NC STATE UNIVERSITY

Tacho Lycos:
NASA Student Launch Project
CDR 2015

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

1. Summary of CDR Report

1.1. Team Summary

1.1.1. Team name and mailing address

Tacho Lycos
911 Oval Drive
Raleigh, NC 27695

1.1.2. Name of mentor, NAR/TRA number and certification level

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 full scale rocket will have a final length of 78 inches, a body diameter of 5.5 inches, and a total weight of 18 pounds. The weight is expected to grow during the final build to no more than 21 pounds due to epoxy, paint, and other miscellaneous weights that will be added during the final build. This added weight will not be an issue as all the experiments have been completed with the assumption of a 30 pound rocket to give a safe margin of error.

1.2.2. Motor choice

The Aerotech K805G has been chosen for the full-scale rocket launch. Based off of preliminary calculations, the K805G will take the vehicle to 3400 feet AGL. While this is a slight overshoot, the results of the full-scale test flight will identify the ballast adjustments necessary to keep the vehicle as close as possible to 3000 feet AGL.

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.

1.2.4. Rail size

The launch rail will have a 1.5 in x 1.5 in cross-section and a length of 96 inches, which gives a velocity of 66 feet per second as the vehicle leaves the launch rail.

1.2.5. Milestone review flysheet

The Milestone Review Flysheet can be found in ***Appendix 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

ATLAS - Autonomous Terrestrial Launch Ascension System

1.3.2. Summarize method for autonomous procedures and the AGSE

The system begins 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 position itself before grasping the center of the sample. With the sample in the arm's gripper, the arm will move to the payload compartment on the launch vehicle and the sample will be placed in a mold located inside 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 will begin to raise the launch vehicle to 5^{o} from vertical. Once the launch position is achieved, the igniter insertion system's stepper motor will raise the igniter into the rocket's motor and cap the end.

1.3.3. Summarize experiment

The team has developed an imaging system capable of picking out the sample from its surroundings and then relaying the location of the sample in the image to the BeagleBone. The end goal of this system is to determine the position of the sample relative to the arm. This allows us to initially place the sample in different locations, all within reach of the arm, while the system determines its position in real time. This image processing system adds both robustness and challenge to the overall task in a meaningful way. For this experiment, thirty-six images were taken and processed to give the pixel count, height, and width of the sample in the images. These curves plotted against distance yield a curve that can be used to determine the sample's position from an inputted image.

In order to test the design and implementation of the robotic arm, 4 pre-determined locations were chosen within reach and the code written for the arm, which calculates the required servo inputs to position the gripper, was executed. These locations were (11,0,-7.7), (15,0,-7.7), (22,0,-7.7), and (22,5,-7.7) inches from the origin (designated as the shoulder of the arm). These 4 locations were chosen since they are realistic distances within the arm's area of travel and they require some range of motion from all of the servos. The pulse widths that the code outputted were then manually inputted to control the arm. The arm was commanded to go to each of the positions twice, and was able to pick up a replica of the sample during each test at the desired locations.

To verify that the planetary gear stepper motor would raise the launch rail in less than 45 seconds, a hanging weight/pulley system was attached to the stepper motor shaft to simulate the 12 foot-pounds loading. The time required to raise the weight through a 90 degree shaft rotation was measured for varying step rates. Our results show that the motor could rotate 90 degrees in 2.38 seconds which would give us a total launch rail raise time of 22.5 seconds. This result demonstrated that the planetary gear stepper motor was more than capable of handling both the loading and speed requirements.

For the igniter insertion stepper motor, a similar experiment was conducted. Confirmation that the igniter plate could translate 16 inches vertically (the internal length of the rocket motor) in under 45 seconds was desired. To accomplish this, an ACME threaded rod driven by the stepper was oriented vertically. A Delrin igniter plate on the rod was prevented from rotating using two parallel metal rods. At 18.4 Volts, the stepper motor successfully raised the igniter plate in as little 33.3 seconds. The important conclusion from this experiment was that the stepper motor performed better above its 12 Volt rated voltage. While the desired translation time was verified through this experiment, it was also determined that this stepper motor performed better when powered by the 37 Volt Thunderpower battery than the 12 Volt battery as originally planned.

2. Changes Made Since PDR

2.1. Changes Made Since PDR

AGSE: For the sake of speed and efficiency, the servo angles for the robotic arm will be calculated in real time rather than using a look-up table of distances and corresponding pulse widths. The principle is still the same, however the camera will now output the xyz location of the arm in space and then a function on the BeagleBone will calculate the required pulse width inputs to move the arm to the desired location. Speed tests showed that it would take upwards of a minute to interpolate in the table, but only a couple of seconds to calculate the angles directly.

Payload Equipment: Due to difficulties in supplier availability, the Quik Klip used for payload retention has been eliminated. To compensate, the payload will be offset from the door when in a closed position by 1/4 inches. On both sides of the door, a rubber stripping will be attached to act as bumpers that will span the length of the sample. These bumpers will be 1/8 inches tall and 1/4 inch wide.

Igniter Insertion: The hexagonal, metal plate used for raising the dowel has changed to a square shape that is composed of two joined plates of Delrin. This material offers lower friction against the metal parallel guides and the square shape prevents any slip that could occur. The parallel guides will no longer have a groove cut out as the Delrin square will sit completely flush against the surface. To prevent any bowing of the threaded rod during the raising process, another single square cut of Delrin will support the rod at the top of the igniter insertion frame. This piece will also have a circular hole slightly larger than the diameter of the dowel to guide it on a straight path upwards.

The location of the igniter insertion system has changed from a fixed location behind the launch rail pivot support. The updated design will incorporate the insertion system on launch rail itself. Below the blast plate, there will be a 19 inch extension of the launch rail and the overall height of the insertion system will be 20 inches. To accommodate for this interference, a rectangular cutout will made in the platform of the AGSE. This will allow the lower portion of the insertion system, primarily the stepper motor, to freely rotate to 5 degrees from vertical. This design change was made to: 1) alleviate concerns about threading the igniter dowel through the blast plate, 2) allow for launch angles other than 85 degrees, and 3) reduce the launch rail stepper motor torque requirement.

Motor Choice:

The motor choice for the full-scale changed from the AeroTech K535-WT to the AeroTech K805G. This change was made because the original motor was only single use and the team found it more desirable to use a reloadable motor. The new motor provides similar flight characteristics to the original choice, but is reusable. Moreover, slightly more weight was added to the rocket (about 5 pounds, bringing the expected weight to about 18 pounds), so a larger motor was needed to allow the vehicle to reach the desired altitude.

3. Vehicle Criteria

3.1. Design and Verification of Launch Vehicle

3.1.1. Mission Statement, requirements, and mission success criteria

The primary mission of the NCSU Tacho Lycos team is to complete the criteria laid out by the NASA Student Launch Handbook. These requirements are to use an autonomous ground support equipment capable of inserting a sample, modeled as a pvc pipe, into a horizontal rocket, raise the rocket from an initial horizontal position to a near-vertical position, and finally inserting an igniter into the motor. The rocket must ascend the payload to 3000 feet AGL before jettisoning the sample compartment at 1000 feet AGL during the descent. The basis of success for the club will be primarily founded on the completion of these criteria in a safe, efficient, and educational manner.

There are also several secondary requirements that will be used by the team to determine the success of the mission that have been defined by both NASA and by the team in an effort to elevate the challenge and robustness of the entire system. One requirement given by NASA is to complete all autonomous procedures in less than ten minutes. The club has set internal goals for times of various operations, which ensures that the ten minute goal will be met with a significant cushion. The club has also created the challenge of placing the sample an unknown location at the start of the autonomous procedures. Since NASA gives requirements for the area that the sample must lie within when the AGSE begins, so we will place the sample within these limits, but at a location that is unknown to the system at its start. The sample will then be located with a USB camera while proprietary image processing software will guide the robotic arm. Both the goals stated by NASA and the goals given by the club will be used when judging the success of the system.

3.1.2. Major milestone schedule

December 18 – Begin construction of AGSE

January 16-23 – Arm & camera experiment

January 17 – Begin FRR writing

January 31 – Receive final vehicle design evaluation from NASA

February 1-3 – Finalize any changes to vehicle design criteria based on feedback

February 4 – Initiate vehicle manufacturing

February 17 – Complete full-scale vehicle construction

February 18 – Complete all ejection tests

February 19-26 – Verify systems meet requirements and are operational

February 28 – Launch full scale

March 16 – Submit FRR

March 17-30 – Verify the abilities of the igniter and rocket ascension systems

March 31 – Finish construction of AGSE

April 1-6 – Test system as a whole

April 7 – Travel to Alabama for the competition and final launch

3.1.3. Design at a system level

3.1.3.1. Drawings and specifications

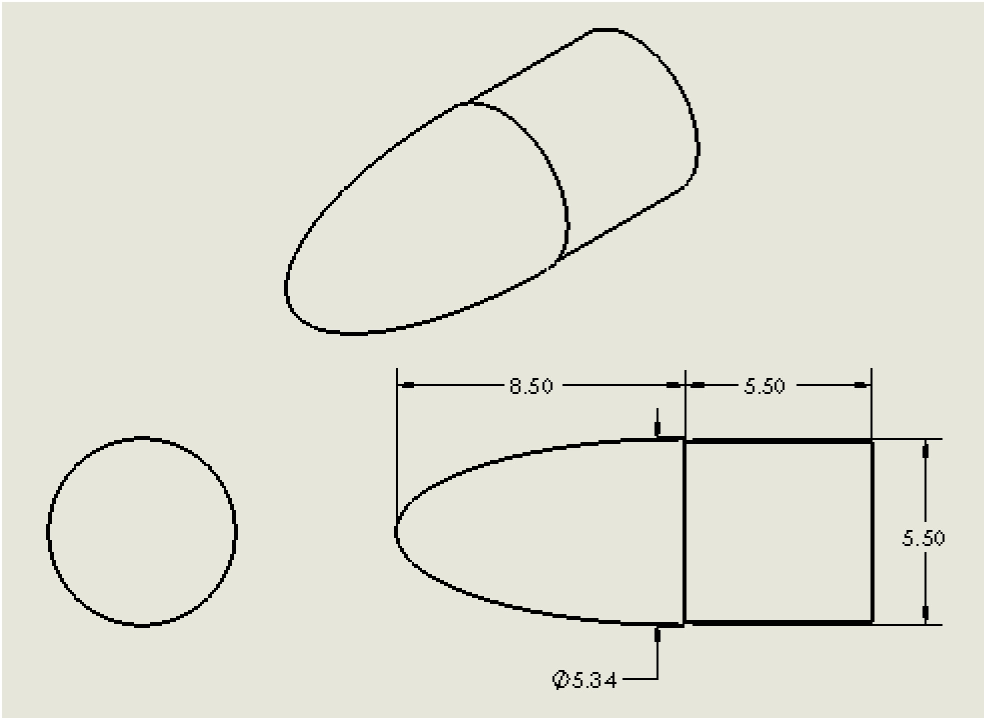

Figure 1: Nosecone Drawing

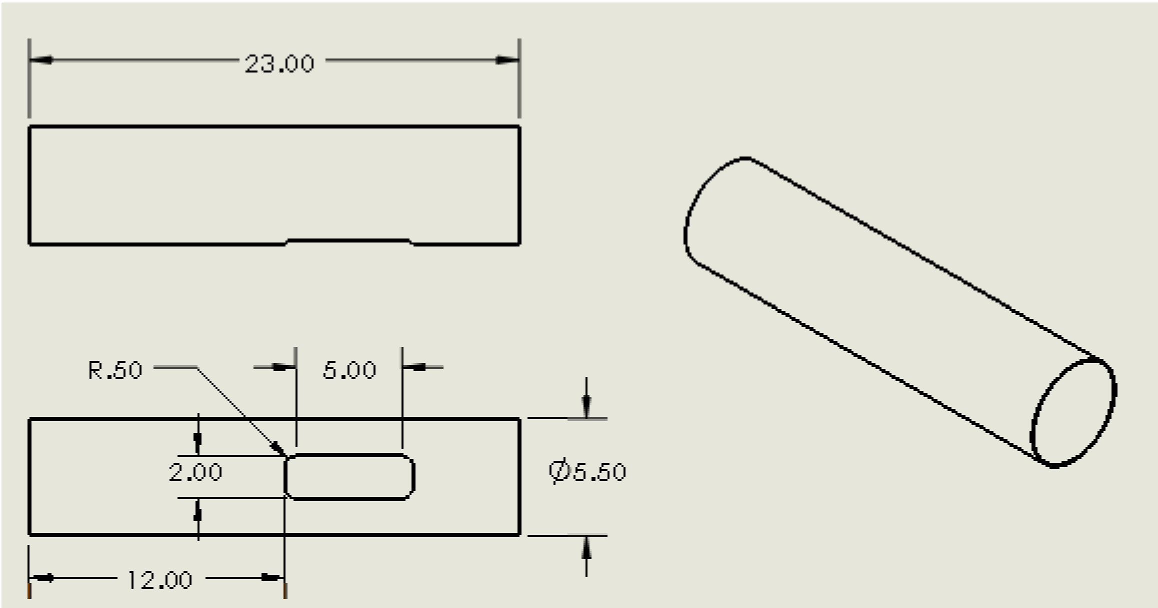

Figure 2: Upper Airframe

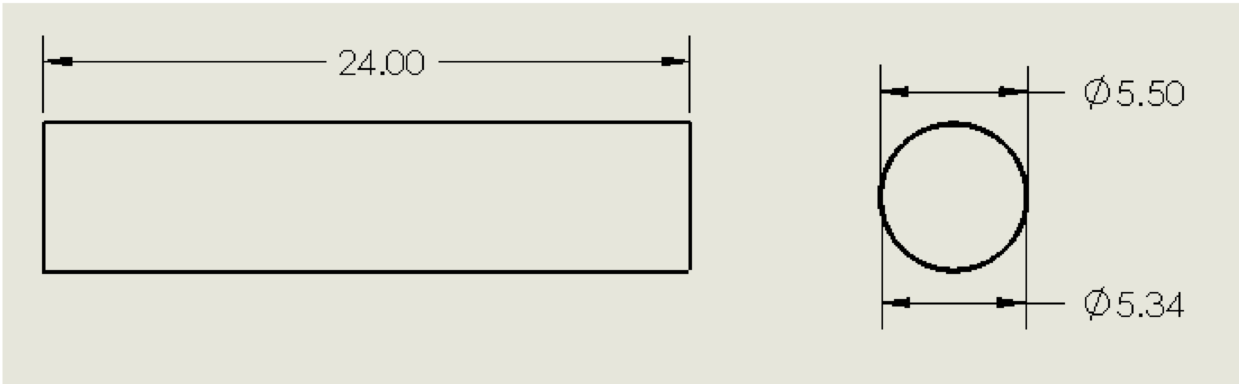

Figure 3: Middle Airframe

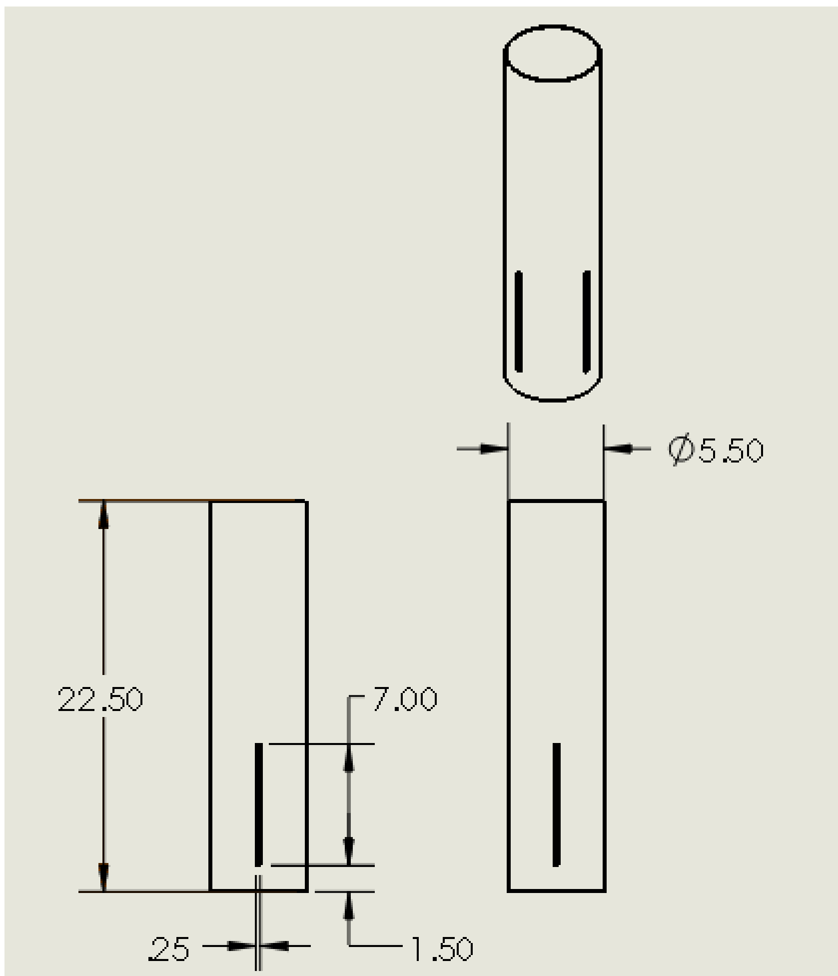

Figure 4: Fin Section Airframe

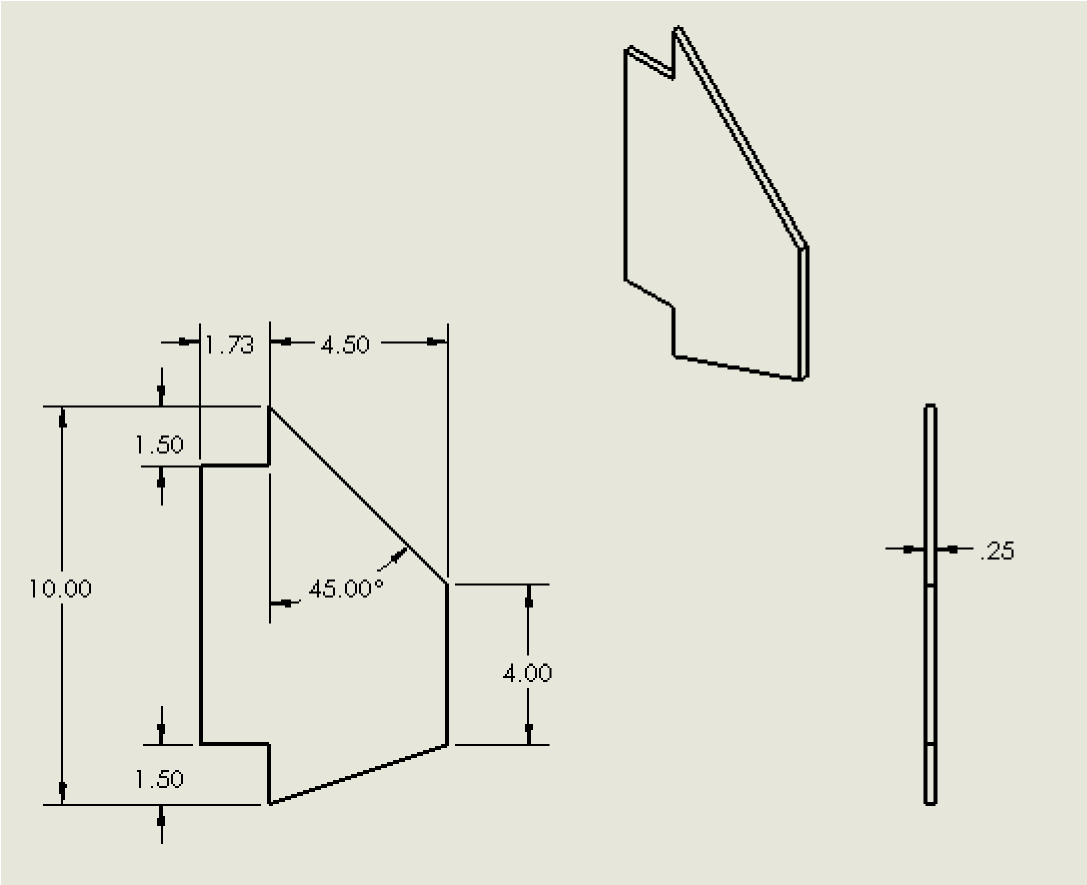

Figure 5: Fin Geometry

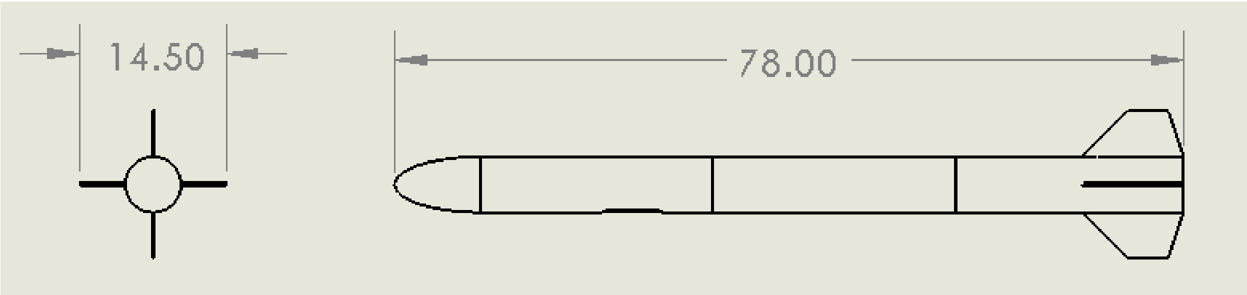

Figure 6: Full-Scale Vehicle Dimensions

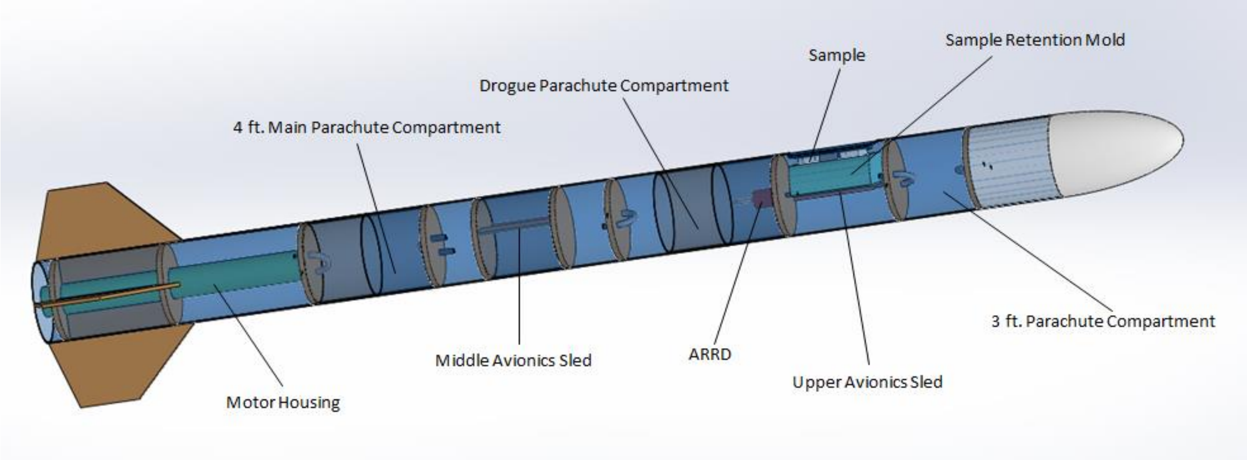

Figure 7: Full-Scale Vehicle Schematic

3.1.3.2. Analysis and model results

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 ***Appendix 9***.

Figure 8: 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 9*** 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.

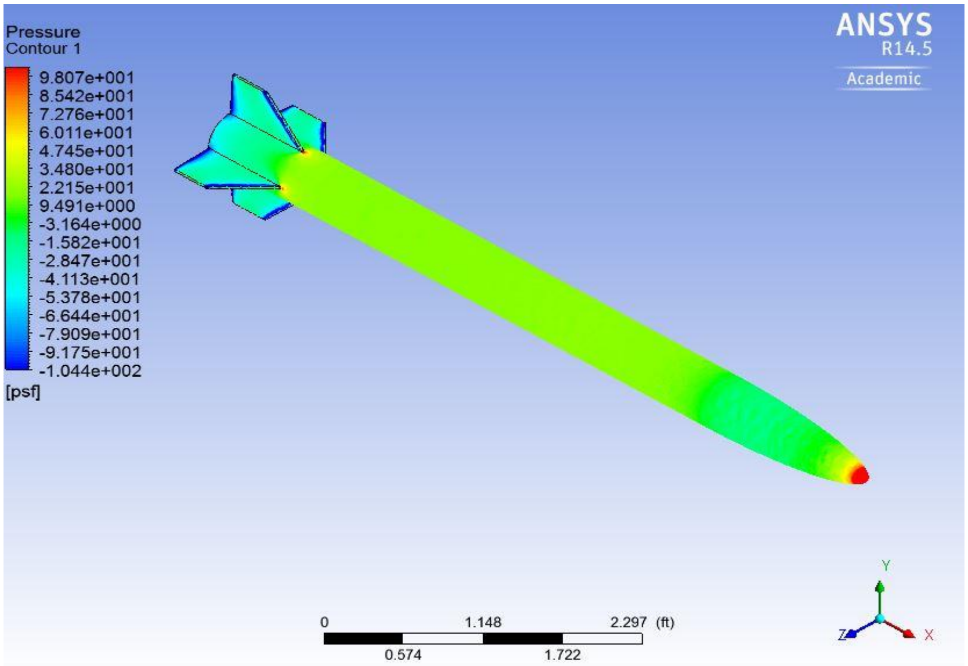

Figure 9: Fluent Model of the Pressure Contour at 700 Feet per Second at 0 Degrees Angle of Attack

The model was then analyzed with a volume rendering of the velocity along half the rocket. As it can be seen in ***Figure 10***, 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 11***, 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.

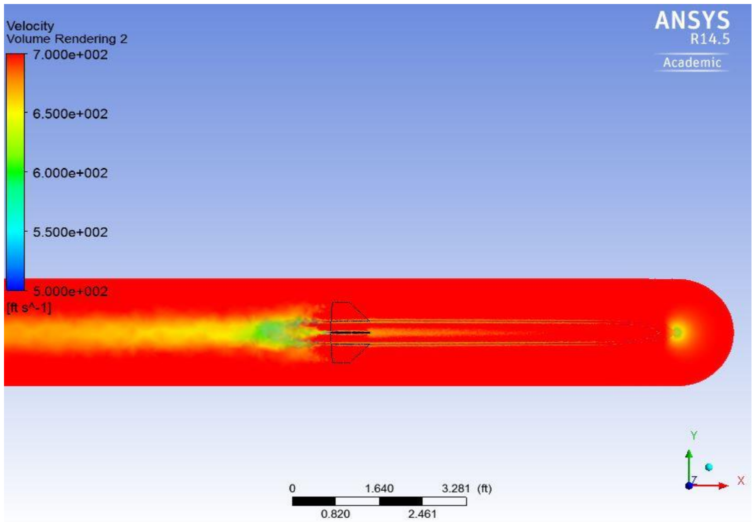

Figure 10: Half Rocket Model Fluent Model of the Velocity Contour at 700 Feet per Second 0 Degrees Angle of Attack

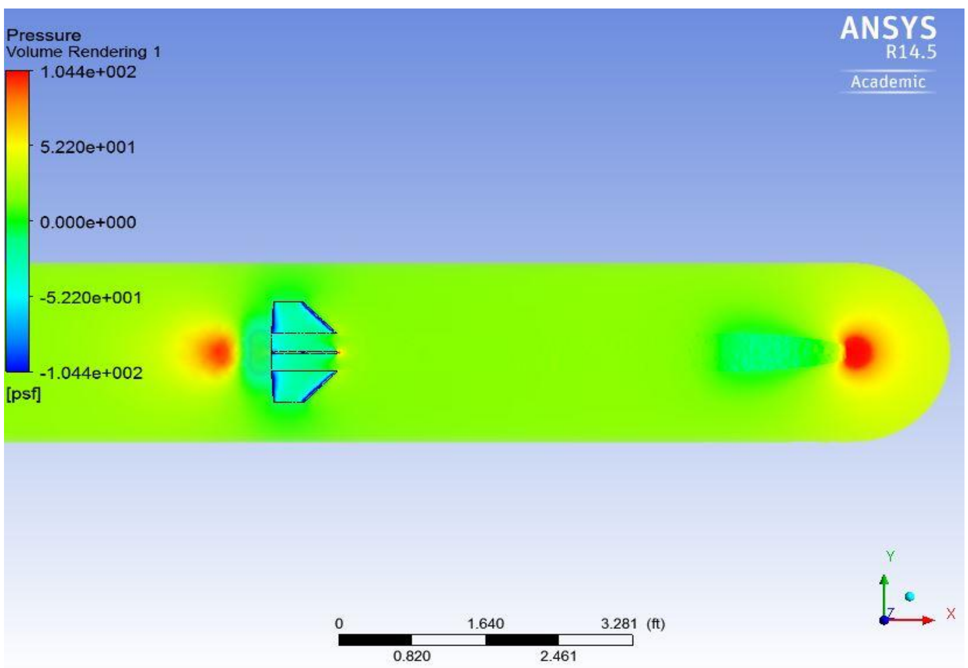

Figure 11: Half Rocket Model Fluent Model of the Pressure Contour at 700 Feet per Second at 0 Degrees Angle of Attack

The same three cases were then run for an angle of attack of three degrees. These results can be seen in ***Figure 12***, ***Figure 13***, and ***Figure 14***. 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.

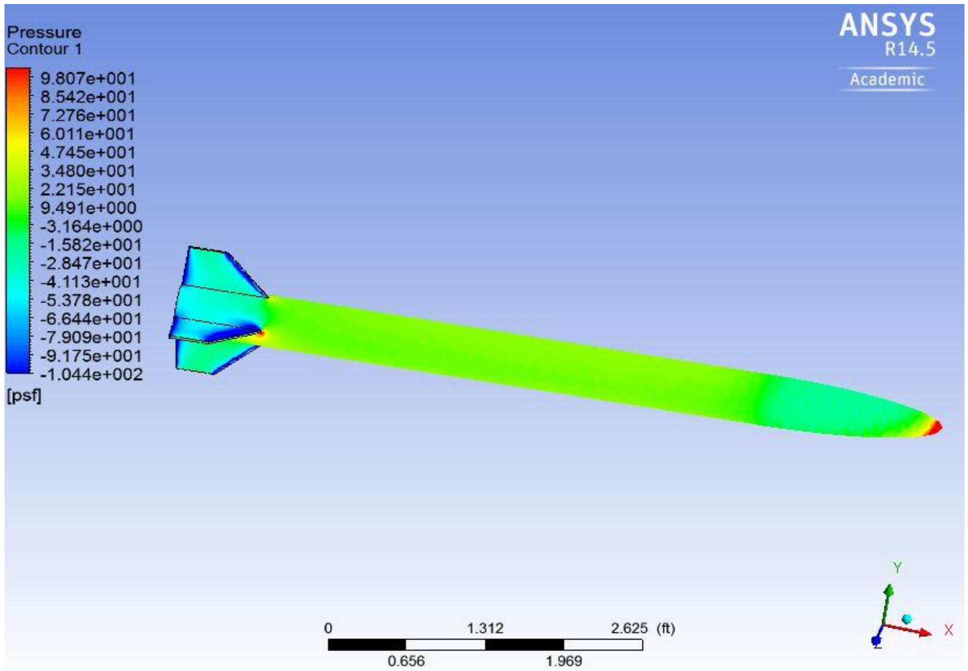

Figure 12: Fluent Model of the Pressure Contour at 700 Feet per Second at 3 Degrees Angle of Attack

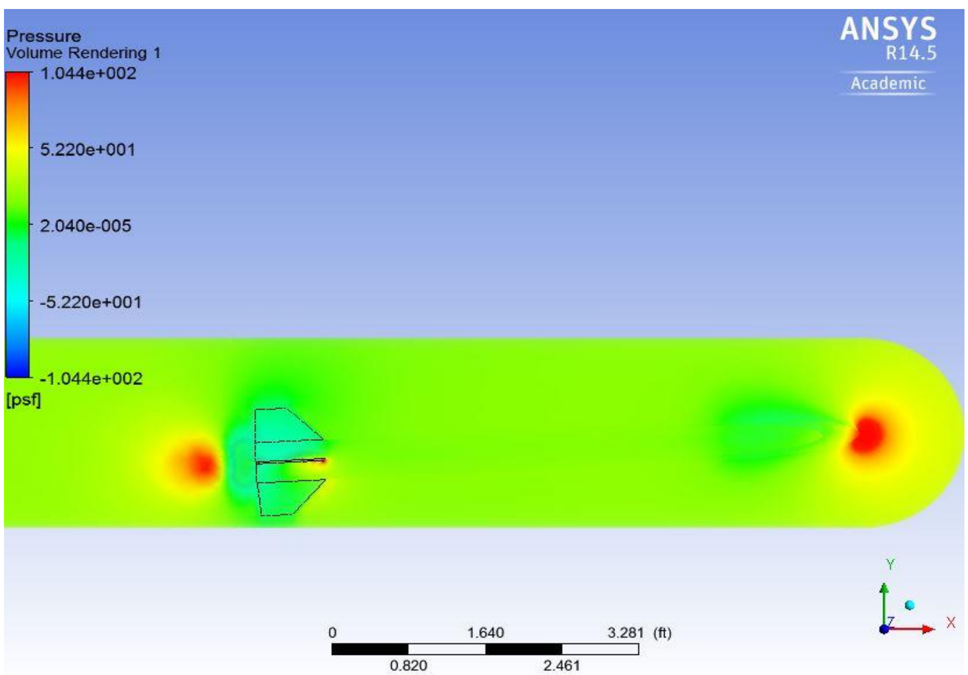

Figure 13: Half Rocket Model Fluent Model of the Pressure Contour at 700 Feet per Second at 3 Degrees Angle of Attack

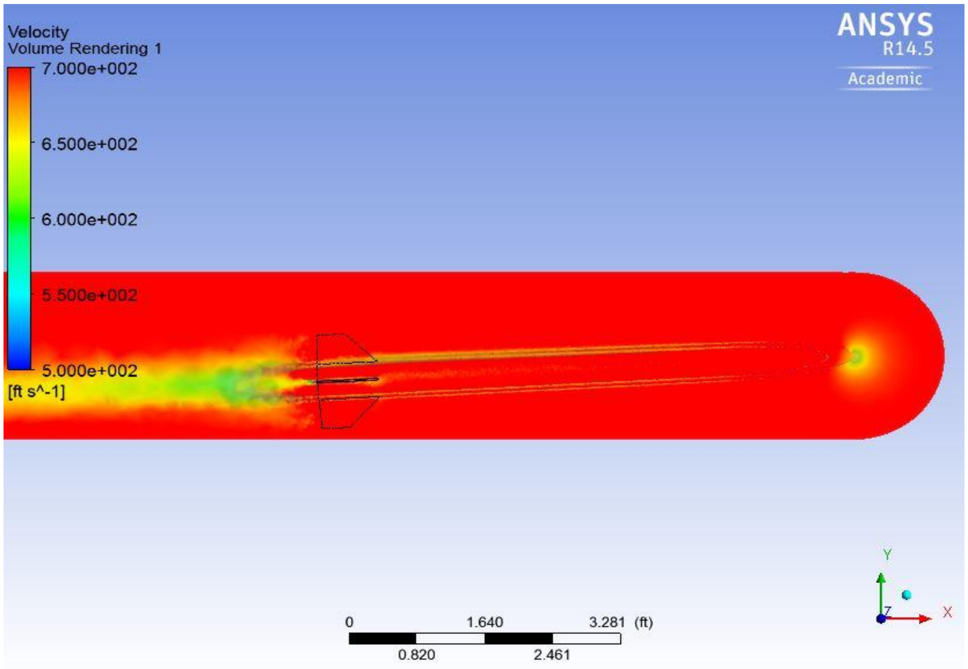

Figure 14: Half Rocket Model Fluent Model of the Velocity Contour at 700 Feet per Second at 3 Degrees Angle of Attack

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 1*** below.

Table 1: 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.

3.1.3.3. Test description and results

Since the full-scale cannot be manufactured before the review of the CDR, the subscale provides a test of the full-scale design. The launch and results of the subscale launch are described in detail in section 3.2 above.

3.1.3.4. Final motor selection

The selected motor is the AeroTech K805G. This motor has a published diameter of 2.13 inches, a length of 16.1 inches, a propellant weight of 1.92 pounds, a total weight of 3.41 pounds, an average thrust of 163 pound-force, and a total impulse of 390 pound-seconds. This motor used the Aerotech 54/1706 motor casing with a rear motor retention.

3.1.4. System level functional requirements

Deliver a payload

To deliver the payload sample, the sample must be have a way to be secured within the launch vehicle. To verify the preliminary design of the payload retention, a mockup was created from a scrap piece of BlueTube 2.0. A 2 x 5 inch door was cut from the BlueTube and sized to fit the cutout by sanding for small adjustments as necessary. To allow for the hinge to operate without any interference between the door and the main tubing, a 1.25 x 0.25 inch cutout was placed and centered on the right edge of the compartment. The door was then attached with screws to the hinge and tested for maneuverability. This apparatus is illustrated in ***Figure 15***.

Figure 15: Payload Compartment Door Apparatus

The foam mold was next created from spare foam located in the Tacho Lycos' lab. Two sheets of 2.75 inch foam were epoxied together where a cylindrical form with a 5.34 inch diameter was then cut from. The cylinder was then cut in half and used to form the payload mold. 1.4 inches downward from the local maxima on the cylinder, a level cut was made to accommodate the fitting of the sample below the vehicle's edges. The sample was then traced onto the foam in the center and an X Acto knife and sandpaper were used in combination to create a cavity for the payload to sit in. Next, a cutout was made on the left side of the foam block to accommodate for the McMaster-Carr spring loaded sliding bolt. This mold is illustrated in ***Figure 16***.

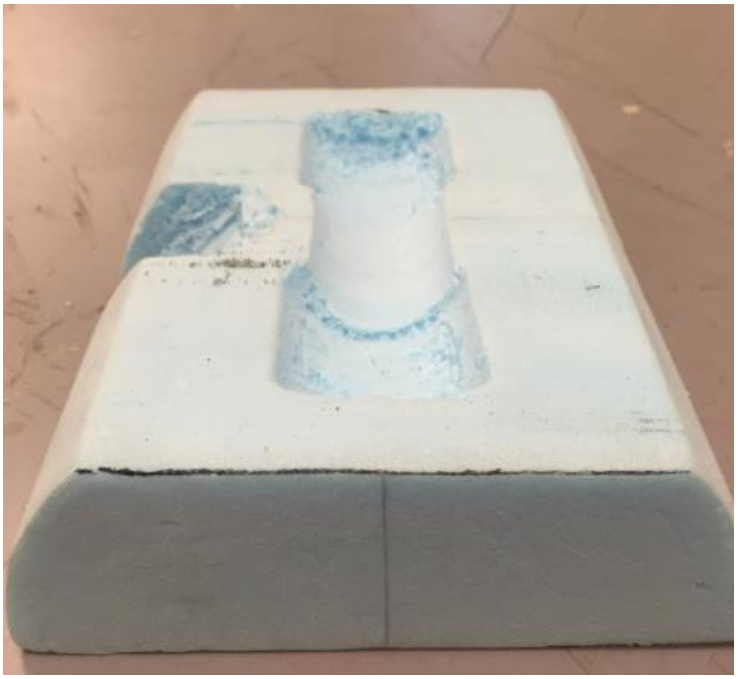

Figure 16: Foam Mold for Payload Sample Retention

This entire setup was placed into the mockup and analyzed as shown in ***Figure 17***. The final stages of testing are to be completed upon full-scale construction approval which includes locking the door with the robotic arm using the sliding bolt.

Figure 17: Preliminary Payload Retention Design Test

The other requirements, as specified in the RFP, and the means by which they are verified are outlined in ***Appendix 6***.

3.1.5. Workmanship

Improper construction of the vehicle may lead to failure of the mission or loss of the vehicle entirely. Therefore, it is imperative that care is taken to uphold quality workmanship when the vehicle is being manufactured. The team believes that the quality of the workmanship is the foundation for success of the mission. To accomplish this mission, all senior members with experience in construction and design will be the primary contributors to manufacturing with guidance given to younger members whenever possible.

3.1.6. Additional testing

Preliminary testing of the payload retention system has been conducted with success. Additional functional testing will be conducted once vehicle construction has begun. This will allow for bulkheads to be put in place inside the body tube to seal off the payload compartment and insert the avionics sled/payload mold along threaded rods. With the mold properly secured on the sled, the arm can then be used to perform a sweeping maneuver to swing the door to a closing position and then push on the door to lock it in place. This testing is necessary to verify that the arm can exert enough force on the door to compress the spring loaded bolt back and lock the door shut.

The release of the spring loaded sliding bolt must also be tested once the payload compartment construction has begun. This can only be performed once all allotted space in the compartment has been used for its design intent. With all components in place, tests will be performed to reach inside the compartment and pull the sliding lock back to unlock the door.

3.1.7. Integrity of design

3.1.7.1. Suitability of shape and fin style for mission

For low altitude and subsonic flight the shape of fins are not of high importance. Nearly any reasonable shape is acceptable as long as the CP-CG relationship is maintained, and the span is sufficient to generate good lifting force. For our launch vehicle, a trapezoidal shape was chosen. One advantage to the trapezoidal shape is since the trailing edge is located forward of the end of the body tube, the fins are partially protected from direct-impact damage. Ideally, if the vehicle falls in a vertical orientation, this places the trailing edge out of plane with the bottom edge of the vehicle.

3.1.7.2. Proper use of materials

The bulkheads and fins will be constructed from 1/8 inch birch aircraft grade plywood laminates using epoxy and a vacuum seal to create ½ inch bulkheads. The 1/8 inch plywood layers will be used to cut twenty-five 5.34 inch diameter circles and 16 fins using NCSU's laser cutter prior to assembly.

A large, clean surface that is free of any debris will be covered with a plastic lining that is sized to accommodate the amount of bulkheads needed. The size of the lining will be such that the desired amount of bulkheads and fins take up half of the sheet's size. This is so the lining can be folded in half over itself. Prior to placing the lining, thin strips of plumber's putty will be placed along the entire outer perimeter of the lining. The bulkheads and fins will then have the epoxy applied using a sponge to evenly spread over the bulkheads surface as shown in ***Figure 18***.

Figure 18: Application of Epoxy to Bulkheads

The bulkheads and fins will be carefully placed on the lining and sheets of peel ply will be cut to cover the items with approximately two inches of overhang along the entire edge. Breather will then be cut to the same size as the peel ply and placed directly over the peel ply. Strips of breather will be bridged from bulkhead to bulkhead and fin to fin all the way to the location of the vacuum tubing as shown in ***Figure 19***. This will ensure no air pockets remain trapped and an even pressure is applied at all points.

Figure 19: Placing Breather over Bulkheads

Plumber's putty will then be 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 will then be inserted in this location and additional putty will be applied around the tubing to keep an airtight seal. The vacuum will then be applied to a pressure of -20 inHg for 8-12 hours minimum. A sample illustration of this setup can be seen in ***Figure 20***.

Figure 20: Fin and Bulkhead Layup

The flight vehicle body tube will be constructed of 5.5 inch diameter Blue Tube 2.0. Blue Tube 2.0 offers greater strength than regular phenolic tubes while weighing less than fiberglass tubing. Designed for artillery illumination rounds, this material is highly resistant to abrasion and cracking which will make it unnecessary to add additional airframe reinforcements. This material has been used in multiple Tacho Lycos flights in previous years and has experienced no previous failures.

3.1.7.3. Assembly procedures, attachments and alignments, connection points, and load paths

To ensure the launch vehicle performs as designed for mission success, it must be constructed exactly as designed. Flight stability will depend heavily on the vehicle's fin alignment. The most rooted component to affect fin alignment will come from the axial alignment of the motor housing and is also where the fin tabs will be attached internally. The motor housing will be axially aligned by making use of the NCSU laser cutter to cut exact dimensions for centering rings. Centering rings will then be epoxied in place using a coupler piece to ensure that they are level. Once the fins are ready to be attached, the method suggested by the club's mentor and used during subscale construction will be implemented again for the full-scale. This involved placing two opposing fins in their respective slots at the same time and placing two pieces of tape over each fin. The fins were then positioned to a vertical alignment and the tape was placed on the body tube to keep the fins orientation. Epoxy was then applied to the joints on the inner and outer sides and allowed to cure before tape removal. This method was validated at the subscale launch as the vehicle maintained a nearly perfectly straight flight. An example of the fin construction is illustrated in ***Figure 21***.

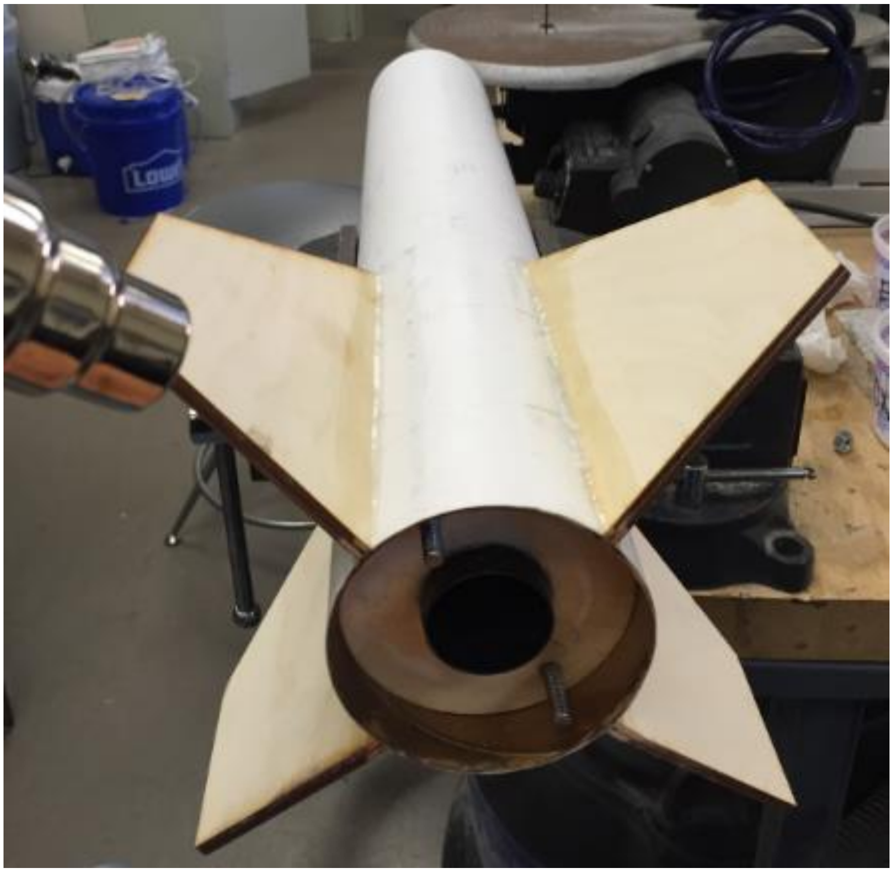

Figure 21: Final Stages of Fin Assembly

The full-scale vehicle will incorporate two coupler pieces to keep the upper, middle, and fin section airframes attached and aligned properly. The coupler that will connect the upper and middle airframes will have a bulkhead epoxied to the top surface. This bulkhead will have external screws inserted from the exterior of the vehicle to hold the coupler in place. The bottom half of this coupler piece and the middle airframe's body tube will have small holes drilled for shear pins to be inserted at 90 degree intervals. These shear pins will provide adequate connection until desired separation occurs from detonation of the black powder charges. This design setup is illustrated in ***Figure 22***.

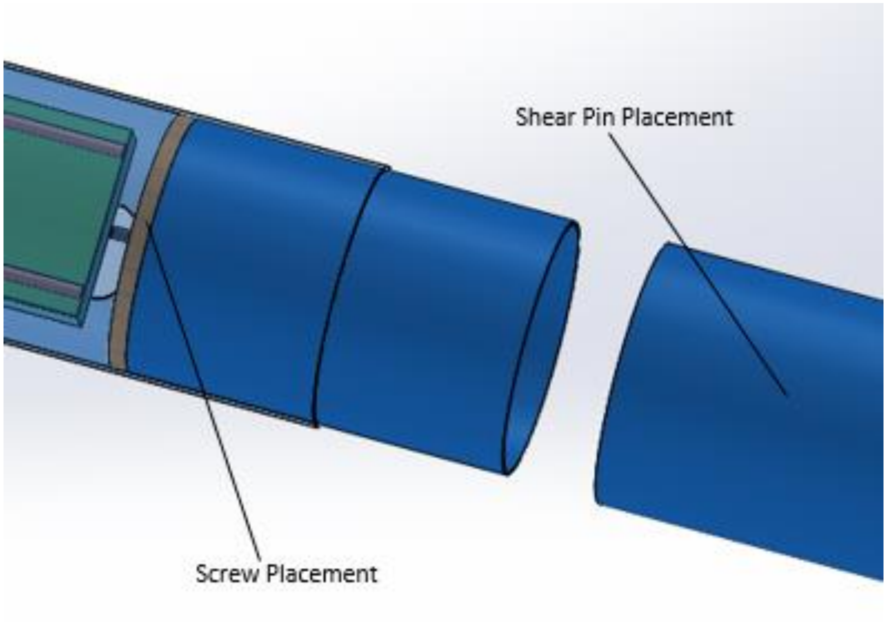

Figure 22: Connection Point between Upper and Middle Airframes

The second coupler will connect the middle airframe and fin section. This coupler will have its upper half permanently attached to the inside of the middle airframe by epoxy. The upper surface of the coupler will have a bulkhead epoxied to it to hold the main parachute harnesses. The lower portion of the coupler and the upper portion of the fin section's body tube will also use 4 shear pins inserted at 90 degree intervals. This design setup is illustrated in ***Figure 23***.

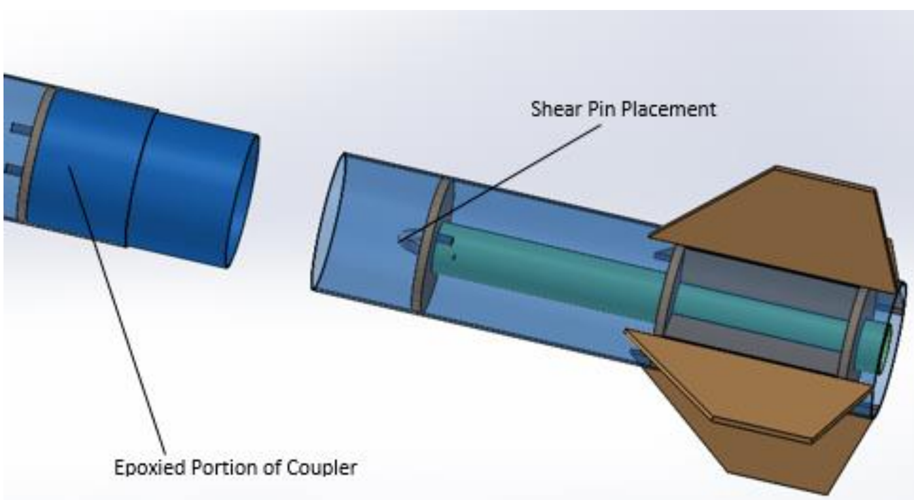

Figure 23: Connection Point between Middle Airframe and Fin Section

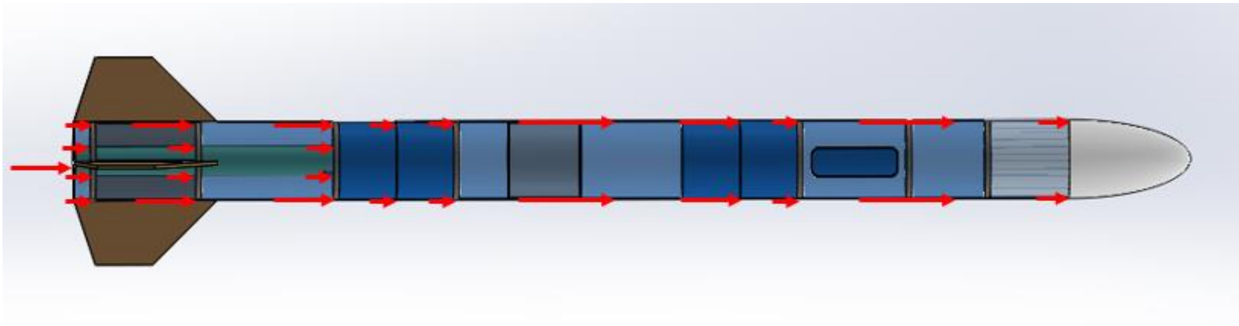

Figure 24: Load Path on Vehicle

3.1.7.4. Motor retention

To properly retain the motor, an Aero Pack 54 millimeter Retainer kit will be purchased from Apogee Components. The motor housing will protrude past the aft-most centering ring. This will allow the threaded portion of the kit to be epoxied around the motor housing and flush to the centering ring. The motor is then inserted into the motor housing and the cap portion is simply twisted on. An example of this apparatus is illustrated in ***Figure 25***.

Figure 25: AeroTech Pack 54mm Retainer

3.1.7.5. Verification

For a complete verification of the integrity of vehicular design, see the verification matrix in ***Appendix 6***.

3.1.7.6. Mass statement

The full-scale vehicle has a projected total weight of 18 pounds as calculated by Openrocket and Solidworks respectively. The weight is expected to grow during the final build to no more than 21 pounds due to epoxy, paint, and other miscellaneous weights that are added during the final build. With a mass calculation performed in Solidworks based on material properties, the mass breakdown for the vehicle was obtained and is shown in ***Table 2***.

Table 2: Launch Vehicle Weight Breakdown

Component	Weight (lbs)
BlueTube 2.0	5.66
Nosecone	1.10
Centering Rings	0.35
Bulkheads	1.80
Fins	1.04
Motor Housing	0.21
Motor	3.40
U-bolts	1.20
Parachutes	0.86
Shock Cord / Recovery Hardware	0.50
Avionics Hardware	0.88
	17.00

3.1.8. Discuss the safety and failure analysis

The cause and effects of failures associated with the vehicle are thoroughly described below in Appendix X. The vehicle will be constructed and flown according to all NAR/TRA regulations. Furthermore, for safety, tasks such as the handling of the motor will only be done with advisor supervision or by the advisor(s) where appropriate. The team is also aware of all of the personnel safety items in section 3.7.2 and will conduct themselves in the lab accordingly when constructing the vehicle. Furthermore, the team will adhere to the checklists outlined in this document to decrease the number of mistakes that can made that will potentially put the team or other personnel at risk.

3.2. Subscale Flight Results

3.2.1. Flight data

The launch on Saturday, 12/20/2014, was a complete success. The team arrived at the field in Bayboro, NC close to 9:30am and immediately started the checklist. For a complete checklist of the subscale test flight from this launch, please see ***Appendix 5***. The temperature was 38 degrees Fahrenheit with slight rain in the forecast. Once assembly was complete, the static margin was verified and found to be 1.75 calibers at flight time. The launch occurred at 11:00am and the vehicle performed flawlessly during the flight. The rocket was very stable and maintained a straight orientation with parachute deployment executed as designed during the descent phase. The rocket drifted around a quarter of a mile from the launch site for an easy retrieval. The launch and retrieval of the vehicle are shown in ***Figure 26*** and ***Figure 27***.

Figure 26: Subscale Test Flight Launch

Figure 27: Subscale Flight Recovery

The Stratologger SL100 was retrieved post-launch with the data shown in ***Figure 28***. From this data, an apogee altitude of 2398 feet was obtained in a little over 12 seconds with a maximum velocity of roughly 600 feet per second. Drogue parachute deployment occurred at 13.05 seconds after a 1 second apogee delay. Main parachute deployment occurred at a preset altitude of 700 feet 51.05 seconds after launch which allowed the vehicle to land safely and softly after a total flight time of 81.50 seconds.

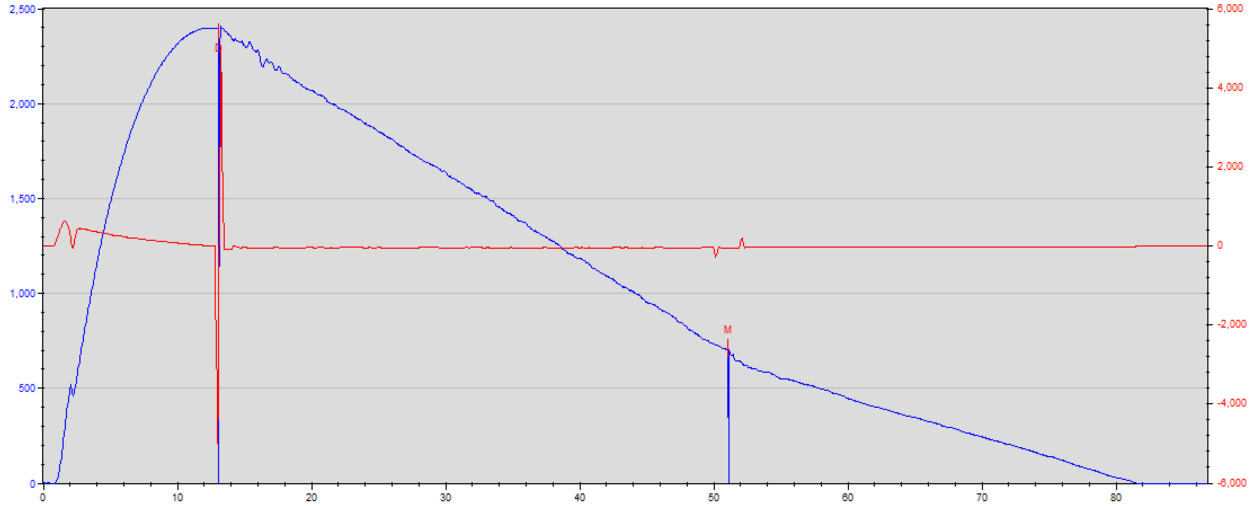

Figure 28: Subscale Recovered Test Flight Stratologger Data

3.2.2. Predicted flight model data comparison

The subscale vehicle was designed using Openrocket which produced flight simulations of a vehicle 68 inches long with a 4 in diameter that weighed 70.3 ounces. For the simulation, an I285R-0 motor was used. Standard atmospheric conditions were applied with an average wind of 5mph. The following are the predicted flight characteristics from the simulation: apogee at 2280 feet, maximum velocity of 577 feet per second, maximum acceleration of 590 feet per second squared, time to apogee of 10.7 seconds, and total flight time of 93.5 seconds. These values are illustrated in ***Figure 29***.

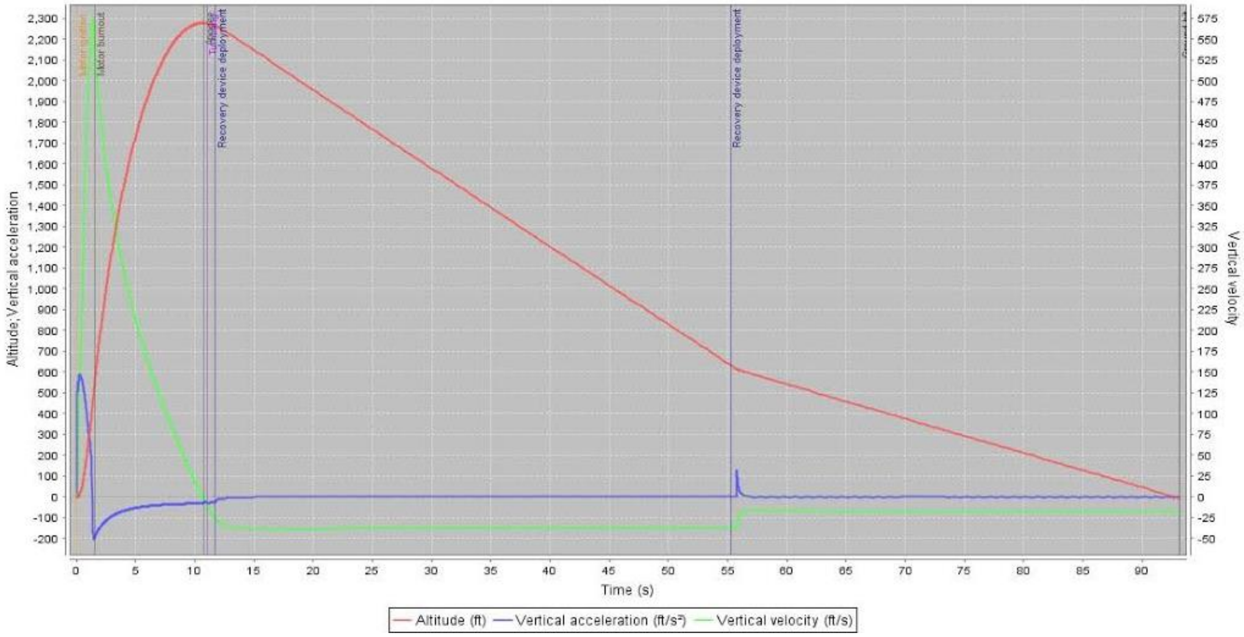

Figure 29: OpenRocket Subscale Flight Simulation

Comparison of flight model data to recorded data showed very similar numbers. Actual apogee was overshot by 118 feet. This was exactly what the design hoped to accomplish if there was any deviation from targeted altitude since having an overshoot is more beneficial in that weight can easily be added to bring apogee down and is the most likely to occur as a result of the manufacturing process. Predicted velocity closely matched recorded values with an undershoot of roughly 25 feet per second. Time to apogee and drogue parachute deployment were also nearly exact matches. Both time to apogee values fell in between the 11–12 second range with drogue parachute deployment in between the 12–13 second range. Actual and calculated main parachute deployment times were a close match as well with a deviation of roughly 4 seconds. The biggest deviation occurred in total flight time with the predicted total flight time being an overshoot of roughly 14 seconds. This shorter flight time is most likely the result of environmental factors such as downdrafts or warm and less dense air that would affect the drag characteristics of the parachute most during the descent phase.

3.2.3. Subscale flight data's impact on full-scale design

Subscale flight test data confirmed most design aspects for the full-scale vehicle and also provided evidence of the need to alter other aspects of the design. The first launch of the subscale did not prove to be as successful as the second and showed that there were some errors with the avionics package which caused the drogue and main parachute black powder charges to fail. The altimeters were retrieved for a data analysis through PerfectFlyte Data Cap along with an inspection of all wiring and power supply sources. All wiring was determined to be correctly assembled with no damage to the wiring itself. However, when the altimeter data was retrieved, an error was observed in the voltage supply. As shown in ***Figure 30***, launch fluctuations in voltage started to occur immediately after launch. This led to the conclusion that faulty batteries were used.

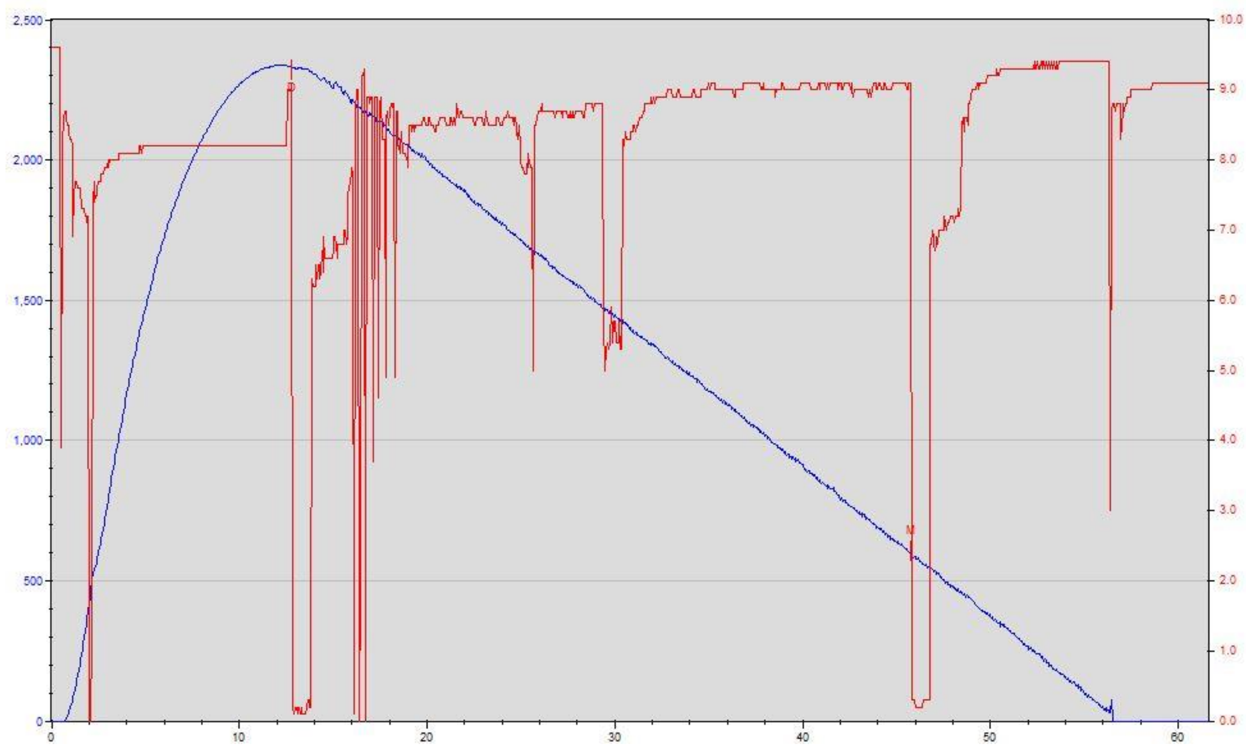

Figure 30: First Subscale Flight SL100 Voltage Readings

For the second launch of the subscale rocket, the 22 gage wiring that was used in the original avionics package was replaced with 18 gage wiring in combination with fresh batteries. The second flight proved to be a complete success as previously discussed. This experience yielded a unanimous decision to construct the full scale model with 18 gage wiring and new batteries for every flight.

Based on the comparison previously discussed between predicted and actual flight data, the full-scale vehicle will be constructed with the same methods as the subscale. All structural components of the vehicle maintained integrity throughout the launch, ascent, drogue and main events, as well as descent and landing. With the use of a larger parachute to accommodate for a higher vehicular weight, the vehicles kinetic energy at landing will remain within acceptable limits to help avoid impact damage.

Subscale construction was completed using a SolidWorks model as a basis for design layout. From the model, dimensions were provided and were transferred onto the manufacturing materials. Using a pencil, several markings were made along the body tube to identify where cuts were to be made, shear pins to be inserted, locations of avionics bays, etc. This helped to make a faster and more accurate manufacturing process.

3.3. Recovery Subsystem

3.3.1. Parachutes, harnesses, bulkheads, and attachment hardware

The parachutes used for the main deployments will be 48 and 36 inch Fruity Chutes elliptical parachutes. An 18 inch Fruity Chutes elliptical parachute will be used as the drogue parachute. These parachutes have been purchased from Apogee Components.

- **C_d:** The C_d for all three parachutes ranges from 1.5 – 1.6.

Material:

- 48 inch
  1.1 ounce Ripstop, 400 pound braided nylon shroud lines with a 5/8 inch nylon bundle attached to a 1500 pound swivel.
- 36 inch
  1.1 ounce Ripstop, 400 pound braided nylon shroud lines with a ½ inch nylon bridle attached to a 1000 pound swivel.
- 18 inch
  1.1 ounce Ripstop, 330 pound braided nylon shroud lines with a 3/8 inch nylon bridle attached to a 1000 pound swivel.

Packing Volume:

- 48 inch - 37.2 inches cubed
- 36 inch - 21.2 inches cubed
- 18 inch – 4.6 inches cubed

2 inch U-bolts purchased from Lowe’s Home Improvement will be used as attachment hardware. Two, collinear, equally-sized holes will be drilled into the bulkheads at equal distances from the U-bolt’s center point of arc along the bulkhead’s centerline. U-bolts will then be inserted and tightly secured with a ratchet or wrench.

3.3.2. Electrical components system to safely recover the launch vehicle

Altimeters to be used will consist of a Stratologger SL100 and an Entacore AIM 3.0. These will be powered by two 9V batteries. For each of the altimeters, a battery snap will be connected to the power terminals on the altimeters and attached to the battery. For power activation, an electrical switch will be wired using 18 gage wire to connect to the altimeters switch terminals. The switch will be mounted such that the mechanical button that is pressed to activate power, is protruding to the outside of the vehicle. The Stratologger SL100 altimeter's main and drogue terminals will each be wired to a 2x2 terminal block that is attached to an upper and lower bulkhead corresponding to a main and drogue charge. This terminal block will be epoxied to the bulkhead and the wires will remain connected to the altimeter. The opposing side of the terminal blocks will be the connecting point for the e-matches. Once the charge has been assembled and placed in the appropriate charge cap, the e-match wiring will be connected to the terminal block and secured.

A Big Red Bee (BRB) GPS Unit will be attached to each separating section of the rocket (2 total). We will be able to view the live GPS coordinates of each independently falling section. The power unit for each BRB is self-contained and will broadcast information for at least 3 hours before losing power.

3.3.3. Drawings/sketches, block diagrams, and electrical schematics

The recovery system utilizes three parachutes, four altimeters, black powder charges, and an Advanced Retention Release Device (AARD). At apogee, a 1.5 foot drogue parachute will deploy. This will separate the middle airframe and fin section from the upper airframe and nosecone. The drogue will be attached to the ARRD in the upper airframe and to a bulkhead in the middle airframe. This event is illustrated in ***Figure 31***.

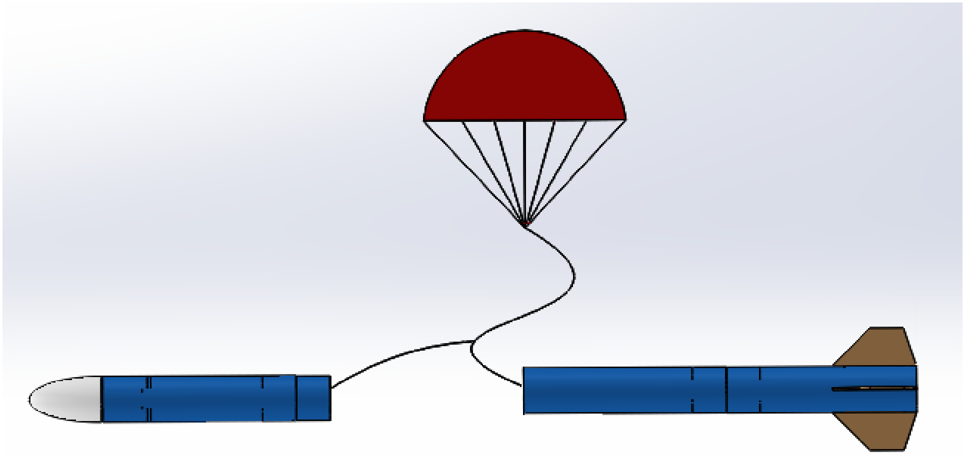

Figure 31: Drogue Parachute Event

At 1100 feet, the ARRD will separate the nosecone and upper airframe from the middle airframe and fin section. Shortly after, at 1000 feet, the sample section and nosecone will separate, releasing a 2.75 foot main parachute. This is event is illustrated in ***Figure 32***.

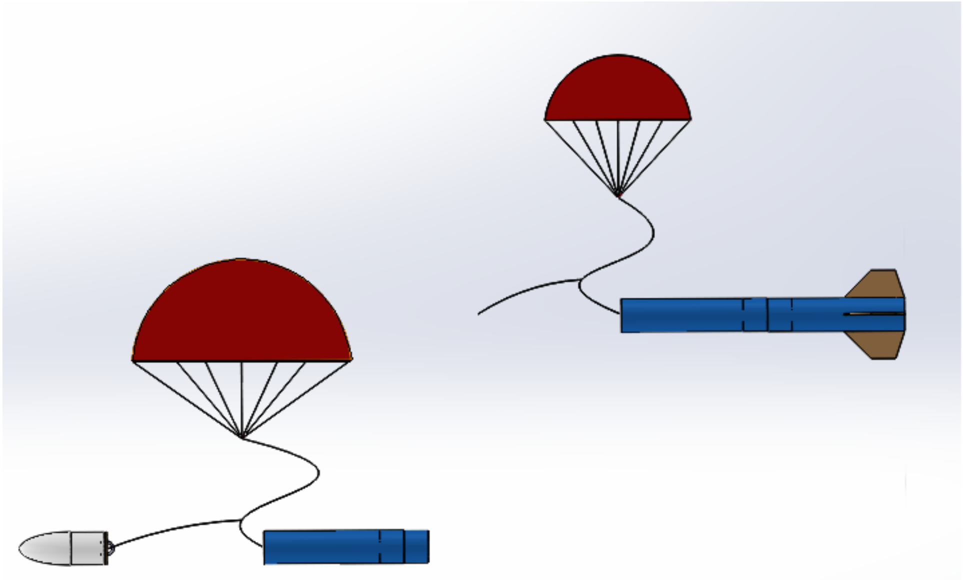

Figure 32: ARRD Release

In order to decrease the drift range, a 3.75 foot main parachute will deploy at 700 feet between the middle airframe and fin section. This event is illustrated in ***Figure 33***.

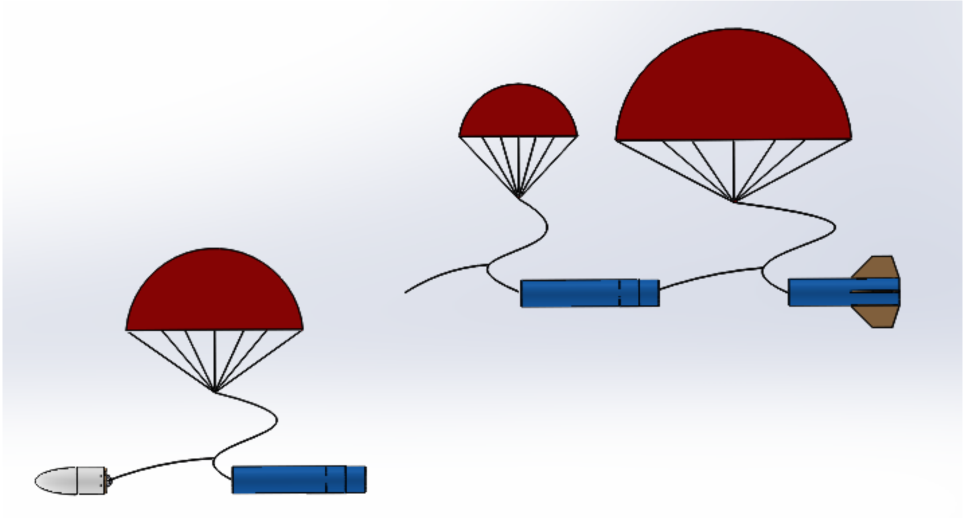

Figure 33: 4 Foot Main Event Parachute

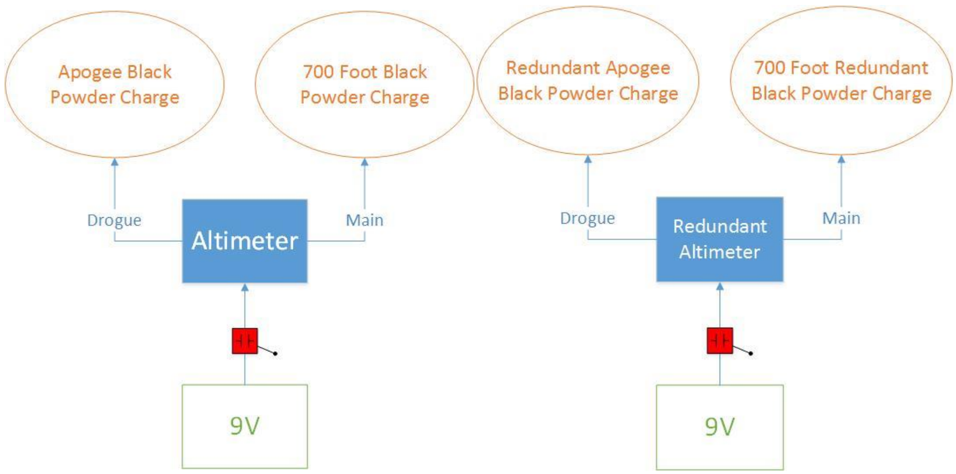

Figure 34: Altimeter Schematics for Fin Section

Figure 34 above shows the electrical schematic for the fin section of the vehicle. The avionics in this section will consist of two altimeters, one as the primary and another for redundancy. Each altimeter is hooked up to its own 9 Volt power supply and two black powder charges. The first black powder charge, set to deploy the drogue parachute, is hooked up to the drogue port on the altimeter. The second charge is set to go off at 700 feet to deploy the main parachute for this section and is hooked up to the main parachute port on the altimeter. As shown the diagram, the redundant altimeter has the same setup, but slightly larger black powder charges.

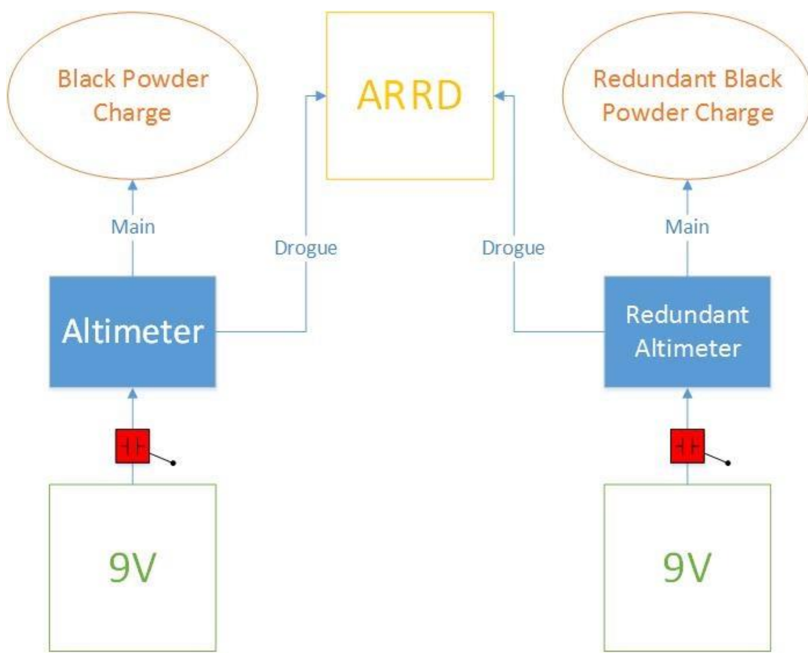

Figure 35: Altimeter Schematic for Nose Section

As shown in ***Figure 35,*** the nosecone section has a similar setup to the fin section. Two altimeters are used, with one set up for redundancy, and are both hooked up to separate 9 Volt power supplies. The main altimeter has its main parachute port hooked up to a black powder charge, set to go off at 1000 feet. The backup altimeter has the same setup, but with a slightly larger black powder charge set to go off at 900 feet. Furthermore, each altimeter has its drogue port hooked up to the ARRD, which is set to go off at 1100 feet.

3.3.4. Kinetic energy

A MATLAB program was written to determine the parachute sizes required to keep the velocity and kinetic energy to acceptable levels. The MATLAB program assumed the drag coefficient of the parachutes to be 1.75. The density was assumed to be standard sea level and was set at 0.002377 slugs per feet cubed. The velocity was calculated using the equation:

$$V = \sqrt{\frac{2D}{C_D \rho A}}$$

Where D equals the weight of the vehicle, C_D equals the drag coefficient, rho represents the density, and A gives the area of the parachute. The kinetic energy KE was found using:

$$KE = 0.5mV^2$$

Where m is the mass of the rocket, and V is the velocity found above. These results were then plotted against different parachute sizes to determine the ideal size required to keep the vehicle reusable.

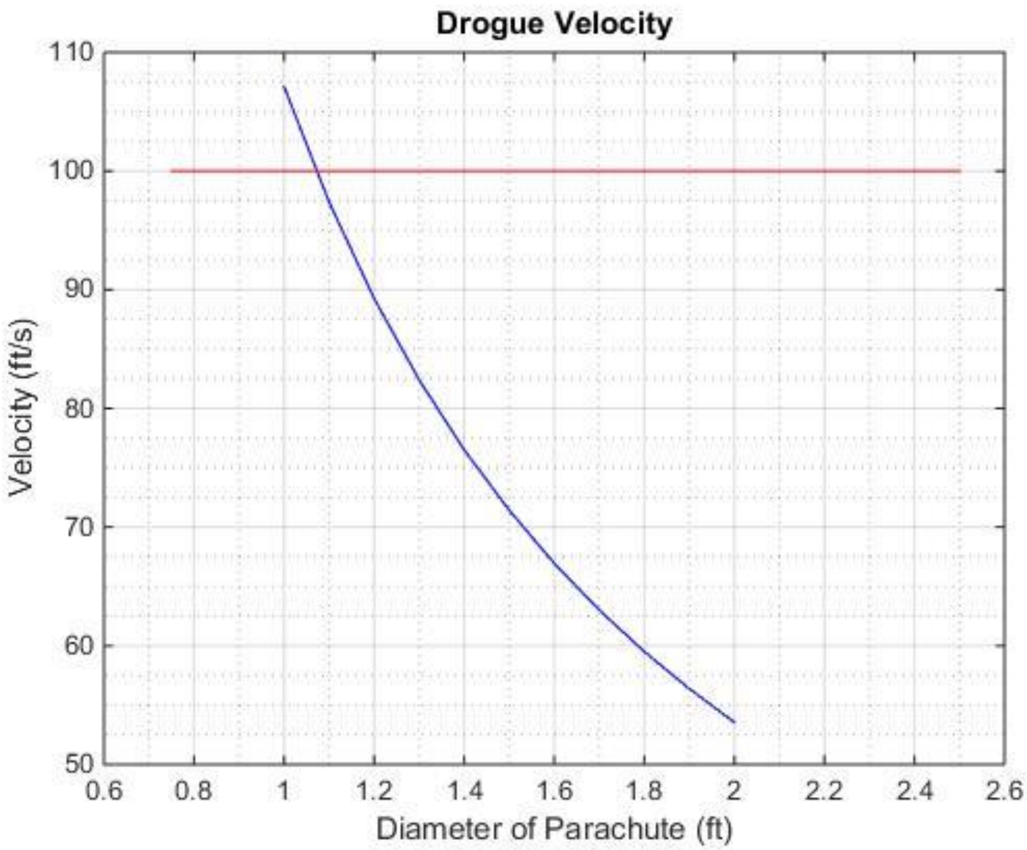

Figure 36: Vehicle Under Drogue Velocity

Under the club mentor's guidance, 100 feet per second was chosen as the maximum velocity the vehicle will fall under drogue. Using that requirement, a 1.5 foot drogue parachute was chosen to deploy at apogee. ***Figure 36*** above shows the parachute diameters required to slow the parachute down to 72 feet per second. The rocket weight, after propellant burn, was used to calculate these values.

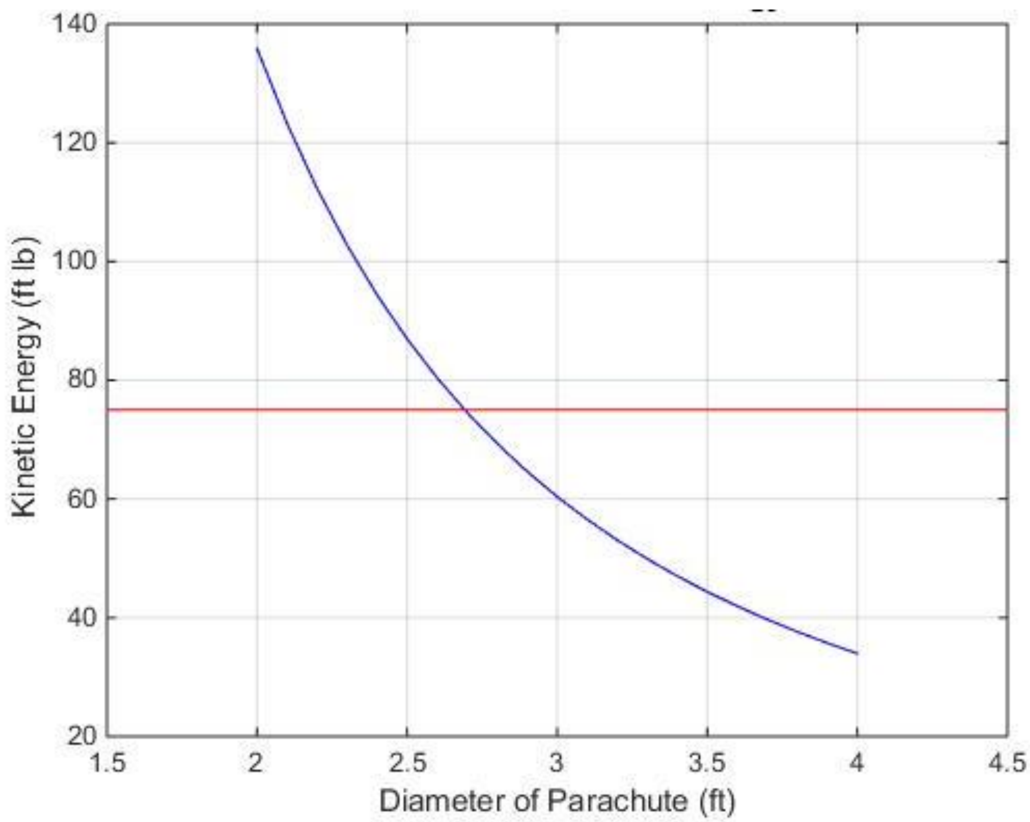

Figure 37: Main Nosecone Kinetic Energy Calculator

At 1000 feet, the main parachute will deploy from the nosecone and payload section of the vehicle. This section must hit the ground with a kinetic energy below 75 foot-pounds. In order to accomplish this, a 3 foot main parachute was chosen, as shown in ***Figure 37*** above. This will slow the nosecone down to 21 feet per second. The rocket weight, determined after propellant burn, was used to calculate these values.

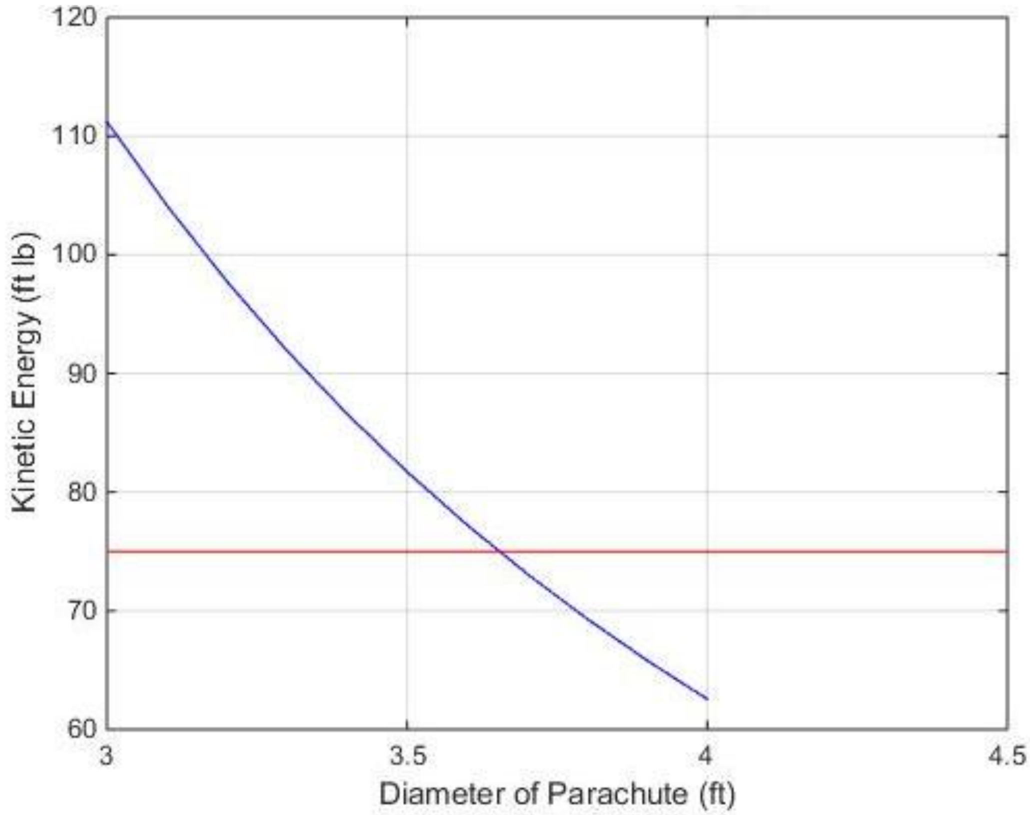

Figure 38: Main Fin Section Kinetic Energy Calculator

Once the fin section reaches 700 feet, the main parachute will come out of that section. This section also has the requirement to land with less than 75 foot-pounds of kinetic energy. Using ***Figure 38*** above, a 4 foot diameter parachute was chosen to allow the fin section to also land safely to allow for reusability. This parachute will slow the fin section down to 24 feet per second. The rocket weight, determined after propellant burn, was used to calculate these values.

3.3.5. Test results

Ejection tests were performed to verify complete separation would occur in flight for the subscale vehicle. Using the following equation provided in the Stratologger SL100 manual,

$$grams\ of\ black\ powder = \pi r^2 h * 0.007$$

where r is radius of the compartment and h is the height of the compartment. The equation shows that the drogue parachute compartment will require 0.83 grams and the main parachute compartment will require 1.28 grams of black powder. Testing would prove that 0.70 and 1.15 grams of black powder for the drogue and main compartments respectively were sufficient for compartment separation. The difference in the actual and calculated values came from starting at a lower amount of black powder and increasing the amount by small increments until separation occurred. This was done to prevent over-pressurizing the compartment and risk to the vehicle's structures. Initial amounts of black powder began at 0.60 and 1.00 grams respectively before stepping up by 0.05 gram increments. At the 0.70 and 1.15 gram amounts, adequate separation occurred and it was deemed that further testing was not needed as the ejection may become too violent.

Release tests were run to ensure a safe and guaranteed separation of the ARRD during descent. Tests were conducted to determining the amount of black powder necessary to cause successful separation. Tests were conducted by mounting the device to a stationary test stand and filling the explosive cavity with varied amounts of black powder. Differing weights; 5lbs, 10lbs and 15lbs, were hung from the eye-bolt to determine if the amount of black powder needed for separation was proportional to the hanging weight from the device. Tests began with 0.1 grams of black powder for each of the weights to determine if more was needed for successful separation of the ARRD with plans to increase black powder by increments of 0.1 grams until separation. Successful separation occurred with 0.1 grams of black powder for each of the tested weights, rendering tests with more powder unnecessary and demonstrating that only 0.1 grams of black powder was necessary to separate the ARRD at any weight.

3.3.6. Safety and failure analysis

For a safe and successful launch, the vehicle and all its components must reach ground-level intact and without causing harm to any individuals or the environment. To ensure that no individuals are harmed, several factors must be accounted for. When preparing the black powder charges for placement, a maximum of two individuals will handle the vehicle and charges at any time. A third individual will read from a checklist to ensure that steps are taken in the correct order and verify when actions are complete. This process will be important make sure that power is not supplied to the altimeters during setup as to not accidentally detonate a charge prematurely. This will be accomplished by keeping the switches in the off position and only connecting the e-matches to their terminals as the last item before the vehicle is finally assembled.

Once the vehicle has been launched, every team member will be required to watch the flight path of the vehicle to the best of their abilities. If the vehicle doesn't leave a perceivable smoke trail or visual contact with the vehicle itself is lost, it must be verbally acknowledged for all present to hear. Continual scanning of the sky will be conducted as to regain contact with the flight vehicle. If the vehicle maintains visual contact throughout the whole flight, or visual contact is regained, its location must be made apparent to all present and the vehicles flight path will be followed to the ground.

In the event that the recovery system doesn't work as designed, failure analysis will be conducted to determine the cause. Initial failure analysis will be conducted at the launch site once the vehicles landing site has been reached and the power has been properly disabled. The initial analysis will be an examination of parachutes. This includes their condition (intact, damaged, tangled etc.), the state of deployment (whether they fully ejected from their compartment, snagged another piece of the vehicle), and whether they remained connected to the vehicle (shock cord condition). The next item to exam will be the connecting harnesses and attachment hardware. Quick links, U-bolts, and bulkheads will be examined to visually confirm whether their structural integrity was compromised during the flight in some way. The next item will be the black powder charges which will be visually analyzed to determine whether they were detonated or remained inactive during the flight. Wiring connections will then be checked to see if a possible disconnection occurred due to inflight forces or other variables. Lastly, a two-part examination of flight data will be analyzed. Once the charges have been properly discarded, power will be resupplied to the altimeters. At the initial startup of the altimeters, audible beeps will be emitted and counted to determine the flight data of the last flight recorded. This will be supplemented by a more in-depth evaluation by connection to a program that reveals altitude, velocity, acceleration, and voltage supply to the altimeters during the previous flight.

3.4. Mission Performance Predictions

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

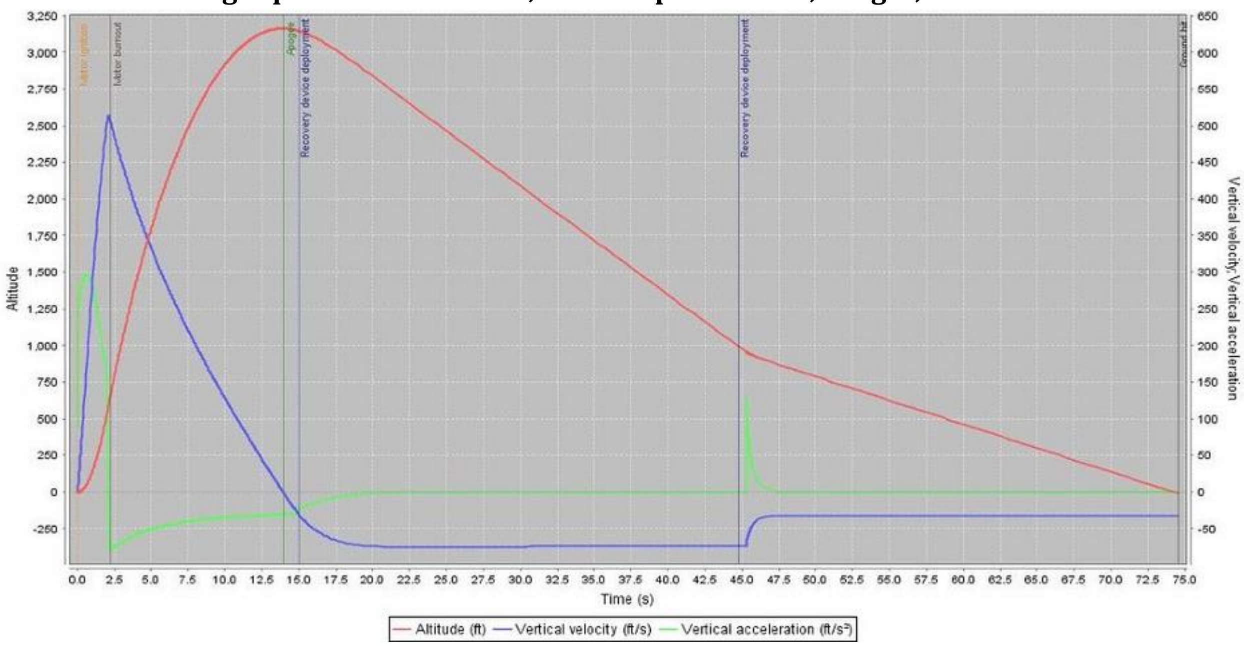

Figure 39: OpenRocket Flight Simulation of Full-Scale

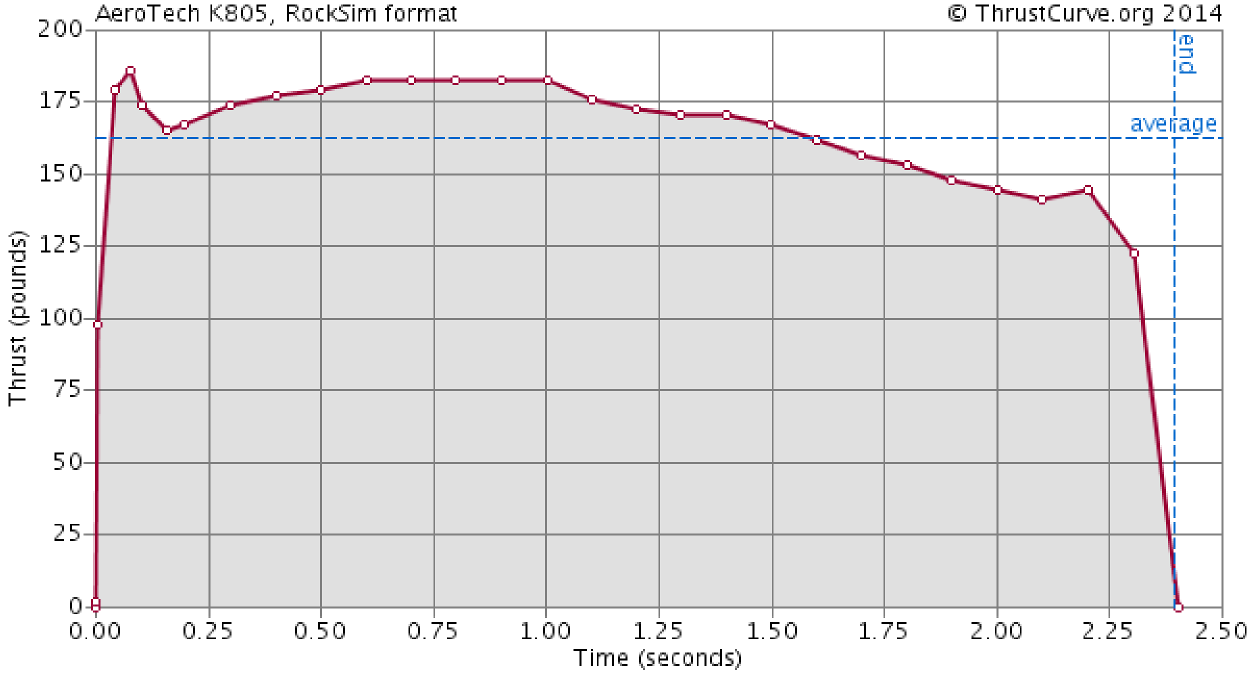

Figure 40: AeroTech K805G Thrust Curve

3.4.2. Stability margin and CP/CG

From OpenRocket software, predetermined values of the CG and CP locations were 47.04 and 56.73 inches. This makes for a stability margin of 1.76 caliber at takeoff which is a sufficient level of stability. As the motor burns out and the CG is moved further forward, the stability will increase even more. The overall rocket with CG and CP locations is represented in ***Figure 41***.

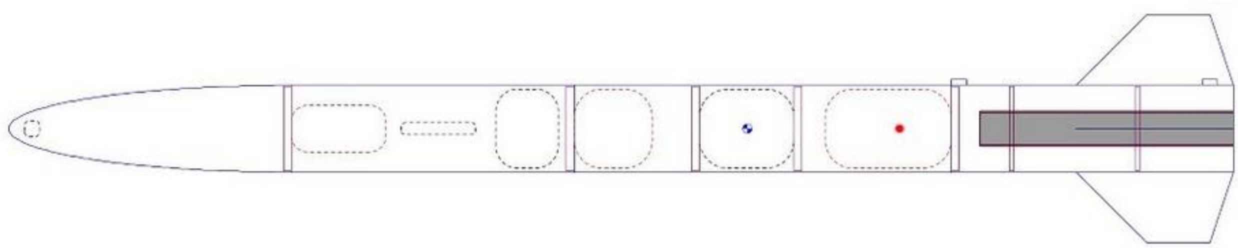

Figure 41: OpenRocket Picture of Full-Scale Model

3.5. AGSE/Payload Integration

3.5.1. Integration plan

Inserting the sample into the vehicle and ensuring the vehicle is ready to launch is a critical starting task for the system. The system begins 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 size in the image to the location of the sample. The robotic arm will take this position and move to 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 rocket. The arm will then close the door and lock it into place. This progression can be seen in ***Table 3*** below.

Table 3: AGSE Progression

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

Main Task	Step
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

3.5.2. Compatibility of elements

In order for the design to be a success, the components must be compatible. For example, the arm requires about 10.4 Volts to run. The presence of the 12 Volt battery ensures that there will be enough power for the arm. Moreover, in order to control the arm and process the images, the BeagleBone requires the programs to be in C. The autocoder in MATLAB allows the current MATLAB scripts to be coded into C for the BeagleBone, making sure that the programs will be compatible with the microprocessor. The 37 Volt power supply is sufficient for the stepper motors used to raise the rocket and insert the igniter; the USB HUB ensures that everything will be able to plug into the BeagleBone. Since the AGSE will be constructed out of aluminum railing, its size and shape can be tailored to fit all of the subsystems and the vehicle. Lastly, the fact that many of the components will be manufactured by the team (such as the gears used to raise the vehicle) will make sure that the elements of the design are compatible.

Simplicity of integration procedure: One way in which the AGSE will be integrated into the vehicle and overall mission is the gearing system used to raise the vehicle. A gearing system is simpler than a complicated linear actuator system or electrical program with complicated motors and circuits. The current design only requires a single motor to raise the rocket. Furthermore, the arm will be used to insert the sample into the vehicle and to close the door to the sample compartment. Utilizing the arm for multiple tasks limits the overall complexity of the design. Moreover, having the arm close the door eliminates the need for an entirely separate system or the necessity of relying on gravity. Each of these subsystems will be placed on the AGSE platform, making sure that they are in the proper positions. As a result, the procedure for implementing the AGSE is simple, yet effective.

3.5.3. Changes to AGSE/payload resulting from the subscale test

Because the subscale launched almost perfectly straight, the subscale showed that the mass distribution and fin design were successful. Since the subscale did not have the added mass of the payload, the team has to make sure to keep a symmetric mass distribution in the full-scale, as it was with the subscale. This may require shifting the components of the payload compartment slightly or adding counterweights to make an even mass distribution. For example, weight will most likely need to be added opposite the side of the door due to the weight of the hinge.

Because the AGSE was not used for the subscale, the subscale test did not add insight to any crucial changes that need to be made to the AGSE design. When the subscale was launched, however, the launch rail had to be exchanged as there was too much friction on the one set up on the pad. Therefore, the team must ensure that the rail buttons on the full-scale can smoothly glide along the launch rail on the AGSE.

3.6. Launch concerns and operations procedures

3.6.1. Final assembly and launch procedures

3.6.1.1. Recovery preparation

- Retrieve nosecone
- Ensure that screws that attach bulkhead to nosecone are tightened
- Retrieve upper mid-section
- Carefully pull avionics bay from upper mid-section making sure not to pull out wiring
- Check that altimeter switches are in the off position
- Insert two fresh batteries into each of the battery trays
- Connect battery snaps on each battery
- Insert avionics sled back into avionics bay making sure no wires are crossed and the sled is oriented with the sled's nuts facing the correctly marked position
- Run avionics bay threaded rods through the lower bulkhead and attach nuts on each; finger tight
- Tighten nuts on both ends of avionics bay with #" ratchet / #" socket and #" ratchet / #" socket
- Attach e-match wiring to terminal block 1 and ensure the wires are secured
- Insert primary main black powder charge into cap 1 on top of upper mid-section avionics bay
- Insert e-match into cap 1
- Insert wadding into cap 1 and cover cap 1 with blue painter's tape
- Repeat steps #-# with redundant main black powder charge into cap 2 on top of upper mid-section avionics bay in terminal block 2
- Assemble ARRD
    - Unscrew base then push piston up to remove toggle
    - With screw driver push piston out; remove the ball bearings careful not to dislodge spring. Remove cartridge from base
    - Place ball bearings in red anodized body

  - Place shackle and toggle assembly into red body; push piston into body up to the end of the threads
  - Place black powder into cartridge; fill cavity. Place 2 e-matches through hole
  - Place blue painter's tape over the end of the cartridge to retain black powder holding base and body; screw together by turning red body until firmly seated
  - Grasp body and base assembly and firmly pull toggle to ensure correct fit
- Insert e-matches into terminal blocks 3 and 4
- Insert upper mid-section avionics bay into upper mid-section
- Remove four screws from pill bottle and screw into four screw holes with Phillips head screwdriver
- Retrieve lower mid-section
- Carefully pull lower mid-section avionics bay from lower mid-section making sure not to pull out wiring
- Check that altimeter switches are in the off position
- Insert two fresh batteries into each of the battery trays
- Connect battery snaps on each battery
- Insert avionics sled back into avionics sled back into avionics bay making sure no wires are crossed and the sled is oriented with the sled's nuts facing the correctly marked position
- Run avionics bay threaded rods through the lower bulkhead and attach nuts on each; finger tight
- Tighten nuts on both ends of avionics bay with #" ratchet / #" socket and #" ratchet / #" socket
- Attach e-match wiring to terminal block 5 and ensure the wires are secured
- Insert primary main black powder charge into cap 3 on bottom of lower mid-section bottom bulkhead
- Insert e-match into cap 3
- Insert wadding into cap 3 and cover cap 3 with blue painter's tape
- Repeat steps #-# with redundant main lack powder charge into cap 6 on bottom of lower mid-section bottom bulkhead in terminal block 6
- Attach e-match wiring to terminal block 7 and ensure the wires are secured
- Insert primary drogue black powder charge into cap 5 on top of upper bulkhead of lower mid-section
- Insert e-match into cap 5
- Insert wadding into cap 5 and cover cap 5 with blue painter's tape
- Repeat steps #-# with redundant drogue black powder charge into cap 5 on top of upper bulkhead of lower mid-section
- Slide avionics bay into lower mid-section making sure that arrows are aligned
- Remove four screws from pill bottle and screw into the four screw holes with Phillips head screwdriver

- Retrieve the 36” main parachute and the shock chord for the nosecone and upper mid-section
- Remove the rubber band from the parachute
- Attach quick link with no blue tape on shock chord to the bottom of the nosecone
- Have another person verify that the quick link is secure
- Insert Kevlar sheet protector and parachute into upper mid-section
- Attach quick link with blue tape to the upper mid-section
- Have another person verify that the quick link is secure
- Insert nosecone and parachute assembly into the upper mid-section making sure that the shear pins are aligned with v’s
- Install four (4) shear pins into the upper mid-section to connect nosecone to the upper mid-section
- Retrieve the 18” drogue parachute and shock chord for the upper and lower mid-sections
- Remove the rubber band from the parachute
- Attach quick link with blue tape to upper bulkhead of lower mid-section
- Have another person verify that the quick link is secure
- Insert Kevlar sheet protector and parachute into lower mid-section
- Attach quick link with blue tape to lower bulkhead of upper mid-section
- Have another person verify that the quick link is secure
- Insert upper mid-section into lower mid-section making sure the shear pins are aligned with v’s
- Install four (4) shear pins into the lower mid-section to connect upper and lower mid-sections
- Retrieve 48” main parachute and the shock chord for the fin can section
- Remove rubber band from the parachute
- Attach quick link with no blue tape to bottom bulkhead of lower mid-section
- Have another person verify that the quick link is secure
- Insert Kevlar sheet protector and parachute into lower mid-section
- Attach quick link with blue tape to bulkhead in fin can section
- Have another person verify that the quick link is secure
- Insert mid-section assembly into fin can section making sure the shear pins are aligned with v’s
- Install four (4) shear pins into fin can section to connect mid-section to fin can section
- Check CG location and verify static margin after inserting motor

3.6.1.2. Motor preparation

Forward Closure Assembly

- Apply a light coat of Synco Super Lube or other grease to all threads and all o-rings.
- Chamfer both inner edges of the delay insulator with fingernail

- Assemble the RMS-Plus delay element, delay insulator, aft delay spacer and delay o-ring
- Insert the forward delay spacer into the delay cavity until it is seated against the forward end of the cavity
- Apply a light film of grease to the inner circumference of the delay cavity (but not the forward end of the cavity)
- Insert the delay charge assembly into the delay cavity, o-ring end first, until it is seated against the forward delay spacer.

Case Assembly

- Install the propellant grains into the liner
- Push the liner assembly into the motor case until it is approximately equally recessed from both ends of the case
- Place the forward insulator (1" O.D. fiber washer) into one end of the case, seated against the liner assembly
- Place the greased forward (3/32" thick X 1" O.D.) o-ring into the forward insulator end of the case until it is seated against the forward insulator
- With the motor case held in a horizontal position, thread the previously assembled forward closure assembly into the forward end of the motor case by hand until it is seated against the case
- Place the aft insulator (1" O.D. fiber washer) into the aft (nozzle) end of the motor case, seated against the liner assembly
- Insert the larger end of the nozzle into the aft end of the case and against the aft insulator
- Place the greased aft (1/16" thick X 1" O.D.) o-ring into the aft end of the motor case, seated in the groove between the nozzle and the case
- Thread the aft (gold) closure into the aft end of the motor case by hand until it is seated against the case

3.6.1.3. Setup on launcher

- Carry assembled rocket to launch pad
- Slide rocket launch lugs onto 15-15 launch rail
- Erect rocket to vertical position and verify its angle into wind and away from spectators
- Flip red switch on upper mid-section and verify continuity
- Flip black switch on upper mid-section and verify continuity
- Flip red switch on lower mid-section and verify continuity
- Flip black switch on lower mid-section and verify continuity

3.6.1.4. Igniter installation

- For full scale test launch, a certified individual will insert igniter
- During flight in Huntsville, igniter will be inserted using the automatic insertion system

3.6.1.5. Troubleshooting

- Check to ensure that correct launch pad is live

- Check for continuity between control booth and launch pad
- Check igniter is fully installed
- Check connections on igniter
    - Check connections are not in contact with each other
    - Ensure igniter leads are securely wrapped around alligator clips
- Check that altimeters are turned on
- Check for correct beeps from altimeters

3.6.1.6. Post-flight inspection

- Ensure that all black powder charges have blown
- Turn off all four (4) altimeters
- Inspect vehicle for cracks or other signs of physical damage
- Inspect parachutes for tears
- Inspect parachute chords for fraying and tangling
- Inspect shock chords for fraying
- Ensure all non-consumable pieces are accounted for (hardware, ARRD parts)
- Ensure rocket is ready to launch again in the same day

3.7. Safety and Environment

3.7.1. Failure Modes and Analysis

Refer to ***Appendix 2*** for failure modes and their integration.

3.7.2. Personnel Hazards

When working in the laboratory there are many materials that can be harmful if misused or used without proper PPE. When working with any of these possibly harmful materials, members of the team follow precautions listed on the various Material Safety Data Sheets such as wearing gloves when handling hazardous materials and working in a ventilated room when sanding or using any spray materials to prevent inhalation. Team members are also instructed on how to use power tools and are closely observed while learning and becoming proficient. Team members always make sure to handle any explosive materials away from any open flame or anything that could possibly ignite said materials. ***Table 4*** and ***Table 5*** below contain the personnel safety matrices.

Table 4: Building 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	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

	operate smoothly and in a manner within operating limits.	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 taking it out to the launch site. The black powder is stored separately in a safe environment away from potential ignition sources.	Black powder is one of the more dangerous substances handled by the club, so extreme caution 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	By ensuring all members are familiar with safe procedures

	location. Team members are instructed to ensure blades are secured tightly and to cut away from their body.	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.

Table 5: Launch 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 speed, precipitation, and	Proper weather forecast monitoring and monitoring the weather at the launch site will

	temperature are within safe limits of operation.	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.

Refer to ***Appendix 3*** for Material Safety Data Sheets.

3.7.3. Environmental concerns

3.7.3.1. Environmental Impact on the Rocket

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. With precipitation normally comes cloud cover that has the potential to obscure the rocket at higher altitudes creating a safety concern. For the recovery of the vehicle, the environmental risk factors include trees, power lines, and cars. 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.

3.7.3.2. Rocket's Impact on the Environment

The rocket has the potential to impact the environment in multiple ways. 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. 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. 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.

4. AGSE/Payload Criteria

4.1. Testing and Design of AGSE/Payload Equipment

4.1.1.1. Drawings and specifications

In ***Figure 42*** below, the AGSE/Full-Scale Vehicle combination is shown. The important components are labeled. The AGSE base, legs, and launch rail pivot supports will be built from 1.5 inch square t-slot aluminum framing. Using t-slot aluminum greatly reduces the component weight as compared to steel and will reduce manufacturing complexity (no welding required). The chosen launch rail is extruded 6105-T5 aluminum from Strongwell Corporation with a 1.5x1.5 inch t-slot cross-section and 96 inch length. For the given rocket weight and rail length, the bending moment at the rail hinge was determined to be approximately 120 ft-lb. Using the moment of inertia provided by the manufacturer, the maximum bending moment in the launch rail was determined to be 4110 psi. The yield stress for 6105-T5 aluminum given by the manufacturer is 35,000 psi, so the expected loading is well within the limit. The vehicle's rail buttons will be matched to fit the launch rail cross-section. The blast plate, mounted to the launch rail, will be water-jetted from a piece of thin steel plate. Steel was chosen over aluminum for the blast plate due to the high heat exposure during launch.

To support the launch rail, the long support arm with travel rearward over a series of ratcheting stops. The support arm will be made from t-slot aluminum framing due to the relatively low loading requirements. The ratcheting support, to be made from two thin steel plates for strength concerns, will be spaced two inches apart. When horizontal, the launch rail will be supported by an extension on the bottom side of the support arm. Between 0 and 30 degrees, the support arm's circular end will not be able to engage on any ratcheting stops. Therefore, an additional extension was added to support the launch rail at 15 degrees in the event of power loss to the planetary gearbox stepper motor. As the launch rail rotates to 85 degrees, the support arm will lock into the final ratcheting stop. The robotic arm, addressed below, will be placed in the front left corner of the AGSE adjacent to the sample compartment door. The launch rail planetary stepper motor will be mounted inside an aluminum blast shield along with both stepper controllers.

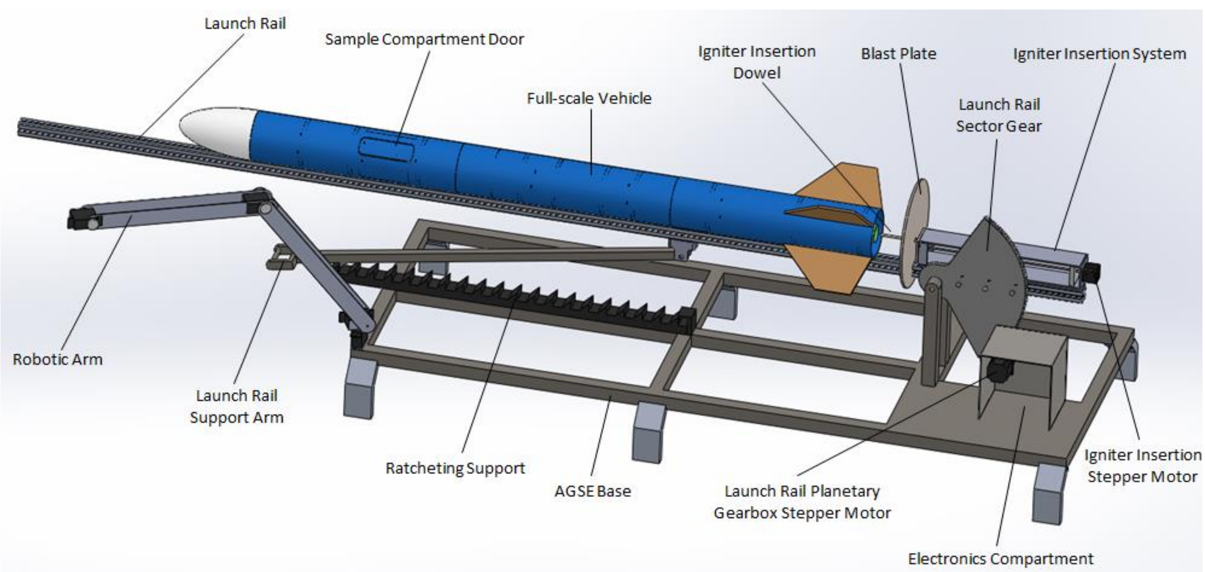

Figure 42: AGSE and Full-Scale Vehicle

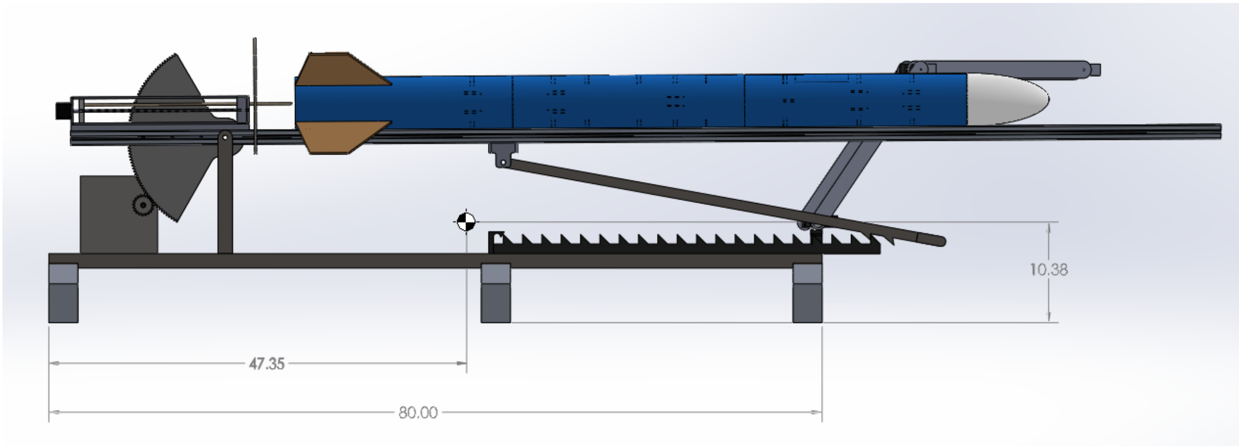

Figure 43: AGSE and Vehicle C.G. Location (Horizontal)

Figure 43 above and ***Figure 44*** below show the C.G. locations for the horizontal and raised orientations. In the horizontal position, the C.G. is 7.35 inches off center front to back, 10.38 inches above the ground and 2.25 inches to the left of the centerline. In the raised position, the C.G. is only 0.73 inches off center front to back and 16.41 inches above the ground. The low, centralized location of the C.G. will ensure that the AGSE remains stable in both the horizontal and raised configurations. Also, ***Table 6*** shows the AGSE component weights and total AGSE weight of 201 lb.

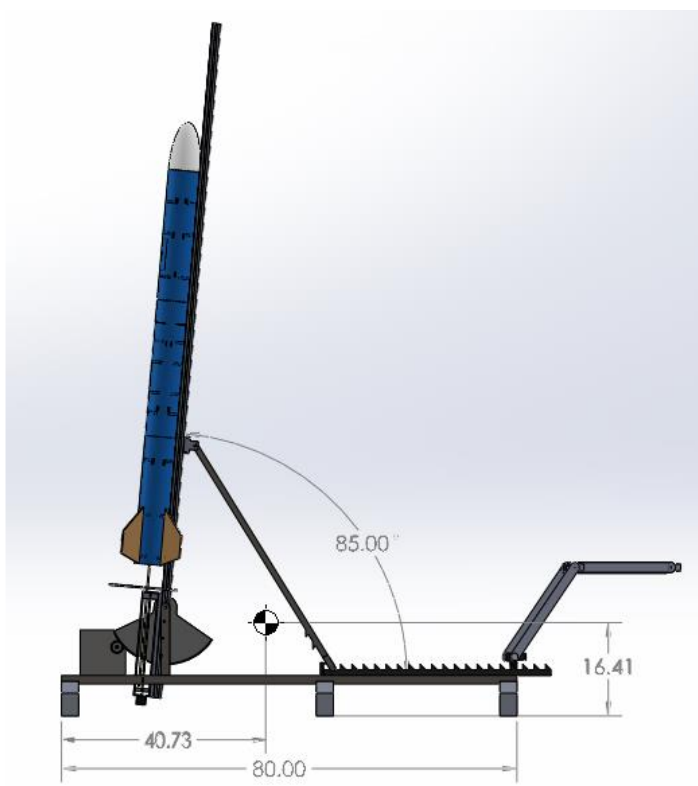

Figure 44: AGSE and Full-Scale Vehicle C.G. Location (Raised)

Table 6: AGSE Component Weights

Element	Weight (lb)
AGSE Base	102.9
Motor Blast Shield	2.2
Launch Gearing Assembly (with motor)	20.1
Launch Rail Pivot Supports	5.46
Launch Rail and Blast Plate	16.03
Ratcheting Steps	29.15
AGSE Base Legs	11.46
Arm Assembly	2.64
Launch Rail Support Arm	4.82
Igniter Insertion System	6.3
Total	201.1

Figure 45: RobotShop M100RAK Robotic Arm

A picture of the RobotShop M100RAK robotic arm during assembly can be seen above in ***Figure 45***. The specifications of the arm are tabulated in ***Table 7***.

Table 7: Robotic Arm Specifications

Property	Value
Degrees of Freedom	6
Max Lifting Capacity	1 lb
Weight	2.64 lb
Shoulder-to-Elbow Distance	9.25 in
Elbow-to-Wrist Distance	14.125 in
Wrist-to-Center of Gripper	5.184 in
Bottom of Base to Shoulder Axis	3.75 in

The arm was chosen because it is a middle-range robotic arm. In other words, the arm is not of the scale of industrial models, but is larger than standard hobby models. Because it is able to lift a maximum weight of about 1 pound at its longest reach of 24 inches, the arm provides sufficient lifting power and reach to accomplish the mission.

Figure 46: Sentech USB 2.0 Camera

For the camera, the Sentech STC-MC36USB-L2.3 Micro CMOS USB 2.0 Camera, as seen above in ***Figure 46*** was selected for its light weight (26 grams), its low image resolution, and its plug and play connectivity. Because the system will be on a BeagleBone Black, the image cannot be extremely pixel dense. A USB 2.0 camera offers a good medium for having enough images to pick out the sample and not too many so that the BeagleBone cannot process the image.

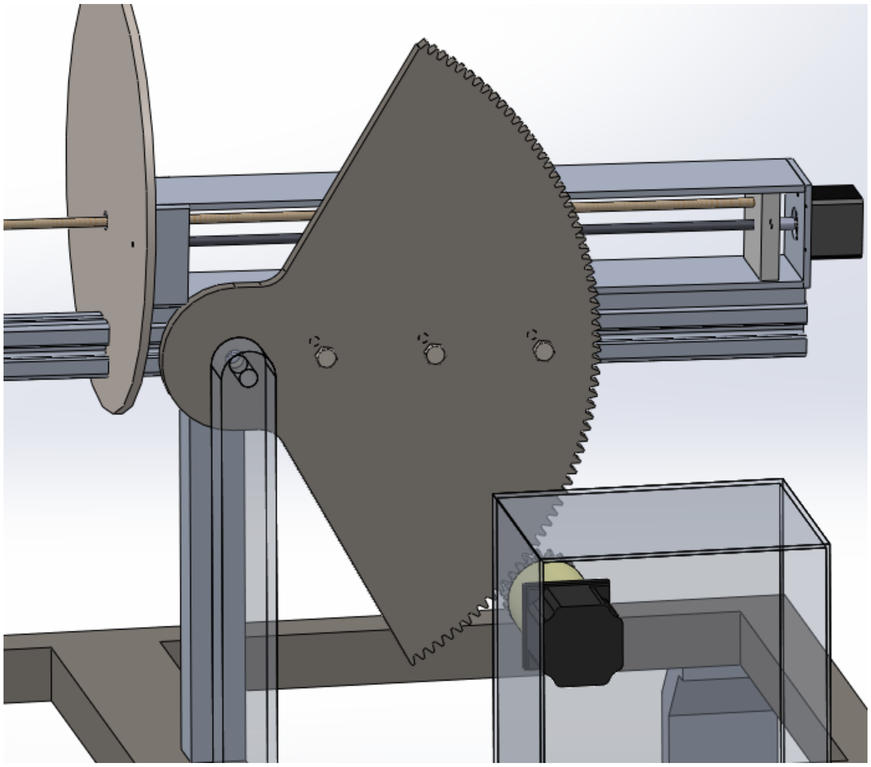

Figure 47: Launch Rail Raising System

The launch rail raising system, consisting of the 10 inch radius launch rail sector gear, 1 inch radius drive gear, and planetary gearbox stepper motor, is shown in ***Figure 47*** above. The sector gear will be mounted to the launch rail rather than the pivot shaft for a number of reasons. First, designing the sector gear to transmit the stepper torque to the launch rail via the pivot shaft would require splines, keyways, or set screws, increasing the manufacturing complexity. In addition, this would put a significant torsional moment (about 120 ft-lb) on the launch rail pivot shaft. Bolting the sector gear directly to the launch rail makes the design simpler and more robust. The sector gear and drive gear will both be water-jetted using rolled steel plate. Steel was chosen over aluminum to reduce wear and ensure these vital components do not fail. The pivot shaft will be 0.5 inch diameter stainless steel to prevent rust build-up that could seize the pivot point.

The planetary gearbox stepper motor was chosen over a regular electric motor for its ability to rotate discrete angular steps. For a pre-determined number of pulses, the stepper motor can be commanded to rotate the sector-shaped gear and launch rail the desired 85 degrees. A picture of the stepper motor to be used and its specifications can be seen below in ***Figure 48*** and ***Table 8*** respectively.

Figure 48: Launch Rail Planetary Gearbox Stepper Motor

Table 8: Launch Rail Raising System Stepper Motor Specifications

Manufacturer Part Number	23HS22-2804S-PG47
Motor Type	Bipolar Stepper
Gearbox Output Step Angle	0.0386 deg.
Gearbox Output Holding Torque	29.5 ft-lb
Gear Ratio	46.656:1
Gearbox Mech. Efficiency	73%
Rated Current/phase	2.8 A
Recommended Voltage	24-48 V

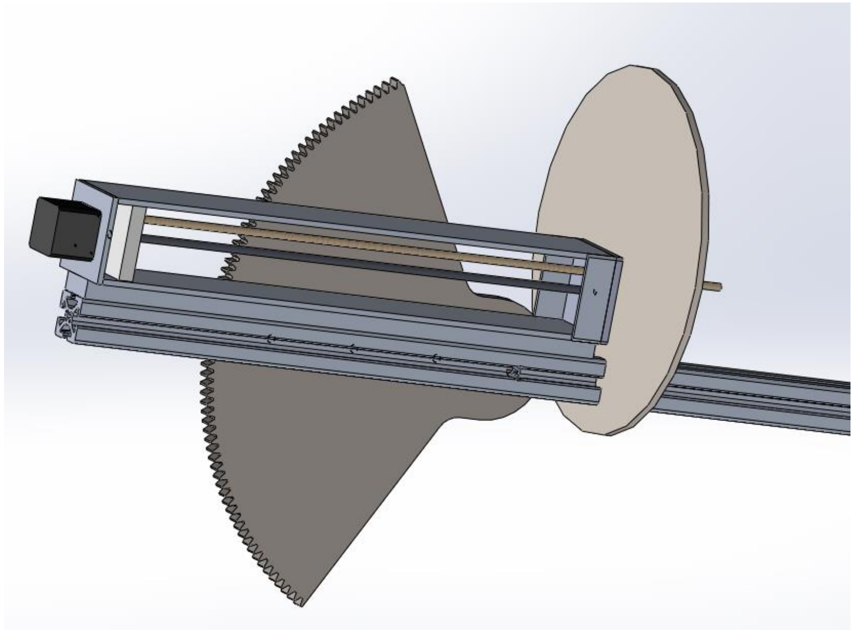

Figure 49: Launch Rail Mounted Igniter Insertion System

Figure 49 above shows the updated igniter insertion system. The system was moved from the AGSE base to the rear of the launch rail to simplify igniter insertion. To insert the igniter, the 17HS15-0404S stepper motor, shown in ***Figure 50*** below, will be attached to an ACME 8 turn per inch threaded rod via a small coupler. The rod will thread through a low friction Delrin plate that is prevented from rotating by the two parallel guides. Attached to the plate will be a dowel holding the igniter. The dowel will protrude through a small hole in the blast plate prior to system start to reduce the required movement. As the stepper motor turns, the Delrin plate/dowel assembly will move upward, inserting the igniter into the base of the rocket. All of the igniter system framing components will be manufactured from thin aluminum plate for weight savings purposes.

Figure 50: 17HS15-0404S Igniter Insertion Stepper Motor

4.1.1.2. Analysis

Arm

Before the arm was physically manipulated, a MATLAB script (***Appendix 8***) was used to analyze and verify the usage of the arm. Furthermore, this script was used to determine the maximum range of the robotic arm. At a height of 10 inches, the arm is capable of reaching out 11 to 22 inches in front of the AGSE, given the maximum range of motion dictated by the servos and the physical restraints of the arm. Given the xyz location of the sample in space with regards to the pivot point of the shoulder, the code uses the Law of Cosines to determine the angles necessary for the arm to reach the desired location. Given the geometry of the arm, the code calculates the required angle of the wrist to point the camera at the sample from any location. When the arm goes to grab the sample, the code transitions over to calculating the angle for the gripper to encompass the sample. In order to verify the angles generated by the code, a virtual representation of the arm is plotted as well. For example, ***Figure 51*** below shows a plot of the arm capturing the sample at a location of (22, 0 ,-7.7) inches from the shoulder.

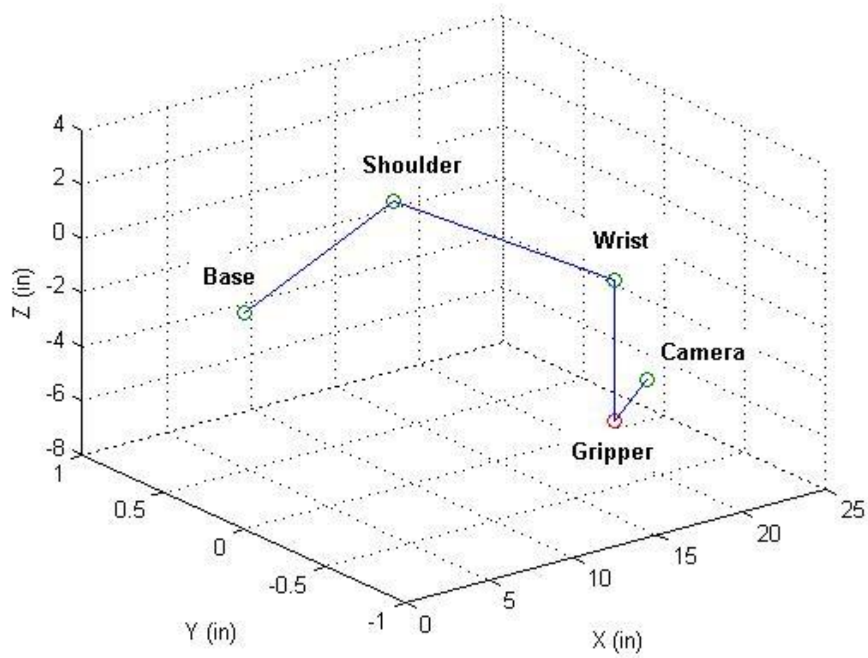

Figure 51: Virtual Arm Capturing the Sample at (22, 0, -7.7) inches

The green circles indicate the joints of the arm and the red circle indicates the desired location. The fact that the gripper and desired location are coincident show that the arm was able to reach the sample. The height of -7.7 inches was chosen because that was the height that was used during the experiments. Furthermore, ***Figure 52*** shows the arm moving only 30% of the way to the (22, 0, -7.7) location and how the camera points at the sample. For this input, the wrist is located at 30 percent of the way to the sample. Note that the camera will be mounted so that its line of sight is along the line between the wrist and the camera.

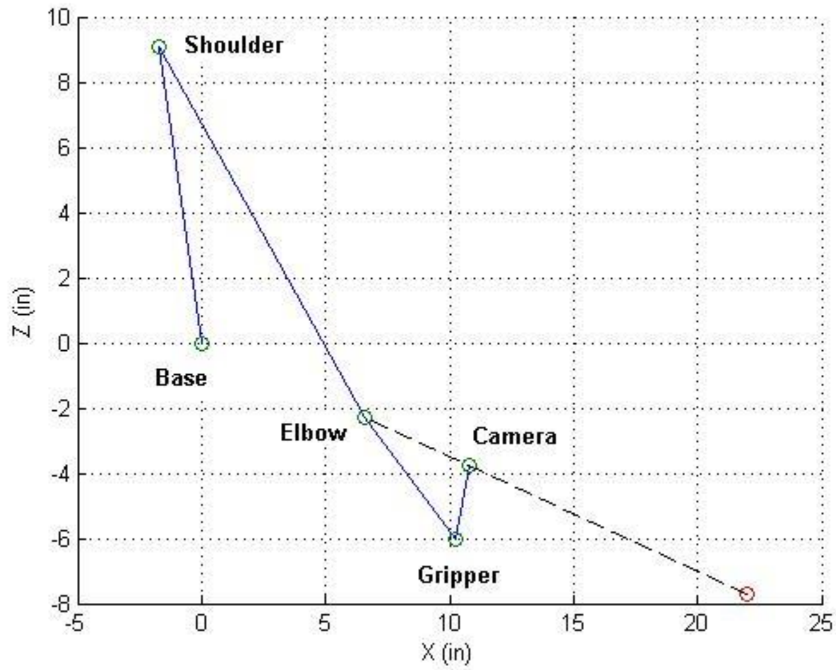

Figure 52: Virtual Arm at 30 Percent of the way to the Sample at (22, 0, -7.7) inches

As shown by the dotted line in ***Figure 52***, the camera is pointing directly at the sample (the red circle). This orientation is important because the camera will need to take several pictures to verify the distance as the arm moves to the sample. The analysis above shows that the arm is capable of both reaching the sample and ensuring that the sample remains in the camera's field of vision. As the arm moves closer to the sample, the distance to the sample will be updated. By comparing the new distance to the sample to the predicted location of the arm from the code, the exact location of the sample can be updated and verified.

4.1.1.3. Integrity of design

All of the elements of the AGSE have been fully analyzed to ensure that they will mesh together in the design. It has been shown that all of the samples are capable of performing their required tasks in the allotted time. The team is proud of its design and believes that it will be sound in construction.

4.1.2. Fulfillment of system-level functional requirements

Imaging Experiment

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 63***. 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 53***. After many pictures, three curves were generated relating the pixel count, height, and width to the distance. These can be seen in ***Figure 55*** and ***Figure 56***. 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 56***. 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 58***. Interestingly, this adds discontinuities to the pixel count curve seen in ***Figure 60***, but it smoothed some discontinuities in the height and width plot in ***Figure 61***. 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. ***Figure 57*** and ***Figure 62*** show the time it took to process each image. These show that the system is quite slow at close distances (less than 8 inches) but reasonable in speed at greater distances. This is because the script builds matrices proportional to the size of the blobs in image, so the closer the sample, the larger the blob and the longer the script takes to be processed. The team has determined the other subsystems will take must less than the given ten minutes, so five minutes is a reasonable amount of time to give the imaging system. The plan is take about five images, and considering the worst case situation takes less than thirty seconds to process the image, there will be sufficient time to process the needed images.

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. Currently, the scripts are being developed in MATLAB in a manner that can be autocoded using MATLAB's embedded coder. This will generate executable C that can run on the BeagleBone.

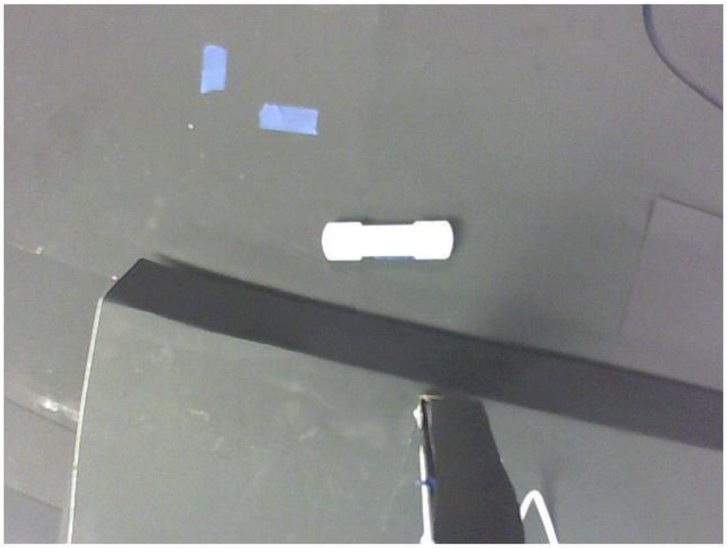

Figure 53: Unfiltered Imaging Experiment Picture

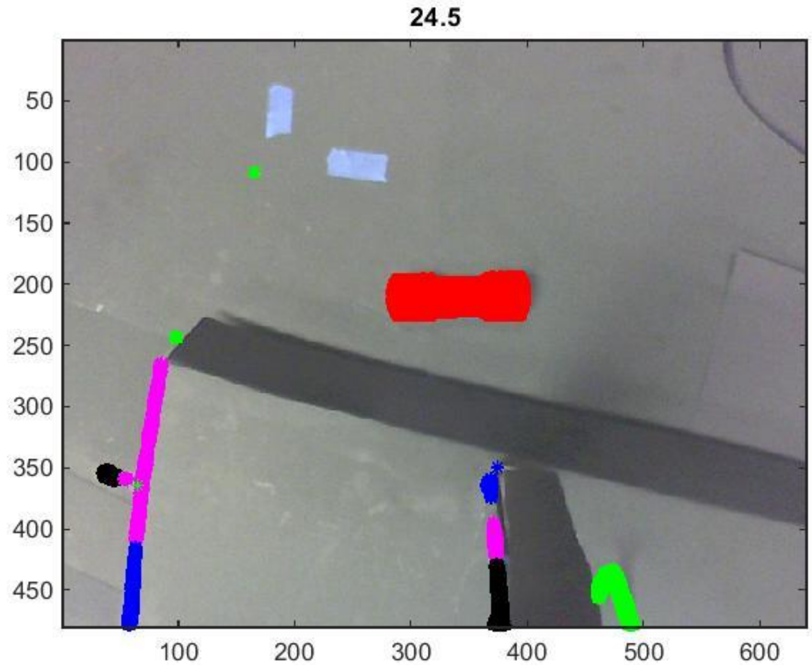

Figure 54: Blobbed, Unfiltered Imaging Experiment Picture

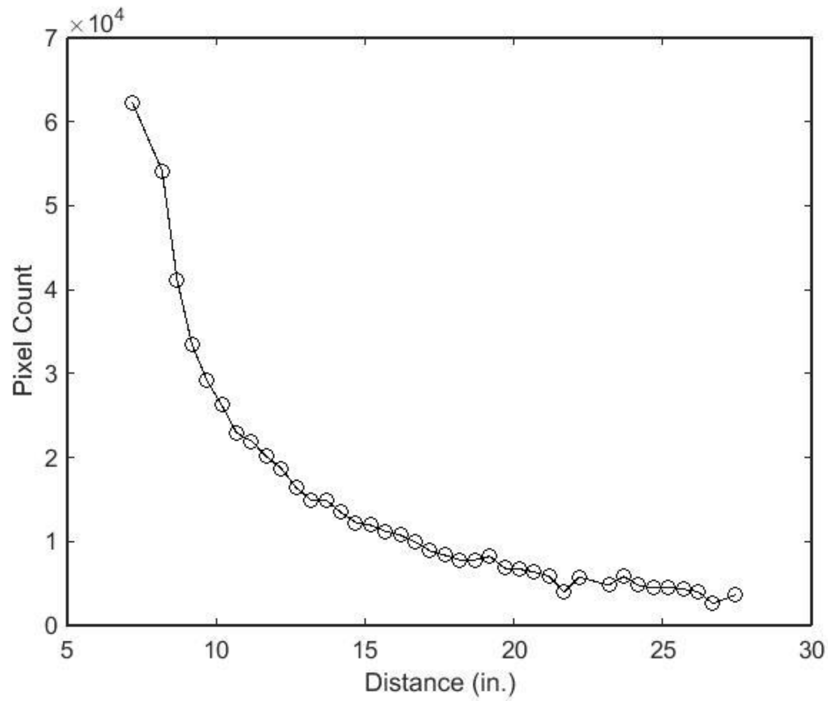

Figure 55: Unfiltered Imaging Experiment Sample Pixel Count vs Distance

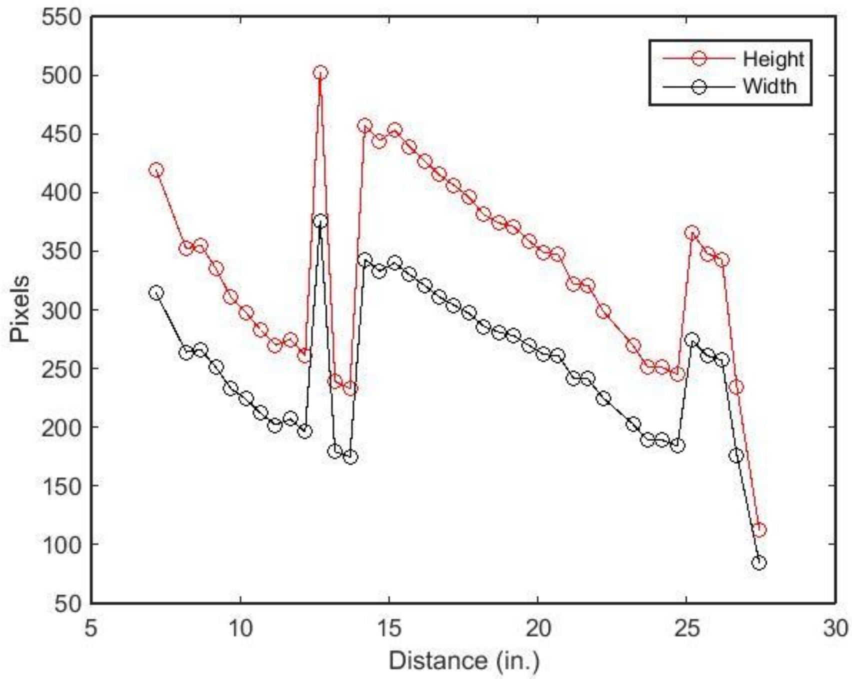

Figure 56: Unfiltered Imaging Experiment Sample Dimensions vs Distance

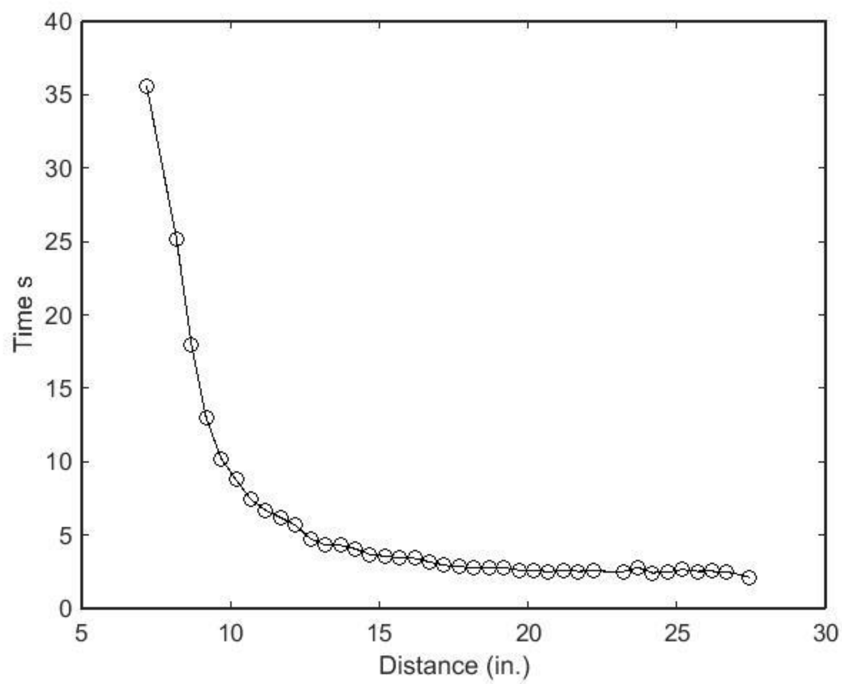

Figure 57: Unfiltered Imaging Experiment Blobbing Runtime vs Distance

Figure 58: Filtered Imaging Experiment Picture

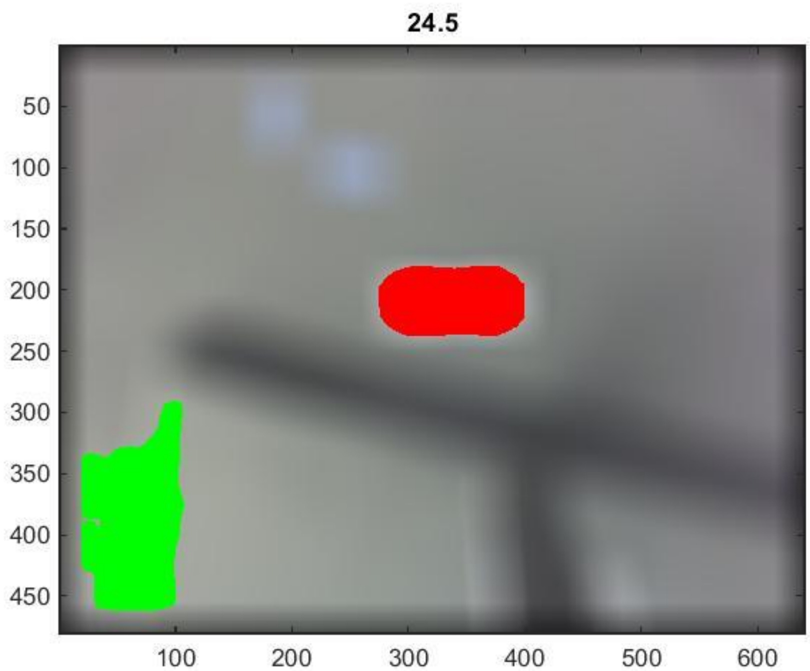

Figure 59: Blobbed, Filtered Imaging Experiment Picture

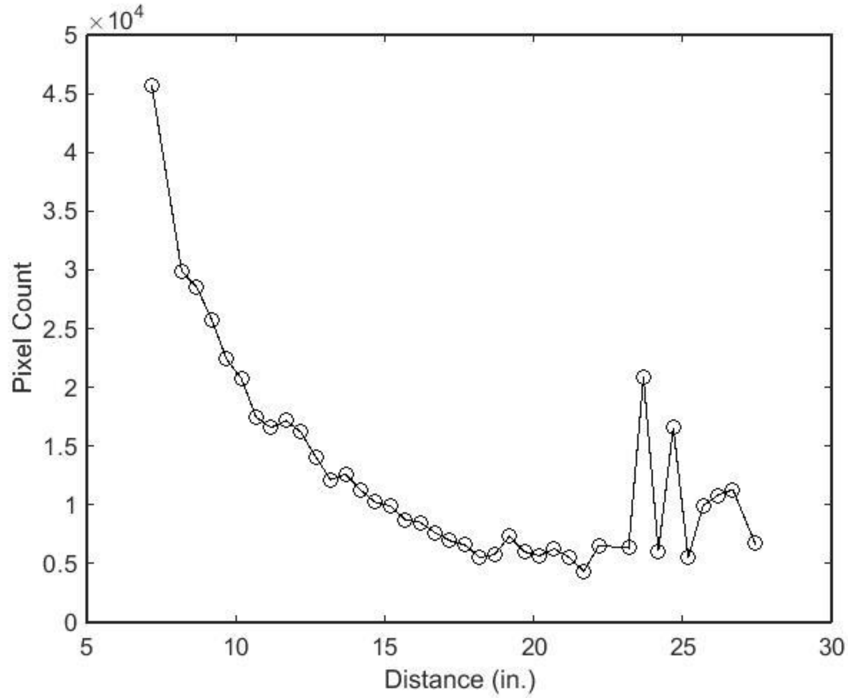

Figure 60: Filtered Imaging Experiment Sample Pixel Count vs Distance

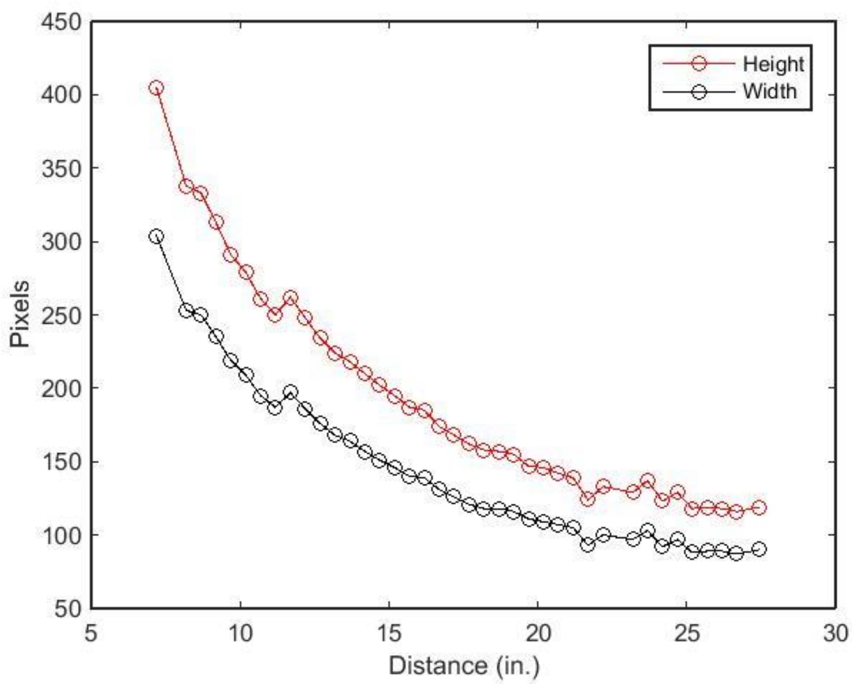

Figure 61: Filtered Imaging Experiment Sample Dimensions vs Distance

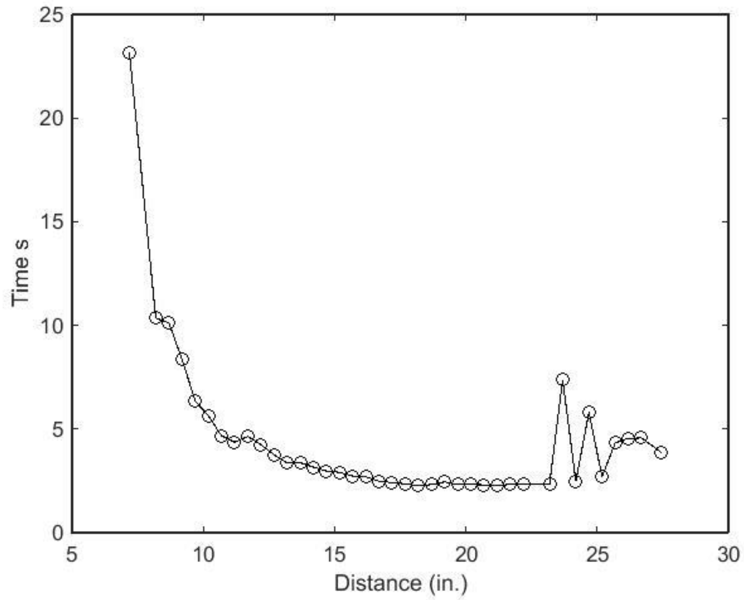

Figure 62: Filtered Imaging Experiment Blobbing Runtime vs Distance

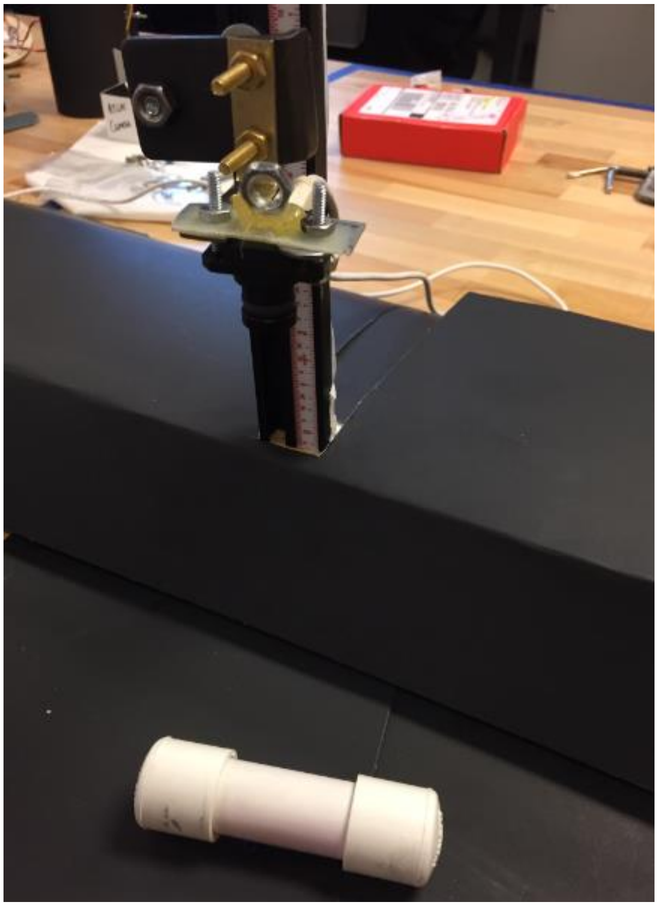

Figure 63: Imaging Experiment Setup

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, as described above. 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, repeatedly moving the arm to the desired location 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 out, 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. The angles of the servos required to reach the four specified locations were founded using a MATLAB program developed by the team. After inputting the desired location in space 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 64*** and ***Figure 65*** 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). 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. This force is enough to close the door with the current design as the spring loaded sliding bolt required a force of roughly 1.6 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.

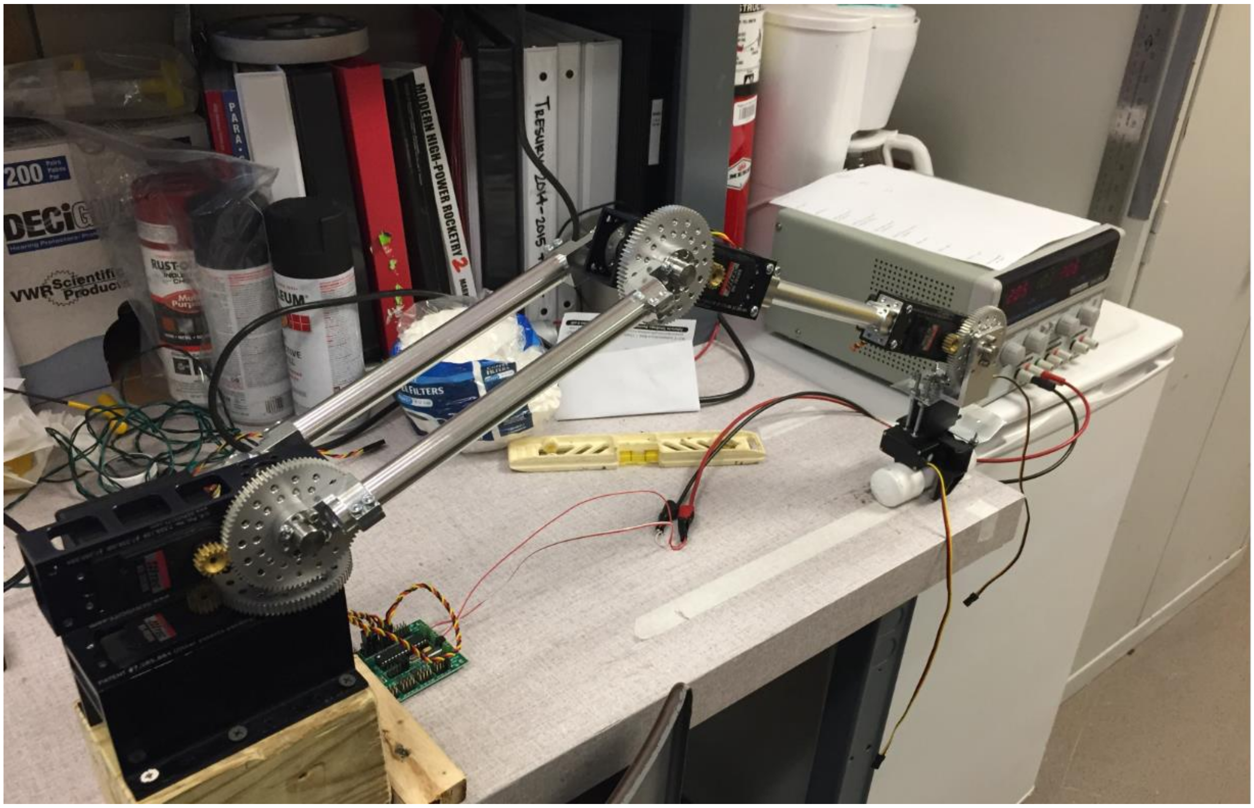

Figure 64: Arm Experiment at (22, 0, -7.7) inches

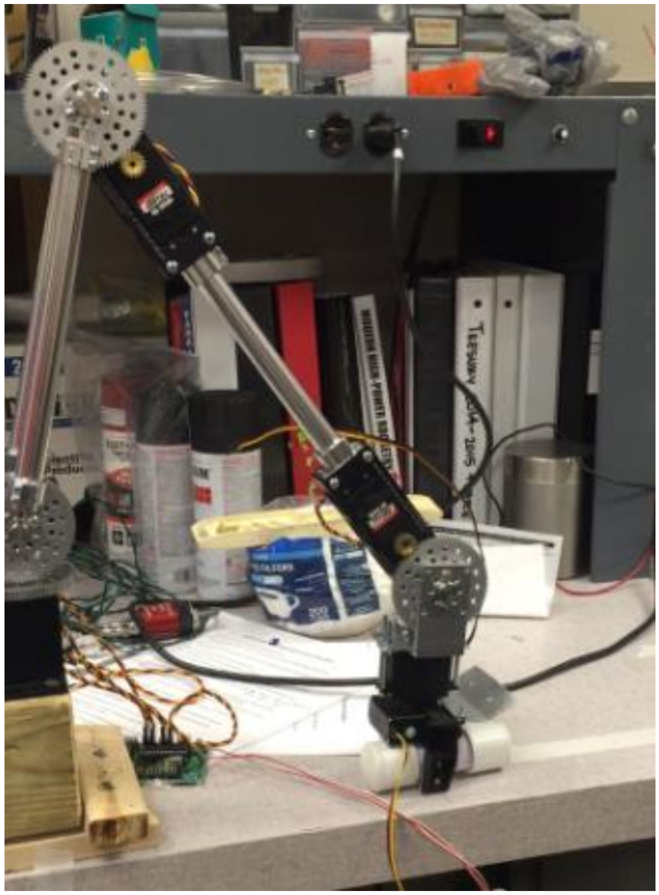

Figure 65: Arm Experiment at (11, 0, -7.7) Inches

The imaging system and robotic arm were originally tested as separate subsystems. As a result, the next step will be to combine the two systems and have the arm move to a location that the camera specifies. In order to conduct this experiment, the sample will be placed at some premeasured position. With the camera mounted to the arm, the arm will then move to various positions on its path to the sample to allow for verification of the distances acquired from the imaging system. The process will occur for several different locations of the sample and be concluded with the arm picking up the sample. Success will be measured by the ability of the imaging system to correctly identify the location of the sample and the ability of the arm to retrieve the sample from the calculated position. The commanding of the arm will also be done on the BeagleBone after compiling the MATLAB code (***Appendix 8***) into C using the embedded autocoder. Manufacturing of the camera mount to the robotic arm is still underway. To decrease the weight of the mount, 0.125 inch sheet metal is being used. The sheet metal will be bolted to the gripper and to the camera. The top half of the sheet metal will be bent so that the correct orientation of the camera is obtained. Although the angle of the camera will be determined by its final horizontal and vertical distances from the wrist, current analysis placed the camera lens at 4 inches out and 2 inches up from the pivot point of the wrist, resulting in a camera angle of 26.5 degrees. It is important that the mount for the camera be manufactured well so that the camera is secure on the gripper. If the camera were to come loose or move during the experiment, then the distances would be thrown off. These incorrect calculations may cause the arm to not be able to capture the sample, resulting in a failure of the mission.

Furthermore, once the final mold for the sample has been made, the arm will be used to place the sample inside of the mold and close the door to the sample compartment. Experimentation has shown that the arm will be able to both insert the sample and seal the compartment autonomously.

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 30 pounds, a 66 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 12 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, the 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 volt maximum holding torque. The 23HS22-2804-PG47 planetary gear stepper motor, attached pulley, and weights can be seen below in ***Figure 66***.

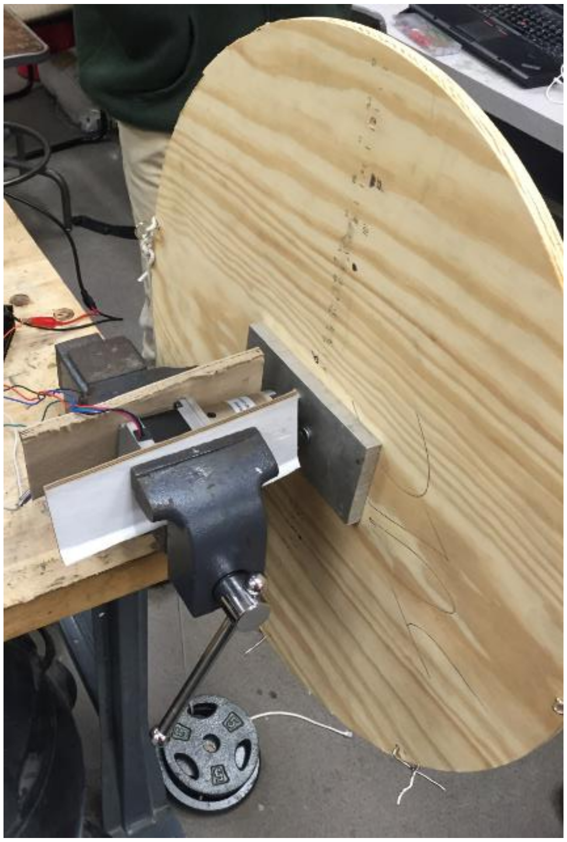

Figure 66: Launch Rail Stepper Motor and Pulley Apparatus

The system used to power and control the stepper motor can be seen below in ***Figure 67***. 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 Thunderpower 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.

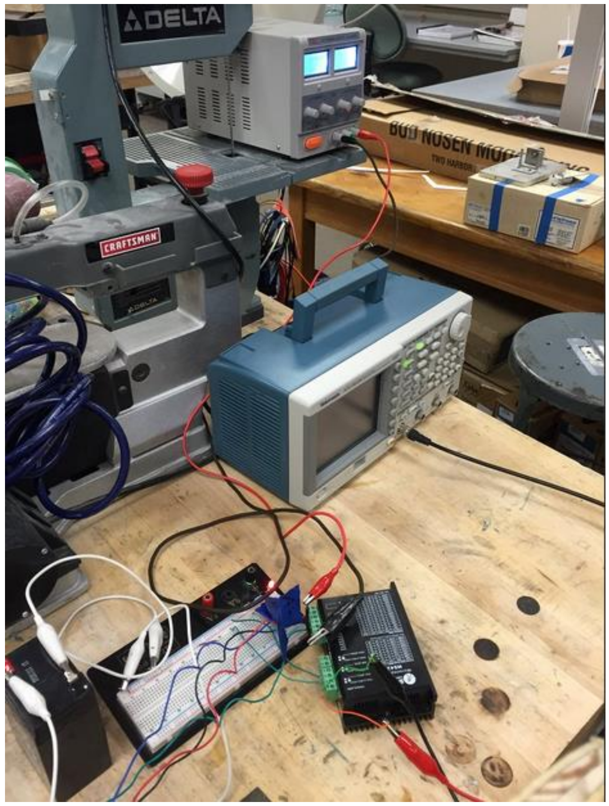

Figure 67: Stepper Motor Power and Control System

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 9*** 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 surprising 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.

Table 9 Square Wave Frequencies and Resulting Launch Rail Rise Times

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

Igniter Insertion Experiment

The goal of the igniter insertion experiment was similar to that for launch rail stepper motor. Verification that the igniter insertion stepper motor could translate the threaded igniter plate vertically in 45 seconds or less was desired. Before insertion, the igniter will sit just behind the vehicle's base. Therefore, the translation distance required for the linear stepper actuator is the internal length of the rocket motor, approximately 16 inches for the AeroTech K805G. So this experiment was designed to time a 16 inch vertical translation along the threaded rod at different stepper motor frequencies. The experiment setup can be seen below in ***Figure 68***. The setup consisted of the 17HS15-0404S stepper motor attached to an 8 turn per inch ACME threaded rod via a coupler, the igniter plate, and two parallel rods to prevent igniter plate rotation. Since the wooden dowel and igniter wire are quite light, their weights were neglected for this experiment. The igniter plate was made out of two 0.25 inch white Delrin plates bolted together with an ACME nut mounted in the lower plate. Delrin was chosen for its low friction coefficient. The power and control system was the same as for the launch rail raising experiment except that the smaller StepperOnline ST-6128 driver was used instead of the Leadshine M542.

After some initial tests, it was determined that the stepper motor performed better above its 12 volt rated voltage. At 12 Volts, the stepper began to misstep at square wave frequencies over 550 hertz. When the power supply voltage was increased to 18.4 Volts, the maximum frequency increased to 750 hertz and output torque improved significantly. These results revealed that powering the igniter insertion stepper motor through the 37 volt Thunderpower battery and a step down regulator rather than the 12 volt Thunderpower would be better from a performance standpoint. Nevertheless, operating above the stepper's rated voltage could cause some reliability issues. In all, when operating at 18.4 Volts, the igniter plate translated 16 inches in 45.1 seconds at

550 hertz and 33.3 seconds at 750 hertz. These results demonstrate that the desired insertion time of 45 seconds is easily achievable.

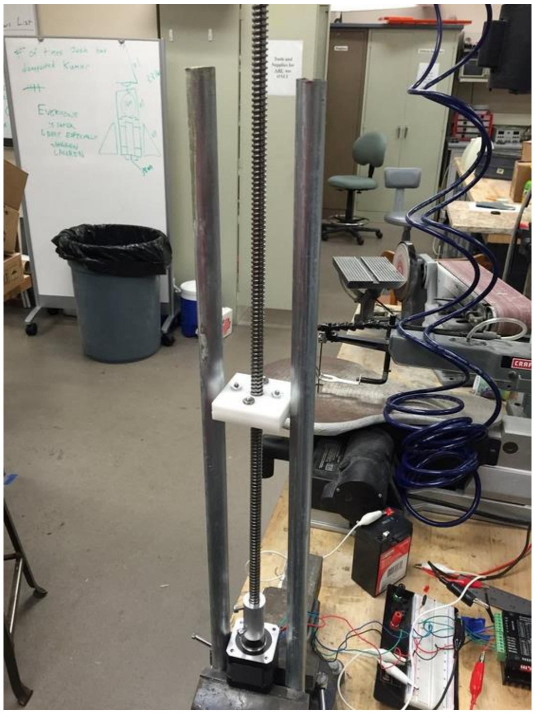

Figure 68: Igniter Insertion Stepper Motor Experiment Setup

Including and in addition to the previously mentioned methods, a full AGSE verification matrix can be seen in ***Appendix 7***.

4.1.3. Discuss the precision of instrumentation and repeatability of measurement

The voltage regulators, stepper motors, and motor controllers were all partially chosen for their accuracy and repeatability. All distances are measured with the most accurate devices available, which range from standard rulers to digital calibers capable of measuring to the nearest thousandth of an inch. To account for any error in the measurement, the appropriate significant figures were used. Each measurement was taken several times to verify its accuracy. Furthermore, the experiments for each subsystem were conducted several times to test their repeatability and accuracy. All of the tests were successful and resulted in repeatable results. As a result, the experiments proved the precision of instrumentation and repeatability of measurement.

4.1.4. Discuss the AGSE/payload electronics with special attention given to safety switches and indicators

Legend for ***Figure 69***:

- Blue zig zag lines: 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

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. We feel 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.

4.1.4.1. Drawings and schematics

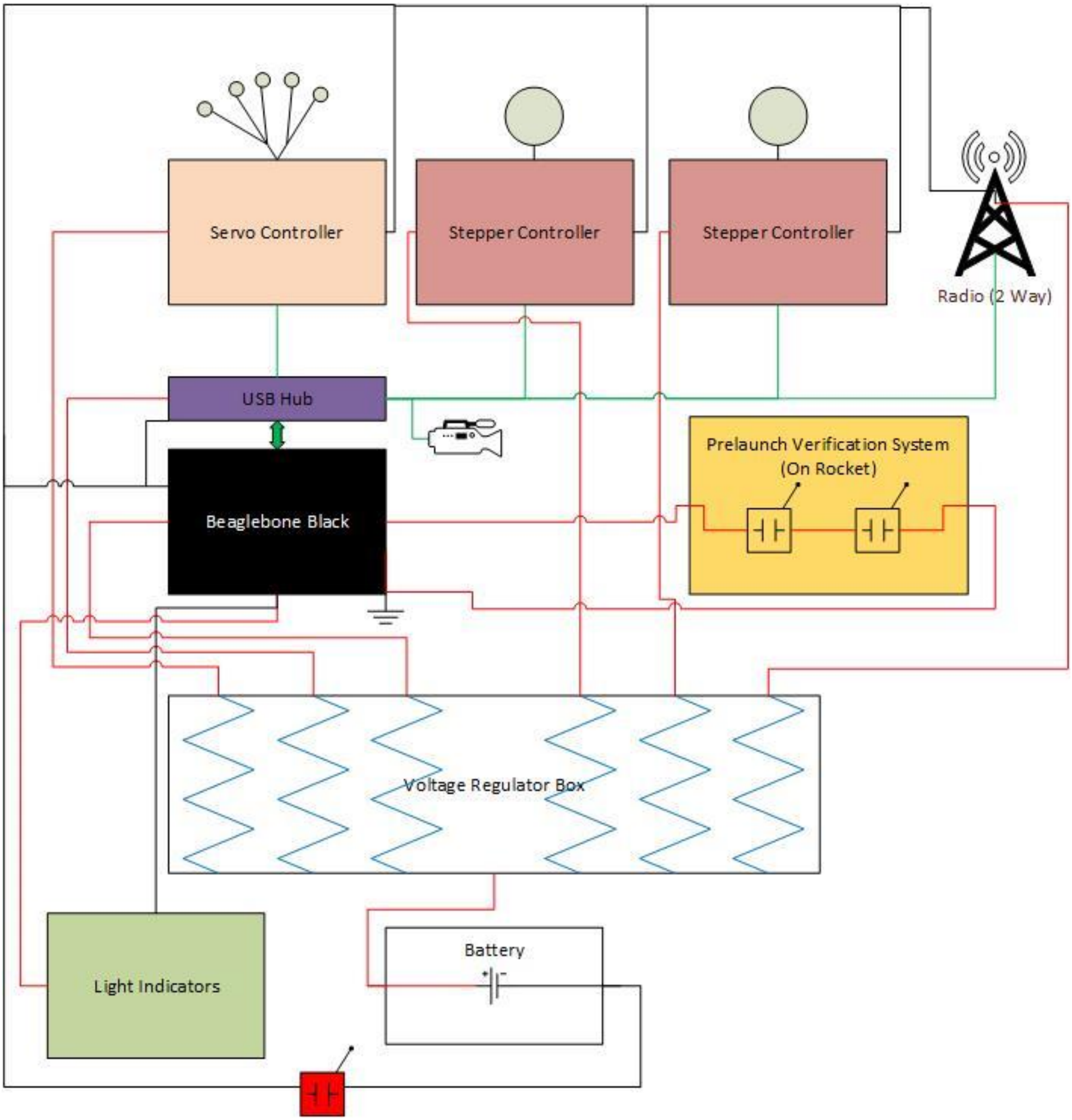

Figure 69: AGSE Electrical Schematic

4.1.4.2. Batteries/power

As described above, the AGSE uses a 37 volt and an 11 volt battery to control all of the components. In order to provide the necessary voltage to the components, step down regulators of various sizes will also be used. These batteries will also be used to power the indicator lights that display when the system is paused and when all systems are go. For safety, the pause and master switches will control the power being delivered to the system.

4.1.4.3. Switch and indicator wattage and location

As per the requirements, the AGSE will utilize a master switch and a pause switch that will be hardwired to the AGSE and easily accessible. The wattages will be clearly visible from the voltage regulator box.

4.1.4.4. Test Plans

Once the circuits are set up, the continuity will be tested throughout the circuit to make sure that everything is hooked up correctly. The master and pause switches will also be tested to ensure that they perform their expected tasks. The indicator lights will also be hooked up for testing to make sure that they are lit when the team expects them to be. Verifying their functionality prior to the experiment will help prevent a malfunction on the day of the competition that would potentially put the team or other personnel at risk.

4.1.5. Provide a safety and failure analysis

Any implications of failure in the electronic systems are adequately outlined in the FEMECA diagrams in ***Appendix 2***. If the indicator lights fail, then the operators may be misinformed about the current state of the AGSE and may be put into danger when they approach the equipment. Furthermore, if the switches malfunction, then the AGSE will not be able to be paused if something were to go wrong. These situations must be avoided; therefore, care will be taken to adequately test the AGSE's electronic systems to make sure that the system can be operated safely.

4.2. AGSE/Payload Concept Features and Definition

4.2.1. Creativity and originality

Although all of the individual subsystems have been done before in other projects, they are all put together in a way that makes the team's design unique. For example, the rocket will be raised for launch using a large gear system and the igniter will be inserted with a threaded rod system. These two systems provide an 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. 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.

4.2.2. Uniqueness or significance

To add robustness to the system, the sample will be found using image processing software. Teams have the option to place the sample in a measured location and have their retrieving system move to the predefined, hardcoded position. Predefined locations rely on accurate setups and could potentially struggle with unanticipated terrain or weather. Wind or ground slope could move the sample from the preset location and cause the entire AGSE to fail because the sample could not be obtained. The imaging system developed by NCSU will help solve the issues with a moving sample or difficult terrain by finding the sample's location in real time during the autonomous procedures. While this adds another level of challenge and system complexity, we believe this task is worthwhile because it adds to the reliability of the system while expanding the technical knowledge of the club to areas outside of traditional high powered rocketry.

4.2.3. Suitable level of challenge

The current plan provides various degrees of challenge to the team. For example, rather than hard code the location of the payload, an imaging system is going to be used that can identify the sample in a varying location. Therefore, the AGSE will determine where the sample is and how it has to move the robotic arm to retain the sample. This system requires a large amount of sophisticated code in order to accomplish its goal and is not a simple task. Furthermore, the arm is to be used to close the hatch door to the sample compartment. In addition to having to coordinate the movement of the arm, the locking mechanism has to be weak enough to allow the arm to close the sample door, yet strong enough for to remain closed during flight.

4.3. Science Value

4.3.1. AGSE/payload objectives

The goal of the AGSE is to retrieve a sample and insert it into the rocket. On Mars, or any other distant body, a similar process will need to be done so that the soil sample can be processed on Earth. Therefore, the processes investigated in the AGSE portion of the experiment have a direct correlation to actual systems that can be used. Having a robotic arm obtain and secure the sample in the rocket is a feasible system.

4.3.2. AGSE/payload success criteria

The AGSE will be successful if it can identify, capture, and retain the sample. After these tasks have been completed, the vehicle will then be erected for launch. Success for the AGSE will only be obtained if these tasks are completed. Success with the AGSE will prove the viability of the system as a whole to be implemented in other tasks, such as missions to Mars.

4.3.3. Experimental logic, approach, and method of investigation

All of the experiments described above are physical tasks that will need to be completed by the team. By testing each of the crucial subsystems (image processing, arm movement, recovery system deployment), overall success of the project can be ensured. It is important that all modes of failure are analyzed to account for any means of failure. Therefore, each test will be performed several times in order to collect sufficient data and prove the repeatability of the processes. It is important that viable data be obtained from each experiment so that the real system will work correctly. As such, each experiment will be approached as if the test was for the actual competition. Improper testing would lead to inaccurate data and failure of the mission, detracting from the scientific value of the project.

4.3.4. Test and measurement, variables, and controls

The data will be collected using accurate measurements, such as with digital calipers and a gram scale. As described above, the variables to be tested are the amounts of black powder needed, and the accuracy of the robotic arm and imaging systems. Since all of the tests are experimental in nature and are rated on a success/failure scale, control tests cannot be used to establish the baseline for the experiments.

4.3.5. Relevance of expected data and accuracy/ error analysis

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.

4.3.6. Experiment procedures

As described above in section 4.1.2, the experiments were carefully conducted so that accurate results could be obtained. 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 present that needed to be investigated or solved. Next, an experiment was formed that tested possible solutions to the problem or provide more insight into the issue. The experiments were design 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 and to preserve their legitimacy. 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.

5. Project Plan

5.1. Status of activities and schedule

5.1.1. Budget plan

The current budget plan is projected as follows:

Table 10: 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	1	$60

	Stepper Motor		
	5mm-5mm Couplers	3	$15
	USB Extension Cable	1	$2
	USB hub	1	$10
	Thunder Power 37 V Battery	1	$340
	12V Step Down to 5 V Power Module	1	$10
	2.1 mm Coax Power Plug	1	$5
	48 V Step Down to 24 V Power Module	1	$40
	12 V Step Down to 6 V 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
	Steel Plate for gears (1'x2'x1/4")	1	$35
	1/2" Dia. X 2' long 1045 Cold Drawn Metal Round	1	$15
	1'x2'x3/16" Aluminum Plate for interior frame	1	$30
	Aluminum Railing	30 ft	$100
	Brackets	15	$80
	Lynxmotion Servo Controller (for arm)	1	$40
	Aluminum square beam (for ratcheting stops)	4 ft	$10
	Miscellaneous hardware (nuts/bolts/washers)	--	$100
	Gripper for Robotic Arm	1	$40
	RobotShop M100 RAK Robotic Arm	1	$600
	Electronic sensors	--	$100
	Balsa wood dowel	1	$5
	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
Rocket	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
	Fiberglass 3k, 2 x 2 Twill Weave Carbon Fiber Fabric (1 yard), 50'' wide, 0.012" 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	$15
	AIM USB Rocket Altimeter	2	$200
	StratoLogger Altimeter	2	$160
	GPS Bee	3	$95
	K805G motor (full scale)	2	$200
	I285R-0 motor (subscale)	2	$125
	Wires	--	$30
	Connectors	--	$20
	Nosecone (full scale)	1	$60
	Nosecone (subscale)	1	$35
	Motor casing (full scale)	1	$100
	Motor casing (subscale)	1	$65
	Kevlar shock cord	60 ft	$60
	18" Fruity Chute Classic	1	$55

	Elliptical Parachute		
	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
	Aero Pack 54mm Retainer	1	$35
Other	Travel expenses (hotel, rental car, gas)	20 people	$3,000
	incidentals (replacement tools, hardware, safety equipment)	--	$1,000
	Shipping costs		$750
Subtotal	--	--	$9,727

The budget plan has remained mostly the same since the PDR. The majority of the changes were made to the budget for the AGSE. For example, the Phidgets controllers were subbed out for the Leadshine and StepperOnline drivers. The sensor board was also eliminated. A few items were added, however, to reflect the recent purchases the club has made. The metal round rod and aluminum plate were added for the pin that will lock the launch rail into place and the frame for the igniter insertion system. The materials to make the replica sample were also added. As for the vehicle, the motors were changed to reflect the final motor choice. Furthermore, the door latch for the payload section, blue foam for the initial sample mold, and rotary switches for arming the altimeters were added. Despite these changes, however, the projected subtotal only changed from $9,585 to $9,727 in the CDR. This leaves slightly over $300 for overages during flight week.

5.1.2. Funding plan

The budget needed to complete this project has been started. The club received $2,000 from the Engineering Technology Fee Fund from the Mechanical and Aerospace Department at North Carolina State University. The Engineering Council at NCSU has also granted the club $1,500 for the fall semester through a proposal, a presentation, and an appeals presentation. The club is looking to receive another $1,500 in the spring semester from the Engineering Council. The Student Government Appropriations committee has given $1,000 through a proposal and interview for the spring semester. Two proposals, for competition and 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 11: Funding Sources

Source	Amount
NCSU MAE Department ETF Funding	$2000
NCSU Engineering Council	$3000
Student Government Appropriations	$1000
North Carolina Space Grant	$7000
Total	$13000

5.1.3. Timeline

Table 12: 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
Initial Calibration of Arm (Experiment)	11/14/2014	11/28/2014
Prepare Subscale for Launch	11/21/2014	11/21/2014
Subscale Launch	11/22/2014	11/23/2014
Camera Experiment	11/24/014	12/1/2014
NCSU Winter Break (no building access)	12/16/2014	1/6/2015
CDR Writing	1/7/2015	1/15/2015
Completed CDR Submission	1/16/2015	1/16/2015
Arm + Camera Experiment	1/16/2015	1/23/2015
Full Scale Construction	1/17/2015	2/17/2015
AGSE Construction	1/17/2015	3/1/2015
CDR Team Teleconference (Tentative)	1/21/2015	1/26/2015
Flight Readiness Review (FRR) Writing	1/17/2015	3/15/2015
Full Scale Launch (Tentative)	2/22/2015	2/23/2015
YMCA Kite and Rocket Day	3/7/15	3/8/15
Completed FRR Submission	3/16/2015	3/16/2015

FRR Team Teleconference (Tentative)	3/18/2015	3/27/2015
Finish Construction	3/31/2015	3/31/2015
Prepare for Competition	3/31/2015	4/6/2015
Sigma Gamma Tau Boy Scout Merit Badge Event	4/4/2015	4/4/2015
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
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

With the due-date of the FRR close approaching, it is critical that the full-scale be ready for launch on the February 28 launch date. That is the first date that the team's mentor will be available for the launch. In the meantime, progress will continue to be made on the AGSE so that construction can be finished by the March 1, 2015 deadline set by the team. Once all of the subsystems have been completed, they will be tested together by the end of March. This will be an entire run through of the system, from capturing the sample to inserting the igniter into the rocket. The model motor will be in place for tests. Testing the complete system by the end of March will allow for any final tweaks to be made to the subsystems before in competition in April.

5.1.4. 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.

Location: Perkins Field, Butner, NC 27509

Dates: May 24th, June 28th, July 26th, and August 16th

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 10:00 – 1:00PM

YMCA Kite and Rocket Day
The High Powered Rocketry Club is planning on continuing the tradition of being a part of the YMCA Kite and Rocket Day in the spring of 2015. The Club plans to set up an informational booth at Carter Finley Stadium to assist young rocketeers with assembling and launching model rockets. Last year's event had over 200 kids attend the Kite and Rocket Day and we expect many more this year. The details will be available as the event gets closer in the spring.
Location: Carter Finley Stadium, 4600 Trinity Rd. Raleigh, NC 27607
Date: March 7-8th, 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 4th, 2015

6. Conclusion

7. Appendices

Appendix 1: Milestone Review Flysheet

Milestone Review Flysheet

Please see Milestone Review Flysheet Instructions.

Institution	North Carolina State University	**Milestone**	CDR

Vehicle Properties	
Total Length (in)	78
Diameter (in)	5.5
Gross Lift Off Weight (lb)	18
Airframe Material	BlueTube 2.0
Fin Material	Plywood/Carbon Fiber
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)	3.40/1.48
Liftoff Thrust (lb)	100

Stability Analysis	
Center of Pressure (in from nose)	57.90
Center of Gravity (in from nose)	47.4
Static Stability Margin	1.91
Thrust-to-Weight Ratio	10.65 : 1
Rail Size (in)/ Length (in)	1.5 / 66
Rail Exit Velocity (ft/s)	66

Ascent Analysis	
Maximum Velocity (ft/s)	547
Maximum Mach Number	.47
Maximum Acceleration (ft/s^2)	266
Target Apogee (1st Stage if Multiple Stages)	3240 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
Terminal Velocity (ft/s)	72
Recovery Harness Material	Braided Kevlar Cord

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)	21/24
Recovery Harness Material	Braided Kevlar Cord

Harness Size/Thickness (in)		0.23		
Recovery Harness Length (ft)		6.8		
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

Harness Size/Thickness (in)		0.23		
Recovery Harness Length (ft)		5.8/6.9		
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		

Recovery Electronics	
Altimeter(s)/Timer(s) (Make/Model)	Perfectflite Stratologger SL100/Entacore AIM 3.0
Redundancy Plan	Apogee charges will have a 2 second delay. Main redundant charge will be programmed for 600 feet AGL at 125% primary charge size.
Pad Stay Time (Launch Configuration)	1 hour

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

Milestone Review Flysheet

Please see Milestone Review Flysheet Instructions.

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 electric match 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	Because of the stable CG location the moment generated from the lifting of the rocket will not tip the AGSE system in reasonable (sub 20 mph) wind conditions.	

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.
Payload 2	Overview
	N/A

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 vial by wadding. Each altimeter will be connected through a USB port to a laptop with the Perfectflite DataCap program. Charge ignition for main and drogue charges are capable of being separately fired at the user's input. If the test is a failure, analysis will be conducted with new tests to follow.
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 is planned to take place in February/March 2015.

Milestone Review Flysheet

Please see Milestone Review Flysheet Instructions.

Institution	North Carolina State University

Milestone	CDR

Additional Comments

Appendix 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			2	Pre/post launch

		maintenance				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 specification				4	Maintain vehicle within design 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 transmitter	Improper design	No ejections or mistimed ejections	Damage from high velocity ejection	2	Complete testing of 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 (ARRD)	Eyebolt fails to detonate	Improper wiring/attachment	Upper and middle airframes do not separate	Rocket is not safely recovered	1	Make sure 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 separate before charges ignite	Deceleration of the rocket	Sections separate early	High velocity separation	1	Make sure shear pins 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: Subsystem	Failure Effects: System	Hazard	Recommendations
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: Subsystem	Failure Effects: System	Hazard	Recommendations

Door	Spring-loaded locks don't lock	Bracket misalignment	Door doesn't shut securely	Rocket is not ready to Launch. Door could open during flight and cause instability.	1	Careful inspection as part of pre-flight checklist.
		Excessive spring force required to lock			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	Poor selection in			3	Testing during build

	gripping force	design process				and pre-flight checklist.

AGSE

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
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	System cannot begin or stops operation.	System does not begin or ceases operation.	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			2	Testing during build process and as a part of pre-flight 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			2	Inspection as part of pre-flight checklist.

		position				
		Registering >1 press			2	Inspection as part of pre-flight checklist.

Appendix 3: 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.

7733830, 7740830, 7794830, 7721830, 7722830, 7723830, 7724830, 7727830, 7729830, ... Page 2 of 7

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

MSDS #206-13a Last Revised: 26APR13

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
Vapor Pressure (mm Hg.) N/A
Vapor Density (Air = 1) N/A
Specific Gravity (H_2O = 1) N/A
Melting Point 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.

Page 1

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.

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Appendix 4: Photo References

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Appendix 5: Subscale Test Launch 12/20/2014

1. Retrieve nosecone/upper airframe section
2. Check that the two screws to hold the nosecone are tight using Philips head screwdriver
3. Check that the four coupler screws to hold coupler (on forward airframe) 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. Unscrew top section nuts
8. Pull avionics sled out of avionics bay
9. Check that the altimeters are off.
10. Connect battery snaps on each battery
11. Insert the two batteries into each of the battery trays
12. Tighten battery box with Philips and #10 wrench.
13. Insert avionics sled back into avionics bay making sure no wires are crossed and the sled is oriented with the sleds rods facing the correctly marked position
14. Attach top nuts to threaded rods of the avionics bay (finger tight).
15. Run avionics bay threaded rods through the lower bulkhead and attach nuts on each (finger tight).
16. Tighten nuts on both ends of avionics bay with 3/8" ratchet / 7/16" socket
17. Attach e-match wiring to terminal block 1 and ensure the wires are secured
18. Insert primary main black powder charge into cap 1 on top of avionics bay
19. Insert e-match into cap 1
20. Insert wadding into cap 1 and cover cap 1 with blue painters tape
21. Repeat steps 17 – 20 with redundant main black powder charge into cap 2 on top of avionics bay in terminal block 2

	Main 1	Main 2
17		
18		
19		
20		

22. Slide avionics bay into middle airframe making sure that the arrows are aligned
23. Remove four screws from pill bottle and screw into the four screw holes on the forward avionics bay with a Philips head screwdriver
24. Repeat steps 17 – 20 with primary drogue black powder charge into cap 1 on bottom of avionics bay with terminal block 1
25. Repeat steps 17 – 20 with redundant drogue black powder charge into cap 2 on bottom of avionics bay with terminal block 2

	Drogue 1	Drogue 2
17		
18		
19		
20		

26. Retrieve green and black main parachute and shock cord for upper airframe
27. Check knot on cord on both sides
27. Remove rubber band from parachute
28. 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)
29. Verify quick link is connected by another individual
30. Insert Kevlar sheet protector and parachute into middle airframe
31. Attach the quick link with blue tape on shock cord to the nosecone U-bolt
33. Verify quick link is connected by another individual
34. Insert nosecone section into middle airframe making sure the shear pin holes are aligned with v's
36. Install two shear pins into middle airframe to connect nosecone to middle airframe
37. Retrieve red and white drogue parachute and shock cord for lower airframe
38. Check knot on cord on both sides
38. Remove rubber band from parachute
40. Attach quick link with no blue tape on shock cord to the avionics bay
41. Verify quick link is connected by another individual
42. Attach quick link with blue tape on shock cord to the fin section U-bolt
43. Verify quick link is connected by another individual
44. Insert Kevlar sheet protector and parachute into fin section
45. Insert middle airframe into fin section aligning the arrow for shear pins
46. Insert two shear pins into fin section using a small flathead screwdriver to connect the fin section to the middle airframe
47. Attach launch lugs and ensure they are tightened with 3/32" Allen key
48. Retrieve motor and assemble in RMS 38/600 motor casing according to manufacturer's instructions
49. Instill motor casing into motor housing
50. Rotate motor retention clips to lock onto motor over the painter's tape
51. Have Conor tighten motor retention clips with ¼" ratchet, 7/16" socket and 3" extension
52. Check CG location and verify static margin. CP is 50.05''
53. Carry assembled rocket to launch pad
54. Slide rocket launch lugs onto 10-10 launch rail
55. Erect rocket to vertical position and verify its angled into the wind
56. Flip ONE switch and verify continuity
57. Flip TWO switch and verify continuity
58. Have certified individual insert igniter into motor

59. Attach leads to igniter from control station
60. Verify which lead number is being used
61. Move to a safe location for launch
62. Observe vehicle through duration of flight trying to maintain visual contact the entire flight
63. Approach vehicle only once all components have safely returned to the ground looking for possible hazards
64. If no hazards are immediately present, carefully switch the altimeters to power off
65. Check all black powder charges to see if the charge has been detonated
66. If the charge is still present, carefully remove e-match from the cap and discard powder into an appropriate waste container
67. Once all hazards are identified and eliminated, carefully gather all vehicle components and relocate to assembly table for post-launch evaluation

Appendix 6: Vehicle Verification Matrix

Number	Requirement	Verification	Status
1.1	The vehicle shall deliver the payload to, but not exceeding, an apogee altitude of 3,000 feet above ground level (AGL).	The AeroTech K805G is projected to send the vehicle to 3486 feet. The addition of weight during manufacturing and ballast added after the full scale test flight will allow the vehicle to reach the desired altitude of 3000 feet.	In Progress. Implemented in design but not built.
	The vehicle will leave the launch rail at 55 feet per second.	Calculations have shown that the vehicle will be able to reach this velocity off of the rail. Furthermore, the first launch button leaves the rail at a minimum of 44 feet per second.	In Progress. Implemented in design but not built.
1.2	The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in the competition scoring.	Out of the 4 altimeters on the vehicle, one of the Stratologger SL100 altimeters will be used for scoring.	In Progress. Implemented in design but not built.
1.2.1	The altimeter will report the official competition altitude via a series of beeps to be checked after the flight completion.	The beeps from the Stratologger altimeter will be used to verify the altitude of the vehicle.	Completed at competition.
1.2.2.1	Official Altimeter must be marked by NASA official.	The team will ensure that the chosen altimeter is identified to the officials on the day of the competition.	Completed at competition.
1.2.2.2	The altimeter beeps must be audible to the NASA official.	The other altimeters will be turned off during scoring so that	Completed at competition.

		the competition altimeter is clearly audible.	
1.2.2.3	All electronics, except for the official altitude-determining altimeter shall be capable of being turned off.	The altimeters will be armed via switches accessible from the outside of the vehicle. Each altimeter will have its own switch.	In Progress. Implemented in design but not built.
1.2.3.1	The altitude must be reported via beeps: the altimeter must not be damaged or lose power.	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 become loose.	Completed at competition.
1.2.3.2	The team must report to NASA official with marked altimeter.	The team will ensure that the chosen altimeter is identified to the officials on the day of the competition.	Completed at competition.
1.2.3.3	The reported altitude must not be over 5000 feet AGL.	The projected ideal altitude of the chosen motor is 3486 feet. Since more weight will be added, the vehicle will not go over 5000 feet AGL.	Completed at competition.
1.2.3.4	The rocket must be flown at the competition launch site.	The rocket will be safely transported to the competition and flown at the launch site.	Completed at competition.
1.3	Launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The vehicle will be well-made so that it will be reusable. Appropriate parachute sizes will also be chosen so that the vehicle safely returns to the ground.	In Progress. Implemented in design but not built.
	The vehicle will land will little to no damage.	Proper parachute sizes have been chosen so	In Progress. Implemented in design

		that the vehicle sections will now come down with enough kinetic energy to damage the vehicle.	but not built.
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.	The vehicle will come down in 2 independent sections: the nosecone and payload compartment, and the lower airframe and fin section.	In Progress. Implemented in design but not built.
	The vehicle's independent sections will not damage other portions of the rocket in anyway upon separation.	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.	In Progress. Implemented in design but not built.
1.5	The launch vehicle shall be limited to a single stage.	The design uses a single stage. The vehicle only separates to release the parachutes after apogee.	In Progress. Implemented in design but not built.
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.	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.	In Progress. Implemented in design but not built.
1.7	The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without	The components on the vehicle are capable of remaining in the launch-ready position for more than 1 hour. The size of the	In Progress. Implemented in design but not built.

	losing the functionality of any critical on-board components.	batteries provide more than enough power to last for the minimum 1 hour requirement	
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.	The igniter used is able to be set off with a 12 V power supply.	In Progress. Implemented in design but not built.
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 of Rocketry (CAR).	The motor chosen is produced by Aerotech and is a certified motor.	Completed.
1.9.1	Final motor choices must be made by the Critical Design Review (CDR).	The motor chosen was the AeroTech K805G.	Completed.
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.	The RSO will be notified of any changes to the motor choice for approval.	In Progress. Implemented in design but not built.
1.10	The total impulse provided by a launch vehicle shall not exceed 1150 pound-seconds (L-class).	The chosen motor has a total impulse of 340 pound-seconds.	In Progress. Implemented in design but not built.
1.11	Any team participating in Maxi-MAV will be	The team will provide a model of the motor to	In Progress. Implemented in design

	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.	be used to show that the igniter system will work.	but not built.
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 supporting design documentation included in all milestone reviews.	The design does not utilize a pressure vessel.	N/A
1.12.2	The low-cycle fatigue life shall be a minimum of 4:1.	The design does not utilize a pressure vessel.	N/A
1.12.3	Each Pressure vessel shall include a solenoid pressure relief valve that sees the full pressure of the tank.	The design does not utilize a pressure vessel.	N/A
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.	The design does not utilize a pressure vessel.	N/A
1.13	All teams shall successfully launch and recover a subscale model of their full-scale rocket prior to CDR. The subscale model	The team successfully flew its subscale model on December 20, 2014.	Completed.

	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.		
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 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.).	The team plans to launch the full-scale either on February 28, 2015 or March 1, 2015.	In Progress. Implemented in design but not built.
1.14.1	The vehicle and recovery system shall have functioned as designed.	The team will do everything it can to ensure that the recovery system will work as designed.	In Progress. Implemented in design but not built.
1.14.2	The payload does not have to be flown during the full-scale test flight. The following requirements still apply:	The payload will be flown during the full-scale test.	In Progress. Implemented in design but not built.
	The payload will not	The mold will be made	In Progress.

	move more than 0.125 in within the mold.	to fit the sample exactly so that there will be minimal movement.	Implemented in design but not built.
1.14.2.1	If the payload is not flown, mass simulators shall be used to simulate the payload mass.	N/A	N/A
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.	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.	In Progress. Implemented in design but not built.
	The door will sit flush on the outside of the vehicle.	The hatch has been designed so that it will have as low a profile as possible.	In Progress. Implemented in design but not built.
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	The team will attempt to use the competition motor for the full-scale flight. If, for some reason, the motor is not available for the full-scale flight, then a comparable substitution will be made.	In Progress. Implemented in design but not built.

	maximum acceleration of the competition flight.		
1.14.4	The vehicle shall be 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.	In Progress. Implemented in design but not built.
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).	The team will not modify its full-scale rocket after the demonstration flight without the approval of the RSO.	Completed at competition.
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.	The team's budget is currently set to $10,000 in accordance with the requirements for the Maxi-MAV challenge.	Complete.
1.16.1	The launch vehicle shall not utilize forward canards.	The design does not utilize forward canards.	Complete.
1.16.2	The launch vehicle shall not utilize forward firing motors.	The design does not utilize forward firing motors.	Complete.
1.16.3	The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark,	The design nodes not utilize motors that expel titanium sponges.	Complete.

	MetalStorm, etc.).		
1.16.4	The launch vehicle shall not utilize hybrid motors.	The vehicle does not use a hybrid motor.	Complete.
1.16.5	The launch vehicle shall not utilize a cluster of motors.	The vehicle uses a single motor.	Complete.
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.	The design deploys a drogue at apogee. A main parachute is also deployed at 1000 and 700 feet AGL.	In Progress. Implemented in design but not built.
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.	The team successfully performed an ejection test before the first subscale launch, and will do the same for the first full-scale launch.	Completed. Verified by testing.
2.3	At landing, each independent section of the launch vehicle shall have a maximum kinetic energy of 75 foot-pounds.	Given the current projections, the nosecone section will have a kinetic energy of 21 feet per second, and the fin section will have a maximum kinetic energy of 24 feet per second.	In Progress. Implemented in design but not built.
2.4	The recovery system electrical circuits shall be completely independent of any	The design does not use payload electrical circuits.	In Progress. Implemented in design but not built.

	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.	The design uses 4 altimeters--two as primary altimeters and two as redundant altimeters. The primary altimeters will be Stratologger SL100 altimeters, and the redundant altimeters will be Entacore AIM 3.0. One of the Stratologgers will be used as the competition altimeter.	In Progress. Implemented in design but not built.
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.	There will be 4 switches accessible to the exterior of the rocket. Each switch will be dedicated to a single altimeter.	In Progress. Implemented in design but not built.
2.7	Each altimeter shall have a dedicated power supply.	Each altimeter will have its own new, Duracell 9 volt battery.	In Progress. Implemented in design but not built.
2.8	Each arming switch shall be capable of being locked in the ON position for launch.	Each altimeter will use a lockable 110/220 volt Rotary Selecting switch.	In Progress. Implemented in design but not built.
2.9	Removable shear pins shall be used for both 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.	In Progress. Implemented in design but not built.
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.	Each section will use a Digi XBee-Pro XSC GPS to transmit the location of the independent sections.	Complete.
2.10.1	Any rocket section, or	Both of the sections of	In Progress.

	payload component, which lands untethered to the launch vehicle shall also carry an active electronic tracking device.	the rocket will have their own electronic tracking devices.	Implemented in design but not built.
2.10.2	The electronic tracking device shall be fully functional during the official flight at the competition launch site.	Testing before the competition will make sure that the electronic tracking devices will be functional for the competition.	In Progress. Implemented in design but not built.
2.11	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The recovery system electronics will be shielded from any on-board electronic devices using bulkheads and foam where applicable.	In Progress. Implemented in design but not built.
2.11.1	The recovery system 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.	In Progress. Implemented in design but not built.
2.11.2	The recovery system electronics shall be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.	As mentioned above, the altimeters will be shielded from any transmitting devices by being put in separate compartments.	In Progress. Implemented in design but not built.
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.	There are no magnetic wave generators on board the vehicle.	In Progress. Implemented in design but not built.

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.	Proper care will be taken to ensure that the altimeters will not malfunction because of other components on the vehicle.	In Progress. Implemented in design but not built.

Appendix 7: AGSE Verification Matrix

Number	Requirement	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 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.	The current design is completely autonomous. The combination of the robotic arm and imaging system allow for the sample to be captured and placed into the vehicle. The 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.	In Progress. The design is fully developed with some components constructed while others are still being built.
3.2.1.1	Teams will position their launch vehicle horizontally on the AGSE.	AGSE starting position places the vehicle horizontally. This position can be seen in ***Figure 43***.	Completed at competition. Verified by design and setup at competition.
	While the rocket is raising, there must be a safety factor of 2.5 for the load on the stepper motor.	The max torque exerted by the rocket can be 12 ft-lb for the highest weight estimates. The stepper motor is rated for 30 ft-lb holding torque. Tests have shown the stepper motor is strong	Complete.

		enough to support the rocket.	
	The rocket must be raised in 45 seconds.	The rig built for testing the stepper motor used for raising the rocket showed it is capable of raising the rockets in 23 seconds and comes in well under the 45 second goal.	Complete.
3.2.1.2	A master switch will be activated to power on all autonomous procedures and subroutines.	The master switch will be hardwired into the system separate from the kill switch. A diagram for this subsystem can be seen in ***Figure 69***.	In Progress. Implemented in design but not built.
3.2.1.3	After the master switch is turned on, a pause 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 pause switch will halt the progression of the AGSE and can be implemented at any time. The handbook states it must activated after the master switch is turned on. A diagram can be seen in ***Figure 69***.	In Progress. 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.	The system requires only one person to operate the master and kill switch so there will only be one team member present at the pad. The remaining team members will evacuate to safe distances.	Completed at competition.
3.2.1.5	After all nonessential personnel have evacuated, the pause switch will be deactivated.	The pause switch will be turned on after safety personnel have checked all but the one designated team	Completed at competition.

		member is away from the pad.	
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 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.	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.	In Progress. Implemented in design but not built.
3.2.1.7	One team member will arm all recovery electronics.	The team lead has been chosen to arm the electronics. The rest of the team will evacuate the launch pad.	Completed at competition.

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.	Ignition procedures will be left to the LSO as specified. A master switch will be provided and used as described above.	Completed at competition.
3.2.1.9	All personnel at the launch pad will evacuate the area.	When the vehicle is ready for launch, there will be no personnel at the launch pad. Everyone will be at the safe distance determined by the officials.	Completed at competition.
3.2.1.10	The Launch Control Officer (LCO) will activate a hard switch, and then provide a 5-second countdown.	The activation of the hard switch will be left to the LCO.	Completed at competition.
3.2.1.11	At the end of the countdown, the LCO will push the final launch button to initiate launch.	Furthermore, the initiation of the launch will be done by the LCO.	Completed at competition.
3.2.1.12	The rocket will launch as designed and jettison the payload at 1,000 feet AGL during descent.	At 1100 feet, the ARRD will separate the nosecone and payload section from the lower body frame. At 1000 feet, a 2.75 feet parachute will deploy.	In Progress. Implemented in design but not built.
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	The team has ensured that all necessary components for the AGSE are implemented.	In Progress. Implemented in design but not built.

	devices, computers, electric motors, batteries, etc.		
	The igniter must be inserted in 45 seconds.	Tests conducted with the stepper motor and raising rig showed the igniter can be inserted in less than 45 seconds.	Completed. Verified by testing.
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 team arms the recovery electronics, and when the LCO initiates launch.	With the exception of the processes listed, all procedures will be controlled and initiated by the BeagleBone Black.	In Progress. Implemented in design but not built.
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.	The AGSE does not utilize a pressure vessel.	N/A
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:	The AGSE does not utilize any of the prohibited systems listed in items 3.2.3.1.1-3.2.3.1.5.	**N/A**
3.2.3.1.1	Sensors that rely on Earth's magnetic field.	Not used.	
3.2.3.1.2	Ultrasonic or other sound-based sensors.	Not used.	**N/A**
3.2.3.1.3	Earth-based or Earth orbit-based radio aids	Not used.	**N/A**

	(e.g. GPS, VOR, cell phone).		
3.2.3.1.4	Open circuit pneumatics.	Not used.	**N/A**
3.2.3.1.5	Air breathing systems.	Not used.	**N/A**
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.	The payload will be provided by the officials on the day of the competition. 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.	In Progress. Implemented in design but not built.
	The arm must move to the sample in 5 minutes (to allow for image processing).	The arm is capable of moving to a specified location near its maximum reach within 10 seconds. Less time will be needed for nearby points so the time required to move the arm fits within the requirement.	Completed. Verified by testing.
	The arm must be accurate to 0.3 inches in its movement.	Testing showed that the arm was able to reach the desired location within 0.125 inches.	Completed. Verified by testing.
	The arm must be capable of closing the door on the rocket.	The arm is capable of pressing down approximately 3 pounds of force according to tests conducted in lab. Tests show the spring on the door requires 1 pound	Completed. Verified by testing.

		of force to depress.	
	The imaging system must be capable of processing 5 images in 5 minutes.	***Figure 62*** shows images can be processed in less than thirty seconds in its worst case.	Completed. Verified by testing.
	The imaging system must reliably pick out the sample from the background.	In tests with 72 separate images, the sample was picked out from the background each time even when many other blobs were present in the image.	Completed. Verified by testing.
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.	A replica of the sample has been made according to the provided specifications for testing. However, only the sample provided from the officials will be used during the competition.	Completed at 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.	The sample will remain unmodified from the condition the officials provide it in.	Completed at competition.
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.	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.	Completed at competition.
3.2.4.5	The payload container must utilize a parachute for recovery and contain a GPS or radio locator.	The payload container will use a Digi XBee-Pro XSC GPS transmitter and a 2.75 foot Fruity Chutes parachute.	Completed. Verified by testing.
3.2.4.6	Each team will be given 10 minutes to	The team plans to raise the rocket and insert	Completed. Verified by testing.

	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.	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.	
3.2.5.1	Each team must provide the following switches and indicators for their AGSE to be used by the LCO/RSO.	As described above, 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.	In Progress. 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.	See above.	In Progress. 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.	See above.	In Progress. Implemented in design but not built.
3.2.5.1.3	A safety light that indicates that the AGSE power is turned on. 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.	See above.	In Progress. Implemented in design but not built.
3.2.5.1.4	An all systems go light	See above.	In Progress.

	to verify all systems have passed safety verifications and the rocket system is ready to launch.		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.	The above verification matrix shows that the team has accounted for all items in Section 3.2.	Completed at competition.

Appendix 8: MATLAB Script for the Robotic Arm

```
clear all; clc; close all

xscale = 0.3; % 1 for no scaling; range: (0,1]
zscale = 0.3; % 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 = 22;
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

%% Plot the arm
% calculate the locations of the nodes
xx = [0 L1*cos(theta_one)*cos(theta_base)
cos(theta_base)*(L1*cos(theta_one)+L2*cos(theta_one+theta_two))
cos(theta_base)*(L1*cos(theta_one)+L2*cos(theta_one+theta_two)+L3*cos(theta_one+theta_
two+theta_wrist))
cos(theta_base)*(L1*cos(theta_one)+L2*cos(theta_one+theta_two)+R_cam*cos(theta_one+th
eta_two+theta_wrist+theta_camera))];
zz = [0 L1*sin(theta_one) L1*sin(theta_one)+L2*sin(theta_one+theta_two)
L1*sin(theta_one)+L2*sin(theta_one+theta_two)+L3*sin(theta_one+theta_two+theta_wrist)
L1*sin(theta_one)+L2*sin(theta_one+theta_two)+R_cam*sin(theta_one+theta_two+theta_wri
st+theta_camera)];
```

```
yy = [0 xx(2)*tand(theta_base*180/pi) xx(3)*tand(theta_base*180/pi)
xx(4)*tand(theta_base*180/pi) xx(5)*tand(theta_base*180/pi)];

% plot the arm
plot3(xx,yy,zz)
hold on
scatter3(xx,yy,zz)
grid on
if (xscale == 1)
   scatter3(x,y,z)
else
   scatter3(x,y,z)
end
xlabel('X (in)')
ylabel('Y (in)')
zlabel('Z (in)')

%% 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;
pulseE = zero_position + ThetaEd/1.475;
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,10);
pulses = zeros(1,4);

for i = 1:4
   if (pulse_rem(i) >= 5)
      pulses(i) = pulse_rounded(i) + (10 - pulse_rem(i));
   else
      pulses(i) = pulse_rounded(i) - pulse_rem(i);
   end
end

pulses

% Convert the angles to degrees
theta_one = theta_one*180/pi;
theta_two = theta_two*180/pi;
theta_base = theta_base*180/pi;
theta_wrist = theta_wrist*180/pi;
```

Appendix 9: Imaging MATLAB 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