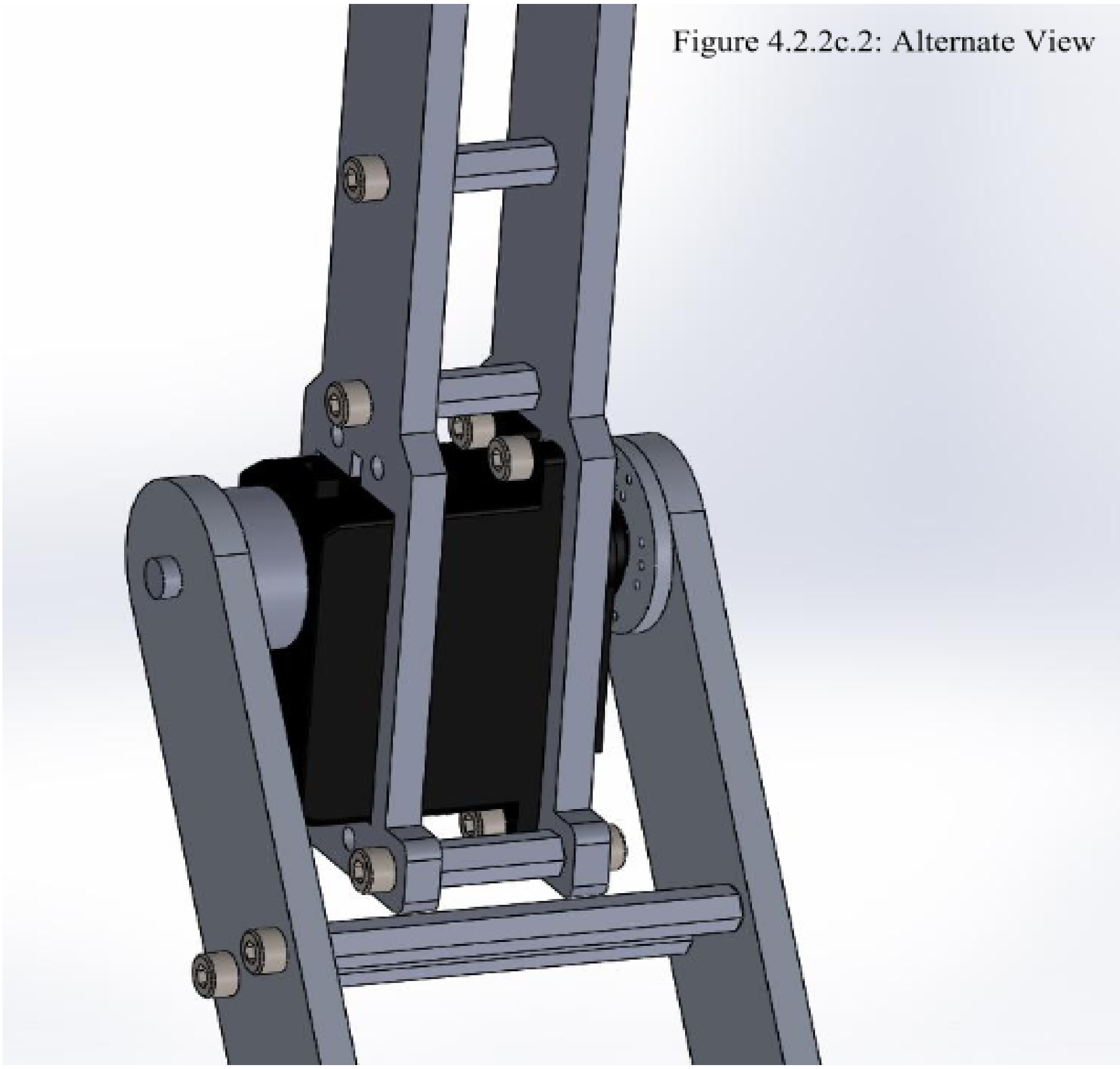


Figure 4.2.2c.1: Front View



4.2.2d Wrist Joint (4th & 5th Degree of freedom)

The wrist joint contains the last two degrees of freedom. One servo is mounted in between the plates from the elbow joint, allowing the end of the arm, or hand, to swing up and down. At the end of the wrist joint is a micro servo, which will allow the gripper to rotate 180 degrees. The micro servo grants the capability of twisting.

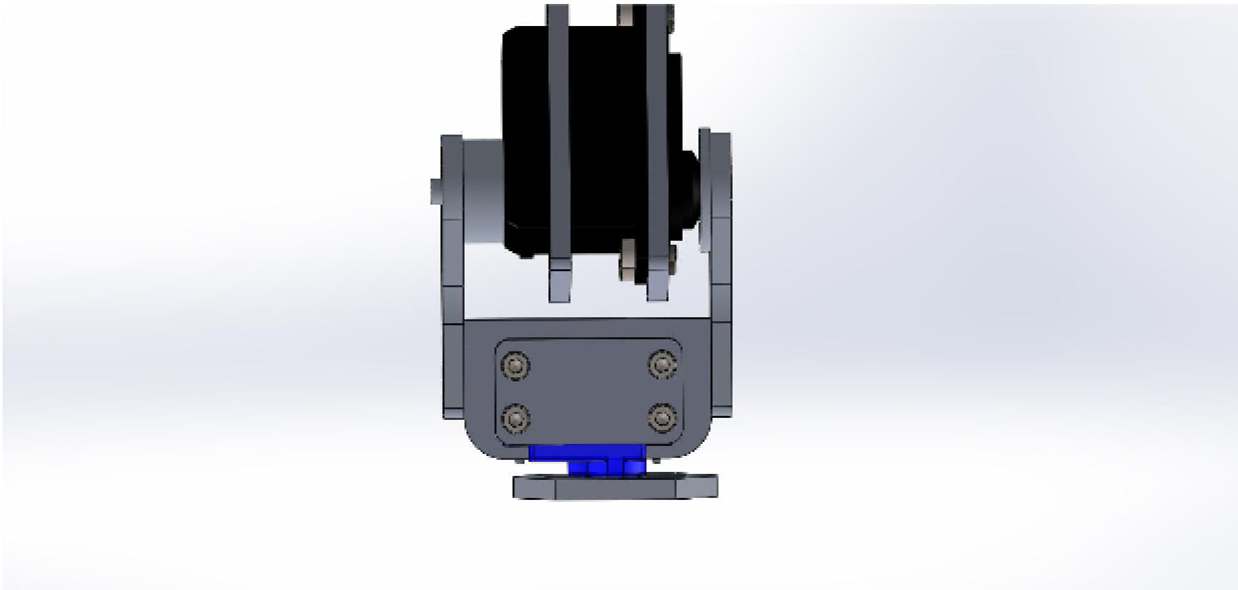


Figure 4.2.2d.1: Top View

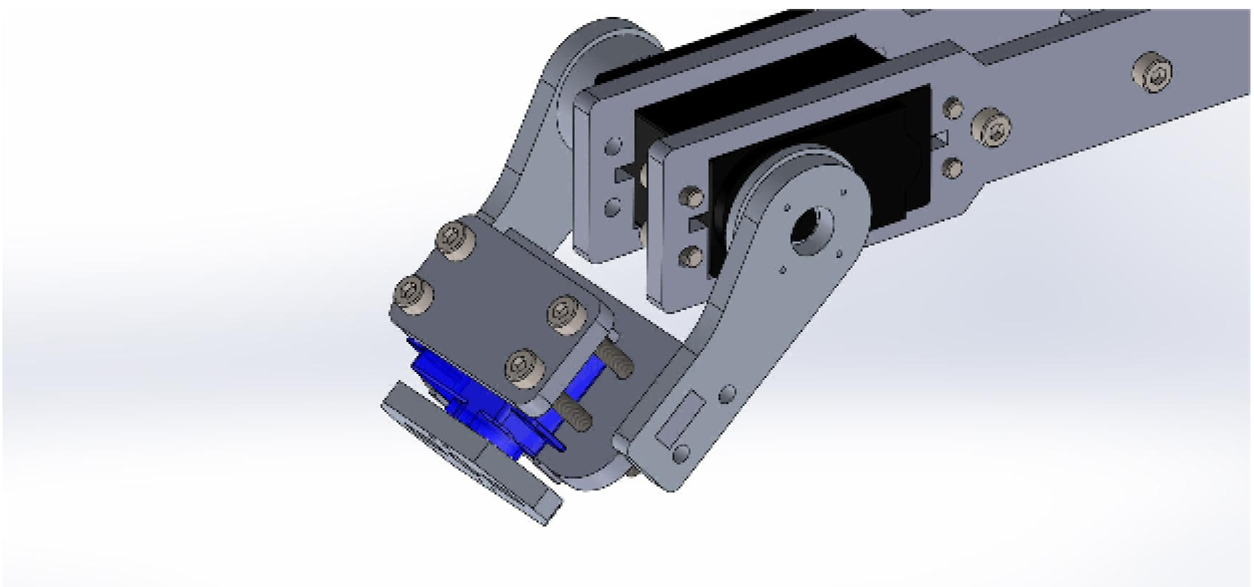


Figure 4.2.2d.2: Alternate View

4.2.2e Gripper Assembly

The gripper assembly consists of two four tooth gears which are turned by one micro servo on the bottom of the left gear. The design is meant to be a simple way to pick up the payload. In Figure 4.2.2e.1 You can see a top view of the gripper assembly which shows the gears and gripper appendages.

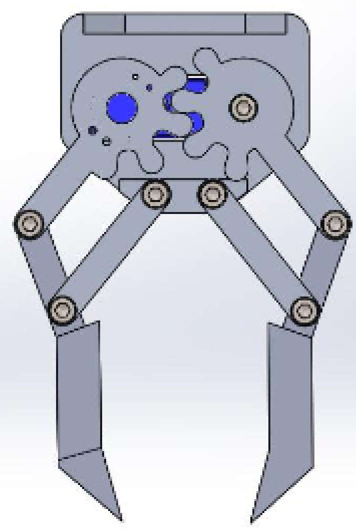


Figure 4.2.2e.1: Top View

Here in the alternate view we can see where the servo will turn the left gear which in turn opens and closes the gripper assembly.

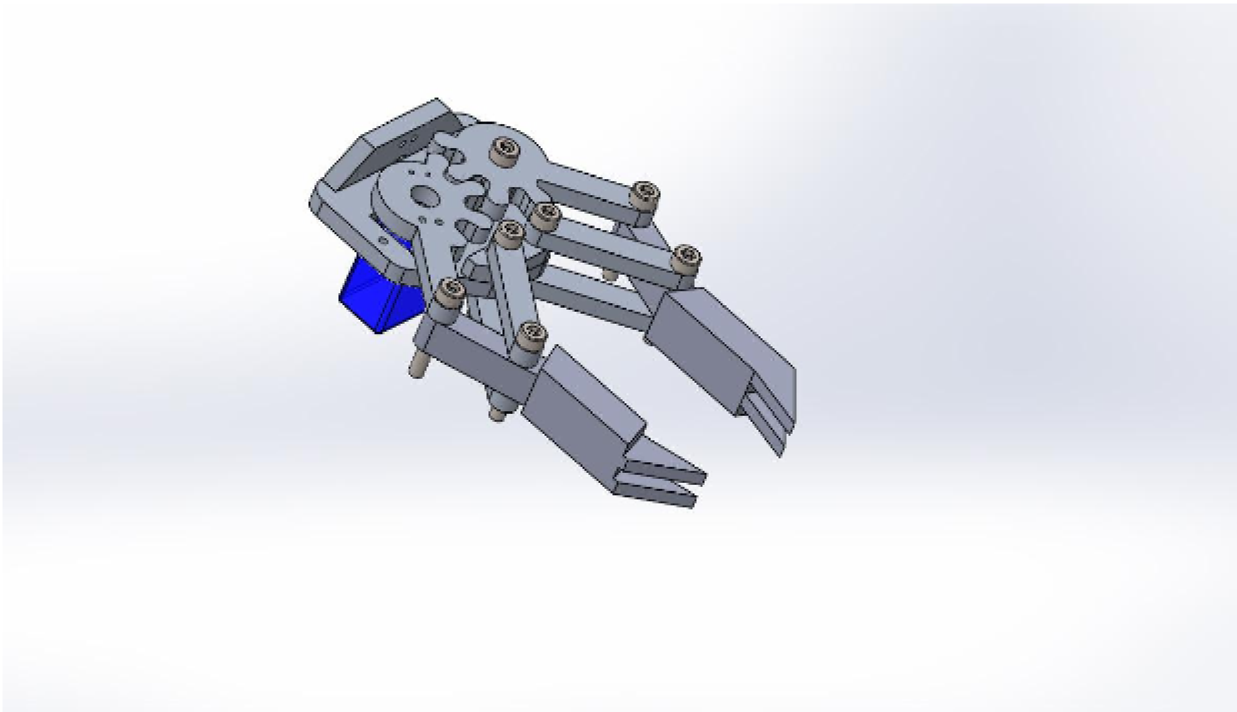


Figure 4.2.2e.2: Alternate View

Finally in Figure 4.2.2e.3 You'll notice the gripper appendages. The gripper appendages are designed to interlock with each other upon closing. They are angled in such a way to direct the cylindrical payload up and into their grasp. The angle and interlocking design allows for a more secure hold, decreasing chances of slip. The grippers were also designed so that they can not only pick up the cylindrical object we were tasked to pick up, but can easily pick up a plethora of different objects.

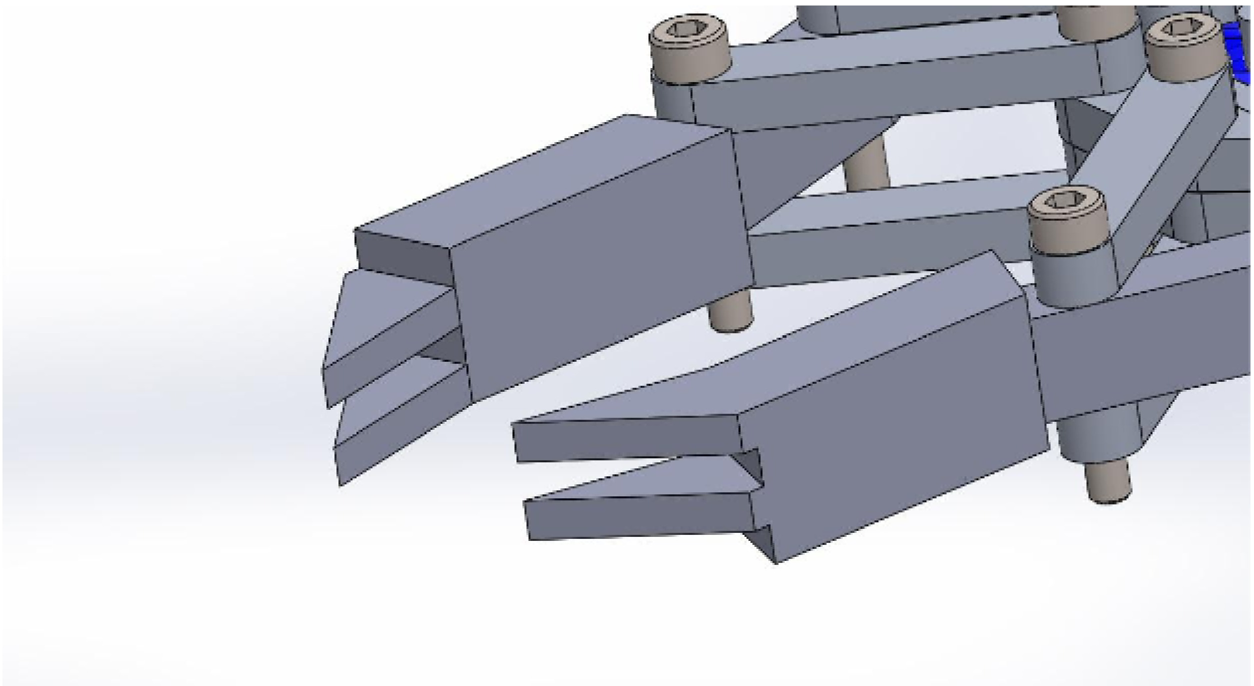


Figure 4.2.2e.3: Gripper Appendages

4.2.2f Complete Robotic Arm

The final design of our robotic arm can be seen below in Figure 4.2.2f.1. You'll notice that all of the preceding parts and assemblies have been assembled into one complete robotic arm.

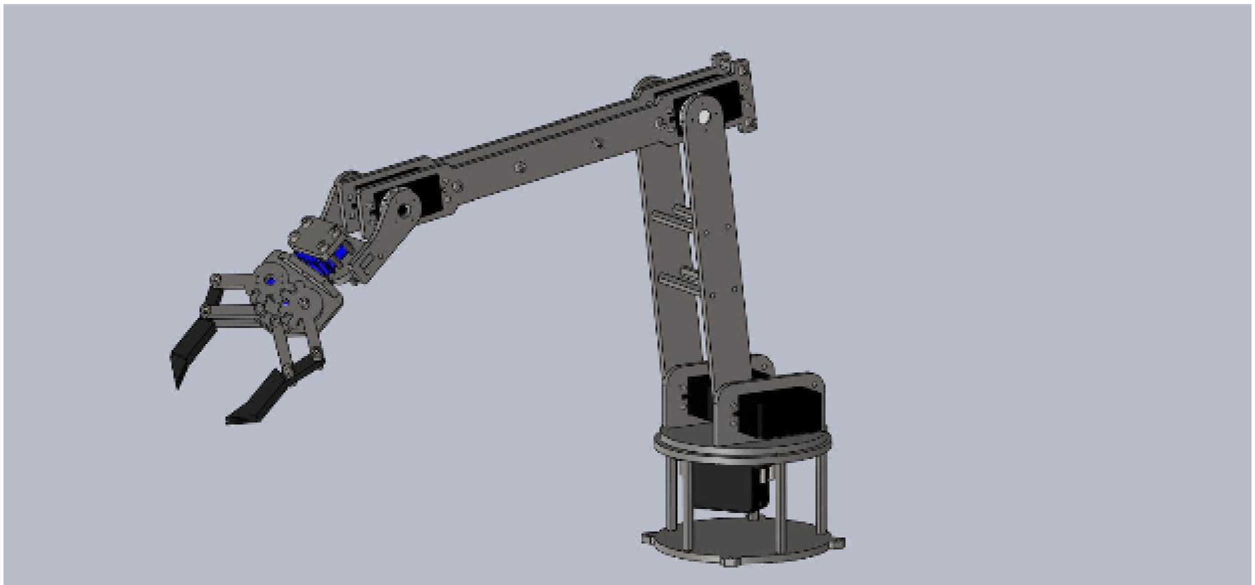


Figure 4.2.2f.1: Complete Robotic Arm

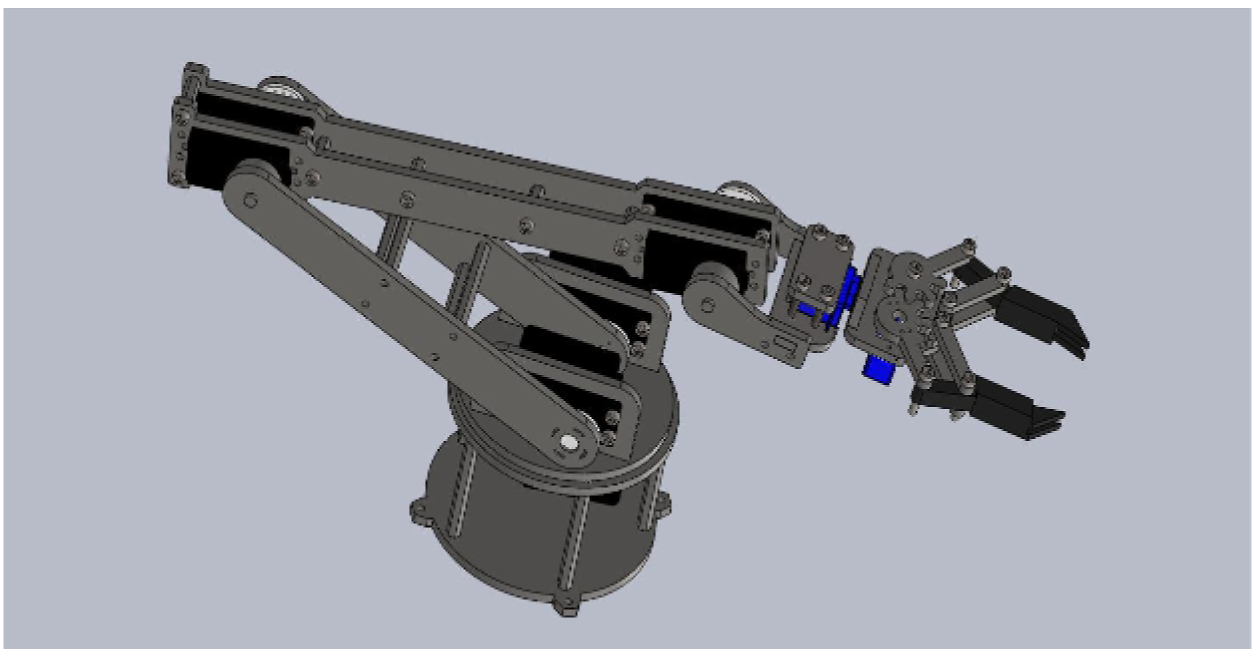


Figure 4.2.2f.2: Complete Robotic Arm

4.2.2g Wheel

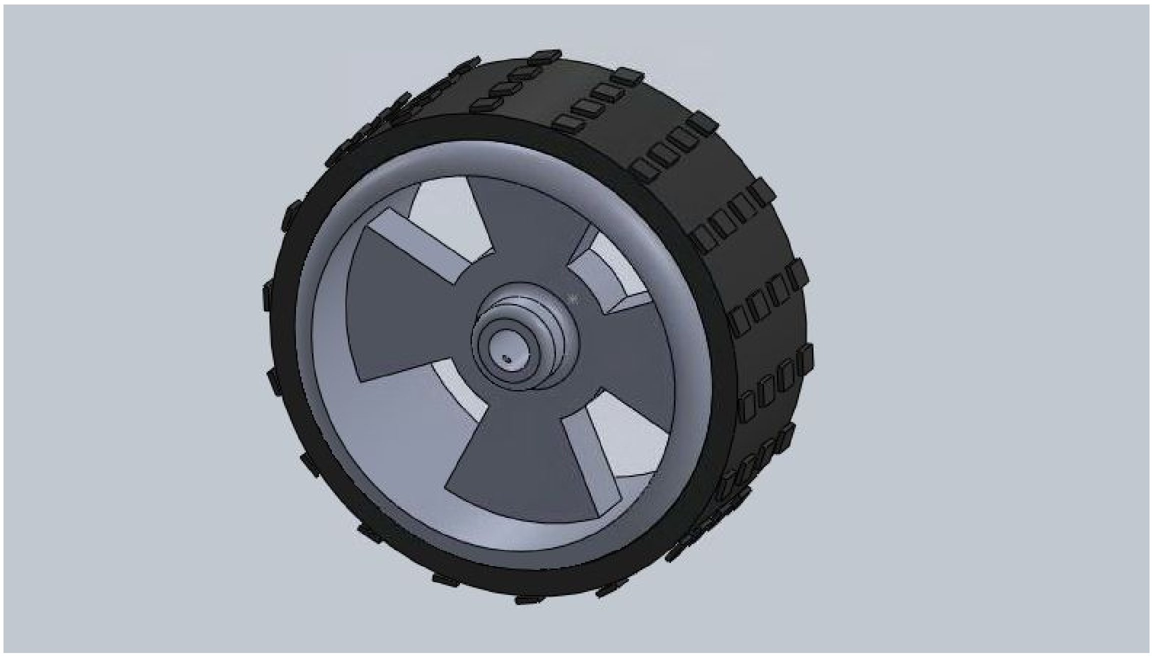


Figure 4.2.2g.1: Outer Wheel

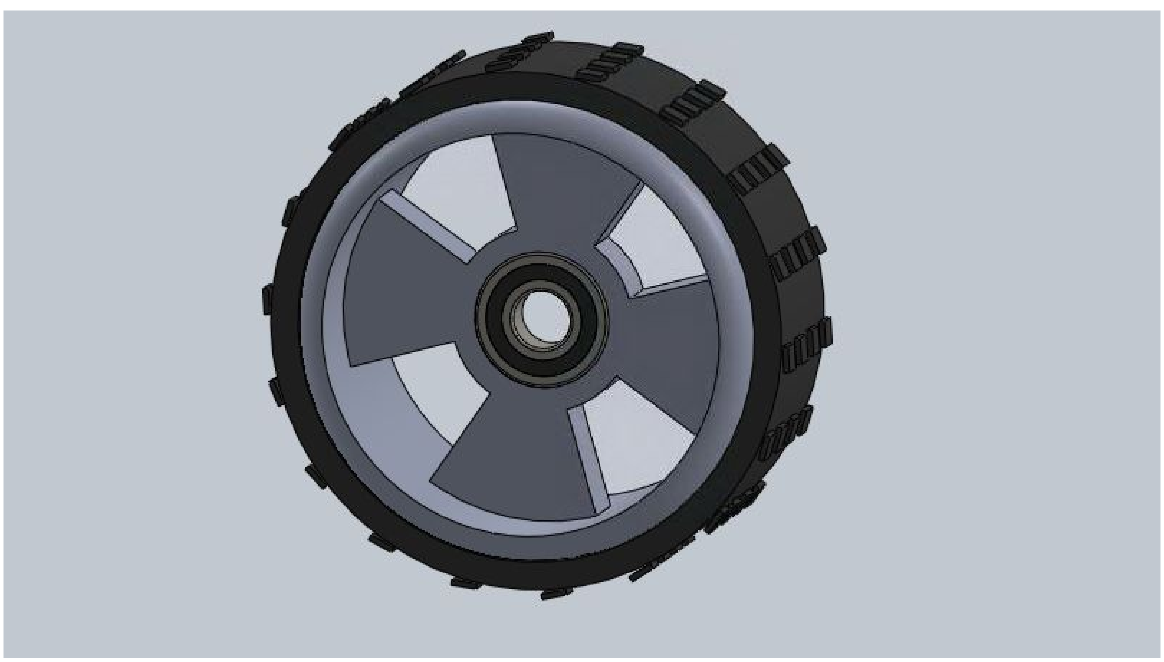


Figure 4.2.2g.2: Inner Wheel and Bearing

The wheels designed by the USF SOAR team feature rubber treading for safe navigation over uncertain terrain, a four inch outer diameter, a steel frame, and an attachment hole for affixing the motor securely to the wheel. We have designed two wheel designs, one for the outer motorized wheels and another for the inner caster wheels. They both feature unique attachments to the rover suspension system. The outer wheels will connect to the motor through a bolt firmly threaded against a flat end of the motor shaft, while the inner wheels will feature an axle running through the bearing, with washers on both sides, and a nut on the exterior end.

4.2.2h Suspension System

Our team decided to use NASA's tried and true model for our simulated planetary rover. Therefore we modeled our rover after the past Mars exploration rovers, a fitting tribute to the Mars Ascent Vehicle challenge. We experienced the struggles firsthand of designing a Rocker-Bogie suspension system. While a plethora of examples exist to study, the trials of designing a novel Rocker and Bogie system still provided a formidable challenge for our young team.

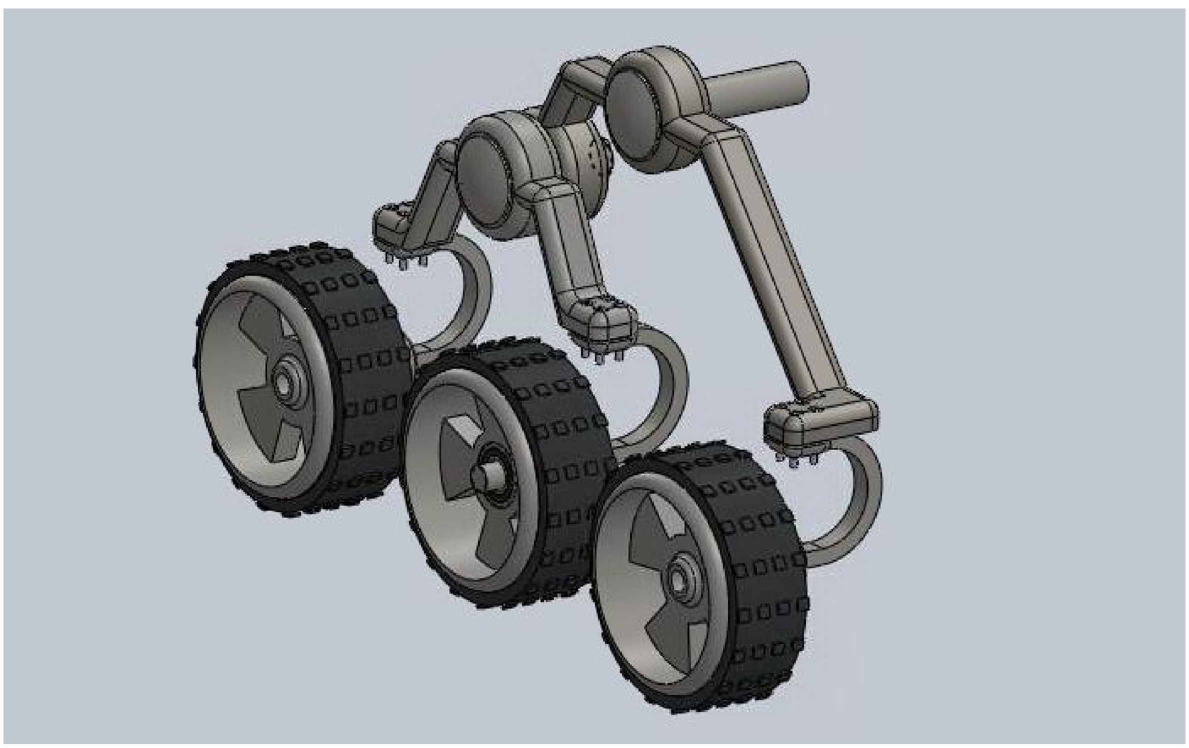


Figure 4.2.2h.1: Rocker-Bogie Suspension

One half of the Rocker-Bogie suspension design can be seen above, where many notable features can be analyzed. Most saliently, the large Rocker connecting to the Bogie beneath it will provide a wide angle of movement for the ability to overcome obstacles, a trademark feature of any successful robotic planetary exploration platform. A deviating feature from our rover to the NASA rovers that can be seen in this picture is the free-spinning, nonmotorized middle wheel, while the NASA rovers feature six independently driven wheels. As documented previously this deviation was for compatibility with the Robot Operating System (ROS) differential drive local base controller. Additionally, this frees desperately needed GPIO pins on the Raspberry Pi, more motors and encoders would necessitate more processing and control.

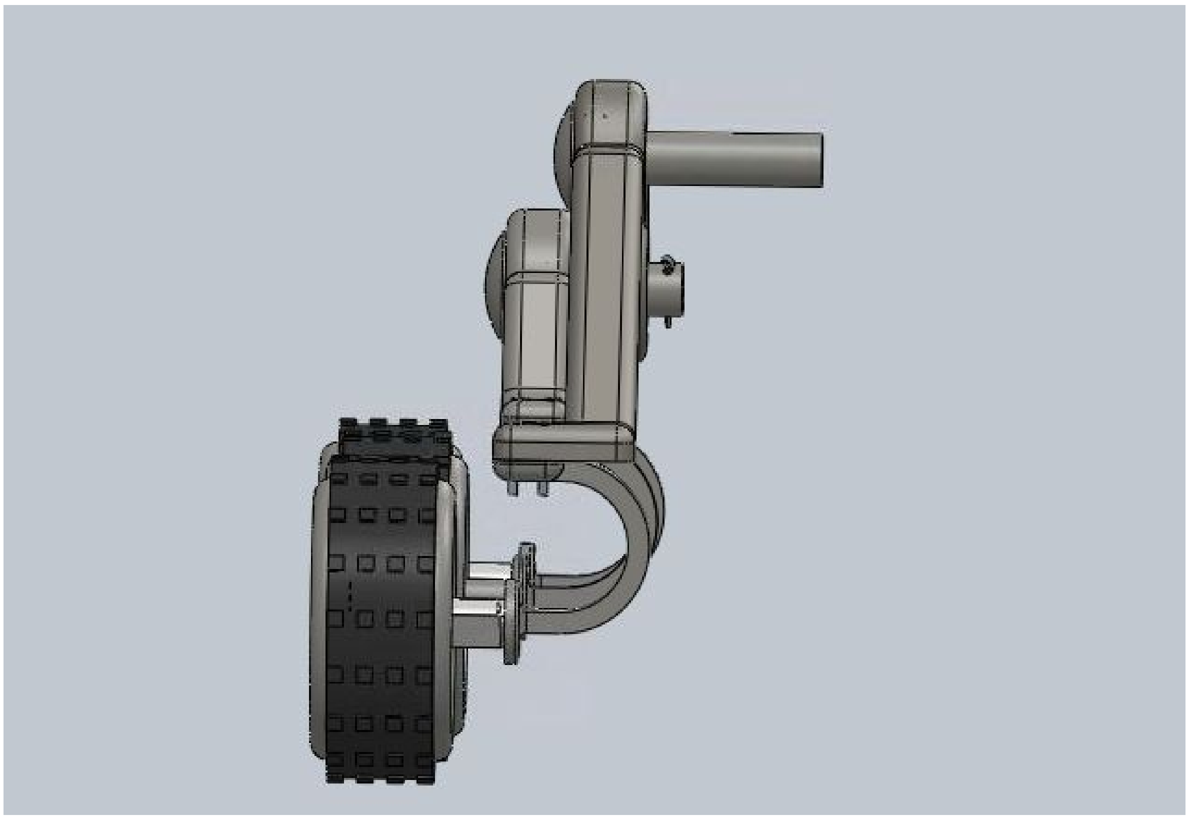


Figure 4.2.2h.2: Side View of Rocker-Bogie Suspension

Here we have a side view, or nearly head-on, of the Rocker-Bogie suspension. This angle allows use to inspect more features of the design. Namely, we can notice that the motor mounts hold one motor each on the outer four wheels. It is important to note that Solidworks has hidden the threading on many screws so that it can retain a low polygon count for faster processing.

4.2.2i Body

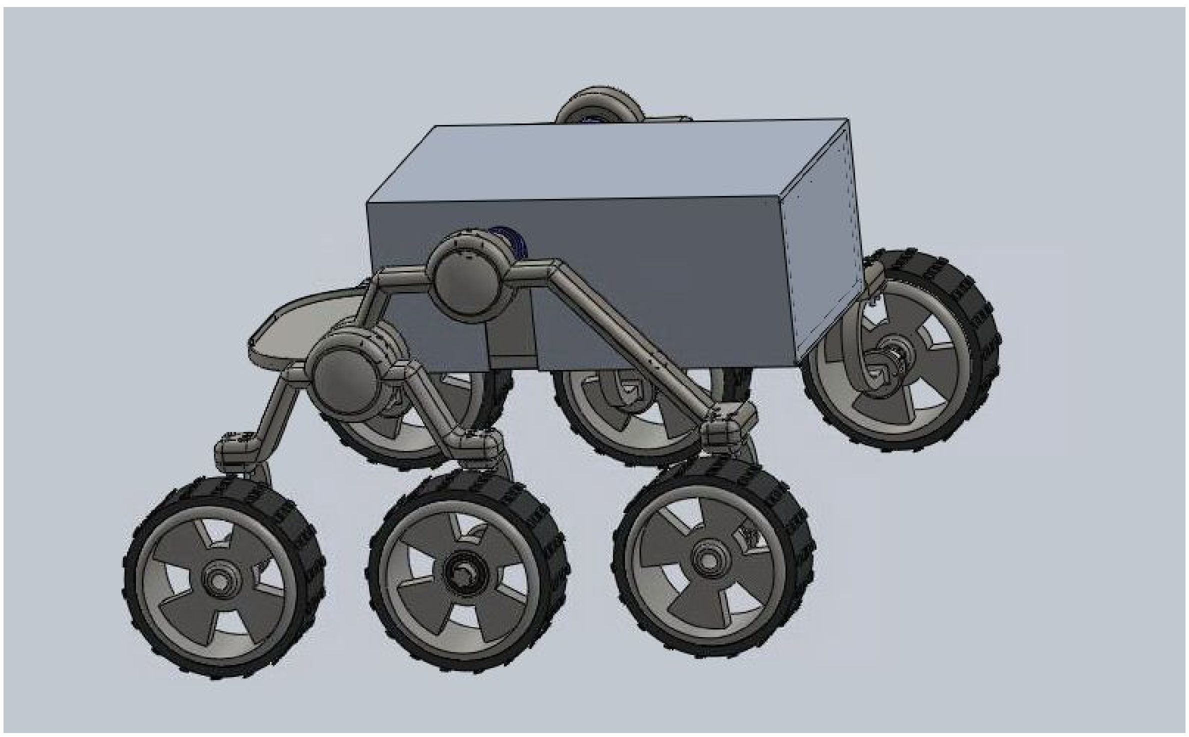


Figure 4.2.2i.1: Rover

A model of the rover can be seen above, this model shows the base where the arm will rest, however it does not currently have the arm bolted on to the front lip designed for it, additionally a kinect will be mounted on a post above the arm angled slightly down so as to allow the image processing to have an unimpeded view of the local environment as well as for functional acquisition of the payload.

4.2.2j Environmental Concerns

It is a critical step to making a sustainable system that it must doubly minimizes its own impact on its environment and be resistant the constant eroding forces of nature. We take pride in knowing that our all electric automated ground support minimizes its impact on the environment through the use of reusable Lithium batteries and lack of byproducts or waste. Other than the batteries charging through the electrical grid, the only environmental impact of our AGSE system is the crushing by rolling of the wheels over the local environment.

However, our system may be vulnerable to harsh planetary environments such as Mars. While we will be well within safety margins for Huntsville, Alabama, our design would need to be environmentally encapsulated for the harsher environments. Dust, grit, sand, dirt, and various other particles that may be introduced by the environment, as well as extreme temperatures, winds, water contact and other environmental features can degrade the structure of the platform over time. In extreme conditions, such as Mars, the length of time required to critical failure will be severely reduced. This is especially true if the delicate sensors and electronics become exposed to these forces of erosion. Proper shielding can safely protect the sensitive components and prolong their lifespan for exploration missions. However, given the mild Earth conditions at Huntsville, Alabama. A cost/benefit decision was made to forgo extensive shielding in favor of saving cost, reducing increased torque about the center axis by adding mass, and to not unnecessarily increase the power demand on the drive motors.

4.2.3 Fabrication

The fabrication of the Automated Ground Support Equipment includes the following:

1. 3 Hitec metal gear servos delivering anywhere from 107-133oz-in of torque.
2. 2 Hitec karbonite gear servos delivering anywhere from 72-89oz-in of torque.
3. 2 Hitec micro servos delivering anywhere from 15-18oz-in of torque.
4. 304 Stainless Steel
5. Socket Head Cap Screw (M3x0.5x8)
6. Socket Head Cap Screw (M3x0.5x12)

7. Socket Head Cap Screw (M3x0.5x20)
8. Socket Head Cap Screw (M3x0.5x30)
9. 4x Castellated Nuts
10. 4x Cotter Pins
11. Toggle Switch
12. Wireless Electrical Kill Switch Relay
13. Epoxy (J-B Weld)
14. 2x Raspberry Pi
15. 4x DC-DC Buck Voltage Regulators (03100233)
16. 16-Channel 12-Bit Servo Driver (PCA9685)
17. Lithium Polymer or Lithium Ion Battery
18. Kinect
19. 3x Xbee Series 1 RF Communication Module
20. DC Motor Controller (RS011MC)
21. 4x Motors with integrated quadrature encoders
22. SPI IC GPIO Expander (MCP23S17)
23. 8x Radial Ball Bearings
24. Rubber Tire Treading

Complementing the resources offered to our team by the University of South Florida, such as two on campus machining shops, access to an undergraduate engineering lab space fit with tools and components, as well as funding from student government, we also appreciate support offered by the local community. Our mission would be in jeopardy without the communities' support. Our team and NAR advisor, Rick Waters, allows us to use workspace for fabrication at his private workshop. Additionally, we have received a pledge from a local welding company to subsidize and aid the construction of the metal components of our AGSE.

At this stage in the development we have fabricated and successfully launched the subscale rocket design, we have sourced all of the components and submitted the parts list for the full scale launch vehicle. We have begun prototyping various features of the AGSE system, these include a miniature robotic arm for simulation and analysis, the Raspberry Pi for network derivation and testing of the ROS architecture, the servo driving board for integration and testing with the microcontroller, and the Xbee modules to test and verify the capabilities of the our communication system. We have also utilized 3D printers for rapid prototyping of mechanical features of the AGSE, such as the differential gear system, and for the final design, such as the gripper appendages.

4.2.4 Mechanics of Solids

4.2.4a Material Properties

The Robotic Arm is made out of 304 stainless steel for its strength to cost ratio. Though it may not be the strongest of metals out there, it is very cost effective. Below in Table 4.2.4.1 you'll see some properties of 304 stainless steel.

Tensile Strength (MPa)	Yield Strength (MPa)	Modulus of Elasticity (GPa)	Poisson's Ratio	Density (g/cm^3)
585	240	193	0.29	7.75

Table 4.2.4.1: Important properties of 304 Stainless Steel

In Figure 4.2.4.2 you'll notice again that 304 stainless steel has a lower yeild point than for instance carbon steel. Carbon steel, though, is much more expensive than 304 stainless steel. Also, the objects that we will be picking up with the robotic arm aren't incredibly heavy and practically speaking, the 304 stainless steel on the robotic arm should never plastically deform.

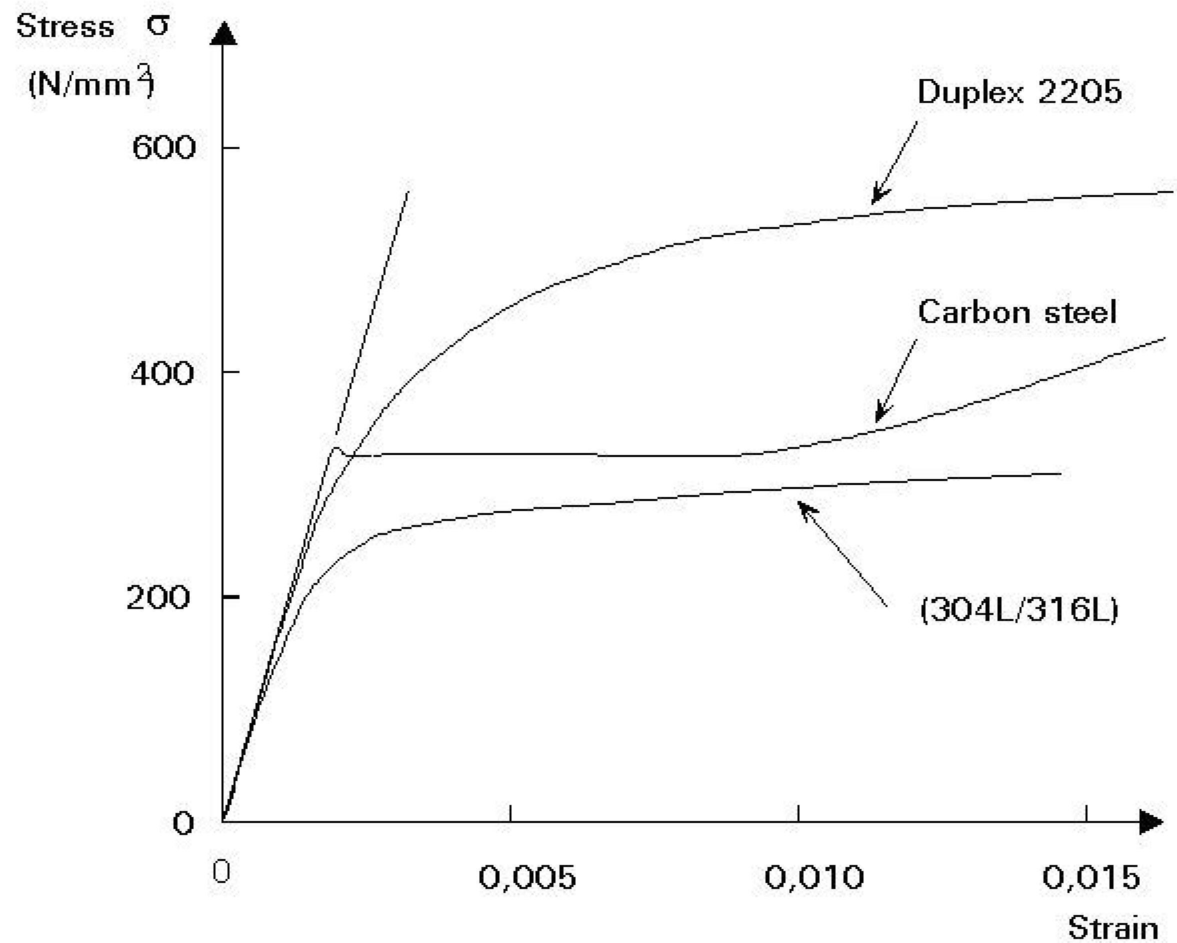


Figure 4.2.4.2: Stress-strain curve for 304 Stainless Steel

4.2.4b Mechanical Torque

A main concern of the design of the rover body is the torque applied on the rover by the weight of the arm, which could cause the rover to tip forward or flip if not balanced by the weight of components in the rear of the rover body. Keeping in mind that force applied further away from the axis of rotation results in a greater torque than a force applied near the axis, the rover has been designed such that its most probable axis of rotation is the axis connecting the two sides of the suspension to the differential gear through the main body. This axis has been placed very close to the arm as to reduce the potential maximum torque caused by the arm's increasing distance from the axis of rotation.

The torque $\vec{\tau}$ caused by a force about a given axis can be calculated by taking the vector cross-product of the position vector $\vec{r}$ pointing from the axis of rotation to the point where the force $\vec{F}$ is acting (which, for a rigid body, can be approximated as the body's center of mass). The primary force applying torque to the rover will be the force of gravity acting on the components of the arm. The vectors $\vec{L_{gi}}$ and $\vec{L_i}$ represent the distance from the joint to the center of gravity for the i^{th} component and the total length of the i^{th} component, respectively. The angles φ_i and θ_i denote the angular degrees of freedom for each segment of the arm, excluding the spin of the wrist which will not significantly contribute to the total length of the arm.

The position vector of each component with respect to the center of mass can be calculated by vector addition, beginning with the vector, $\vec{v}$, spanning the horizontal distance from the center of mass of the entire system to the origin of motion for the shoulder of the arm. We then continue by summing the relevant vectors for each center of gravity, *exempli gratia*,

$$\vec{r_1} = \vec{v} + \vec{L_{g1}}$$
$$\vec{L_{g1}} = q(L_1 \sin\varphi_1 \cos\theta_1,\ L_1 \sin\varphi_1 \sin\theta_1,\ L_1 \cos\varphi_1)$$
$$\vec{r}_1 = (qL_1 \sin\varphi_1 \cos\theta_1,\ qL_1 \sin\varphi_1 \sin\theta_1 + v,\ qL_1 \cos\varphi_1)$$

which yields the position vector for center of gravity of the first arm segment with respect to the system's center of gravity.

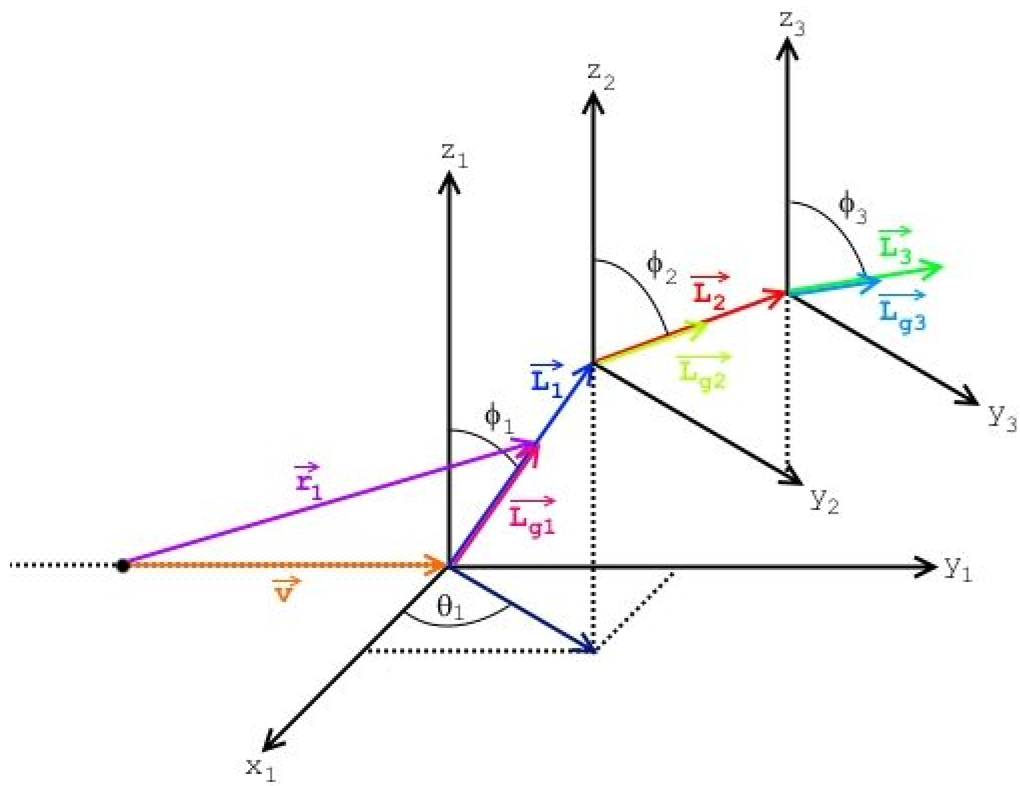


Figure 4.2.4.3: Vector addition diagram of possible arm positions.

After the acquisition of the position vectors, we move on to the evaluation of the cross-product for the torque, keeping in mind that $\vec{L}_{gi}$ is some fraction, q_i, of $\vec{L}_i$. We have,

$$\vec{\tau} = \vec{r} \times \vec{F} = \vec{r} \times m\vec{g}$$

An analytic form of the torque due to the force of gravity on the i^{th} segment of the arm:

$$\vec{\tau}_i = \vec{r}_i \times \vec{F}_i = (r_{iy}F_{iz} - r_{iz}F_{iy},\ r_{iz}F_{ix} - r_{ix}F_{iz},\ r_{ix}F_{iy} - r_{iy}F_{ix}) = F_{iz}(r_{iy},\ -r_{ix},\ 0)$$

where only the z term of $\vec{F}$ remains, because the force here is the force of gravity, which only acts in the negative z direction. For the 1^{st} segment, the torque looks like

$$\vec{\tau}_1 = m_1 g\,(-q_i L_1 \sin\varphi_1 \sin\theta_1 - v,\ q_i L_1 \sin\varphi_1 \cos\theta_1,\ 0),$$

where m_1 is the mass of the first arm segment, and each new segment acquires a few additional terms.

The total torque on the rover about the axle due to the arm can then be calculated by adding all of the torque vectors:

$$\vec{\tau}_{total} = \sum_i \vec{\tau}_i .$$

The torque due to the three main arm segments at a given moment, with respect to their angular positions φ_i and θ_i in their respective coordinate systems, and the fractions q_i of lengths L_i between their joints and centers is:

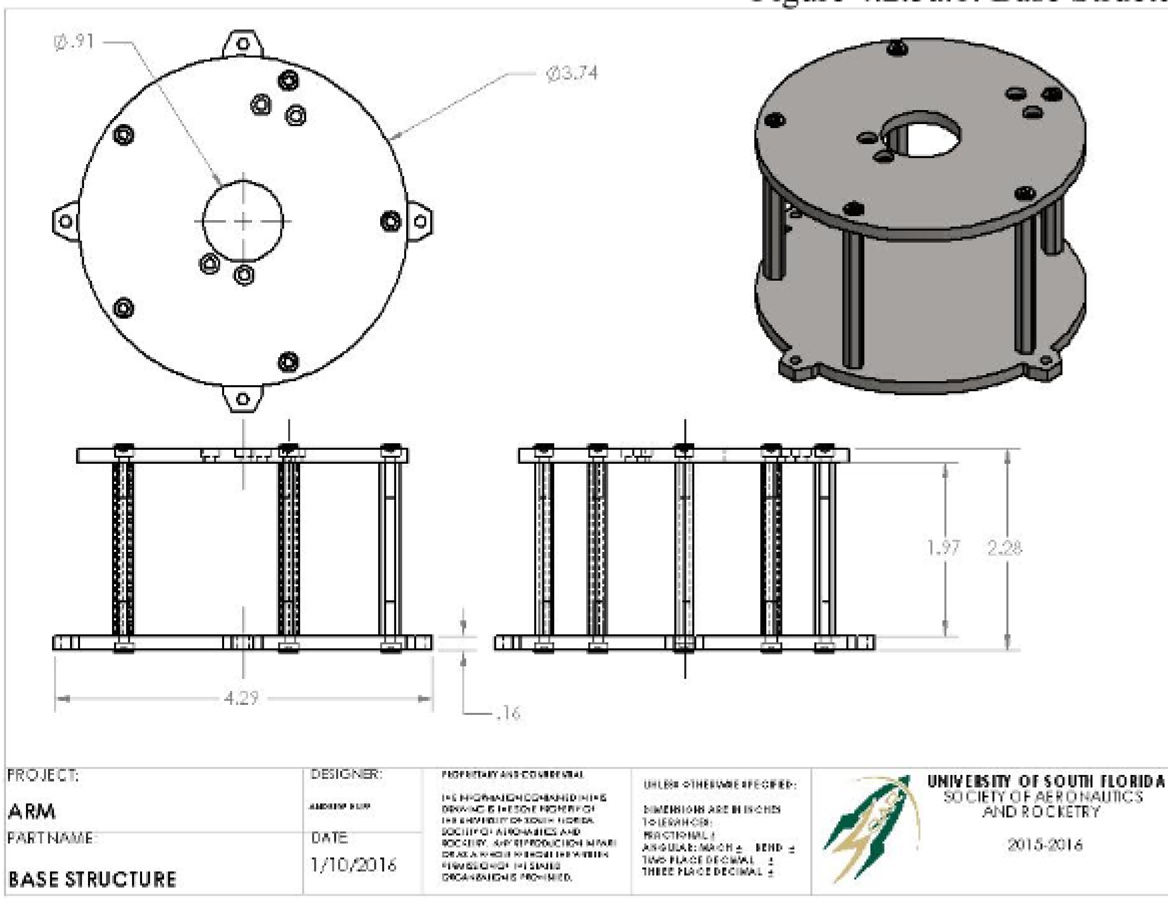
$$\vec{\tau}_{total} = -g\,[\,(\; L_1(q_1 m_1 + m_2 + m_3)\sin\varphi_1 \sin\theta_1 \;+\; v(m_1 + m_2 + m_3) \;+ L_2(q_2 m_2 + m_3)\sin\varphi_2 \;+\; L_3 q_3 m_3 \sin\varphi_3, \\ -L_1 \sin\varphi_1 \cos\theta_1 (q_1 m_1 + m_2 + m_3),\; 0\;)]$$

4.2.5 Arm Modeling and Schematics

4.2.5a Base Structure

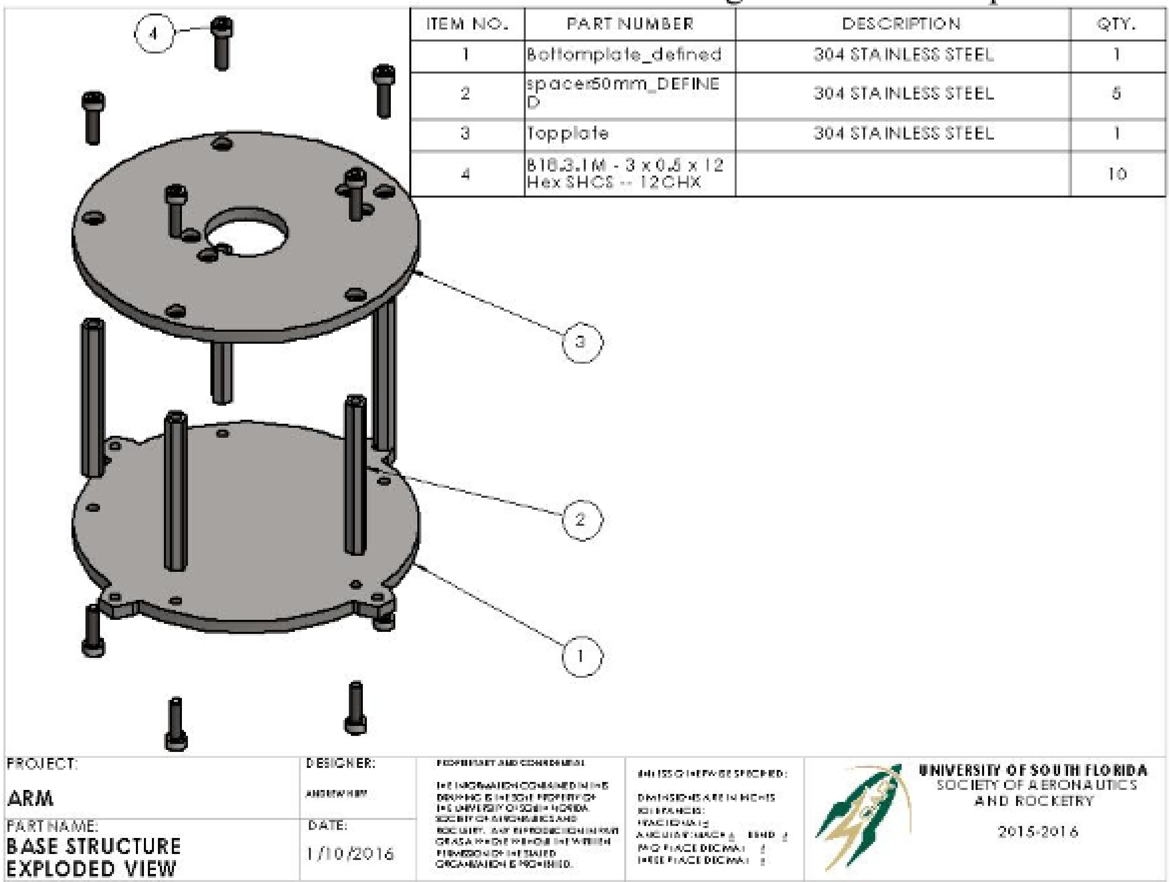
In Figure 4.2.5a.1 below, the Base Structure is shown to have a diameter of 3.74 inches with a inner hole of diameter 0.91 inches. Standing up, it has a total height of 2.28 inches. The bottom plate of this assembly has four small spaces for possibly mounting to a rover or other structure.

Figure 4.2.5a.1: Base Structure



In Figure 4.2.5a.2 below, the Base Structure and all of its components are displayed.

Figure 4.2.5a.2: Exploded View



4.2.5b Shoulder to Elbow

Figure 4.2.5b.1 below displays the Shoulder to Elbow assembly. It is constructed of a mounting plate of diameter 3.54 inches and two plates that are 7.28 inches from end to end. The plates are separated a distance of 1.85 inches and have a total width of 2.17 inches.

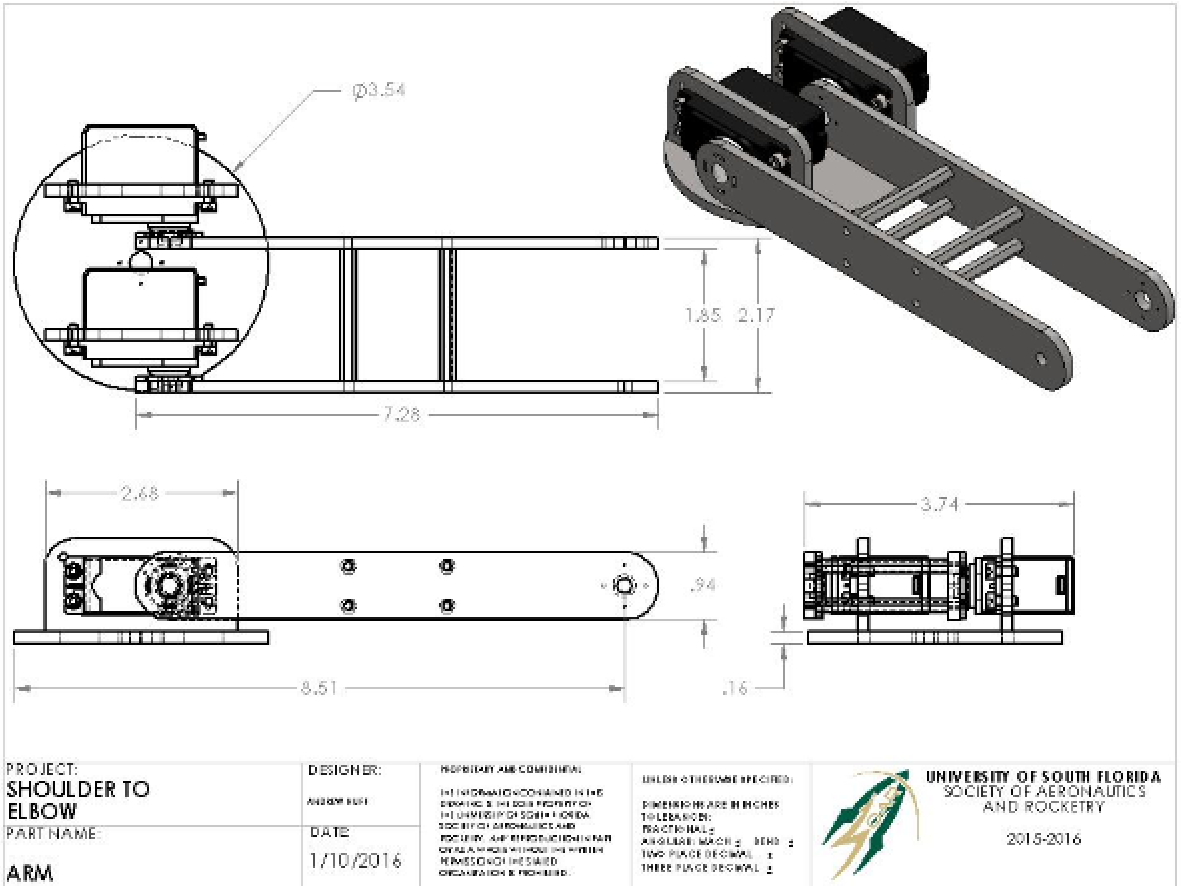
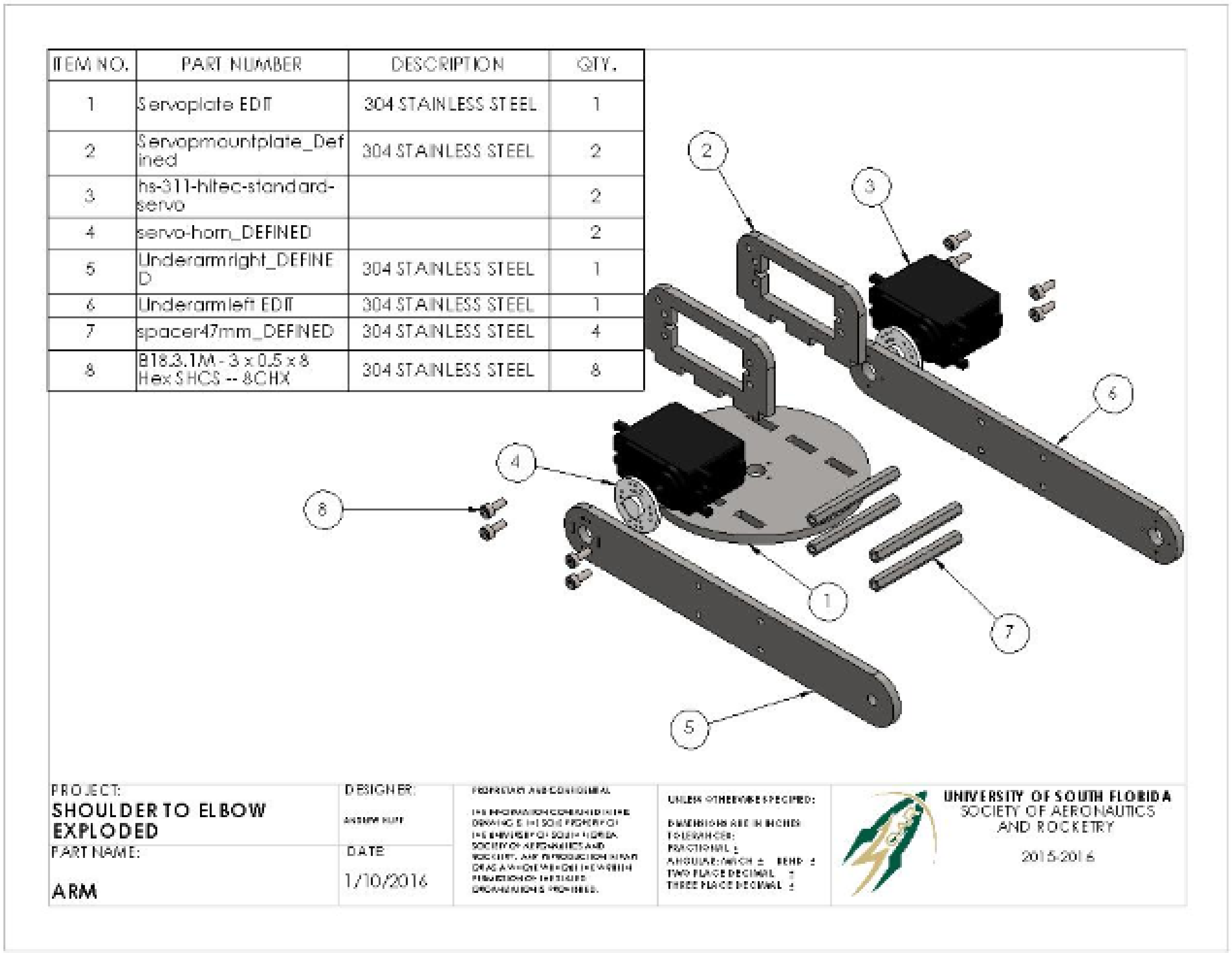


Figure 4.2.5b.1: Shoulder to Elbow

In Figure 4.2.5b.2 below, the exploded view of the Shoulder to Elbow is displayed with all of its components.

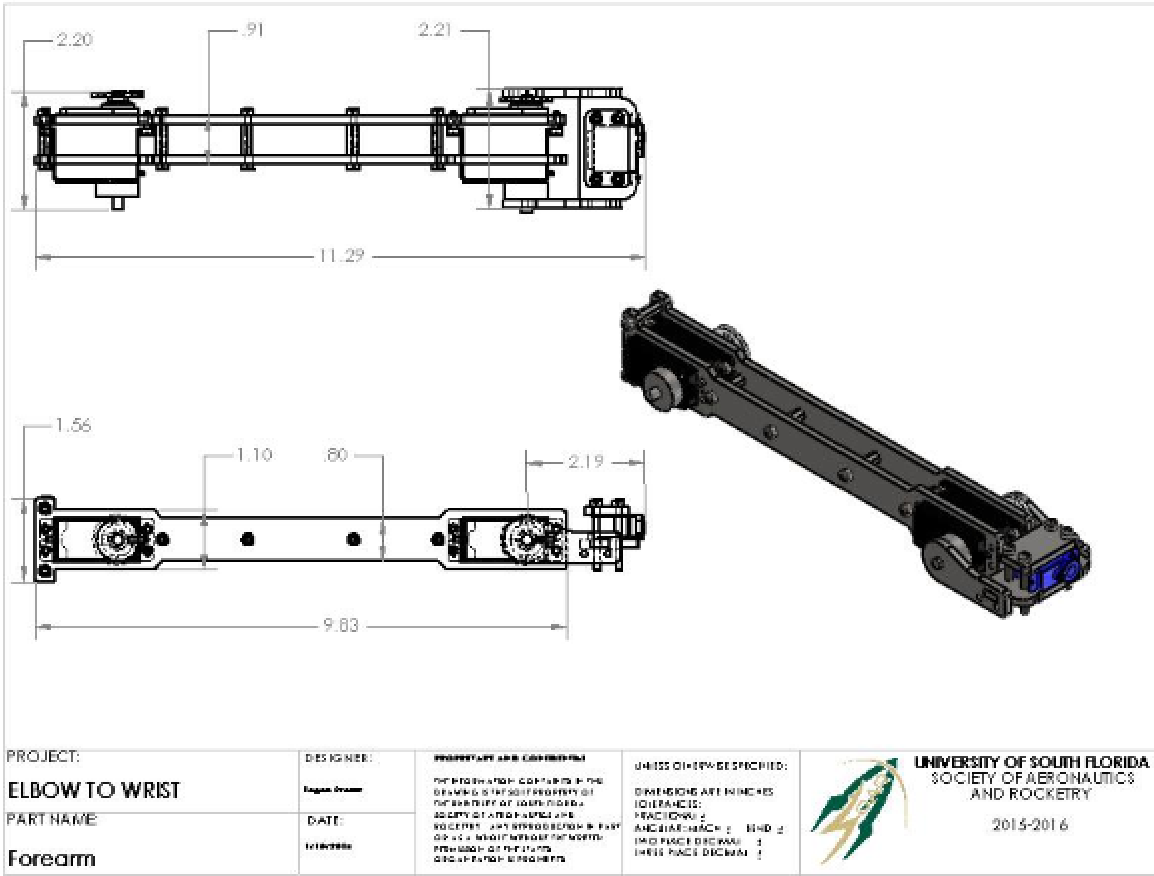


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Servoplate EDIT	304 STAINLESS STEEL	1
2	Servopmountplate_Defined	304 STAINLESS STEEL	2
3	hs-311-hitec-standard-servo		2
4	servo-horn_DEFINED		2
5	Underarmright_DEFINED	304 STAINLESS STEEL	1
6	Underarmleft EDIT	304 STAINLESS STEEL	1
7	spacer47mm_DEFINED	304 STAINLESS STEEL	4
8	B18.3.1M - 3 x 0.5 x 8 Hex SHCS -- 8CHX	304 STAINLESS STEEL	8

4.2.5c Elbow to Wrist

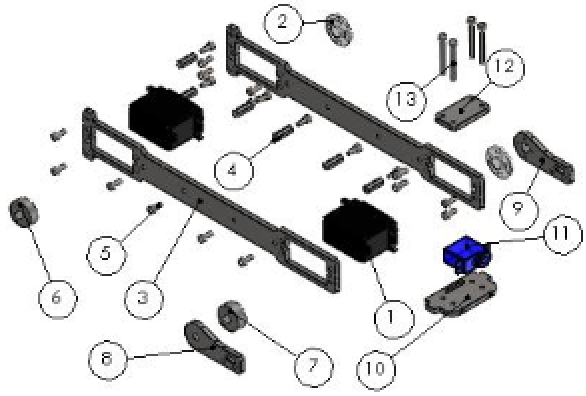
Below in Figure 4.2.5c.1 is a Schematic from the elbow to the wrist (including the wrist) of the robotic arm. From the elbow to the end of the wrist is 11.29 inches. Without the wrist attachment the length of this segment is 11.29 inches. The wrist itself has a reach of 2.19 inches and a width of 2.21 inches.

Figure 4.2.5c.1: Elbow to Wrist



Below in Figure 4.2.5c.2 you'll see an exploded view of Figure 4.2.5c.1 and every part involved in its creation.

Figure 4.2.5c.2: Exploded View



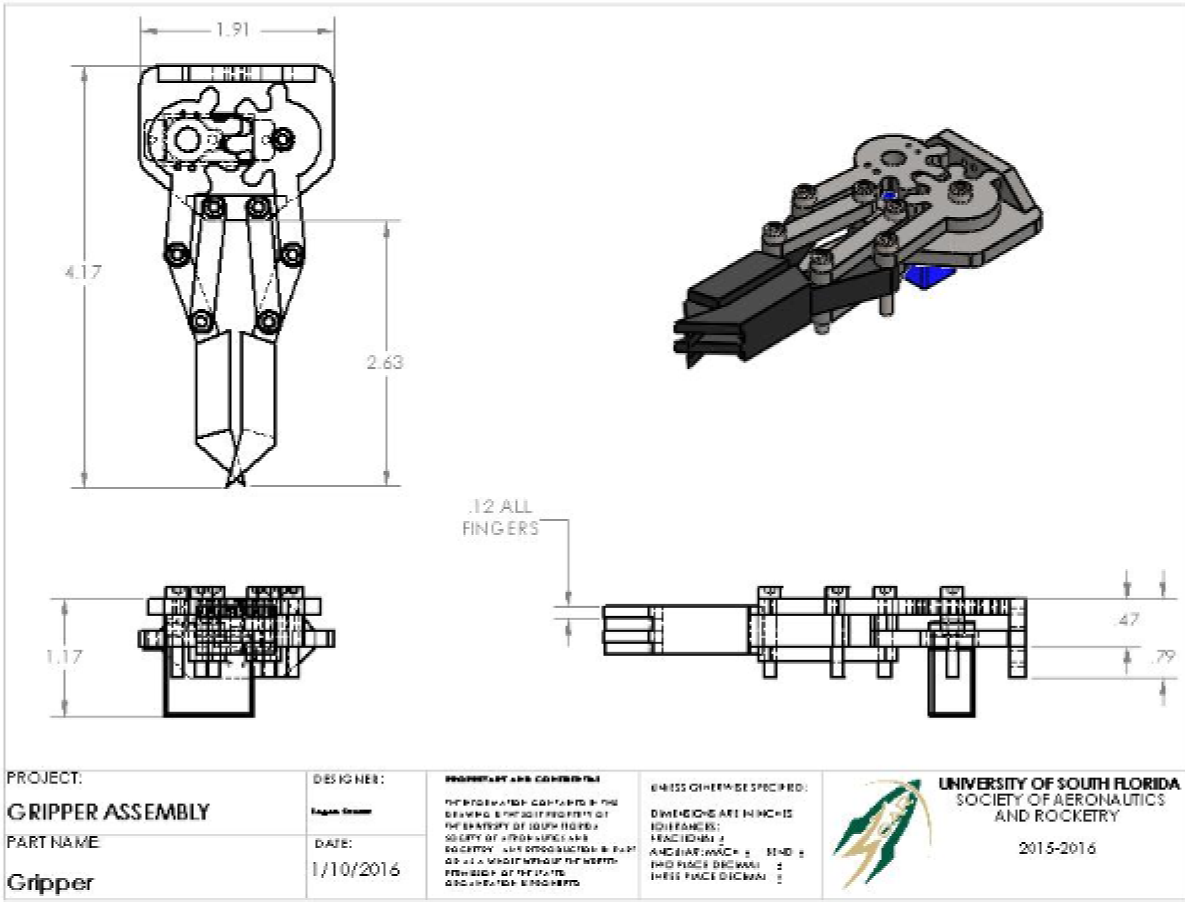
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	hs-311-hitec-standard-servo		2
2	servo-horn_DEFINED		2
3	Upperarm EDIT	304 STAINLESS STEEL	2
4	spacer15mm_DEFINED	304 STAINLESS STEEL	6
5	B18.3.1M - 3 x 0.5 x 8 Hex SHCS -- 8CHX		20
6	bearingelbow EDIT	304 STAINLESS STEEL	1
7	bearingwrist EDIT	304 STAINLESS STEEL	1
8	Wristrightside EDIT	304 STAINLESS STEEL	1
9	Wristleftside EDIT	304 STAINLESS STEEL	1
10	Wristservoplate EDIT	304 STAINLESS STEEL	1
11	Servo		1
12	Wristclampplate EDIT	304 STAINLESS STEEL	1
13	B18.3.1M - 3 x 0.5 x 30 Hex SHCS -- 30CHX		4

PROJECT: ELBOW TO WRIST EXP VIEW
DESIGNER:
PART NAME: Forearm
DATE: 1/10/2016
UNIVERSITY OF SOUTH FLORIDA SOCIETY OF AERONAUTICS AND ROCKETRY 2015-2016

4.2.5d Gripper Assembly

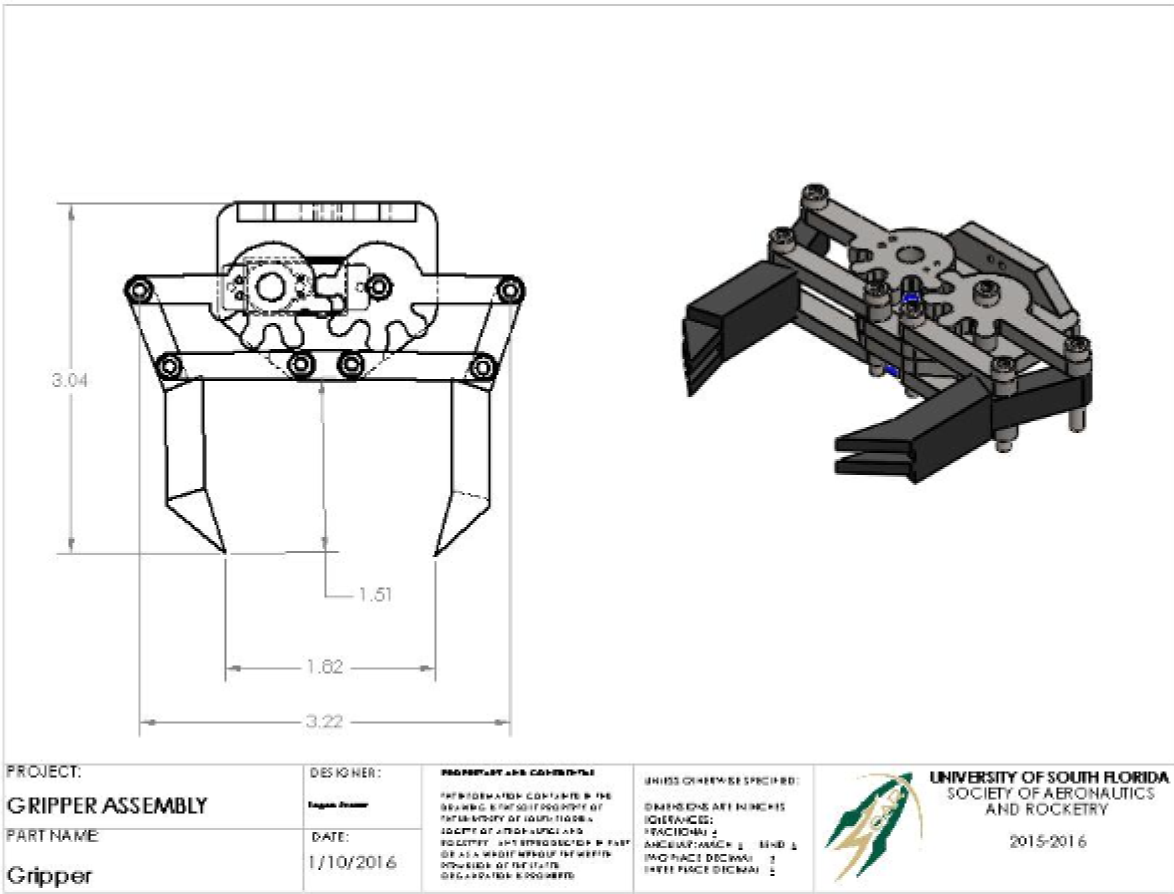
Below in Figure 4.2.5d.1 the gripper assembly is shown fully closed. When fully closed the gripper can reach approximately 4.17 inches from the wrist joint and the fingers themselves have 2.63 inches of reach themselves. The gripper assembly is only a mere 1.17 inches in height including the micro servo.

Figure 4.2.5d.1: Fully Closed



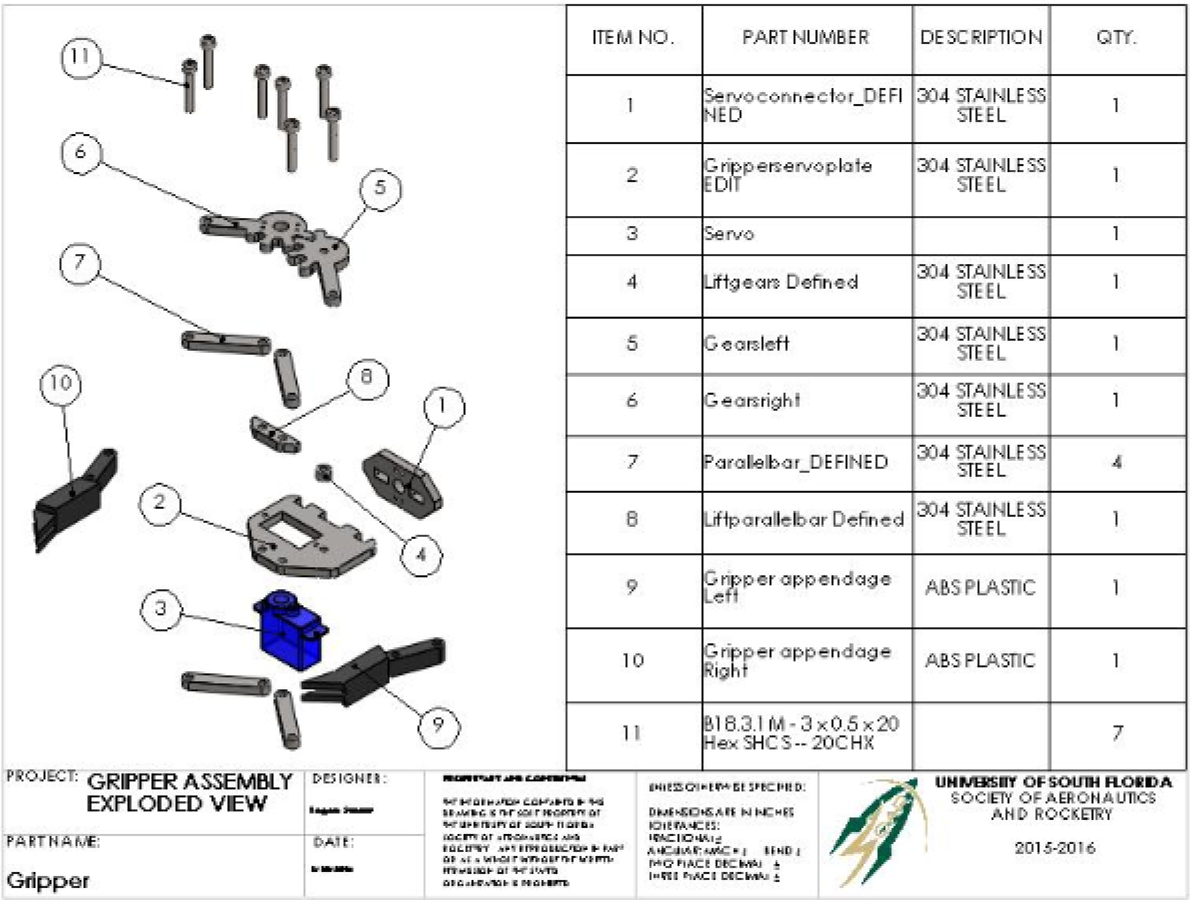
In Figure 4.2.5d.2 we can see the gripper fully open. When fully open the gipper has approximately 1.62 inches of clearance between the left and right grippers. In this position the gripper becomes 3.04 inches long and is now 3.22 inches in width. This is the widest our gripper assembly will ever become.

Figure 4.2.5d.2: Fully Open



In the following figure, figure 4.2.5d.3, you will be able to see the explodes view of the gripper assembly and every part that is involved with its creation.

Figure 4.2.5d.3: Exploded View

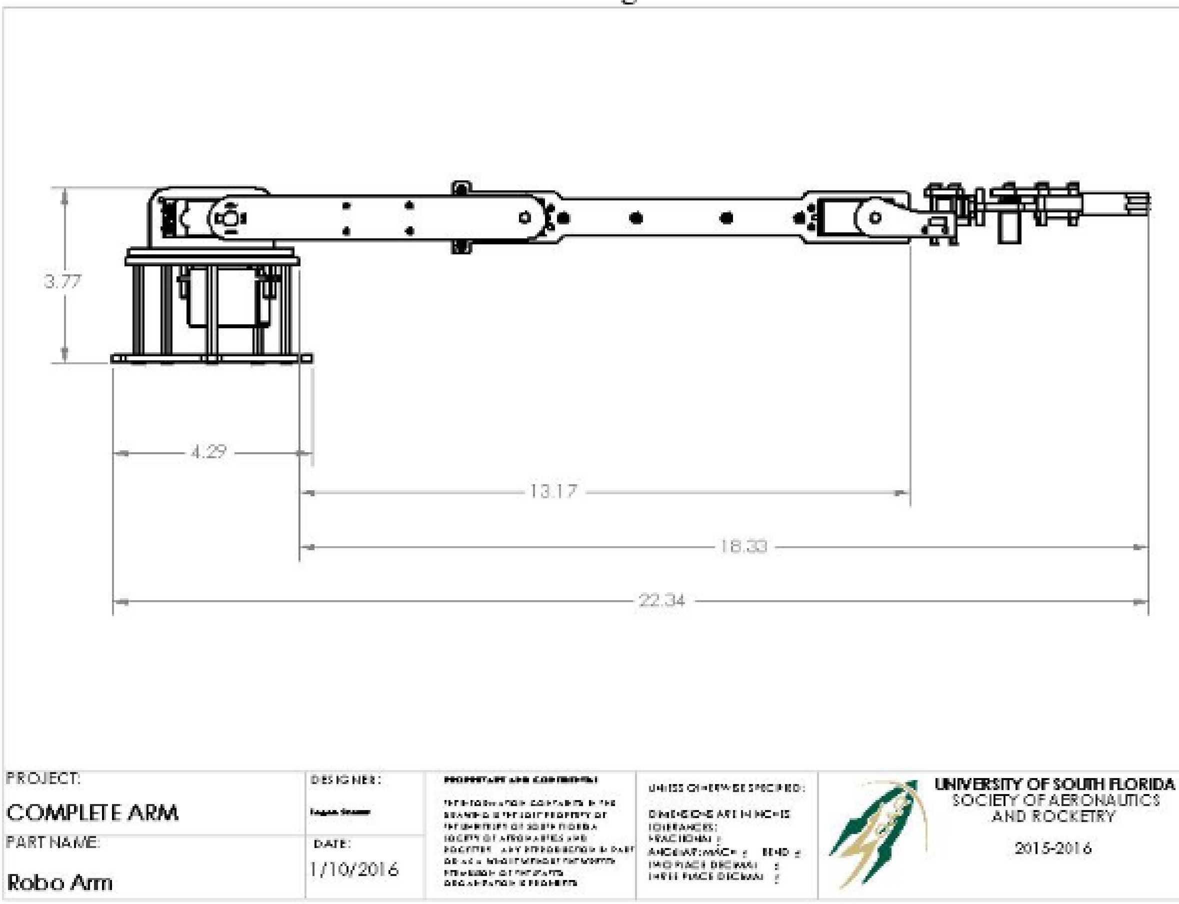


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Servoconnector_DEFINED	304 STAINLESS STEEL	1
2	Gripperservoplate EDIT	304 STAINLESS STEEL	1
3	Servo		1
4	Liftgears Defined	304 STAINLESS STEEL	1
5	Gearsleft	304 STAINLESS STEEL	1
6	Gearsright	304 STAINLESS STEEL	1
7	Parallelbar_DEFINED	304 STAINLESS STEEL	4
8	Liftparallelbar Defined	304 STAINLESS STEEL	1
9	Gripper appendage Left	ABS PLASTIC	1
10	Gripper appendage Right	ABS PLASTIC	1
11	B18.3.1M - 3 x 0.5 x 20 Hex SHCS -- 20CHX		7

4.2.5e Completed Robotic Arm

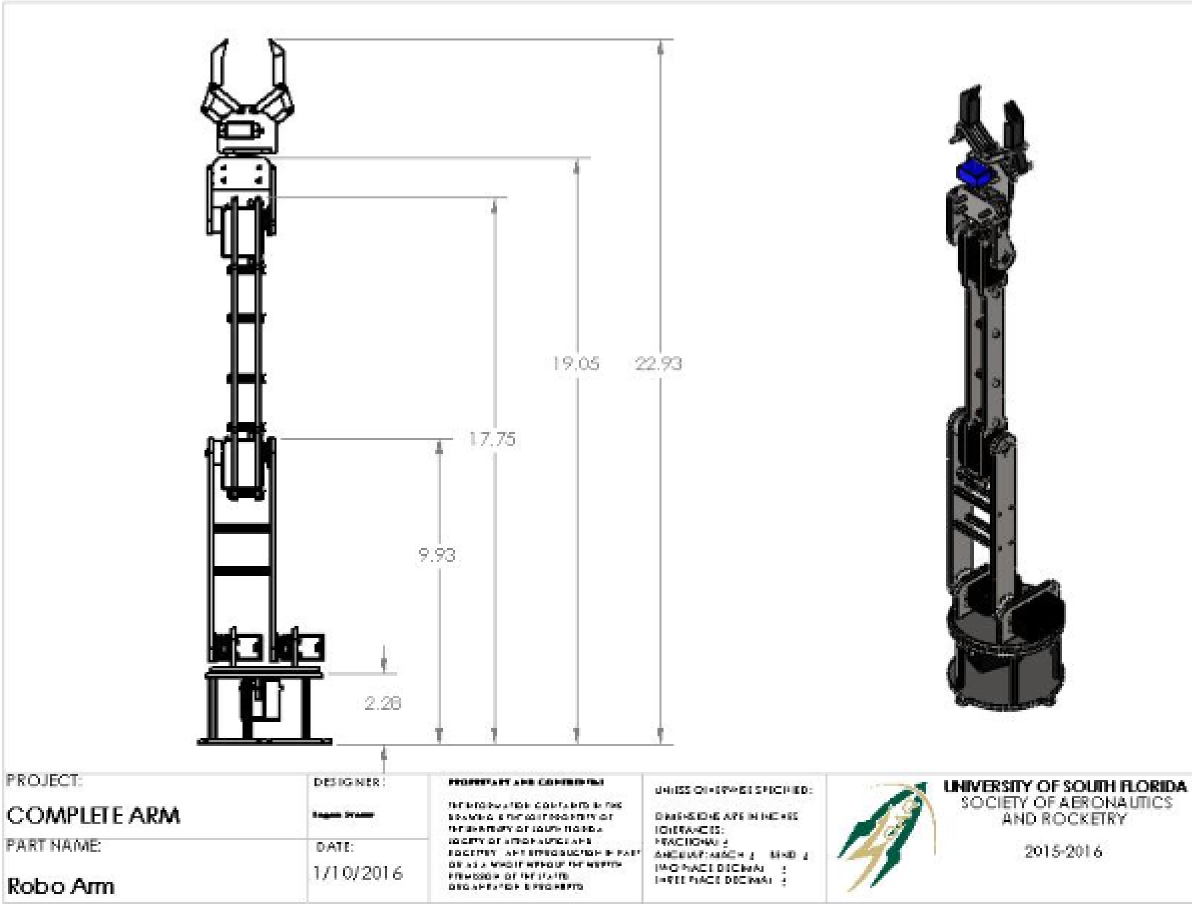
Figure 4.2.5e.1 shows the extended robotic arm. Here we can clearly see that from base to wrist the robotic arm had approximately 13.17 inches of reach. From the base to the very tips of the gripper there is 18.33 inches of reach. The total length of the robotic arm is 22.34 inches. When the arm is extended linearly from the base at 90 degrees the height of the arm assembly is 3.77 inches.

Figure 4.2.5e.1: Extended Robo Arm at 90°



The Robotic arm while extended straight up in the air reaches an approximate height of 22.93 inches from the very bottom of the base structure. The distance from the bottom of the structure to the wrist of the robotic arm is 17.75 inches. This is the distance the robotic arm can comfortably reach objects above. See Figure 4.2.5e.2 below for more information on height.

Figure 4.2.5e.2: Extended Robo Arm at 180°



4.2.7 Challenges and Verification Plan

4.2.7a Challenges

Design Impediment	Solution
Discern when the payload has been captured by the Robotic Arm.	The Raspberry Pi will be able to read the degree orientation of the robotic gripper. If the servo controlling the gripper reads a degree measurement less than the pre-set limit, than the system knows that the payload has not been obtained.
Lift the payload off of the ground a certain distance X.	A robotic arm with 5 degrees of freedom and gripper assembly with approximately 14 inches of reach.
Rotate the robotic arm to prepare for payload insertion.	Robust servo to rotate the robot arm assembly from capture to containment
Place payload into the containment bay.	Hardcode motions for the robotic arm to succefully place the payload into the payload bay from a specified position.

4.2.7b Verification Plan

Requirement	Method of Completion	Method of Verification
Arm and gripper assembly must capture and hold payload.	AGSE team will design and fabricate a mechanical arm that will pick up the payload from the ground to then be placed in the rocket.	Each subsystem of the mechanical arm will be tested individually.
If at anytime during the autonomous process the pause button is pressed the	The Raspberry Pi on board will continuously be running in a conditional statement	The pause button will be tested thoroughly throughout every process

system must stop immediately.	looking for any signal triggered by the pause button.	during the capture and containment process to ensure complete halt of all actions.
We will be allotted 10 minutes to capture the payload, contain the payload, lift the rocket, and launch the rocket.	The servos on the robotic arm and gear ratio on the launch rail were chosen for their robustness and speed.	Test and time the entire process to make sure the allotted time limit is not only met but that we fall well below the 10 minute time limit.
The entire AGSE system will be completely autonomous.	The robotic arm and all other subsystems will be controlled by a Raspberry Pi.	Test the Raspberry Pi with all the subsystems to make sure each can perform its task with no human interaction.

4.2.8 Payload Containment

The payload containment system consists of three unique features that help it achieve it's purpose; an L16 linear actuator, a custom 3-D printed payload sled, and a sealing coupler setup. The linear actuator is radio controller, allowing the AGSE to communicate with it within the rocket, sending it commands to open or close the payload sled. The payload sled will be 3-D printed out of ABS plastic, it is being shaped for both the constraints of the coupler tubing as well as for the shape of the MAV payload itself. Ultimately the payload containment design is made to nest two sections of fiberglass together, with o-ring closure to seal and reveal the payload inside. See section 3 for structure description of the containment system.

4.2.9 Payload Modeling

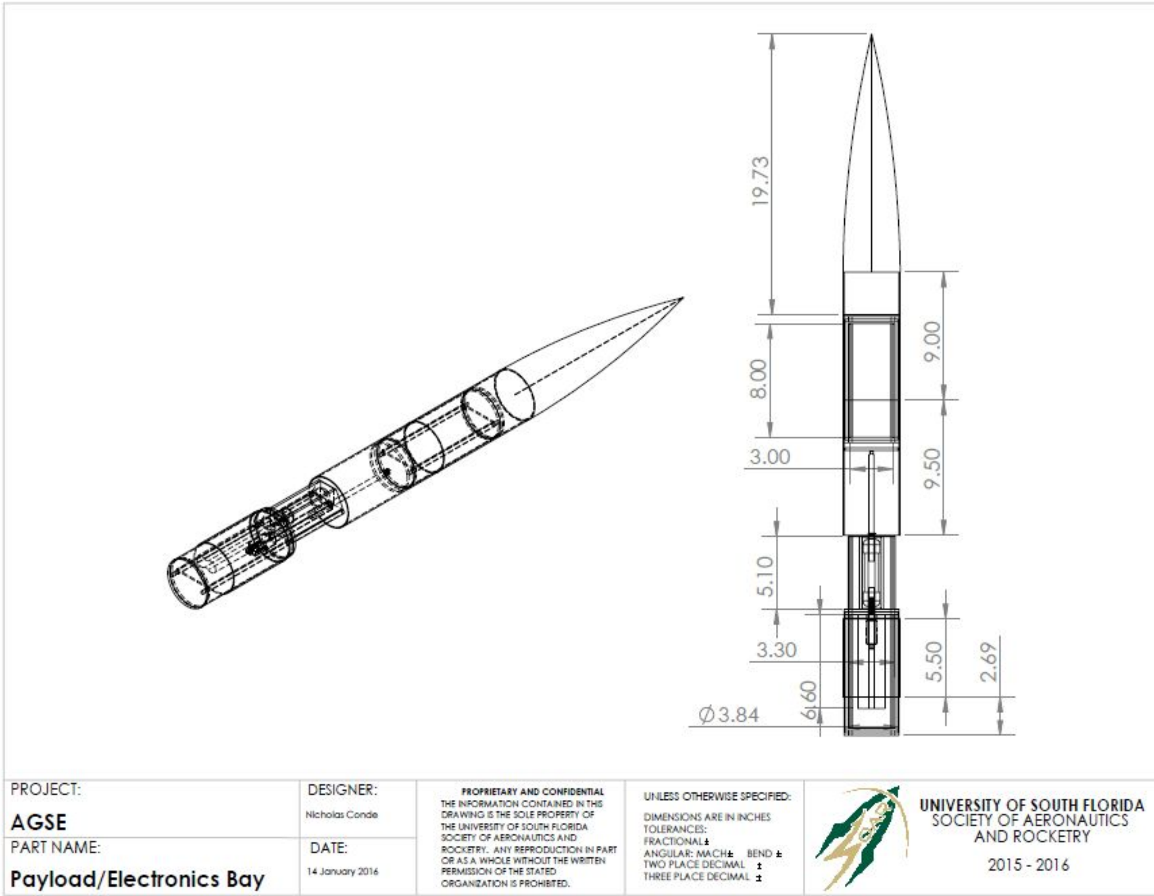


Figure 4.2.9.1 Dimensional Drawing of the Payload System

4.3 Launch Platform

4.3.1 Vehicle Erection System Overview

The vehicle erection system must raise the rocket from a horizontal position to 85 degrees from horizontal. This will be accomplished by coupling the launch rail to a shaft which is driven by an electric linear actuator. The drive system is mounted on a rectangular base. The figure below shows the design of our vehicle erection system.

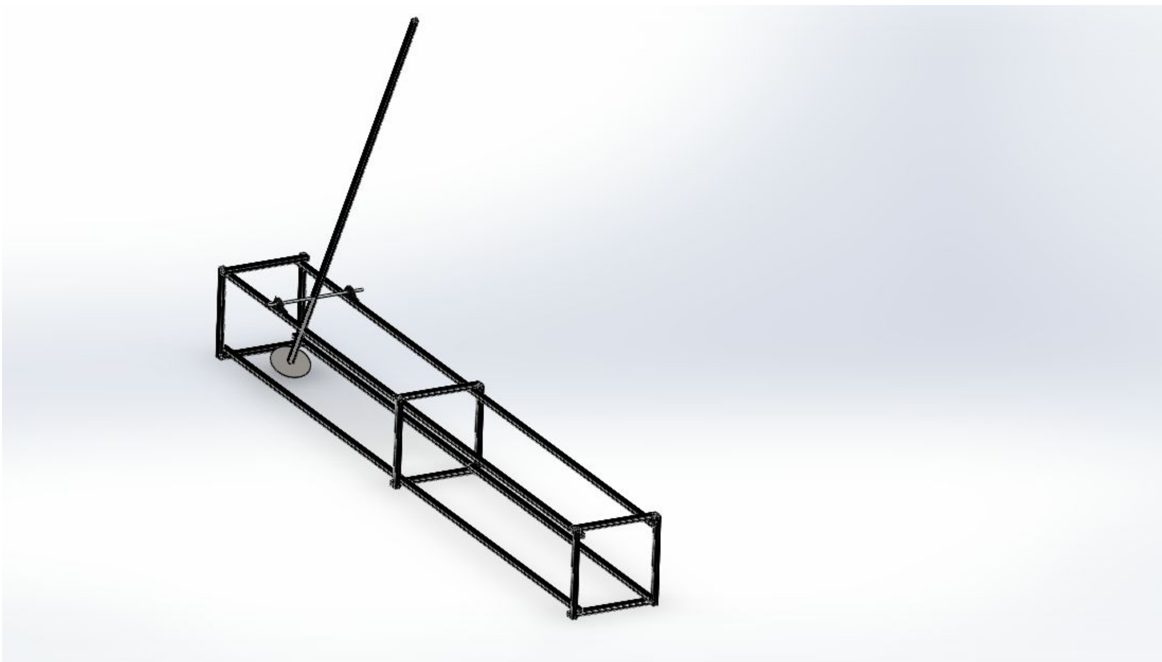


Figure 4.3.1. 1: Launch vehicle erection system

4.3.2 Design of Vehicle Erection System Components

4.3.2.a Linear Actuator Selection

The mass properties of the rocket and launch rail were used to compute the maximum torque required to lift the rocket from the horizontal position using the formula below.

$$T_{max} = X_{gv} * W_v + X_{gr} * W_r$$

The variable are defined and their values are given in the table below.

Table 4.3.2.a. 1: Explanation of variables in above equation.

Variable	Value
X_{gv}, Launch vehicle C_g measured from axis of rotation	138 in
X_{gr}, Launch rail C_g measured from axis of rotation	60.0 in
W_v, Weight of the launch vehicle	22.82 lb
W_r, Weight of the launch rail	10.5 lb

$$W_{wt} = W_{gt} * \frac{cos(\phi)*sin(\lambda) + \mu*cos(\lambda)}{\mu*sin(\lambda) - cos(\phi)*cos(\lambda)}$$

Where W_{wt} is the worm tangential force. The results are W_{gt} = 417 lb and W_{wt} = -99.2 l lb. The input torque can be calculated from:

$$T_{in} = d * W_{wt}/2$$

The resulting Tin is 62.02 in-lb of torque.

Input Voltage	12V DC
Stroke (Movement)	30"
Force	350lbs (1500N)
Speed (mm/sec)	5mm/sec
IP Rating (Protection Class) - IP54	*Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment *Water splashing against the enclosure from any direction shall have no harmful effect
Operational Temperature	-4°F ~ +149°F
Noise	<45db
Limit Switch	Built in, Non-Adjustable
Current	6.5 Amps
Mounting Hole	6mm
Fully Retracted	34 1/4"
Full Extended	64 1/4"
Cycle	25%
Warranty	12 Months

Figure 4.3.2a.1: Linear Actuator Specifications

4.3.2.b Launch Rail

The launch rail chosen must be able to support the launch vehicle during erection and hypothetically guide it during takeoff. Therefore the stiffness and mass of the launch rail is a concern. The launch rail must also accommodate the launch lugs in order to guide the rocket during takeoff. A logical choice for the launch rail is T-slotted extruded aluminum. Adequate stiffness is ensured by selecting a large enough cross-section.

4.3.2.c Platform and Mounting of Drive System

The platform will be constructed of T-slotted extruded aluminum and plywood. A metal frame will be constructed to fix the bearings in place. The actuator will be mounted to the bottom railing of the platform frame.

4.3.3 Ignition Station

The igniter will be fed into the rocket motor via two opposing rollers. The rollers will be driven by a small electric motor and the igniter wires will be driven by friction into the rocket motor. Experimentation will be done to find the most reliable place to mount this mechanism. An elastomer covering will ensure a large coefficient of friction between the rollers and igniter.

4.7 Electronics Systems

4.7.1 Overview

The electronic systems for the AGSE will be centered around two separate processing units: Raspberry Pi system housed on the rover, and an external processing platform that will perform a majority of the image processing computations to reduce the computational requirements of the Raspberry Pi. The Raspberry Pi will be interfaced with a Kinect sensor, an Xbee transmitter and receiver, all servo motors for the robotic arm, and the motors that correspond to each wheel of the rover. Upon initialization of the system, the central PC will retrieve the necessary information from the Kinect sensor to generate a 3D point cloud of the scene and recognize the payload. With the 3D point cloud data and payload location within the point cloud as a goal, the navigation system within ROS will guide the rover to the payload. Once the rover has reached the payload, the PC will retrieve the necessary information from the Kinect to determine the location of the payload in world units via stereo parameters. Given a distance in world units from the rover, the robotic arm will reach the specified distance in front of the rover and retrieve the payload. Upon recognition that the payload has been secured within the claw of the robotic arm, ROS will update the new goal of the rover to be the rocket. Once the rover has reached the rocket, the arm will place the payload inside the rocket.

4.7.2 Components

4.7.2.a Raspberry Pi and Accompanying Software

The Raspberry Pi will be interfaced with the following hardware:

Kinect Sensor via USB
Servo Motors for the Robotic Arm controlled via PWM
Motors for the rover wheels controlled via GPIO

The Kinect sensor will serve the primary role in acquiring the necessary images for generating the 3D point cloud to be used for the rover navigation in ROS. The Kinect will also be responsible for acquiring the necessary images for stereo vision so that the location of the payload can be described in world units. The Kinect will be connected to the Raspberry Pi via USB, and all necessary images for object recognition, 3D point cloud generation, and depth estimation will be streamed wirelessly to the PC for processing. The Kinect will also be used locally on the Raspberry Pi to interface with ROS and perform the rover navigation.

Servo Motors were chosen for the robotic arm due to the motors ability to rotate to a certain angle. The chosen Servo Motors respond to a PWM signal generated on the Raspberry Pi. Due to the limited availability of PWM pins on the Raspberry Pi, a PWM controller from Adafruit was selected that uses the I2C pins on the Raspberry pi to generate several PWM outputs. Two functions will be designed, one function that will generate the appropriate PWM commands to move the claw robotic arm to the ground a certain distance from the rover defined by the input, and one function that will raise the arm to place the payload into the rocket.

Finally, the motors for controlling the rover wheels will be interfaced to the Raspberry Pi via a controller that uses the SPI pins of the Raspberry Pi to control multiple GPIO pins. The appropriate GPIO outputs will be generated through the navigation system in ROS which will be discussed in more detail in later sections.

4.7.2.b Master PC and Computer Vision

The main purpose of the external PC is to handle the computations of the image processing functions. Image processing functions will be performed via MATLAB and the image processing and image acquisition toolbox. The image acquisition toolbox includes a function for importing a 3D point cloud from the Kinect sensor. Additionally, MATLAB includes several functions and methods for object recognition and stereo vision and calibration.

4.7.2.c Subsystem Communication

The wireless communication module in this design uses the Xbee Radio frequency transmitter and receiver. This 2.4 GHz device operates on what is colloquially referred to as the ISM band, for its extensive use by Industrial, Scientific, and Medical communities. As such, the device is in accordance with IEEE 802.15.4 specifications. The theoretical range of the Xbee series one module in use is one mile, far exceeding the demands for the NASA Student Launch Initiative.

The Robot Operating System employs the universal asynchronous receiver/transmitter (UART) devices to establish a network of point-to-point communication between the offboard processing and the embedded robotic frame. The offboard processor initializes a "Master Node" through Matlab and as Master stores all network messages published by the nodes. Messages are the prototypical communication method for the ROS network, publishers subscribe to topics in which they stream information, while subscribers "listen" to the information published on those topics.

For inter-subsystem communication between electrical components we will use two separate and familiar methods. Those being the Serial Peripheral Interface (SPI) bus and the

Inter-Integrated Circuit (I2C) bus. These communication protocols both use the hierarchical master-slave relationship between the communicating systems, with the Raspberry Pi being the master to the MCP23S17 GPIO extender for seamless functional control of the motor controller and of the PCA9685 servo driving board for the robotic arm's servos. Utilizing these components will take processing and hardware strain off of the Raspberry Pi, expanding the capability that this embedded system has for control.

4.7.2.d Rover Controls and Navigation

The rover will be controlled via an automatic navigation system included in ROS.

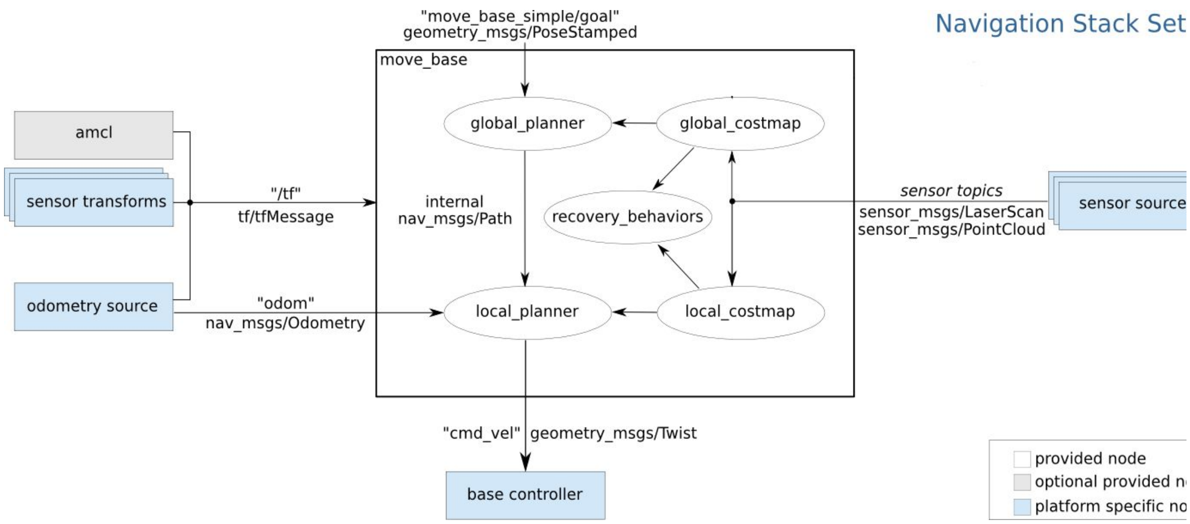


Figure 4.7.2.d.1 - ROS Navigation Overview

This flow chart is a modified form of one found at wiki.ros.org and shows the flow of the rover navigation software architecture. As can be seen on the right hand side, sensor topics, the ROS navigation requires a 3D point cloud, or laser scan, of the desired area, the local and global maps therefore subscribe to the topics in which the sensor streams are publishing to generate a global and local mapping and overlay these maps with a cost map around obstacles. A destination, which in this case is the payload, is set by color and shape object recognition through MATLAB and published to a topic subscribed to by the global planner. The local planner will jointly use information from the cost mappings, the global planner, and with the optical incremental encoders, a form of odometry sensors, on the motor to implement a trajectory planner to plot a course to the destination. The ROS navigation uses the laser scanner within the Kinect as well as odometry sensors on the rover wheels to localize the robot in the map and to keep track of the rover's progress to the destination. We will also attempt to implement the amcl probabilistic localization system, which uses only the visual data to track the pose of the robot in the generated map. Finally, the base controller will publish a command velocity geometry message. This will take the form of a linear and angular velocity vectors to be interpreted by the differential drive controllers. In turn, the differential drive controllers will send a PWM signal to the motor controllers to directly control the speed of the wheels on each side of the rover. Finally, the recovery behaviors serve to shut down the robotic platform in the event of sensor or motor failure, or in the event of encountering an obstacle. This will protect the safety of the AGSE system as well as the safety of operators and spectators.

4.7.3 Challenges and Verification Plan

In order to verify the correct operation of the AGSE as a whole, preliminary tests on individual components and subsystems will be performed as follows. First a test will be conducted with the Kinect camera and accompanying object recognition and 3D point cloud software operating in isolation i.e. the mechanical arm and accompanying software for controlling the arm, as well as the communication system will not be connected. For this test the image processing software will be configured for recognition of the payload given video input from the Kinect, and the generation of a 3D point cloud of the surrounding area, as well as the determination of the payload location within the generated 3D point cloud. The purpose of this test is to verify that the image processing software is working correctly with the Kinect camera and that the payload can be correctly recognized and located within the generated 3D point cloud. Additionally, this test will determine the limitations of the payload recognition and location such as the maximum distance where the payload can be accurately recognized and located. Next the arm will be tested in isolation. The mechanical arm will be connected to the Raspberry Pi and a program will be run that controls the operation of the arm. During this test the mechanical arm's ability to respond to location information and directions from the Raspberry Pi software will be evaluated. Additionally, during this test the mechanical arms physical ability to successfully retrieve and secure the payload will be evaluated. For example, is the mechanical arm physically able to grab the payload? What is the maximum range for which the arm can still accurately retrieve and secure the payload? After testing the the abilities of the image processing software and the mechanical arm individually, the abilities of the image processing software working in collaboration with the mechanical arm will be evaluated. For this test the main concern is with the high level operation i.e. can the image processing software communicated accurate stereo parameter information to the mechanical arm and can the mechanical arm properly use the real world location of the payload to accurately secure the payload.

The communication capabilities of the Xbee systems will be evaluated in isolation. First the communication link itself will be verified by sending and receiving simple messages. Once the communication link is verified the integrity of the data to be sent will be evaluated. For example, 3D point cloud data will need to be sent from the main image processing platform to the Raspberry Pi. In order to test the capability of sending 3D point cloud data, a previously generated and examined 3D point cloud will be sent via the Xbee system and observed on the receiving end. Rover navigation will also be tested using a known 3D point cloud and goal. During this test the features, capabilities and limitations of the ROS navigation will be tested.

Once the performance of the operations involving the retrieval of the payload is understood, the transportation of the payload to the rocket, and the payload's security within the rocket will be evaluated. The first test in this section will evaluate the capability of the software to locate and realise the destination within the rocket. Next an evaluation of the physical interaction between the mechanical arm and the compartment within the rocket for securing the payload will take place. For example, are the mechanical arm and payload compartment within the rocket physically compatible in that the mechanical arm can successfully reach and interact with the payload compartment to the extent that the payload can be properly released and secured? Finally, the systems ability to recognize and communicate the payload being successfully transported and secured within the rocket will be evaluated along with the systems ability to successfully prepare the rocket for launch given that the payload has been properly secured.

4.7.4 Schematics

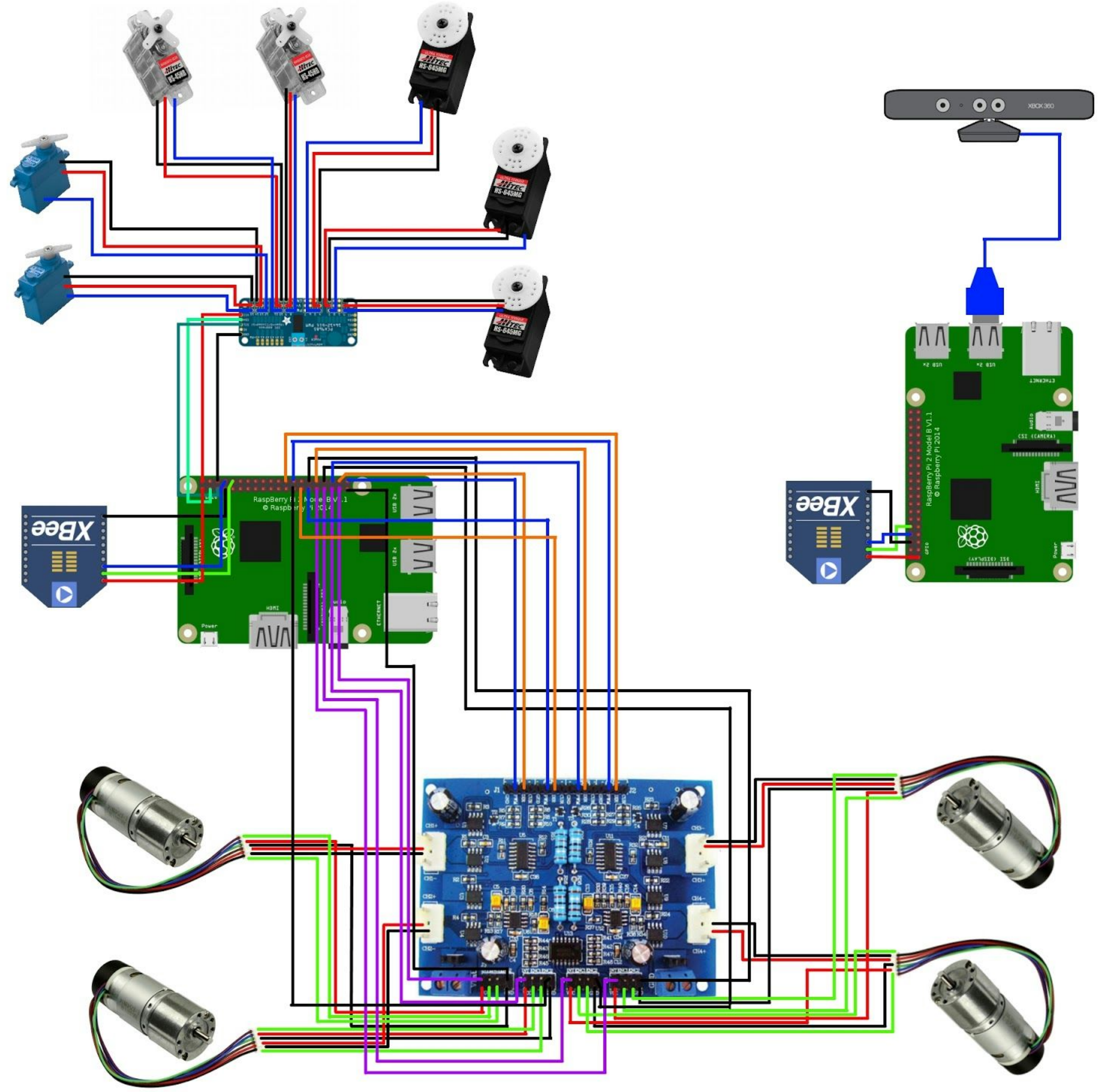


Diagram 4.7.4.1: Electrical Systems Overview

4.8 AGSE Safety

All potential failures and consequences of these failures of the AGSE have been analyzed and considered in detail. All failures modes are included in Appendix I: Risk Assessment on page 135. Listed below are the five most critical risks, including their analysis and detail.

1. **Unstable launch rail**
   Probability: 2, Likely
   Severity: 1, Catastrophic

   Outcome: An unstable launch rail causes the flight path of the launch vehicle to be unpredictable, potentially ruining a successful launch. The safety of the launch personnel and spectators could be jeopardized.

   Mitigation: It will be ensured that all personnel and individuals are at the minimum safe distance from the launch pad as established by the TRA and/or NAR. Prior to launch it will be ensured that the launch pad is stable and properly secured.

2. **Pause function fails to activate**
   Probability: 3, Moderate
   Severity: 2, Critical

   Outcome: The pause function of the AGSE system is to be used when risk of failure or harm is involved. If the pause function were to malfunction at a time of impending harm of the system itself or of a human being, this could be a potentially harmful safety risk.

   Mitigation: All personnel are required to stand a specified distance away from the AGSE while it is operating. Redundancies will be implemented to ensure pause function will perform properly. All codes, systems and functions will be tested as it is written in addition to being tested and checked for errors prior to the competition.

3. **Failure to insert igniter into motor cavity fully**
   Probability: 3, Moderate
   Severity: 2, Critical

   Outcome: Failure to insert the igniter inside of the motor all the way could cause the rocket motor to be lit in the wrong position. Thus potentially causing the fuel grain of the motor to burn in an irregular pattern and possibly having the rocket fire off in a direction that isn't up. This would cause serious damage to the rail system and possibly the entirety of the AGSE system. Not only is there a possibility for our equipment to be destroyed, but a personal safety risk as well. One that could seriously harm anyone within a 10-20ft radius around the AGSE system.

Mitigation: To avoid not placing the igniter where it shouldn't be we will be attaching the igniter on a metal rod that will be lifted straight up and into the motor cavity with a linear actuator.

4. **Carriage jams**
   Probability: 3, Moderate
   Severity: 2, Critical

   Outcome: If the carriage jams, the vehicle erector is incapable of raising the rocket, which may cause damage to rocket and rocket components, resulting in possible unsuccessful launch and risk of personnel safety.

   Mitigation: Tolerances of tracks have been noted during fabrication of the launch rail. Deflection of the rail has been analyzed and corrected to be within the specified tolerances. The geometry of the base was chosen for its ability to better distribute the load and reduce impact of uneven loading. Appropriate fasteners and preload on installed fasteners have been used in assembly process. Prior to launch and testing the tracks and carriage will be cleared of any debris and or buildup.

5. **Worm and gear system fails to lift rocket**
   Probability: 3, Moderate
   Severity: 2, Critical

   Outcome: Failure of the worm and gear entails the rocket not reaching 5 degrees from vertical. A possible launch from a lower angle can occur, resulting in an unexpected flight path.

   Mitigation: Tests and calculations will confirm that the worm and gear system will lift our rocket properly.

5) Project Plan

5.1 Budget Plan

Figure 5.1.1 Total Projected Budget

BUDGET	Amount
Structure	$766.64
Recovery	$697.28
Propulsion	$710.85
AGSE	$2,761.80
Subscale	$1,175.58
Travel	$4,200.00
TOTAL	**$10,312.15**

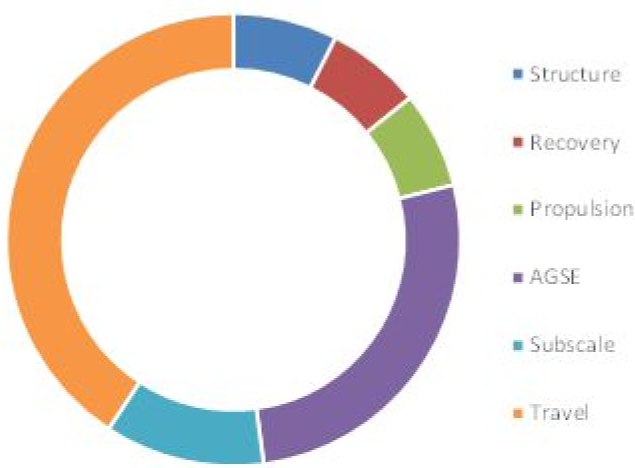


Figure 5.1.2 Structure Budget

STRUCTURE PROJECTED BUDGET			
ITEM NAME	PRICE	QUANTITY	SUBSYSTEM
Kevlar Tape 1" - 10 yard roll	$27.45	1	STRUCTURE
1/2 INCH G10 FIBERGLASS SHEET 2 SQUARE FOOT	$72.00	2	STRUCTURE
Retainer Assembly, 75 mm	$50.00	1	STRUCTURE
Centering Rings	$4.64	4	STRUCTURE
Fiberglass Wrapped Payload Section	$45.29	1	STRUCTURE
Couple/Bulkhead Assembly	$10.34	1	STRUCTURE
Phenolic Airframe Tubing	$22.49	1	STRUCTURE
Bulkplate 3.0"	$1.99	3	STRUCTURE
Phenolic Coupler Tube	$3.69	1	STRUCTURE
3.9" Plastic Nosecone	$21.95	1	STRUCTURE
3.9" Coupler/Bulkhead Assembly	$6.89	4	STRUCTURE
98mm G12 Fiberglass Tube 3 ft.	$92.30	1	STRUCTURE
98mm G12 Fiberglass Tube 4 ft.	$93.38	2	STRUCTURE
30 Minute Epoxy	$17.98	4	STRUCTURE
Hardware	$38.40	1	STRUCTURE

Figure 5.1.3 Propulsion Budget

PROPULSION PROJECTED BUDGET			
ITEM NAME	PRICE	QUANTITY	SUBSYSTEM
L910 Motor	$132.95	3	PROPULSION
75mm 1400Ns - complete motor	$312.00	1	PROPULSION

Figure 5.1.4 Recovery Budget

RECOVERY PROJECTED BUDGET			
ITEM NAME	PRICE	QUANTITY	SUBSYSTEM
Strap Nylon Shock Cords 2"	$2.49	26	RECOVERY
Tubular Nylon Shock Cords 1" x 7 yards	$2.49	26	RECOVERY
RRC3 Altimeters	$69.95	2	RECOVERY
Nomex Chute Protector 9x9 for 3" Tube	$6.95	2	RECOVERY
Cert 3 Drogue	$27.50	2	RECOVERY
Cert 3 Large Parachute	$145.00	1	RECOVERY
TeleGPS	$214.00	1	RECOVERY

Figure 5.1.5 Travel Budget

TRAVEL PROJECTED BUDGET			
ITEM NAME	PRICE	QUANTITY	SUBSYSTEM
Accomadations	$90.00	30	TRAVEL
Bus	$1,500.00	1	TRAVEL

Figure 5.1.6 Subscale Budget

SUBSCALE PROJECTED BUDGET			
ITEM NAME	PRICE	QUANTITY	SUBSYSTEM
75mm G12 Fiberglass Tube 5 ft.	$102.55	1	SUBSCALE
75mm G12 Fiberglass Tube 3 ft.	$61.53	1	SUBSCALE
75mm G12 Fiberglass Tube 4 ft.	$93.38	1	SUBSCALE
Plastic Nosecone	$21.23	1	SUBSCALE
Phenolic Coupler Tube	$3.69	3	SUBSCALE
2.0" Bulkhead	$1.90	4	SUBSCALE
K630BT Motor	$195.00	2	SUBSCALE
54mm 1400Ns - complete motor	$145.00	1	SUBSCALE
54 mm Retainer Assembly	$38.00	1	SUBSCALE
Baltic Birch 3 SQ FT	$8.17	1	SUBSCALE
Phenolic Airframe Tubing	$14.99	1	SUBSCALE
Strap Nylon Shock Cords 2"	$2.49	7	SUBSCALE
Tubular Nylon Shock Cords 1" x 7 yards	$2.49	7	SUBSCALE
RRC3 Altimeters	$69.95	2	SUBSCALE
Nomex Chute Protector 9x9 for 3" Tube	$6.95	2	SUBSCALE
Cert 3 Drogue	$27.50	2	SUBSCALE
Hardware	$38.40	1	SUBSCALE

Figure 5.1.7 AGSE Budget

AGSE PROJECTED BUDGET			
ITEM NAME	**PRICE**	**QUANTITY**	**SUBSYSTEM**
Tetrix Max	$595.00	1	AGSE
Tetrix Prime	$329.00	1	AGSE
Tetrix Gripper	$9.95	1	AGSE
Servos	$22.95	5	AGSE
Lynx Motion Arm	$300.00	1	AGSE
Microcontrollers	$15.00	3	AGSE
worm shaft	$21.10	1	AGSE
gear shaft	$18.27	1	AGSE
worm shaft key	$15.00	1	AGSE
gear shaft key	$15.00	2	AGSE
worm	$43.13	1	AGSE
worm gear	$196.10	1	AGSE
bearings 1	$65.70	2	AGSE
bearings 2	$11.78	2	AGSE
3ft extruded aluminum	$21.78	2	AGSE
10ft extruded aluminum	$61.94	5	AGSE
6ft extruded aluminum	$39.31	1	AGSE
brackets and joints	$50.00	1	AGSE
plywood	$24.92	1	AGSE
Nuts/bolts/screws	$30.00	1	AGSE
L16-R Miniature Linear Servo for RC	$70.00	1	AGSE
12V Tenergy 2000mAh NiMH Battery Pack with Bare Leads for RC Airplanes	$23.92	2	AGSE
Microsoft Kinect Xbox One	$149.99	1	AGSE
Raspberry Pi Kit	$86.27	1	AGSE
Xbee Pro	$37.95	1	AGSE

5.2 Funding Plan

To complete this project our organization has largely been relying on the student organization funding our team receives through our university. Moving into a new semester we intend to achieve sponsorships from local businesses, develop several crowdfunding projects, and to accept donations for SOAR merchandise and apparel. In addition to these sources of revenue, in regards to our significant travel needs we are applying for a travel grant from our university to cover the entirety of that budget item.

5.3 Timeline

Table 5.3.1 Key Dates Taken from SOAR NSL Gaant Chart

Proposal Due	8/7	9/11
Design		
Website Established	10/23	10/23
Rocket Design	10/2	10/14
Rocket Models Developed	10/15	10/21
AGSE Design	10/2	10/14
AGSE Models Developed	10/15	10/21
Budget Estabished	10/21	10/28
Subteams Establish	10/14	10/21
Subteam Budgets Established	10/21	10/28
Subscale Materials Ordering	10/21	10/28
Subscale Materials Shipping	10/28	11/6
PDR		
First Draft	10/21	10/28
Editing	10/29	11/4
Completion	11/5	11/5
Powerpoint	10/29	11/4
Presentation	11/23	11/23
Subscale Rocket		
Vehicle Design	10/21	10/28
OpenRocket Simulation	10/28	11/6
Motor Can Fabrication	11/8	11/13
Altimeter Bay Fabrication	11/14	11/16
Recovery Systems Fabrication	11/16	11/18
Payload/Nosecone Fabrication	11/14	11/16
Vehicle Assembly	11/16	11/20
Subscale Launch	11/21	11/21
CDR		
First Draft	12/14	12/27
Editing	12/28	1/14
Completion	1/15	1/15
Powerpoint	12/14	12/27
Presentation	TBA	TBA

Full Scale Rocket		
Vehicle Design	12/14	12/27
OpenRocket Simulation	12/28	1/8
Motor Can Fabrication	1/22	2/4
Altimeter Bay Fabrication	2/5	2/11
Recovery Systems Fabrication	2/5	2/11
Payload/Nosecone Fabrication	2/5	2/11
Vehicle Assembly	2/12	2/19
Test Launch	2/20	2/20
AGSE		
Overall System Design	10/28	11/6
Vision System Development	11/8	11/29
Arm Design	11/8	11/29
Launch Rail Design	11/8	11/29
Rover Design	11/8	11/29
Containment Design	11/8	11/29
Systems Fabrication	1/8	1/29
Prototyping	1/30	2/12
Testing	2/13	3/5
Educational Outreach		
Great American Teach In	11/19	11/19
USF Engineering Expo	2/19	2/20
Local High School Outreach	1/21	1/21
FRR		
First Draft	2/15	2/1
Editing	3/1	3/13
Completion	3/14	3/14
Powerpoint	2/15	2/19
Presentation	TBA	TBA
Competition	4/12	4/17
PLAR		
First Draft	4/18	4/25
Editing	4/25	4/28
Completion	4/29	4/29

5.4 Educational Engagement

We maintain that one of the simplest and most effective methods of engaging students is to visit the schools and personally speak to students about STEM. These meetings will be established by contacting local schools and requesting permission to speak in the classroom as well as give demonstrations. This will be organized by the Education Engagement Officer.

Engagement at Local Schools

We will be visiting Young Middle Magnet school in the Spring to share with them our work on the AGSE. This will serve to further inspire the students at this school, which is geared toward STEM education and specifically robotics. In addition we will be reaching out to other schools and after-school programs for opportunities to showcase STEM.

Engagement at USF

Our team participated in the Engineering Expo hosted by the University of South Florida. This event is designed for campus organizations to showcase a STEM related project to both the USF community and local schools.

Our organization gave a presentation on the importance of STEM Education and the Aerospace field. We quizzed students about their fundamental knowledge of space science. We allowed participants to get hands-on with the rocket components we brought to the event. We taught the students about the procedure of fabricating and launching a rocket.

Participants and chaperones left the event enthusiastic about STEM education and rocketry. A few participants asked for information and insight on how to get involved in SOAR and rocketry. We were asked numerous rocket-related questions that intrigued the audience members. In general, participants were captivated by our presentation and display of our rockets, creating an initiative to get involved in STEM and rocketry.

Online Engagement

In addition to sharing our events online we will host videos and presentations online that look at the different STEM fields. These will allow our team to engage a wider audience outside of the immediate Hillsborough County area. These will be hosted on our organization's website, along with interactive forums and chat boxes where individuals may ask questions of our group or start discussions.

6) Conclusion

The Society of Aeronautics and Rocketry at USF is a group of aspiring scientists, engineers, and more, seeking to further mankind's pursuit of space exploration, and inspire an appreciation for STEM in the local community. The NASA Student Launch and the Centennial Challenge have been a significant guiding force for our organizations goals for this academic year, introducing many new members to our growing team and passing knowledge to many other students. As we move forward towards final fabrication we are determined to put our best foot forward, make our organization a longstanding cornerstone of our university, and establish the NASA Student Launch Initiative as a yearly endeavor to improve upon every year.

7) Appendix I – Risk Assessment

Severity		
Description	Value	Criteria
Catastrophic	1	Could result in death, significant irreversible environmental effects, complete mission failure, and/or monetary loss greater than $5000
Critical	2	Could result in severe injuries, significant reversible environmental effects, partial mission failure, and/or monetary loss between $500 and $5000
Marginal	3	Could result in minor injuries, moderate reversible environmental effects, and/or monetary loss between $100 and $500
Negligible	4	Could result in insignificant injuries, minor reversible environmental effects, and/or monetary loss of less than $10

Probability		
Description	Value	Criteria
Almost Certain	1	Greater than 90% chance of occurrence
Likely	2	Between 50% and 90% chance of occurrence
Moderate	3	Between 25% and 50% chance of occurrence
Unlikely	4	Between 1% and 25% chance of occurrence
Improbable	5	Less than 1% chance of occurrence

Risk Assessment Matrix				
Probability Value	Severity Value			
	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Almost Certain (1)	2- High	3- High	4- Moderate	5- Moderate
Likely (2)	3- High	4- Moderate	5- Moderate	6- Low

Moderate (3)	4- Moderate	5- Moderate	6- Low	7- Low
Unlikely (4)	5- Moderate	6- Low	7- Low	8- Low
Improbable (5)	6- Low	7- Low	8- Low	9- Low

Lab and Workshop Risk Assessment						
Hazard	Cause/Mechanism	Outcome	Severity of Risk	Probability of Risk	Risk Level	Mitigation
Using power tools	1. Improper training with power tools, hand tools, and/or other lab equipment 2. Improper use of PPE	1a. Mild to severe cuts and/or burns to personnel 1b. Damage to rocket and/or rocket components 1c. Damage to equipment/tools	3	3	Low	1. All individuals to use tools with be trained on each tool. No individual will attempt to learn how to use the tool on their own and no individual will use the tool who is not trained on that tool. Safety glasses will be worn at all times within the lab and workshop. Lab and workshop will be kept clean and cleaned after each use to ensure no debris is left that may cause injury 2. Any additional PPE will be worn as instructed by the tool manufacturer or as required. All individuals will be instructed on proper use of PPE
Working with chemical components including Fiberglass Resin, Slow Cure Epoxy, Lacquer Thinner, Primer, and Paint products	1. Chemical splash 2. Chemical fumes	1. Mild to severe burns 2. Skin and/or lung aggravation and/or damage due to inhalation of fumes	3	4	Low	1. MSDS documents will be readily available at all times for all chemicals. MSDS documents will be reviewed before each use of chemicals. Gloves and safety goggles designed for chemical splash will be worn at all times by all personnel when working with and/or near hazardous chemicals 2. When working with chemicals that will generate fumes all work is to be done in a well-ventilated area. All personnel will minimize inhalation by wearing appropriate PPE which may include vapor masks when there is a risk of serious fume inhalation

Metal and/or carbon fiber shards	1. Sanding and/or grinding rocket components	1a. Splinters and/or shard in personnel skin and/or eyes 1b. damage to rocket and/or rocket components	3	3	Low	1. All members will be trained in proper methods in sanding and grinding. No member who is untrained will attempt to sand and/or grind any materials. All personnel will wear proper safety glasses and gloves while in the vicinity of any sanding/grinding

AGSE-Launch Pad Functionality Risk Assessment						
Hazard	Cause/Mechanism	Outcome	Severity of Risk	Probability of Risk	Risk Level	Mitigation
Unstable launch platform	1. Unlevel ground 2. Unbalanced Design of base	1. Unpredictable rocket path from launch	1	2	High	1. It will be ensured that all personnel and individuals are at the minimum safe distance from the launch pad as established by the TRA and/or NAR. Prior to launch it will be ensured that the launch pad is stable and properly secured 2. Statics equations have been developed to ensure proper balancing of the 1010 launch platform, and all fastenings are composed of ¼” carriage screws for the 1” cross section extrusions.
Unlevel launch platform	1. Improperly leveled launch tower	1. Launch tower could tip during launch, making rocket flight path unpredictable	4	2	Low	1. Prior to launch, the launch tower will be tested on level ground to ensure that the launch tower is properly leveled 2. The launch tower shall be secured by a angled extension from the linear actuator as well as stabilized at the axis by appropriate shaft collars and pillow block bearings
Rocket experiences high frictional forces on the launch rail and/or becomes stuck on launch rail	1. Improperly sized or flawed launch buttons on the rocket 2. Deflection or misalignment of launch rail	1. Rocket may not exit launch rail at correct velocity and/or may be damaged on launch 2. Rocket flight path may become unpredictable	4	2	Low	1. Before attaching the rail buttons to the rocket they will be tested on the launch rail to ensure that they are properly sized and not flawed 2. Prior to launch the launch tower will be inspected to ensure proper fit. A spare portion of air frame will be tested with the launch rail to ensure that there is no undue friction between the launch rail and the rocket

		and/or rocket may not leave the launch rail				
Sharp edges on launch pad and/or rail	1. Manufacturing and fabrication	1. Minor cuts to personnel	4	2	Low	1. All sharp edges will be deburred and filed to reduce likelihood of cuts. When possible sharp edges will also be taped over
Brush fire during launch	1. Dry launch conditions	Small brush fire	3	4	Low	1. The range safety officer will determine if conditions are acceptable for launch. If a fire does occur the range safety officer will determine if and when personnel may approach the launch pad to extinguish the fire
Improper vehicle alignment	1. Incorrect loading of vehicle	1a. Payload may not be able to be inserted 1b. Vehicle instability 1c. Igniter can't install correctly	2	4	Low	1. A device has been constructed and added to the launch platform to ensure correct alignment of the rocket for payload retrieval The motor retainer contains a bottom plate for proper alignment for the ignition and launch platform.

AGSE-Vehicle Erector Risk Assessment						
Hazard	Cause/Mechanism	Outcome	Severity of Risk	Probability of Risk	Risk Level	Mitigation
Sharp edges on the vehicle erector	1. Manufacturing and fabrication	1. Minor cuts to personnel	4	2	Low	1. Sharp edges of the vehicle erector will be filed down and deburred to reduce likelihood of cuts. When possible, sharp edges will also be taped over.
Carriage jams	1. Carriage tracks not square 2. Too much rail deflection under load 3. Uneven loading 4. Nylon guides dislodge 5. Buildup of foreign	1,2,3,4,5. Vehicle erector is incapable of raising the rocket. 2,3,4,5. May cause damage to rocket and/rocket components	2	3	Moderate	1. Tolerances of tracks will be noted during fabrication of the vehicle erector. 2. Deflection of the rail will be analyzed and corrected to be within the specified tolerances. 3. The geometry of the base was chosen for its ability to better distribute the load and reduce impact of uneven loading. 4. Appropriate fasteners and preload on installed fasteners will be in assembly process

	objects and debris (FOD) on tracks and/or carriage					5. Prior to launch and testing the tracks and carriage will be cleared of any debri and or buildup
Actuator Overextension	1. Improper voltage applied 2. Positions incorrect	1. Rocket in unsafe position 2. Inappropriate balancing of the base	2	3	Moderate	1. Design for position and stability at all points of extension 2. Use appropriate 12 V source

AGSE-Ignition Installation Risk Assessment						
Hazard	Cause/Mechanism	Outcome	Severity of Risk	Probability of Risk	Risk Level	Mitigation
Igniter is not fully installed inside the motor cavity	1. Igniter gets caught before installation 2. Initial misalignment of igniter causes it to miss the motor cavity.	1. Motor is not ignited.	2	3	Moderate	1,2. Igniter will be attached to a stiff object to ensure proper installation. Tests of installation system will be performed prior to competition
Motor Failure	1. Inconsistency in motor grain.	1. Catastrophic explosion resulting in major risk	1	4	Moderate	1. All motors will be purchased from reputable suppliers and inspected when possible.
Gear Mechanical Failure	1. Gear material failure	1. Igniter is not installed	2	3	Low	1. The use of high strength material will be used to ensure proper ignition installation.

AGSE-Ground Station Risk Assessment						
Hazard	Cause/Mechanism	Outcome	Severity of Risk	Probability of Risk	Risk Level	Mitigation
Sharp edges on tip of rail.	1. Manufacturing of the rail	1. Cuts of team members may occur.	4	2	Low	1. Sharp edges will be filed/sanded down.

AGSE-Payload Retrieval Arm Risk Assessment						
Hazard	Cause/Mechanism	Outcome	Severity of Risk	Probability of Risk	Risk Level	Mitigation
System Failure	1. Code does not work properly. 2. Servos aren't responsive.	1,2. Arm fails to retrieve and place the payload in the rocket.	2	3	Moderate	1. Tests will be run to test all code and its operational ability 2. All servos will be tested to ensure they are in proper working order. All servos must deliver the required torque and will be tested accordingly
Robotic arm unable to pick up payload	1. Servos don't provide enough torque.	1. Arm fails retrieve and place the payload in the rocket.	2	3	Moderate	1. Metal gear servos will be used to provide the required torque.
Robotic gripper unable to pick up payload	1. Coefficient of friction is too small. 2. Servo doesn't have the required torque to hold gripper closed.	1. Payload is not loaded into the rocket.	2	4	Low	1. Will use liquid rubber to coat the gripper appendages. 2. Will use karbonite gear servos to ensure a secure clasp on the payload.
Robotic arm drops payload in a random place	1. System failure 2. Loss of power 3. Failure of the servos	1. Challenge may not be completed in under 10 minutes. 2. Vision system may not be able to locate payload again.	2	3	Moderate	1. Ensure that our robot can pick up the payload in under 20-30 seconds. We will also ensure that the gripping force is great enough to prevent the load from slipping out of the robot's grasp. 2. Ensure that the vision system is placed near the front of the robot so that it can sense where they payload will be in any direction.

Control Risk Assessment						
Hazard	Cause/Mechanism	Outcome	Severity of Risk	Probability of Risk	Risk Level	Mitigation
Pause function fails to activate	1. Mechanical failure in switch 2. Communicati	1. Damage to AGSE. 2. Injury to personnel near AGSE.	2	3	Moderate	1. All personnel are required to stand a specified distance away from the AGSE while it is operating.

	on failure between switch and controller 3. Code error					2. Redundancies will be implemented to ensure pause function will perform properly. 2,3. All codes, systems and functions will be tested as it is written in addition to being tested and checked for errors prior to the competition
Pause function fails to deactivate	1. Mechanical failure in switch 2. Communication failure between switch and controller 3. Code error	1. AGSE mission failure	2	3	Moderate	1. Redundancies will be implemented to ensure pause function will perform properly. 2,3. All codes, systems and functions will be tested as it is written in addition to being tested and checked for errors prior to the competition
Boot function fails to activate	1. Mechanical failure in switch 2. Communication failure between switch and controller 3. Code error	1. AGSE mission failure	2	3	Moderate	1. Redundancies will be implemented to ensure boot function will perform properly. 2,3. All codes, systems and functions will be tested as it is written in addition to being tested and checked for errors prior to the competition
Boot function activated at power up	1. Mechanical failure in switch 2. Communication failure between switch and controller 3. Code error	1. Unpredictable boot sequence	2	3	Moderate	1. Redundancies will be implemented to ensure boot function will perform properly. 2. Reminder that boot function is disabled before powering on the AGSE will be included in pre-launch procedure list. 3. The code will be tested as it is written in addition to being tested and checked for errors prior to the competition
Failure to start and/or boot up	1. Error in code 2. No power or lose in power	1. AGSE mission failure.	2	4	Low	1. Testing will be done to ensure power is properly connected for the AGSE controllers.

Stability and Propulsion Risk Assessment

Hazard	Cause/Mechanism	Outcome	Severity of Risk	Probability of Risk	Risk Level	Mitigation
Motor ignition failure	1. Damaged motor 2. Ignition delayed 3. Faulty e-match	1,3. Rocket unable to launch 2. Rocket fires at an unexpected time	1	3	Moderate	1. Follow TRA safety code and wait a minimum of 60 seconds before approaching the rocket to ensure that the motor is not just delayed in launching. 2. If there is no activity after 60 seconds, the safety officer will check the ignition system for a lost connection or a bad igniter. 3. In the event of a faulty ematch, the safety officer or project lead will remove the ignition system from the rocket motor, retrieve the motor from the launch pad and replace the motor with a spare.
Motor explodes upon ignition on the launch pad	1. Failure in the manufacturing of the motor.	1. Severely damaged or complete loss of rocket	1	4	Moderate	1. Assure that 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 when it is safe to approach the pad.
Optimum velocity is not reached upon leaving the launch rail	1. Rocket has too much mass 2. Motor impulse is too low 3. Friction built up between rocket and launch rail	1,2,3. Unstable launch and may result in unpredictable flight path	2	3	Moderate	1. Simulations have been run to confirm that the necessary velocity can be achieved by the motor selected. 2. Motor has been selected based on simulation data to meet lift off and flight requirements. 3. Prior to installation and launch, the launch buttons will be tested for fitting on the launch rail.
Internal bulkheads fail during ascent/flight	1. Forces during ascent are too much for the bulkheads to withstand	1. Components inside the rocket being held by the bulkheads will no longer be secure and could cause an anomaly 2. Parachutes attached to	1	4	Moderate	1. All bulkheads will be secured with high strength 30 minute epoxy. 2. Bulkheads that have parachutes attached will have extra epoxy around eyebolts to ensure the bulkhead and eyebolts are secure within the rocket. 3. In the event that the rocket may pose a threat to any individual, all

		bulkheads will be left ineffective. 3. Rocket may pose a threat individuals at the field				individuals at the launch will be notified immediately
Alignment of fins is not optimized	1. Geometry of mounted fins are not straight or not equally spaced around	1. Rocket becomes unstable or spins	2	2	Mode rate	1. All fin slots will have a specified tolerance that will devastate the rocket after launch.
Fins fracture and/or shear off during flight	1. Epoxy fillets are not properly applied to edges of fins	1. Rocket flies in an unpredictable path 2. Fins fall completely off. 3. Rocket and or components pose a hazard to those at the launch field	1	4	Mode rate	2. Carbon fiber stands are mixed in with the epoxy fillets to increase the shear strength of the epoxy fillets along the fins. 1,2. Mentor, project lead, and safety officer will examine all epoxy fillets to ensure there are no cracks or deficiencies both during fabrication and after. 3.In the event taht the rocket poses a hazard to any individual at the launch all individuals will be notifed immediately
Motor Retainer Failure (falls off)	1. Improper preload or thread engagements	1. Motor and its casing release from rocket upon parachute deployment	1	4	Mode rate	1. Tests will be done to ensure proper motor retainment. Analysis will be done to ensure the current design is stable enough under the forces in flight.
Bending at Joints	1. Large L/D Ratio	1. Potential shearing of joints and shaky flight patterns	2	3	Mode rate	1. Include long couplers, 8 inch shoulders for the altimeter bay and 4+ inch shoulders otherwise.

Recovery and Recovery Systems Risk Assessment						
Hazard	Cause/Mecha nism	Outcome	Severi ty of Risk	Probab ility of Risk	Risk Level	Mitigation

Separation of rocket at apogee and/or 800ft does not occur	1. Not enough pressurization to break shear pins 2. Coupling fit too tight	1,2. Rocket becomes ballistic	1	3	Mode rate	1. Separation sections of rocket will be designed to ensure that the black powder charges provide enough force to cause the pins to shear. Ground test will be done to ensure the correct amount of black powder is used 2. 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
Parachute does not deploy due to size in relation to rocket diameter	1. Parachute is stuck in body tube 2. Parachute lines are tangled	1, 2. Rocket becomes ballistic	1	3	Mode rate	1,2. The packing of each parachute will be checked by our mentor prior to launch to ensure proper packing. In addition the parachute size has been selected to fin within the body tube but not so tightly as to become stuck due to the size of the parachute. In the event that the rocket does become ballistic, all individuals at the launch field will be notified immediately. Black powder charges have been tested an appropriate mass of charge will be chosen to ensure separation without damage.
Altimeter and/or e-match failure	1. Parachute does not deploy	1. Parachute becomes ballistic	1	4	Mode rate	1. We will have a redundancy by including two altimeters each with their own e-matches and black powder charges, wired in series. In the event that the rocket does become ballistic, all individuals at the launch field will be notified immediately
Rocket descent is too rapid despite parachute deployment	1. Parachute is not properly sized	1. Rocket poses hazard to those at launch field 2. Rocket and/or component parts are	2	4	Low	1. In the event that the rocket is descending too quickly and may pose a hazard to those at the field, all individuals will be notified immediately. 2. The parachutes have been selected according to load capacity size and coefficient of drag of the parachute. In addition several

		damaged in landing				simulations were run to ensure the correct sizing of the parachute and descent of the rocket.
Rocket descent is too slow	1. Parachute is improperly sized	1. Rocket may drift beyond desired range, and may damage surroundings or become unreachable	2	3	Mode rate	1. Each parachute has been selected to fall within the desired coefficient of drag to prevent too great of a drift. Simulations were performed to ensure that the rocket does not descend too slowly with the chosen parachutes. In the event that the rocket does drift to prevent loss of the rocket it will be tracked both visually and by GPS.
Parachute does not have enough time to fully unfold	1. Main separation t 500 feet 2. Long Shock Cord	1. Rocket hits ground with greater kinetic energy	2	3	Mode rate	1. Change main deployment to 800 feet
Parachute is torn or ripped	1. Parachute is less if not completely ineffective in controlling rocket descent	1a. Rocket may damage environment 1b. Rocket and/or components may become damaged upon landing 1c. rocket may pose a hazard to individuals at the field	2	4	Low	1. Prior to launch and packing, each parachute will be checked for tears or rips. In addition we will bring backup parachutes to replace any torn parachute. 1c. In the event that the rocket does pose a hazard to individuals at the field, all individuals will be notified immediately.
Parachute and/or cord is burnt	1. Parachute becomes less or entirely ineffective	1a. Rocket may damage environment 1b. Rocket and/or components may become damaged upon landing 1c. Rocket may pose a hazard to individuals at the field	2	3	Mode rate	1. To prevent damage to the cords and parachutes from black powder charges, rocket recovery wadding will be packed into the spaces containing the parachutes and cords. Each parachute will be packed in Nomex to aid in burn prevention. In the event that the parachutes separate from any rocket component, all individuals at the field will be notified immediately.
Parachutes separate	1. Bulkhead is dislodged	1,2,3. One or more	1	4	Mode rate	1. Bulkheads will be secured by 30 minute epoxy and inspected by the

from one or more rocket components	2. Parachute disconnect from eyebolt 3. Eyebolts shear through bulkhead	components of the rocket become ballistic				mentor, project lead, and safety officer 2. Prior to launch the connection of the parachute to the eyebolts will be inspected by the mentor, project lead, and safety officer 3. Eyebolts will be epoxied to the bulkheads. In addition the bulkheads have been chosen to be baltic birch to meet shear and strength requirements. In the event that the rocket becomes ballistic all individuals at the field will be notified immediately.

Vehicle Assembly Risk Assessment						
Hazard	Cause/Mechanism	Outcome	Severity of Risk	Probability of Risk	Risk Level	Mitigation
Dropping of rocket	1. Mishandling of rocket in transit	1. Minimal damage to rocket components	3	4	Low	1. Careful handling will be executed while transporting the rocket.The rocket has been designed to withstand flight and landing conditions.

Environmental Hazards Assessment						
Hazard	Cause/Mechanism	Outcome	Severity of Risk	Probability of Risk	Risk Level	Mitigation
Strong winds and/or rain	1. Disruption of rocket stability both on the platform and in flight	1a. rocket path may become unpredictable 1b. rocket may become damaged 1c. rocket may pose a hazard to those at the launch 1d. rocket systems may be damaged	2	2	Moderate	1. If the winds are greater than 5 mph then the rocket will not be launched. If there is any rain then the rocket will not be launched. Weather conditions will be checked the day before and the morning of the launch Ultimately, the range safety officer of the field will determine whether conditions are acceptable for launch
Harmful substances contaminati	1. Improper disposal of batteries	1. Reversible to irreversible damage to	2	4	Low	1. All batteries and chemicals will be disposed of according to the associated MSDS. In the event of

ng water and/or ground	and/or chemicals	local environment				an accidental chemical spill then members are to follow the regulations of EHS for the given chemical spill.
Brush fire	1. Flames from ignition	1. reversible damage to local environment	2	4	Low	1. All required fire hazard equipment will be brought to the launch. The blast plate will be sized to minimize the risk of fire hazard. In the event of a fire the range safety officer will be to determine if the fire is small enough to be put out without the need of emergency service. All members will wait until signal from the range safety officer to approach the region in which the fire occurred.

8) Appendix II - Safety Checklists

Safety Checklist: Recovery

To be checked by Safety Officer and Subsystem Lead

Launch Preparation

Materials Required

- Precision Screwdriver
- 2 x 9 Volt Batteries
- Altimeter Sled
- 2 x RRC3 Altimeters
- Digital Multimeter
- Battery Holders
- 22 Gauge Wire
- 2 x E-Matches
- 2 x Key Switches

Altimeter Sled

1. Verify that the RRC3 altimeters are properly configured for the 800 feet separation as opposed to the default settings.
2. Verify batteries have a minimum voltage of 9V.
3. Mount RRCS Altimeters onto standoffs and screw into designated areas on the sled.
4. Mount Batteries into battery holders and screw into designated areas on the sled.
5. Mount the LCD screen onto standoffs and screw into dedicated area on the sled.
6. Verify that both key switches are in the off position.
7. Wire switches to switch terminals on the RRC3s.
8. Wire Batteries to RRC3s.
9. Wire E-matches to RRC3s.
10. Verify all correct and continuous connections.
11. Install altimeter sled into the altimeter bay.
12. Secure Rear altimeter bay bulkhead and tighten wingnuts securely.

<u>Launch Day</u>

Materials Required

- Splash-proof goggles
- Gloves
- Zip Ties
- Scissors

Altimeter Bay

1. Key switches in off position
2. Check connection between the battery wires and RRC3 altimeters
3. Ensure all adhesives and screws are adequately fastening the altimeters, batteries, and LCD display.
4. Ensure connection between e-matches in the bulkheads and the altimeter.
5. Insert altimeter sled into bay and bulkhead securely tightening wingnut closure.

6. Our mentor will carefully measure out black powder for all 4 charge caps while wearing appropriate safety equipment, 4 grams for the main chute and 3.5 grams for the drogue chute.
7. Flame retardant material will be inserted into the charge pipe before being covered by a blast cap.

Parachutes

The following procedures are to be followed for both the drogue chute and the main chute:
1. Inspect parachute cloth, cord, and seams for any visible signs of wear or damage.
a. If damage is found on the parachute immediately inform the team mentor, safety officer, and team captain for corrective action.
2. Lay out the parachute canopy flat, ensuring that all shroud lines and shock cord are untangled and straight.
3. Insert section of nomex cloth on shock cord between the blast cap and parachute location.
4. Tie tail end of shock cord to altimeter bay quick link, using a parachute knot as outlined in the SOAR Share Drive Launch procedures guidelines.
5. Pull on knot firmly to ensure proper connection.
a. If the knot is not firm or is unraveled during the pull test please consult the team safety officer and team captain for corrective action.
6. Fold parachute as outlined in SOAR Share Drive Launch procedures guidelines.
7. Knot quik link at half along the shock cord.
8. Tie parachute shroud lines to quick using a butterfly hitch, further secure with a zip tie.
9. Tie head of shock cord to payload bay eye bolt using parachute knot (for main chute).
10. Perform pull test at other knot.
11. Inspect all recovery connections for adequate hold and damage.
a. If any condition s noted that deem the launch vehicle unsuitable for launch lease contact the safety officer and team captain immediately.

Safety Checklist: Propulsion

To be checked by Safety Officer and Subsystem Lead

<u>Launch Preparation</u>

Materials Required

· Splash-Proof Goggles
· Gloves
· Snap Ring Plyers
· Grease

Motor

1. Visually inspect the motor casing for signs of wear or damage, especially towards the top bulk plate.
a. If any damage is found please consult the team safety officer immediately to determine whether the casing is suitable for flight.
2. Ensure the case has been properly cleaned with no material present on neither the inside or outside.
3. One qualified team member will carefully insert the grains and spacers into the motor casing while wearing splash-proof goggles and gloves, and using an appropriate amount of grease.
4. Place snap ring at the bottom of the motor casing.
5. Store the completed motor in a safety certified casing for transportation on launch day.

Launch Day

Materials Required

· Rocket Stand

Motor

1. Visually inspect the motor casing for any signs of damage.
2. Carefully insert motor into launch vehicle motor mount.

Fin Can

1. Inspect the airframe and fins of the fin can for any damage.
a. If there is any damage seen immediately report to safety officer and team captain.
2. Visually inspect motor retainer screws.
3. Screw on Aeropack motor retainer cap, being careful not to overtighten.
4. Place completed propulsion bay upright on rocket display stand.

Safety Checklist: Launch Pad

To be checked by Safety Officer and Subsystem Lead

Launch Day

Materials Required

· Black electrical tape
· Igniter
· Flight card
· Pencil/pen

Launch Pad

1. Complete Flight Card and have it approved by the RSO.
2. Inspect rocket once more for any damage, and ensuring key switches remain in off position with key inserted.
3. Once permission has been given by the RSO to step onto the launch field place the launch vehicle onto launch rail carefully.

a. Note: Stay alert to your surroundings and what people are doing around you. Never step onto the field while rockets are being fired, and follow the RSO and the safety officer's directions.

4. Carefully place the launch rail upright, at the angle and direction specified by the RSO
5. On attached rod insert igniter into motor grain until resting at the top of the casing.
6. Tape igniter to the leg of the launch rail to ensure stability.
7. Ensure proper connection with the ground support equipment.
8. Arm the key switches, and listen for the three beeps from the RRC3.
9. Before leaving the launch pad double check all connections carefully.
10. Clear the launch pad area and do not step back onto the field until directed to do so by the RSO.

Safety Checklist: Launch

To be checked by Safety Officer and Subsystem Lead

<u>Launch Day</u>

Observation

1. All observers must be standing at a distance specified by the RSO.
2. Team members must remain observant of their surroundings, remain standing or sitting at a safe distance and following instructions of the RSO first and foremost the team safety officer.
3. At launch a timer should be kept to later compare against the altimeter.
4. Line of sight must be maintained at all times, any anomalies must be reported immediately to the RSO.

5. Note the time and success of first separation.
6. Note the time and success of second separation.
7. Note the time and success of landing.
8. Wait for RSOs direction before going to retrieve the rocket.

Safety Checklist: Post-Flight

To be checked by Safety Officer and Subsystem Lead

Launch Day

Post-Flight Inspection

1. In event of maximum drift scenario, retrieval team must be on hand with a vehicle and the gps coordinates.
2. Await RSOs instructions before going to retrieve the launch vehicle.
3. Take a photo of the rocket at landing before recover and note it's gps coordinates.
4. Very carefully test the temperature by the motor mount, await for it to cool to an appropriate level before attempting to lift.

5. Note any damages or other anomalies on the rocket before moving. Document if there is any observed.
6. Have at least one person pick up each of the three separate sections of the launch vehicle
a. Important note, DO NOT disarm the altimeters until after the data has been collected. Preemptively turning off the system will reboot the altimeters and delete all flight data.
7. Once back at base immediately remove altimeter sled and record data.
8. Once the motor cools down very carefully remove the motor casing and begin cleaning.
9. Perform detailed inspection of the rocket for any damage, wear, or fatigue.

Safety Checklist: Troubleshooting Guide

To be checked by Safety Officer and Subsystem Lead

<u>Troubleshooting</u>

In the event of a situation arising the following troubleshooting guidelines may be followed in order to determine and solve for a problem. Before beginning troubleshooting please contact the team safety officer and team captain for an overview and validation.

Electronics

1. In the event of electronics failure first inspect all connections.
2. Use a multimeter to ensure the power systems are at functioning capacity.

3. If the problem persists, reboot the electronics and redo all connections.

Recovery

1. In the event of torn or damaged parachute or shock cord immediately notify the RSO and team safety officer to determine if the flight should be aborted.
2. In the event of lose connections, retie knot. If the problem persists switch from the parachute knot to the figure 8 knot. If the problem still persists used epoxy and zip ties to secure line after firmly knotting.