NC STATE UNIVERSITY

Tacho Lycos: NASA Student Launch Project FRR 2015

High-Powered Rocketry Team
911 Oval Drive
Raleigh NC, 27695
March 16, 2015

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1 Summary of FRR Report

1.1 Team Summary

1.1.1 Team Name and Mailing Address

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1.1.2 Name of Mentors and TRA Numbers

Alan Whitmore	James Livingston
acwhit@nc.rr.com	livingston@ec.rr.com
TRA Certification: 05945	TRA Certification: 02204
Certification level: 3	Certification level: 3

1.2 Launch Vehicle Summary

1.2.1 Size and Mass

The launch vehicle has a total length of 78 inches with a 5.5 inch maximum diameter. Launch ready, the vehicle has a total weight of 19.9 pounds. This weight will increase slightly once paint has been applied to the vehicle.

1.2.2 Final Motor Choice

The final motor chosen was the AeroTech K805G. With a weight of 19.9 pounds the vehicle is projected to reach an altitude of 3200 feet.

1.2.3 Recovery System

The recovery system will consist of an 18 inch drogue parachute, a 36 inch main parachute for the nose section, and a 48 inch parachute for the fin section. The parachutes will be deployed by a combination of two Stratologger SL100 altimeters and two Entacore AIM 3.0 altimeters. A Rattworks ARRD will be used to separate the nose section from the fin section during descent.

1.2.4 Rail Size

The launch rail will have a 1.5 x 1.5 inch cross-section and a length of 96 inches, which gives a velocity of 72 feet per second as the vehicle leaves the launch rail.

1.2.5 Milestone Review Flysheet

The Milestone Review Flysheet can be found in **9.1** of this document. It can also be obtained from the Tacho Lycos website at www.ncsurocketry.com.

1.3 AGSE/Payload Summary

1.3.1 AGSE/Payload Title

Autonomous Terrestrial Launch Ascension System (ATLAS)

1.3.2 AGSE Summary

The system will begin by identifying the location of the sample. The image processing system will use the USB camera to pick the sample from the background and relate the sample's pixel size in the image to the location of the sample. Both the image processing and the arm movement calculations are done on the BeagleBone Black in real-time. The robotic arm will use this information to move into a position above the target before moving to grasp the center of the sample. With the sample secure in the gripper, the arm will move to the payload compartment on the launch vehicle before placing the sample in a mold located within the vehicle. After securing the sample, the arm will move itself to close and lock the compartment door. The arm will then move to a safe position away from the rocket before the larger stepper motor raises the launch vehicle to an orientation 5° from vertical. Once the launch position is achieved, the igniter insertion system's stepper motor will raise the igniter into the rocket motor.

1.3.3 Experiment Summary

The purpose of the experiment is to demonstrate a proof of concept for a Mars sample return mission. The vehicle needs to be loaded with a payload that was taken from the Martian surface to be sent back to Earth. The entire system will need to be sent to Mars in a compact package without the chance of the motor igniting before it is required. The initial orientation of the vehicle will be horizontal which will allow for a more compact package when sent to Mars. For this experiment, the Martian sample is represented by a closed PVC container filled with sand. The robotic arm will pick up the sample and secure it within the vehicle while still in the horizontal configuration. The launch rail and vehicle will then be raised to a nearly-vertical launch position before the igniter insertion system prepares the motor for launch.

2 Changes Made Since CDR

2.1 Changes Made to Vehicle Criteria

The dimensions of the vehicle's middle and upper airframes have been changed to 21 and 26 inches respectively. This change was made to increase the compartment size for the 4 foot main parachute as recommended per the CDR review. Consequentially, one bulkhead in the middle airframe was removed as the lower avionics compartment will now act as the point of attachment for the main parachute shock cord.

Material used for the avionics sleds has changed from a sheet of fiberglass to a 3D printed custom sled for each compartment. This design change will provide better organization and a more secure fit for the altimeters, batteries, and wires as well as a more aesthetic appeal.

The lower avionics compartment will now make use of one Stratologger SL 100 and one Stratologger CF. This is due to an error from the distributer, however, and will not affect the vehicle's performance.

Rather than attaching a bulkhead to the bottom of the nosecone shoulder, it is now inserted and attached 5.5 inches inside. This allows for more size for in the upper parachute bay and enables the team to have access to a GPS unit.

The upper airframe will now have a 3 x 5 inch cut extrusion with 0.5 inch radius corners. This will allow access to the payload compartment and also be the attachment point for the door's two hinges.

2.2 Changes Made to AGSE/Payload Criteria

Rather than outputting a coordinate location of the sample, the imaging system will instead find the straight-line distance to the sample. With both the straight-line and vertical distance from the arm to the sample known, the coordinate location can be determined using geometry. The code to calculate the arm movements is now retaining its status as an m-file instead of converting it to C/C++. Leaving the code in the MATLAB language allows the team to work with a more familiar language. The imaging scripts are being written in C++ to improve processing efficiency and speed.

The latching mechanism on the sample compartment door has been changed to utilize three Neodymium magnets. This new method is simpler to implement and decreases the chance of the door opening unexpectedly during flight which may allow the sample to fall from the vehicle and pose a risk to ground personnel.

2.3 Changes Made to Project Plan

There have not been any major changes to the project plan since the CDR. Although some minor alterations have been made to the timeline (most notably delaying the arm + camera experiment), the critical path and general plan is still in place. The budget did not experience any significant changes and has been updated to reflect the recent purchases by the club. The funding plan is still as projected, and the team has received $14,100.

3 *Vehicle Criteria*

3.1 Design and Construction of Vehicle

3.1.1 Vehicle Construction

The vehicle airframe was constructed from 5.5 inch outer diameter BlueTube 2.0. Before cuts to the tubing were made, a complete layout of the vehicle's three main airframe sections and internal components were outlined on the outside in pencil. Once the measurements were confirmed, cuts were made along the lines that separated each section.

DXF files were created using SolidWorks models of the fins, bulkheads, and centering rings to be used in the NCSU's Flight Research Lab's laser cutter. Using sheets of 1/8 inch birch aircraft grade plywood, the components were precisely cut to be used for layups as shown in **Figure 1**.

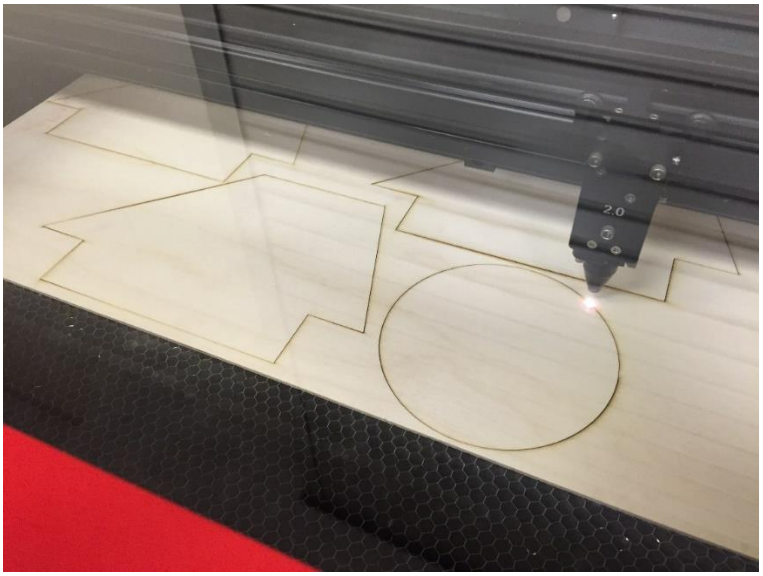

Figure 1 Laser Cutting of Fins and Bulkheads

Each fin and the motor block were constructed from 4 sheets of plywood to achieve a 1/2 inch thickness while the bulkheads used 3 sheets for a thickness of 3/8 inches. For laminations, a large, clean surface that was free of debris was covered with a plastic lining large enough to accommodate the amount of components needed. The size of the lining was such that the desired amount of bulkheads and fins took up half of the sheet's size so that it could be folded in half over itself. Prior to placing the lining, thin strips of plumber's putty were placed along the entire outer perimeter of the lining. Epoxy was applied on the bulkheads and fins using a sponge to ensure it was spread evenly across the surface of each component layer.

The bulkheads and fins were then carefully placed on the lining and sheets of peel-ply were cut to cover the items with approximately 2 inches of overhang around the entire edge. Breather was then cut to the same size and placed over the peel-ply. Strips of breather were bridged from each component all the way to the location of the vacuum tubing. This setup ensured no air pockets would remain trapped and an even pressure could be applied at every point.

Plumber's putty was then placed adjacent to and along the entire previous putty lining on the inside edge, except for a one inch gap at the open end of the plastic lining fold. The vacuum tubing was then inserted in this gap and additional putty was applied around the tubing to keep an airtight seal. The vacuum was then applied at a pressure of -20 inHg for approximately 10 hours. The setup for the lamination process is illustrated in **Figure 2Figure 2**

Figure 2 Fin and Bulkhead Layup

The slots in which the fins would be placed in the fin section body tube were numbered 1-4 and matching numbers were written on the fins. Each rectangular slot was cut out using a circular saw tooth blade on the Dremel tool. Each slot was sanded until each corresponding fin had a tight fit. This process can be seen in **Figure 3**.

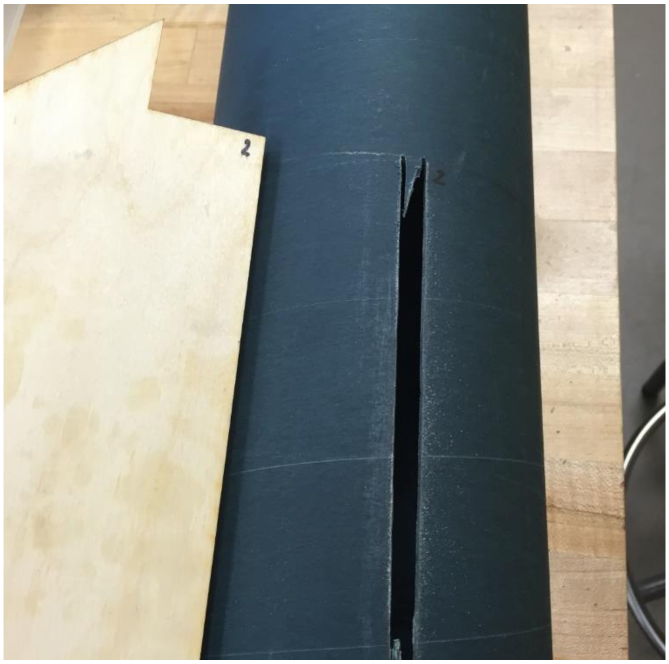

Figure 3 Fin Fitting

Centering rings were placed by inserting all four fins into the tubing and sitting the top centering flush against the fin tabs. Epoxy that was thickened by placing cotton flock on the top surface of the upper centering ring which also prevented excessive dripping that could have prematurely attached the fins. Using a heat gun, the epoxy was cured at a temperature of 300°F.

Once the first layer of epoxy had cured, the fins were removed and the motor housing was inserted with the motor retention hardware attached. The vehicle was set vertically to allow the retention hardware to sit flush with the bottom edge of the body tubing and had epoxy applied to the top and lower centering ring-motor housing joints. To keep the motor housing concentric with the body tubing, the lower centering ring was inserted during the curing process.

The lower centering ring and motor retention were then removed and fins 1 and 3 were inserted into their proper slots. The fins were aligned and held in place within their respective slots by wrapping tape from the body tube over the fin and back to the body tube on the other side. A small amount of epoxy was then applied to the motor housing-fin, upper centering ring-fin, and body tube-fin interior joints while the lower centering ring was held in place. This same process was repeated for fins 2 and 4. Once all fins were attached, the lower centering ring was set flush against the fin tabs and epoxied in place. Final work to the fins was completed by applying a fillet of epoxy to the body tube-fin joints which was sanded after curing. Launch lugs were then screwed into the lower centering ring and the motor block. The fin section construction process described above is shown in **Figure 4.**

Figure 4 Fin Section Construction

A 2.75 inch U-bolt was inserted through the motor block and epoxy was placed on the upper and lower side nuts to act as thread lock since this component would be inaccessible once set in place. The motor block was then placed in the fin section and set flush against the motor housing. A coat of epoxy was placed at the joint between the body tube and motor block and was allowed to run slightly to coat the maximum surface area along the joint and motor block. Another coat of epoxy with cotton flock was later applied in the same location to ensure maximum strength along the joint.

Construction on the payload compartment and upper avionics bay began by cutting a 2 x 5 inch extrusion with 0.5 inch radius corners into the center of the tubing. The sled was then inserted with the foam payload molding on the back side and adjusted until the mold was centered in the cutout. This alignment was marked on the bulkhead and Bluetube to ensure proper assembly. To fit the Advanced Retention Release Device (ARRD) on the lower bulkhead, foam and avionics sled had to be positioned slightly off center. This setup can be seen in **Figure 5.**

Figure 5 Upper Avionics and Payload Compartment Fitting

Once the bay was inserted into the body tube, measurements were taken to confirm its position within the vehicle. When confirmed, a 3 x 5 inch cut extrusion with 0.5 inch radius corners was then cut from the upper airframe. Its position was slightly off to the right side from the vertical of the launch lugs to allow for access to the altimeter's switches. To have an operating door on hinges, two rectangular cuts measuring 1 x 0.5 inches were cut from the left side of the body tube's opening. The compartment was then rotated such that the smaller extrusion was off center from the larger one to prevent a large opening between the body tube and bay coupler. This also allowed for space to insert the door locking mechanism to be described later. Screws were used to attach the door to the avionics bay as shown in **Figure 6**.

Figure 6 Payload Compartment Door

To lock the door, a series of three Neodymium magnets were placed along the side opposite of the hinges. Three 0.5 inch holes were drilled in the space to fit the cups that house the magnets. A strip of sheet metal was then cut and shaped to form a bracket along the span of the holes on the inside of the avionics bay and epoxied in place. The cups for the magnets have a hole for screws which allowed for them to be screwed to the bracket to retain their position. These cups were placed far enough beneath the surface of the coupler that the door would sit flush when closed. The magnets were placed in the cups and metal disks were epoxied to the door. This mechanism is illustrated in **Figure 7**.

Figure 7 Payload Compartment Locking Mechanism

To secure the avionics compartments and nosecone, a series of 4 screws per bulkhead were inserted from the outer body tubing into the bulkheads. Screws were inserted into both bulkheads on the lower avionics compartment, the top bulkhead on the upper avionics compartment, and the bulkhead in the nosecone. To attach the three main airframe sections, shear pins were inserted in the fin section, the upper portion of the middle airframe, and the upper portion of the upper airframe. These locations are illustrated in **Figure 8**.

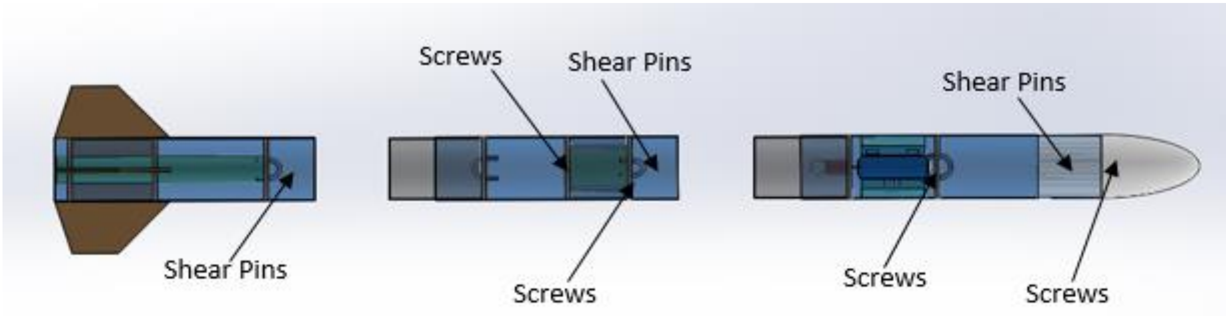

Figure 8 Screw and Shear Pin Locations on Launch Vehicle

3.1.2 Electrical Elements

Both the upper and lower avionics compartments were constructed from 5.36 inch O.D. coupler and sealed by bulkheads secured with two threaded rods. The rear avionics bay housing the Stratologger altimeters used two 9.5 inch long threaded rods. The forward avionics bay housing the Entacore altimeters used 9.375 inch threaded rods. To provide the best organization and retention of avionics components inside, two sleds were custom made to fit the Entacore and Stratologger altimeters along with a battery for each. To secure the altimeters, screws were threaded into tapped holes placed in the sleds. Similarly, the batteries are retained by placing a metal clip over each and screwed to the sled through tapped holes. Two switches, one for each altimeter, were epoxied into a cylindrical hole that was drilled in the center of the sleds. Both switches and altimeters were wired using 20 gage Radioshack brand speaker wire. An example of the upper avionics sled that houses the Stratologger altimeters is shown in **Figure 9**.

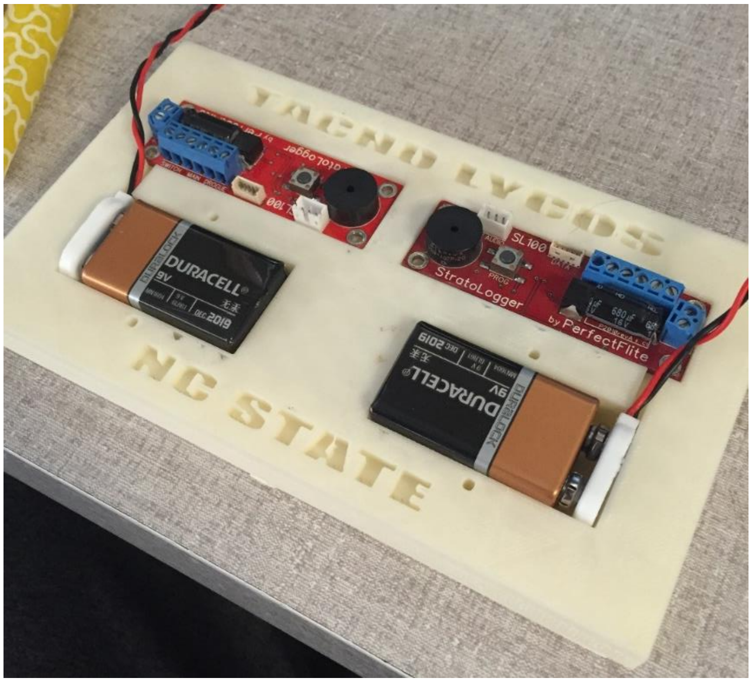

Figure 9 Avionics Sled for Stratologger Altimeters

3.2 Flight Reliability Confidence

3.2.1 Test Data

Altimeters were tested using a vacuum chamber and LEDs. Each altimeter was connected to a computer for programming and data analysis. Each altimeter was set to deliver a main charge at 2000 feet and a drogue charge at 700 feet. A resister was wired to a small LED in series for each main and drogue terminal block. Altimeters were placed in a six inch tall mason jar with tubing connected to a vacuum pull and sealed. Initial tests were performed by pulling the vacuum to -8 inHg and releasing the vacuum after 5 seconds. Results from the first three tests showed indicated altitudes reaching over 30,000 feet with inconsistent altitudes for charge detonation with two other tests not delivering a charge at all. Two more tests were performed with adjustments made to the application and release of the vacuum to more accurately model a flight profile. It took a time of 4 seconds to achieve a vacuum pressure of -5 inHg and was held for roughly 4 more seconds before releasing the vacuum pressure over the course of 8 seconds. During these tests, both LED lights illuminated. Altimeters were connected to their respective data transfer programs to verify the altitudes for charge detonation. The altitude flight profiles from these tested matched closely with previous launches where both main and drogue detonations were within 300 feet of their designated altitude.

3.2.2 Mission Success through Workmanship

Proper workmanship of the flight vehicle components is crucial to ensure mission success. To ensure concentricity between the motor casing and the body tubing, the centering rings were precision laser cut as previously discussed. Using a piece of unaltered coupler, the centering rings were set flush against their ends. The precise shape and fit of the fins was also made possible by precision laser cutting.

Pipets were used to keep excessive epoxy from being applied at joints. This reduced the spreading of the epoxy which could go to waste and ultimately add unnecessary weight.

To ensure that avionics bays, coupler pieces, and body tubing were cut perfectly, a drop saw in the NCSU machine shop was used. This allowed for quick, clean, and accurate cuts.

3.2.3 Safety and Failure Analysis

The FMECA tables are located in **9.2.**

3.2.4 Full-Scale Test Flight Results

The launch vehicle was modeled in OpenRocket to match the CAD model from SolidWorks prior to launch. From this model, the vehicle's simulated mass was 19.8 lbs with a length of 78 inches and a diameter of 5.5 inches. The CG was located at 46.5 inches aft of datum and the CP was located 56 inches aft of datum. This provided a static margin of 1.7 caliber. This model is shown in **Figure 10**.

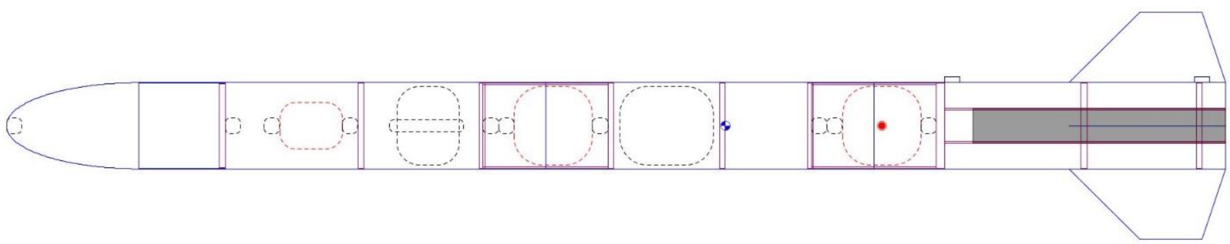

Figure 10 OpenRocket Model of Launch Vehicle Layout

Flight conditions were modeled based on predicted weather for launch day. The pressure was set to 30.17 inHg, temperature set as 43° Fahrenheit, and winds set to 14 miles per hour. From these parameters, the following flight characteristics are presented in **Table 1** with the flight profile plotted in **Figure 11**.

Table 1 OpenRocket Flight Characteristics

Exit Rail Velocity (ft/s)	71.1
Apogee (ft)	3189
Max Velocity (ft/s)	542
Max Acceleration (ft/s^2)	318

Time to Apogee (s)	13.3
Flight Time (s)	87.5

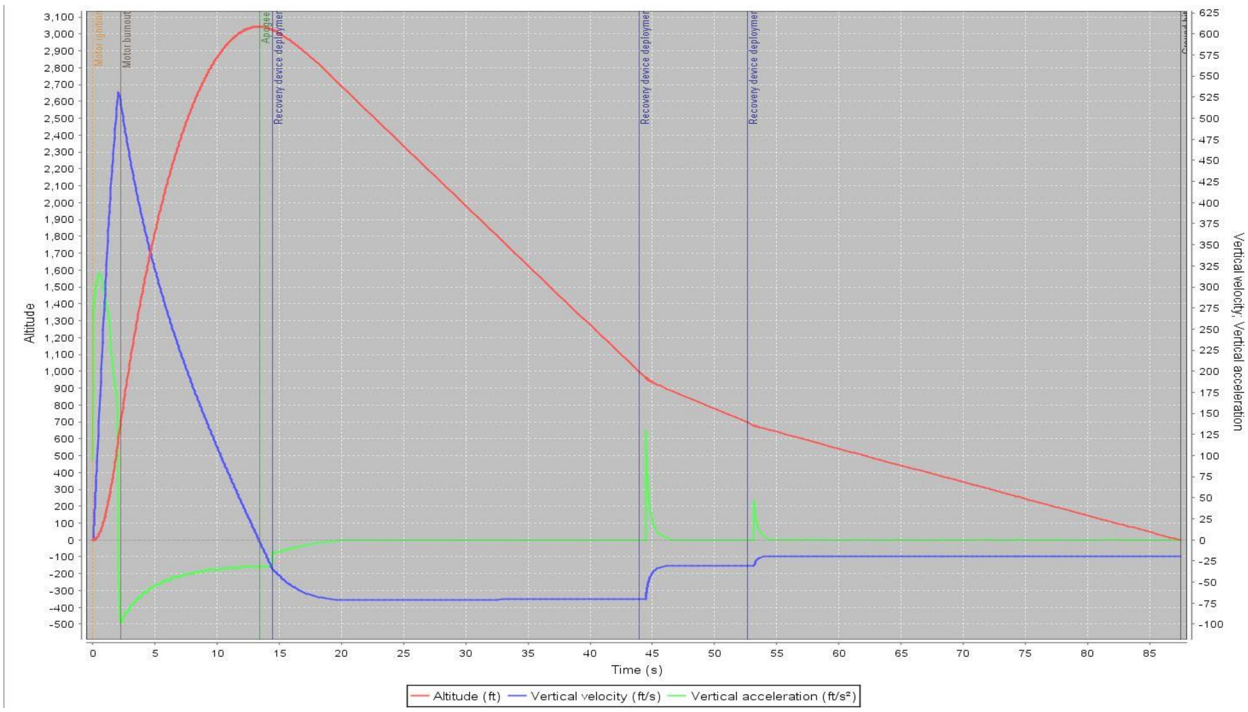

Figure 11 OpenRocket Flight Simulation for Full-Scale

The full-scale test launch occurred in Bayboro, NC on Saturday, February 28 at approximately 12 pm. Temperatures were between 40° and 45° Fahrenheit with winds gusting to 15 miles per hour. Visual observation showed a perfect launch and sequence of recovery events.

Initial flight path deviated slightly from vertical due to the relatively strong winds as expected. Using later analysis from video recordings, it was observed that the vehicle experienced no roll during ascent. At apogee, the vehicle's drogue parachute was deployed and the vehicle was observed on its decent to 1100 feet. At this point, the ARRD activated and released the middle airframe and fin section from the upper airframe and nosecone. Moments after, the 36 inch main parachute for the upper airframe and nosecone was deployed at its target altitude of 1000 feet and the 48 inch main parachute for the fin section and middle airframe was deployed at its target altitude of 700 feet. Once the range was cleared, the vehicle was retrieved and post-launch checklists were initiated. Images from this flight as shown in **Figure 12** and **Figure 13**.

Figure 12 Full-Scale Test Flight Launch

Figure 13 Full-Scale Launch Vehicle Retrieval

Altimeters were connected to data transfer programs for detailed flight analysis. Stratologgers were first evaluated using PerfectFlite DataCap. From the primary CF, it was determined that apogee occurred at 3345 feet in 14.55 seconds with a flight time of 85.3 seconds and a maximum velocity of roughly 560 feet per second. The secondary SL100 altimeter showed nearly identical results. The plot for only the CF is shown in **Figure 14** due to the strong similarities between the two plots.

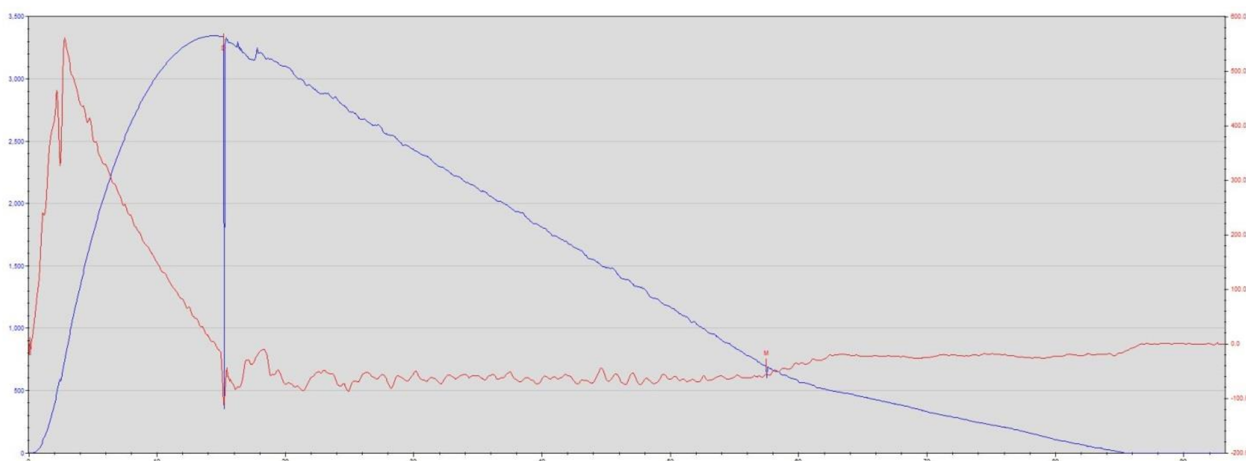

Figure 14 Stratologger CF Altitude and Velocity vs. Time

The curve for the CF indicates a large pressure spike at the drogue event. The orientation of the altimeters on the sled places the CF closest to the black powder charges that detonate at apogee. Because of this, it is believed this altimeter received the largest effects from the blast. Although it did not affect the performance of the altimeters, this pressure spike should be eliminated or at least reduced by sealing the compartment during charge detonation with a weather stripping at the top of the avionics sled. If this is not sufficient to reduce the spike, the Stratologger altimeters are programmed with a spike recognition. If the pressure spike does not last longer than a pre-determined amount of time, the altimeter recognizes that is not at that indicated altitude and proceeds to activate the main charge at the set altitude.

Comparing actual to predicted results, the data validates the design and performance for a successful mission based on the selected atmospheric and environmental conditions expected. Recorded apogee overshot expected by 156 feet. An overshoot was preferred as weight was added after the test flight from painting. This also compensates for any future ballast that may be necessary to achieve a 1.7 caliber static margin at the Huntsville launch site. Maximum velocity was approximated from PerfectFlite which makes the 560 feet per second value well within the predicted range. Total flight time was remarkably close to predicted values, only differing by 2.2 seconds.

Using AIM USB 3.01, the Entacore altimeters' data showed different results. Apogee for the primary was determined to be 2798.88 feet achieved in 15.5 seconds with a maximum velocity of 462.97 feet per second. These results closely matched the redundant Entacore's as well and are shown in **Figure 15**.

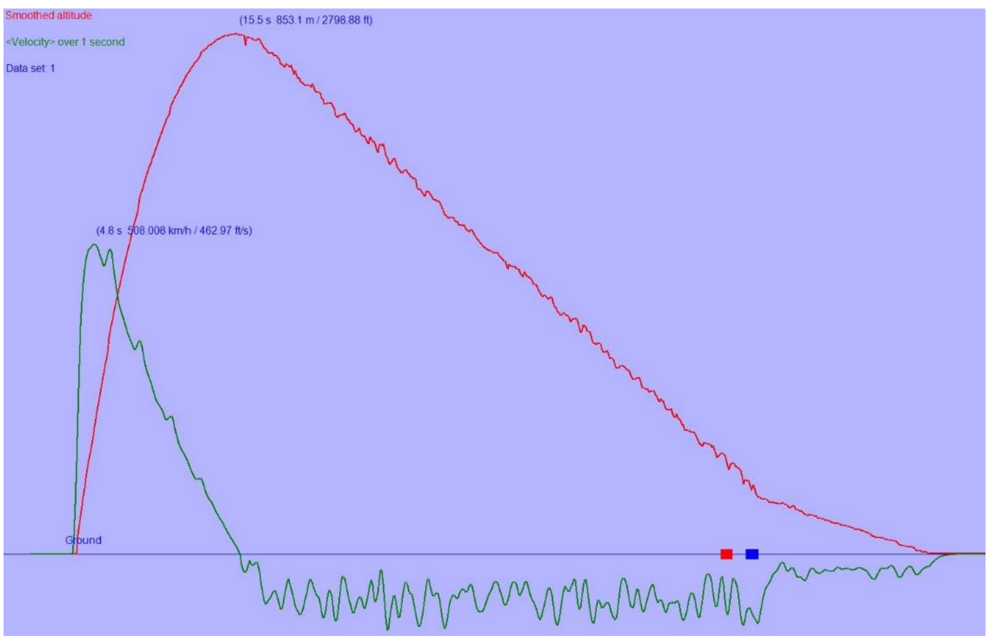

Figure 15 Entacore AIM 3.0 Data

These readings largely differ from the Stratologger's. This could be due to the calibration and hardware for the pressure sensors from each brand. Although the total altitude was much lower, the overall trend of readings is accurate. Also, the altitudes read for the ARRD and 36 inch main parachute event sequenced perfectly with the Stratologger's on the decent making for a successful recovery system.

3.2.5 Mass Report

Table 2 Mass Report

Component	Pounds	Ounces
Nosecone	1	1 1/8
Upper and Mid-Section (Empty)	3	13
Fin Section	4	8 5/8
Motor	3	6 2/5
Parachutes	1	3 1/8
Shock Cord and Recovery Hardware	1	7
Avionics Hardware	4	4 3/4
General Hardware	0	13 3/8
Total	19	14 2/5

3.3 Recovery System

3.3.1 Robustness of Structural Components

Bulkhead construction techniques were previously described in section 3.1.1. As confirmed by the club's two mentors, 3/8 inch thick bulkheads would be sufficient for the mission criteria and vehicle mass during all regimes of flight.

All three parachutes are constructed from 1.1 ounce Ripstop nylon. The 18 inch parachute uses braided nylon shroud lines rated for 330 pounds attached to a swivel rated for 1000 pounds. The 36 and 48 inch main parachutes use braided nylon shroud lines rated for 400 pounds. The 36 inch parachute uses a 1/2 inch nylon bridle attached to a 1000-pound-rated swivel while the 48 inch parachute uses a 5/8 inch nylon bundle attached to a 1500-pound-rated swivel.

3.3.2 Electrical Elements

Each avionics compartment contains one primary and one redundant altimeter. The upper avionics compartment contains two Entacore AIM 3.0 altimeters. Each altimeter is wired such that the main charge port is connected to the terminal blocks on the top bulkhead. These terminals are then connected to the black powder charges and are responsible for the 36 inch parachute event at 1000 feet. The secondary charge ports are wired to the terminal blocks on the bottom bulkhead of the avionics bay. From these terminals, e-matches connect to the ARRD and are programmed to detonate at 1100 feet.

The lower avionics compartment houses one Stratologger SL100 and one Stratologger CF. Each is wired such that the main charge port is wired to the terminal blocks on the top bulkhead. These terminals are then connected to the black powder charges and are responsible for the 1.5 foot drogue parachute event at apogee. The drogue charge ports are wired to pass through the bottom bulkhead of the lower avionics bay and connect to the terminal blocks on the bulkhead and the aft section of the middle airframe. These terminals are then connected to the black powder charges responsible for the 48 inch main parachute event at 700 feet.

Switch placement is described in section **3.1.2.** To activate the switches, a flathead screwdriver is inserted through two small holes drilled through the body tube and avionics bay that simultaneously act as pressure ports. The screwdriver fits into the slots of the switches and is rotated clockwise from the 110 setting to the 220 setting.

3.3.1 Redundancy Features

The upper avionics bay has the Entacore with serial number 585 designated for primary charges and the other with serial number 721 as the redundant. Entacore 585 has the main charge (A) set to separate the nosecone from the upper airframe at a primary altitude of 1000 feet and the secondary charge (B) for the detonation of the first e-match in the ARRD at 1100 feet. The Entacore 721 has the main charge (A) set to separate the nosecone from the upper airframe at a redundant altitude of 900 feet and the secondary charge (B) for the detonation of the second E-match in the ARRD at 1000 feet.

The lower avionics bay houses the Stratologger CF designated for primary charges and the Stratologger SL100 for redundant charges. The CF has an apogee charge set to activate with a 1 second delay and the main charge at 700 feet. The SL100 has a redundant apogee delay of 2 seconds and a redundant primary charge set to activate at 600 feet.

3.3.2 Parachute Sizes

The vehicle will incorporate three parachutes. The drogue is 18 inches across, the upper airframe-nosecone main parachute is 36 inches across, and the fin section-middle airframe main parachute is 48 inches across.

3.3.3 Electrical Schematics

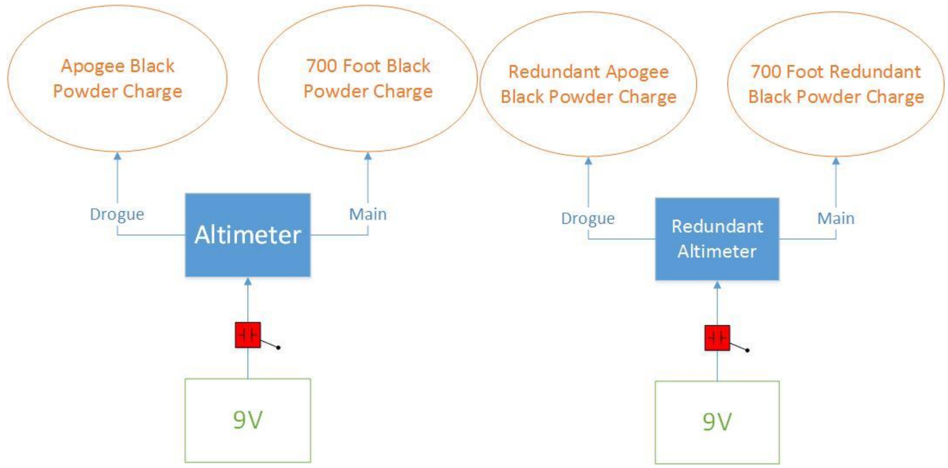

Figure 16 Electrical Schematics for Fin Section and Middle Airframe

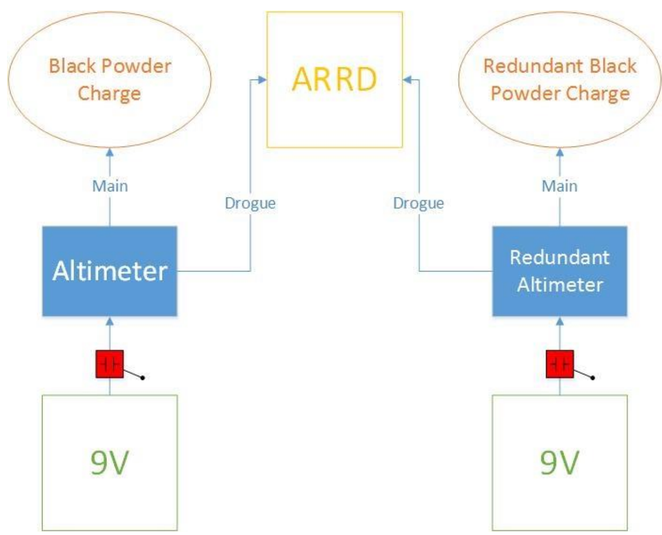

Figure 17 Electrical Schematics for Upper Airframe and Nosecone

3.3.4 Rocket-locating transmitters

In order to track the separate sections of the launch vehicle, we will be using 2 BigRedBee 900 MHz 250 mw GPS Units. These units are completely independent of all systems in the rocket, and are self-powered. They will transmit well beyond the needed radio range. Data from both the GPS units will be read by one receiver, which we can hook up to a computer and monitor the vehicle's movement in real time (**Figure 18**).

Figure 18 Forward and Rear Section GPS Transmitters and Receivers

3.3.5 Sensitivity to Electromagnetic Fields

To prevent interference between the closely mounted altimeters and GPS unit in the lower avionics bay, both sides of the lower avionics bay's bottom bulkhead were covered with a layer of adhesive aluminum foil. This shielding method has been used by teams in previous years with success and was used for this year's full-scale flight as well. The shielding can be seen below in **Figure 19**. The GPS unit mounts to the three wood screws shown, just outside the lower avionics bay. For the upper airframe, the GPS unit was placed above the nosecone bulkhead. This is a considerable distance from the upper avionics bay so no shielding was used. All altimeters and GPS units functioned as planned thus validating both methods.

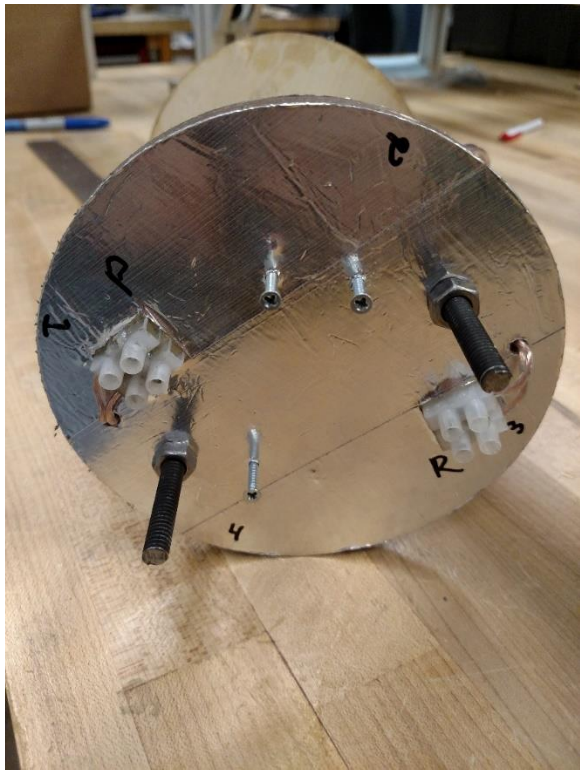

Figure 19 Shielded Bottom Bulkhead of Lower Avionics Bay

3.3.6 Parachute Sizing

The parachutes are deployed in a specific chain of events dependent on vehicle altitude during flight. Once at apogee, the lower avionics bay will be responsible for the 18 inch drogue parachute event. The vehicle will descend with the middle airframe and fin section attached to the upper airframe and nosecone by shock cord until 1100 feet. At this point, the upper avionics bay will activate the ARRD which will separate the fin section and middle airframe from the upper airframe and nosecone. At 1000 feet, the upper avionics bay will detonate a charge responsible for deploying the 36 inch main parachute that will be connected to the upper airframe and nosecone. The fin section and middle airframe will continue to descend until 700 feet where the lower avionics bay will detonate a charge to deploy the 48 inch main parachute that connects the two. Prior to the full-scale test flight, ejection tests were performed for all three planned events. Using the equation,

$$BP = Volume\ x\ 0.007$$

where BP is amount of black powder in grams and volume is the volume of the parachute bay in cubic inches, the proper amount of black powder necessary for ejection at each event was determined. The drogue parachute was found to need 1.2 grams of black powder, the nosecone parachute needed 2.0 grams, and the fin section needed 1.2 grams.

Figure 20 Example of Ejection Test

The FMECA tables are located in Appendix ##.

3.4 Mission Performance Predictions

3.4.1 Flight profile simulations, altitude predictions, and motor thrust curve

Figure 21shows the predicted flight profile for Huntsville, AL. Using the data received from the full scale test flight and transferring that to the warmer climate of Huntsville, AL, the predicted altitude is 3,068 feet. The maximum velocity will be 520 feet per second, with a maximum acceleration of 302 feet per second squared. This flight profile also uses our total vehicle weight and correct stability margin.

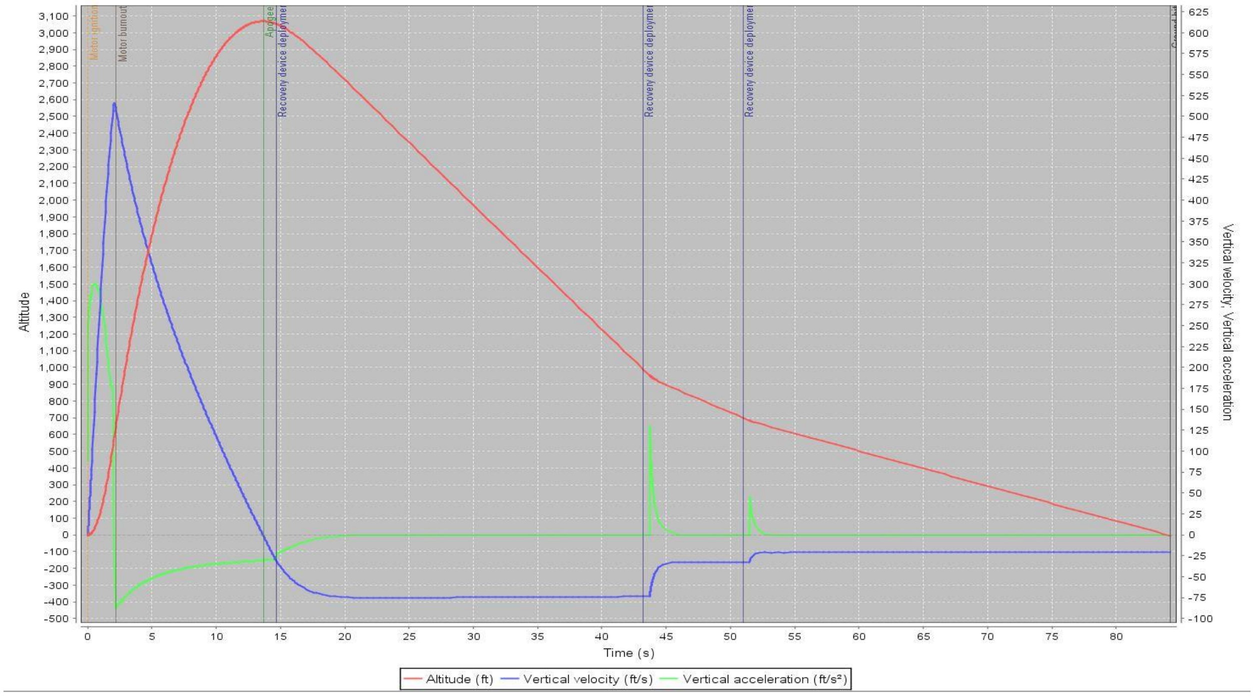

Figure 21 Flight Profile Simulation for Huntsville, AL

The thrust curve for the AeroTech K805G is given in **Figure 22**. This gives a maximum thrust of 180 pounds and an average thrust of 163 pounds.

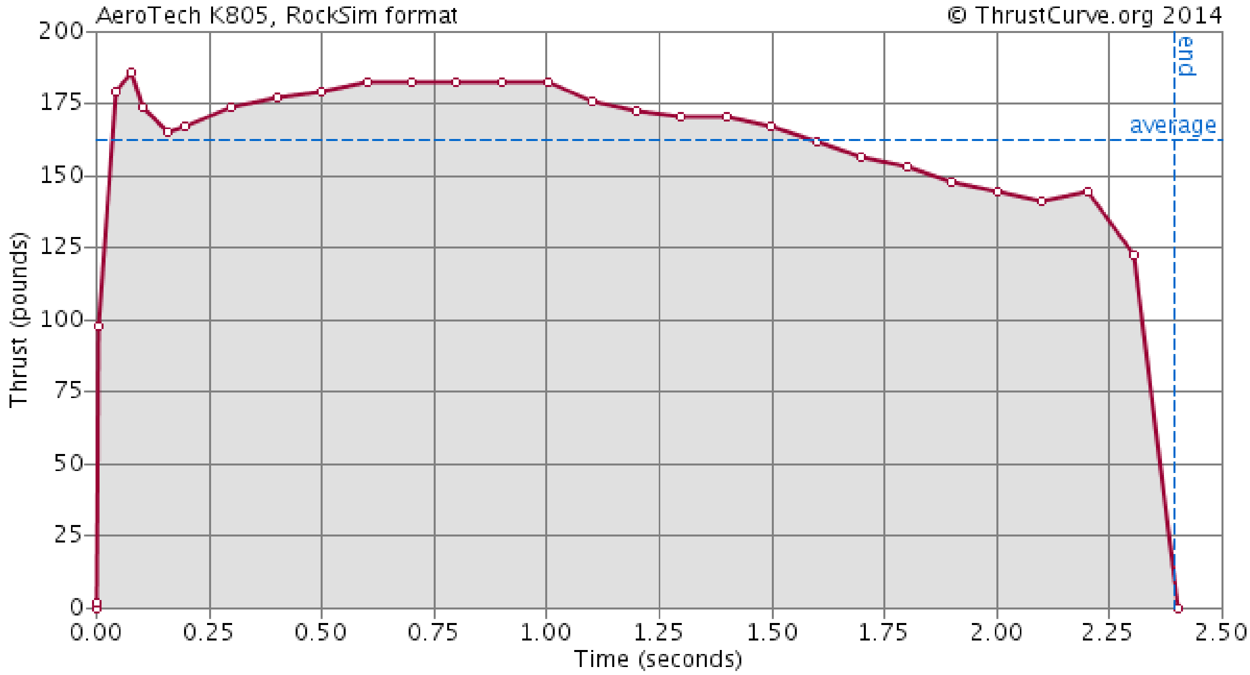

Figure 22 AeroTech K805G Thrust Curve

3.4.2 Drag Assessment

The full scale rocket model was analyzed using computational fluid dynamics in the ANSYS Fluent software package. The rocket was run at two different angles of attack, zero degrees and three degrees. The rocket was cut out of an inner domain, and the rocket and inner domain were both placed within an outer domain as can be seen in **Figure 23**.

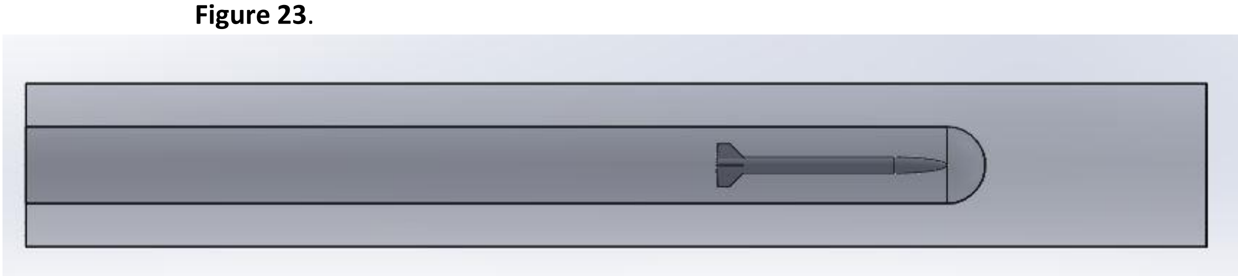

Figure 23 Inner and Outer Domain Model in Solidworks

The rocket was modeled as an open section and the two domains were modeled as fluids. The two domains were used so that the model could be meshed finer close to the rocket and coarser farther away. This was necessary to reduce computational time required and to keep the model under the 1.5 million element limit given by the Student License of ANSYS. The model was run with 1.3 million elements with the element size for the outer domain, inlet, and outlet set at 3 inches. The inner domain was set at 1.5 inches and the element size for the rocket was given to be 0.25 inches.

The model was then run using the Spalart-Allmaras equation. The velocity magnitude at the inlet was set to 700 feet per second. The reference values used were one foot squared for the area, and one foot for the length. The model could be farther refined by using better reference values, but was not needed because of the closeness of the results to expected actual values. While running 1000 iterations the residuals, drag coefficient, lift coefficient, and the moment coefficient were monitored to make sure they had an absolute convergence of 0.0001. The hybrid initialization was used and 1000 iterations were set as the limit for convergence. All of the cases that were run converged by 1000 iterations which gave confidence in the results.

The results were then visualized in the ANSYS Fluent post processing software. **Figure 24** shows the results of a pressure contour across the body of the rocket between -104 pounds per square foot and 104 pounds per square foot. This shows the stagnation pressure at the nose and high pressure zones at the base of the fins along the leading edge. The symmetry of the pressure contours along the rocket gave us confidence in the aerodynamic design of the rocket.

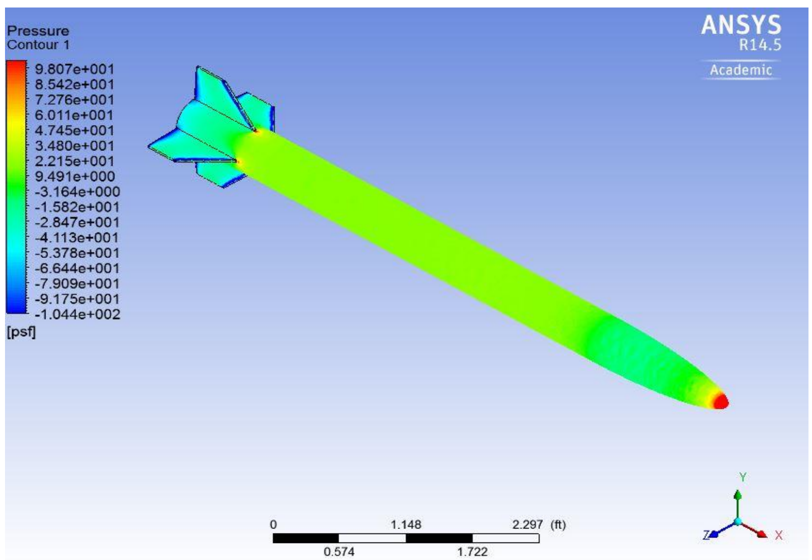

Figure 24 Fluent Model of the Pressure Contour at 700 feet per second at 0 Degree Angle of Attack

The model was then analyzed with a volume rendering of the velocity along half the rocket. As it can be seen in **Figure 25**, the velocity stayed fairly consistent at 700 feet per second except at the nose of the rocket, and directly behind the rocket which was expected for our model. In **Figure 26**, a volume rendering was analyzed using pressure contours along half of the rocket. The results are the same as the pressure contours along the body as seen above. This visualization was used as a redundant check to the first analysis of the pressure.

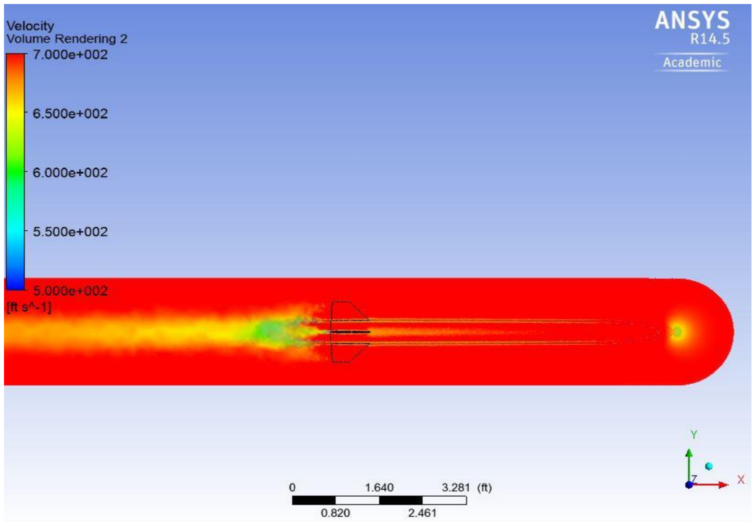

Figure 25 Half Rocket Fluent Model of the Velocity Contour at 700 feet per second 0 Degree Angle of Attack

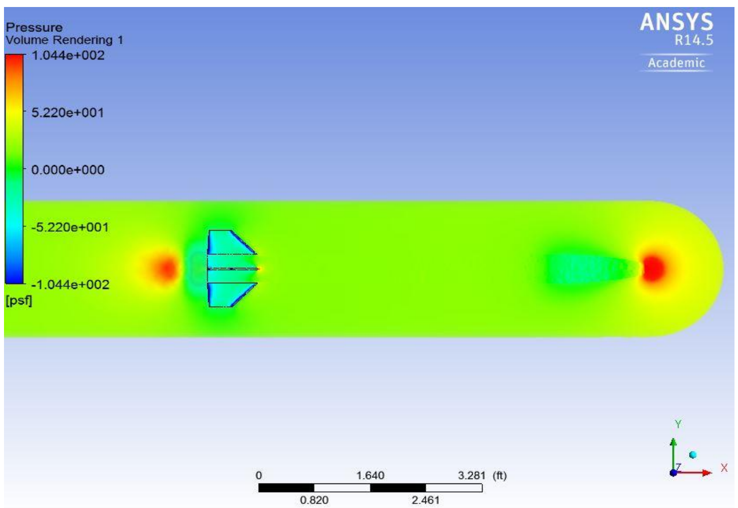

Figure 26 Half Rocket Fluent Model of the Pressure Contour at 700 feet per second at 0 Degree Angle of Attack

The same three cases were then run for an angle of attack of three degrees. These results can be seen in **Figure 27**, **Figure 28**, and **Figure 29**.These models were run to have multiple moment coefficients and lift coefficients. These coefficients were used to find the static margin to verify the results from Barrowman's equations and OpenRocket.

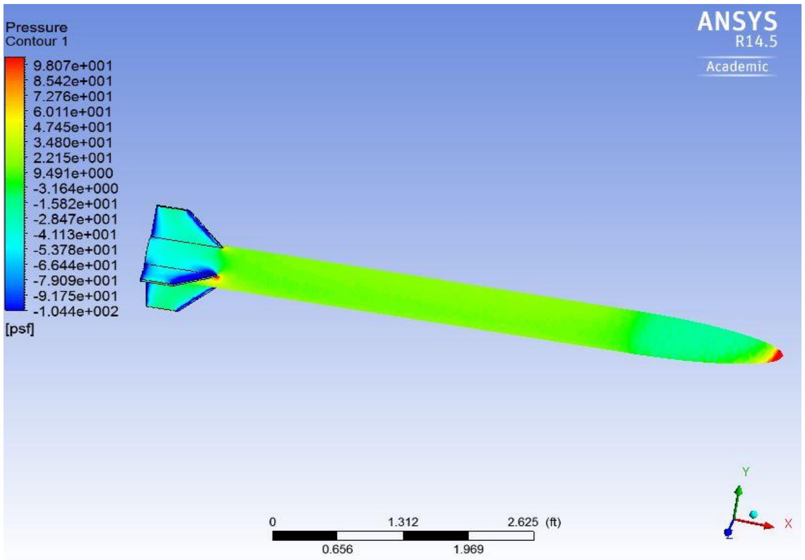

Figure 27 Fluent Model of the Pressure Contour at 700 feet per second at 3 Degrees Angle of Attack

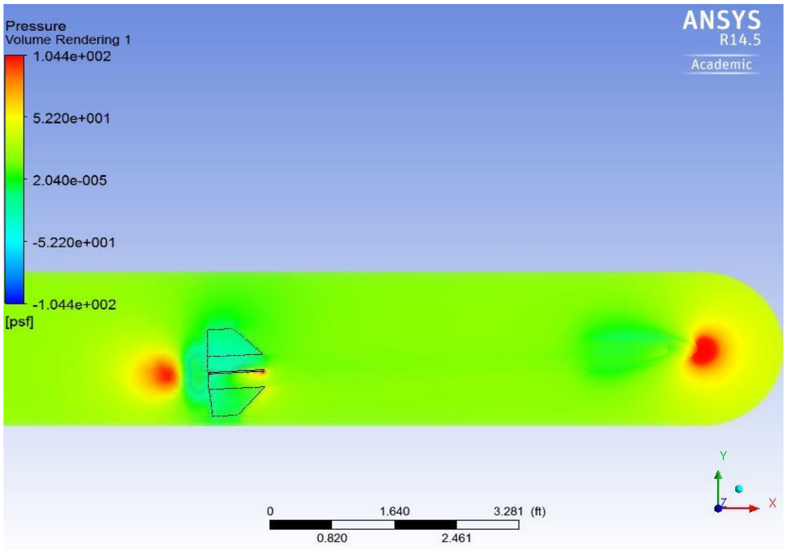

Figure 28 Half Rocket Fluent Model of the Pressure Contour at 700 feet per second at 3 Degrees Angle of Attack

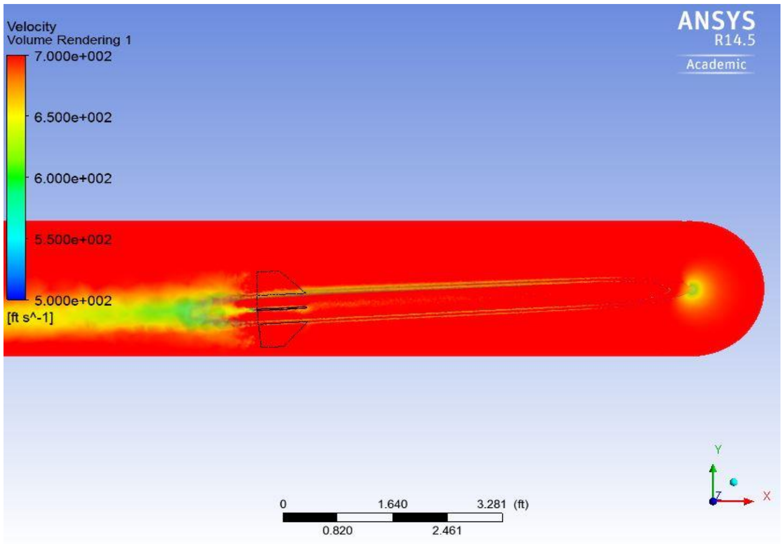

Figure 29 Half Rocket Fluent Model of the Velocity Contour at 700 feet per second at 3 Degrees Angle of Attack

The results from ANSYS were then exported as an excel document in order to be imported into a MATLAB code, written by Lars Soltmann, who is an Aerospace Engineering Doctoral student, for finding the resulting coefficients. The MATLAB code returned the lift, drag, lift coefficient, drag coefficient, and moment coefficient of the vehicle. The drag on the vehicle was found to be 82 pounds at zero angle of attack and 84 pounds at a three degree angle of attack. The coefficients can be seen in **Table 3** below.

Table 3 Coefficients from Fluent

	0 Degree AOA	3 Degree AOA
CD	0.0705	0.0726
CL	-0.000612	-0.000426
CM	0.00165	0.000101

Using the coefficients found from the MATLAB code, the static margin was verified to be 1.53. Barrowman's equations and OpenRocket gave a static margin of 1.7 calibers. This slight difference in the static margin can be attributed to the refinement of the Fluent model. This model needs to be further refined in order to be more accurate, but the results give confidence in the design and model.

3.4.3 *Stability Margin, CG location, and CP location*

The stability margin for our full scale vehicle was 1.7 calibers found by subtracting the difference in the CG *(46.5 inches from the nose) and the CP (56 inches from the nose), and then dividing by the main body diameter of the vehicle (5.5 inches). The CG is shown on* **Figure 30** *and is denoted by dowel pin and the CP is denoted by the red circle.*

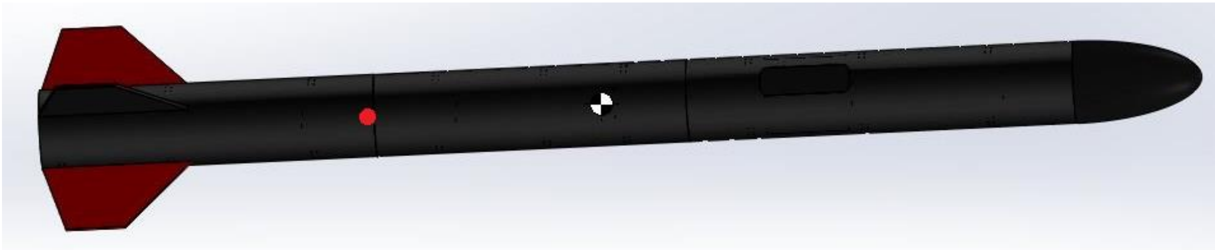

Figure 30 CG and CP Location

3.4.4 Kinetic Energy and Descent Rates

The kinetic energy of each part of the rocket during different stages in the recovery operation was found by squaring the velocity of the component and then multiplying it by half of the mass. This yielded the results in **Table 4**.

Table 4 Kinetic Energy and Descent Rates

Stage #	Lower Airframe Kinetic Energy (foot-pounds)	Upper Airframe Kinetic Energy (foot-pounds)	Decent Rates of Lower Airframe (Feet/second)	Decent Rates of Upper Airframe (feet/second)
Stage 1 (Apogee-1100 feet)	1342.4	1342.4	71.8	71.8
Stage 2 (1100 – 1000 feet)	--	524.5	--	56.8
Stage 3 (1000 – 700 feet)	48.8	524.5	22.3	56.8
Stage 4 (700-0 feet)	48.8	66.8	22.3	18.7

*Note, because the upper and lower airframes are connected during stage 1 of the recovery sequence, the kinetic energy and decent rates of the two connected pieces is shown in both columns.

3.4.5 Wind Effects

The maximum altitude for all components (upper airframe, middle airframe, and fin section) will be at the projected apogee of 3000 feet.

A MATLAB code was written to determine the lateral drift of the two parts of the rocket that come down separately. This drift would be caused by wind, or by both wind and a launch angle of 5° upstream or downstream of the wind. Wind speeds of 0, 5, 10, 15, and 20 miles per hour. Using the C_d of the various parachutes (1.55 for the 18", and 1.5 for the 36" and the 48"), assuming that the density of air stays constant at 0.002377 slugs/feet^3, and assuming that drag equals weight, the terminal descent velocity was obtained by utilizing the equation

$$V_{Term.} = \sqrt{\frac{2 * Drag}{C_d * \rho * Area}} \qquad \text{Equation 1}$$

The terminal velocities of the different parachute set-ups were as follows:
-71.8 feet per second for the drogue slowing the rate of the entire rocket at apogee
-56.76 feet per second for the drogue slowing the rate of only the lower airframe
-22.3 feet per second for the 36" main slowing the upper airframe
-18.7 feet per second for the 48" and drogue slowing the lower airframe

Using these descent velocities of the various configurations that the rocket undergoes after apogee, the amount of time that the decent would take was derived; this time was multiplied by the hypothetical wind speed to get an approximate drift radius for the two parts of the rocket that come down separately. These distances are shown in **Table 5**.

Table 5 Lateral Drift Due to Wind, 0 Degree Launch Angle

Wind Speed (Miles per Hour)	Lateral Drift of Upper Airframe (feet)	Lateral Drift of Lower Airframe (feet)
0	~0	~0
5	522	521
10	1045	1041
15	1567	1562
20	2089	2083

Once the 0° Launch Angle drift radii were found, it was necessary to determine the drift distances with the Launch angle of 5°. A simulation was run in OpenRocket, as shown in **Figure 31**, where the wind conditions were set to zero, and the launch angle was set to 5°. The lateral distance shown (roughly 640 feet from launch rail) was then added to or subtracted from (depending on launch direction) the wind drift values found above to get a total drift radius once wind and launch angle were taken into account. These values are shown in **Table 6** and **Table 7**.

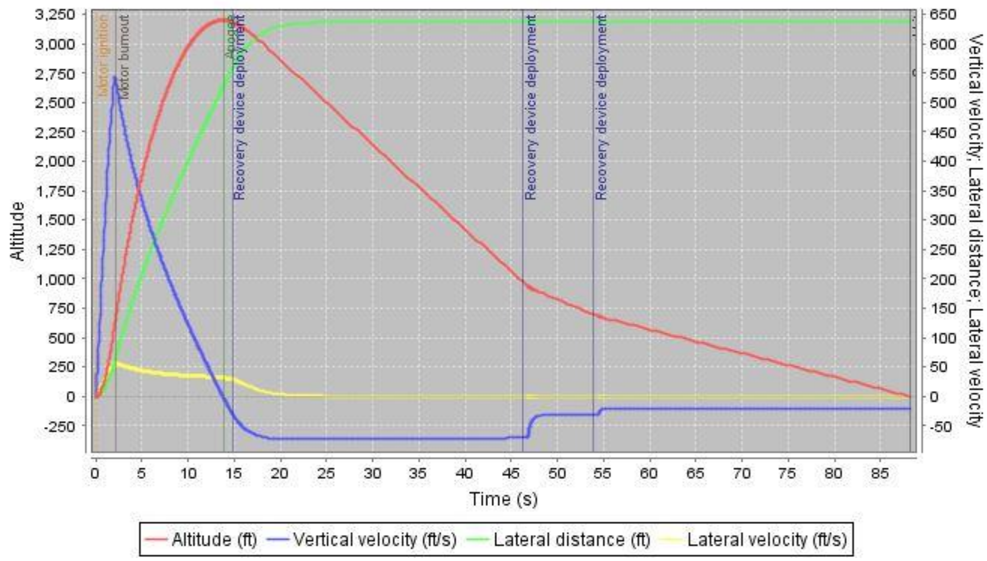

Figure 31 OpenRocket Simulation showing Zero Wind Conditions, with 5 Degrees Launch Angle

Table 6 Lateral Drift Due to Wind, 5 Degree Launch Angle into the Wind

Wind Speed (Miles per Hour)	Downstream Lateral Drift of Upper Airframe (feet)	Downstream Lateral Drift of Lower Airframe (feet)
0	641	640
5	79	78
10	698	695
15	1317	1313
20	1936	1930

Table 7 Lateral Drift Due to Wind, 5 Degree Launch Angle with the Wind

Wind Speed (Miles per Hour)	Downstream Lateral Drift of Upper Airframe (feet)	Downstream Lateral Drift of Lower Airframe (feet)
0	641	640
5	1159	1158
10	1778	1775
15	2397	2393
20	3016	3010

Due to the 2500 foot drift limitation, it has been decided that if the rocket has to necessarily be launched in the same direction as 20 mile per hour wind, the ARRD will separate at 800 feet instead of 1100 feet, the 36 inch parachute will deploy at 700 feet, and the 48 inch parachute would deploy at 500 feet. This would result in maximum drift radii of 2457 and 2479 feet for the upper and lower airframe, respectively.

Variations in wind also affect the apogee of the rocket. Using simulations in OpenRocket, we were able to predict how wind speed effects the apogee of the rocket launching with a launch angle of 5°. The results of these simulations are shown below in **Table 8**.

Table 8 Apogee Differences due to Variations in Wind Speed

Wind Speed (Miles per Hour)	Apogee (feet)
0	3227
5	3196
10	3151
15	3102
20	3057

3.5 Verification (Vehicle)

3.5.1 Vehicle Verification

The verification matrices for the vehicle can be found in **9.3.**

3.6 Safety and Environment (Vehicle)

3.6.1 Safety and Mission Assurance Analysis

The FMECA diagrams can be found in **9.2**. In terms of structures, the nosecone separating prematurely from the vehicle may result in the parachutes being deployed too early. If the vehicle is still in the thrusting phase, then the parachutes or other structural components may be damaged if the parachutes deploy prematurely as well. Because this error will most likely occur as a result of poor handling or maintenance, this error is unlikely if the team properly handles the nosecone. As for the recovery system, a malfunction in the avionics due to a dead battery has some of the worst consequences. If the altimeters do not function, then the black powder charges will not go off, resulting in a failure of the parachutes being deployed. As a result, the vehicle may be destroyed or it may damage other objects as it falls back to the ground. Unfortunately, dead batteries are likely if the team is not careful. However, replacing the batteries is in the checklist, making this error unlikely.

A third significant failure mode is the separation of the vehicle from a parachute due to a failure in the bulkhead and/or U-bolt. Similar to the failure in the altimeters, the vehicle separating from a parachute may result in significant damage to the vehicle or other objects (including personnel). Because the team thoroughly tests all epoxied joints and U-bolts for this failure, this is unlikely to occur during the competition. Furthermore, the motor breaking through the bulkhead would cause catastrophic failure of the vehicle. If the propellant escapes the motor housing, then the vehicle will most likely be destroyed. The team realizes this risk and will ensure that the motor block is structurally sound. Finally, a miscalculation of the static margin may result in the vehicle flying in an unexpected path. A drastic miscalculation of this value may even cause the vehicle to tumble. An unsuccessful flight would result in a failure of the overall mission and would thus have severe consequences. However, this failure mode is unlikely since the team has already flown a successful demonstration flight of its full-scale vehicle.

3.6.2 Personnel Safety Hazards

As more construction occurs, the team will be exposed to potentially-dangerous machines. An outline of these construction hazards is located in **9.7**. In building the vehicle, the team will also be exposed to hazardous materials such as black powder and epoxy. The MSDS sheets for such materials are included in **9.5**. In order to mitigate the risks associated with these materials, the team will follow the procedures outlined within the documentation. Furthermore, the personnel hazards on the launch site are described below in **Table 9**.

Table 9 Launch Site Personnel Hazards

Safety Concern	Mitigation	Confidence
Assembly of Rocket Motor	The rocket motor is carefully carried from the car to the rocket assembly point under close supervision by other team members and Alan. During assembly, all points specified by the manufacturer's instructions are followed step by step.	Assembling the rocket motor is a critical procedure to ensure the safety and success of the launch. Special attention to manufacturer's as well as advisor's instructions ensures the motor ignites and burns properly.
Handling of Vehicle	Two hands are used to transport each component when taking the rocket from the car to the assembling area. Electronics and blast caps are armed and filled shortly before launch.	Cautious handling protects the rocket from falls that could damage components and harm the launch.
Launch Vicinity	Monitoring the location of everyone that is in attendance on the launch site and preventing them from getting to close will be a simple task by giving warnings prior to launch.	This concern is mitigated by having set distances specified by launch officials.
Weather	For every launch we make sure that the conditions such as wind	Proper weather forecast monitoring and monitoring the

	speed, precipitation, and temperature are within safe limits of operation.	weather at the launch site will eliminate the risk of weather.
Location	Launches are only done at locations specified by the North Carolina Rocketry Association or NASA Student Launch.	We are confident in these organizations to choose proper locations for launches.

3.6.3 Environmental Concerns

A thorough discussion of the environmental concerns of the project are described in section **5.2.3.**

3.7 AGSE Integration

3.7.1 Integration of the AGSE into the Launch Vehicle

In terms of static integration, the launch vehicle will integrate with the AGSE through two launch rail buttons and a rear fin section support. The large airfoiled rail buttons, purchased from Apogee Rocketry, match the profile of the 80/20 t-slot aluminum launch rail. The rear fin section support will serve two functions. First, it will prevent the vehicle from sliding down the launch rail during the raising process. Second, the rear support will reduce side to side movement of the vehicle on the launch rail during sample insertion and closing of the payload door.

Moving on to dynamic integration, the AGSE begins by identifying the sample location. Using a USB camera, the image processing system will identify the sample and relate the sample size in the image to the location of the sample. The robotic arm will move to this position and grasp the sample at its center. Both the image processing and the arm movement calculations are done on the BeagleBone Black in real time. With the sample in the arm's gripper, the sample will be placed in a mold inside the opened door of the vehicle. The arm will then close the door which locks into place using three neodymium magnets. This progression can be seen in **Table 10** below.

Table 10 AGSE Progression

Main Task
BeagleBone Control
Power on a System
Power off a System
Switch Verifying Progress

Start System

Start BeagleBone subroutines and verify all devices are working

Grab the sample

- Power on arm and camera
- Arm and imaging startup program
- Find sample
- Move arm closer to sample
- Find sample, move, repeat until close
- Grab sample with gripper

Insert sample in rocket

- Move sample to mold in rocket with arm
- Place sample into the mold inside the rocket
- Release hand
- Close rocket door with arm
- Trigger switch to verify door is closed
- Move arm to preset location out of rocket path.
- Power off arm and camera

Raise the rocket

- Power on stepper motor
- Run stepper motor
- Trigger verticality switch when rocket at desired position
- Power off step motor

Insert the igniter

- Power on igniter motor
- Operate igniter motor until igniter is in position
- Power off igniter motor

System ready to launch

Once the sample is secured, the vehicle will be raised using the gearing system on the AGSE. The stepper motor used to raise the vehicle will stop when the vehicle has reached 5° from vertical. Ratcheting stops on the base of the AGSE will prevent the launch rail from falling down which could potentially damage the vehicle or the AGSE and cause harm to any ground personnel. The AGSE will then insert the igniter into the motor autonomously using a 1/8 inch wooden dowel and linear actuator system.

3.7.2 Compatibility of Elements

Dimensionally correct CAD models of the RobotShops robotic arm and LynxMotion gripper were used to ensure that the real robotic arm will interface properly with the payload compartment and launch vehicle. In **Figure 32** below, the gripper is shown placing the sample into the payload compartment. In this configuration, the robotic arm has sufficient space to clear the open payload compartment and door.

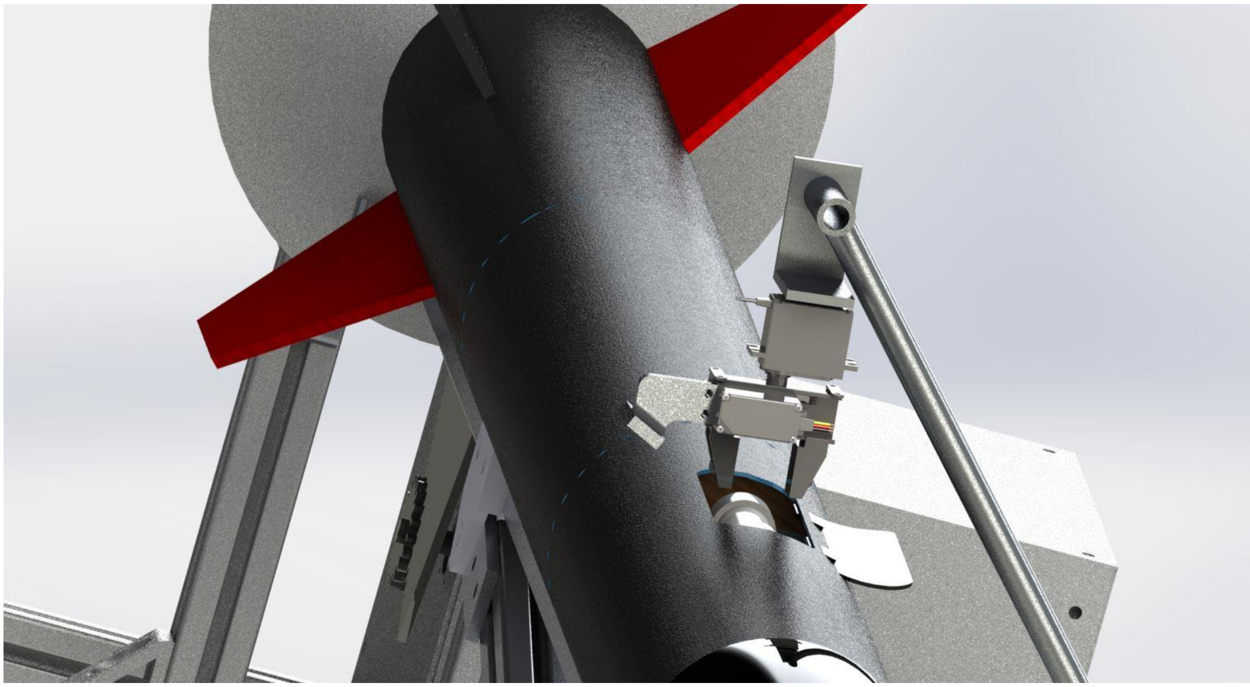

Figure 32 Robotic Arm Gripper Placing Sample into Payload Compartment

In **Figure 33**, included below, the robotic arm is shown closing the payload compartment door. Testing will be done to find the robotic arm locations necessary to produce the desired pushing motion to close the door. Using magnets as the locking mechanism, the robotic arm will need only need to rotate the door just past vertical. After this point, gravity and magnetic forces will take over, securing door shut.

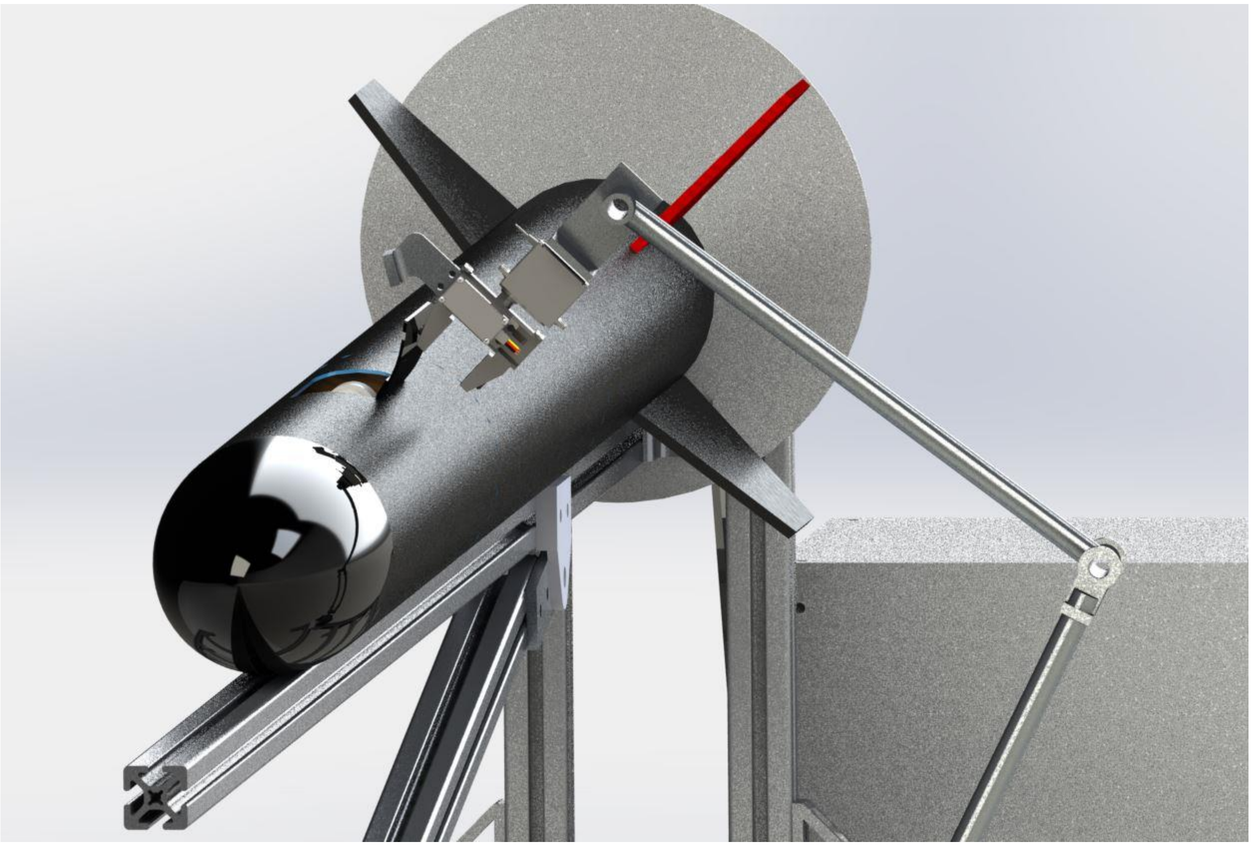

Figure 33 Closing the Payload Compartment Door

3.7.3 Payload-Housing Integrity

A thorough description of the payload compartment construction process can be found above in section 3.1.1. Due to the fact that this section of the vehicle underwent thorough design review and had a small team involved in its accurate and meticulous construction, we can ensure that it is of sound integrity. To ensure that the compartment door remained attached during the entire flight and recovery process, the hinges were secured using screws and epoxy. Strong Neodymium magnets are used to hold the compartment door shut during the entire flight and both static and flight tests have confirmed that the magnets are strong enough to hold the door shut. These tests have also confirmed that these magnets do not cause any interference with the onboard electronics. The mold for the payload was custom-made to fit the sample exactly within the payload compartment. Because there is less than a 1/8-inch gap between the sample and the door, the sample will be unable to move around and damage any surrounding equipment. The full-scale flight test has proven the integrity of the payload housing and the team is confident in the integrity of the design.

4 AGSE/Payload Criteria

4.1 Experiment Concept

4.1.1 Creativity and originality

Although each subsystem is not revolutionary, they are all put together in a way that makes the team's design unique. For example, the rocket will be raised using a large gear system, and the igniter will be inserted with a threaded rod system. These systems provide effective mechanical means of preparing the vehicle for launch without increasing the modes of failure due to a complex electrical system of motors and actuators. The team has also expressed its creativity in making the entire AGSE out of aluminum railing, allowing the platform to be efficiently assembled. The originality of the ratcheting stops is a creative solution to the problem of the vehicle falling back down onto the AGSE. Furthermore, the arm will be able to adapt to different orientations of the sample through the use of the imaging system. Rather than hard coding in the location of the PVC and only having the arm move to that specific location, the arm will move to a unique location each time.

4.1.2 Uniqueness or significance

The image processing system adds significant difficulty to the system. Teams have the option to place the sample in a measured location and hardcode this position into their system. However, predefined locations could struggle with unanticipated terrain or weather; wind or ground slope could move the sample from the pre-set location and cause the entire AGSE to fail because the sample could not be obtained. The imaging system developed by the team will accommodate these issues by locating the sample in real time during the autonomous procedures. While this adds a significant level of challenge and system complexity, the team believes this task is worthwhile because it adds to the reliability of the system while expanding the technical knowledge of the team to areas outside high-powered rocketry.

4.2 Science Value

4.2.1 Describe AGSE/payload objectives in a concise and distinct manner.

The goals of the AGSE are to: 1) retrieve a sample,2) insert and secure the sample into the vehicle's payload compartment autonomously, 3) erect the vehicle to 85 degrees from horizontal, 4) insert the motor igniter for launch. On Mars, or any other distant body, a similar process will need to be done so that a soil sample can be processed on Earth. After obtaining a soil sample, the sample will need to be placed into orbit so that it can rendezvous with another vehicle to bring it back to Earth. This is the ultimate application of the AGSE. Therefore, the processes investigated in the AGSE portion of the experiment have a direct correlation to actual systems that can be used.

4.2.2 State the mission success criteria.

The AGSE will be successful if it can prepare the vehicle for launch and identify, capture, and retain the sample. In addition, all AGSE procedures must be completed in less than 10 minutes. To achieve success with these criteria, the team has placed its own restrictions on the AGSE subsystems. The AGSE must identify, capture, and place the sample into the vehicle within 5 minutes. The vehicle must be raised and the igniter inserted within 90 seconds (45 seconds for each process). Success for the AGSE will only be obtained if these tasks are completed within the time allotted. The 3.5 minutes remaining will be used as a buffer to handle unforeseen issues. Post-launch success criteria include: sample retention through the entirety of the flight including ground impact, deployment of the drogue parachute, separation of the forward section from the drogue via the ARRD, deployment of forward and rear section main parachutes, and low speed ground impact allowing for reusability of the launch vehicle. Mission success will prove the viability of the system as a whole to be implemented in other projects, such as actual sample return missions.

4.2.3 Experimental logic, scientific approach, and method of investigation.

In order for the mission to be a success, each of the subsystems must be thoroughly tested. Creating experiments that verify these subsystems in controlled settings is the best way to test the AGSE. By measuring out predetermined locations for the robotic arm, the accuracy and repeatability of the arms movements can be confirmed. Furthermore, testing the stepper motors under load ensures that they will be able to handle lifting the rocket and inserting the igniter during the competition. These tests were performed under controlled conditions to preserve the relevance and accuracy of the data. However, for the data to be accurate, the results must be repeatable. Therefore, each test will be performed several times in order to collect sufficient data and prove the repeatability of the processes. Each experiment has been and will continue to be approached as if the test were for the actual competition. Improper testing would lead to inaccurate data and failure of the mission, detracting from the scientific value of the project.

4.2.4 Test and Measurements Significance

The AGSE is designed to test the integration of each of the subsystems into a whole process. For example, the AGSE will test how the imaging and robotic systems work together. The success of the mission will be a measurement of the viability of these subsystems. When performing experiments, care was taken to isolate variables to preserve the legitimacy of the test. For instance, when performing the experiment to test raising the vehicle, the pulley was fixed so that it did not provide undesired torque on the stepper motor. As a result, the team could solely test the stepper motor's ability to function under loading. In this case, the weight on the motor was the control, and the time it took the motor to raise the load 12 inches was the variable being tested.

The data was collected using accurate measurements, such as with digital calipers and a gram scale. As described above, other variables to be tested are the amounts of black powder needed, and the accuracy of the robotic arm and imaging systems. The success of the AGSE will be a measurement of the viability of all of the subsystems.

4.2.5 Relevance of Expected Data

The data collected during the experiments will show if the current plan will work. The data is critical to the success of the project, and is thus relevant to the tasks at hand. By using the most-precise instruments available to *the team (such as a gram scale and digital calipers), the team can achieve high levels of accuracy. The gram scale used is capable of measuring to the nearest 0.01 grams, and the calipers can measure to 0.001 inches. Furthermore, by taking measurements of the same items several times, the accuracy of measurements can be increased, while decreasing error. Although there will always be some error in measurements, the team is attempting to minimize that error to preserve the scientific value of the system and relevance of expected data.*

4.2.6 Detailed Experiment Process Procedures

Careful experimentation preserves the scientific value of the experiments and keeps the results indicative of the project. Each experiment followed the general guidelines of any scientific study: A problem was identified. Next, an experiment was formed to test possible solutions to the problem. The experiments were designed to account for any issues that might arise and to test the capabilities of the design. The experiments were then carefully conducted so as to not taint the results. The results were then analyzed to make sure that the initial requirements were met and that the data received was accurate. This process of experimentation is valid for any scientific study, and thus the experimental process procedures have scientific value.

Arm Experiment

In order for the system to be a success, the robotic arm must be able to repeatedly and accurately reach a specified location. In Alabama, this location will be determined by the imaging system. Therefore, in order to test the robotic system, desired locations for the sample could be measured out and having the arm move to those locations would test its accuracy. Furthermore, moving the arm to the desired location several times would test the repeatability of the motion of the arm. The verification of the repeatability and accuracy of the arm was the driving force behind the robotic experiments.

For the robotics experiment, four desired locations were measured, taking the origin to be the pivot point of the shoulder. These locations were (11, 0, -7.7), (15, 0, -7.7), (22, 0, -7.7), and (22, 5, -7.7) inches from the origin. At each location, a replica of the sample was placed to test if the arm could both move to the location and be capable of picking up the sample. The points used test the range of motion of the arm and are comparable to the values that will be used during the competition. Each of the servos on the arm was hooked up to a Lynxmotion SSC-32 servo controller, which in turn was connected to a computer running the SSC-32 Servo Sequencer Utility. The servo controller was powered by a GW Instek GPS-3303 DC power supply set to 10.4 Volts. Although the servos themselves only require 6 Volts individually, running all of the necessary servos at once requires additional voltage. **Table 11** below shows the experimentally-determined required voltages to run the arm's servos simultaneously.

Table 11 Voltages Required to Run the Arm's Servos

Number of Servos	Required Voltage (V)
1	6.4
2	7.0
3	8.6
4	10.4
6	11.4

The angles of the servos required to reach the four specified locations were founded using a MATLAB program developed by the team. After specifying the desired location and the fraction of that distance the user wants the arm to move, the code calculates the servo angles required to reach the position as well as the pulse widths corresponding to those servo displacements. By commanding each joint in the arm to move 90 degrees and measuring the change in pulse widths required for that displacement, calibration factors were found for each servo. These values are 1.488, 1.475, 1.475, and 1.607 for the base, shoulder, elbow, and wrist respectively. The pulse widths that the code outputted were then manually entered into the utility to control the arm. The arm was commanded to go to each location twice. Furthermore, the arm was commanded to go only halfway to the (22, 0, -7.7) inch location to test whether it would move to the correct position while keeping the camera pointed at the sample. As above, this test was successful in that it was able to move to the desired location and move the wrist the desired angle to point the camera at the sample.

The results from the experimentation with the arm showed that the current design will work. The arm was able to reach each of the desired locations within the desired tolerance of 0.3 inches. In fact, the arm was able to encompass the gripper at each of the destinations. **Figure 34** and **Figure 35** show the arm with the gripper at (22, 0, -7.7) and (11, 0,-7.7) inches during the experiment. Therefore, the accuracy and repeatability of the arm was verified from the experimentation. Furthermore, because the code was used to find the required servo angles, the accuracy of the code used to control the arm was verified as well. Separate tests showed that the arm is capable of grabbing the sample and lifting it off of the ground along with the other components that will be mounted to the arm itself (i.e. the camera). It was found that a pulse width of 1820 is required to grasp the sample, and a pulse of 1600 releases the sample level. The strength of the gripper was verified by pinching the sample and then removing the gripper from the rest of the robotic arm. With the sample still in its grasp, the gripper was then manually flung around in different directions and speeds with sudden changes. At the end of the test, the sample was still within the gripper's grasp and experienced movement less than 0.25 inches. Finally, the strength of the arm was also tested to ensure that it could be able to close the door to the sample compartment. By pushing down on a gram scale, it was found that the arm could exert about 3.5 pounds of force. As a result, the testing of the robotic arm verified the design and showed that the arm is capable of reaching all of its functional requirements.

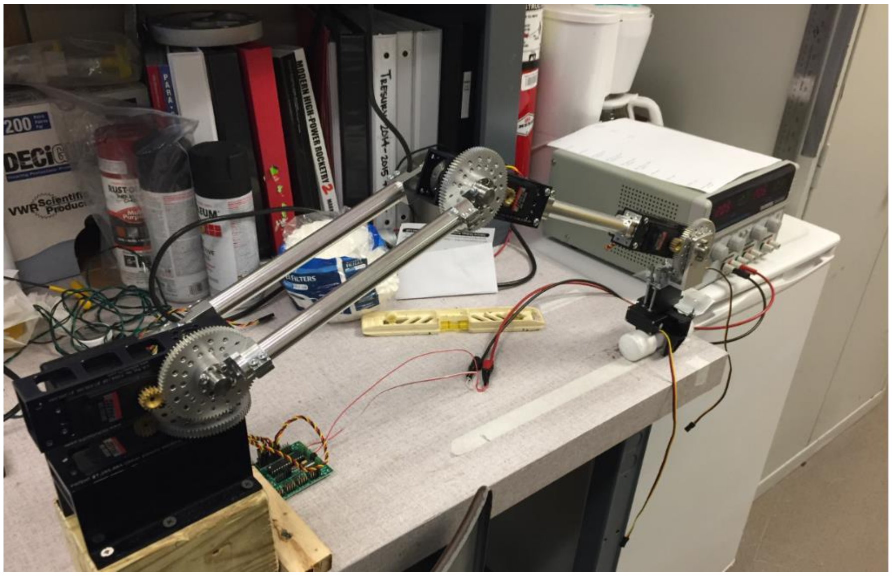

Figure 34 Arm Experiment at (22, 0, -7.7) inches

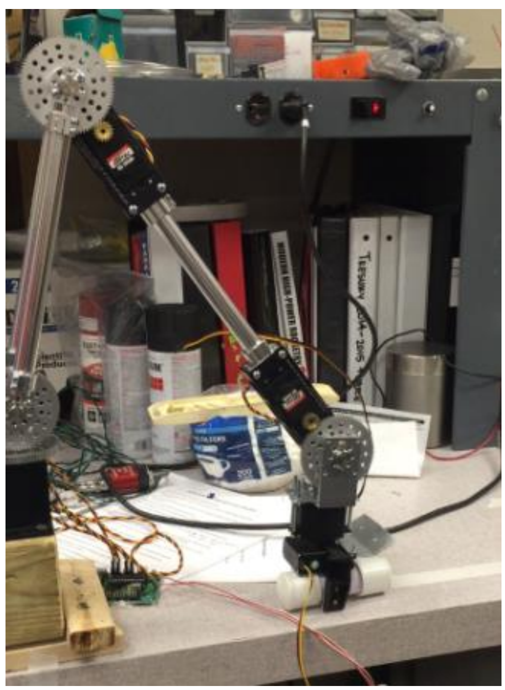

Figure 35 Arm Experiment at (11, 0, -7.7) inches

Once the arm was mounted to the AGSE, additional tests were done with the arm. Before these tests could be performed, however, extension wires had to be made for the majority of the servos. The wires were made with 22 gage Hitec servo wire and Molex three-pin lockable connectors. Therefore, these additional tests verified that the wiring was done correctly. Once the wiring was completed, the arm was controlled with a separate code that interacts with the servo controller through the BeagleBone. The arm was commanded to move to different locations and grasp the sample. No locations were measured out for this experiment as it was designed to test the wiring and the code. The arm was able to move exactly as the team commanded, verifying the accuracy of the code and the completion of the wiring. Ultimately, the imaging system code and the code used to calculate the arm angles will be incorporated into this main program. A picture of this test is shown below in **Figure 36**.

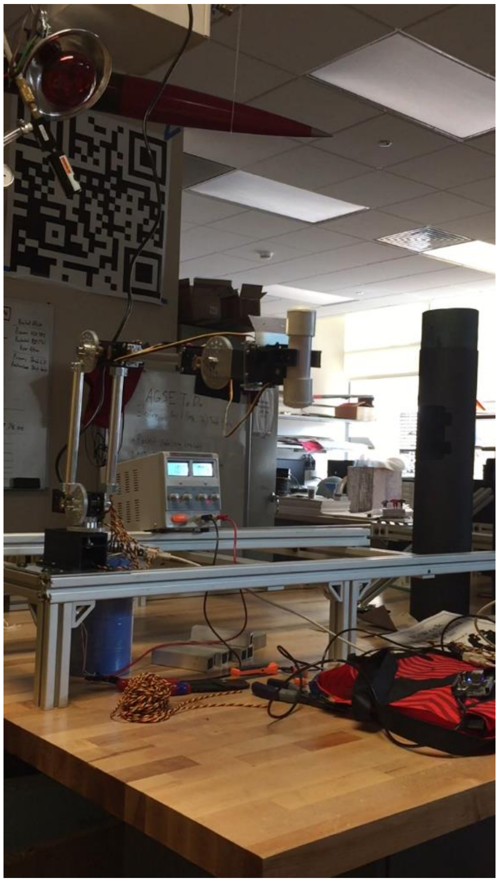

Figure 36 Arm Mounted on AGSE

GPS Experiment

We are using two BigRedBee 900 MHz GPS units to track both pieces of the launch vehicle. In order to test the transmission of data from both units simultaneously, we sent two team members to run around campus (at least travel .5 km away) so that we could test the GPS tracking on both units. **Figure 37** shows the paths traveled. This data was collected live and plotted on Google Earth to show what places on campus were traveled to. Each color represents the different paths traveled by the two team members.

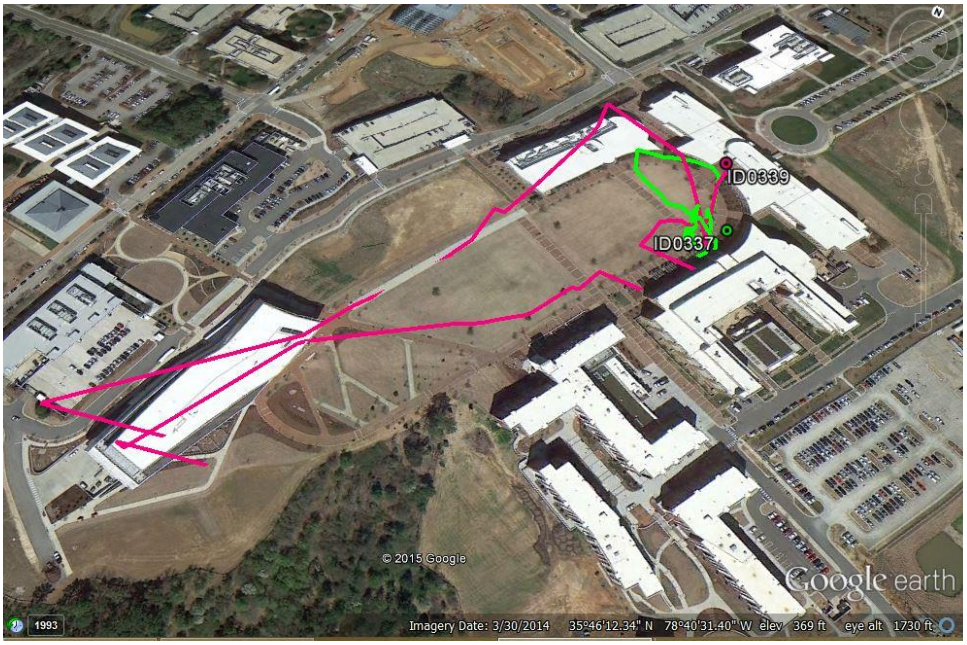

Figure 37 Big Red Bee 900 Test

Serial Radio Experiment

The goal of this experiment is to test how well serial data can be transmitted to the ground station. We will be using several protocols to identify what type of data each data packet contains. The radios were able to communicate simple text data, however we wanted to see if it was possible to send images from the camera to the ground station. In order to do this, the BBB must convert the image into a text file. That text file must then be streamed through the radio byte by byte. The text will then be rebuilt back into the image. **Figure 38** is the result of converting the image to text, sending the text across serial radio, and then rebuilding the image on the ground station.

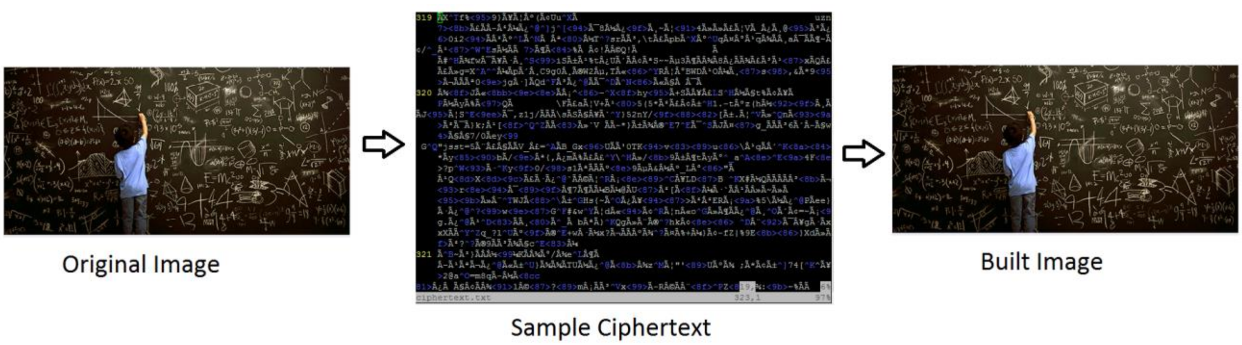

Figure 38 Conversion of Image across Radio Transmission

Launch Rail Raising Experiment

The goal of the launch rail raising experiment was to determine if the launch rail stepper motor would be able to meet the required torque and speed values. Using a vehicle weight of 20 pounds, a 96 inch launch rail, and launch rail sector gear and drive gear radii of 10 inches and 1 inch respectively, the required stepper motor holding torque was 10 foot-pounds. In addition, a launch rail rise time of 45 seconds or less was desired to allow sufficient time for other AGSE processes. Lacking a completed AGSE for the experiment, a 125% torque load was simulated with three weights totaling 12.5 pounds hanging vertically from a rope attached to the perimeter of a 24 inch diameter plywood pulley. The resulting torque of 12.5 foot-pounds is slightly higher than the required holding torque but well below the stepper motor's 30 foot-pound maximum holding torque. The 23HS22-2804-PG47 planetary gear stepper motor, attached pulley, and weights can be seen below in **Figure 39**.

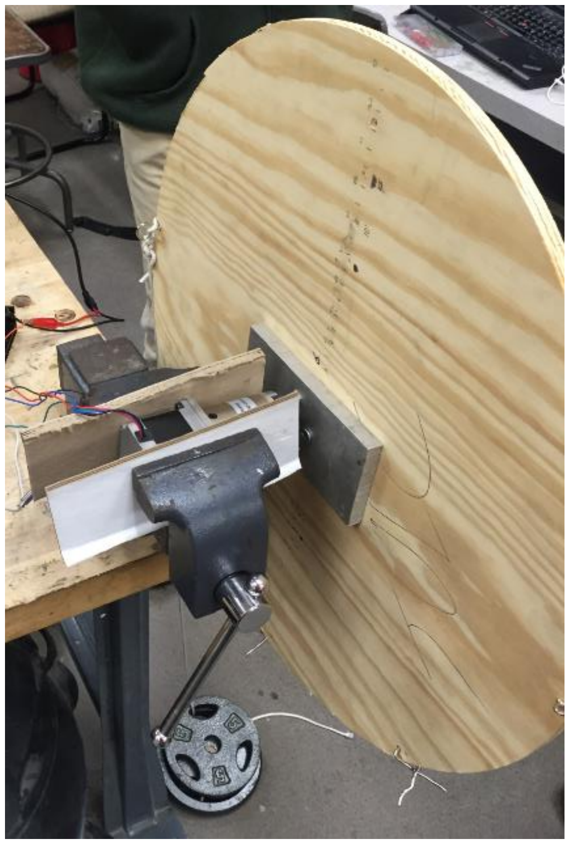

Figure 39 Launch Rail Stepper Motor and Pulley Apparatus

The system used to power and control the stepper motor can be seen below in **Figure 40.** At the bottom center of the picture is the Leadshine M542 stepper motor driver. Attached to this is a Mastech HY5003D DC power supply (in the upper center) set at 38 Volts and 3.0 amps to approximate the 37 Volts 5000 milliamp-hour Thunder Power battery. The power supply powered both the driver and stepper motor. Below the power supply is a Textronix AFG 3022B function generator. This acted as the stepper motor controller, generating a 4.5 volt amplitude square wave. In the future, this square wave will be generated using the Beaglebone Black. For each square wave cycle, the stepper motor was set to rotate by one step. The rotation rate of the stepper motor was adjusted by varying the square wave frequency. In the bottom left of the picture is a 6 volt battery and breadboard used to control the stepper motor's rotation direction.

Completing the battery circuit yielded counterclockwise stepper rotation and disconnecting it yielded clockwise rotation when viewed from the front of the pulley.

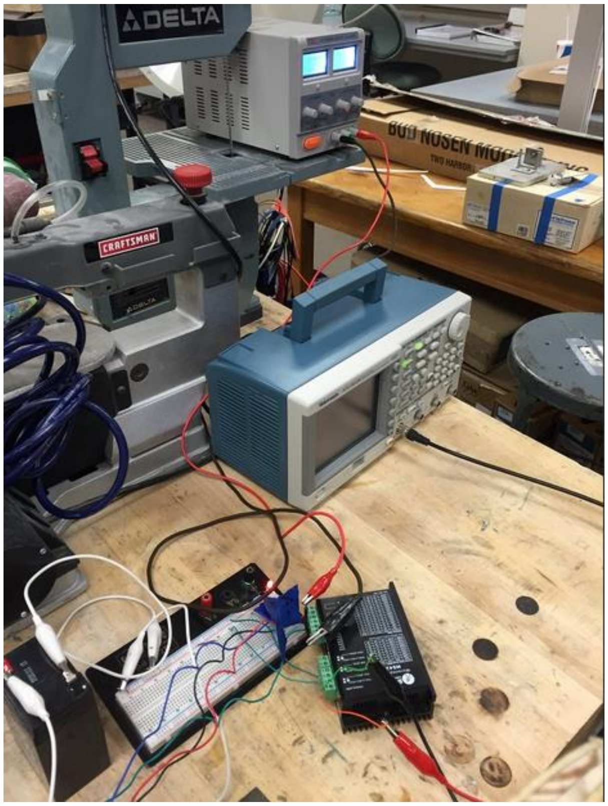

Figure 40 Stepper Motor Power and Control System

To conduct the test, the time required for the pulley to rotate 90 degrees under the 12.5 foot-pound load was recorded for different square wave frequencies. A 90 degree rotational angle was chosen to keep the hanging weights from touching the ground during the test. The 90 degree rotation time could then be easily converted to the total launch rail rise time knowing the required rotations of the stepper motor output shaft (2.36 rotations for an 85 degree launch rail angle). The results are shown in **Table 12** below. This table illustrates that launch rail rise times as low as 22.5 seconds were achieved, well below the desired value of 45 seconds. The ease and speed at which the stepper motor rotated under the 12.5 foot-pound load at all tested frequencies clearly demonstrated its ability to accomplish the required task. Additional testing showed that a torque load as high as 17.5 foot-pounds (175% operating load) can be supported at any frequency shown in **Table 12**.

Table 12 **Square Wave Frequencies and Resulting Launch Rail Rise Times (12.5 foot-pounds)**

Function Generator Square Wave Frequency (Hz)	90 Degree Rotation Time (s)	Calculated Launch Rail Rise Time (s)
940	5.0	47.2
1000	4.35	41.0

1250	3.73	35.2
1500	3.11	29.4
1750	2.56	24.2
2000	2.38	22.5

4.3 AGSE/Payload Design

4.3.1 Design and Construction of the AGSE/Payload

Prior to assembly the entire AGSE structure was modeled in SolidWorks from aluminum t-slot railing. The 1.5 inch t-slot railing was delivered in 12 foot increments. From these, the proper lengths based on the CAD model were marked and the cut with the drop saw in the EB3 machine shop. Assembly of the AGSE can be seen in **Figure 41** and **Figure 42** below. Diagrams of the AGSE and attached launch vehicle CAD model can be seen in **Figure 44** - **Figure 46** in section **4.3.3** that follows. The AGSE design has remained largely unchanged since the Critical Design Review. A robotic arm and attached camera, located in the front left corner of the AGSE, will be used in conjunction with the BeagleBone to locate, retrieve, and secure the sample in the launch vehicle autonomously. The launch rail sector gear, drive gear, and the geared stepper motor will be used to raise the launch rail to 85 degrees from vertical prior to launch. The igniter insertion system, operating using a linearly actuating stepper motor, will insert the motor igniter.

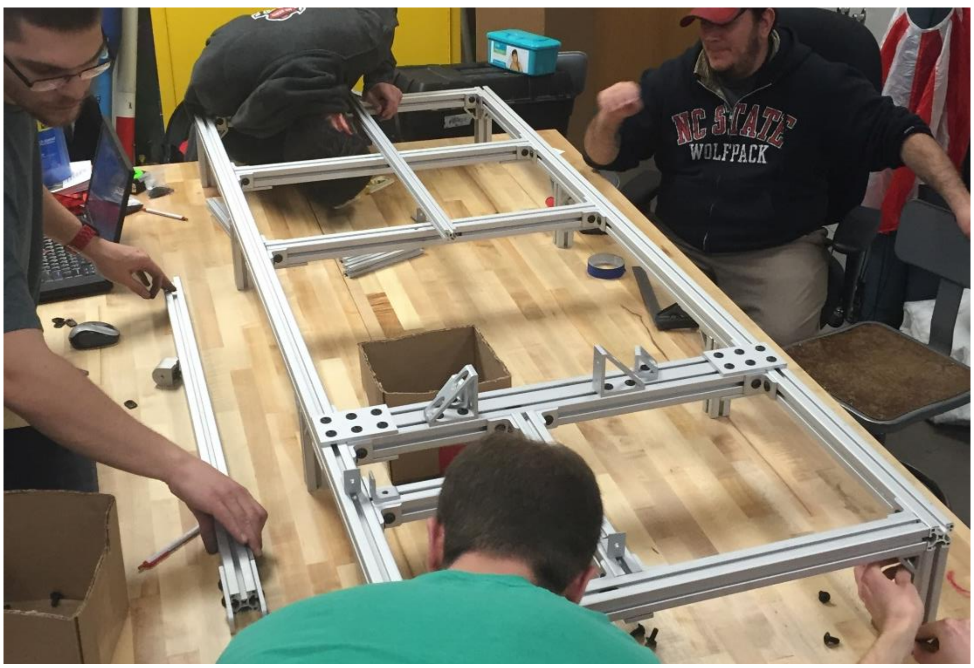

Figure 41 AGSE Construction

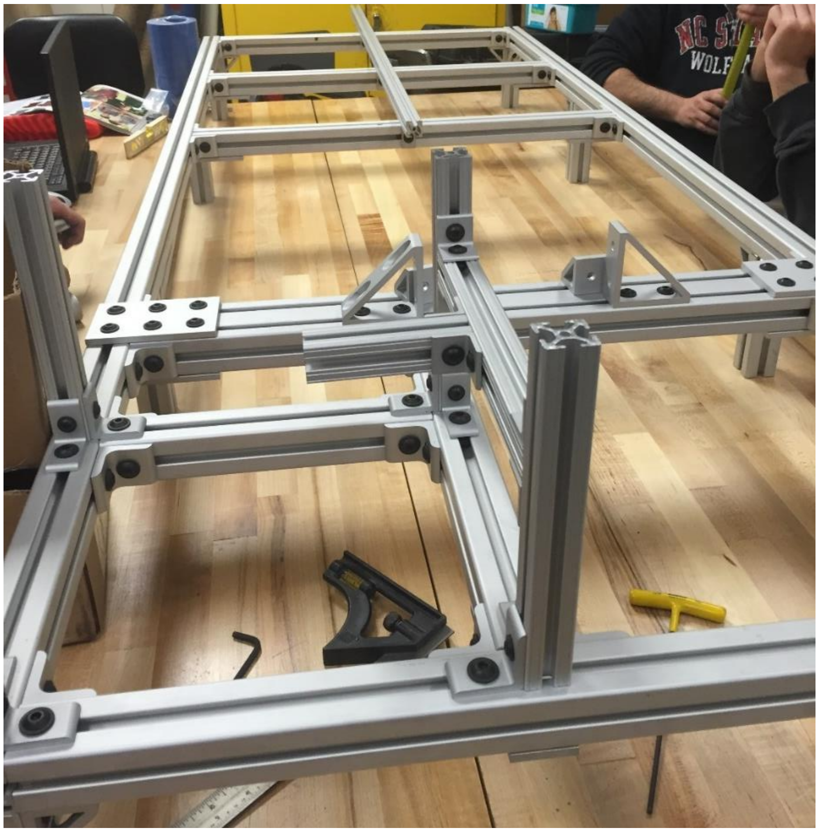

Figure 42 AGSE Construction

4.3.2 Electrical elements

- Beaglebone Black (BBB) - This is a credit card sized Linux computer that will do all the processing for the mission. It has a 1GHz Texas Instruments AM Processor, 512 MB of RAM, and 4 GB of internal (expandable) storage.
- M542 Stepper Controller - Connected to the BBB using a Digital connection. It is used for the large stepper motor which is used to erect the launch vehicle.
- ST-6128 Stepper Controller - Connected to the BBB using a Digital connection. It is used for the small stepper motor which is used to insert the igniter into the launch vehicle.
- SSC-32 Servo Controller - This servo controller provides an interface to the BBB to move the 6 servos that make up the arm. We will be using a USB to RS-232 serial connection.
- Sentech STC-MC36USB - This low resolution camera is connected to the BBB using a USB connection. The camera will be mounted at the end of the robotic arm and used to take pictures in order to find the payload.
- Digi Xtend 1W 900Mhz Serial Radio - We will use a pair of these radios to communicate the status of the AGSE to the ground station.
- Amazon Basics Powered USB Hub - Since the BBB only has one USB port, we will need a powered USB hub to extend the number of connections possible.

- LED Indicators and switches - The AGSE will have an onboard control panel that consists of 4 LED's and 2 switches. One switch is a full system on/off control. The other switch will be used to pause and resume the AGSE operations.
    - Red LED 1: Power is flowing to BBB and other important electronics.
    - Red LED 2: Power is flowing to Radio.
    - Amber/Orange LED: Flashes based on whether the system is paused or in progress.
    - Green LED: The AGSE has finished all of its tasks, and the rocket is ready to be launched.
- Voltage Regulator Box - Since the AGSE has so many electrical components, we will need voltage regulators to control the power flow to these electronics. The configuration should allow for the voltage to be changed easily, and should allow for additional electronics to be added if more need to be added.

- Ground Station - The ground station will consist of at least one computer, a GPS Receiver, and a Digi Xtend Radio. The ground station is purely for communicating AGSE and launch vehicle data back to the team while the mission is in progress. We have also developed our own software for interpreting data coming from the AGSE including (but not limited to) battery life, current mission phase, connection strength, and camera images (if possible).

  Legend for **Figure 43**:
  Blue zig zag connectors*: resistors (resistance based on the device being supplied)*
  Black connectors*: Ground/Negative (does not include connections to motors)*
  Red connectors*: Positive*
  Green connectors: USB connection
  Magenta connectors: Digital data connection

  The voltage regulator box will control voltage input to any device that requires direct power (note: some USB devices do not need a direct power source). There will be two separate power supplies. One 37 volt, three cell, LiPo battery will be for the stepper motor used to raise the rocket and the stepper motor used to raise the igniter. The second battery system will be an 11.1 *volt, three cell, LiPo battery used to power the BeagleBone Black, robotic arm servos, robotic arm controller, and stepper controllers. A BeagleBone Black (BBB) Linux Computer will be used to do all of the primary processing onboard the AGSE. The team feels the BBB has the necessary specifications to process images, control motors, process sensor data, and communicate with the ground station. The BBB will utilize primarily USB connections to the devices we need. A USB hub (marked as hub) is needed since the BBB has only one USB output. A servo controller board will be used to control the six servos on the robotic arm. A stepper controller will be used to control a high torque stepper motor to raise the rocket into launch position. A second stepper controller will be used to control a much lower torque stepper motor that will insert the igniter. There will also be a camera onboard the AGSE robotic arm to identify where the payload sample is located. A 2-way Digi Xtend radio will be used to radio stats and a video feed back to the ground station. To comply with NASA's safety requirements, a master power is switch connected between the batteries and the regulator box. A physical pause switch implemented on the BeagleBone can hold the system while other teams compete. The Prelaunch Verification System (PVS) used the BBB to* *make sure that the sample is safely contained within the rocket, and that the rocket is lifted to the correct position.*

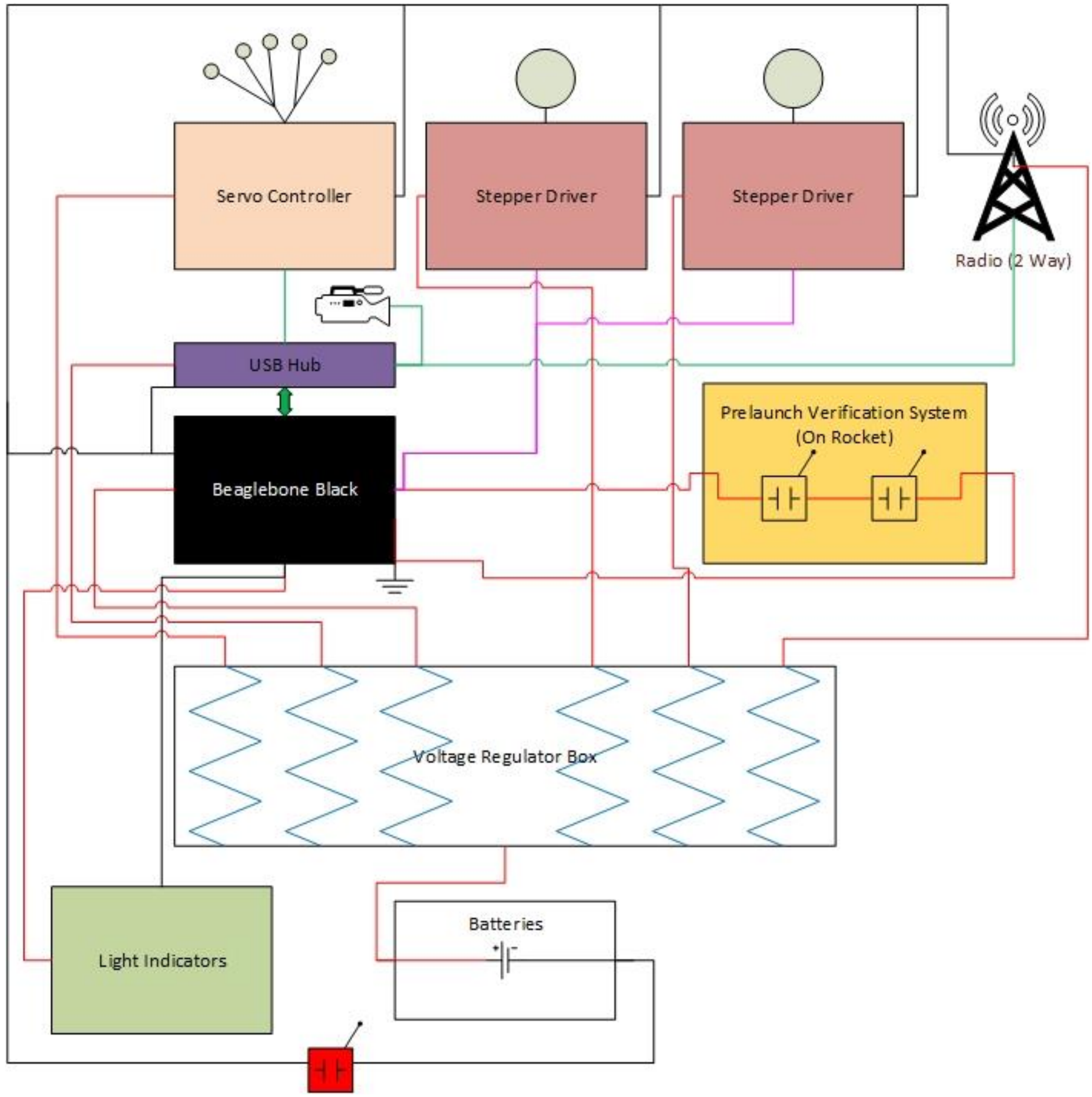

Figure 43 AGSE Electrical Schematic

4.3.3 AGSE/payload Drawings and schematics

Figure 44 below shows the AGSE with the launch vehicle in the horizontal position. The robotic arm is also shown in position above the payload compartment.

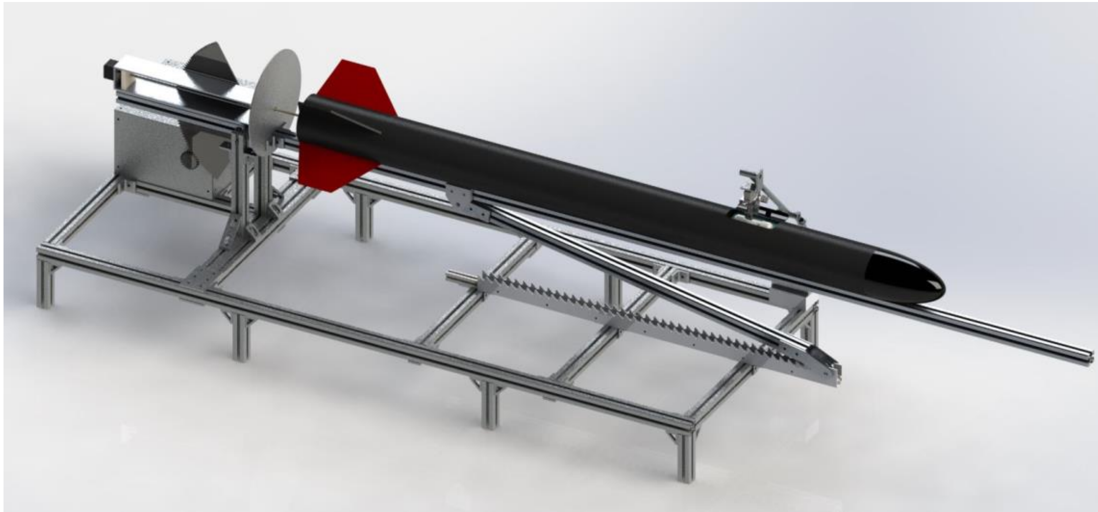

Figure 44 AGSE with Launch Vehicle in Horizontal Position

Figure 45 below shows the AGSE from the rear. The electronics bay in the rear left corner of the AGSE base will house the launch rail geared stepper motor, both stepper motor drivers, the BeagleBone Black, and both Thunder Power batteries.

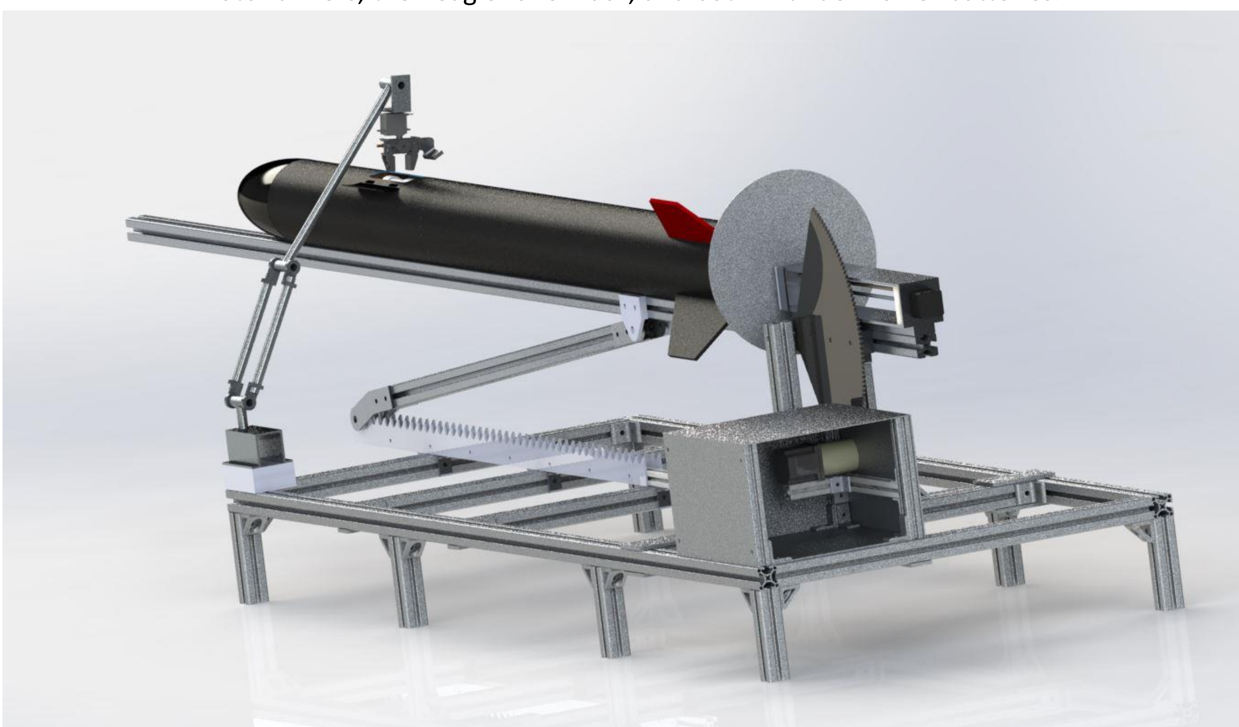

Figure 45 AGSE from the Rear

In **Figure 46** below, the AGSE is shown with the launch vehicle in the vertical position. The robotic arm is shown in its launch position, stowed parallel to the AGSE side rails.

Figure 46 AGSE with Launch Vehicle in Vertical Position

4.3.4 Precision of Instrumentation and Repeatability of Measurement

The team strives to use the most accurate tools available for measurements. For example, the gram scale used by the team is accurate to 0.01 grams, and the digital calipers are accurate to 0.001 inches. As described above in Section **4.2.6**, the arm and imaging systems were calibrated using experiments. The arm is accurate to 0.125 inches based on the experiments conducted by the team. The repeatability of the stepper motors were also tested in the experiments described above. Conducting these experiments several times proves the repeatability of measurement with the arm, camera, and stepper motors. As a result, the data obtained in the experiments was verified.

4.3.5 Approach to Workmanship

The AGSE is constructed of 80/20 t-slot aluminum framing and hardware. These components are used in industry for many types of durable fixtures. Employing 80/20's framing components in the AGSE design ensures that the system will be easy to assemble/disassemble and remain rigid during all procedures.

4.3.6 Discuss the test and verification program.

To support the imaging system, a relation between sample image properties and distance was needed. The primary metrics for determining the sample distance was the pixel count of the sample blob in the image and the dimensions of the blob in the image. An experiment was conducted where pictures were taken of the sample at varying heights above the ground and these images were run through the script to yield the blob size, width, and height. Plotting the height versus the determined metrics yields a second degree curve. This curve can be used in real time by inputting an image, measuring the blob properties, and interpolating these properties into curves to yield the sample location.

The first round of testing used the rig used in **Figure 55**. Pictures were taken of the sample at heights above the ground between 5 inches and 28 inches and processed with the imaging script. The testing area attempted to control the lighting to limit the number of shadows on the sample, and the camera had a constant focal length. The sample was close to the center of each image but there were some slight inconsistencies. The script picked out the brightest areas of the image and grouped them into blobs. It then picked out the blob representing the sample by its height to width ratio and its pixel count. One of these pictures can be seen in **Figure 47**. After many pictures, three curves were generated relating the pixel count, height, and width to the distance. These can be seen in **Figure 49** and **Figure 50**. The pixel count curve shows a general second degree trend with a few outliers. These outliers can be attributed to a number of problems in the experimental setup including: variation in lighting, the sample not being in the exact center of every image, or variable angle of the lens relative to the sample. This curve shows that this imaging concept can work and will be successful, but the outliers show that the system is not finalized and requires more testing to be completely reliable. For the best calibration, pictures will be taken when the camera is mounted on the arm. The arm will be commanded to move to a location and a picture will be taken. Because mounting the camera on the arm most accurately reflects the final situation, the curve generated from these tests will be the curve used during the week in Alabama.

One problem with the imaging scripts is they currently do not account for rotation of the sample in the image by measuring the left, right, top, and bottom most pixels in the blob. This is shown in the height and width curves in **Figure 50**. The length of the sample was placed almost perpendicularly to the image plane, but in a few images, it was slightly rotated. To account for large rotations, logic that processes the geometry of the blob can be implemented. For the problem of very slight rotation, like what is seen in the test pictures, a Gaussian blur can be implemented to reduce the sharpness of edges. This blur can be seen in **Figure 52**. Interestingly, this adds discontinuities to the pixel count curve seen in **Figure 53**, but it smoothed some discontinuities in the height and width plot in **Figure 54**. It also adds some definition to the curves at distances greater than 15 inches. The height and width curves might be the best method when calibrating the arm to the imaging system.

This experiment shows the imaging system, while requiring additional work, will add consistency and challenge to the system. The scripts created by the team so far are successful in picking out the sample from backgrounds and giving basic information about its properties in the image. Going forward, logic needs to be added that accounts for rotation of the sample relative to the camera. This will add robustness to the system that can account for a spinning sample caused by wind, terrain, or poor setup. The final calibration curve will be done by mounting the camera to the arm and controlling the arm motion and taking pictures and using these images in a similar manner as was used to produce the curves shown above.

The scripts and logic were developed in MATLAB and the team planned to use the MATLAB auto-coder to generate C code that could be run on the BeagleBone. Unfortunately, the auto-coder plan did not work, so the team needed to find another option for implementing the scripts on the BeagleBone. Our next plan involved using Octave, an open-source MATLAB compiler. This process was successful for the script calculating the servo pulses needed to move the arm, but the process was too slow for the imaging scripts. Imaging scripts that took .2s in MATLAB and on a PC took upwards of five minutes through Octave on the BeagleBone. The team has decided to implement the imaging scripts in C++ themselves. Without much background in real code development, this is taking longer than expected. This code will run on the BeagleBone and will be used to generate the final calibration curve.

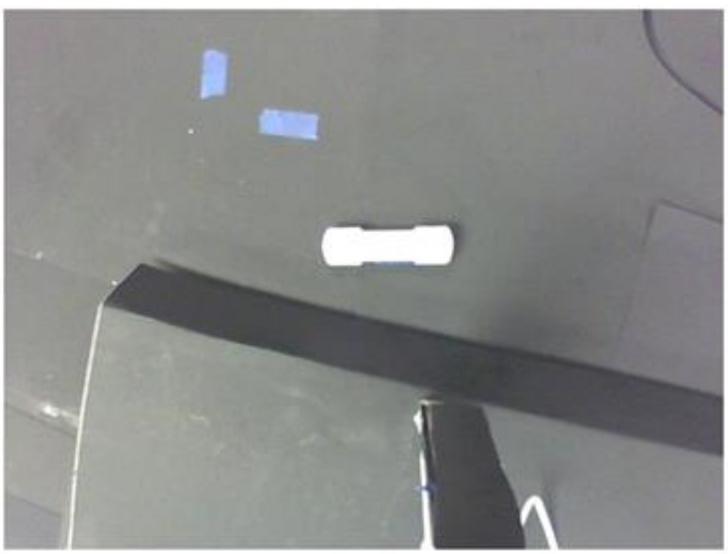

Figure 47 Unfiltered Imaging Experiment Picture

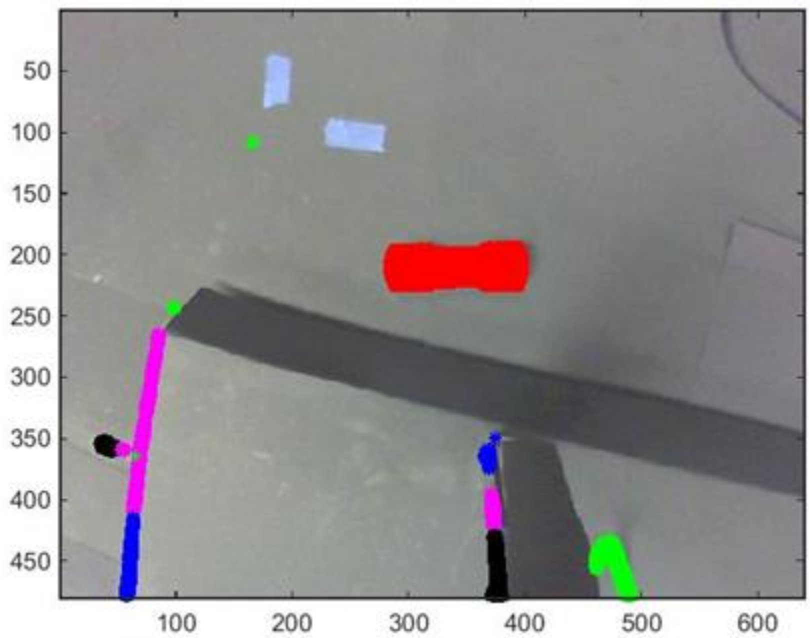

Figure 48 Blobbed, Unfiltered Imaging Experiment Picture

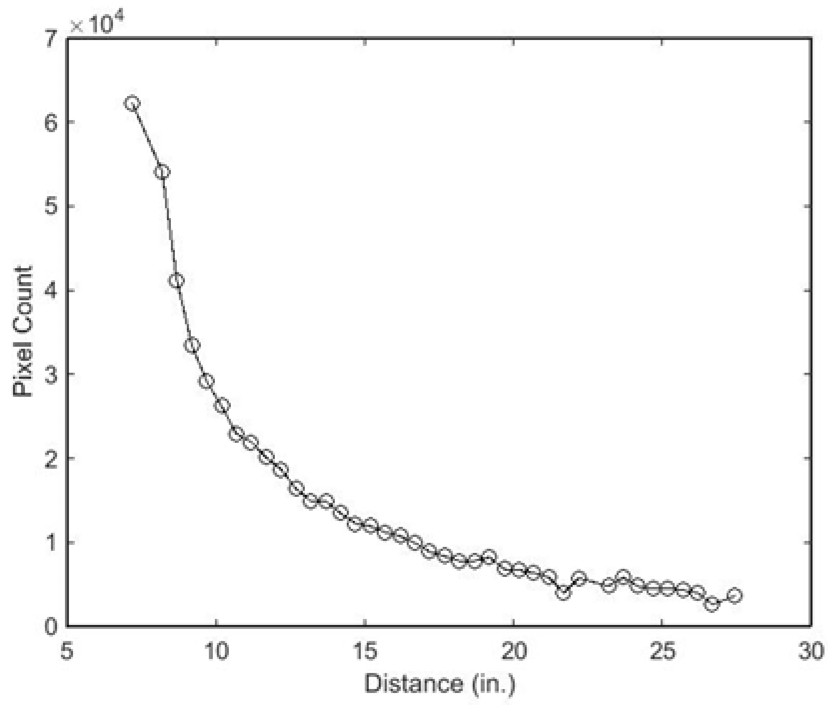

Figure 49 Unfiltered Imaging Experiment Sample Pixel Count vs. Distance

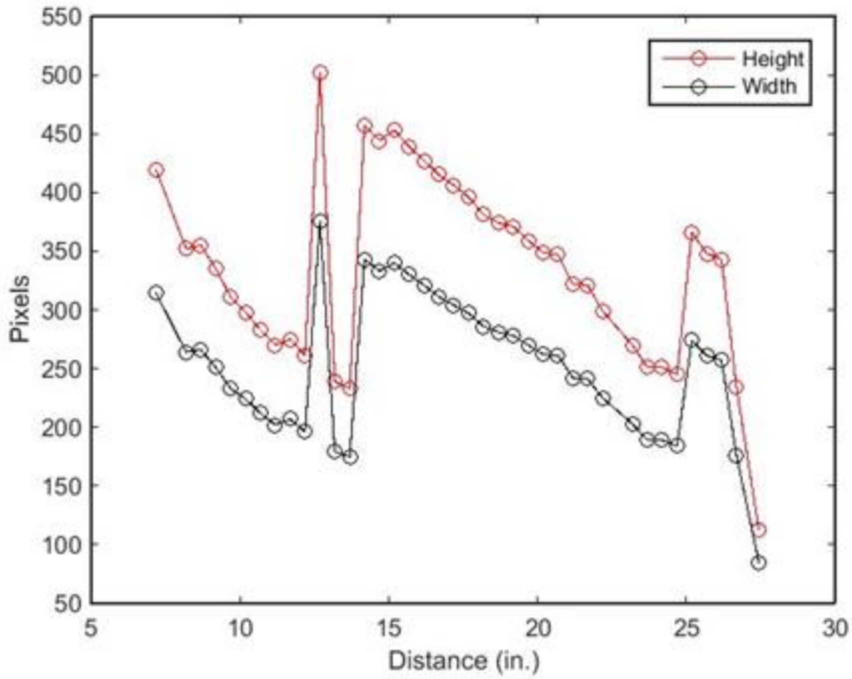

Figure 50 Unfiltered Imaging Experiment Sample Dimensions vs. Distance

Figure 51 Filtered Imaging Experiment Picture

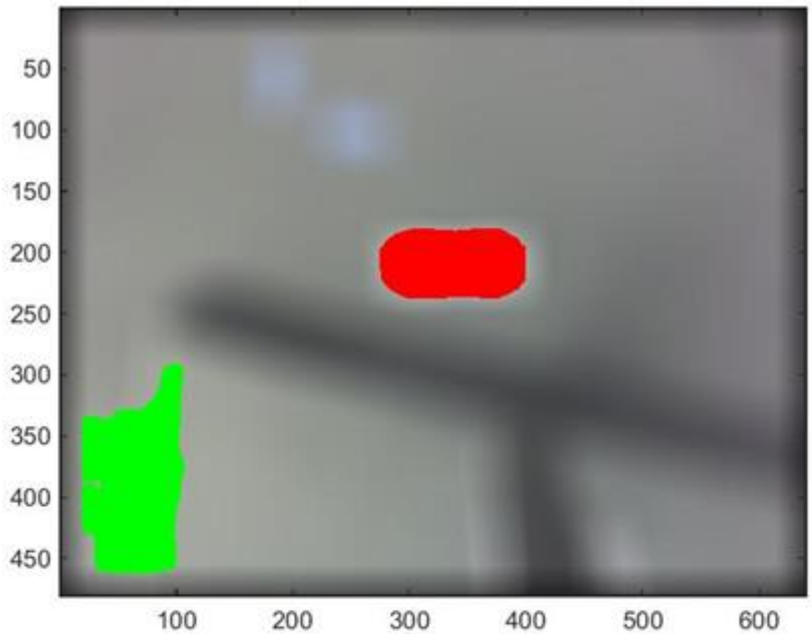

Figure 52 Blobbed, Filtered Imaging Experiment Picture

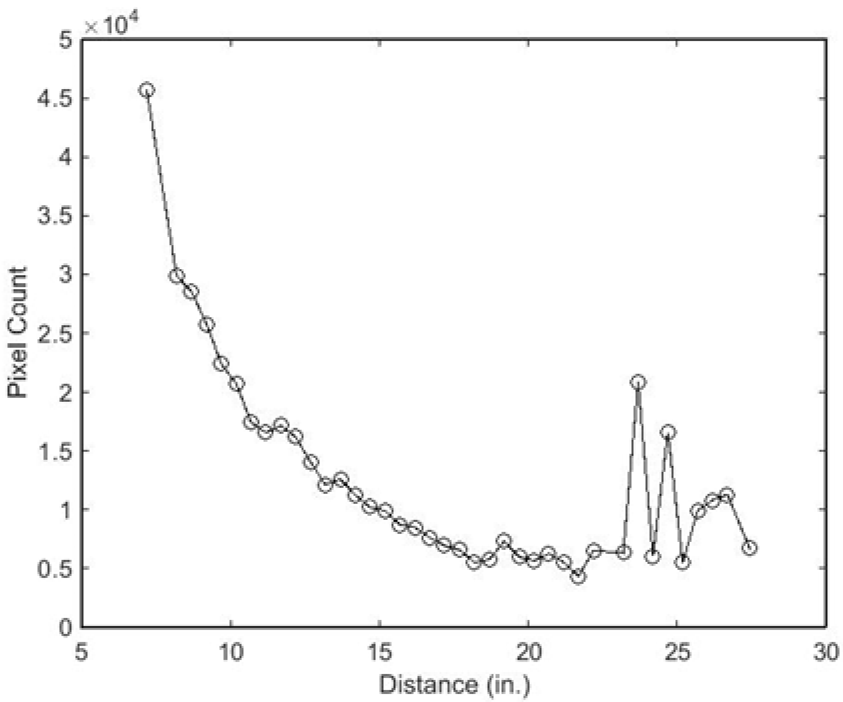

Figure 53 Filtered Imaging Experiment Sample Pixel Count vs. Distance

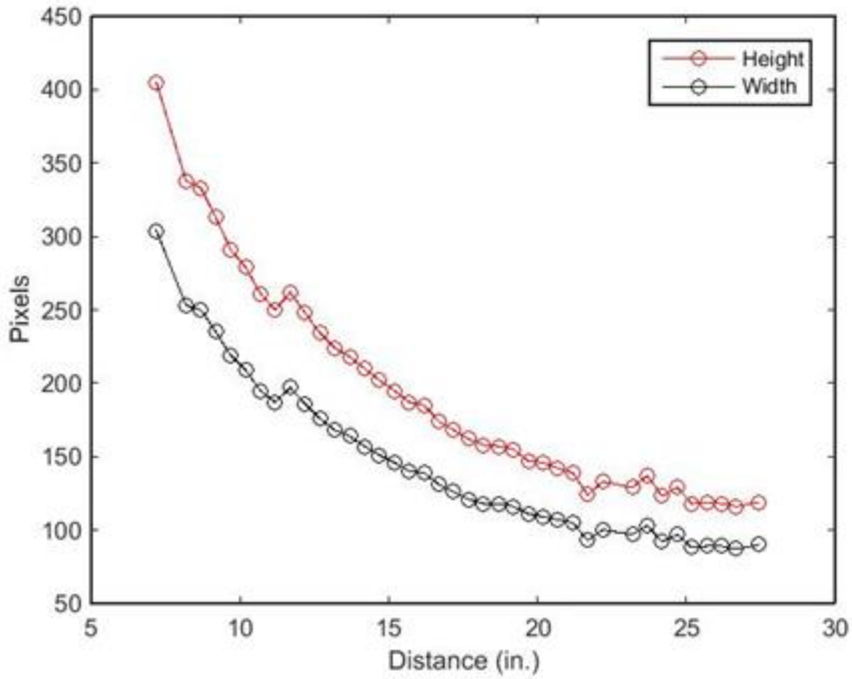

Figure 54 Filtered Imaging Experiment Sample Dimensions vs. Distance

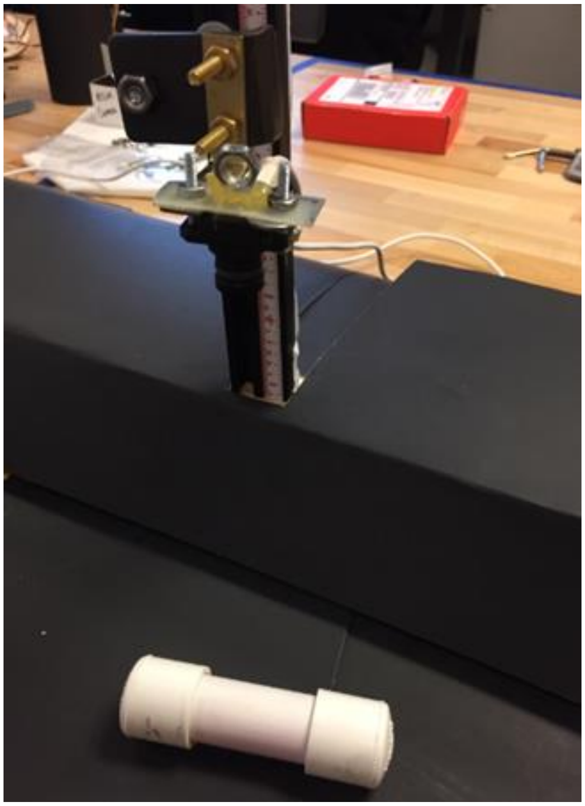

Figure 55 Imaging Experiment Setup

4.4 Verification

4.4.1 AGSE/Payload Verification

The verification matrices for the AGSE can be found in **9.4**.

4.5 Safety and Environment (AGSE/Payload) –This will describe all concerns, research, and solutions to safety issues related to the AGSE/Payload

4.5.1 Safety and mission assurance analysis.

The FMECA diagrams can be found in **9.2**. Of all of the failure modes listed, the gearing slipping out of plane has one of the worst consequences. Not only will the vehicle not be in the proper position for launch, but the vehicle may fall and damage other components. If the processes are not stopped early enough, then the gears may damage themselves or other components, preventing the AGSE from operating again. However, this failure is unlikely because the team is bolting the gear to the launch rail and has the ratcheting stops that will prevent the vehicle from falling back down onto the AGSE. The driving gear (3/8 inch) is also slightly smaller than the sector gear (1/4 inch) to prevent the gears from slipping out of plane. Similarly, structural failure of the gearing system would render the AGSE functionless. As a result, it would not be able to accomplish its mission. Because the team is making the gears themselves out of steel, this failure is unlikely. A third significant error is a short circuit in the wiring for the imaging system may also have catastrophic effects. In addition to the camera not working and preventing the AGSE from accomplishing its mission, a short circuit may cause an electrical fire. Because the team is using lithium polymer batteries, an electrical fire may cause catastrophic results. Care will be taken during construction so that this failure mode is unlikely.

Dead batteries would prevent the AGSE from performing any of its tasks. Every system, including the BeagleBone, relies on the batteries being operational. Dead batteries would result in complete mission failure. If the team is not careful, this failure mode could be likely to occur. Lastly, the BeagleBone resetting upon a power outage has one of the worst consequences as well. If the BeagleBone resets, then the pause function of the AGSE would be rendered useless as the system would not be able to resume processes from where it left off. The team will develop a system so that this failure will not occur. Sufficient testing will make this error unlikely.

4.5.2 Personnel Hazards

As the competition gets closer, more construction will need to be done. Consequently, the team will need to use more power tools and machines, such as the drill press and band saw. These machines pose significant risks to the team if they are misused. As indicated in the timely, construction of the AGSE will continue into the end of March. Therefore, these safety hazards will exist after the FRR. The table in **9.7** outlines the hazards the team is exposed to and the mitigations they will use in constructing the AGSE.

4.5.3 Remaining Environmental Concerns

In addition to the environmental concerns expressed in section 5.2.3, the proximity of personnel and other objects to the AGSE during operation is an important concern as well. If personnel are too close to the AGSE, then they may be injured during processes. Furthermore, the AGSE may be prevented from fully performing its tasks. In theory, there is the potential that the AGSE will tip over due to high winds. However, hand calculations have shown that the AGSE will only tip over if the winds are in excess of 38 miles per hour. Therefore, the AGSE tipping over is not a concern as the competition would be canceled in such weather.

5 Launch Operations Procedures

5.1 Checklists

5.1.1 Recovery preparation

1) Retrieve nosecone
2) Retrieve nosecone bulkhead with GPS attached
3) Connect battery on GPS
4) Insert bulkhead and install 4 screws
5) Ensure that screws that attach bulkhead to nosecone are tightened
6) Retrieve upper mid-section
7) Retrieve upper mid-section avionics bay
8) Remove nuts from forward avionics rear bulkhead (the one with ARRD)
9) Remove rear bulkhead
10) Remove forward avionics bay coupler
11) Insert a fresh battery into each of the two battery trays
12) Connect battery snaps on each battery
13) Screw down battery clips
14) Make sure switches are set to 220 Volts
15) Install payload foam on top of altimeter sled
16) Insert avionics sled back into coupler
17) Thread wires through hole in bulkhead
18) Reattach forward avionics rear bulkhead
19) Tighten nuts on both ends of avionics bay with 7/16 inch socket
20) Attach wire leads into closest blocks on forward avionics rear bulkhead
21) Install e-matches in primary and redundant blocks on forward avionics forward bulkhead
22) Insert 2 grams of black powder in primary cap on forward avionics forward bulkhead
23) Insert 2.2 grams of black powder in secondary cap on forward avionics forward bulkhead
24) Install e-match into black powder, add wadding, and cover both black powder charges with tape
25) Remove ARRD red section
26) Install 2 e-matches into ARRD (thread wire side first)

27) Install primary and redundant e-match wires on forward avionics read bulkhead terminal blocks (2 for upper mid-section, 2 for ARRD)
28) Install 0.2 grams of black powder in ARRD
29) Install red section onto ARRD
30) Tighten red section by hand
31) Install forward avionics bay into upper airframe
32) Install 4 bulkhead screws into forward avionics bay
33) Install door with 4 small screws using the middle sized Phillips driver
34) Attach compartment door, tighten halfway
35) Put upper airframe aside
36) Retrieve lower mid-section
37) Retrieve lower avionics bay
38) Remove forward bulkhead
39) Install batteries
40) Screw down battery clips
41) Make sure altimeters are off (set to 220 Volts)
42) Insert rear avionics sled into rear avionics bay coupler
43) Thread wires through forward bulkhead on rear avionics bay
44) Install 2 nuts on forward bulkhead of rear avionics bay with 7/16 inch socket
45) Attach wire leads into closest blocks on rear avionics forward bulkhead
46) Install e-matches in primary and redundant blocks on rear avionics forward bulkhead
47) Plug GPS battery into GPS unit on rear avionics rear bulkhead
48) Install rear avionics bay into lower mid-section
49) Install 8 screws into lower avionics bay
50) Insert 1.2 grams of black powder in primary cap on rear avionics forward bulkhead
51) Insert 1.4 grams of black powder in secondary cap on rear avionics forward bulkhead
52) Install e-matches on rear avionics rear bulkhead through permanent bulkhead in lower mid-section (shorten e-match copper wire does not touch aluminum shielding)
53) Install primary and redundant e-match wires on rear avionics rear bulkhead terminal blocks
54) Retrieve green/black parachute, shock cord, Kevlar protector, and D-links
55) Attach short end of shock cord to nosecone bulkhead
56) Attach long section of shock cord to forward avionics bay bulkhead
57) Remove rubber band from parachute
58) Double check connection of D-links on both bulkheads
59) Insert parachute, sheet protector, and shock cord into upper mid-section
60) Insert nosecone and line up numbers
61) Install 4 shear pins in nosecone/upper mid-section connections
62) Retrieve drogue parachute, shock cord, Kevlar sheet, and D-links
63) Attach short end of shock cord to ARRD in upper mid-section
64) Attach long end of shock cord to forward bulkhead of lower avionics bay
65) Attach long end of shock cord to forward bulkhead of lower avionics bay
66) Remove rubber band from drogue
67) Double check two D-link connections

68) Install drogue, Kevlar sheet, and shock cord into lower mid-section
69) Connect the two mid-sections
70) Add 4 shear pins in between the two middle sections (technically in lower mid-section)
71) Retrieve red/white main parachute, shock cord, Kevlar sheet, and D-links
72) Attach short end of shock cord to fin section
73) Attach long end of shock cord to permanent bulkhead in lower mid-section
74) Connect lower mid-section and fin section
75) Install 4 shear pins into lower mid-section/fin section connection

5.1.2 Motor preparation

Forward Closure Assembly

1) Apply a light coat of Synco Super Lube or other grease to all threads and all o-rings
2) Chamfer both inner edges of the delay insulator with fingernail
3) Assemble the RMS-Plus delay element, delay insulator, aft delay spacer, and delay o-ring
4) Insert the forward delay spacer (1-1/8 inch outer diameter) into the delay cavity until it is seated against the forward end of the cavity
5) Apply the light film of grease to the inner circumference of the delay cavity (but not the forward end of the cavity)
6) Insert the delay charge assembly into the delay cavity, o-ring end first, until it is seated against the forward delay spacer

Case Assembly

1) Insert the nozzle into one end of the liner tube until the nozzle flange is seated against the liner
2) Push the liner assembly, open end first, into the motor case until the nozzle protrudes from the case about 1.25 inches
3) Place greased aft (1/8 inch thick, 2 inch outer diameter) o-ring into the groove in the nozzle insert
4) Thread the aft closure into the motor case by hand until 1/16 inch gap remains between the case and the closure
5) Install the propellant grains into the liner
6) Place greased forward seal disk (1/16 inch thick, 1-7/8 inch outer diameter
7) Insert the smaller (o-ring) end of the seal disk into the open end of the liner tube until the seal disk flange is seated against the end of the liner
8) Place the greased forward (1/8 inch thick, 2 inch outer diameter) o-ring into the case, seated against the forward seal disk
9) With the motor case held in a horizontal position, thread the completed forward closure assembly into the open end of the motor case by hand until it is seated against the case
10) Finish tightening the aft closure by hand until it is seated against the case

5.1.3 Setup on launcher

1) Insert motor into launch vehicle
2) Verify CG location (CP is at 56 inches)
3) Carry assembled rocket to AGSE

4) Slide rocket launch lugs onto 15-15 launch rail on AGSE

5.1.4 Igniter installation

1) Ensure that igniter lead is connected to correct control terminal

5.1.5 Launch procedure

1) Arm the 4 altimeters using a small screwdriver inserted through marked pressure ports
2) Clear personnel from launch area
3) Check that there are no environmental hazards or vehicle remnants nearby

5.1.6 Troubleshooting

1) Check for continuity between control booth and launch pad
2) Check igniter is fully installed
3) Check connections on igniter
   a. Check connections are not in contact with each other
   b. Ensure igniter leads are securely wrapped around alligator clips
4) Check for correct beeps from altimeters

5.1.7 Post-flight inspection

1) Ensure all black powder charges have fired
2) Inspect vehicle for visible external damage
3) Turn off all altimeters and electronic components except marked competition altimeter
4) Inspect parachutes for tears
5) Collect all parts of vehicle
6) Remove and clean motor casing

5.2 Safety and Quality Assurance

5.2.1 Acceptable Risk Levels

As described above, the team was able to successfully fly its full-scale vehicle. Because no one was injured as a result of the flight, this launch shows how the current risks to personnel as a result of the team's design are at acceptable levels.

5.2.2 Risk Assessment

When working with explosives, attention to safety and mitigating risks is essential. It is important that all personnel all well-versed with working with vehicle and other hazardous materials. However, the team will default to the LSO to make all final calls on the safety of the launch operations. Furthermore, the LSO will be the one to initiate the launch procedures. Inserting the igniter autonomously also poses additional risks to the team and other personnel. There will inevitably be a longer delay to respond to issues since the igniter is not being insert manually. As a result, the team will thoroughly practice inserting the igniter with its system to ensure that there is minimal risk and error. Having a dowel in the motor also creates the risk of choking the flow, causing a motor failure. However, the team will mitigate this risk by using a 0.125-inch dowel, the size recommended by the manufacturer of the motor.

5.2.3 Environmental Concerns

The environment can play a significant impact in preventing a safe and successful vehicle launch. Precipitation is one of the key environmental risks when launching a rocket as it has the potential to short any electronics contained within the rocket or on the AGSE. Water could also weaken the structural properties of various rocket components (e.g. the body tube) creating potential safety hazards. Moreover, cloud cover has the potential to obscure the rocket at higher altitudes, resulting in a safety concern. When the vehicle or the payload stages float down in the recovery stage, the parachutes can potentially become entangled in the power lines or trees, preventing a safe and total recovery. To account for these potential hazards, the team will check to make sure that there are no power lines or other hazards nearby. This check will be done before the vehicle is launched.

However, the vehicle has the potential to impact the environment as well. The most unavoidable impact would be the pollution caused by the combustion products of the motor. This impact cannot be mitigated without entirely scrubbing the launch. Another environmental impact would occur if there was any debris caused by a failed or damaged rocket. If not all collected/recovered after the completion of the launch, any material would become litter. Therefore, the team will check to make sure that there is no debris nearby, and that it collects all pieces of its own vehicle for the safety of others. Fire is a possible environmental impact that could occur if either the motor casing (being hot after full burn of the motor) comes in contact with something flammable or if the rocket impacts something while still under power. Although this risk cannot be mitigated with an item in the checklists, this risk is being mitigated by choosing a long enough descent and by ensuring that the rocket leaves the launch pad at a velocity high enough to prevent it from going off course. The final possible environmental impact would be any damage caused by collision with the rocket. This risk is being mitigated by using redundant charges for each parachute as well as redundant altimeters to lower the risk of the parachutes not deploying. The team's checklists include making sure that these redundancies are implemented.

5.2.4 Safety Officer

Jamie Region is the team's safety officer. As a result, she is responsible for making sure the team follows all safety regulations. She is also the primary lead in following the checklists. To provide redundancy, two other members of the team will be chosen to check if the checklist is followed. Having three people monitoring the team's actions will ensure that the team remains safe and follows quality and procedure protocols.

6 Project Plan

6.1 Budget plan

	Item	Amount	Total Price
AGSE	BeagleBone Black	1	$40
	Leadshine M542 Stepper Motor Driver (for launch rail)	1	$45
	StepperOnline Microstep Driver (for ingiter)	1	$20
	Nema 17 Bipolar Stepper	1	$10
	Nema 23 Geared Stepper Motor	1	$60
	5mm-5mm Couplers	1	$5
	USB Extension Cable	1	$2
	USB hub	1	$10
	Thunder Power 37 V Battery	1	$340
	12V Step Down to 5V Power Module	1	$10
	2.1 mm Coax Power Plug	1	$5
	48 V Step Down to 24V Power Module	1	$40
	12V Step Down to 6V Power Module	1	$10
	Thunder Power 12 V Battery	1	$100
	Xtend Radio Units	2	$600
	Camera (for video feed)	1	$30
	Camera (for image processing)	1	$100
	1/16" x 3' x 2' Sheet metal	1	$20
	Steel Plate for gears (1'x2'x1/4")	1	$35
	3/16" Steel Plate (for ratcheting stops)	4 ft	$45
	3/4" Dia. X 2' long 1045 Cold Drawn Metal Round	1	$20
	1"x1" Aluminum Railing	8 ft	$15
	Aluminum Railing 1.5"x1.5"	48 ft	$200
	10 S 2 Hole Inside Corner Bracket	6	$13
	10 S to 15 S 2 Hole Corner Bracket	14	$38
	15 S 2 Hole Inside Corner Bracket	29	$68
	15 S 4 Hole Inside Gusset Corner Bracket	2	$10
	15 S 6 Hole Joining Plate	4	$19
	15 S 2 Hole Inside Gusset Corner Bracket	18	$62
	15 S 3 Hole Joining Strip	6	$21
	15 S 3 Hole Pivot Plate	2	$17
	15 S 4.5" Pivot Arm	2	$9
	1/4-20 T-nut	60	$22
	5/16-18 T-nut	200	$96
	Lynxmotion Servo Controller (for arm)	1	$40

	22 gage servo connector wire	100 ft	$32
	Molex lockable connectors and pins	50	$40
	Miscellaneous hardware (nuts/bolts/washers)	--	$100
	Gripper for Robotic Arm	1	$40
	RobotShop M100 RAK Robotic Arm	1	$600
	1/8" Balsa wood dowel	1	$1
	Crystal Oscillator	2	$25
	12"x12"x1/4" Delrin Sheet	1	$25
	3/8"-8 Acme nut	2	$10
	Threaded Rods	5 ft	$35
	3/4" x 2' PVC Pipe	1	$2
	PVC Caps	2	$5
	Super Lube	2	$8
Vehicle	LOC 4" Kraft Paper Body Tube	2	$25
	ARR Standard Coupler 5.5" x .077 wall x 12"	1	$20
	ARR Airframe 5.5" x .077 wall x 48" Airframe/MMT	1	$60
	ARR Airframe 5.5" x .077 wall x 72" Airframe	1	$90
	LOC 3.814" Coupler	3	$15
	Fiberglast 3k, 2 x 2 Twill Weave Carbon Fiber Fabric (1 yard), 50'' wide, .012" Thick	1	$60
	Aircraft Spruce Domestic Birch Plywood ¼" x 4 x 4	1	$120
	Aircraft Spruce Domestic Birch Plywood ⅜" x 4 x 4	1	$140
	Epoxy and hardener	1	$50
	Paint	--	$30
	Rail buttons	4	$10
	AIM USB Rocket Altimeter	2	$200
	StratoLogger Altimeter	2	$160
	GPS Bee	3	$95
	K805G motor (full scale)	2	$230
	I285R-0 motor (subscale)	2	$125
	Wires	--	$30
	Nose cone (full scale)	1	$60
	Nose cone (subscale)	1	$35
	Motor casing (full scale)	1	$100
	Motor casing (subscale)	1	$65
	Kevlar shock cord	60 ft	$125
	18" Fruity Chute Classic Elliptical Parachute	1	$55
	48" Fruity Chute Classic Elliptical Parachute	1	$115

	36" Fruity Chute Classic Elliptical Parachute	1	$85
	Black powder	1 lb	$20
	RATTworks ARRD	1	$95
	Igniters	5	$10
	Door latch	1	$20
	2"x4'x8' Blue Foam	1	$40
	Lockable Rotary Selecting Switches	4	$25
	Motor Retainer (for K805G)	1	$31
	Neodymium magnets	6	$20
Subtotal	--	--	$5,461
Other	Travel expenses (hotel, rental car, gas)	12 people	$3,000
	Incidentals (replacement tools, hardware, safety equipment)	--	$1,000
	Shipping costs		$750

The current budget plan reflects the purchases and updates made since the CDR. The majority of the changes were made to the budget for the AGSE. For example, the brackets, railing, and bolts that the team purchased for the AGSE were added. The wires and connectors necessary to rewire the robotic arm have been included as well. As for the vehicle, the magnets to seal the sample compartment were also added to the vehicle portion of the budget. Although the 5mm couplers for the AGSE and the door latch are no longer being used in the project design, they are still included in the project budget since they have already been purchased by the team. At a total of $5,461, the team is currently well under-budget. Because some items for the AGSE need to be purchased (most notably the steel plate and sheet metal), this total may fluctuate slightly as the expected and some unforeseen items are purchased. However, the buffer between the current projected budget and the total allowable budget is large enough that these small changes will not make a significant difference. Because the team is well under-budget, any overages in the budget during flight week will not severely impact the team. These overages may result from under-estimating the price of the hotel or rental car. Moreover, if something breaks or is lost, then the team will need to find a replacement in Huntsville. By thorough planning and careful work, the team hopes to limit any overages during flight week.

6.2 Funding plan

The team received $2,600 from the Engineering Technology Fee Fund from the Mechanical and Aerospace Department at North Carolina State University after a proposal was submitted. After a proposal, interview, and appeal, the Engineering Council at NCSU has also granted the club $1,500 for the fall semester and $2,000 for the spring semester. The Student Government Appropriations committee has given $1,000 through a proposal and interview for the spring semester. Two proposals, one for competition and one for senior design, were submitted to the

NC Space Grant. NC Space Grant has granted the club $5,000 for the competition and $2,000 for senior design. **Table 13** below contains a summary of the funding sources described above.

Table 13 Funding Sources

Source	Amount
NCSU MAE Department ETF Funding	$2,600
NCSU Engineering Council	$3,500
Student Government Appropriations	$1,000
North Carolina Space Grant	$7,000
Total	$14,100

6.3 Timeline

Table 14 Timeline of Major and Minor Events

Event/Task	Start Date	Finish Date
Completed PDR Submission	11/5/2014	11/5/2014
PDR Team Teleconference	11/18/2014	11/18/2014
Critical Design Review (CDR) Writing	11/6/2014	12/15/2014
Build Subscale	11/5/2014	11/20/2014
Ejection Testing on Subscale	11/20/2014	11/20/2014
Prepare Subscale for Launch	11/21/2014	11/21/2014
Initial Subscale Launch	11/22/2014	11/22/2014
Camera Experiment	11/24/014	12/1/2014
NCSU Winter Break (no building access)	12/16/2014	1/6/2015
Successful Subscale Launch	12/20/2014	12/20/2014
CDR Writing	1/7/2015	1/15/2015
Initial Calibration of Arm (Experiment)	1/8/2015	1/13/2015
Completed CDR Submission	1/16/2015	1/16/2015
Astronomy Days Outreach Event	1/24/2015	1/25/2015
CDR Team Teleconference	1/26/2015	1/26/2015
NC Science Olympiad Outreach Event	2/7/2015	2/7/2015
Construction of Full-Scale Vehicle	2/10/2015	2/27/2015
Raleigh Charter Outreach Event	2/20/2015	2/20/2015
Full-Scale Ejection Tests	2/26/2015	2/26/2015
Run-through of Checklist for Full-Scale	2/27/2015	2/27/2015
Successful Full-Scale Flight	2/28/2015	2/28/2015
Construction of AGSE	3/3/2015	3/31/2015
Construction of Electronics Bay for AGSE	3/9/2015	3/9/2015

Construction of Mount for Arm	3/10/2015	3/10/2015
Construction of Launch Rail/Vertical Supports	3/11/2015	3/11/2015
Writing of FRR	3/7/2015	3/15/2015
Completed FRR Submission	3/16/2015	3/16/2015
Finish Translating Imaging Code	3/16/2015	3/20/2015
FRR Team Teleconference (Tentative)	3/18/2015	3/27/2015
Camera + Arm Experiment and Painting Full-Scale	3/23/2015	3/27/2015
Integrate Gearing System/Igniter Inserter	3/25/2015	3/31/2015
Prepare for Competition and Test AGSE Integration	3/31/2015	4/6/2015
Team Travel to Huntsville, Alabama	4/7/2015	4/7/2015
Launch Readiness Review (LRR)	4/7/2015	4/7/2015
NASA Safety Briefing	4/8/2015	4/8/2015
Rocket Fair and Tours of MSFC	4/9/2015	4/9/2015
Launch Day	4/10/2015	4/10/2015
Sigma Gamma Tau Boy Scout Merit Badge Event	4/11/2015	4/11/2015
Backup Launch Day	4/12/2015	4/12/2015
Senior Picnic (full scale launch)	4/27/2015	4/27/2015
Post-Launch Assessment Review	4/29/2015	4/29/2015
Winning Team Announced by NASA	5/11/2015	5/11/2015

The team is confident that it will have a fully-working AGSE by competition in April. With a successful full-scale flight on February 28, the team almost finished with the vehicle. The only major task left to be done is painting the vehicle for the competition. Meanwhile, construction of the AGSE has already begun. The base is fully assembled, and the launch rail, ratcheting stops, arm base, and electronics bays are nearly complete. After the completion of the FRR, the team will continue to finalize these components. It is critical that the arm and camera experiments be finished by March 27 to allow time to debug the processes. By finishing the construction of the AGSE by March 31, the team will allow for several days to test the overall system and eliminate any remaining flaws. By doing tests along the way, the team is confident it will have enough time and deliver a completed, successful project.

6.4 Educational Engagement plan and status

Tripoli Summer Low-Mid Power Launches

During the summer, NCSU High Powered Rocketry Club attended Tripoli-hosted low-mid power rocket launches on May 24th, June 28th, July 26th, and August 16th. During these launches the club members Chris Celestino, Emily Gipson, Jamie Region, Josh Pickles, and Will Martz assisted the Tripoli organization with setting up and taking down the launch site in Butner, NC, setting up an information table for kids and adults to learn about High Powered Rocketry, launching our subscale demonstrators from previous years, and helping to recover rockets. There were 50-150 people that attended each of these launches. The team participated in this event again on

January 31, 2015. This time, however, Chris Celestino, Emily Gipson, Joshua Pickles, Will Martz, Andrew McKeon, and Mitchell Plyler participated in the event.
Location: Perkins Field, Butner, NC 27509
Dates: May 24, 2014; June 28, 2014; July 26, 2014; August 16, 2014; January 31, 2015

GE Aviation – Manufacturing Day
Chris Celestino and Collin Bolton attended GE Aviation's Manufacturing day at the GE Aviation plant in Durham, NC. This event was open to a number of students from the surrounding area and had approximately 80 high school students from 4 different high schools (including the early-college STEM school at NC State) and another 25 students from the NC State Career Development Center. These students made up a majority of the audience, but adults participated as well. Roughly 150 people were in attendance.
NC State's High Power Rocketry Club hosted a display table for an information fair to provide some "next step" ideas for students who are interested in aerospace manufacturing. The members engaged participants about NC State Aerospace Engineering, Rocketry, and the High Power Rocketry Club with a table top display, hands-on and interactive elements, and hand-out information about the club and NC State's Aerospace program.
Location: GE Aviation 3701 S. Miami Boulevard, Durham, NC 27703
Date: Friday, October 3rd, 2014, 10:00 – 1:00PM

Astronomy Days
Astronomy Days is a yearly event that celebrates aviation and rocketry, and was held over two days at the Museum of Natural Sciences in Raleigh. The team was able to send 3-5 people to volunteer at the event on both days. Tacho Lycos was invited to host a table at the event and educate children and adults about the basics of rocketry. The team used the opportunity to show the public rockets from the club's past and to discuss the project for this year. Over 14000 people attended Astronomy Days this year, and the club was able to outreach to almost 6000 kids (grades K-12) and adults. The event was also used to promote the Low-Mid Powered Tripoli event to be held on January 31.
Location: North Carolina Museum of Natural Sciences, 11 W Jones St, Raleigh, NC 27601
Dates: January 24-25, 2015

North Carolina Science Olympiad
Chris Celestino, Joshua Pickles, Will Martz, and Emily Gipson assisted in the NC Science Olympiad in February 2015. Each team member was assigned different tasks by the even coordinator. Chris was the event lead for the "Egg-O-Naut" competition where middle and high school students had to safely launch and recover an egg with a water bottle rocket. Chris was in charge of judging the event and coordinating with other volunteers. Emily and Will were judges and event leads for the "Air Trajectory" event in which students had to hit a target with a ping-pong ball. Joshua acted as a judge for the simple and compound machine events. In this event, the middle and high school students had to determine the ratio of three unknown masses within a time limit. The team was able to reach out to over 400 middle and high school aged kids and their families.
Location: Campbell University, 143 Main St, Buies Creek, NC 27506

Date: February 7, 2015

Raleigh Charter Outreach Event
The team was invited to give a presentation to the Astronomy Club at Raleigh Charter high school. This club is interested in all aspects of space as was connected to the club after the NC State Engineering Open House (at which the team hosted a table to represent the club). Chris Celestino, Emily Gipson, Mitchell Plyler, Zach Giankos, Braedon Earp, and Daniel Mahinthakumar gave a presentation that covered the basics of flight, rocketry, stability, and the NASA 2014-2015 student launch competition. All 20 students at the event were fascinated in what the team had to say, and spent the majority of an hour asking questions.
Location: Raleigh Charter High School, 1307 Glenwood Ave, Raleigh, NC 27605
Date: February 20, 2015

Sigma Gamma Tau Boy Scout Merit Badge Event
The club is also planning on partnering with NCSU's chapter of Sigma Gamma Tau to host their annual Boy Scout Merit Badge Event in the spring of 2015. On the morning of this event, the club launches a model rocket for the enjoyment of the Boy Scouts and their families. Sigma Gamma Tau then gives a presentation for those attending before the Space Exploration badges are awarded. This even takes place at NCSU's campus and involves around 30-40 Boy Scouts and their families. The details of this event will be finalized in spring 2015.
Location: North Carolina State University's campus, Raleigh, NC 27695
Date: April 11, 2015

7 Conclusion

The team is satisfied with the design that we have created and presented for the NASA Student Launch Competition. The analysis and experiments preformed lead the team to believe that we will be successful in Huntsville, AL and look forward to the next challenge.

8 Alternate Checklists

8.1 Sub-scale

1) Retrieve nose cone/upper airframe section
2) Check that the two screws to hold the nose cone are tight using Philips head screwdriver
3) Check that the four coupler screws to hold coupler are tight using Philips head screwdriver
4) Retrieve middle airframe with avionics bay
5) Carefully pull avionics bay from middle airframe making sure not to pull out wiring
6) Unscrew lower section nuts and pull bulkhead off threaded rods
7) Pull avionics sled out of avionics bay with upper nuts still through the threaded rods
8) Insert the two batteries into each of the battery trays
9) Connect battery snaps on each battery
10) Insert avionics sled back into avionics bay making sure no wires are crossed and the sled is oriented with the sleds nuts facing the correctly marked position
11) Run avionics bay threaded rods through the lower bulkhead and attach nuts on each finger tight
12) Tighten nuts on both ends of avionics bay with 3/8” ratchet / ½” socket and ½” ratchet / ¼” socket

13) Attach e-match wiring to terminal block 1 and ensure the wires are secured
14) Insert primary main black powder charge into cap 1 on top of avionics bay
15) Insert e-match into cap 1
16) Insert wadding into cap 1 and cover cap 1 with blue painters tape
17) Repeat steps 13 – 16 with redundant main black powder charge into cap 2 on top of avionics bay in terminal block 2
18) Slide avionics bay into middle airframe making sure that the arrows are aligned
19) Remove four screws from pill bottle and screw into the four screw holes with a Philips head screwdriver
20) Repeat steps 13 – 16 with primary drogue black powder charge into cap 1 on bottom of avionics bay with terminal block 1
21) Repeat steps 13 – 16 with redundant drogue black powder charge into cap 2 on bottom of avionics bay with terminal block 2
22) Retrieve green and black main parachute and shock cord for upper airframe
23) Remove rubber band from parachute
24) Attach quick link with no blue tape on shock cord to the top of the avionics bay (should be the long section of shock cord that attaches to the avionics bay)
25) Verify quick link is connected by another individual
26) Insert Kevlar sheet protector and parachute into middle airframe
27) Attach the quick link with blue tape on shock cord to the nose cone U-bolt
28) Verify quick link is connected by another individual
29) Insert nose cone section into middle airframe making sure the shear pin holes are aligned with V's
30) Install two shear pins into middle airframe to connect nose cone to middle airframe
31) Retrieve red and white drogue parachute and shock cord for lower airframe
32) Remove rubber band from parachute
33) Attach quick link with no blue tape on shock cord to the avionics bay
34) Verify quick link is connected by another individual
35) Attach quick link with blue tape on shock cord to the fin section U-bolt
36) Verify quick link is connected by another individual
37) Insert Kevlar sheet protector and parachute into fin section
38) Insert middle airframe into fin section aligning the arrow for shear pins
39) Insert two shear pins into fin section using a small flathead screwdriver to connect the fin section to the middle airframe
40) Attach launch lugs and ensure they are tightened with 3/32" Allen key
41) Retrieve motor and assemble in RMS 38/600 motor casing according to manufacturer's instructions
42) Instill motor casing into motor housing
43) Rotate motor retention clips to lock onto motor over the electrical tape
44) Have Conor tighten motor retention clips with ¼" ratchet, 7/16" socket and 3" extension
45) Check CG location and verify static margin
46) Carry assembled rocket to launch pad
47) Slide rocket launch lugs onto 10-10 launch rail
48) Erect rocket to vertical position and verify it's angled into the wind
49) Flip red switch and verify continuity
50) Flip black switch and verify continuity

51) Have certified individual insert igniter into motor
52) Attach leads to igniter from control station
53) Verify which lead number is being used
54) Fire the missile/rocket

9 Appendix

9.1 Milestone Review Flysheet

Milestone Review Flysheet

Institution	North Carolina State University	Milestone	CDR

Vehicle Properties

Total Length (in)	78
Diameter (in)	5.5
Gross Lift Off Weight (lb)	19.9
Airframe Material	BlueTube 2.0
Fin Material	Plywood
Drag	

Motor Properties

Motor Manufacturer(s)	AeroTech
Motor Designation(s)	K805G
Max/Average Thrust (lb)	180 / 163
Total Impulse (lbf-sec)	390
Mass (before, after burn) (lb)	3.40/1.48
Liftoff Thrust (lb)	100

Stability Analysis

Center of Pressure (in from nose)	56.0
Center of Gravity (in from nose)	46.5
Static Stability Margin	1.7
Thrust-to-Weight Ratio	9 : 1
Rail Size (in)/ Length (in)	1.5 / 96
Rail Exit Velocity (ft/s)	72

Ascent Analysis

Maximum Velocity (ft/s)	547
Maximum Mach Number	.47
Maximum Acceleration (ft/s^2)	266
Target Apogee (1st Stage if Multiple Stages)	3100 ft
Stable Velocity (ft/s)	44
Distance to Stable Velocity (ft)	3.85

Recovery System Properties

Drogue Parachute

Manufacturer/Model	Fruity Chutes Drogue Chute
Size	18 in
Altitude at Deployment (ft)	3000
Velocity at Deployment (ft/s)	0

Recovery System Properties

Main Parachute

Manufacturer/Model	Fruity Chutes Classic Elliptical
Size	36 in / 48 in
Altitude at Deployment (ft)	1000 / 700
Velocity at Deployment (ft/s)	72

Terminal Velocity (ft/s)	72
Recovery Harness Material	2000 lb-test Flat Kevlar
Harness Size/Thickness (in)	1
Recovery Harness Length (ft)	25
Harness/Airframe Interfaces	Forward: AARD on Sample/Nosecose section Aft: U-bolt on middle airframe

Kinetic Energy of Each Section (ft-lbs)	**Section 1**	**Section 2**	**Section 3**	**Section 4**
	1400	N/A	N/A	N/A

Recovery Electronics	
Altimeter(s)/Timer(s) (Make/Model)	Perfectflite Stratologger SL100/Perfectflite Stratologger CF/Entacore AIM 3 (2)
Redundancy Plan	Redundant apogee charge will have a 2 second delay. Main redundant charges will be programmed for 900 and 600 feet AGL at 125% primary charge size.
Pad Stay Time (Launch Configuration)	1 hour

Terminal Velocity (ft/s)	21/24
Recovery Harness Material	2000 lb-test Flat Kevlar
Harness Size/Thickness (in)	1/1
Recovery Harness Length (ft)	25/25
Harness/Airframe Interfaces	Forward: U-bolt on middle airframe Aft: U-bolt on fin section bulkhead

Kinetic Energy of Each Section (ft-lbs)	**Section 1**	**Section 2**	**Section 3**	**Section 4**
	62	61	N/A	N/A

Recovery Electronics	
Rocket Locators (Make/Model)	Digi XBee-Pro XSC
Transmitting Frequencies	900 MHz
Black Powder Mass Drogue Chute (grams)	1.2
Black Powder Mass Main Chute (grams)	2/1.2

Milestone Review Flysheet

Institution	**North Carolina State University**	**Milestone**	**CDR**

Autonomous Ground Support Equipment (AGSE)	
Capture Mechanism	Overview A purchased robotic arm will use an image recognition system based on color identification to locate and direct itself to the sample to be grappled.
Container Mechanism	Overview A 3D printed mold will be placed inside the door and be attached to the avionics sled. The mold will be able to fit the sample and the door closing will lock the sample into place.

Launch Rail Mechanism	Overview	
	The launch rail will be raised by a geared stepper motor. While being raised, the rail will be supported by a ratcheting brace in case of a loss of power. Once fully raised, a pin will engage into a hole in the side of the launch rail sector gear to lock it in place.	
Igniter Installation Mechanism	Overview	
	Stepper motor powered linear actuator will raise the igniter into the rocket on a wooden dowel.	
CG Location of Launch Pad (in inches) When Rail is Horizontal (Use Base of Rail as the Reference Point)		25.1 inches
Moment Analysis	The tipping side wind speed with the launch vehicle in the vertical position is 38 mph. The tipping headwind speed with the launch vehicle in the vertical position is 51 mph. Both values are above the Tripoli Rocketry Assoc. 20 mph maximum launch wind speed.	
Payload		
Payload 1	Overview	
	The payload will be made of 0.75 x 4.75 inch PVC tubing filled with sand and weigh approximately 4 ounces. The payload will be a cylindrical shape approximately with a 0.75 inch diameter and a 4.75 inch length. Ends of the tubing will be secured with domed PVC caps.	
Test Plans, Status, and Results		
Ejection Charge Tests	Ejection charges will be sized specific to the compartment to be separated. Charges will be constructed with black powder in a PVC cap with an e-match secured in the PVC by wadding and painters tape. Each altimeter will be connected through a USB port to a laptop with the Perfectflite DataCap program. The drogue and main charges deployed as expected and successfully.	
Sub-scale Test Flights	The subscale flight tests occurred on November 22nd, 2014 and December 20th, 2014. The December 20th launch was a complete success and a proof of concept for the full scale launch vehicle.	
Full-scale Test Flights	The full scale flight test took place on February 28, 2015 and was a complete success with 7 black powder charges fired, 3 parachutes deployed, and the ARRD separating the two sections.	

Milestone Review Flysheet

Institution	North Carolina State University	Milestone	CDR

9.2 FMECA Failure Modes

Structures

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Blue Tube Airframe	Cracks or breaks	Manufacturing defect	Individual sections structural integrity at risk	Unintended launch vehicle separation	1	Visual inspection prior to use
		Loads beyond design specification			1	Maintain vehicle within design specifications
		Damaged during handling			1	Adhere to proper handling procedure
		Improper maintenance			1	Pre/post launch inspections
Bulkheads	Separation of bulkhead from other structural members	Poor design	Unable to transfer loads	Increased loads on other structural members	2	FEA of bulkhead fixed support
		Manufacturing defect			2	QC of manufacturing process
		Loads beyond design specification			2	Maintain vehicle within design specifications
		Damaged during handling			2	Ensure analysis includes handling loads/adhere to proper handling procedure
		Improper maintenance			2	Pre/post launch inspections

	Damage/separation from parachute deployment	Poor design	Unable to support loads of chute deployment	Loss of safe and effective recovery system	2	FEA of bulkhead stress
		Manufacturing defect			2	QC of manufacturing process
		Loads beyond design specification			2	Maintain operations within design specifications
		Improper Maintenance			2	Pre/post launch inspections
	Non-compromising cracks	Poor Design	Potential for future damage	No system level safety effect	4	FEA of bulkhead stress
		Manufacturing Defect			4	QC of manufacturing process
		Loads beyond design specification			4	Maintain operations within design specifications
		Damaged during handling			4	Adhere to proper handling procedure
		Improper maintenance			4	Pre/post launch inspections
Fins	Damage from impact	Poor design	Loss of future fin use	Possible damage to other components	2	FEA
		Manufacturing defect			2	QC of manufacturing process
		Damaged during handling			2	Adhere to proper handling procedure
		Loads beyond design specification			2	Maintain operations within design specifications
		Improper maintenance			2	Pre/post launch inspections

Shear Pins	Breaking before charge detonation	Manufacturing defect	Loose assembly of compartment	Separation of vehicle compartments	3	QC of parts received
		Loads beyond design specification			3	Maintain vehicle within design specifications
		Improper maintenance			3	Use of new pins after each launch
Avionics Sleds	Detaches from secured position	Poor design	Damage to/loose wiring of avionics components	Loss of recovery system initiation	3	Design to ensure secure sled with redundancy
		Manufacturing defect			3	QC of manufacturing process
		Damaged during handling			3	Adhere to proper handling procedure
		Loads beyond design specification			3	Maintain operations within design specifications
		Improper maintenance			3	Pre/post launch inspections
Nosecone	Non-compromising cracks	Manufacturing defect	Potential for future damage	No system level safety effect	4	QC of part received
		Damaged during handling			4	Adhere to proper handling procedure
		Loads beyond design			4	Maintain vehicle within design

		specification				specifications
		Improper maintenance			4	Pre/post launch inspections
	Damage from impact	Manufacturing defect	Loss of future nosecone use	No system level safety effect	3	QC of part received
		Damaged during handling			3	Adhere to proper handling procedure
		Loads beyond design specification			3	Maintain vehicle within design specifications
		Improper maintenance			3	Pre/post launch inspections

	Pre-mature separation from other structural members	Damaged during handling	Potential for structural damage	Loss of controlled and stabilized flight	1	Adhere to proper handling procedure
		Improper maintenance			1	Pre/post launch inspections

Recovery

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Black Powder Charges	Deployment failure	Charge is too small	Unsuccessful parachute deployment	Rocket is not safely recovered	1	Complete experimental testing to ensure proper charge sizing
	Violent ejection causes accidental separation	Charge is too big			1	
Avionics	No power to avionics or igniters	Dead battery	No ejections	Rocket is not safely recovered	1	Use new batteries for each launch
	Interference from RF	Improper design	No ejections	Damage from	2	Complete testing of

	transmitter		or mistimed ejections	high velocity ejection		electronic devices
	Bug in altimeter coding	Manufacturer defect		Large drift from early ejection	4	Test two altimeters for redundancy
Bulkhead and U-bolt	U-bolt failure	Improper attachment	Separation of rocket section from parachute	Rocket is not safely recovered	1	Make sure components are adequately constructed
	Bulkhead failure	Improper attachment			1	
Parachute deployment	Parachutes (3) fail to deploy correctly	Parachute tangling	Parachutes do not correctly deploy	Rocket is not safely recovered	1	Ensure that parachutes and shock cord are folded correctly
		Remote sensor of rocket section from parachutes			3	Construct the rocket so the wires are out of the way
		Parachute bags do not fully open			1	Fold bags correctly and make sure nothing can snag the parachutes
		Shock cord connections come loose			1	Check all shock cord
Exploding Eyebolt	Eyebolt fails to	Improper	Upper and	Rocket is not	1	Make sure

(ARRD)	detonate	wiring/attachment	middle airframes do not separate	safely recovered		components are adequately constructed
		Manufacturer defect			4	Test two eyebolts for redundancy
	Premature detonation	Improper wiring/attachment	Premature separation of connections between lower and middle airframe	Large drifting distance of lower airframe	3	Make sure components are adequately constructed
		RF interference			3	Complete testing of electronic devices

Aerodynamics

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Fins	Fins layout cause unexpected trajectory	Fins are not attached at the correct angle	Aerodynamic forces from fins are not the same from each fin	Trajectory is different than expected	3	Use fin jig to ensure angles are correct
		Fins are not symmetric			4	Shape fins to specifications before installation
Nosecone	Nosecone imperfections lead to altered trajectory	Manufacture defect	Aerodynamic forces are greater on one side of the nosecone	Trajectory is different than expected	4	Inspect nosecone and sand to correct shape
Rocket Sections	Rocket sections	Deceleration of	Sections	High velocity	1	Make sure shear pins

	separate before charges ignite	the rocket	separate early	separation		and screws can hold
				Premature parachute deployment at high altitudes	4	

Propulsion

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Bulkhead	Motor breaks through bulkhead	Material or construction flaws	Motor system is compromised	Motor damages rocket frame or contents	1	Inspect bulkhead prior to launch
Motor Casing	Damage to motor casing	Superficial damage	Motor is not safe if major damage occurs	Rocket is not safe to launch if damage is major	4	Check motor casing before launch, remove foreign objects from motor area
		Motor inoperable			2	
		Motor casing fracture			1	
Fuel	Contamination of fuel	Rocket fails to launch	Reduced performance of rocket motor	Rocket does not launch or perform as expected	2	Store and maintain motor fuel properly and in isolation / order from reputable source
		Over-oxidized reaction			2	
		Reduced fuel efficiency			3	
Construction	Motor misalignment	Construction or measurement error	Thrust is not in expected direction	Unpredicted trajectory	1	Check motor alignment during construction
		Rocket frame fracture			1	

Launch	Launch interference from foreign object	Unpredictable rocket trajectory	Launch when clear		3	Launch in an open area, wait for clear airspace before launch
		Rocket frame fracture			2	

Stability

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Cg	Expected numbers are different from actual	Error in calculations and measurements	Stability characteristics are different than projected	Flight path and characteristics in jeopardy	1	Physically measure the location of the center of gravity
Cp						Use Barrowman's method/OpenRocket to determine location of center of pressure
Static Margin						Calculate by using the locations of the center of gravity and pressure
Weight Shift	Weight shift causes center of gravity shift	Large acceleration or deceleration forces an object to shift	Static margin change due to shift in center of gravity		1	Ensure all rocket components are secure during construction process

Sample Compartment

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Door	Spring-loaded locks don't lock	Bracket misalignment	Door doesn't shut securely	Rocket is not ready to Launch. Door	1	Careful inspection as part of pre-flight checklist.

		Excessive spring force required to lock		could open during flight and cause instability.	1	Calculation based on energy required to compress spring. Tests during build process.
		Debris in lock			1	Inspection as part of pre-flight checklist.
	Hinges Fail	Excessive arm pressure			1	Tests during build process to ensure the arm behaves correctly.
		Manufacturing defect			1	Inspection and tests during build.
Sample Mold	Breaks	Excessive loading	Sample free to move and at risk of damage	Mission requirements not met	2	Build to withstand max force of arm.
	Doesn't hold sample securely	Misalignment of mold			3	Inspection during pre-flight checklist.
		Sample cut out improperly sized			3	Verified during build and pre-flight checklist.
Clamps	Breaks	Excessive loading by arm			3	Visualization design needs to register proper location of clamp.
	Insufficient/excessive gripping force	Poor selection in design process			3	Testing during build and pre-flight checklist.

AGSE

Function / Component	Failure Mode	Causal Factors	Failure Effects: Subsystem	Failure Effects: System	Hazard	Recommendations
Robotic Arm	Pivot points seize	Debris	Arm cannot move to retrieve sample	Failure of mission requirements	2	Inspection during pre-flight checklist.
		Binding of gears			2	Inspection during pre-flight checklist.
	Arm will not move	Rust			2	Inspection during pre-flight checklist.
		Power failure			2	Power backup as part of design.
	Unwanted movement	Signal interference			2	EMF Shielding for servo controller.
	Cannot grab with claw	Gearing slips			2	Testing during build and pre-flight checklist.
Erecting System	Gearing	Structural failure	Rocket not in proper vertical position for launch.	System requires human intervention to launch.	1	Inspection during pre-flight checklist.
		Gearing slips out of plane			1	Inspection during pre-flight checklist. Monitor during competition.
		Debris in gearing			2	Inspection during pre-flight checklist.
	Motor	Over/under torqued			2	Testing during build. Monitor during competition.
	Moves beyond 5 degrees from vertical	Inaccuracies in setup			2	Testing during build. Monitor during competition.

Igniter insertion system	Does not insert all the way	Igniter falls off rail	Failure to activate propulsion system	System requires human intervention to launch.	2	Testing during build. Monitor during competition.
		Rollers stop			2	Testing during build. Monitor during competition.
	Falls out	Cap not completely inserted			2	Inspection during pre-flight checklist.
	No ignition	Bad igniter			2	Inspection during pre-flight checklist.
		Short in wiring			2	Inspection during pre-flight checklist.
Imaging system	PVC not recognized in image	Debris on lens	Failure to capture sample autonomously	Autonomous requirement of competition is not met.	2	Inspection during pre-flight checklist.
		Focus of camera			2	Camera should be selected to be focused for small distances in competition.
		Brightness			2	Positioning of camera during competition should not be facing the sun.
	No image	Camera not detected in system			2	Camera detection as part of pre-flight checklist.
	Incorrect distance calculations	PVC in unexpected orientation			2	Proper' PVC placement as part of pre-flight checklist.
		PVC at a distance not in distance curve			2	Proper' PVC placement as part of pre-flight checklist.
	Power supply failure	Distribution failure	System cannot begin or stops	System does not begin or ceases	2	Testing during build process and as a part of pre-flight

			operation.	operation.		checklist.
		Dead batteries			1	Testing during pre-flight checklist.
		Short circuits			1	Testing during pre-flight checklist.
		Insufficient voltage supply			1	Testing during build process and as a part of pre-flight checklist.
		Insufficient current supply			1	Testing during build process and as a part of pre-flight checklist.
	BeagleBone malfunction	Reset upon a power outage			1	Testing during build process and as a part of pre-flight checklist.
	Electrical connections	Corroded connections			2	Inspection as part of pre-flight checklist.
		Loose connections pre-launch			2	Inspection as part of pre-flight checklist.
		Loose connections from launch/movement			2	Inspection as part of pre-flight checklist.
	Switches	Sticks in close/open position			2	Inspection as part of pre-flight checklist.
		Registering >1 press			2	Inspection as part of pre-flight checklist.

9.3 Vehicle Verification Matrix

Number	Requirement	Satisfied by:	Verification Status
1.1	The vehicle shall deliver the payload to, but not exceeding, an apogee altitude of 3,000 feet above	**Motor choice.** The AeroTech K805G is projected to send the vehicle to 3068 feet.	**Verified.** The full-scale was flown to an altitude of 3345 feet according to

	ground level (AGL).	The addition of weight/ballast during manufacturing will allow the vehicle to reach the desired altitude of 3000 feet.	the Strattologer altimeters, and 2800 feet according to the Entacore altimeters on the K805G motor.
	The vehicle will leave the launch rail at 55 feet per second.	**Motor choice and vehicle design.**	**Verified.** Calculations have shown that the vehicle will be able to reach 72 ft/s off of the rail. The full-scale was able to safely leave the launch rail, verifying the calculations.
1.2	The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in the competition scoring.	**Vehicle design.** Out of the 4 altimeters on the vehicle, one of the Stratologger SL100 altimeters will be used for scoring.	**Verified.** The full-scale was successfully flown on all 4 altimeters which reported altitudes of 3345 feet and 2800.
1.2.1	The altimeter will report the official competition altitude via a series of beeps to be checked after the flight completion.	**Altimeter choice.** The beeps from the Stratologger altimeter will be used to verify the altitude of the vehicle.	**Verified.** The altitudes from the full-scale flight could be read from the beeps. The readings were verified on the computer.
1.2.2.1	Official Altimeter must be marked by NASA official.	**NASA action.** The team will ensure that the chosen altimeter is identified to the officials on the day of the competition.	**Not Verified.** Completed at competition.
1.2.2.2	The altimeter beeps must be audible to the NASA official.	**Altimeter choice.** Each of the altimeters will have loud, audible beeps.	**Verified.** Each altimeter can be heard from outside the vehicle and can be easily removed from the avionics sleds. Beeping is loud and audible.

1.2.2.3	All electronics, except for the official altitude-determining altimeter shall be capable of being turned off.	**Vehicle design.** The altimeters are armed via switches accessible from the outside of the vehicle. Each altimeter has its own switch.	**Verified.** Each altimeter is armed individually. The GPS units and radios can be turned off by removing their power supplies.
1.2.3.1	The altitude must be reported via beeps: the altimeter must not be damaged or lose power.	**Vehicle design.** The altimeters will be set securely and safely on the sled within the vehicle. The batteries used to power the altimeters will be new for the competition and secured so that they do not disconnect.	**Verified.** The altitudes from the full-scale flight could be read from beeps. The altimeters did not lose power, as indicated by the power graphs they reported.
1.2.3.2	The team must report to NASA official with marked altimeter.	**Team action.** The team will ensure that the chosen altimeter is identified to the officials on the day of the competition.	**Not verified.** Completed at competition.
1.2.3.3	The reported altitude must not be over 5000 feet AGL.	**Motor choice and vehicle design.** The projected ideal altitude of the chosen motor is 3068 feet. Since more weight will be added, the vehicle will not go over 5000 feet AGL.	**Verified.** The full-scale reached reported altitudes of 3345 and 2800 feet during testing.
1.2.3.4	The rocket must be flown at the competition launch site.	**Team action.** The rocket will be safely transported to the competition and flown at the launch site.	**Not verified.** Completed at competition.
1.3	Launch vehicle shall be designed to be recoverable and reusable. Reusable is	**Vehicle design.** The vehicle is reusable. Appropriate parachute	**Verified.** Calculations show that the vehicle will land

	defined as being able to launch again on the same day without repairs or modifications.	sizes were chosen so that the vehicle safely returns to the ground.	with little kinetic energy (see section Error! Reference ource not found.). The full-scale safely returned to the ground after flight. It remained fully intact and reusable.
	The vehicle will land will little to no damage.	**Vehicle design.** Proper parachute sizes have been chosen so that the vehicle sections return safely.	**Verified.** Section Error! eference source not found. reports the kinetic energy calculations. The full-scale was recovered with no damage.
1.4	The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle .using its own parachute.	**Vehicle design.** The vehicle will come down in 2 independent sections: the nosecone and payload compartment, and the lower airframe and fin section.	**Verified.** The vehicle was built with these two independent sections. The full-scale successfully separated during flight as planned.
	The vehicle's independent sections will not damage other portions of the rocket in anyway upon separation.	**Shock cord lengths.** The shocks cords will be measured to be 3-5 times the overall length of the rocket so that sections will not hit each other upon ejection.	**Verified.** No sections impacted each other the full-scale test.
1.5	The launch vehicle shall be limited to a single stage.	**Vehicle design.** The design uses a single stage. The vehicle only separates to release the parachutes after apogee.	**Verified.** The vehicle was constructed to only use a single stage.

1.6	The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the Federal Aviation Administration flight waiver opens.	**Team action.** The design is simple enough that it will be able to be fully prepared for flight within 2 hours. Practicing the launch procedures will also make sure the team is efficient at assembling and preparing the vehicle.	**Verified.** The team as able to assemble the vehicle for launch in 1.5 hours. This time will improve with more 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 components.	**Vehicle design and component choice.** The components on the vehicle are capable of remaining in the launch-ready position for more than 1 hour. The batteries provide more than enough power to last for the minimum 1 hour requirement.	**Verified.** The batteries can hold their charge for ~15 hours, and the GPS units can remain powered for 3 hours.
1.8	The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system provided by the NASA-designated Range Services Provider.	**Igniter choice.** The igniter used is able to be set off with a 12 V power supply.	**Verified.** The full-scale was launched with a 12 V power supply successfully.
1.9	The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association	**Motor choice.** The motor chosen is the Aerotech K 805G and is a certified motor.	**Verified.** The full-scale was flown on the K805G motor. An additional motor was purchased for the competition.

	of Rocketry (CAR).		
1.9.1	Final motor choices must be made by the Critical Design Review (CDR).	**Motor choice.** The motor chosen was the AeroTech K805G.	**Verified.** The motor chosen was the AeroTech K805G.
1.9.2	Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO), and will only be approved if the change is for the sole purpose of increasing the safety margin.	**Team action.** The RSO will be notified of any changes to the motor choice for approval.	**Verified.** The motor choice has not changed.
1.10	The total impulse provided by a launch vehicle shall not exceed 1150 pound-seconds (L-class).	**Motor choice.** The chosen motor has a total impulse of 340 pound-seconds.	**Verified.** The K805G has a total reported impulse of 350 pound-seconds.
1.11	Any team participating in Maxi-MAV will be required to provide an inert or replicated version of their motor matching In both size and weight to their launch day motor. This motor will be used during the LRR to ensure the igniter installer will work with the competition motor on launch day.	**Team action.** The team will provide a model of the motor to be used to show that the igniter system will work.	**Not verified.** Completed at competition. The model has not yet been constructed.
	The wooden dowel will not choke the flow in the motor.	**Dowel selection.**	**Verified.** The motor manufacturer assured the team that a 0.125 inch wooden dowel will not choke the flow.
1.12.1	For pressure vessels, The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) shall be 4:1 with	**Vehicle design.**	**Verified.** The vehicle was constructed without a pressure vessel.

	supporting design documentation included in all milestone reviews.		
1.12.2	The low-cycle fatigue life shall be a minimum of 4:1.	**Vehicle design.**	**Verified.** The vehicle was constructed without a pressure vessel.
1.12.3	Each Pressure vessel shall include a solenoid pressure relief valve that sees the full pressure of the tank.	**Vehicle design.**	**Verified.** The vehicle was constructed without a pressure vessel.
1.12.4	Full pedigree of the tank shall be described, including the application for which it was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.	**Vehicle design.**	**Verified.** The vehicle was constructed without a pressure vessel.
1.13	All teams shall successfully launch and recover a subscale model of their full-scale rocket prior to CDR. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model.	**Team action.**	**Verified.** The team successfully flew its subscale model on December 20, 2014.
1.14	All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The	**Team action.**	**Verified.** The team successfully flew its full-scale vehicle on February 28, 2015. All components and hardware functioned as planned, and the vehicle reflected its launch-day

	purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.).		configuration.
1.14.1	The vehicle and recovery system shall have functioned as designed.	**Vehicle design.** The team will do everything it can to ensure that the recovery system works as designed.	**Verified.** The full-scale was recovered as the team planned. The drogue opened at apogee, the ARRD set off at 1100 feet, and main parachutes deployed at 1000 and 700 feet.
1.14.2	The payload does not have to be flown during the full-scale test flight. The following requirements still apply:	**Team action.**	**Verified.** The full-scale was flown with the payload intact.
	The payload will not move more than 0.125 inches within the mold.	**Vehicle design.** The mold will be made to fit the sample exactly so that there will be minimal movement.	**Verified.** The gap in the sample compartment is less that the desired space. There were no signs that the sample moved during flight when the full-scale was recovered.
1.14.2.1	If the payload is not flown, mass simulators shall be used to	**N/A**	**N/A**

	simulate the payload mass.		
1.14.2.2	The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.	**N/A**	**N/A**
1.14.2.3	If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems shall be active during the full-scale demonstration flight.	**Vehicle design.** The payload will not change the external surface of the rocket. The door will have a slight effect on the rocket's profile, and will be implemented during the full-scale launch.	**Verified.** The payload compartment door was utilized on the demonstration flight. The door sits flush to minimize its effect on flight/drag.
	The door will sit flush on the outside of the vehicle.	**Vehicle design.** The hatch has been designed so that it will have as low a profile as possible.	**Verified.** The door sits flush on the external surface of the vehicle.
1.14.3	The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulate, as closely as possible, the predicted maximum velocity and maximum acceleration of the competition flight.	**Team action and motor choice.**	**Verified.** The competition motor, the K805G, was used during the full-scale demonstration flight.
1.14.4	The vehicle shall be	**Team action.**	**Verified.**

	flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the competition flight.	The team will fly the full-scale in its fully ballasted configuration.	The team flew its full-scale vehicle in its competition configuration. The only change was that it had not yet been painted.
1.14.5	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO).	**Team action.** The team will not modify its full-scale rocket after the demonstration flight without the approval of the RSO.	**Verified.** With the exception of painting, the team does not plan to change the configuration of the full-scale vehicle.
1.15	Each team will have a maximum budget they may spend on the rocket and the Autonomous Ground Support Equipment (AGSE). Teams who are participating in the Maxi-MAV competition are limited to a $10,000 budget while teams participating in Mini-MAV are limited to $5,000.	**Team action.**	**Verified.** The team's budget is currently set to $10,000 in accordance with the requirements for the Maxi-MAV challenge.
1.16.1	The launch vehicle shall not utilize forward canards.	**Vehicle design.**	**Verified.** The completed full-scale does not utilize forward canards.
1.16.2	The launch vehicle shall not utilize forward firing motors.	**Vehicle design.**	**Verified.** The completed full-scale does not utilize forward firing motors.
1.16.3	The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark,	**Vehicle design and motor choice.**	**Verified.** The completed full-scale does not utilize

	MetalStorm, etc.).		motors that expel titanium sponges.
1.16.4	The launch vehicle shall not utilize hybrid motors.	**Motor choice.**	**Verified.** The K805G is not a hybrid motor.
1.16.5	The launch vehicle shall not utilize a cluster of motors.	**Motor choice.**	**Verified.** The K805G is not a cluster motor.
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. Tumble recovery or streamer recovery from apogee to main parachute deployment is also permissible, provided the kinetic energy during drogue-stage descent is reasonable, as deemed by the Range Safety Officer.	**Vehicle design.** The design deploys a drogue at apogee. A main parachute is also deployed at 1000 and 700 feet AGL.	**Verified.** The full-scale demonstration flight deployed a drogue at apogee, and full scale parachutes at 1000 and 700 feet.
2.2	Teams must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.	**Team action.** The team performed an ejection test before the first subscale launch, and will do the same for the first full-scale launch.	**Verified.** The team performed successful ejection tests before the subscale and full-scale launches. The results of the full-scale tests are described in section **3.3.6.**
2.3	At landing, each independent section of the launch vehicle shall have a maximum kinetic energy of 75 foot-pounds.	**Parachute selection.**	**Verified.** According to calculations, the nosecone section landed with a kinetic energy of 21 foot-pounds, and the fin

			section will had a kinetic energy of 24 foot-pounds.
2.4	The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	**Vehicle design.**	**Verified.** The constructed full-scale does not utilize payload electrical circuits.
2.5	The recovery system shall contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers. One of these altimeters may be chosen as the competition altimeter.	**Vehicle design.**	**Verified.** The full-scale uses all 4 altimeters. One of each of the Stratologger SL100 and Entacore AIM 3.0 altimeters are primaries. One of the Stratologgers will be used as the competition altimeter.
2.6	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.	**Vehicle design.** There will be 4 switches accessible to the exterior of the rocket. Each switch will be dedicated to a single altimeter.	**Verified.** Testing has shown that 4 of the full-scale's pressure port holes can be used as access points to the altimeter switches. Each altimeter has its own switch.
2.7	Each altimeter shall have a dedicated power supply.	**Vehicle design.** Each altimeter will have its own new, Duracell 9 volt battery.	**Verified.** The full-scale was flown with each altimeter having its own 9 volt battery.
2.8	Each arming switch shall be capable of being locked in the ON position for launch.	**Vehicle design.** Each altimeter will use a lockable 110/220 volt rotary selecting switch.	**Verified.** The full-scale successfully utilized these 4 lockable rotary switches. Each altimeter remain on during flight.
2.9	Removable shear pins shall be used for both	**Vehicle design**	**Verified.**

	the main parachute compartment and the drogue parachute compartment.	2-56 Nylon shear pins will be used for both the main and drogue parachute compartments.	During ejection tests and the full-scale flight, each section was able to break the shear pins and deploy its parachute.
2.10	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.	**Vehicle design.** Each section will use a BigRedBee GPS to transmit its location.	**Verified.** The full-scale demonstration flight successfully used these GPS units to transmit the location each section. It was found that the nosecone and fin sections drifted about ¼ mile.
2.10.1	Any rocket section, or payload component, which lands untethered to the launch vehicle shall also carry an active electronic tracking device.	**Vehicle design.** Both of the sections of the vehicle will have their own electronic tracking devices.	**Verified.** Both sections of the vehicle recorded data with their GPS units, as noted above.
2.10.2	The electronic tracking device shall be fully functional during the official flight at the competition launch site.	**Team action.** Testing before the competition will make sure that the electronic tracking devices will be functional for the competition.	**Verified.** The GPS units were fully functional before and after the full-scale test. They will be tested again immediately before the competition.
2.11	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	**Vehicle design.** The recovery system electronics will be shielded from any on-board electronic devices using bulkheads and aluminum duct tape where applicable (such as to block the GPS transmissions from the altimeters).	**Verified.** The full-scale flight did not result in any noticeable interaction between electronic devices. Each electronic system was shielded from any others.
2.11.1	The recovery system	**Vehicle design.**	**Verified.**

	altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The altimeters will not be placed inside the same compartment as the GPS for both sections of the rocket.	The full-scale was constructed so that the altimeters and GPS units are in separate compartments.
2.11.2	The recovery system electronics shall be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.	**Vehicle design.** As mentioned above, the altimeters will be shielded from any transmitting devices by being put in separate compartments.	**Verified.** There was no noticeable interaction between electronic devices.
2.11.3	The recovery system electronics shall be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	**Vehicle design.**	**Verified.** There are no magnetic wave generators on board the vehicle.
2.11.4	The recovery system electronics shall be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	**Vehicle design.** Proper care will be taken to ensure that the altimeters will not malfunction because of other components on the vehicle.	**Verified.** The full-scale demonstration flight revealed that the team successfully shielded the altimeters from other devices.

9.4 AGSE Verification Matrix

Number	Requirement	Satisfied by:	Verification Status
3.2.1	The Maxi-MAV will provide each team with the opportunity to develop a unique method to capture, contain, launch, and eject a payload with limited human	**AGSE design.** The combination of the robotic arm and imaging system allow for the sample to be captured and placed into the vehicle. The	**Partially Verified.** The imaging system is still being finalized. Testing has shown that the robotic arm can move to the sample with 0.125 inch

	intervention. In addition, teams will develop a launch system that erects a rocket from a horizontal to vertical position, and has its igniter autonomously installed. On launch day, each launch will follow this general procedure.	mold within the vehicle will contain the sample and the robotic arm will seal the container. The stepper motors will raise the rocket via a gearing system and insert the igniter with a threaded rod.	accuracy. The stepper motors can raise the rocket and insert the igniter in 70 seconds.
3.2.1.1	Teams will position their launch vehicle horizontally on the AGSE.	**AGSE design.** The AGSE starts with the vehicle in the horizontal position. This position can be seen in **Figure 44**.	**Verified.** Initial construction of the AGSE places the rocket in the horizontal position when it is at rest.
	While the rocket is raising, there must be a safety factor of 2.5 for the load on the stepper motor.	**Stepper motor selection.**	**Verified.** The max torque exerted by the rocket can be 12 foot-pounds for the highest weight estimates. The stepper motor is rated for 30 foot-pounds holding torque. This results in a factor of safety of 2.5.
	The rocket must be raised in 45 seconds.	**Stepper motor selection.**	**Verified.** The stepper motor used for raising the rocket can complete its task in 23 seconds.
3.2.1.2	A master switch will be activated to power on all autonomous procedures and subroutines.	**AGSE design.** The master switch will be hardwired into the system. A diagram for this subsystem can be seen in **Figure 43**.	**Not verified.** Implemented in design but not built.
3.2.1.3	After the master switch is turned on, a pause	**AGSE design.**	**Not verified.**

	switch will be activated, temporarily halting all AGSE procedure and subroutines. This will allow the other teams at the pads to set up, and do the same.	The separate pause switch will halt the progression of the AGSE and can be implemented at any time. A diagram can be seen in **Figure 43**.	Implemented in design but not built.
3.2.1.4	After setup, one judge, one launch services official, and one member of the team will remain at the pad. The rest of the team must evacuate the area. The one team member is only there to answer questions the launch services official may have, and is not permitted to interact with the AGSE in any way.	**AGSE design and team action.** The system requires only one person to operate the master and pause switches so only one team member will be present at the pad.	**Not verified.** Completed at competition.
3.2.1.5	After all nonessential personnel have evacuated, the pause switch will be deactivated.	**Team action.**	**Not Verified.** Completed at competition.
3.2.1.6	Once the pause switch is deactivated, the AGSE will progress through all subroutines starting with the capture and containment of the payload, then erection of the launch platform, and lastly the insertion of the motor igniter. The launch platform must be erected to an angle of 5 degrees off vertical pointed away from the spectators. The launch services official may re-enable the pause switch at any time at his/her	**AGSE design.** The subsystems will be set up to run in the correct order on the BegleBone. The 5 degrees will be ensured with the ratcheting stops and support bar. System checks on the BeagleBone will make sure that the system processes will resume from where they left off.	**Not verified.** The subsystems have not yet been combined into the final AGSE construction. Therefore, the pause switch has not been tested yet.

	discretion. If the pause switch is re-enabled all systems and actions shall cease immediately. The launch services official will only do this if there is an obvious safety hazard. The judge, launch services official, and team leader will meet to discuss and decide if the team will be allowed to do a reset and rerun of their attempt. No modifications to the hardware will be allowed prior to a rerun.		
3.2.1.7	One team member will arm all recovery electronics.	**Team action.** The team lead has been chosen to arm the electronics. The rest of the team will evacuate the launch pad.	**Verified.** The team lead was able to arm all altimeters during the full-scale demonstration flight.
3.2.1.8	Once the launch services official has inspected the launch vehicle and declares that the system is eligible for launch, he/she will activate a master arming switch to enable ignition procedures.	**Team action.** Ignition procedures will be left to the LSO as specified. A master switch will be provided and used as described above.	**Not verified.** Completed at competition.
3.2.1.9	All personnel at the launch pad will evacuate the area.	**Team action.** When the vehicle is ready for launch, all personnel at the safe distance determined by the officials.	**Not verified.** Completed at competition.
3.2.1.10	The Launch Control Officer (LCO) will activate a hard switch,	**Team action.** The activation of the	**Not verified.** Completed at

	and then provide a 5-second countdown.	hard switch will be left to the LCO.	competition.
3.2.1.11	At the end of the countdown, the LCO will push the final launch button to initiate launch.	**Team action.** Furthermore, the initiation of the launch will be done by the LCO.	**Not verified.** Completed at competition.
3.2.1.12	The rocket will launch as designed and jettison the payload at 1,000 feet AGL during descent.	**Vehicle design.** At 1100 feet, the ARRD will separate the nosecone and payload section from the lower body frame. At 1000 feet, a 2.75 foot parachute will deploy.	**Verified.** The full-scale successfully deployed the ARRD and main parachute at the desired altitudes.
3.2.2.1	For the purpose of this challenge, ASGE is defined as all mechanical and electrical components not part of the launch vehicle, and is provided by the teams. This includes, but is not limited to, the payload containment and igniter installation devices, computers, electric motors, batteries, etc.	**AGSE design.** The team has ensured that all necessary components for the AGSE are implemented.	**Not verified.** Although each system has be thoroughly tested, the final AGSE has not been built.
	The igniter must be inserted in 45 seconds.	**Stepper motor selection.**	**Verified.** Tests conducted with the stepper motor and raising rig showed the igniter can be inserted in 33 seconds.
3.2.2.2	All AGSE systems shall be fully autonomous. The only human interaction will be when the launch services official pauses or arms any equipment, when the	**AGSE design.** With the exception of the processes listed, all procedures will be controlled and initiated by the BeagleBone Black.	**Not verified.** The final AGSE has not been built. Testing of each subsystem shows that the BeagleBone will be able to control each subsystem.

	team arms the recovery electronics, and when the LCO initiates launch.		
3.2.2.3	Any pressure vessel used in the AGSE will follow all regulations set by requirement 1.12 in the Vehicle Requirements section.	**AGSE design.**	**Verified.** The AGSE does not utilize a pressure vessel.
3.2.3.1	As one of the goals of this competition is to develop equipment, processes, and technologies that could be implemented in a Martian environment, the AGSE and any related technology cannot employ processes that would not work in such environments. Therefore, prohibited technologies include:	**AGSE design.**	**Verified.** The AGSE does not utilize any of the prohibited systems listed in items 3.2.3.1.1-3.2.3.1.5.
3.2.3.1.1	Sensors that rely on Earth's magnetic field.	**AGSE design.**	**Verified.** The AGSE does not utilize these sensors.
3.2.3.1.2	Ultrasonic or other sound-based sensors.	**AGSE design.**	**Verified.** The AGSE does not utilize these sensors.
3.2.3.1.3	Earth-based or Earth orbit-based radio aids (e.g. GPS, VOR, cell phone).	**AGSE design.**	**Verified.** The AGSE does not utilize and of these systems.
3.2.3.1.4	Open circuit pneumatics.	**AGSE design.**	**Verified.** The AGSE does not utilize open circuit pneumatics.
3.2.3.1.5	Air breathing systems.	**AGSE design.**	**Verified.** The AGSE does not utilize air-breathing

			systems.
3.2.4.1	Each launch vehicle must have the space to contain a cylindrical payload approximately 3/4 inch in diameter and 4.75 inches in length. The payload will be made of ¾ x 3 inch PVC tubing filled with sand and weighing approximately 4 oz., and capped with domed PVC end caps. Each launch vehicle must be able to seal the payload containment area autonomously prior to launch.	**Vehicle and AGSE design.** The mold used will be made to fit the sample so that it is secure. The robotic arm will autonomously insert the sample and close the door to the sample compartment, sealing the sample inside the rocket.	**Verified.** The full-scale demonstration flight used the mold to secure a model of the payload. The robotic arm has been placed on the AGSE so it can reach the compartment on the vehicle.
	The arm must move to the sample in 5 minutes (to allow for image processing).	**Servo motor selection.**	**Verified.** Testing has shown that the arm can of moving to a specified location within 5 seconds. The image processing system is still being developed.
	The arm must be accurate to 0.3 inches in its movement.	**Servo motor selection and team's code.**	**Verified.** Testing showed that the arm is able to reach the desired location within 0.125 inches.
	The arm must be capable of closing the door on the rocket.	**Servo motor selection and team's code.**	**Verified.** Because the arm is accurate in its movements, it is capable of closing the sample compartment door, which is secured by 3 strong magnets.
	The imaging system must be capable of processing 5 images in	**Team's code.**	**Not verified.** Time trials are still

	5 minutes.		being performed as the code is translated into C++.
	The imaging system must reliably pick out the sample from the background.	**Team's code.**	**Verified.** In 72 different tests, the imaging system correctly identified the sample even when other blobs were present in the image.
3.2.4.2	Teams may construct their own payload according to the above specifications, however, each team will be required to use a regulation payload provided to them on launch day.	**Team action.**	**Verified.** A replica of the sample was used during the full-scale demonstration flight. However, only the sample provided from the officials will be used during the competition.
3.2.4.3	The payload will not contain any hooks or other means to grab it. A diagram of the payload and a sample payload will be provided to each team at time of acceptance into the competition.	**Team action.**	**Verified.** The final vehicle design and robotic arm can accommodate an unmodified sample. Both were verified during tests.
3.2.4.4	The payload may be placed anywhere in the launch area for insertion, as long as it is outside the mold line of the launch vehicle when placed in the horizontal position on the AGSE.	**AGSE design and team action.** The sample will be placed between 11 and 22 inches to the side of the AGSE for insertion. This location is not within the mold line of the vehicle.	**Verified.** The arm has been placed at a location where it can reach the sample outside of the mold line of the vehicle. Testing has shown that the arm can reach the sample 11-22 inches away.
3.2.4.5	The payload container must utilize a parachute for recovery and contain a GPS or radio locator.	**Vehicle design.** The payload container will use a GPS transmitter and a 2.75	**Verified.** The full-scale was successfully flown with the nosecone and

		foot parachute.	sample compartment as an independent section. A GPS was placed in the nosecone and the parachute was attached in between the two components.
3.2.4.6	Each team will be given 10 minutes to autonomously capture, place, and seal the payload within their rocket, and erect the rocket to a vertical launch position five degrees off vertical. Insertion of igniter and activation for launch are also included in this time. Going over time will result in the team's disqualification from the Maxi-MAV competition.	**AGSE design.** The team plans to raise the rocket and insert the ignitor within 1 minute. A constraint of 5 minutes has been placed on the imaging system. The sample will be inserted and the vehicle will be activated for launch within the remaining 4 minutes.	**Partially verified.** Testing has shown that the vehicle can be raised in 37 seconds, the igniter inserted in 33 seconds, and the arm can move to a desired location in 5 seconds. Time trials are still being performed on the imaging system.
3.2.5.1	Each team must provide the following switches and indicators for their AGSE to be used by the LCO/RSO.	**AGSE design.** The team has planned for each of the required switches and safety indicators described in items 3.2.5.1.1-3.2.5.1.4.	**Not verified.** Implemented in design but not built.
3.2.5.1.1	A master switch to power all parts of the AGSE. The switch must be easily accessible and hardwired to the AGSE.	**AGSE design.**	**Not verified.** Implemented in design but not built.
3.2.5.1.2	A pause switch to temporarily terminate all actions performed by AGSE. The switch must be easily accessible and hardwired to the AGSE.	**AGSE design.**	**Not verified.** Implemented in design but not built.
3.2.5.1.3	A safety light that indicates that the AGSE power is turned on.	**AGSE design.**	**Not verified.** Implemented in design

	The light must be amber/orange in color. It will flash at a frequency of 1 Hz when the AGSE is powered on, and will be solid in color when the AGSE is paused while power is still supplied.		but not built.
3.2.5.1.4	An all systems go light to verify all systems have passed safety verifications and the rocket system is ready to launch.	**AGSE design.**	**Not verified.** Implemented in design but not built.
3.2.6.1	Any team who fails to complete any of the procedures in requirement 3.2 will be ineligible of obtaining Centennial Challenges prizes.	**AGSE design.** The above verification matrix shows that the team has accounted for all items in Section 3.2.	**Not verified.** The team has accounted for all requirements, but has not yet verified every system.

9.5 MSDS for Hazardous Materials

GOEX Black Powder

STORAGE CONDITIONS
Store in a cool, dry place in accordance with the requirements of Subpart K, ATF: Explosives Law and Regulations (27 CFR 55.201-55.219).

Rust-oleum

*** Emergency Overview ***: Harmful if inhaled. May affect the brain or nervous system causing dizziness, headache or nausea. Contents Under Pressure. Vapors may cause flash fire or explosion. Extremely flammable liquid and vapor. Harmful if swallowed.

Effects Of Overexposure - Eye Contact: Causes eye irritation.

Effects Of Overexposure - Skin Contact: May be harmful if absorbed through skin. Prolonged or repeated contact may cause skin irritation. Substance may cause slight skin irritation.

Effects Of Overexposure - Inhalation: High vapor concentrations are irritating to the eyes, nose, throat and lungs. Avoid breathing vapors or mists. High gas, vapor, mist or dust concentrations may be harmful if inhaled. Harmful if inhaled.

Effects Of Overexposure - Ingestion: Aspiration hazard if swallowed; can enter lungs and cause damage. Substance may be harmful if swallowed.

Effects Of Overexposure - Chronic Hazards: IARC lists Ethylbenzene as a possible human carcinogen (group 2B). May cause central nervous system disorder (e,g.,narcosis involving a loss of coordination, weakness, fatigue, mental confusion, and blurred vision) and/or damage. Reports have associated repeated and prolonged occupational overexposure to solvents with permanent brain and nervous system damage. Overexposure to xylene in laboratory animals has been associated with liver abnormalities, kidney, lung, spleen, eye and blood damage as well as reproductive disorders. Effects in humans, due to chronic overexposure, have included liver, cardiac abnormalities and nervous system damage. Overexposure to toluene in laboratory animals has been associated with liver abnormalities, kidney, lung and spleen damage. Effects in humans have included liver and cardiac abnormalities.
Contains carbon black. Chronic inflammation, lung fibrosis, and lung tumors have been observed in some rats experimentally exposed for long periods of time to excessive concentrations of carbon black and several insoluble fine dust particles. Tumors have not been observed in other animal species (i.e., mouse and hampster) under similar circumstances and study conditions. Epidemiological studies of North American workers show no evidence of clinically significant adverse health effects due to occupational exposure to carbon black.
Carbon black is listed as a Group 2B-"Possibly carcinogenic to humans" by IARC and is proposed to be listed as A4- "not classified as a human carcinogen" by the American Conference of Govermental Industrial Hygienists. Significant exposure is not anticipated during brush application or drying. Risk of overexposure depends on duration and level of exposure to dust from repeated sanding of surfaces or spray mist and the actual concentration of carbon black in the formula.

Primary Route(s) Of Entry: Skin Contact, Skin Absorption, Inhalation, Eye Contact

Section 4 - First Aid Measures

First Aid - Eye Contact: Hold eyelids apart and flush with plenty of water for at least 15 minutes. Get medical attention.

First Aid - Skin Contact: Wash with soap and water. Get medical attention if irritation develops or persists.

First Aid - Inhalation: If you experience difficulty in breathing, leave the area to obtain fresh air. If continued difficulty is experienced, get medical assistance immediately.

First Aid - Ingestion: Aspiration hazard: Do not induce vomiting or give anything by mouth because this material can enter the lungs and cause severe lung damage. Get immediate medical attention.

Section 5 - Fire Fighting Measures

Flash Point: -156 F
(Setaflash)

LOWER EXPLOSIVE LIMIT: 1.0 %
UPPER EXPLOSIVE LIMIT : 9.5 %

Extinguishing Media: Dry Chemical, Foam, Water Fog

Unusual Fire And Explosion Hazards: Vapors can travel to a source of ignition and flash back. Vapors may form explosive mixtures with air. Closed containers may explode when exposed to extreme heat. Water spray may be

ineffective. FLASH POINT IS LESS THAN 20 °. F. - EXTREMELY FLAMMABLE LIQUID AND VAPOR! Perforation of the pressurized container may cause bursting of the can. Isolate from heat, electrical equipment, sparks and open flame. Keep containers tightly closed.

Special Firefighting Procedures: Evacuate area and fight fire from a safe distance.

Section 6 - Accidental Release Measures

Steps To Be Taken If Material Is Released Or Spilled: Contain spilled liquid with sand or earth. DO NOT use combustible materials such as sawdust. Remove all sources of ignition, ventilate area and remove with inert absorbent and non-sparking tools. Dispose of according to local, state (provincial) and federal regulations. Do not incinerate closed containers.

Section 7 - Handling And Storage

Handling: Wash thoroughly after handling. Wash hands before eating. Use only in a well-ventilated area. Follow all MSDS/label precautions even after container is emptied because it may retain product residues. Avoid breathing vapor or mist.

Storage: Keep containers tightly closed. Isolate from heat, electrical equipment, sparks and open flame. Do not store above 120 ° F. Store large quantities in buildings designed and protected for storage of NFPA Class I flammable liquids. Contents under pressure. Do not expose to heat or store above 120 ° F.

Section 8 - Exposure Controls / Personal Protection

Engineering Controls: Use explosion-proof ventilation equipment. Prevent build-up of vapors by opening all doors and windows to achieve cross-ventilation. Use process enclosures, local exhaust ventilation, or other engineering controls to control airborne levels below recommended exposure limits.

Respiratory Protection: A respiratory protection program that meets OSHA 1910.134 and ANSI Z88.2 requirements must be followed whenever workplace conditions warrant a respirator's use. A NIOSH/MSHA approved air purifying respirator with an organic vapor cartridge or canister may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits.

Protection provided by air purifying respirators is limited. Use a positive pressure air supplied respirator if there is any potential for an uncontrolled release, exposure levels are not known, or any other circumstances where air purifying respirators may not provide adequate protection.

Skin Protection: Use impervious gloves to prevent skin contact and absorption of this material through the skin. Nitrile or Neoprene gloves may afford adequate skin protection.

Eye Protection: Use safety eyewear designed to protect against splash of liquids.

Other protective equipment: Refer to safety supervisor or industrial hygienist for further information regarding personal protective equipment and its application.

Hygienic Practices: Wash thoroughly with soap and water before eating, drinking or smoking.

Klean Strip Denatured Alcohol

3. Hazards Identification

Emergency Overview

Danger! Flammable! Keep away from heat, sparks, flame, and all other sources of ignition. Do not smoke. Extinguish all flames and pilot lights, and turn off stoves, heaters, electric motors and all other sources of ignition during use and until all vapors are gone. Beware of static electricity that mat be generated by synthetic clothing and other sources.

OSHA Regulatory Status: This material is classified as hazardous under OSHA regulations.

Health Hazards (Acute and Chronic)

Inhalation Acute Exposure Effects:
Vapor harmful. May cause dizziness, headache, watering of eyes, irritation of respiratory tract, irritation to the eyes, drowsiness, nausea, other central nervous system effects, spotted vision, dilation of pupils, and convulsions.

Skin Contact Acute Exposure Effects:
May cause irritation, drying of skin, redness, and dermatitis. May cause symptoms listed under inhalation. May be absorbed through damaged skin.

Eye Contact Acute Exposure Effects:
May cause irritation.

Ingestion Acute Exposure Effects:
Poison. Cannot be made non-poisonous. May be fatal or cause blindness. May produce fluid in the lungs and pulmonary edema. May cause dizziness, headache, nausea, drowsiness, loss of coordination, stupor, reddening of face and or neck, liver, kidney and heart damage, coma, and death. May produce symptoms listed under

inhalation.

Chronic Exposure Effects:
May cause symptoms listed under inhalation, dizziness, fatigue, tremors, permanent central nervous system changes, blindness, pancreatic damage, and death.

Signs and Symptoms Of Exposure

No data available.

Medical Conditions Generally Aggravated By Exposure

Diseases of the liver.

OSHA Hazard Classes:

HEALTH HAZARDS : N/E
PHYSICAL HAZARDS : N/E
TARGET ORGANS & EFFECTS: N/E

4. First Aid Measures

Emergency and First Aid Procedures

Inhalation:
If user experiences breathing difficulty, move to air free of vapors. Administer oxygen or artificial respiration until medical assistance can be rendered.

Skin Contact:
Wash with soap and water.

Eye Contact:
Flush with large quantities of water for at least 15 minutes. If irritation from contact persists, get medical attention.

Ingestion:
Call your poison control center, hospital emergency room or physician immediately for instructions to induce vomiting.

Note to Physician

Poison. This product contains methanol. Methanol is metabolized to formaldehyde and formic acid. These metabolites may cause metabolic acidosis, visual disturbances and blindness. Since metabolism is required for these toxic symptoms, their onset may be delayed from 6 to 30 hours following ingestion. Ethanol competes for the same metabolic pathway and has been used as an antidote. Methanol is effectively removed by hemodialysis. Call your local poison control center for further instructions.

5. Fire Fighting Measures

Flammability Classification:	OSHA Class IB
Flash Pt:	45.00 F Method Used: SCC
Explosive Limits:	LEL: 1.00 UEL: No data.
Autoignition Pt:	No data.

Special Fire Fighting Procedures

Self-contained respiratory protection should be provided for fire fighters fighting fires in buildings or confined area. Storage containers exposed to fire should be kept cool with water spray to prevent pressure build-up. Stay away from heads of containers that have been exposed to intense heat or flame.

Unusual Fire and Explosion Hazards

No data available.

Extinguishing Media

Use carbon dioxide, dry powder, or foam.

Unsuitable Extinguishing Media

No data available.

6. Accidental Release Measures

Steps To Be Taken In Case Material Is Released Or Spilled

Clean-up:
Keep unnecessary people away; isolate hazard area and deny entry. Stay upwind, out of low areas, and ventilate closed spaces before entering. Shut off ignition sources, keep flares, smoking or flames out of hazard area.

Small spills:
Take up liquid with sand, earth or other noncombustible absorbent material and place in a plastic container where applicable.

Large spills:
Dike far ahead of spill for later disposal.

7. Handling and Storage

Precautions To Be Taken in Handling

Read carefully all cautions and directions on product label before use. Since empty container retains residue, follow all label warnings even after container is empty. Dispose of empty container according to all regulations. Do not reuse this container.

Precautions To Be Taken in Storing

Keep container tightly closed when not in use. Store in a cool, dry place. Do not store near flames or at elevated temperatures.

8. Exposure Controls/Personal Protection

Respiratory Equipment (Specify Type)

For OSHA controlled work place and other regular users. Use only with adequate ventilation under engineered air control systems designed to prevent exceeding appropriate TLV. For occasional use, where engineered air control is not feasible, use properly maintained and properly fitted NIOSH approved respirator for organic solvent vapors. A dust mask does not provide protection against vapors.

Eye Protection

Safety glasses, chemical goggles or face shields are recommended to safeguard against potential eye contact, irritation, or injury. Contact lenses should not be worn while working with chemicals.

Protective Gloves

Wear impermeable gloves. Gloves contaminated with product should be discarded. Promptly remove clothing that becomes soiled with product.

Other Protective Clothing

Various application methods can dictate the use of additional protective safety equipment, such as impermeable aprons, etc., to minimize exposure. A source of clean water should be available in the work area for flushing eyes and skin. Do not eat, drink, or smoke in the work area. Wash hands thoroughly after use. Before reuse, thoroughly clean any clothing or protective equipment that has been contaminated by prior use. Discard any clothing or other protective equipment that cannot be decontaminated, such as gloves or shoes.

Ventilation

Use only with adequate ventilation to prevent build-up of vapors. Open all windows and doors. Use only with a cross ventilation of moving fresh air across the work area. If strong odor is noticed or you experience slight dizziness, headache, nausea, or eye-watering -- Stop -- ventilation is inadequate. Leave area immediately.

Klean Strip Acetone

3. Hazards Identification

Emergency Overview

Danger! Extremely Flammable. Keep away from heat, sparks, flame and all other sources of ignition. Vapors may cause flash fire or ignite explosively. Vapors may travel long distances to other areas and rooms away from the work site. Do not smoke. Extinguish all flames and pilot lights, and turn off stoves, heaters, electric motors and all other sources of ignition anywhere in the structure, dwelling, or building during use and until all vapors are gone from the work site. Keep away from electrical outlets and switches. Beware of static electricity that may be generated by synthetic clothing and other sources.

OSHA Regulatory Status:

This material is classified as hazardous under OSHA regulations.

Potential Health Effects (Acute and Chronic)

Inhalation Acute Exposure Effects:
Vapor harmful. May cause dizziness, headache, watering of eyes, irritation of respiratory tract, drowsiness, nausea, and numbness in fingers, arms and legs.

Skin Contact Acute Exposure Effects:
May cause drying of skin, and numbness in fingers and arms. Liquid is absorbed readily.

Eye Contact Acute Exposure Effects:
This material is an eye irritant.

Ingestion Acute Exposure Effects:
Harmful if swallowed. May cause dizziness, headache, nausea, and irritation of the mouth, throat, and stomach.

Chronic Exposure Effects:
Reports have associated repeated and prolonged overexposure to solvents with neurological and other

physiological damage. May cause weakness, fatigue, skin irritation, and numbness in hands and feet.

Signs and Symptoms Of Exposure

Primary Routes of Exposure:
Inhalation, ingestion, and dermal.

Medical Conditions Generally Aggravated By Exposure

Skin, eye, lung (asthma-like conditions)

4. First Aid Measures

Emergency and First Aid Procedures

Inhalation:
If user experiences breathing difficulty, move to air free of vapors. Administer oxygen or artificial respiration until medical assistance can be reached.

Skin Contact:
Wash with soap and water.

Eye Contact:
Flush with large quantities of water for at least 15 minutes and seek immediate medical attention.

Ingestion:
Call your poison control center, hospital emergency room, or physician immediately for instructions.

Note to Physician

Call your local poison control center for further instructions.

6. Accidental Release Measures

Steps To Be Taken In Case Material Is Released Or Spilled

Clean Up:

Keep unnecessary people away; isolate hazard area and deny entry. Stay upwind, out of low areas, and ventilate closed spaces before entering. Shut off ignition sources; keep flares, smoking or flames out of hazard area. For small spills, take up liquid with sand, earth, or other noncombustible absorbent material and place in a container for disposal. For large spills, dike far ahead of spill and use sand, earth, or other noncombustible absorbent material and then place material in a container for disposal.

Waste Disposal:

Dispose in accordance with applicable local, state, and federal regulations.

7. Handling and Storage

Precautions To Be Taken in Handling

Read carefully all cautions and directions on product label before use. Since empty container retains residue, follow all label warnings even after container is empty. Dispose of empty container according to all regulations. Do not reuse the container.

Precautions To Be Taken in Storing

Keep container tightly closed when not in use. Store in a cool, dry place. Do not store near flames or at elevated temperatures.

8. Exposure Controls/Personal Protection

Respiratory Equipment (Specify Type)

For OSHA controlled work place and other regular users. Use only with adequate ventilation under engineered air control systems designed to prevent exceeding appropriate TLV. For occasional use, where engineered air control is not feasible, use properly maintained and properly fitted NIOSH approved respirator for organic solvent vapors. A dust mask does not provide protection against vapors.

Eye Protection

Safety glasses, chemical goggles or face shields are recommended to safeguard against potential eye contact, irritation, or injury. Contact lenses should not be worn while working with chemicals.

Protective Gloves

Wear chemical resistant gloves suited for use with acetone. Gloves contaminated with product should be discarded. Promptly remove clothing that becomes soiled with product.

Other Protective Clothing

Various application methods can dictate use of additional protective safety equipment, such as impermeable aprons, etc., to minimize exposure.

Engineering Controls (Ventilation etc.)

Use only with adequate ventilation to prevent build-up of vapors. Open all windows and doors. Use only with a cross ventilation of moving fresh air across the work area. If strong odor is noticed or your experience slight dizziness, headache, nausea, or eye-watering - STOP - ventilation is inadequate. Leave area immediately.

Work/Hygienic/Maintenance Practices

A source of clean water should be available in the work area for flushing eyes and skin.
Do not eat, drink, or smoke in the work area.
Wash hands thoroughly after use.
Before reuse, thoroughly clean any clothing or protective equipment that has been contaminated by prior use.
Discard any clothing or other protective equipment that cannot be decontaminated, such as gloves or shoes.

West System 105 Epoxy Resin

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

HMIS Hazard Rating: Health - 2 Flammability - 1 Physical Hazards - 0

WARNING! May cause allergic skin response in certain individuals. May cause moderate irritation to the skin. Clear to light yellow liquid with mild odor.

PRIMARY ROUTE(S) OF ENTRY:............ Skin contact.

POTENTIAL HEALTH EFFECTS:

ACUTE INHALATION:............ Not likely to cause acute effects unless heated to high temperatures. If product is heated, vapors generated can cause headache, nausea, dizziness and possible respiratory irritation if inhaled in high concentrations.

CHRONIC INHALATION: .... Not likely to cause chronic effects. Repeated exposure to high vapor concentrations may cause irritation of pre-existing lung allergies and increase the chance of developing allergy symptoms to this product.

ACUTE SKIN CONTACT: .... May cause allergic skin response in certain individuals. May cause moderate irritation to the skin such as redness and itching.

CHRONIC SKIN CONTACT:............ May cause sensitization in susceptible individuals. May cause moderate irritation to the skin.

EYE CONTACT: .... May cause irritation.

INGESTION:............ Low acute oral toxicity.

SYMPTOMS OF OVEREXPOSURE: .... Possible sensitization and subsequent allergic reactions usually seen as redness and rashes. Repeated exposure is not likely to cause other adverse health effects.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE:............ Pre-existing skin and respiratory disorders may be aggravated by exposure to this product. Pre-existing lung and skin allergies may increase the chance of developing allergic symptoms to this product.

4. FIRST AID MEASURES

FIRST AID FOR EYES............ Flush immediately with water for at least 15 minutes. Consult a physician.

FIRST AID FOR SKIN............ Remove contaminated clothing. Wipe excess from skin. Remove with waterless skin cleaner and then wash with soap and water. Consult a physician if effects occur.

FIRST AID FOR INHALATION............ Remove to fresh air if effects occur.

FIRST AID FOR INGESTION............ No adverse health effects expected from amounts ingested under normal conditions of use. Seek medical attention if a significant amount is ingested.

6. ACCIDENTAL RELEASE MEASURES

SPILL OR LEAK PROCEDURES: .... Stop leak without additional risk. Dike and absorb with inert material (*e.g.,* sand) and collect in a suitable, closed container. Warm, soapy water or non-flammable, safe solvent may be used to clean residual.

7. HANDLING AND STORAGE

STORAGE TEMPERATURE (min./max.): .... 40°F (4°C) / 120°F (49°C)

STORAGE:............ Store in cool, dry place. Store in tightly sealed containers to prevent moisture absorption and loss of volatiles. Excessive heat over long periods of time will degrade the resin.

HANDLING PRECAUTIONS: .... Avoid prolonged or repeated skin contact. Wash thoroughly after handling. Launder contaminated clothing before reuse. Avoid inhalation of vapors from heated product. Precautionary steps should be taken when curing product in large quantities. When mixed with epoxy curing agents this product causes an exothermic, which in large masses, can produce enough heat to damage or ignite surrounding materials and emit fumes and vapors that vary widely in composition and toxicity.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

EYE PROTECTION GUIDELINES: .... Safety glasses with side shields or chemical splash goggles.

SKIN PROTECTION GUIDELINES:............ Wear liquid-proof, chemical resistant gloves (nitrile-butyl rubber, neoprene, butyl rubber or natural rubber) and full body-covering clothing.

RESPIRATORY/VENTILATION GUIDELINES:............ Good room ventilation is usually adequate for most operations. Wear a NIOSH/MSHA approved respirator with an organic vapor cartridge whenever exposure to vapor in concentrations above applicable limits is likely.

Note: West System, Inc. has conducted an air sampling study using this product or similarly formulated products. The results indicate that the components sampled for (epichlorohydrin, benzyl alcohol) were either so low that they were not detected at all or they were significantly below OSHA's permissible exposure levels.

ADDITIONAL PROTECTIVE MEASURES:............ Practice good caution and personal cleanliness to avoid skin and eye contact. Avoid skin contact when removing gloves and other protective equipment. Wash thoroughly after handling. Generally speaking, working cleanly and following basic precautionary measures will greatly minimize the potential for harmful exposure to this product under normal use conditions.

OCCUPATIONAL EXPOSURE LIMITS: .... Not established for product as whole. Refer to OSHA's Permissible Exposure Level (PEL) or the ACGIH Guidelines for information on specific ingredients.

West System 206 Hardener

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

DANGER Causes burns to eyes and skin. Harmful if swallowed. Harmful if absorbed through the skin. May be harmful if inhaled. Can cause allergic reaction. Aspiration hazard. Clear liquid with ammonia odor.

PRIMARY ROUTE(S) OF ENTRY: .... Skin and eye contact, inhalation.

POTENTIAL HEALTH EFFECTS:

ACUTE INHALATION:.. Excessive exposure to vapor or mist is irritating to the upper respiratory tract, causing nasal discharge, coughing, and discomfort in eyes, nose, throat and chest. Severe cases may cause difficult breathing and lung damage.

CHRONIC INHALATION: .... May cause lung damage. May cause respiratory sensitization in susceptible individuals. Repeated exposures may cause internal organ damage.

ACUTE SKIN CONTACT:.. Corrosive. Prolonged contact may cause skin damage with burns and blistering. Wide spread contact may result in material being absorbed in harmful amounts.

CHRONIC SKIN CONTACT:.. May cause persistent irritation or dermatitis. Repeated contact may cause allergic reaction/sensitization and possible tissue destruction. Can be absorbed through the skin in amounts that can cause internal organ damage.

EYE CONTACT: .... Corrosive. May cause blurred vision. May cause irritation with corneal injury resulting in permanent vision impairment or even blindness.

INGESTION:... Moderately toxic. May cause gastrointestinal irritation or ulceration. May cause burns of the mouth and throat. Aspiration hazard.

SYMPTOMS OF OVEREXPOSURE:... Skin irritation, burns and blistering. Irritation of the nose and throat, possible headache. Eye irritation and blurred vision.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: .... Existing respiratory conditions, such as asthma and bronchitis. Existing skin conditions.

4. FIRST AID MEASURES

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West System Inc. Page 2 of 4 WEST SYSTEM® 206™ Hardener

FIRST AID FOR EYES: .... Immediately flush with water for at least 15 minutes. Get prompt medical attention.

FIRST AID FOR SKIN: .... Remove contaminated clothing. Immediately wash skin with soap and water. Do not apply greases or ointments. Get medical attention if severe exposure.

FIRST AID FOR INHALATION: .... Move to fresh air and consult physician if effects occur.

FIRST AID FOR INGESTION: .... Give conscious person at least 2 glasses of water. Do not induce vomiting. Aspiration hazard. If vomiting should occur spontaneously, keep airway clear. Get medical attention.

6.	ACCIDENTAL RELEASE MEASURES

SPILL OR LEAK PROCEDURES: .... Stop leak without additional risk. Wear proper personal protective equipment. Dike and contain spill. Ventilate area. Large spill - dike and pump into appropriate container for recovery. Small spill - recover or use inert, non-combustible absorbent material (*e.g.*, sand, clay) and shovel into suitable container. Do not use sawdust, wood chips or other cellulosic materials to absorb the spill, as the possibility for spontaneous combustion exists. Wash spill residue with warm, soapy water if necessary.

7.	HANDLING AND STORAGE

STORAGE TEMPERATURE (min./max.):... 40°F (4°C) / 90°F (32°C).

STORAGE:.. Store in cool, dry place with adequate ventilation.

HANDLING PRECAUTIONS: .... Use only with adequate ventilation. Do not breath vapors or mists from heated material. Avoid contact with skin and eyes. Wash thoroughly after handling. When mixed with epoxy resin this product causes an exothermic reaction, which in large masses, can produce enough heat to damage or ignite surrounding materials and emit fumes and vapors that vary widely in composition and toxicity.

8.	EXPOSURE CONTROLS/PERSONAL PROTECTION

EYE PROTECTION GUIDELINES:.. Chemical splash goggles, full-face shield or full-face respirator.

SKIN PROTECTION GUIDELINES:... Wear liquid-proof, chemical resistant gloves (nitrile-butyl rubber, neoprene, butyl rubber or natural rubber) and full body-covering clothing.

RESPIRATORY/VENTILATION GUIDELINES: .... General mechanical or local exhaust ventilation. With inadequate ventilation, use a NIOSH/MSHA approved air purifying respirator with an organic vapor cartridge.

Note: West System, Inc. has conducted an air sampling study using this product or similarly formulated products. The results indicate that the components sampled for (amines) were either so low that they were not detected at all or they were well below OSHA's permissible exposure levels.

ADDITIONAL PROTECTIVE MEASURES:... Use where there is immediate access to safety shower and emergency eye wash. Provide proper wash/cleanup facilities for proper hygiene. Contact lens should not be worn when working with this material. Generally speaking, working cleanly and following basic precautionary measures will greatly minimize the potential for harmful exposure to this product under normal use conditions.

OCCUPATIONAL EXPOSURE LIMITS: .... Not established for product as whole. Refer to OSHA's Permissible Exposure Level (PEL) or the ACGIH Guidelines for information on specific ingredients.

J-Tek Electric Matches

Material Safety Data Sheet

NOTICE

ALL INFORMATION APPEARING HEREIN IS BASED UPON DATA OBTAINED FROM THE MANUFACTURER AND/OR RECOGNIZED TECHNICAL SOURCES. THIS INFORMATION IS BELIEVED TO BE CORRECT, BUT DOES NOT PURPORT TO BE ALL INCLUSIVE AND SHALL BE USED ONLY AS A GUIDE. MJG TECHNOLOGIES INC. MAKES NO WARRANTY, EXPRESS OR IMPLIED, AS TO THE ACCURACY OR COMPLETENESS OF THIS INFORMATION. IT IS THE USER'S RESPONSIBILITY TO DETERMINE THE SUITABILITY OF THIS INFORMATION FOR THE ADOPTION OF NECESSARY SAFETY PRECAUTIONS AND/OR COMPLIANCE WITH LOCAL, STATE, AND FEDERAL LAWS AND REGULATIONS.

Section I. - General Information

Identity: *(As used on label and list)*
UN0454 Igniters 1.4S
Manufacturer's Name & Address:
MJG Technologies, Inc.
832 Camden Avenue
Blenheim, NJ 08012

Trade Name: J-Tek
Emergency Telephone: 1-800-535-5053 Contract # 100588
Telephone Number: 856-228-6118
Date Prepared: February 21, 2011
Prepared By: J. Genzel

Section II. - Hazardous Ingredients / Identity Information

Per OSHA 29 CFR 1910.1200

Chemical Name:	CAS#	Exposure Limits OSHA (PEL)	ACGIH (TLV)	Other Limits %
Bismuth Trioxide	1304-76-3	15 mg / m3	10mg / m3	
Boron	7440-42-8	15 mg / m3	10mg /m3	orl rat LDLo; 32g/kg/30 days
Potassium Perchlorate	7778-74-7	Not Established	Not Established	orl rat LDLo: 2,100 mg/kg
Titanium	7440-32-6	Not Established	Not Established	ims-rat LDLo:114 mg/kg/77W-1

Section III. - Physical / Chemical Characteristics

Boiling Point (deg. F.) N/A
Specific Gravity (H_2O = 1) N/A
Vapor Pressure (mm Hg.) N/A
Melting Point N/A
Vapor Density (Air = 1) N/A
Evaporation Rate (Butyl Acetate = 1) N/A

Solubility in Water: Insoluble with lacquer coating intact.

Appearance and Odor: Medium brown colored bead of pyrotechnic composition on a copper-clad chip with two PVC insulated connecting wires of various lengths. Red or blue lacquer coating on igniter head.

Section IV. - Fire and Explosion Hazard Data

Flash Point: N/A

Flammable Limits	LEL	UEL
N/A	N/A	N/A

Extinguishing Media: N/A

Special Fire Fighting Procedures: Do not use suffocating methods - devices contain their own oxygen. If conditions permit, separate burning from unburned igniters.

Unusual Fire and Explosion Hazards: Burning igniters will project sparks several feet and can cause secondary fires. Igniters may rupture a container if ignited under confinement. Igniters may be ignited by extreme impact, friction or electrostatic discharge.

Section V. - Reactivity Data

Stability: Stable **Conditions To Avoid:** Sources of ignition - heat, sparks, open flames and smoking. Do not subject igniter heads to impact or friction.
Incompatibility (Materials to Avoid): Acids and reducing agents.
Hazardous Decomposition or Byproducts: Smoke contains oxides of Boron and Titanium.
Hazardous Polymerization: Will not occur.

Section VI. - Health Hazard Data

Route(s) of Entry:	Inhalation?	Skin?	Ingestion?
	Not with match head intact.	No	Not with match head intact.

Health Hazards (Acute and Chronic): Primary hazard is from thermal burns caused by accidental ignition of igniters Deliberate inhalation or ingestion of large amounts of crushed igniter head composition may cause respiratory discomfort. Not absorbed through skin.

Carcinogenicity:	NTP?	ARC Monographs?	OSHA Regulated?
	No	No	No

Signs and Symptoms of Exposure: See Boric Acid exposure. Large doses of Boron compounds can cause depression of the circulation, persistent vomiting and diarrhea, followed by shock and coma.
Bismuth Trioxide ingestion has no known adverse effects. However, ingestion is not advised.

Medical Conditions Generally Aggravated By Exposure: Smoke generated by burning igniters may cause respiratory irritation in those individuals with asthma, allergies or other preexisting respiratory conditions.

Emergency First Aid Procedures: Move patient to source of fresh air. Do not induce vomiting. Get prompt medical attention from qualified medical personnel.

Section VII. - Precautions For Safe Handling And Use

Steps To Be Taken In Case Material Is Released Or Spilled: Immediately remove sources of ignition and isolate spill from any other flammable or pyrotechnic materials. Sweep up any crushed igniter heads using non-sparking tools. Avoid inhaling igniter head dust.

Waste Disposal Method: Dispose of in accordance with local, state and federal regulations. Small quantities can be disposed of by open burning if permitted.

Precautions To Be Taken In Handling And Storage: Keep away from sources of heat and ignition, such as sparks or open flames. Avoid impact or friction to match head. Store igniters in accordance with local, state and federal regulations. Keep dry and avoid temperatures above 120 F. Keep out of the reach of children and uniformed persons.

Other Precautions: Avoid sources of strong electromagnetic fields and static electricity. Do not pick up with a vacuum cleaner

Section VII. - Control Measures

Respiratory Protection (Specify Type): Nuisance dust/particulate filter mask if large numbers of igniters are ignited in a confined area.
Ventilation: Yes. **Local Exhaust:** Acceptable.
Mechanical (General): **Special:**
Protective Gloves: Not normally required. **Other:**
Eye Protection: Goggles or safety glasses with side shields.
Other Protective Clothing or Equipment: Long sleeve cotton garments advised if handling a large quantity of igniters.
Work / Hygienic Practices: Wash thoroughly after handling igniters and before eating, drinking or smoking.

Page 2

9.6 Code

Arm Code

```
function [pulses, camx, camy, camz] = arm_angle_calc_function(x, y, z, xscale, zscale)
% #codegen
%UNTITLED2 Summary of this function goes here
% Detailed explanation goes here

%xscale = 1; % 1 for no scaling; range: (0,1]
%zscale = 1; % 1 for no scaling; range: (0,1]

% Lengths of arm pieces in inches
L1 = 9.25; % length of shoulder to elbow
L2 = 14.125; % length of elbow to wrist
L3 = 5.1835; %5.125; % length of wrist to center of gripper
camera_x = 4; % length of wrist to camera in x-direction
camera_z = 2; % length of wrist to camera in z-direction

% x,y,z location in space of wrist
```

```
% for z = -10; 11 <= x <= 22
% x = 11;
% y = 0;
% z = -7.7;
theta_camera = atan(camera_z/camera_x);
R_cam = sqrt(camera_x^2 + camera_z^2);
%% Quadrant 1
if (x>0 && z>0)
if (xscale == 1 && zscale == 1)
xp = (x)*xscale;
zp = (z*zscale) + L3;
elseif (xscale == 1 && zscale ~= 1)
xp = (x*xscale);
zp = (z*zscale) + camera_x/cos(theta_camera);
else
xp = (x)*xscale;
zp = (z)*zscale;
end
R = sqrt(xp^2 + zp^2 + y^2); % distance between shoulder and (x,y,z)
phi = asin(zp/R);
theta_one = acos((R^2 + L1^2 - L2^2) / (2*L1*R)) + phi;
theta_two = -(pi - acos((L1^2 + L2^2 - R^2) / (2*L1*L2)));
theta_base = atan(y/x);
R_arm_proj = sqrt(x^2 + y^2);
if (abs(((R_arm_proj) - (L1*cos(theta_one)+L2*cos(theta_one+theta_two)))) <= 1e-7)
if (xscale == 1 && zscale ~= 1)
theta_wrist = -theta_one - theta_two - pi/2 - theta_camera;
else
theta_wrist = -theta_one - theta_two - pi/2;
end
else
theta_wrist = -theta_one - theta_two + atan(((z) -
(L1*sin(theta_one)+L2*sin(theta_one+theta_two)))/((R_arm_proj) -
(L1*cos(theta_one)+L2*cos(theta_one+theta_two))))-theta_camera;
end
%% end quadrant 1
%% Quadrant 2
```

```
elseif (x<0 && z>0)
if (xscale == 1 && zscale == 1)
xp = (x)*xscale;
zp = (z*zscale) + L3;
elseif (xscale == 1 && zscale ~= 1)
xp = (x*xscale);
zp = (z*zscale) + camera_x/cos(theta_camera);
else
xp = (x)*xscale;
zp = (z)*zscale;
end

R = sqrt(xp^2 + zp^2 + y^2); % distance between shoulder and (x,y,z)
phi = asin(zp/R);
theta_one = acos((R^2 + L1^2 - L2^2) / (2*L1*R)) + phi;
theta_two = -(pi - acos((L1^2 + L2^2 - R^2) / (2*L1*L2)));
if (y > 0)
theta_base = atan(y/x) + pi;
else
theta_base = atan(y/x) - pi;
end

R_arm_proj = sqrt(x^2 + y^2);

if (abs((abs(R_arm_proj) - (L1*cos(theta_one)+L2*cos(theta_one+theta_two)))) <= 1e-7)
if (xscale == 1 && zscale ~= 1)
theta_wrist = -theta_one - theta_two - pi/2 - theta_camera;
else
theta_wrist = -theta_one - theta_two - pi/2;
end
else
theta_wrist = -theta_one - theta_two + atan(((z) -
(L1*sin(theta_one)+L2*sin(theta_one+theta_two)))/((R_arm_proj) -
(L1*cos(theta_one)+L2*cos(theta_one+theta_two))))-theta_camera;
end

%% end quadrant 2

%% Quadrant 3
elseif (x<0 && z<0)
if (xscale == 1 && zscale == 1)
xp = (x)*xscale;
```

```
zp = (z*zscale) + L3;
elseif (xscale == 1 && zscale ~= 1)
xp = (x*xscale);
zp = (z*zscale) + camera_x/cos(theta_camera);
else
xp = (x)*xscale;
zp = (z)*zscale;
end
R = sqrt(xp^2 + zp^2 + y^2); % distance between shoulder and (x,y,z)
phi = asin(zp/R);
theta_one = acos((R^2 + L1^2 - L2^2) / (2*L1*R)) + phi;
theta_two = -(pi - acos((L1^2 + L2^2 - R^2) / (2*L1*L2)));
if (y > 0)
theta_base = atan(y/x) + pi;
else
theta_base = atan(y/x) - pi;
end
R_arm_proj = sqrt(x^2 + y^2);
if (abs((abs(R_arm_proj) - (L1*cos(theta_one)+L2*cos(theta_one+theta_two)))) <= 1e-7)
if (xscale == 1 && zscale ~= 1)
theta_wrist = -theta_one - theta_two - pi/2 - theta_camera;
else
theta_wrist = -theta_one - theta_two - pi/2;
end
else
theta_wrist = -theta_one - theta_two + atan(((z) -
(L1*sin(theta_one)+L2*sin(theta_one+theta_two)))/((R_arm_proj) -
(L1*cos(theta_one)+L2*cos(theta_one+theta_two))))-theta_camera;
end
%% end quadrant 3
%% Quadrant 4
else
if (xscale == 1 && zscale == 1)
xp = (x)*xscale;
zp = (z*zscale) + L3;
elseif (xscale == 1 && zscale ~= 1)
xp = (x*xscale);
```

```
zp = (z*zscale) + camera_x/cos(theta_camera);
else
xp = (x)*xscale;
zp = (z)*zscale;
end
R = sqrt(xp^2 + zp^2 + y^2); % distance between shoulder and (x,y,z)
phi = asin(zp/R);
theta_one = acos((R^2 + L1^2 - L2^2) / (2*L1*R)) + phi;
theta_two = -(pi - acos((L1^2 + L2^2 - R^2) / (2*L1*L2)));
theta_base = atan(y/x);
R_arm_proj = sqrt(x^2 + y^2);
if (abs(((R_arm_proj) - (L1*cos(theta_one)+L2*cos(theta_one+theta_two)))) <= 1e-7)
if (xscale == 1 && zscale ~= 1)
theta_wrist = -theta_one - theta_two - pi/2 - theta_camera;
else
theta_wrist = -theta_one - theta_two - pi/2;
end
else
theta_wrist = -theta_one - theta_two + atan(((z) -
(L1*sin(theta_one)+L2*sin(theta_one+theta_two)))/((R_arm_proj) -
(L1*cos(theta_one)+L2*cos(theta_one+theta_two))))-theta_camera;
end
%% end equadrant 4
end
% find the location of the camera
camx =
cos(theta_base)*(L1*cos(theta_one)+L2*cos(theta_one+theta_two)+R_cam*cos(theta_one+thet
a_two+theta_wrist+theta_camera));
camy = camx*tand(theta_base*180/pi);
camz =
L1*sin(theta_one)+L2*sin(theta_one+theta_two)+R_cam*sin(theta_one+theta_two+theta_wrist
+theta_camera);
%% Find the rotation of the little gear required
ThetaS = 5*theta_one;
ThetaE = 5*theta_two;
ThetaW = 5*theta_wrist;
ThetaB = 5*theta_base;
%% Find the required pulses to the servos to move the required angles
```

```
% convert the servo angles to degrees
ThetaSd = ThetaS*180/pi;
ThetaEd = ThetaE*180/pi;
ThetaWd = ThetaW*180/pi;
ThetaBd = ThetaB*180/pi;
% assuming that the 0 poisition of the arm corresponds to a 1500 pulse
zero_position = 1500; % microsec pulse
% find the required pulse in microseconds
pulseS = zero_position + ThetaSd/1.475; % need to change
pulseE = zero_position - ThetaEd/1.475; % need to change
pulseW = zero_position + ThetaWd/1.607; % 90deg arm = 1220 micros
pulseB = zero_position + ThetaBd/1.4876; % 180deg arm = 895 micros
pulse_matrix = [pulseB pulseS pulseE pulseW];
pulse_rounded = round(pulse_matrix);
pulse_rem = rem(pulse_rounded,5);
pulses = zeros(1,4);
for i = 1:4
if (pulse_rem(i) >= 3)
pulses(i) = pulse_rounded(i) + (5 - pulse_rem(i));
Else
pulses(i) = pulse_rounded(i) - pulse_rem(i);
End
End
End
```

Main MATLAB Script

```
% #!/usr/bin/octave -qf
function [output] = main_script()
% accept input from octave
% arg_list = argv ();
% pic_name = arg_list{3};
% pic_num = str2double(arg_list{4});
% xscale = str2double(arg_list{5});
% zscale = str2double(arg_list{6});
% ### Input Needed:
% picture name
```

```
% picture number
% camx, camy, camz--load from text file
% xscale, zscale


% Define the scaling for moving the arm several times ### Taken from Octave call
xscale = 1;
zscale = 1;
pic_num = 1;
% Define the initial camera location and distance to ground (d2g)
initial_camera_location = [5 0 5]; % ### Need to Change ###
d2g = -7.7; % ### Need to Change ###
%% Determine distance to sample with imaging code
jpegmatrix = imread ("pvclegit.jpg"); % ### Need to Change to accept input ###
sumgrid = make_bw_image(jpegmatrix);
keep = 0.8;
straight_line_distance = autoblob(sumgrid, keep);
%straight_line_distance = 15.5;
%% Determine location of sample
zlocation = d2g - initial_camera_location(3);
xlocation = sqrt(straight_line_distance^2 - zlocation^2);
ylocation = 0;
sample_location = [xlocation+initial_camera_location(1) ylocation+initial_camera_location(2)
d2g];
% determine the input into the arm code
if (pic_num == 1)
x = sample_location(1);
y = sample_location(2);
z = sample_location(3);
else
x = xlocation + camx;
y = sample_loction(2) + camy;
z = sample_location(3);
end
%% Calcualte the servo inputs
```

[pulses, camx, camy, camz] = arm_angle_calc_function(x, y, z, xscale, zscale)

%% Output pulses to rest of C code to control arm

output = [pulses, camx, camy, camz];

dlmwrite = ('arm_output.txt',output);

Imaging Code

```
% Main for Testing Imaging System
% NCSU Tycho Lycos 2014-2015
close all; clc; clear;
%picnums = [8.5,9.5,11,12,13.5,14.25,15,16.5,17.75,18.25,19.75,21,22.75,26];
%picnums = [15:.5:20,21:.5:24.5,25.25,25.5];
%picnums = [5,6,6.5:.5:20,21:.5:24.5,25.25];
picnums = 24.5;
actualdistance = picnums + 3 + 7/8 - 1 - 11/16;
var2 = 45;
var1 = 50;
ploton = 0;
saveploton = 0;
keepwhat = .8;
for k = 1:length(picnums)
   k
   close all
   thepicture = [num2str(picnums(k)),'.jpg'];
   thejpgmatrix = imread(thepicture);
%   kLap = fspecial('unsharp');
%   kLap = [-1, -1, -1;
%          -1,  8, -1;
%          -1, -1, -1];
%
%   thejpgmatrix = imfilter(thejpgmatrix,kLap,'replicate');
   h = fspecial('gaussian', var1, var2);
   thejpgmatrix = imfilter(thejpgmatrix, h);
%   h = fspecial('laplacian');
%   thejpgmatrix = imfilter(thejpgmatrix, h);
   tStart = tic;
   [bigblob,thetoc1,height,width,labels,bloblabel,keys,parents,isize,imx,jmx] =
blob_finder(thejpgmatrix,keepwhat);
   tElasped = toc(tStart);
   [labels ] = relabel_blobs( labels,parents,keys,imx,jmx,isize);
   slidetitle = picnums(k);
```

```
    [tElapsedplot ] = blobplotter( k,thejpgmatrix,labels,bloblabel,slidetitle,ploton,saveploton );
    sizeblob = length(bigblob);
    tabletrack(k,1) = picnums(k);
    tabletrack(k,2) = sizeblob;
    tabletrack(k,3) = tElasped;
    tabletrack(k,4) = height;
    tabletrack(k,5) = width;
    tabletrack(k,6) = height./width;
end
ox = 4.16;
x = width;
sx = 0.00141732283;
f = 0.178346;
px = 600;
d = ox.*f.*px./(x.*sx);
tabletrack(:,1) = actualdistance;
ploton = 1
if ploton == 1

    if saveploton == 1
        ppt=saveppt2('batch.ppt','init');
    end
    figure(100)
    plot(tabletrack(:,1),tabletrack(:,2),'k-o')
    %title('Size')
    ylabel('Pixel Count')
    xlabel('Distance (in.)')
    if saveploton == 1
        saveppt2('ppt',ppt)
        saveppt2('batch.ppt','ppt',ppt,'close');
        close all
    end
    figure(200)
     if saveploton == 1
        ppt=saveppt2('batch.ppt','init');
    end
    plot(tabletrack(:,1),tabletrack(:,3),'k-o')
   % title('Time')
    ylabel('Time s')
    xlabel('Distance (in.)')
     if saveploton == 1
        saveppt2('ppt',ppt)
        saveppt2('batch.ppt','ppt',ppt,'close');
        close all
```

```
    end
    figure(300)
     if saveploton == 1
        ppt=saveppt2('batch.ppt','init');
    end
    plot(tabletrack(:,1),tabletrack(:,4),'r-o')
    %title('Dimensions')
    ylabel('Pixels')
    xlabel('Distance (in.)')
    hold on
    plot(tabletrack(:,1),tabletrack(:,5),'k-o')
    legend('Height','Width')
     if saveploton == 1
        saveppt2('ppt',ppt)
        saveppt2('batch.ppt','ppt',ppt,'close');
        close all
    end
end

function [ bigblob,thetoc1,height,width,labels,bloblabel,keys,parents,isize,imx,jmx ] =
blob_finder(thejpgmatrix,keepwhat )
% function to find the blob representing the sample
% NCSU Tycho Lycso 2014-2015
counter = 1;
bloblabel = 99;
%rgbmat = imread('pvc4.jpg');
%rgbmat = imread(thejpg);
rgbmat = thejpgmatrix;
sizeof =  size(rgbmat);
xs = sizeof(1);
ys = sizeof(2);
spacer = 1;
[imx,jmx,depth] = size(rgbmat);
imx = int32(imx);
jmx = int32(jmx);
summat = zeros(imx,jmx);
n = 0;
n = int32(n);
for j = 1:jmx;
    for i = 1:imx;
        % summat is the sum of red green and red values and is analogous to
        % the intensity valeus of each pixel in the jpg
        summat(i,j) = rgbmat(i,j,1) + rgbmat(i,j,2) + rgbmat(i,j,3);
    end
```

```
end
%spacer can be used to adjust how many pixels to put in a comparison group
%if spacer > 1
sumgrid = zeros(imx,jmx);
for j = 1:jmx/spacer-1;
   for i = 1:imx/spacer-1;
      % imxtatrt and rowend mark the start and end of each group in i
      imxtart = i *spacer;
      rowend = imxtart + spacer;
      % jmxtatrt and columnend mark the start and end of each group in j
      jmxtart = j*spacer;
      columnend = jmxtart +spacer;
      % sumgrid is the intensity value of each group of pixels
      sumgrid(i,j) = sum(sum(rgbmat(imxtart:rowend,jmxtart:columnend)));
   end
end
%else
% pretty sure there is a problem if spacer is 1, this is a get around.
% sumgrid = summat;
%end

% maxval is the most intense pixel, aka the whitest pixel
maxval = max(max(sumgrid));
%  [maxr,maxc]=find(sumgrid == maxval);
%
% [xg,yg] = find(sumgrid > maxval*.9 );
% this loop changes how many pixels you want to pull as 'bright' by
% comparing each pixel to the brightest pixel. changing the decimal
% changes the percentile of the bright pixels you want to keep. isize
% stores whether each pixel is bright by marking it as 1. others are 0
isize = zeros(xs,ys);
for j = 1:jmx/spacer-1;
   for i = 1:imx/spacer-1;

      if sumgrid(i,j) > maxval*keepwhat;
         isize(i,j) = 1;
      end

   end
end

%isize2 = zeros(xs,ys);
labels = zeros(xs,ys);
%isize2(xg,yg) = 1;
```

```
keys = zeros(xs,ys)*10^7;
int8(keys);
%nei = 0;
nextlabel = 1;
% http://en.wikipedia.org/wiki/Connected-component_labeling
parents = zeros(imx,1);
int8(parents);
for i = 1:imx/spacer-1;
  %    if i == 100
  %        keyboard
  %    end

  for j = 1:jmx/spacer-1;
%              if i == 165  && j == 389
%                  keyboard
%              end
    nei = 0;
    %       if i == 2 && j == 72
    %           keyboard
    %       end
    if isize(i,j) == 1
      % n is the pixel index in the image
      n = (j-1)*imx/spacer + i;
      %           if n ==    143477
      %               keyboard
      %           end
      [nei] = find_neighbors_sub(i,j,imx,jmx,isize); % 12/10 changed isize to labels
      if sum(nei) == 0
        % keys is  a matrix where each row is distinguishing
        % a group of similarily grouped pixels
        % nextlabel is keeping track of which label you should
        % assign to a new blob
        keys(nextlabel,1) = n;
        labels(i,j) = nextlabel;
        %             if nextlabel == 17
        %                 keyboard
        %             end
        parents(nextlabel) = nextlabel;
        nextlabel = nextlabel + 1;
      else
        %             if i == 1 && j == 57
        %                 keyboard
        %             end
```

```
            if find(parents(1:nextlabel-1)==0) > 0
               keyboard
            end
             tic
            [nei_labels,parents_local] =
find_nei_lables2_sub(isize,i,j,nei,labels,parents,keys,imx/spacer,jmx/spacer);
            thetoc1(counter) = toc;
            parents_local = parents_local(find(parents_local ~= 0 ));
%              if find(parents_local ==0)
%                 keyboard
%              end

            nei_labels = nei_labels(find(nei_labels));
            labels(i,j) = min(nei_labels);
            minrow = min(nei_labels);
            %               if minrow == 7
            %                              keyboard
            %                           end
            %nexttochange = min(find(keys(min(nei_labels),:) == 0 ));

            %nexttochange = find(keys(min(nei_labels),:),1,'last')+1;
             brotochange = (keys(min(nei_labels),:)) < 1;
             bro2 = keys(min(nei_labels),brotochange);
             lengthbro = length(keys) - length(bro2);
             nexttochange = lengthbro +1;
%               if nextbrotochange ~= nexttochange
%                  keyboard
%               end

            %keys(min(nei_labels),:) = [keys(min(nei_labels),:),n];

             counter = counter+1;

            keys(min(nei_labels),nexttochange) = n;

            for m = 1:length(nei_labels)
               %m = nei_labels(v);
               % logic to merge two sets that are found to be next to
               % each other
               if minrow ~= nei_labels(m)
                  v1 = find(keys(minrow,:) ~= 0);
                  v2 = find(keys(nei_labels(m),:) ~= 0);
                  s = 1;
                  for q = (max(v1) + 1) : (max(v1) + length(v2))
```

```
                %                    if keys(minrow,q) == 24181
                %                      keyboard
                %                    end
                if keys(v2(s)) ~= keys(minrow,q-1)

                  keys(minrow, q) = keys(v2(s));
                else
                  break
                end
                s = s+1;
              end %q

              %lsets(min(nei_labels),:) = union(lsets(min(nei_labels),:),lsets(nei_labels,m));
              %keys(min(nei_labels),:) = union(v1,v2);
              v1 = 0;
              v2 = 0;
              if parents(nei_labels(m)) > min(parents_local) %min(parents)
                %keyboard
                if find(parents(1:nextlabel-1)==0) > 0
                  keyboard
                end
%                 if parents(m) ==0
%                   keyboard
%                 end
                parents(nei_labels(m)) = min(parents_local);

              else

              end
            end
          end
        end
      end
    end
end
found = 0;
labelsog = labels;
parents = parents(find(parents));
for h = 1:length(parents)
  if parents(h) ~= h
    oldparent = parents(h);
    parents(h) = parents(oldparent);
  end
```

```
end
keys = keys(1:length(find(keys(:,1))),:);

%% Process the blobs
for mm = 1:length(keys(:,1));
   bigblob = keys(mm,:);
   [rowsind, colsind] = find(keys(mm,:));
   bigblobcount = length(colsind);
   iblob = zeros(1,bigblobcount);
   jblob = zeros(1,bigblobcount);

   for kk = 1:bigblobcount
      kind = bigblob(kk);
      iblob(kk) = floor(kind/jmx)+1;
      jblob(kk) = (kind-iblob(kk))./imx + 1;%abs(kind - (iblob(kk)-1).*jmx);
   end

   [leftest,leftind] = min(iblob);
   [rightest,rightind] = max(iblob);
   [top,topjnd] = max(jblob);
   [bottom,bottomjnd] = min(jblob);
   topind = iblob(topjnd);
   bottomind = iblob(bottomjnd);
   leftjnd = jblob(leftind);
   rightjnd = jblob(rightind);
   height = (top - bottom);
   width  = rightest-leftest;
   ratio = height./width;
   if ratio > 1.25 && ratio < 1.4 && bigblobcount > 500
      bloblabel = mm;
      break
   end

end
%%
   function [ nei_labels,parents_local] = find_nei_lables2_sub(isize, x,y,nei,
labels,parents_nei_l,keys_nei_l,imx,jmx )
      [rows, cols] = size(nei);
      breaker = 0;
      nei_labels = 0;
      parents_local = 0;
      for k = 1:cols
         %      if parents(k) ==0
         %                keyboard
```

```
        %              end
        ind = nei(1,k);
        jnd = nei(2,k);
        nei_labels(k) = labels(ind,jnd);
        nei_n = (jnd-1)*imx + ind;
        %
        %
        mind = nei_labels(k);
        parents_local(k) = parents_nei_l(mind);
        if parents_local == 0
            keyboard
        end
    end
end

function [ nei] = find_neighbors_sub( i, j , imx, jmx, isize )
    % finds neighbors that are in foreground, W, NW, N, NE
    % xcoord stored in nei(1,:)
    % ycoord stored in nei(2,:)
    lnei = 0;
    nei = 0;

    if i == 1

        if j == 1
            icoord = [ 0];
            jcoord = [ 1];
        elseif j == jmx
            icoord = [ 0];
            jcoord = [-1];
        else
            icoord = [0];
            jcoord = [-1];

        end
    elseif i == imx

        if j == 1
            icoord = [ -1 -1];
            jcoord = [ 0  1];
        elseif j == jmx
            icoord = [ 0 -1 -1 ];
            jcoord = [-1  -1 0  ];
        else
```

```
            icoord = [ 0 -1 -1 -1];
            jcoord = [-1  -1 0  1];
         end
      else
         if j == 1
            icoord = [ -1 -1];
            jcoord = [0  1];
         elseif j == jmx
            icoord = [ 0 -1 -1 ];
            jcoord = [-1  -1 0 ];
         else
            icoord = [ 0 -1 -1 -1];
            jcoord = [-1  -1 0  1];
         end

      end

      for k = 1:length(jcoord)
         if isize(i+icoord(k),j+jcoord(k)) == 1
            lnei = lnei + 1;
            nei(1,lnei) = i+icoord(k);
            nei(2,lnei) = j+jcoord(k);



         end
         if k == 4 && lnei ==0
            nei = 0;
         end
      end
      if nei(1,1) == i  && nei(2,1) == j
         nei = 0;
      end
   end
end


function [labels ] = relabel_blobs( labels,parents,keys,imx,jmx,isize)
% update labels on image grid
% NCSU Tycho Lycos 2014-2015
for i = 2:imx-1;
   for j = 2:jmx-1;
      if isize(i,j) == 1

         n = (j-1)*imx + i;
```

```
            [ifound,jfound] = find(keys == n);
        labels(i,j) = parents(ifound(1));
        %            if found == 0;
        %               keyboard
        %            end

      end
   end
end
end


function [tElasped  ] = blobplotter( k,rgbmat,labels,bloblabel,thedistance,ploton,saveploton )

% Function used to plot image with blob groupings on top

% NCSU Tycho Lycos 2014-2015

%close all

tStart = tic;

if ploton == 1;

   figure(k)

   %rgbmat = label2rgb(labels);

   image(rgbmat)

   hold on

   colorpic1 = {'g','m','b','k'};

   p = 0;

   if saveploton == 1

   ppt=saveppt2('batch.ppt','init');

   end

   for b = 1:max(max(labels))

      if b == bloblabel
```

```
        p = p+1;
        [row,column] = find(labels == b);
        plot(column,row,'x','MarkerSize',5,'Color','r')
        title(num2str(thedistance))
        if p == 4
            p = 0;
        end
    else
        p = p+1;
        [row,column] = find(labels == b);
        plot(column,row,'*','MarkerSize',5,'Color',colorpic1{p})
        title(num2str(thedistance))
        if p == 4
            p = 0;
        end
    end
end
if saveploton == 1
saveppt2('ppt',ppt)
saveppt2('batch.ppt','ppt',ppt,'close');
close all
end
```

```
end

tElasped = toc(tStart);

end
```

9.7 Construction Personnel Hazards

Safety Concern	Mitigation	Confidence
Drill Press	All persons in the lab space are notified shortly before powering on the drill press. Safety goggles and earplugs are worn by persons using press. Precise setup techniques are used to ensure the press will operate smoothly and in a manner within operating limits.	The drill press is a relatively safe piece of machinery when all precautions are taken seriously. Lab members were taught at a safety seminar and practice these safety procedures to ensure confidence in the safety of the lab.
Band Saw	All persons in the lab space are notified shortly before powering on the band saw. Safety goggles and ear protection are worn by operating persons. Saw calibration and setup are checked prior to use. Only select materials are used on the saw.	Proper material selection, prior checkup (with special attention paid to the tightness and alignment of the band), and safety goggles will ensure the lab uses this equipment in a safe manner.
Belt Sander	All persons in the lab space are notified shortly before powering on the belt sander. Safety goggles and ear protection are worn by operating persons. Sander calibration and setup are checked prior to use. Only select materials are used on the sander. Dust products are collected after use.	Proper material selection, pre checkup, and safety goggles will ensure the lab uses this equipment in a safe manner.
Manual Mill	For rocketry club items, the manual mill is only operated by the director of the shop who is a professional hired by the school.	The manual mill operator ensures the safety of his lab for a living and helps teach these concerns to club members.
Black Powder	Black powder is handled in an isolated location, premeasured, and placed into vials before	Black powder is one of the more dangerous substances handled by the club, so extreme caution

	taking it out to the launch site. The black powder is stored separately in a safe environment away from potential ignition sources.	is taken when handling. There is minimal chance for problems with black powder.
Epoxy	Epoxy is applied in ventilated areas. Gloves and eye protection are worn by persons using epoxy.	Safety procedures and observers ensure epoxy is a minimal safety concern in the lab.
Layups	Layups are done with calibrated vacuum system. All personnel are trained to use the vacuum system and to properly create sealing apparatuses.	The vacuum system and lay up systems are monitored to ensure safety and quality when creating components.
X Acto Knife	X Acto knives are stored with their covers on in a specified location. Team members are instructed to ensure blades are secured tightly and to cut away from their body.	By ensuring all members are familiar with safe procedures concerning sharp objects in the laboratory, the team is confident X Acto knives are a minimum safety concern.
Power Supplies	Power supplies are left unplugged when not in use. They are not used near water and cords are inspected for bare wires before use. Circuitry is checked prior to use to ensure they can handle the applied loads.	Relatively low power uses with stringent safety requirements ensure proper use and safety when using electrical equipment.
Soldering Iron	Soldering irons are left unplugged when not in use. They are not used near water and cords are inspected for bare wires before use. Proper spacing is ensured by user during operation.	Primary concerns with soldering irons focus around electrical safety and minimizes the misplacement of the heat source. Keeping these two risks in check ensures the safety of the equipment operation.