NUMAV

Maxi-MAV

Northeastern University

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Mentor

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1. Summary of CDR Report

1.1. Team Summary

Team Name: NUMAV (Northeastern University Mars Autonomous Vehicle)

Address: Northeastern University, 360 Huntington Avenue, Boston, MA, 02115

1.2. Launch Vehicle Summary

Dimension: 86 in. length and 4 in. diameter Blue Tube

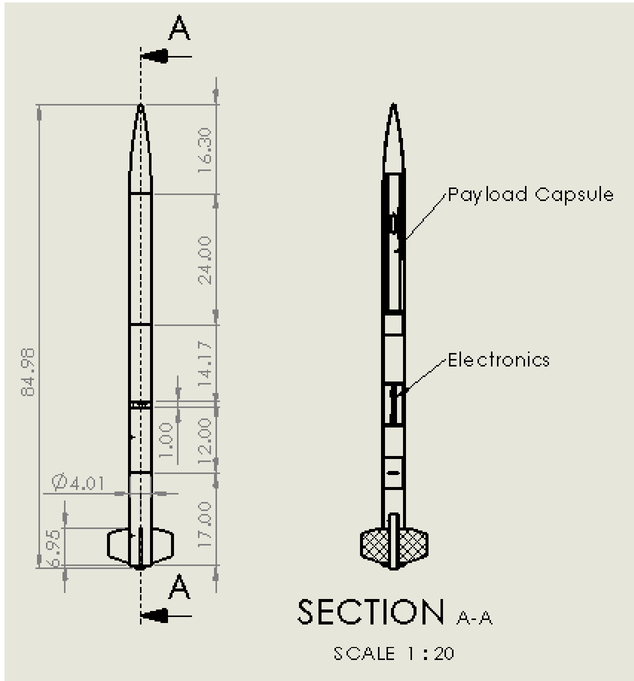

Figure 1.1: Dimensioned Drawing of Rocket

Mass: 5.75 kilograms (~12.7 lbs)

Motor: K360 - White Cesseroni

Recovery System: 18 in. drogue, deployed at apogee, 16 in. chute for payload, deployed at 1000 ft, 60 in. main chute for launch vehicle, deployed at 500 ft.

1.3 AGSE Summary

Title: Sideswipe

The AGSE will capture the payload by first scanning an area of 14.2 square feet using a multispectral camera. Using a custom image recognition algorithm, the payload's location and orientation will be relayed to the microprocessor, which will position a mobile conveyor belt in the proper alignment. Once in position, the belt will use laser-cut wooden rakes to bring the payload into a loading tray. The tray will enable the system to capture the payload and will securely hold the payload while the conveyor-tray assembly moves to the vertical belt. This belt has a laser cut cradle, which will act as an elevator and lift the payload up and allow it to roll off into the payload bay by means of a ramp.

The microprocessor will receive a signal that the payload has been inserted and will proceed to close the rocket. A wooden claw will grasp the nose cone and shut the rocket as it is driven forward on a timing belt. The rocket will push the ramp out of the way. Laser-cut snap features inside the rocket will ensure that the rocket is securely closed and ready for flight. Once the snap features are engaged, the claws will recede to make room for the rocket's erection.

Next, the solenoid latches, which hold down the rocket, will be disengaged, allowing the closed-system gas springs to lift the rocket up to a position that is 5 degrees from vertical. Finally, a threaded rod will push the motor igniter into the motor and the AGSE will pause for final inspection.

The purpose of this mission is to demonstrate the feasibility of an autonomous sample retrieval mission. NUMAV will use off-the-shelf parts coupled with custom designed software and machined, laser-cut, and 3D printed components to ensure a successful mission. The NUMAV team believes in the future of autonomous space missions and will continue to dedicate time and intellectual effort towards the exploration of the solar system.

2. Changes made since PDR

2.1. Launch Vehicle Changes

A few changes have been made since PDR, including changes to the launch vehicle and recovery systems.

After two previous 3D printed components both failed due to tolerance issues, we decided to remove the 3D printed snap feature, which held the payload bay closed. The tolerance capability of the printer was not precise enough for this application. However, we have found that laser cutting has much better precision, around 1/100th of an inch. It also allows us to inexpensively and rapidly test our prototypes. We have full access to an Epilog Zing 16 laser cutter, which we have used in the past for bulkheads and centering rings. We have decided to laser cut a wooden snap feature out of ¼ inch plywood. The snap feature is designed with an arm and flexible neck. This allows the wood to bend and snap into place. The clip-in ring, where the snap feature mates, is designed similarly to child lock tops. In order to be removed, there has to be an inward applied force and a rotational turn of 90 degrees. We are confident that this will prevent the nose cone from falling off at any time during flight. Further details and analysis are provided in the Vehicle Criteria section below. Figures can be seen in section 3.

We also decided to switch the motor from the K530 to the K360. The switch was made because the K530 gives us an expected altitude of approximately 1500 feet over our target altitude. The K360 gives us an expected apogee of 3510 feet, which only overshoots our target altitude by 510 feet. We want to overshoot our altitude because in the past we have found Open Rocket simulations are not the most accurate altitude projections, as things like wind speed, temperature, humidity, and motor tolerances are things that Open Rocket does not account for. However, it was decided that 1500 over target was too high, so we adjusted our plan to only overshoot by approximately 500 feet, and then dial in our altitude from there by adding mass.

Additionally, the parachute deployment system has been altered. In order to meet the kinetic energy requirements, the main parachute needs to be a minimum of 60 inches in diameter. In our previous design, we intended to eject the main parachute at the same time as the payload jettison event. After further drift analysis, this was deemed too high for our main chute to open (1000 feet). Therefore, we have moved the main parachute to the same section as the drogue parachute. Instead of creating another ejection event, we have decided to use the Tender Descender dual deployment system. This allows us to have a single black powder separation point, which releases the drogue parachute at apogee. The main parachute will remain stored in a bag, which will fall with the rest of the rocket. At 500 feet, the altimeter will tell the Tender Descender to let go of the rocket and pull the bag off of the main parachute. This lower altitude deployment will limit the drift, even in a worse case wind scenario. A drift analysis can be seen in the Vehicle Criteria section.

2.2. AGSE Changes

Several changes to the AGSE design have been made, yet all concepts from the PDR have been maintained. The most visible change to the design is that thinner belts have replaced all the 5.5 in rubber conveyor belts. A pair of timing belts driven by a common axle has replaced the conveyor belt that rakes in the payload. The two small belts and their supporting assembly will be significantly lighter than a conveyor. The functionality of driving the payload with rakes is maintained.

Some 3D printed AGSE components from the PDR have been changed to laser cut components. This includes the clamps that will push the nose cone shut and the supporting structure of the ramp. These changes have been made in light of the Epilog cutter's exceedingly tight tolerances and cutting speed. The snap feature will require several prototypes before an acceptable holding strength can be achieved. Prototypes of varying snap sizes can be created within minutes on the laser cutting as opposed to hours on a 3D printer.

2.3. Project Plan Changes

There were a few minor changes made to our Project Plan. Unfortunately, due to weather concerns, we've had two launch cancellations, preventing us from being able to fly our sub scale launch vehicle. The next possible launch time is January 17th with the CMASS NAR club. The necessary changes have been made in our Gantt chart.

We have also added a few more practice launches to our Gantt chart to ensure mission success. After missing the last two scrubbed launches, we feel we needed to add two more in the coming months to guarantee payload jettison success. One of the added launches will include the integration with the AGSE. This test will be full scale and staged to mirror the launch at SL by

March 28th. We have also increased the number of static tests for the AGSE. Allowing for multiple tests will help us find areas of improvement in our payload capture process.

3. Vehicle Criteria

3.1. Design and Verification of Launch Vehicle

3.1.1. Mission Statement and Mission Success Criteria

The Northeastern University student chapter of AIAA wants to push the boundaries of autonomous rocket systems. A sample retrieval mission in which autonomous robotics perform all dangerous tasks would revolutionize our accessibility to the Solar System. Through NASA's USLI competition, NUMAV plans to demonstrate unique solutions to this problem. In our demonstration, a payload will be swiftly captured and gently placed into our rocket for launch, upon which, our AGSE will then arm and fire the launch vehicle. Our prototype hopes to prove the possibilities for a sample return mission through quick and successive demonstrations.

We are focusing our design around technology that would be applicable to a Martian Environment, as per NASA's suggestions. On Mars, there are two main concerns: functionality and reliability. With billions of dollars spent on a mission to Mars, it is important to ensure maximum design reliability. Especially with all of the complex moving parts in the AGSE system, it is important for the launch vehicle to be completely dependable.

Mission success will be upheld through a number of static and live tests with AGSE and the launch vehicle. Compounded with our tests will be computer simulations and analysis. Tests that have already been completed include a demonstration of our vision recognition algorithm. Simulations have also been completed on the stress seen by our laser cut components.

Further simulations and testing will be done to ensure mission success. At least two full-scale launch vehicle tests will be completed prior to the LRR. The AGSE will also undergo rigorous testing. Both the software and hardware will be tested in a laboratory setting to accurately capture and maneuver the payload. Once a high level of confidence is met with the laboratory testing of the AGSE, a full AGSE launch vehicle integration test will occur. Our personal criteria for success is a minimum of two fully successful tests of payload capture, launch and deployment, prior to departure for Huntsville. Further stipulations for each test are listed in the respective verification sections.

3.1.2 Major Milestone Schedule

Below is a detailed list of launch vehicle milestones and their corresponding dates. An overview of all milestones can be seen in the project plan.

Milestone	**Date**	**Description**
Project Initiation	September 29, 2014	Brainstorming for launch vehicle began
Preliminary Design	October 3 - 4	Several iterations of the launch vehicle were designed in Open Rocket
Proposal	October 6, 2014	
Secondary Design	October 13 - 27	Approximate dimensions, weight, and method of payload containment was determined
Simulations	October 13 - 27	Structural load test on snap feature, Open Rocket simulations on overall design
PDR	November 5, 2014	
Additional Simulations	November 18 - December 1	Finalizing design based on PDR feedback
Manufacturing of Subscale Model	December 1-21	Subscale rocket built
Subscale Ejection Test	Tentative due to weather	Ensure all electronics are working properly and the proper amount of black powder is used

Subscale Launch	Tentative due to weather	Initial test flight
CDR	January 16, 2015	
Manufacturing of Full Scale Model	January 19 - February 2, 2015	Final rocket design built
Full Scale Ejection Test	February 1, 2015	Ensure all electronics are working properly and the proper amount of black powder is used
Full Scale Launch 1	February 13, 2015	Initial test flight
Full Scale Launch 2	February 20, 2013	Second test flight, adjustments made to reach proper height
Flight Readiness Review	March 16, 2015	
Launch Readiness Review	April 7, 2015	

3.1.3 Systems Review

Figure 3.1: Full Launch Vehicle with payload bed extended

3.1.3.1 Motor System

We will be using a 3-Grain 54mm K360 motor made by Cesaroni Technologies. This motor has a peak thrust of 405.5 N occurring at ignition. Because of this, our rocket will be in a stable flight when the rail is cleared. The motor was chosen because we estimate there will be a 10% mass increase (roughly 562 grams) from the CDR design to the finished product. This increased in the subscale model, leading us to believe there will be a similar percentage increase with the full scale.

The K360 will be held in place by a 54 mm motor tube that will be centered using 98mm OD, 54mm ID centering rings. The centering rings will be secured to the motor tube via heat resistant epoxy. An Aeropack 54mm screw-on motor retainer will actively retain the motor. This allows for easy loading into the launch vehicle.

3.1.3.1.1. Motor specifications

Total Impulse	1280.9 N·s
Average Thrust	363.6 N
Peak Thrust	405.5 N
Burn Time	3.52 s
Launch Mass	1232 g
Empty	485 g

Table 3.1: Motor Specifications

3.1.3.1.2. Motor Thrust Curve

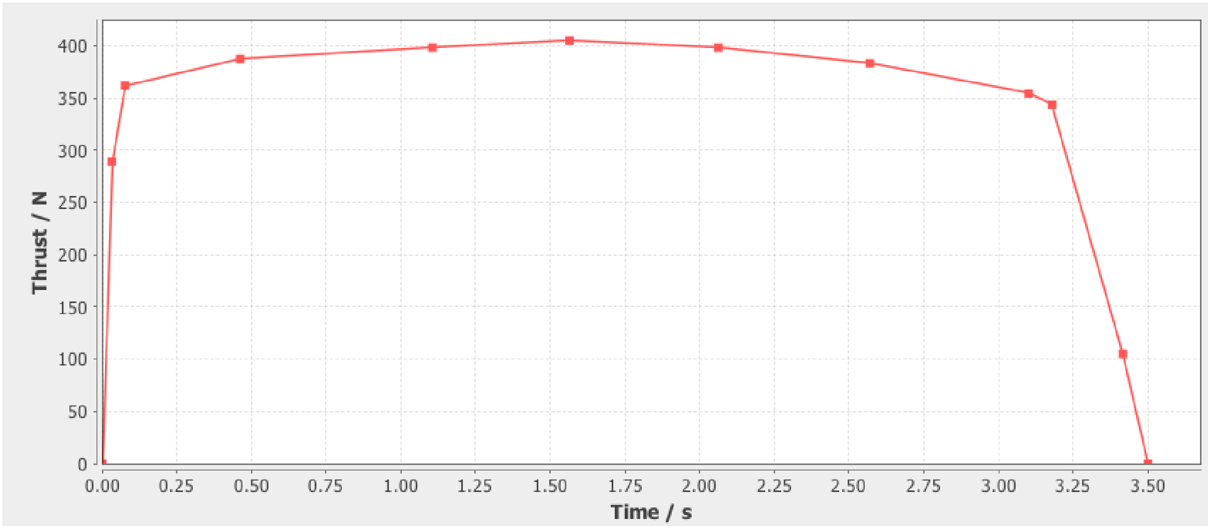

Figure 3.2: K360 Thrust Curve

A coupler tube will be epoxied to the motor bay at 18.5 in from the bottom of the bay. Half of the coupler tube will be exposed above the motor bay to allow the motor section to connect to the drogue parachute section. This coupler tube will have a ¼ in bulkhead epoxied inside it ⅓ of the way up. This will seal off the motor section from the drogue parachute ejection charges. An eye bolt will be in the center of the bulkhead, which will serve as an attachment point for the shock cord.

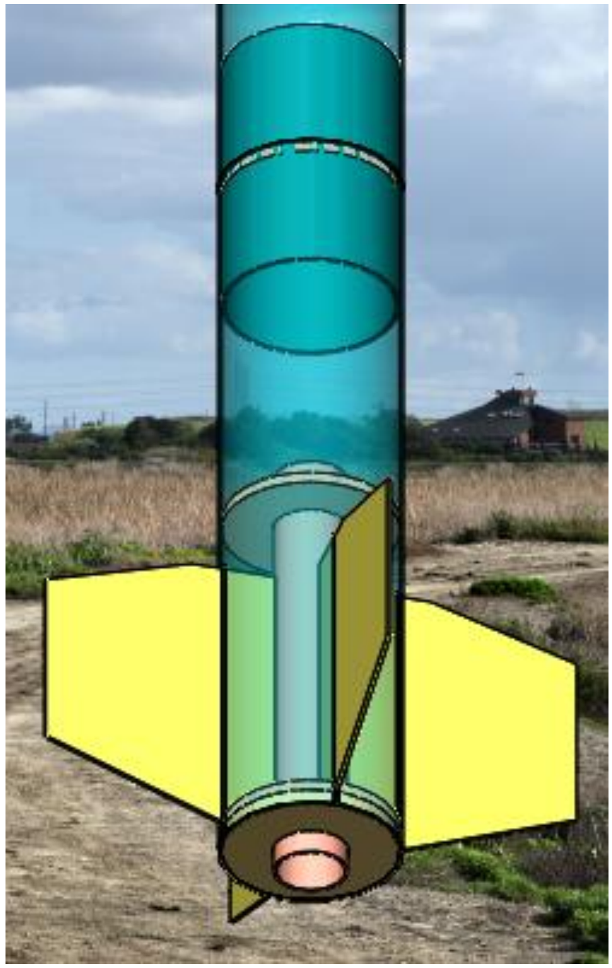
Figure 3.3: Close up view of the motor section of the launch vehicle

3.1.3.2.Recovery System

3.1.3.2.1. Main Avionics Bay

The main avionics bay will consist of an extra long piece of coupler tube with bulkheads semi-permanently secured to either end. Each bulkhead will have two 0.5 in diameter PVC end-caps to hold black powder and terminal blocks for wire connections. An eye bolt in the center of each bulkhead act as an attachment point for the shock cord. The bulkheads will be held in place by threaded rods that will run the length of the avionics bay.

3.1.3.2.2. Avionics

Inside the avionics bay will be 3 Perfectflite Stratologger altimeters and a BigRedBee GPS tracker. All electronics will be mounted to a wooden sled that will slide onto the threaded rods that run the length of the main avionics bay. In order to protect the altimeters from interference from the GPS transmitter, we plan to store the Stratologgers in a Faraday cage on the sled. To add insurance, the GPS will be mounted on top of the altimeter housing and separated by a layer of aluminum and another wooden sled. Each Stratologger is connected to a 9V battery and an electronic relay. Each relay is soldered to a set of brass screws, which will be exposed to the outside air. This allows us to arm the rocket safely and ensure all sections are closed and locked up. The relay removes a mechanical switch from arming the Strattologgers, which could be moved, and turn off the ejection system by accident. The relay requires a 5 second closed loop with two brass screws to be turned off.

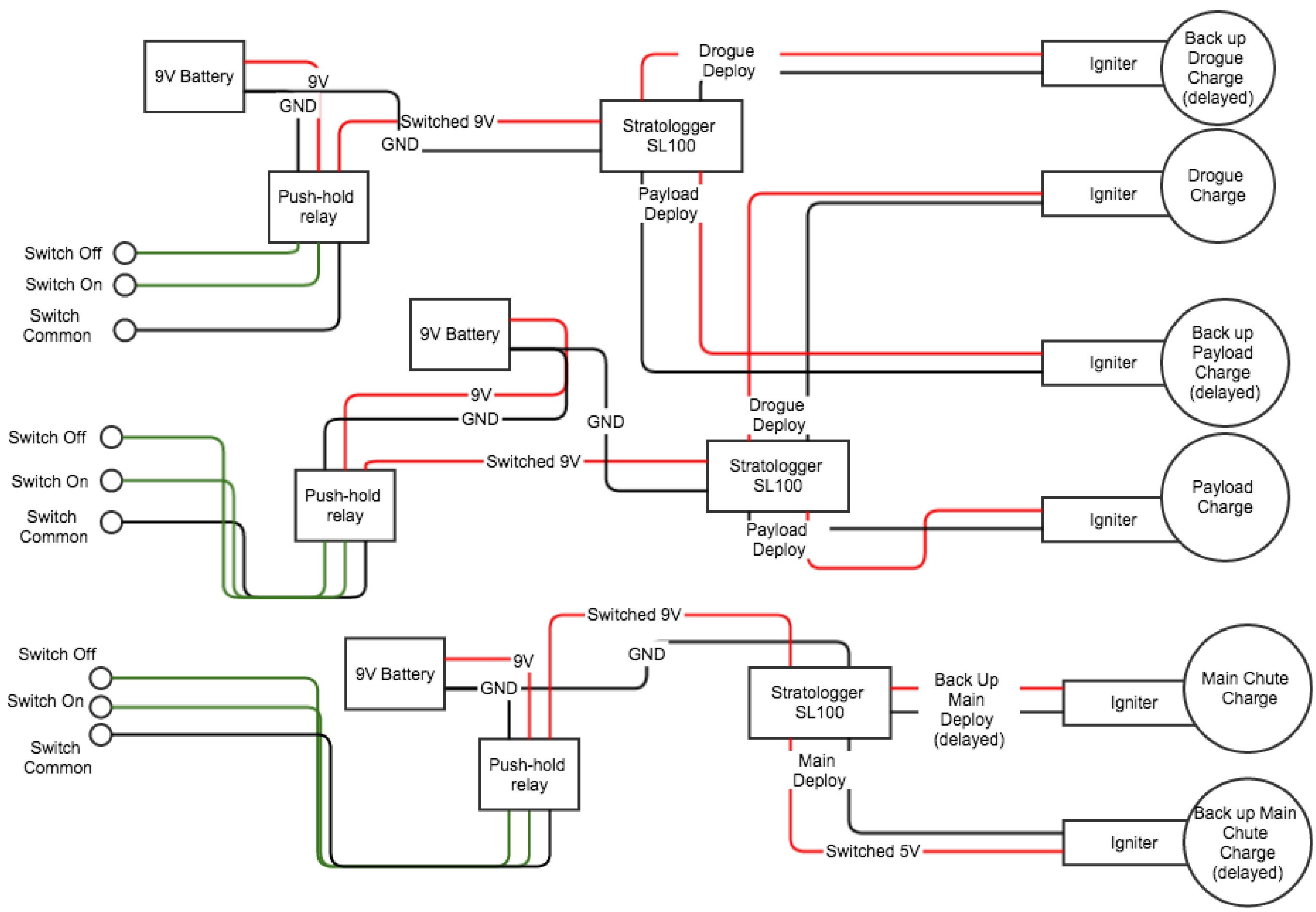

Figure 3.4: Recovery System Electrical Diagram

Stratologger SL100 Specifications:

- pressure based altimeter
- 69.85mm x 22.86mm x 12.7mm
- powered by 9V battery
- 12.76 grams without battery
- 3 events
  - 1 Apogee
  - 1 at 1000 to eject payload
  - 1 at 500 feet for tender descender to release main parachute

Big Red Bee 70cm GPS Specifications:

- Completely integrated: RF transmitter, GPS and RF antennas, GPS Module, and battery
- 56-Channel u-blox 7 GPS engine.
- Lithium-Polymer battery - 8 hours
- Transmits frequencies in the 70cm band (in 125 hz steps) (33cm band optional)
- APRS compatible -- uses standard decoding hardware
- User programmable transmit rates and output power
- Range: 20 miles line of site. (>40 miles for 100mw version)
- Flight data stored in non-volatile memory (2+ hours @ 1 hz) -- compatible with Google Earth
- 1.25" x 3", weighs about 2 ounces, and fits in a 38mm body tube (or a 54mm nose cone)
- Transmits latitude, longitude, altitude, course and speed

3.1.2.3.3. Drogue Parachute

The Drogue parachute will be a 18 inch parachute made by Fruity Chutes. It will be protected from the heat of ejection by Nomex wadding. The drogue parachute will be secured to the top of the motor stage and the bottom of the avionics bay. The purpose of the drogue parachute is to slow its descent to a safe velocity for the main parachute to deploy. At this velocity, the force of the main parachute opening will not overcome the connection between the epoxied bulkheads and the airframe.

3.1.2.3.4. Main Parachute

The main parachute, also made by Fruity Chutes, will have a 60 inch diameter. This parachute will be deployed from the same section as the drogue parachute. The main chute will be stowed in a parachute bag and held together using a Tender Descender. The Tender Descender allows us to deploy two parachutes (drogue and main) from one airframe separation. At 500 feet, the Tender Descender will release the main chute after receiving a current from the altimeter. The main parachute will be protected from ejection by a sheet of Nomex wadding. The parachute will be attached to the launch vehicle with a Kevlar shock cord. The shock cord will be secured to the avionics bay and be covered in a Nomex sheath.

3.1.2.3.5. Payload Parachute

The payload parachute, made by Fruity Chutes, will have a 16 inch diameter. The payload parachute will be protected from ejection via the Nomex wadding that lies between the Avionics bay and the payload parachute. The parachute will be attached to the payload with Kevlar shock cord that will be able to withstand the impact of the parachute opening when it is ejected at 1000.

3.1.3.3. Aerodynamics System

3.1.3.3.1. Nose Cone

The nose cone on our launch vehicle will be made out of polypropylene plastic and will be a tangent ogive shape, which is cut from a segment of a circle. It will be 16.5 inches long, and 4 inches in diameter at the base. The nose cone will be secured to the payload capsule using laser-cut snap features.

3.1.3.3.2. Body Tube

The launch vehicle will be made of 4 in diameter Blue Tube. The body tube will be 86 inches long and split into 3 main sections: the motor section (15.5

inches), the payload section (38.5 in), and the parachute section (31.5 inches). Blue Tube is a special type of body tube made by Always Ready Rocketry. It is highly durable, and it is a very popular alternative to phenolic tubing due to its high impact resistance. We have chosen Blue Tube rather than fiberglass or other materials because it is very easy to work with and very strong.

3.1.3.3.3. Fins

The launch vehicle's fins will be made out of G10 garolite composite. G10 has a significant flight history in high-power rockets. It is incredibly durable and will hold up to the impact of any hard landing while being rigid enough to retain the flight characteristics of the vehicle under high aerodynamic forces.
In order to secure the fins to the body, the body tube will have four fin slots cut in the bottom of it. The slots will allow the fins to be secured to the launch vehicle's motor mount tube and body tube with heat resistant cold-weld epoxy. As an additional strengthening measure, the internal cavities around the motor mount tube will be filled with polyurethane foam. This method provides maximum sturdiness with minimum weight. We have used the two part expanding foam in the past with impressive results.

3.1.3.3.4. Payload System

Figure 3.5: Payload Bay Extended

Figure 3.6: Payload bed sealed inside the launch vehicle (bottom)

3.1.3.3.4.1. Payload Bed

The AGSE deposits the payload into the payload bed. The bed will be made out of a 2.56 in coupler tube with a window cut into it. The window opens to a small, 5 in long compartment closed off with bulkheads on either side. This will provide an area for the payload to rest in without disturbing the electronics in the capsule. The payload bed slides in and out of a 2.56 inch Blue Tube body, which is mounted on two centering rings. This body tube acts as a sheath for the payload bay tube and covers the window when the nose cone is snapped closed.

A bulkhead will be epoxied to the bottom of the payload bed so it cannot slide past the body tube sheath. The bulkhead will not be secured to the inside of the launch vehicle, allowing it to slide around. Furthermore, this will provide an extra layer of strength, as the nose cone will be in a cantilevered position.

3.1.3.3.5 Nose Cone Hooks

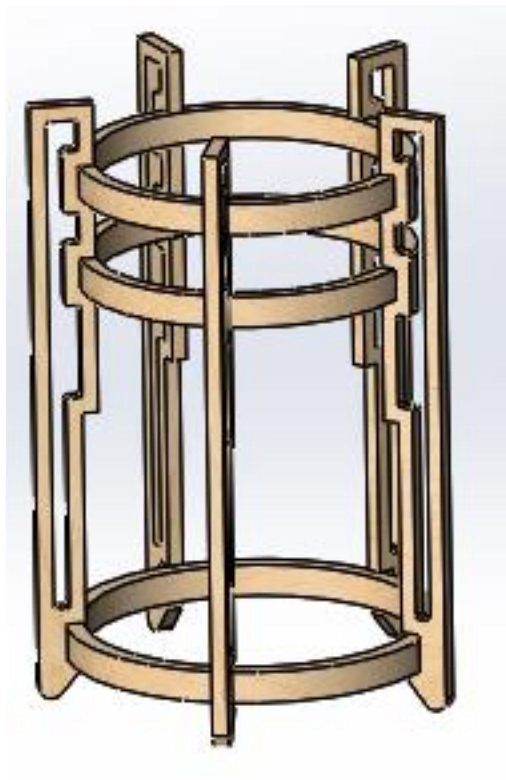

Figure 3.7: Nose Cone Snap Feature

The nose cone will be actively held in place by laser-cut snap features that will extend from the inside the nose cone (Figure 3.5). The hooks will clasp on the ring shown in the lower end of the picture and will secure the nose cone in place throughout the flight. This system allows for the launch vehicle to be sealed after the payload bed is inserted.

3.1.4. Functional Requirements

Requirement	How the design meets	Verification that

	requirement	**requirement has been met**
The vehicle must fly to a target altitude of 3000 feet.	The launch vehicle motor will provide enough thrust to exceed the altitude. Mass will then be added, allowing us to dial in the flight height.	Launch vehicle altimeter data will report peak altitude.
The vehicle must deploy a drogue parachute at apogee.	Two pressure based altimeters will be programmed to set off the drogue ejection charge at apogee.	Visible deployment of drogue parachute.
The launch vehicle must be recovered in a state where it could potentially be used again.	The vehicle's main parachute gives a projected ground hit speed of 6.7 m/s. Combined with a robust construction, this will allow the launch vehicle to be used more than once.	When the launch vehicle lands, in depth visual inspections will occur. If all critical parts are intact and all systems can be reintegrated, the vehicle is considered airworthy.
The vehicle has a maximum of 4 separate sections.	The design calls for the launch vehicle to split into three sections, one of which is the payload section. The main parachute/drogue parachutes deploy from the	Our rocket only has 3 sections. Testing the full scale rocket will show that it only splits into 3 sections.

	same section.	
The launch vehicle shall be limited to a single stage.	The design is for a launch vehicle of a single stage. Only one motor is going to be inserted into the launch vehicle.	-
The launch vehicle shall be capable of remaining in a launch ready configuration for a minimum of 1 hour without losing functionality.	The launch vehicle will have switches that will enable us to turn the altimeters off in the case of an extended launch delay, as it would be unsafe to leave altimeters armed on the launch pad for an extended period of time.	We will do tests with our rocket without ejection charges that test the time our vehicle can sit on the launch pad.
The launch vehicle will be capable being launched by a 12 volt DC firing system.	Our motors use standard e-match igniters, which can be activated by a standard 12-volt launch system.	FRR tests will prove that vehicle will launch with a standard 12 volt DC firing system.
The launch vehicle will use a commercially available solid launch vehicle motor propulsion system using ammonium perchlorate composite propellant which is approved and certified by the National Association of Rocketry, the Tripoli	The Cessaroni K350 is a commercially available motor that has been certified by CAR.	-

Rocketry Association, or the Canadian Association of Rocketry.		
The total impulse of the motor shall not exceed 5,120 Newton-seconds (L-class).	The impulse of a K530 motor is 1414 N*s.	-
An inert or replicated version of the motor must be available for LRR to ensure the motor igniter ignition system functions.	-	-
Pressure vessels on the vehicle shall be approved by RSO and meet the criterion described in the USLI handbook SOW Section 1.12.1-1.12.4.	Our design does not include any pressure vessels to be included in the launch vehicle.	There will be no pressure vessels in our launch vehicle.
A subscale model of the launch vehicle must be flown prior to CDR.	-	We were unable to launch the vehicle because two launches were scrubbed due to weather. We will launch the scale model as soon as possible after CDR.
A full scale successful launch and recovery shall	-	Videos will be taken of the successful

occur by FRR. The flight will comply with all the requirements in section 1.14.1-1.14.5 in SOW.		flight and included in the FRR presentation.
There is a $10,000 maximum budget for everything that sits in the launch area.	The parts list of the current design does not exceed $10,000.	A full bill of materials will be included in every report. The final BOM will not exceed $10,000.
The vehicle will not have any of the prohibited items described in section 1.16 in SOW.	None of the items labeled prohibited are part of the current design.	The safety check will establish and confirm that none of the items labeled prohibited are part of the design.

3.1.5. Mass Statement

Component Mass (g) Nose Cone 300 Payload Tube 326.8 Tube coupler 123.2 Bulkhead 10.2 Sample capsule 113 Payload tracking equipment 100 Main Tube 294 Main parachute 13320 Shock cord 390 Thermal wadding 22.2 Payload thermal wadding 22.2 Payload shock cord 390 Payload parachute 11.3 Electronics Bay 601.8 Coupler 123.2 Drogue Tube 253 Thermal wadding 32.1 Shock cord 293 Drogue parachute 284 Motor Module 595.1 Tube coupler 123.2 Bulkhead 16.3 Motor mount tube 16.8 Centering ring 13.3 Centering ring 13.3 Fin set 222 Total Mass 4823 Table 3.5:

All the masses in this estimate are based off of the specifications of the items found on the Apogee Rockets website except for the weight of the electronics in both the payload and the electronics bay which were estimated to be about 100 grams and 600 grams respectively, based on previous as-built designs. This estimate is very accurate in terms of the components but does not take into account masses such as the amount of hardware or epoxy used in the system. We placed a margin in the system to account for growth using the 25%-33% growth rule of thumb and we have enough room left to add 33% of our current weight and still reach the target altitude of 3000 feet.

3.1.6. Safety and Failure Analysis for Launch Vehicle and Recovery System

The bulk of this section is described below. We will cover all of the failure modes of the rocket and the recovery system. This includes, but is not limited to, possible failures such as a parachute not deploying and accidental motor ignitions. Each of the failure modes are rated using a standard scale in how likely it is to happen and how hazardous each of the failure modes are. See section 3

3.1.7. Workmanship as Related to Mission Success

In order to complete the mission successfully, our team has relied on prior tests and extensive analyses rather than simple trial and error methodology. Whenever possible, we have relied on computer simulations to model the anticipated performance of the AGSE and launch vehicle. For example, an extensive simulation using SolidWorks determined that the AGSE assembly will not tip over in the presence of high winds at the launch site. We also used Open Rocket to simulate the flight path of our launch vehicle to ensure that it reaches 3000 feet without significant horizontal drift. Dozens of mathematical analyses on various design components ensures that they will perform as anticipated.

In order to ensure safety and success when launching the rocket, we rely on literature and calculations to determine the correct amount of black powder needed. This circumvents a potentially dangerous trial and error method. We also complete static ground tests before actually launching the rocket.

When machining the parts, we plan on implementing careful planning and a "measure twice, cut once" mindset to prevent errors and save time. This ideology will also save money because we will be able to minimize the amount of raw materials we need to buy.

3.1.8. Remaining Assembly and Manufacturing

The full-scale launch vehicle is currently in the early stages of assembly. At the moment, we are working on acquiring all of the supplies needed to assemble the vehicle in its entirety. We still have to machine the fin and body tube parts, custom design and manufacture centering rings and bulkheads, and laser cut our custom wood clips as seen in Figure 3.7 (above).

The electronics bay, and the electronics contained within the vehicle, are also currently in development. Many of our electronics will need to be wired and soldered prior to final mechanical assembly. These parts will require extra attention to detail in final assembly, as the area they will be mounted to is very small.

All custom parts necessary for the vehicle have been designed and are currently scheduled to be manufactured. After all of the pieces have been acquired, we can begin the final assembly. This includes many sub-assemblies that will need to be assembled further into the final launch vehicle. These sub-assemblies include the motor tube configuration, the electronics bay, and the payload assembly. After this stage of assembly is completed, final integration steps can begin. This includes assembling the rocket in its entirety and connecting the sections with set screws and shear pins. In the last step of assembly, we will insert the parachutes and Nomex wadding. The rocket will then be prepared for launch.

3.2. Test/Analysis of Launch Vehicle

3.2.1. Drift Analysis

Open rocket software, which is the freeware we used to design our launch vehicle, allows us to run drift predictions based on varying wind speeds. As noted by weatherspark.com [1] the highest average wind speeds for the month of April in Huntsville Alabama since 1974 were 22.4 mph. Using this knowledge,

Best Case					
Wind Speed (mph)	Lateral Distance (Motor) (ft)	Lateral Distance (Payload) (ft)	Ground Hit (ft/s) Payload	Ground Hit (ft/s) Motor	Launch Rod Direction
0	859	831	27.5	13.75	Into Wind
5	727	672	27	14	Into Wind
10	462	438	27.5	14	Into Wind
15	105	175	27.9	14.8	Into Wind
20	415	265	27.9	12.79	Into Wind

Worst Case					
Wind Speed (mph)	Lateral Distance (Motor) (ft)	Lateral Distance (Payload) (ft)	Ground Hit (ft/s) Payload	Ground Hit (ft/s) Motor	Launch Rod Direction
0	859	831	27.5	13.75	With Wind
5	938	953	29.5	16	With Wind
10	962	997	27.5	13.6	With Wind
15	1372	1427	27.8	15.6	With Wind
20	1855	1931	27.6	13.12	With Wind

we performed a worse case wind scenario of 25 mph. Below are two tables with drift predictions for the payload capsule and the launch vehicle. The simulation helped us come to the conclusion that we needed to deploy our main parachute at a lower altitude, which is why we decided to implement a Tender Descender.

3.2.2. Impact Analysis and Testing

Both the payload capsule and launch vehicle were scrutinized to ensure they met to 75 foot*lbs (101.68 Joules) requirement imposed by NASA. Below is a table of the ground hit velocity for each section, and their respective kinetic energies.

	Payload	Motor
Kinetic Energy on Impact (ft*lbs)	47.99	27.63

Structural analysis was done on the payload section due to the intricate laser cut snap feature in the nose cone. The nose cone material is not as durable as blue tube and allows more for flexing. We ran an impact test on this section of the rocket in SolidWorks using our ground hit velocity found in Open Rocket. Below it was figure of the test. The results showed that the stress seen by the nose cone was exceedingly low. We concluded that the epoxied bond between the snap feature and the nose cone will not be under enough duress to be damaged.

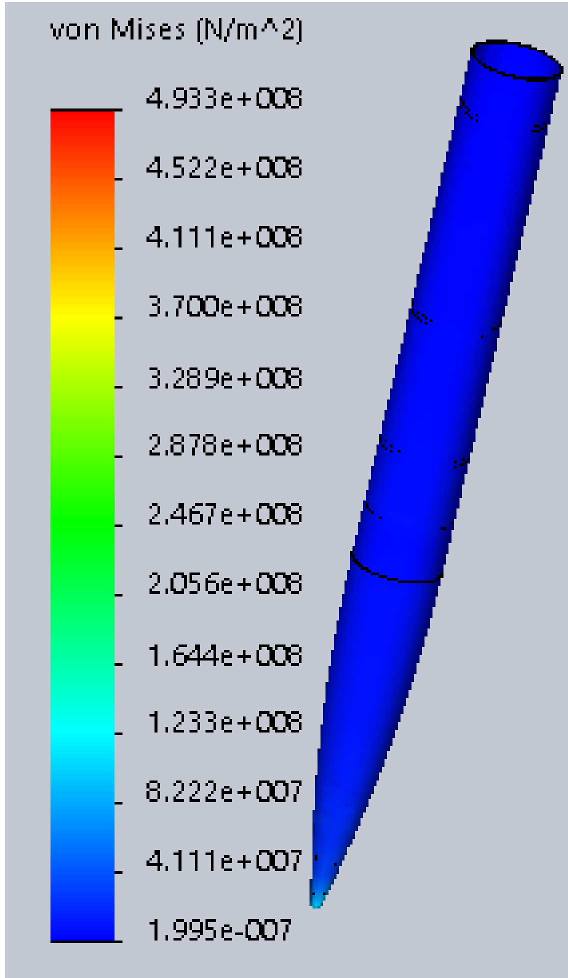

Figure 3.8

3.2.3. Additional Component and Static Testing

Prior to every launch, a stat ejection test will be performed to ensure all electronics are working properly and wired correctly. We use a program created to calculate the amount of black powder needed for ejection, depending on the volume of the pressurized section. This provides us with an accurate amount for each section that needs to separate.

The static tests are run in an open field, using straps told hold the rocket to a heavy fixture. The e-bay is wired to a computer, which is at a safe distance from the test thanks to a 30 ft long mini USB cable. These static ejection tests have been very beneficial in the past. Often times our program has provided us a mass of black powder, which was too small, or too big. The static test helps us hone in on a more precise amount of charge we use. This procedure leaves us with complete confidence that our rocket will separate.

Both the payload and Launch vehicle will be transmitting GPS data to our ground station. Telemetry allows us to have fewer wires in our rocket, which of course have the potential to be damaged or unplugged. We are planning for a location update from our on board GPS transmitters every 5 seconds. All this data will be received and uploaded in real time allowing us to monitor both sections trajectories. Both of these, along with the rest of the avionics, will be fully tested in the lab prior to use.

We will be implementing a faraday cage to our avionics in the launch vehicle to prevent our transmitter from prematurely triggering our altimeters/e-matches. The system will be tested in a laboratory, static test. Our avionics will be wired up, in a controlled environment, without black powder. Using an ammeter, we will measure if there is any signal penetrating our faraday cage as we transmit GPS data across the room.

3.3. Mission Performance Criteria

The launch vehicle must be loaded with a payload, sealed, erected to five degrees off of normal, and launched to an altitude of 3000 feet above the ground. Next, it must deploy a drogue parachute at apogee and then deploy the payload, or a section containing the payload, at 1000 feet. Finally, the launch vehicle must deploy its main parachute and touchdown with less than 75 ft*lbs of kinetic energy.

In order to be successful, the launch vehicle and payload must be fully recoverable and able to fly again without any major modifications or repairs. The launch vehicle must not exceed an altitude of 5000 feet. It must also be recovered an acceptable distance from the launchpad, as the further away from the launchpad the vehicle goes, the more likely the launch vehicle could land in an unrecoverable location.

3.3.1. Launch Vehicle Profile

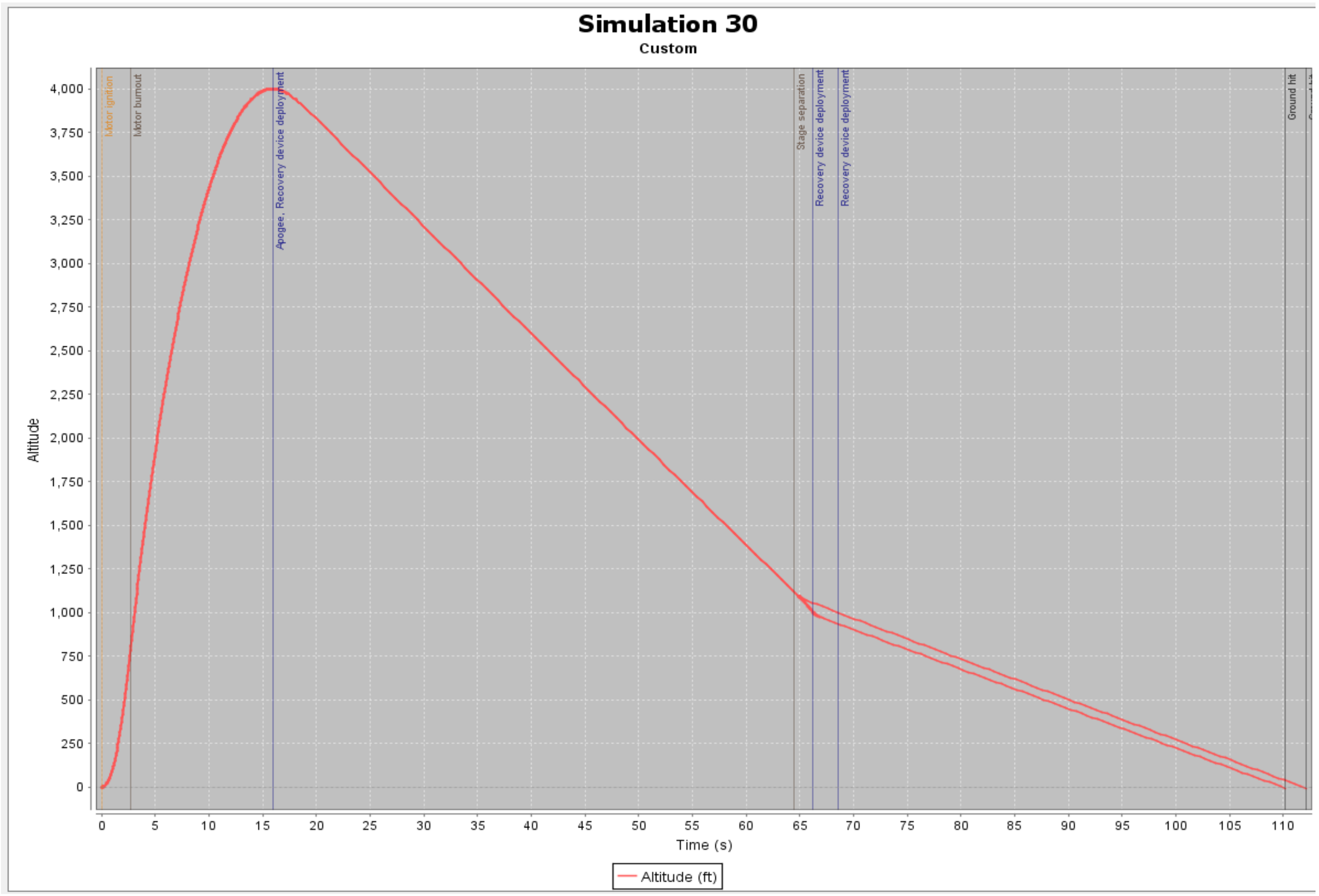

Figure 3.9: Launch Vehicle flight profile

Figure 3.9 is a simulation of our launch vehicle's flight profile from OpenRocket. The launch vehicle currently has an apogee of 4016 feet, which gives us a bit of tolerance with respect to mass.

3.3.2. Static Stability Margin

The static stability margin for our launch vehicle with the chosen motor was calculated to be 2.36 calibers. We found this value using an Open Rocket simulation.

3.3.3. Kinetic Energy on Impact

We calculated kinetic energy as $0.5*m*v^2$ where v is the ground hit velocity in m/s and m is the mass in kg. We obtained the following values:

The payload section will hit the ground at approximately 3.18 m/s, with 4.91 J (3.62 ft*lb) of kinetic energy.

The main body section will hit the ground at approximately 6.7m/s with 90.26 J (66.5 ft*lb) of kinetic energy.

Section	Descent Rate (m/s)	Energy (J)	Energy (Ft*lbs)
Main Body	6.7	90.26	66.5
Payload	3.18	3.18	3.62

Table 3.2

3.3.4. Launch Vehicle Drift

The values in table 3.2 were determined from simulations in Open Rocket based on a launch rail angled 5 deg into the wind.

3.3.5. Assembly Procedures

1. Cut rocket body into tubes
2. Cut fin slots in rocket
3. Cut fins
4. Laser cut centering rings and bulkhead
5. Epoxy centering rings to motor tube
6. Epoxy motor tube and centering rings into rocket
7. Epoxy fins to motor fins
8. Epoxy coupler tube to top of motor section
9. Epoxy motor bulkhead with eye bolt to middle of coupler tube
10. Assemble electronics bay
11. Insert avionics in avionics bay
12. Wire avionics
13. Attach shock cords to respective eye bolts
14. Attach main parachute to shock cord above electronics bay
15. Attach drogue parachute to shock cord

16. Drill holes for set screws and shear screws
17. Screw in set screws and shear screws

Two rail buttons will connect the launch vehicle to the launchpad. These buttons will help guide the launch vehicle off the launchpad to ensure it leaves the pad in a straight manner and give it some initial vertical momentum. The launch rail is made of 10-10 aluminum.

3.4. Interfaces and Integration

It is critical that all parts of the vehicle are able to interface properly with each other. In order to ensure this, the vehicle has been designed so that the payload is completely compatible with the launch vehicle. As seen in the design, the payload bay is in the body of the vehicle. This design enables the vehicle to interface directly with the payload. It also allows easier final stage assembly as the body tubes are concentric and designed to be placed within one another using centering rings. We felt this eased our insertion over custom made payload capsules

This allows us to concentrate on the interfaces on the inside of the vehicle, such as between compartments or separate subsystems. In order to do this, we designed the vehicle so that all separate systems can fit together easily. Each of the different sections of the rocket will be designed with standard pieces that can be purchased online and have been machined to fit together. The sections of the rocket will need to have enough tolerance to slide together easily, but also fit tightly enough to not come apart easily. We designed the rocket sections on the large size and corrected for snugness with other methods such as screwing the sections together with either metal screws (for sections meant to remain connected throughout the flight) or nylon shear pins. These screws are designed to break at a determined shear force from an ejection charge but are strong enough to hold the sections together during set-up and flight.

It is also important during design to consider how the vehicle will interface with the ground while in flight, during descent, and after landing. The launch vehicle will be monitored in real time from our ground station using a telemetry system. Both the payload capsule and the launch vehicle have GPS tracking devices. Each will be wired with a X-bee radio communication unit, which allows for wireless data transfer. The ground station will receive real time data from each Stratologger, providing altitude and velocity data, as well as ejection events. Our team will be able to track the rockets location, stability, and progression from the safety of our computers.

The final consideration for interfaces and integration is how the launch vehicle will interface with the launch system. This includes all aspects including: the launch rail and the rail buttons, the igniter insertion, the closure system, and the payload loading system. It is designed to interface smoothly so loading and launching processes work as intended. The automated closure drive uses laser cut wedges with the same profile as the nose cone for an easy mate and closure. The payload is placed in the rocket using a ramp which is designed to rest on the rocket during insertion. The ramp is fixed to hinges which allows it to be moved out of the way as the gas springs lift the entire rocket and launch rail. The AGSE also contains a thermally shielded trench where the rocket lifts. This compartment houses the hot gases from motor ignition and contains a small lightweight hinged door for the gasses to escape. The trench will be lined with aluminum to allow for thermal dissipation throughout the frame. All these components work with one another seamlessly to ensure the rocket will be prepared for launch.

3.5. Confidence and Maturity of Design

In the past six months, we have experimented with launch vehicles that deploy payloads mid-flight, so we are very confident in our current launch vehicle design. The vehicle design that we tested this summer is very similar to our NUMAV design.

The launch vehicle will need to have an apogee as close to 3000 feet as possible; it must not exceed 5000 feet. In order to dial in on this height, we will have multiple full scale test launches to adjust the mass and mass distribution in our launch vehicle. The launch vehicle will deploy the drogue parachute at apogee and the payload capsule at 1000 feet. The main parachute will be released from a Tender Descender deployment bag at 500 feet. The Tender Descender allows us to have two parachute events in a single airframe separation event. We have three altimeters in our avionics bay to control each altitude event and allow for redundancy. Each event has a dedicated altimeter, as well as a back up charge firing 10 feet after the planned ejections. This is a common practice and we have used it before with a 100% flight success rating.

Another feature of the launch vehicle is the payload bed design. The payload will be inserted in this area of the launch vehicle by the AGSE. The AGSE will then push the nose cone into the launch vehicle, seal the vehicle, and ready it for launch. We have tested two prototypes and determined that our current design is optimal with respect to strength and reliability.

3.6. Environmental Safety and Analysis

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3.6.1. Safety Officer Responsibilities

The safety officer is responsible for monitoring team activities during the design, construction, and assembly of the vehicle and launcher. Safety personnel will also supervise the ground, subscale, and full-scales tests, as well as the competition launch ensuring that all launch recovery activities take place safely. In addition, the safety officer will oversee the educational engagement activities.

The safety officer will supervise the implementation of procedures developed by the team for construction, assembly, launch, and recovery activities. The officer will also manage and maintain current revisions of the team's hazard analyses, failure mode analyses, procedures, MSDS/chemical inventory data, and other safety related documents. In addition to these documents, the safety official will assist in the writing and development of the team's hazard analysis, failure mode analysis, and procedures.

The safety presentation and corresponding quiz is administered by the safety official. This presentation covers all of the methods for creating a safe workspace including tool safety, chemical safety, material safety, and personal safety among others. The quiz consists of 20 multiple choice questions covering the material from the presentation. All team members have to pass the quiz with a score of 80% in order to participate in any construction or testing activities.

3.6.2. Launch Checklist

1. Rocket Assembly
    1. Electronics bay assembly
        1. Attach primary altimeter to altimeter sled.
        2. Attach main parachute primary ejection wires to the main output on the primary Stratologger altimeter.
        3. Attach drogue parachute primary ejection wires to the drogue output wires on the primary altimeter.
        4. Attach secondary altimeter to altimeter sled.
        5. Attach main parachute secondary ejection wires to the main output on the secondary altimeter
        6. Attach drogue parachute secondary ejection wires to the drogue output on the secondary altimeter.
        7. Attach 9-Volt batteries to the primary 9-Volt battery leads.
        8. Attach 9-Volt batteries to the secondary 9-Volt battery leads.
        9. Insert altimeter sled into electronics bay.
        10. Attach bottom bulkhead and insert threaded rod through the guide tubes on the bottom of the altimeter sled

11. Attach top bulkhead.
12. Secure bulkheads with lock washers and nuts.
13. Connect primary main parachute ejection charge igniter to top bulkhead terminal block.
14. Put the igniter end of the primary main parachute ejection charge igniter into the primary main parachute ejection charge cap.
15. Pour 1.75 gram of black powder into the main parachute primary ejection charge cap.
16. Seal the primary main parachute ejection charge cap with masking tape.
17. Put the igniter end of the secondary main parachute igniter into the secondary main parachute ejection charge cap.
18. Pour 1.75 gram of black powder into the secondary main parachute ejection charge cap.
19. Seal the secondary main parachute ejection charge cap with masking tape.
20. Flip over the electronics bay. Ensure that the black powder does not leak.
21. Connect primary drogue parachute ejection charge igniter to top bulkhead terminal block.
22. Put the igniter end of the primary drogue parachute ejection charge igniter into the primary drogue parachute ejection charge cap.
23. Pour 1.75 gram of black powder into the drogue parachute primary ejection charge cap.
24. Seal the primary drogue parachute ejection charge cap with masking tape.

25. Put the igniter end of the secondary drogue parachute igniter into the secondary drogue parachute ejection charge cap.
26. Pour 1.75 gram of black powder into the secondary drogue parachute ejection charge cap.
27. Seal the secondary drogue parachute ejection charge cap with masking tape.
28. Proceed to Parachute and rocket assembly.

2. Parachute System and Rocket Assembly
    1. Attach main parachute shock cord to main parachute shock cord eye bolt.
    2. Attach main parachute flame protector about ¾ of the way down the main parachute shock cord.
    3. Secure main parachute fireproofing with a knot.
    4. Conduct a pull test to ensure that fireproofing is secured.
    5. Attach main parachute swivel about ½ way down main parachute shock cord.
    6. Secure main parachute swivel with knot.
    7. Ensure that main parachute is not tangled.
    8. Secure main parachute to main parachute swivel; attach with a secure knot.
    9. Ensure that main parachute is secured to the main parachute swivel; conduct a pull test to verify.
    10. Fold main parachute.
    11. Wrap main parachute fire-protection around the bottom end of the main parachute.
    12. Insert main parachute, fire proofing, and shock cord into the bottom of the payload bay.
    13. Insert the top of the electronics bay into the bottom of the payload bay.

14. Secure electronics bay to payload bay with nylon shear pins in the appropriate holes.
15. Attach drogue parachute shock cord to drogue parachute shock cord eye bolt.
16. Attach drogue parachute flame protector about ¾ of the way down the drogue parachute shock cord.
17. Secure drogue parachute fireproofing with a knot.
18. Ensure that fireproofing is secured; conduct a pull test to verify.
19. Attach drogue parachute swivel about ½ way down drogue parachute shock cord.
20. Secure drogue parachute swivel with knot.
21. Ensure that drogue parachute is not tangled.
22. Secure drogue parachute to drogue parachute swivel, attach with a secure knot.
23. Ensure that drogue parachute is secured to the drogue parachute swivel; conduct a pull test to verify.
24. Fold drogue parachute.
25. Wrap drogue parachute fire-protection around the bottom end of the drogue parachute.
26. Insert drogue parachute, fire protection, and fireproofing into the top of the drogue parachute section of the rocket.
27. Insert the bottom of the electronics bay into the top of the drogue parachute section of the rocket.
28. Secure the bottom of the electronics bay to the top of the drogue with nylon shear pins.

3. Vehicle Final Assembly
    1. Insert top of motor section into bottom of drogue parachute section.

    2. Secure the motor section to the drogue parachute section with metal set screws.
    3. Continue to checklist 2.
2. AGSE Assembly
    1. AGSE Initial Electrical Checklist
        1. Master Power Switch OFF
        2. Assemble all components in proper starting positions
        3. Tension Belts
        4. Examine electrical connections and wiring
        5. Evacuate personnel from operation area
        6. Set Program switch to 'Diagnostic' Mode
        7. Master Power Switch ON
        8. Observe AGSE activity for operation within normal limits
        9. Master Power Switch OFF
        10. Make adjustments and repeat 2.1.6 - 2.1.10 as necessary
        11. Set Program switch to 'Run' Mode
        12. Master Power Switch ON
    2. AGSE Mechanical setup
        1. Ensure all batteries are charged and disconnected.
        2. Bring payload elevator to its bottom starting position.
        3. Put mobile belt in home position.
        4. Rotate rakes to rake starting position.
        5. Bring belt to vertical starting position
        6. Check camera alignment with ground.
        7. Check filter alignment with camera.
        8. Return igniter loader to lowest starting position.
        9. Attach igniter to igniter loader head.
        10. Run igniter wires through fume door.
        11. Shut the front door.
        12. Move nose-cone pusher to home position.

13. Angle launch rail so that rocket until team members can reach tip
14. Put vehicle on launch rail.
15. Raise launch rail to firing position to check motor igniter alignment.
16. Lower launch rail to horizontal position.
17. Ensure rail is locked in position with solenoid latches.
18. Unscrew motor retainer.
19. Insert motor into launch vehicle.
20. Screw motor retainer.
21. Ensure motor is locked in place.
22. Ensure payload bay is open.
23. Lower payload ramp into payload bay.
24. Shut top door.

3. Final Integration & Inspection
    1. Verify all set screws on launch vehicle are screwed properly.
    2. Verify all nylon shear pins on launch vehicle are properly inserted.
    3. Verify AGSE is in proper starting position and has power.
    4. Wait for NASA inspector to give final "GO" for launch.

3.6.3 Hazard Analysis

Likelihood scale (from least to most probable): Probable, Remote, Extremely Remote, Extremely Improbable

Severity scale (from least to most severe): No safety effect, Minor, Major, Hazardous, Catastrophic

Hazard	Effect	Proposed Mitigations	Likelihood	Severity

Accidental Motor Ignition	Potential Injury to Personnel	Follow MSDS storage, transportation, and handling requirements	Extremely Remote	Hazardous
Drogue Parachute fails to deploy	Potential System Damage	Correctly measure and double check black powder amounts and confirm altimeter functionality and igniter connections	Extremely Remote	Minor
Main Parachute fails to deploy	Potential System Damage	Correctly measure and double check black powder amounts and confirm altimeter functionality and igniter connections	Extremely Remote	Minor
Explosive Motor Failure on launchpad	System Damage	Transport and handle motors in a safe manner as the MSDS dictates. Keep personnel at safe distance from launchpad during launch sequence (Minimum 200 feet per NAR High Power Safety Code). Check motor casing before every use.	Extremely Improbable	Major
Total Recovery System failure	System Damage & Potential Injury to	Correctly measure and double check black powder amounts and confirm altimeter	Extremely Improbable	Hazardous

	Personnel	functionality and igniter connections		
Payload does not deploy	None	Correctly measure and double check black powder amounts and confirm altimeter functionality and igniter connections. Payload will simply descend inside the rocket and is not a hazard but is still a system failure	Extremely Remote	No Hazard
Payload Parachute does not deploy	System Damage & Potential Injury to Personnel	Correctly measure and double check black powder amounts and confirm altimeter functionality and igniter connections	Extremely Remote	Minor
Shock Cord Failure	System Damage & Potential Injury to Personnel	Inspect shock cord thoroughly before flight	Extremely Improbable	Major
Humidity	System damage due to expansion of coupler tubes	Design rocket with tolerances for expansion of parts due to humidity	Extremely Improbable	Minor

In addition, for all launches, we will follow the NAR High power safety code guidelines to avoid potential injuries or hazards to launch personnel and to persons not involved in the launch. In accordance with these guidelines, we will adhere to a minimum distance of 1500 feet between our launch pad and any trees, buildings, or power lines.

3.6.4. Personnel Hazard Analysis

Hazard	Effect	Proposed Mitigations	Likelihood	Severity
Hand Tools	Potential bodily harm	Training of all members on proper handling	Remote	Major
Epoxy Usage	Respiratory and eye irritation	Ventilation hood	Remote	Minor
Heavy - machinery	Possible appendage loss and general injury to personnel	Only members trained to use the heavy machinery will be allowed to use it	Extremely Remote	Hazardous
Defective Tools	Serious injury to personnel	Inspect tools prior to use	Extremely Remote	Major
Defective Personal Protective Equipment	Serious injury to personnel	Inspect PPE prior to use. Maintain proper supply of PPE	Extremely Remote	Major
Fire	Serious injury to personnel and	Training of members on fire safety.	Extremely Remote	Hazardous

	equipment	Maintain proper Fire PPE		
Slipping	Minor Injuries	Avoid spillages of any kind and	Remote	Minor
Heavy lifting	Minor Injuries	Use groups for lifting heavy objects. Emphasize proper lifting techniques.	Remote	Minor
Exhaustion	Minor Injuries	Maintain schedule and avoid last minute cramming	Probable	Minor
Electric Shock	Minor Injury to personnel	Install electronics safely and take steps to ensure user safety on all electronic devices	Remote	Minor

3.7. Environmental Concerns

We will be using components and materials in our AGSE and on our launch vehicle that can be considered hazardous to the environment. Two 12V lithium batteries will be used to power our AGSE operations; if these batteries leak or break they could present a hazard to the environment. We will avoid this by handling the batteries in a safe manner and having a neutralizing agent, such as baking soda, nearby in order to neutralize any potential leak. We also have 9V batteries on board our rocket, which require a similar procedure, to use in case anything happens to the lithium batteries. All batteries will be recycled after use. The 12V batteries are rechargeable and will be recycled at the proper locations when they can no longer take a charge.

We will be using black powder charges on our rocket to eject the parachutes and payloads. Spilled black powder will have a negative impact on the environment. In addition to storing the black powder in a safe, dry place as per safe black powder storage rules, we will also be using igniters to ignite our ejection charges and motor. These will be stored in alignment with the rules laid out in the MSDS for the igniters and will be disposed of in inert trash after usage to avoid any unnecessary impact on the environment.

Another major concern for our rocket launches is the effect the rocket motor will have on the environment. Unfortunately, the ecotoxicity of the Cesaroni motors is not determined (via the Pro 54 MSDS). To avoid any negative environmental effects, steps will be taken to minimize the motor's impact on the environment. Flame retardant mats or tarps will be placed beneath our launch pad in order to avoid singeing the surface below, and a metal launchpad and rail will be used to mitigate risk of fire. After the flight, we will dispose of both the spent motor and igniter in inert trash as per the MSDS.

We do not want to negatively affect the environment by leaving pieces of our rocket or AGSE at the launch site. To avoid this, our AGSE and launch vehicle are designed to stay connected so no fragments are expelled during preparation or the launch itself. In addition, we will be sure not to leave materials or parts behind after the launch.

The reverse of these considerations, the effect that the environment has on our vehicle, is also an issue. Weather is the major concern: rain, sleet, snow, and any other form of precipitation could be harmful to our rocket because the body material, blue tube, as it is not 100% waterproof. Along the same line, saturated ground could also be detrimental. If our rocket is submerged in a body of water, we run the risk of damaging the electronics as well as the body elements.

Trees also present an environmental concern of a different level. Our vehicle could get stuck in a tree upon descent with no apparent recovery method that does not cause harm to the environment or rocket. In all cases where the environment could be potentially harmful to the vehicle, the best action is preventive. For example, we will avoid launching during a period where the weather would adversely affect the integrity of our rocket or near sources of potential damage including water and trees.

The AGSE is vulnerable to similar environmental hazards as the launch vehicle. Any form of precipitation, or moist ground can do damage to the electrical components in the AGSE. Another environmental issue for the AGSE would be a "dusty" day where very dry and windy conditions cause surface dirt to become airborne. This would damage many of the large scale moving parts which rely on low friction tracks to function properly. It will also cause issues for the vision system as it may cloud the lens. As a preventative measure, the AGSE can be left in the stowed position, shielding it from the dust outside.

4. AGSE Criteria

1. Mission Motivation

The mission of the AGSE is to locate and capture a payload, insert it into a rocket, erect a launch tower, and insert the igniter in the allotted ten minutes.

This competition is a simulation of a Mars mission. On Mars, the main concerns for the AGSE are durability, reliability, and portability. Therefore, the AGSE will be designed to perform these tasks autonomously and as reliably as possible. To meet durability and portability requirements, it will be designed to be entirely encapsulated within a frame. This will simulate a scenario in which the AGSE would be delivered from a Mars orbit to perform its tasks.

The dynamic Martian environment may make detection of a payload on the surface a difficult endeavor. Variable terrain types and the possibility of dust storms make advanced detection techniques a requirement. In order to successfully detect the payload, we will implement a novel combination of multispectral imaging and cutting-edge image classification techniques.

We believe that remote operation of an Automated Ground Support System on another planet necessitates wireless telemetry. Because of this, we will be implementing a radio system to trigger initiation of the AGSE sequence and to transmit important system status information to a remote base station.

2. Concept of Operations

The AGSE will consist of a set of subsystems acting in series, initially triggered by a wireless command. Upon receiving the initiation message, AGSE will first open its sealed container as if it has just touched down on the surface of Mars. This will be accomplished by two gas springs. A retrieval system will partially deploy from its stored position to aim the camera towards the ground. The camera will scan along a linear path. Meanwhile, the multispectral vision system will take a series of images and determine if the payload is visible in the shot. If it is visible, the system calculates its position, orientation, and the surface type it is located on. The retrieval system then travels linearly along the length of the box and adjusts its angle to match that of the payload. Once aligned, a conveyor will pivot down to make contact with the payload and pull it into the base of the retriever. The retriever will return to a home position where a vertical lift will bring the payload to the level of the rocket. At the top of the elevator, the payload will roll down a small ramp and fall into the containment area within the launch vehicle. A linear actuator orientated along the launch vehicle's long axis utilizes a component to close the launch vehicle with the payload secured inside. A third gas spring will then erect the launch vehicle to 5 degrees off of vertical. A power screw will insert the igniter in the motor.

The launch vehicle will then be inspected and launched. It will travel to an apogee of 3000 ft where it will deploy a drogue parachute. Upon descent to 1000 ft, the payload section of the rocket will separate and both sections will drift to the ground on main parachutes. They will be recovered using GPS tracking.

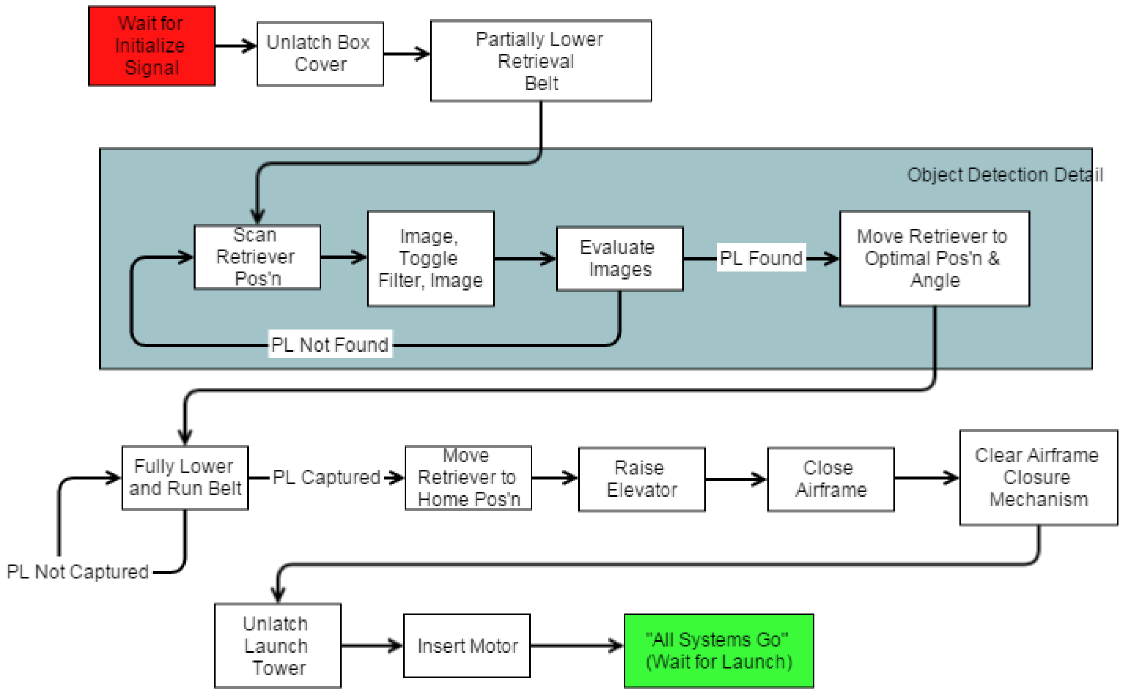

Figure 4.1: Concept of Operations

3. Basis of Vision System

1. Overview

In order to locate the payload, we will employ a multispectral vision system. We will use a Raspberry Pi NoIR camera board as the camera itself does not contain a built in infrared filter. A mechanical servo with attached filters will be attached in front of the lens to switch between infrared and visible spectrum filters. Ratios between the two spectral regimes will be used to enhance the recognition of PVC, which has high infrared absorption. The multispectral information will be combined with features calculated based off the visible light RGB image to increase accuracy. The image will then be classified on a pixel by pixel basis to determine if it belongs to the payload or the ground. This task will be performed with a Linear Discriminant Analysis (LDA) based decision algorithm as proposed by Dr. Jia Li of The Pennsylvania State University. The algorithm is currently being developed by a team at Northeastern University for medical imaging applications. If it is decided that the pixels in the image belong to the payload, information such as location and angular orientation will be calculated from the pixel distribution and converted to commands to move the conveyor. Our decision algorithm will also determine which type of ground the payload is on, grass, clay, soil, or gravel, and will then instruct the conveyor on how to approach the terrain based on previous testing of the hardware.

2. Multispectral Camera

Exact specifications of the Raspberry Pi NoIR's infrared response are poorly documented. Therefore, extensive testing will be done using different infrared LEDs and materials with known infrared absorption spectrums. The infrared absorption of PVC is used as an identifying feature for material determination for single stream recycling. Our camera will not have full spectroscopic capabilities capable of picking out the absorption peaks associated with the bonding structures in PVC. Therefore, our multispectral application will look at the relative levels of the visible light, split into red, green and blue, and infrared light. This feature will also give increased recognition of which surface the PVC is laying on.

3. Decision Algorithm

The LDA algorithm requires inputted training data to calculate the multidimensional probability density function for each of the ground and payload classes. The training data will be taken once the system has been assembled. Images using both filters will be taken for a variety of payload orientations on all surfaces of interest. The images will be sorted by hand to classify each pixel's class. Once we have amassed a training set, the pixels and their manual classifications will be fed into a custom written linear discriminant analysis function based on the methods proposed by Dr. Jia Li outlined at: http://sites.stat.psu.edu/~jiali/course/stat597e/notes2/lda.pdf. For each class, the algorithm outputs a constant and a multiplicative weight for each feature. To classify the pixels of the image, the approximated probability density function for each class is evaluated using the features of the pixel. After evaluating all of the classes, the class which has the highest approximate probability is assigned to the pixel in question. We will do the calculation of the probability density functions in MATLAB due to its ease of matrix manipulation. The coefficients will be outputted into a text file which will be read at run time by the Raspberry Pi.

4. Decision Features

The features will be computed based on either the pixel itself or the local neighborhood. The final features will be chosen after performing Principal Component Analysis for dimensionality reduction, but we plan on using the following:

- Brightness: The PVC should be more reflective than the surrounding area, making it appear brighter in the image. We will calculate the brightness as the magnitude of the vector composed of the red, green and blue elements of the image.

- Redness, Greenness and Blueness: PVC has no distinguishable absorption features in the visible spectrum. Therefore the components of each should be approximately equal. The component for each pixel will be normalized by that pixels brightness to remove shadowing from the calculation.

- Standard Deviation: The standard deviation of the image will be calculated using a neighborhood around the pixel measuring 9 pixels by 9 pixels. The standard deviation of the pixels central to the payload should be very small, while the edges of the payload and the ground will be less uniform and give a larger standard deviation. This metric along with skewness, can be done on either the red, green, blue, magnitude of the image, or multiple features. The decision on which set to operate on will be made after initial data is taken.

- Skewness: The skewness of the local neighborhood is a measure of how symmetric the distribution of points is. The edges of the payload will have a large skewness compared to all other sections of the image. This is because of the sharp contrast between the background and the PVC container. The inclusion of this feature should allow the edges of the payload to be isolated.

- Standard Deviation of the Gradient: This looks at the spread in the rates of change in 9 pixel by 9 pixel neighborhoods. This method is good for detecting areas with lots of small scale changes, such as gravel or grass. Just taking the gradient does not work because in any object of macroscopic size, the majority of pixels will be similar to the neighbors.

- Filtering: A 700 nm Shortpass filtered image will be taken and processed into the brightness map. Then the servo will remove the Shortpass and swivel the 700 nm longpass filter into the field of view and a second image will be taken. Having not moved the camera, the images will be of the same area. The magnitude of the filtered image will be taken and the ratio of the infrared to visible image will be used. PVC and plastics in general have large absorptions in the infrared due to their characteristic bonding energies. This means the ratio around the PVC should be drastically different than the surrounding areas.

5. Decision Classes

The decision algorithm will assign a class to each pixel. The classes we plan on using are central payload, edge of payload, piece of AGSE, clay, soil, grass and gravel. These classes may be changed at a later point to account for any unanticipated surfaces we may encounter. We have chosen an LDA-based algorithm over binary decision algorithms, such as support vector machines, because of its native ability to make decisions between many classes without building complex multi-tiered decision trees. The determination of surface type has two beneficial aspects. The first is from a feature standpoint; different surfaces have very different signatures. For example, gravel would have a large standard deviation while clay would have a minimal standard deviation. If these two were included in the same class, the metric would span the entire range and remove the distinguishing power of the feature. The second benefit is the ability to make an adaptive conveyor system which does not require apriori information about the surface. A case where this would be beneficial is in the treatment of the payload on grass versus gravel. In grass, the conveyor may want to apply more force on the top surface to move the payload through the restrictive grass, while in gravel, this action would cause the payload to sink, making it harder to retrieve. The exact treatment on each surface will have to be determined experimentally upon completion of the AGSE.

6. Output Operations

The output of the decision algorithm will be a map showing the type of surface and where the payload is located. The map will be divided into a mask, which labels the image pixels as payload and ground. All pixels of a non-payload class will be polled and will cast a vote for what surface the payload is sitting on. Incorporating a voting mechanism increases the statistics of our decision with small computational overhead. The covariance of the x and y pixel coordinates of payload class pixels will be calculated to determine the orientation of the payload with respect to the conveyor. This information will be used to rotate the conveyor to be perpendicular with the long axis of the payload. This action will aid in payload retrieval by making the motion of the payload behave more reliably.

7. Preliminary Test Results

Prototyping of the vision system has been completed with promising results. A proof of concept has been developed in MATLAB, which is capable of distinguishing the payload from its background. Images of the payload were taking using the camera on a iPhone 6, and then downsampled to 490 x 653 pixels to represent the quality capable of being captured and processed by the final system. The actual camera for the system is not currently operational, so our current results do not incorporate an accompanying infrared image. The infrared image is expected to give increased detection of the PVC payload, so the results will be more accurate. The detection results for a simple case, the payload on a dark countertop, are shown in the following figure.

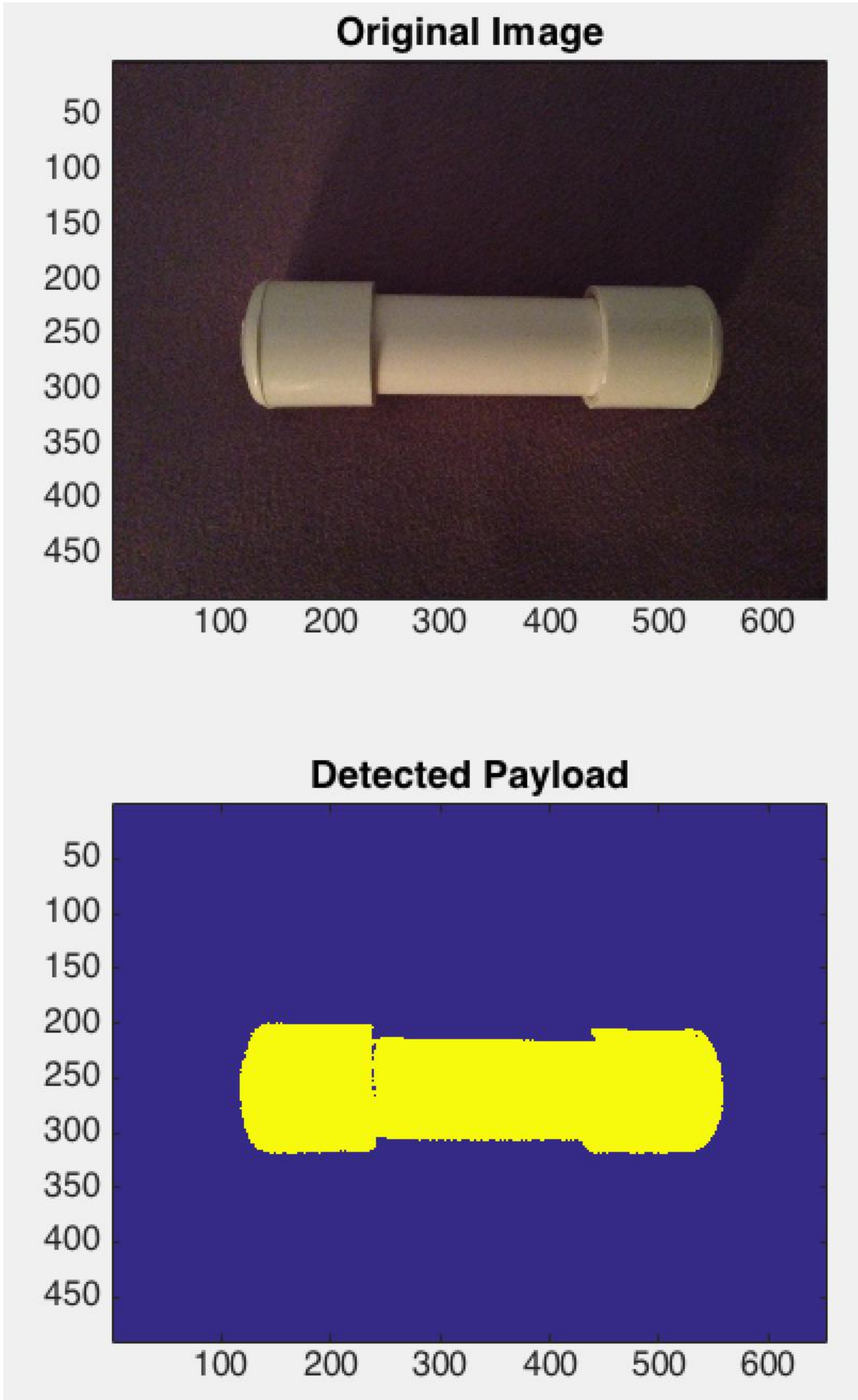

Figure 4.2: Current progress on payload Detection in a MATLAB implementation

For the creation of Figure 4.2, the features we used were brightness, redness, greenness, blueness, standard deviation, skewness, and standard deviation of the gradient. The original image was split into two classes, payload and non-payload, and the above features were calculated for each pixel. This data was fed into the linear discriminant analysis function to create a decision boundary custom to the image. The results of applying this decision back to the boundary show strong differentiation of the payload from its surroundings. These results are a very promising proof of concept because it shows that our current methods are capable of determining the location of the payload.

Moving forward, we need to transition to images taken using the Pi NoIR camera to the camera that will be employed in the final system. This will allow us to capture the visible and infrared images and increase the accuracy of the payload detection. Currently, downsampling the image will serve to align the infrared and visible images based on the assumption that system movement will be small relative to the enlarged pixel size used for classification. Verifying this will be a large part of switching to the camera set up for the final system. We will also need to work on developing a version of the software in Python, which is quick enough to run on our Raspberry Pi, under the time constraint of the entire competition.
Once the system is running, a database of training data will be collected by taking images of a sample payload on a variety of surfaces under a variety of lighting conditions. MATLAB will be used to segment the images into the proper class of object, payload or type of ground, and will be used to make the decision coefficients. The decision coefficients will be loaded into the Raspberry Pi system and extensive testing will be conducted to ensure proper payload locating. To finish the testing we will hook the Raspberry Pi to the accompanying motors

and test the ability of the system to place the conveyor on top of payload reliably.

4. Systems Summary

1. Structural System

1. Frame

The main structural frame of the AGSE will consist of 1 inch aluminum extrusion rail. (10-10 80/20), covered with polycarbonate, simulating the fully-enclosed initial configuration of a hypothetical system delivered from Martian orbit.

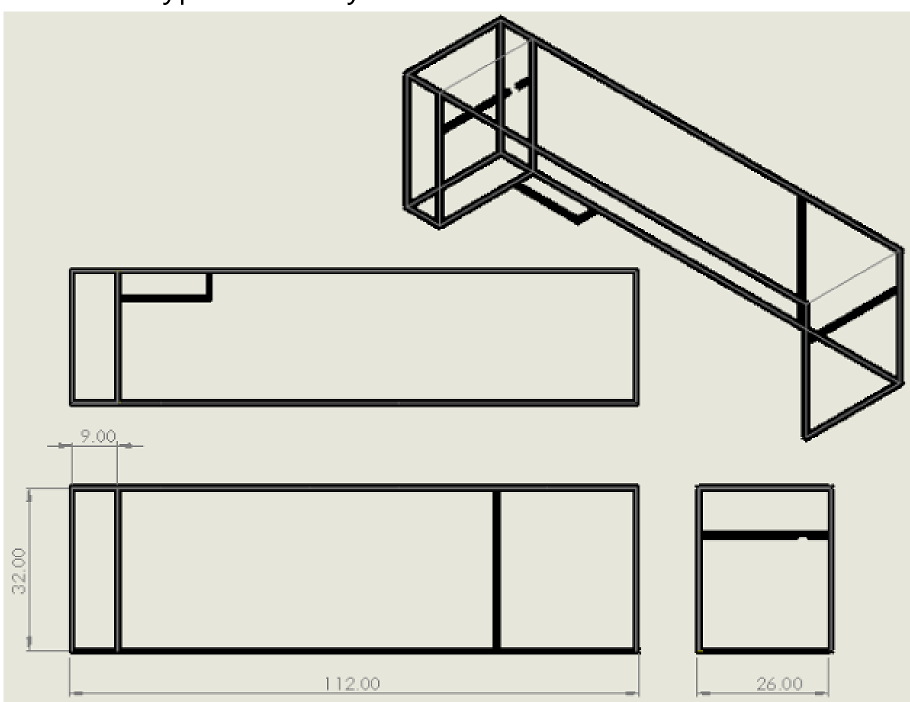

Figure 4.3: Frame Dimensions in inches

2. Hatches

There will be two doors on the structure. One hatch will be the vertical wall closest to the AGSE retrieval belt. That entire polycarbonate window will open out and up 90 degrees by means of 2 gas springs. Each gas spring will provide 75 N of force which gives enough lifting force and torque required to open the door, with a tolerance cushion. The maximum torque from the door applied to the rest of the structure is 33.25 N*m, which is one-third the torque applied by the rest of the structure in the opposite direction. Therefore, the box will not tip over.

The other door is on the top of the structure, which will open to reveal the rocket when the payload insertion is finished. Only half of the top panel will open, extending slightly past 90 degrees to ensure the rocket can lift
smoothly. Two gas springs will be used for this lift as well, both of which will need to apply 30N of force.

Swift & Sure Size Range	Range of Stroke Lengths (in 5mm increments)	Range of Tube Lengths (in 1mm increments)	Force Range (in 10 Newton increments)	Thread Type (M)
6-15	40-200	75-230	50-400 (11-90lbs)	M5 x 0.8
8-18	40-300	85-345	100-650 (22-146lbs)	M6 x 1.0
10-23	40-400	85-445	150-1200 (34-269lbs)	M8 x 1.25
14-28	40-500	95-555	200-2500 (45-562lbs)	M10 x 1.5

Table 4.1: Stroke Length, Tube Length, Force Range, and Thread Type for gas springs

This lifting force and resultant torque of 8.9 N*m includes a 10% tolerance to ensure rotation of the door. The torque from the open door is minimal: 1.27 N*m to be exact. This is negligible compared to the structure.

Both doors are secured by an electromagnetic solenoid latch.

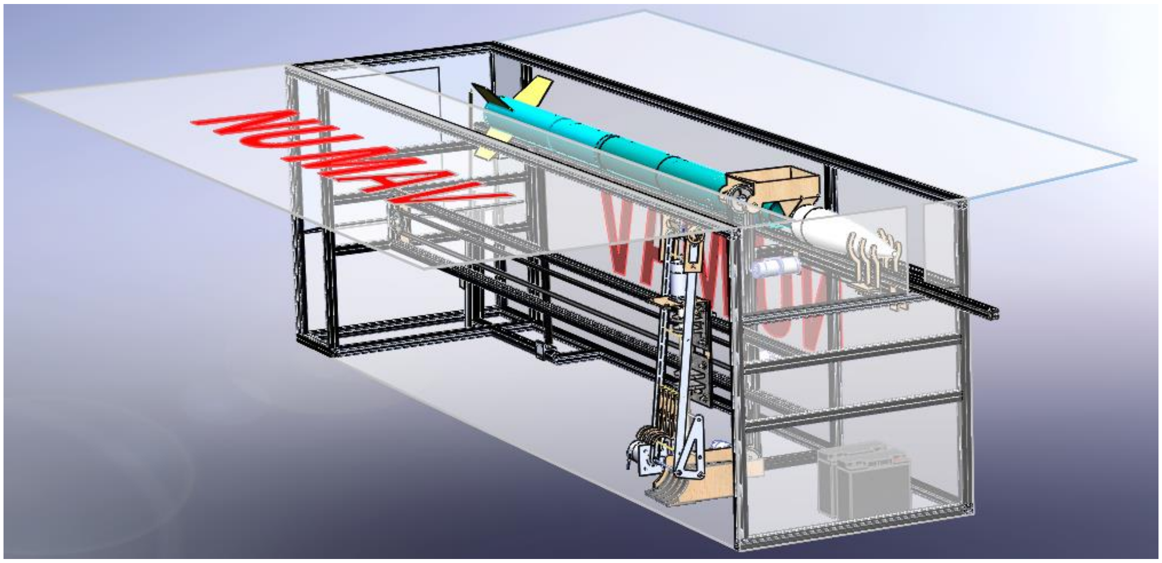

Figure 4.4: AGSE with front hatch deployed.

3. **Thermal Protection System**

   The thermal protection system consists of 1/16" aluminum sheeting backed with Nomex cloth. The system covers the area immediately below the rocket nozzle when in launch position. This creates a "flame trench" that directs the hot exhaust gas away from sensitive electronic components and actuators.

2. Payload Retrieval System

1. **Retrieval Belt Subsystem**

   The retrieval belt will consist of two, 0.5 in wide, drive belts, which run parallel to each other along the length of a 24 in arm and are separated by six inches of space. A wooden bridge piece will run from one belt to the other, perpendicular to the long axis of the arm. Four wooden prongs will be attached to the wooden bridge and will be used to rake in the payload (Figure 4.5).

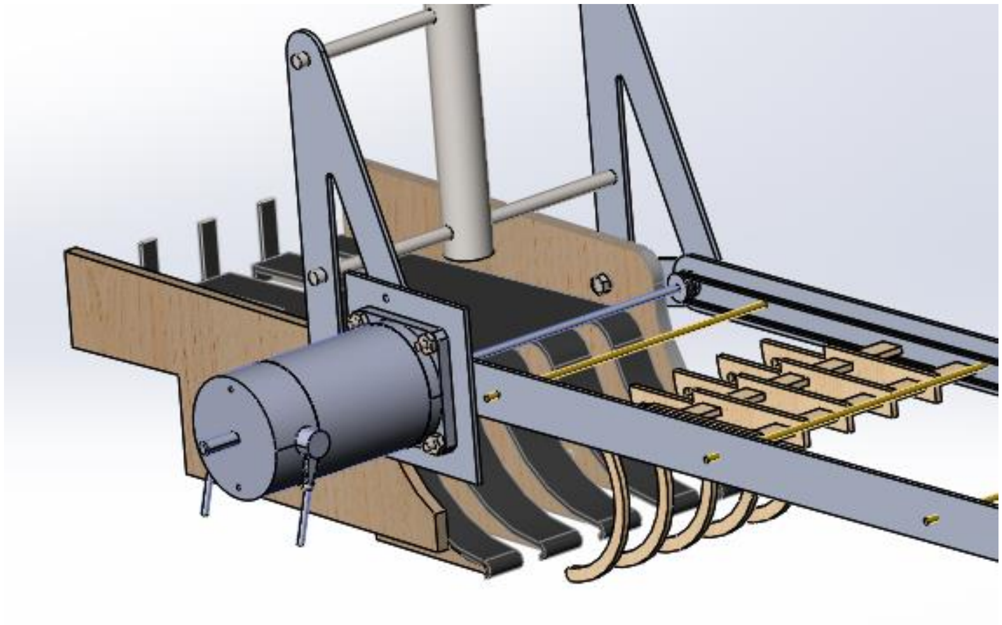

Figure 4.5: Payload Belt Subsystem

The entire belt assembly will pivot about the bottom rollers, and will be initially stowed in the vertical configuration. It will pivot out to the horizontal position when driven by the DC motor. The arm, which provides the structural support for the belt assembly, will be made of thin aluminum to minimize the load on the motor. The motor specifications are given in table 4.2.

Manufacturer	Cytron		
Name	RB-Hsi-06		
Voltage	12 VDC		
	Min	Nominal	Stall
Torque	N/A	14.44 oz-in	138.9 oz-in
Current	157 mA	443 mA	3.8 A

Speed	253 rpm	224 rpm	N/A

Table 4.2: DC Motor Specifications

2. Position/Angle Subsystem

This subsystem consists of a linear bearing and a rotational bearing, each driven by a NEMA-17 stepper motor and belt, whose positions are tracked using rotary encoders.

Manufacturer	Omega Engineering, Inc.
Part Number	OMHT17-275
Holding Torque	62.3 oz-in
Voltage	5.7V
Current	0.85A
Dimensions	1.7in x 1.7in x 1.90in

Table 4.3: High Torque Stepper Motor Specifications

Manufacturer	Yumo
Name	E6A2-CW3C
Pulses per revolution	200
Voltage	5 - 12 VDC
Max Speed	5000 rpm

Table 4.4: Rotary Encoder Specifications

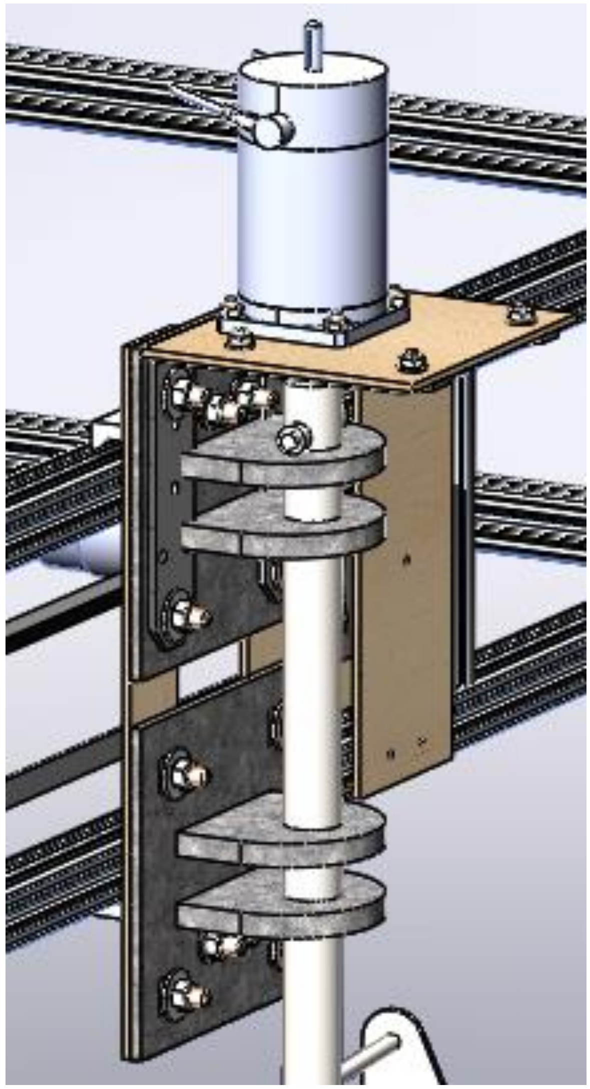
Figure 4.6: Retrieval System Angle Motor

3. Payload Capture Subsystem

The payload capture ramp consists of a custom-fabricated structure which holds the payload after it is retrieved by the belt. The ramp and the prongs on the retrieval rake are designed to interface so they can push the payload up the ramp. Once the payload reaches the top of the ramp, it will roll down the back of the ramp into the elevator subsystem. It is shaped to align the payload in a known position using the force of gravity. Its frame can be fabricated by laser cutting plywood sheets.

Manufacturer	Adafruit Industries
Name	Laser Break Beam Sensor
Max Sensing Distance	1 Meter
Voltage	4.5 VDC - 5.5 VDC
Current	25 mA
Dimensions	20mm x 18 mm x 10 mm

Table 4.4: Laser Sensor Specifications

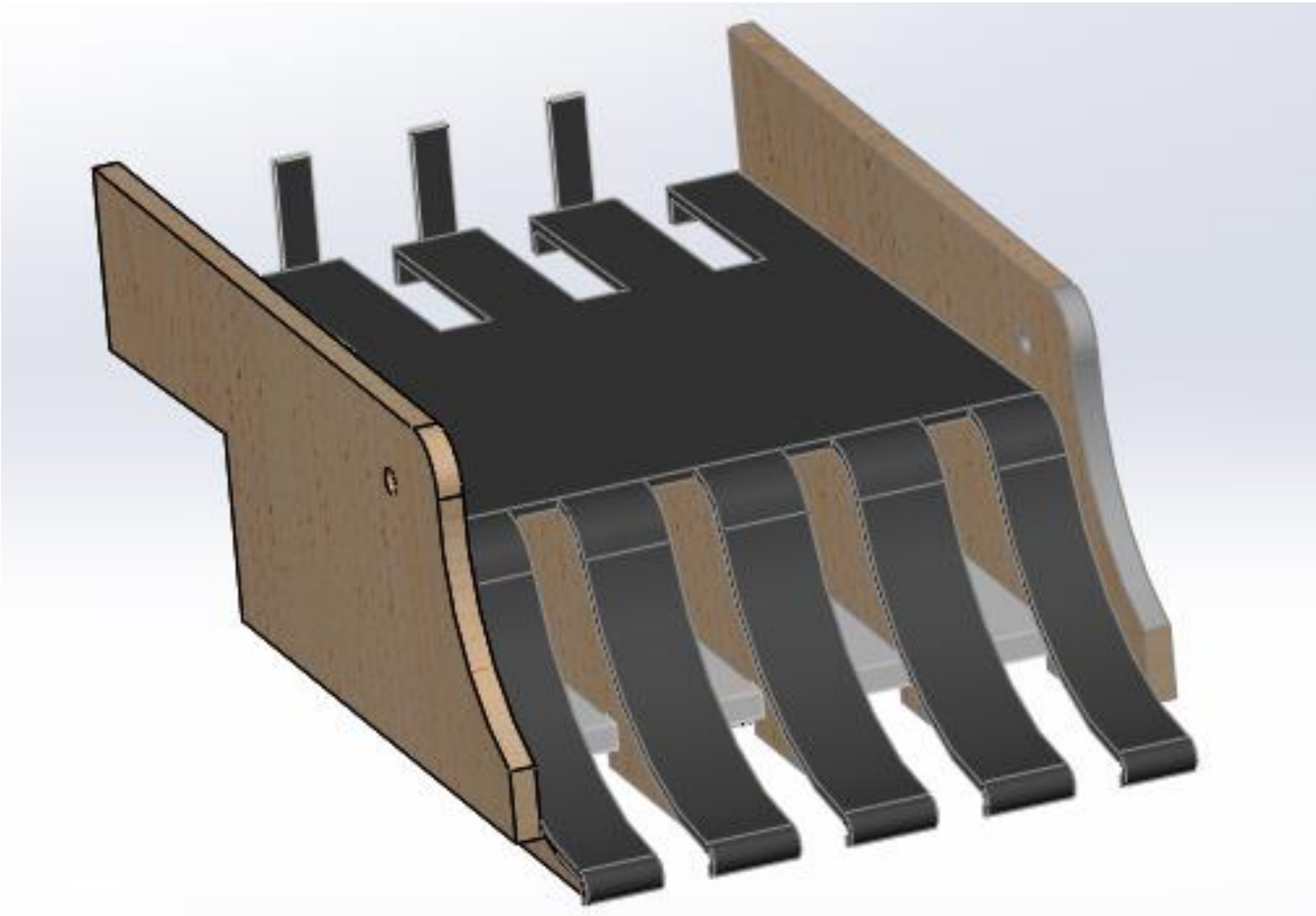

Figure 4.7: Payload Capture Device

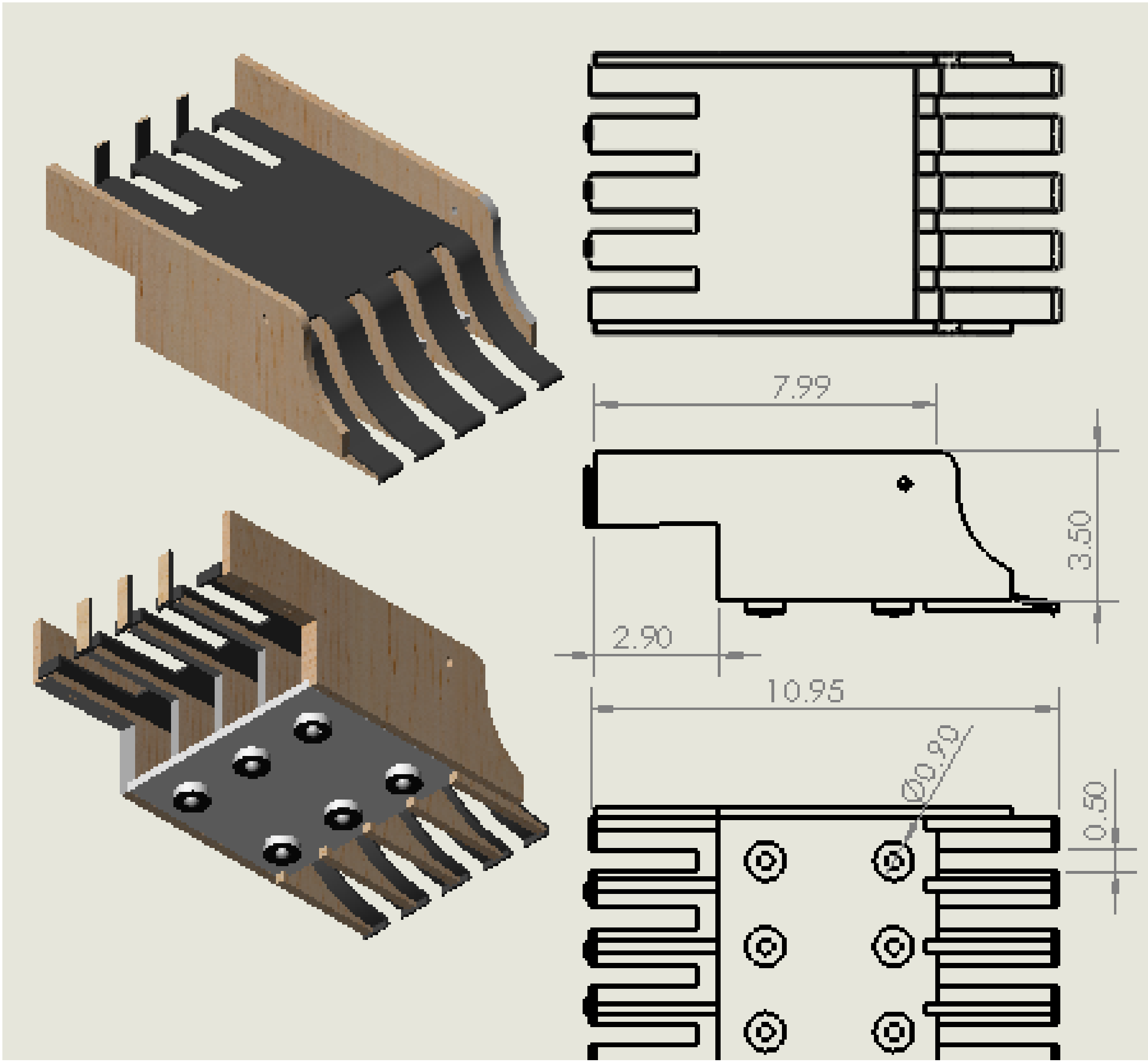

Figure 4.8: Drawing of Payload Capture Device

3. **Payload Insertion System**

1. **Elevator Subsystem**

This subsystem consists of a belt with a set of curved prongs attached to it. These prongs will interface with the end of the payload capture device, which allows it to lift the payload from the payload capture subsystem to the payload insertion ramp. It is driven by a geared DC motor, and its motion is limited using a micro switch.

Manufacturer	Baolian
Max Current	3 Amps
Max Voltage	250 VAC
Dimensions	28mm x 50mm

Table 4.5: Microswitch Specifications

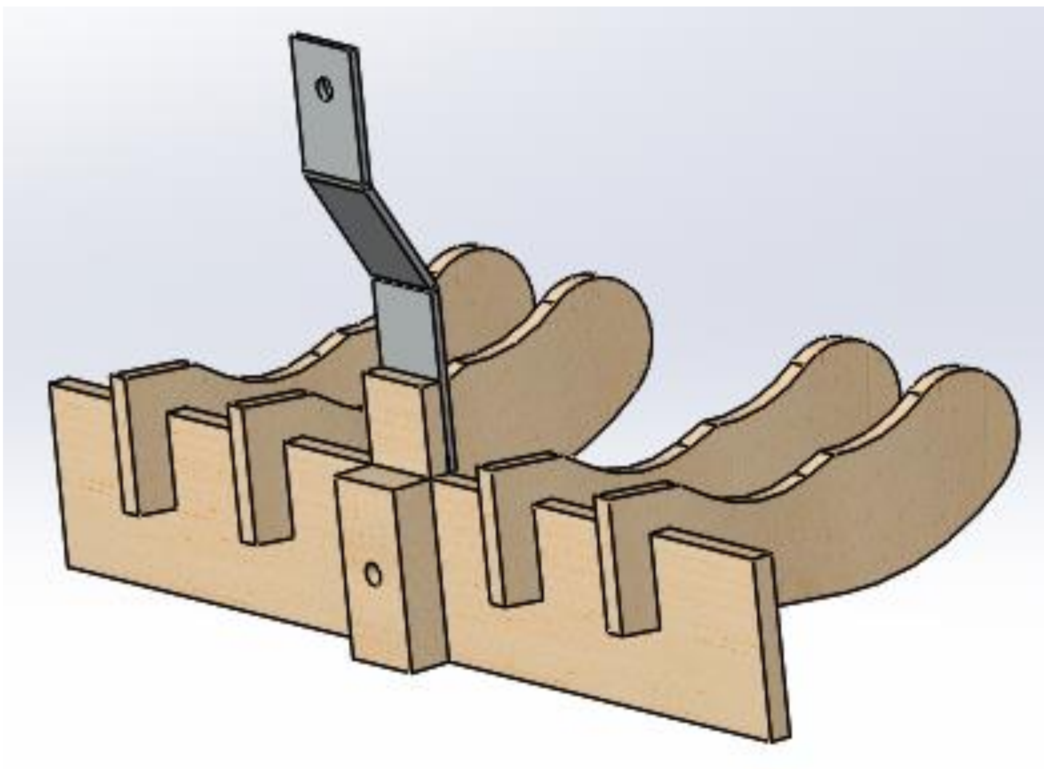

Figure 4.9: Bottom of Elevator Subsystem

2. Payload Insertion Slide

This part accepts the payload at the top of the elevator. It uses the force of gravity to roll the payload into the waiting payload bay of the launch vehicle. It is mounted on a hinge so that it is easily pushed out of the way during airframe closure and launch tower erection.

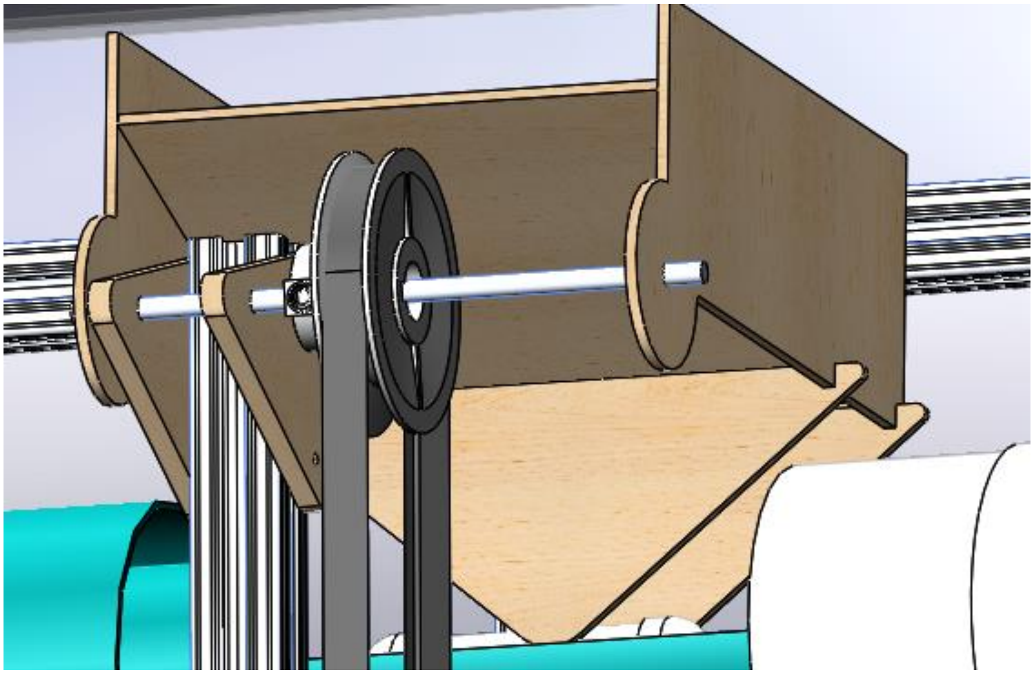

Fig. 4.10: Payload insertion ramp with payload in payload bed

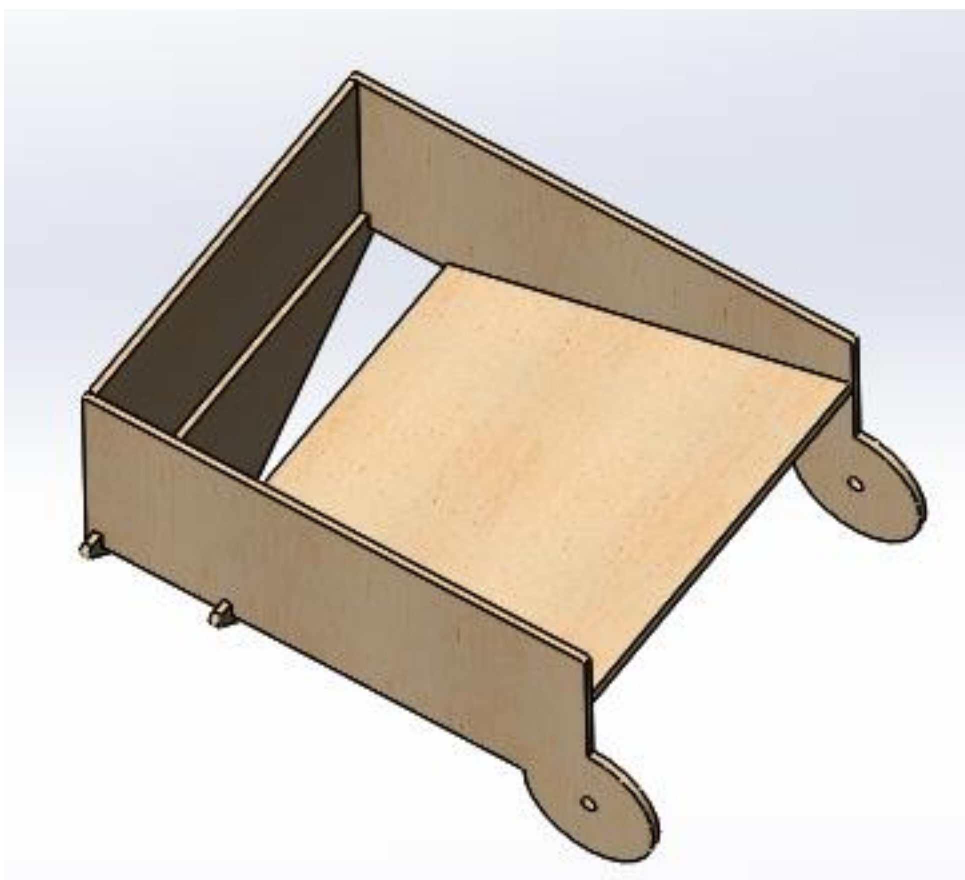

Figure 4.11: Payload Insertion Ramp Drawing

3. **Airframe Closure Subsystem**

This subsystem pushes the nosecone of the rocket towards the forward body tube sections, closing the payload bay and engaging the laser cut snap closure system. The closure subsystem consists of laser cut claws that are form fitted to the outer face of the nose cone. It slides along the 80/20 rail on a linear motion bearing, and is driven by a timing belt and geared DC motor. It includes a microswitch to limit the motion to the desired range.

In operation, the slider will push the nose cone closed until reaching the limit switch, and then back slightly to allow clearance for the rocket to be raised.

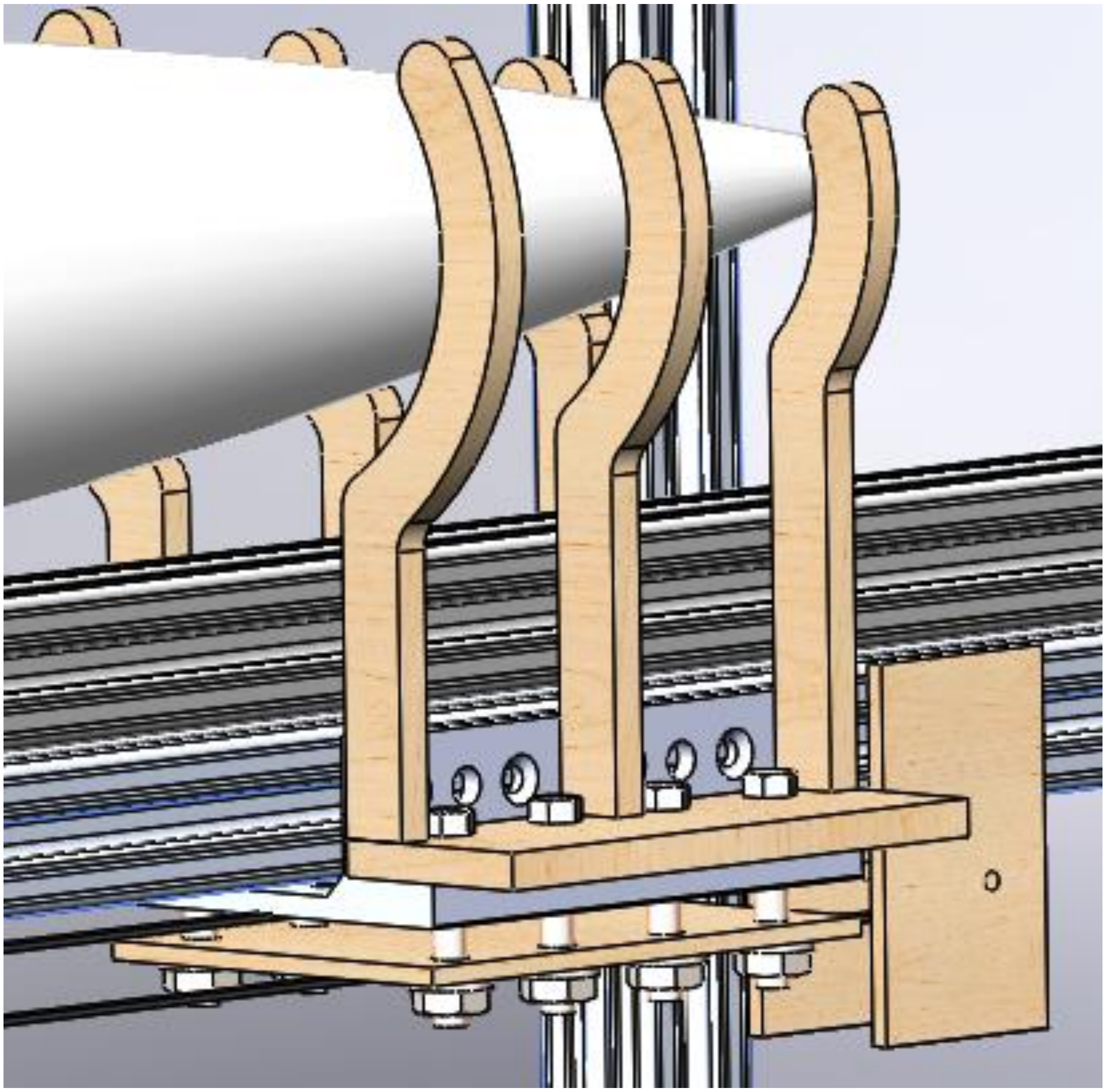

Figure 4.12: Airframe Closure Subsystem

4. Launch Tower Erector System

The launch tower, along with the rocket will be forced into the upright position using one gas spring. The gas spring is a stored energy, closed system, which will be held down via an electromagnetic solenoid latch. The gas springs will be purchased with custom dimensions and placed in pre-determined positions which will upright the rocket at 5 degrees off vertical. With a 10% tolerance, the gas spring needs about 195 N of lifting force, which will provide the required torque to lift the launch tower/rocket. When the rocket is upright, the torque it applies to the rest of the structure is 54.4 N* m, which is minimal compared to the weight of the entire structure. The rocket/launch tower will not fall back on the gas spring because the effective weight in the direction of the gas spring 51 N, or roughly ¼ the lifting force provided by the gas spring.

Once the launch tower in in place, a mechanical latch will engage to ensure launch tower stability. A microswitch will detect that the rocket is in its final configuration.

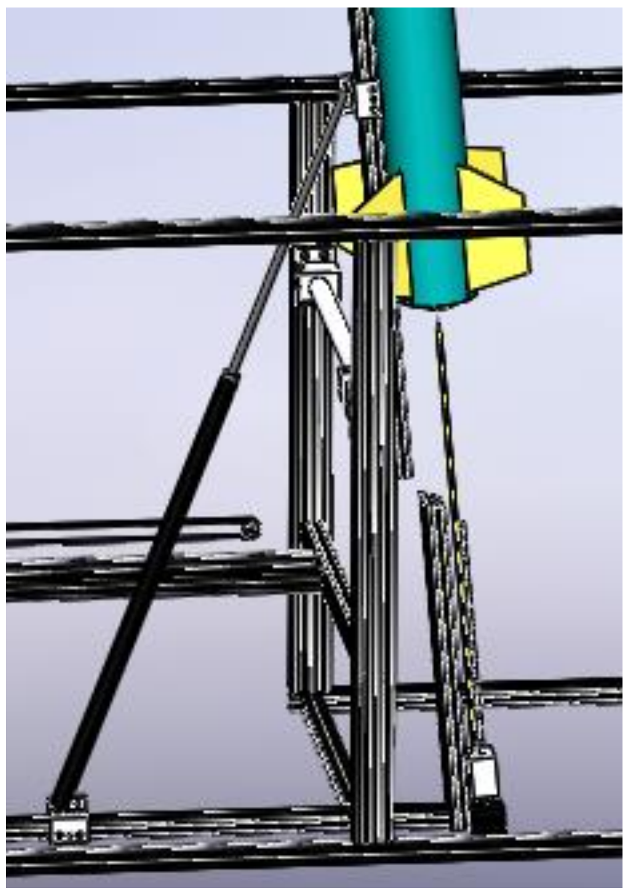

Figure 4.13: Gas spring in launch tower erector

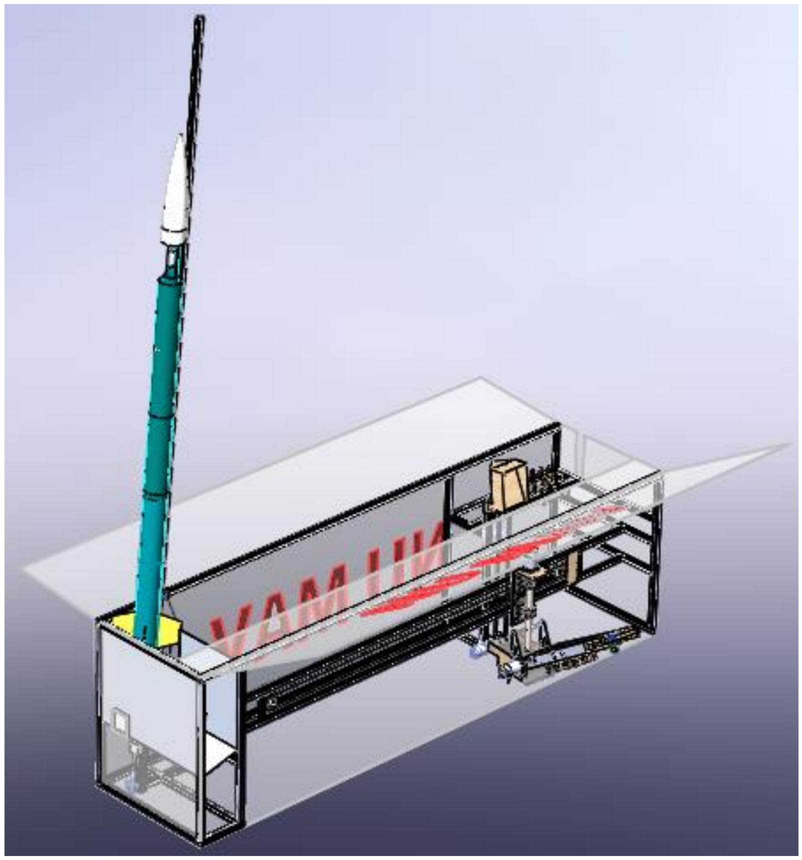

Figure 4.14: Rocket in final launch position

5. Igniter Insertion System

The igniter will be inserted into the upright rocket using an expendable wooden dowel. The dowel will be attached to a linear actuator consisting of a threaded (via Heli-Coil inserts) aluminum block on a linear bearing. The block will be driven using a power-screw attached to a DC motor. Two linear 80/20 bearings will allow the block to move along the 80/20 rails. There were concerns raised by the review board during the PDR presentation regarding the risk of premature ignition of the E-Match due to induced current from the motor's magnetic flux. We verified that this would not be an issue by wrapping the E-Match around the motor on a test bench and ensuring that no ignition occurred even after running it at full power.

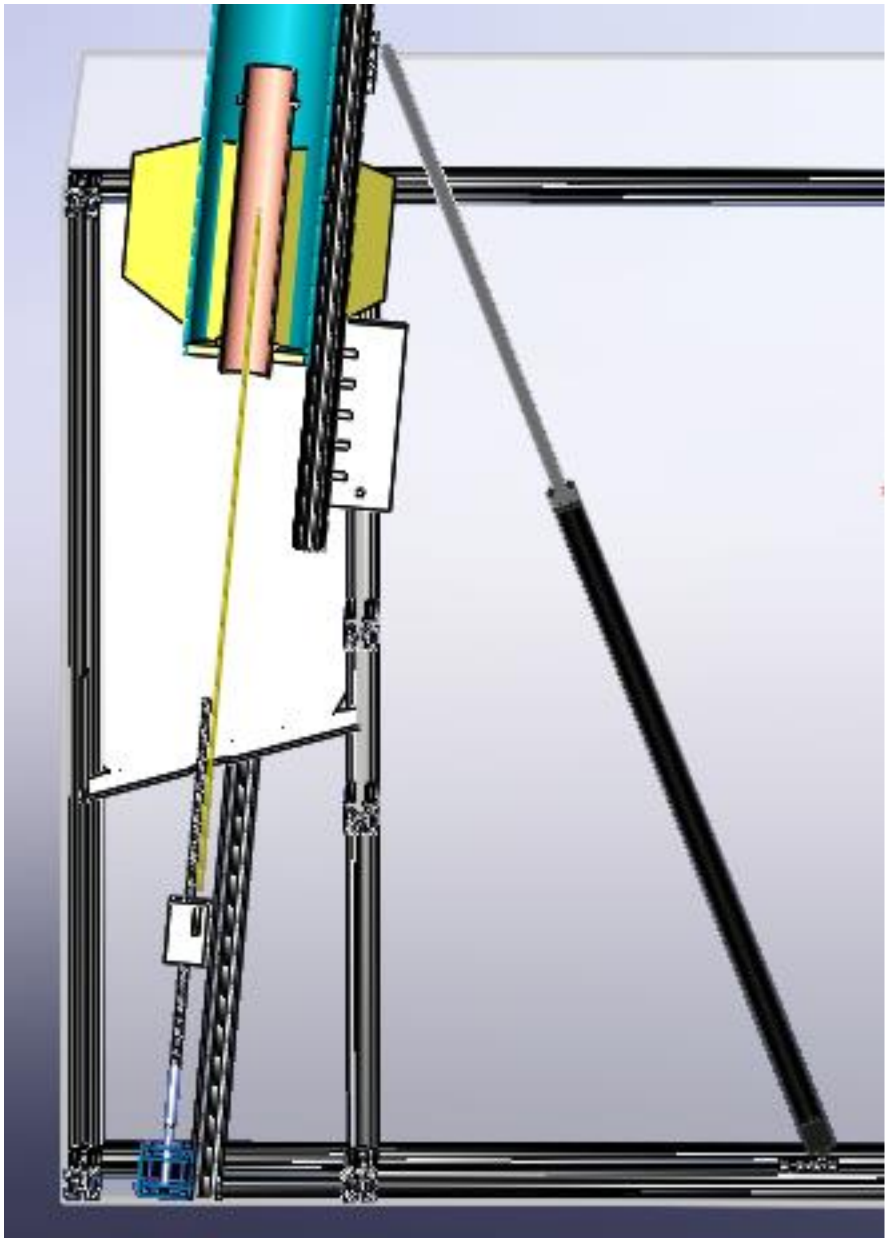

Figure 4.15: Igniter insertion system

6. Electronics/Control System

As the electronics are integrated into the mechanical system, some of the above content is reviewed for clarity. The system features a microcontroller for real-time logic and control, as well as a single-board Linux computer for vision processing.

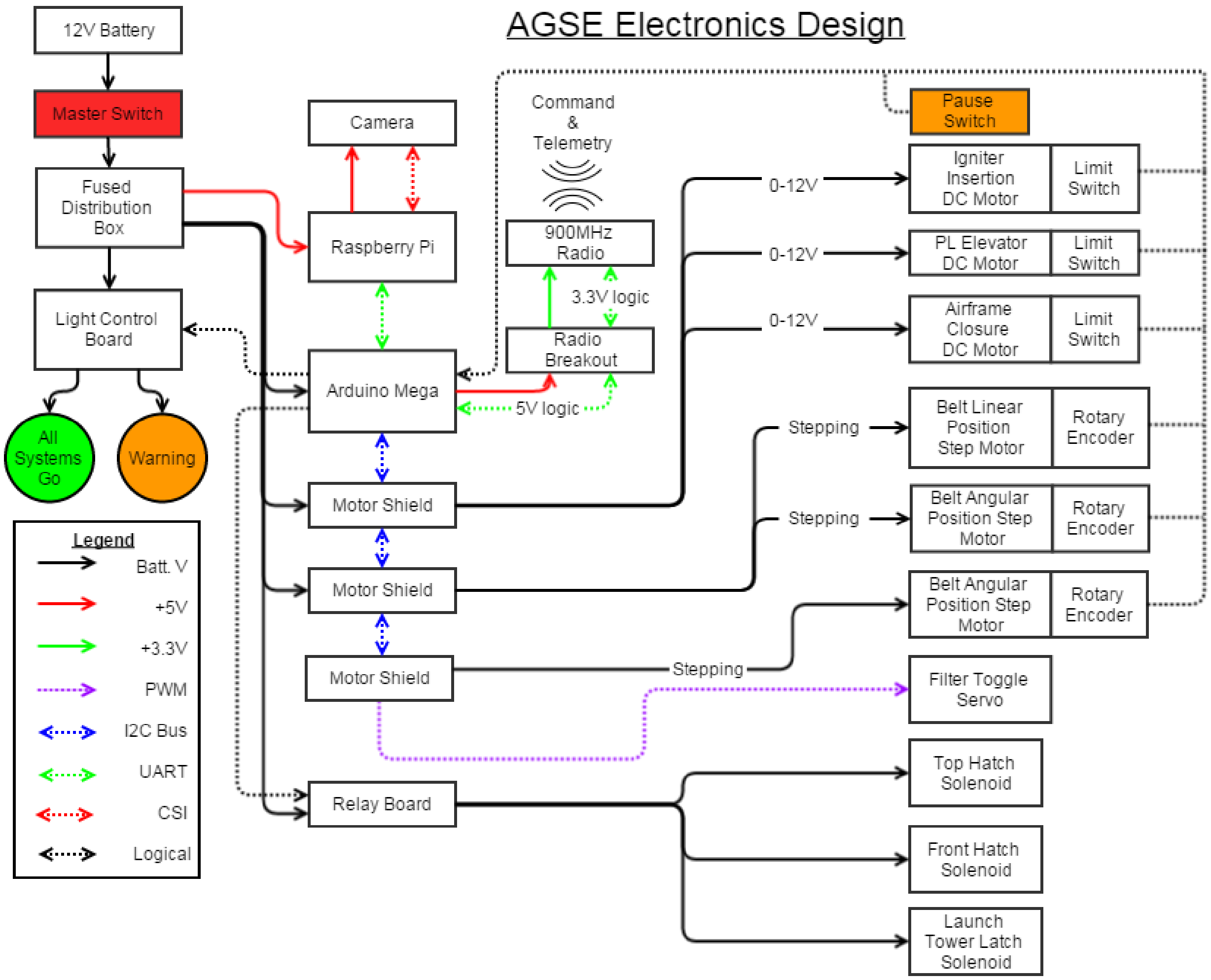

Figure 4.16: AGSE Electronics Block Diagram

1. Control and Logic System

1. Hardware

The actions of the AGSE will be coordinated by an Arduino Mega microcontroller board, which interfaces with necessary sensors, relays, motor drivers, and the vision processing system.

Manufacturer	SmartProjects
Board Name	Arduino Mega 2560 R3
Microcontroller	ATmega2560
Input Voltage (recommended)	7-12V
Digital I/O Pins	54

Analog Input Pins	16
Flash Memory	256 KB
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

Table 4.6: Microcontroller Specifications

Stepper motors, DC motors, and servos will be powered through motor control shields that stack on the Arduino. They will communicate using the Arduino's I2C bus.

Manufacturer	Adafruit Industries
Name	Adafruit Motor/Stepper/Servo Shield for Arduino v2
Voltage	5VDC-12VDC
H-bridges	4
Current (Per bridge)	1.2A (3A peak)
Interface	I2C
Dimensions	70mm x 55mm x 10mm

Table 4.7: Motor shield specifications

Solenoids will be controlled using a standalone relay board, with individual relays controlled directly by Arduino digital out channels. The board's inputs are optically isolated from the relays, to reduce any transient effects at the microcontroller.

Manufacturer	Puyu

Name	4 Channel Relay Control Module
Maximum load	AC 250V/10A, DC 30V/10A;
Relay Configuration	Normally open
Logic level	5V-active high

Table 4.8: Relay board specifications

2. Software

The control algorithms will be written in Arduino's C-derived "Wiring" language, taking advantage of readily available open-source libraries for interfacing with stepper motors, the motor shield, encoders, and servos. See figure 4.4.16 for a simplified state diagram.

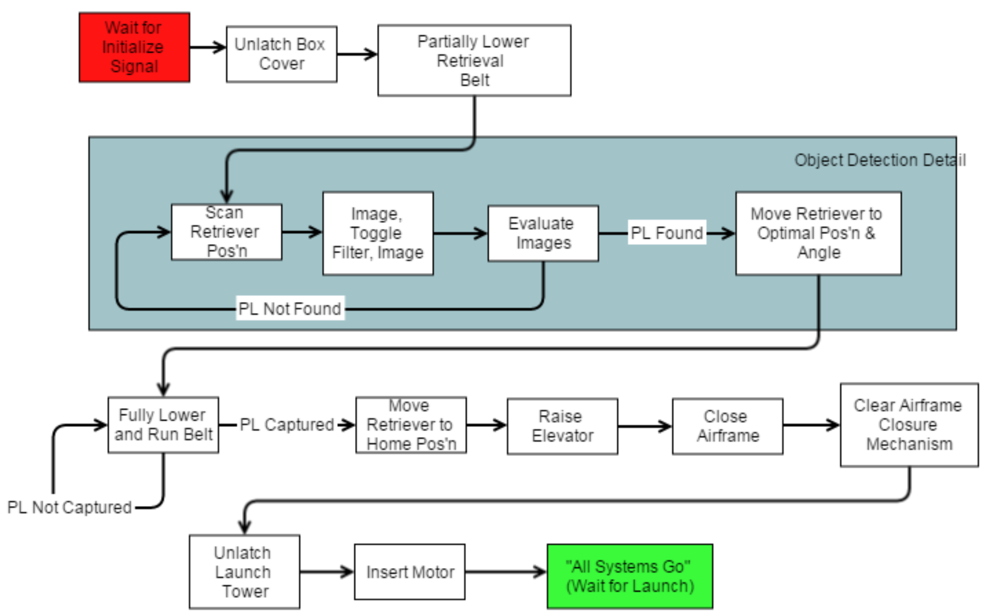

Figure 4.17: Concept of operations / State Diagram

2. Vision Processing System

1. Hardware

The vision processing system consists of a single-board, Linux-based computer, with an infrared-sensitive camera, which is used to determine the position and orientation of the payload in the scanning area.

Specifically, we will use a Raspberry Pi for the image processing calculations. For the camera, we have chosen a Raspberry Pi camera that is sensitive to the infrared and visual spectrum. It communicates directly with the Pi’s processor using the Camera Serial Interface (CSI) bus, which decreases processor overhead while imaging when compared to USB interface cameras. In addition, a servo will be used swap optical filters to create a multi-spectral imaging capability. ThorLabs FEL0700 and FES0700 are the edgepass filters which will be attached to the servo.

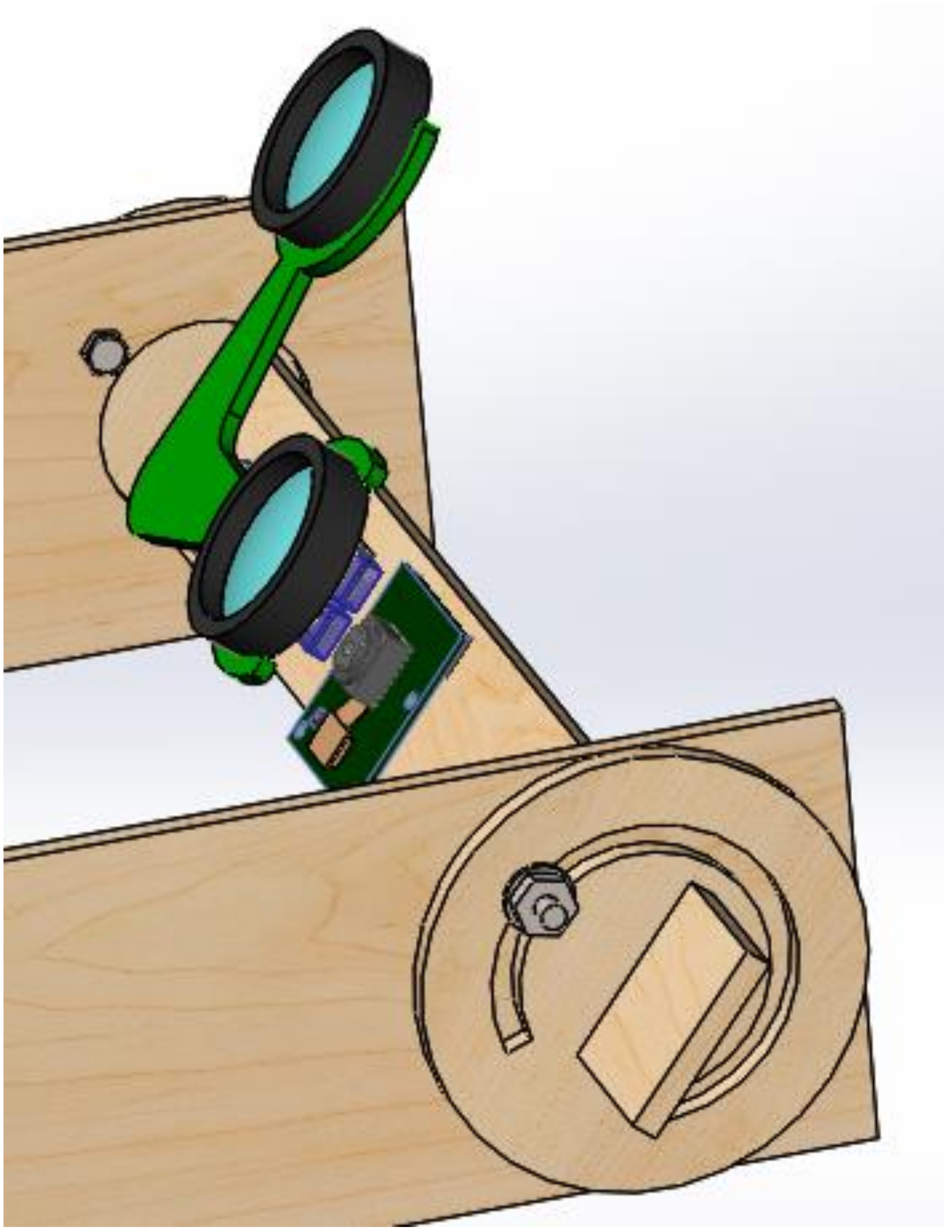
Figure 4.18: Raspberry Pi NoIR camera (bottom left) with switchable filters.

The Pi will exchange state information and target location/orientation data with the microcontroller via Universal Asynchronous Receiver/Transmitter (UART).

Manufacturer	Raspberry Pi foundation

Name	Raspberry Pi B+
Operating system	Linux
Power	3.0 W, 5VDC
CPU	ARM1176JZF-S 700 MHz[1]
Memory	512 MB
Dimensions	56mm x 85mm x 17mm / 2.2" x 3.4" x 0.7"
Mass	42g

Table 4.9: Raspberry Pi B+ Specifications

Manufacturer	Raspberry Pi foundation
Name	Raspberry Pi NoIR Camera
Sensor	5MP (2592×1944 pixels) Omnivision 5647
Interface	CSI Bus
Dimensions	25mm x 20mm x 9mm

Table 4.10: Raspberry Pi NoIR Camera Specifications

Name	Servo - ROB-10333
Vendor	Sparkfun Industries
Voltage	4.8-6.0V
Torque	38.8/44.4 oz-in. (4.8/6.0V)
Speed	0.20/0.18 sec/60° (4.8/6.0V)

Rotation	180°
Dimensions	28.8 x 13.8 x 30.2mm
Mass	20g

Table 4.11: Servo Specifications

2. Operational Software

Figure X shows the conceptual design of the algorithm and data flow for payload detection.

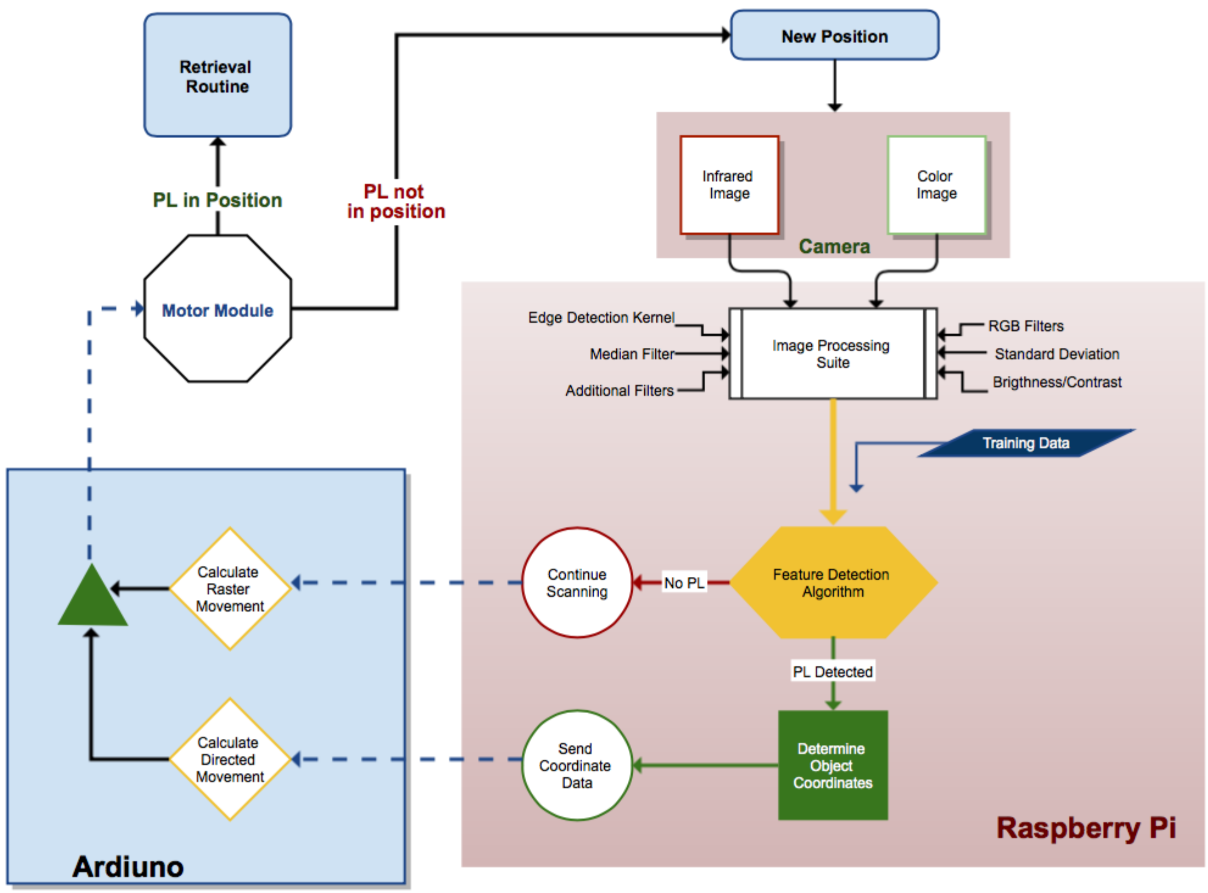

Figure 4.19: Vision processing algorithm design

3. Safety Systems

1. **Pause Switch**

A switch will be located on the outside of the AGSE, and connected to the microcontroller, which will be programmed with an interrupt to halt all actions when the switch is in the stop position

2. **Safety Lights**

A 12V amber safety light will be mounted on top of the AGSE such that it is visible from all directions. The light will flash at 1Hz when the system is powered, and will light solid when the pause switch is activated. A similar green light will illuminate when the AGSE had completed the launch preparation procedure, and will signal the LSO to begin the pre-launch inspection. They will be powered and controlled with a custom MOSFET circuit.

4. **Power System**

The AGSE will be powered using a 12V sealed lead-acid battery, connected to the system with a master switch located on the outside of the AGSE. The 12V power, which will be broken out to the Arduino, motor shields, and relay board using a fused distribution box. This adds a layer of safety, by preventing any high-current mishaps. It also has a regulated 5V output that will be used to power the Raspberry Pi.

Manufacturer	MK Battery
Model	ES17-12
Nominal Voltage	12V
Nominal Capacity	18Ah @ 0.9A 17.1Ah @ 1.8A 15.3Ah @ 3.1A 8.1Ah @ 18A
Max. Discharge Current (for 30 sec)	360A

Weight	13.82Lbs. (6.28kg)

Table 4.12: Battery Specifications

Input Voltage	6v-24v DC
Current Limit	Channel 1 & 2: 40A Total, Chanel 3-5: 10A Each
Aux. Output	5VDC Regulated
Dimensions	160x60x41
Mass	240g

Table 4.13: Distribution Box Specifications

5V power will be supplied to the XBee radio support board from the Arduino’s onboard regulator, and 3.3V power will be supplied to the XBee from the support board’s onboard regulator.

5. Communication System

System state data will be telemetered to the base station using a pair of XBee 900MHz radio. One will communicate with the microcontroller using UART and a level shifter to convert between the Arduino’s 5V logic and the XBee’s 3.3V. The other radio will be connected to the base station laptop using a USB dock.

Manufacturer	Digi International
Name	XBee® Pro 802.15.4
Vendor	Mouser Electronics
Voltage	2.8-3.4V

Current	215 mA
Data Rate	250 kbps
Frequency Band	2.4 GHz
Line of Sight Range	1 mile
Dimensions	32.9 x 22.0 x 2.8mm

Table 4.14: XBee Radio Specifications

7. Base Station

Our base station will consist of a laptop with an XBee 900MHz radio, connected via USB through a dedicated interface module. The laptop will run a custom python-based graphical user interface (GUI) that will allow the initiation signal to be sent to the AGSE through the XBee. The interface will also display real-time status telemetry from the AGSE.

Additionally, the base station will contain a 440MHz radio, which will receive APRS location packets from the BigRedBee GPS transmitters onboard the rocket and payload capsule. The laptop will run the open-source Qtmm AFSK1200 software to decode APRS data from the radio through the laptop's sound card.

Manufacturer	Alinco
Model	DJ-V47T
Supply Voltage	7VDC-16VDC
Power	5W
Tx Freq.	430 - 449.995 MHz

Rx Freq.	410 - 469.995 MHz

Table 4.15: 440MHz Radio Specifications

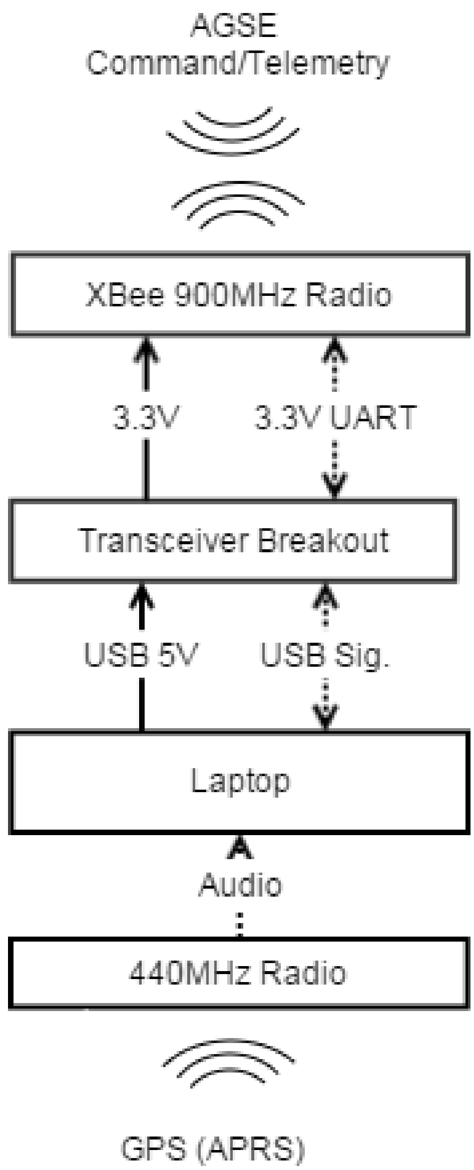

Figure 4.20: Ground station Block diagram

5. Concept Features and Originality

1. Payload Retrieval System

The Payload Retrieval System is defined as both the vertical and horizontal conveyor belts that deliver the payload to the rocket. The horizontal conveyor belt is equipped with wooden prongs that create a series of rake-like configurations. The prongs will pull the payload into a waiting cradle. This cradle will then be lifted up to the rocket by the vertical conveyor belt. Generally, a situation of this nature would call for a robotic arm. We, however, decided to approach the problem in a more unique and versatile way. Our conveyor belt system provides a reliable alternative to the conventional solution. It requires less precision than a robotic arm, and is therefore a more dependable operation. A robotic arm would require very precise motor control in order to successfully reach the payload; this precision could potentially be damaged during transportation or deployment. The mechanical components in our system are designed to be durable and resistant to damage during transportation. Additionally, a robotic arm would have to align itself very accurately with the payload in order to capture it. Our system is able to approach the payload from a variety of orientations and still effectively capture it because of the forgiving range permitted by the design of the pronged conveyor belt.

2. Vision System

We plan to build a custom vision system that utilizes multispectral imaging for classification of payload location and orientation, while simultaneously determining the type of surface and best approach for payload capture. Our approach will determine the type of each pixel in the image, removing the need for edge detection and traditional object recognition. This allows for true universality in the recognition of the payload in any orientation with respect to the camera. The pixel based classification is being adapted from novel medical imaging techniques being researched at Northeastern University. A natural byproduct of our classification scheme is the identification of surface type, which will provide additional information to aid in the capture of the payload.

3. **Contained System**

   Our AGSE is unique in that is contained within a convertible polycarbonate box. The rocket and AGSE are both initially enclosed in a sealed apparatus. This concept allows for a well protected and portable system that will be able to unfold once it reaches its destination. Gas springs will be utilized to open two "doors" in our contained system and also to erect the rocket from the horizontal position. Because everything is inside the box, there are two hinged doors. These doors, once opened, will reveal the payload capture mechanism and will clear the path for the rocket to be lifted to the vertical position.

4. **Data Telemetry**

   Our telemetry system will give a live stream of what is happening in the AGSE. It will give a live record of what is happening, such as "payload has been captured" or " launch vehicle has been successfully sealed". The telemetry system will also work two ways and allow for the "go" signal to be sent to the system from a safe distance. The telemetry system models a real mission to Mars, where there would be no visual cues only a live stream of data being reported back to the ground control station by the AGSE.

6. Verification Plan

Requirement	How the design meets requirement	Method of verifying requirement has been met
The AGSE must pick up a payload off the ground and place it in the launch vehicle.	The AGSE has a series of conveyor belts that will grab the payload off the ground, place it into the launch vehicle's payload bed.	We will do testing where we ensure that the AGSE is able to pick up the payload and properly insert the launch vehicle.
The AGSE must seal the launch vehicle if necessary.	The AGSE will have a 12 DC motor that will push in the nose cone. This mechanism will be mounted in a way that when the mechanism retracts, it is out of the way of the launch vehicle path.	We will test the airframe closure subsystem, and ensure that it full seals the nose cone onto the launch vehicle.
A master switch will be activated to power on all autonomous procedures and subroutines.	The design includes a master on/off switch, which will supply or cut off all power to the AGSE.	The AGSE will have an orange LED blinking at a frequency of 1 Hz at confirmation that it is powered on. This will be easily seen and verified.
A switch will be able to pause the AGSE.	The AGSE will have a hard wired button that disables all functionality when it is pressed.	The orange LED will stop blinking when it is paused. This will be easily seen and verified.

The AGSE will erect the Launch Vehicle to 5 degrees off vertical.	The gas spring mechanism will provide more than enough torque to lift the launch rod to a position of 5 degrees off of vertical.	We will geometrically lock the launch rail that will give it a final position of 5 degrees off of vertical. We will test this during the full scale AGSE test.
After the erection, the AGSE must insert an igniter into the motor.	The AGSE has a mechanism that will uses a rack and pinion system to vertically insert the motor igniter.	The motor igniter will be visibly inserted into the motor, LSO will observe this when they judge the rocket as safe to launch. This will be tested in our full scale AGSE test.
The launch vehicle will launch as designed and jettison the payload 1,000 feet AGL.	The launch vehicle will eject the payload with the parachute at 1,000 feet.	The launch vehicle will visually jettison the payload about ⅔ the way down.
Teams will be required to use a regulation payload at the competition.	-	The payload will be handed to us during the competition.
Launch Vehicle must be able to seal the payload prior to launch.	The payload bed allows the launch vehicle to autonomously seal the payload in the rocket prior to launch.	The airframe closure subsystem will be tested, and a visual inspection will show that the rocket is fully sealed inside the rocket body.

The task must be completed within 10 minutes.	The AGSE is designed to capture the payload as quickly as possible.	We will do a full test of the AGSE and ensure that it performs all tasks within the required 10 minutes.
The AGSE must include a safety light to indicate it is on.	The safety light will be hooked into the control systems power input. It will comply with all the requirements outlined in the USLI SOW 3.2.5.1.3.	The safety light will be visibly on and blinking at the appropriate times.
The AGSE must have an all systems go light to signal ready for launch.	A "go" button will toggle a green LED which will signify that the vehicle is ready for launch.	A visual inspection will show that the "go for launch" light is activated when the rocket is ready.

7. Preliminary Integration Plan

Plan for building the AGSE

1. Cut rails to correct length
2. Assemble outer frame
3. Cut polycarbonate sheets to size
4. Insert internal rails
5. Assemble vertical conveyor belt
6. Assemble moving conveyor belt
7. Mount camera hardware
8. Assemble both rack and pinions
9. Insert all motors and gas springs
10. Attach polycarbonate walls and doors

11. Install flame shield
12. Install microprocessors
13. Connect all electronics
14. Put on decals

8. Precision of AGSE

The precision of the AGSE will rely on the various systems we choose to incorporate. The first is the vision system, which will be able to recognize the payload on any surface and precisely move the horizontal conveyor belt to its position. It will then also be able to move back to precisely the correct position to allow the other conveyor to bring it to the rocket. These systems, by necessity, need to be very precise or we might miss the payload. The classification scheme we will employ has the benefit of treating each pixel as an individual data point, therefore significantly increasing the statistics of pixel classifications. The rest of the system, however, will be precise by mechanical design. The shapes of the custom printed parts will drive the payload into the correct position.

9. Safety and Failure Analysis

With a system this large it is crucial to plan for the failure modes to ensure the safety of everyone involved in the project. The failure modes of the AGSE include a lot of minor failures. This list includes anything from and operation not working due to a wiring issue or perhaps even a coding or mechanical issue. For example if one of the belts doesn't move it is possible that it is due to the fact that the motor isn't spinning because of some minor issue. There are many minor issues that fall under the same category as this. All of these issues can be found and addressed through the rigorous testing that we have planned for the AGSE sub-systems.

It is possible, though, for a major problem to occur. A major problem, in this case, would be considered anything that causes serious damage to the AGSE or to any personnel. This includes, but is not limited to, electrical fires, currents induced by the motor in the engine igniter, which cause early motor ignition, and electric shock. These problems will all be taken into account during the building and testing processes and during testing we will continue to check for any issues that might cause any problem, but most of all any problem that could be hazardous to anyone's health.

10. Science Value

The objectives of the AGSE are: to locate a payload on the ground, capture it, insert it into the rocket, seal the rocket, erect the rocket from horizontal to vertical, and insert the igniter. In order for the system to be successful, it will need to be able to accomplish all of these tasks in less than ten minutes. In designing a system to accomplish these goals, we kept in mind the basis for the competition and designed a system that would work on the Martian surface to pick up a payload off the ground and launch it back to Earth. Although our system would be ill-suited to perform on Mars as is, it represents a scale model and prototype of the technology and system integration which would be necessary for such a mission.

In designing for the Martian surface, we put a large focus on reliability, as we only have one chance to successfully complete the mission. Two systems on the AGSE aim at solving this: the conveyor and vision system. The conveyor belt affects a large area of the surface and can pull in the payload from anywhere along its track. This increases the probability of a successful payload retrieval when compared with other methods like robotic arms. The conveyor also contains a small number of moving parts, which increases its reliability. The vision system will incorporate information from the visible and infrared spectrums to increase its accuracy. A novel classification method is being used for the location of the payload as well as the precise determination of its orientation. Our vision system will need to be experimentally verified within the context of the AGSE, and will be modified until we have accurate payload recognition.

11. Wind Analysis

In order to analyze the effect of wind on the box, we set the moment provided by the wind to the opened door and box. We determined that a wind speed of 50 miles per hour would topple the AGSE. This speed is significantly greater than the maximum wind speed for a safe rocket launch, therefore in operating configuration wind will not be an issue for the AGSE. We also calculated the minimum wind speed required to prevent the main door from opening. We found that the gas springs would not be able to open the door in wind speeds higher than about 30 miles per hour. Since this is also greater than the maximum wind speed for a safe rocket launch, the AGSE should have no trouble opening its doors.

5. Project Plan

1. Budget and Funding

Item	Description	Price	Quantity	Total
Launch Vehicle				
Body Tube	Blue Tube 4 inch diameter	$38.95	8	$311.60
Coupler Tubes	2*payloads 2*coupler tubes	$10.95	8	$87.60
Nose Cone	4-inch	$21.50	2	$43.00
Bulkheads	4 inch Coupler Bulkheads	$4.05	6	$24.30
Altimeter Bay	4 inch Blue Tube Altimeter Bay	$42.95	2	$85.90
Main Chute	24 inch Fruity Chute	$62.06	1	$62.06
Drouge Chute + Payload Chute	12 inch Fruity Chute	$45.00	2	$90.00
Shock Cord	Kevlar #1500	$0.92	80	$73.60
Fin Material	G10 Fiberglass Sheet	$47.86	1	$47.86
Motor Tube	54mm Motor Mount tube	$8.09	2	$16.18
Plywood	Hobby shop Plywood	$10.00	4	$40.00

Motor Casing	54mm Pro 54 Case	$69.39	1	$69.39
Motor	J380	$91.50	6	$549.00
Retaining Ring	Aeropack	$36.38	2	$72.76
Stratologger Altimeter	Perfectflite Stratologger	$85.55	2	$171.10
GPS Tracker	The Big Red Bee GPS locater	$230.00	2	$460.00
Radio Beacon	The Big Red Bee Radio Beacon	$89.00	1	$89.00
Push Hold Switch	Apogee	$20.00	4	$80.00
Ejection Caps	Apogee	$3.00	2	$6.00
AGSE				
Adhesives		$250.00	1	$250.00
3-D printed parts		$300.00	1	$300.00
Black Powder (gram)		$1.00	50	$50.00
Igniters (40pk.)		$41.16	1	$41.16
Lights		$12.51	2	$25.02
Electronics				
Raspberry Pi B+		$35.00	1	$35
Arduino Mega 2560 R3		$45.00	1	$45
Adafruit Arduino Motor Shield		$20.00	3	$20
XBee® Pro 802.15.4		$35.00	1	$35
Relay board	Puyu 4-Channel Opto-coupled	$18.99	1	$18.99
HobbyKing Powerstrip		$14.00	1	$14
XBee Explorer Regulated		$9.95	1	$9.95
XBee Explorer USB		$24.95	1	$24.95
Alinco DJ-V47T		$69.95	1	$69.95
Thor Labs FEL0700 Filter		$73.00	1	$73.00
Thor Labs FES0700 Filter		$73.00	1	$73.00
12V 10 aH Battery ES17-12	Andymark	$35.00	2	$70.00
Battery Charger 1 bank 6 amp	Andymark	$97.00	1	$97.00
Sensors				
E6A2-CW3C Encoder		$39.95	2	$79.90
Adafruit Micro Switch with Roller		$1.95	4	$7.80
Adafruit LASER BREAK BEAM SENSOR		$17.95	1	$17.95
Raspberry Pi NoIR Camera		$29.95	1	$29.95
Actuators				
OMHT17-275	Stepper Motor	$49.00	3	$147.00

Cytron RB-Hsi-06	DC Motor	$29	3	$87.00
Amico DC 12V	Solenoid Latch	$19.00	1	$19.00
ROB-10333	Servo	$10.95	1	$10.95
Hardware				
Large Polycarbonate Sheets	.125" x 10' x 48"	$123.76	4	$495.04
Polycarbonate sheets	.125" x 2' x 4'	$96.70	1	$97
Hex bore ball bearing	Motion Industries 2AH05-7/8	$31.25	1	$31
Gas Springs	Camloc, 14 inch stroke, 26 retractable length	$100	4	$400
8020 Rail	1" x 1"	$31.59	8	$252.72
Linear bearings	1 inch	$43.51	4	$174.04
90 degree brackets	1 inch	$5.51	45	$247.95
Rod holders	1 inch	$34.10	3	$102.30
Timing Belt (inch)	high preformance urethane, 3/4 in wide	$1.09	250	$272.50
Conveyor Belt (ft)	SRB rubber flat belting, 5.5 inch wide	$5.71	5.5	$31.41
steel rod (ft)	high strength impact, 1 in diameter	$27.17	2.5	$67.93
hinge (each)	8020 to panel, 1.5"	$14.59	5	$72.95
aluminum panel (each)	24x48	$46.05	4	$184.20
Miscellenous Hardware	Bolts, nuts, washers	$350.00	1	$350.00
Cable				
Audio Cable	1/4" to 3.5mm audio, 3 ft	$4.99	1	$4.99
ON THE PAD SUBTOTAL				$6,814.94
Support				
Testing				$1,000.00
Hotel-5 nights-4 rooms				$2,600.00
Gas-2 vans				$1,000.00
Tolls-2 cars				$280.00
SUPPORT TOTAL				$4,880.00
GRAND TOTAL				**11,694.94**
Funding Sources				
COE Scranton Fund	Received			**$2,750.00**

SGA Equipment Fund	Planned request			**$5,944.94**
Provost Grant	Received			**$3,000.00**
TOTAL FUNDING				**11,694.94**

Funding Plan

Since PDR, we have received two out of our three sources of funding within Northeastern University. We have been granted the College of Engineering's Richard J. Scranton Endowment Fund and the Provost's Undergraduate Research Grant. We have also applied to the Student Government Association's student-group equipment fund and should hear back soon.

The Scranton Fund was founded by a retired Associate Dean with the purpose of providing funding to College of Engineering affiliated student groups. Money is awarded from a yearly pool on the basis of technical acumen, project plans, and community impact. We have been awarded $2,750 from the fund and have full access to these funds.

The Provost's Grant is awarded to undergraduate students or teams who are undertaking original research or projects in STEM fields, the arts, or the social sciences. The application process requires submitting a written proposal and a recommendation letter from a faculty advisor. We have been awarded $3,000 from this grant.

The SGA's equipment fund is collected from all students through the Student Activity Fee and disbursed to Student Groups by the SGA funding committee. We have a working relationship with the funding committee and have received funding in the past for our high-altitude balloon, introductory rocketry, and unmanned aerial vehicle activities. We will be presenting on January 28th for the SGA funding committee. At this meeting we will ask for the remaining budget required for the project.

Additional funding sources are being explored for any contingencies. In the past, we have successfully used Catalyst, Northeastern's internal crowdfunding platform, to raise funding for competition transport. We are also exploring an application for funding from the Massachusetts Space Grant Association.

2. Timeline

Below is a Gantt chart outlining our previous work as well as our plan to finish the project.

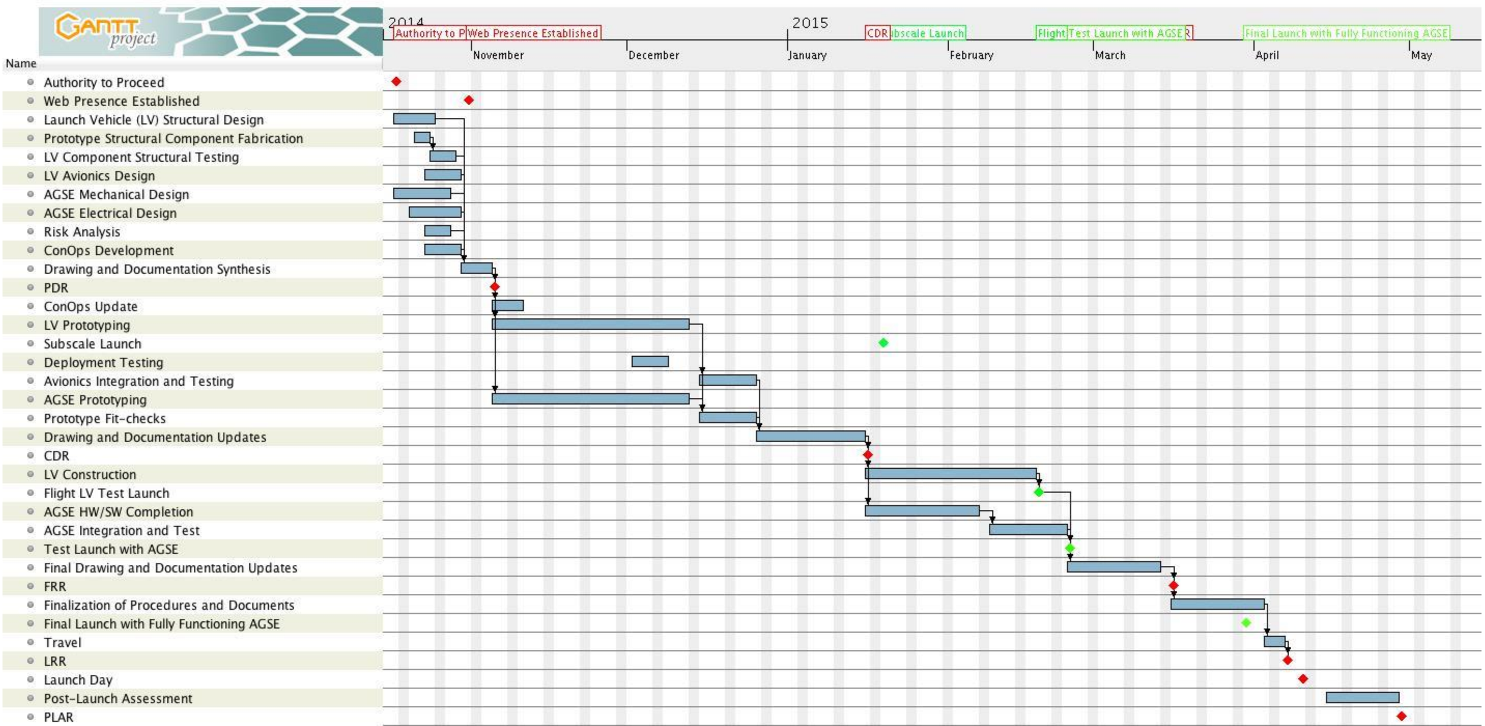

Figure 1: Gantt chart for past and projected timeline of events

Since PDR, we have built our subscale launch vehicle and started prototyping our AGSE. Unfortunately, two possible launch dates for the subscale launch were cancelled due to weather. We plan to launch the subscale launch vehicle at the next possible launch date. This will hopefully either be on the January 17th or February 14th. We have also started prototyping the vision system for the AGSE. The vision algorithm has been tested in MATLAB, and we are confident that our system will work effectively.

Moving forward, upon completion of the CDR, we plan to start building our full scale launch vehicle. We will test our full-scale vehicle several times to ensure that everything is working properly and to obtain the ideal weight to reach our target altitude. Simultaneously, we will be prototyping and building our AGSE. Our final test launch integrate the AGSE, testing if the AGSE can smoothly erect our rocket to 5 degrees off normal. We plan to have this test completed by March 8th, before the Flight Readiness Review milestone on March 16th. We will begin documentation for the FRR by February 20th, giving us plenty of time to deliver a quality document. Many tests will be done to ensure that the payload can be retrieved within the specified 10 minutes. This means that our vision system must be tested to ensure that it can process in a timely manner. By March 28th, we will have a fully functioning and tested AGSE that can capture the payload and launch our rocket.

3. Outreach Plan

Our outreach program is one of our highest priorities. STEM demonstrations sparked our imaginations at a young age and inspired us to pursue careers in science and engineering. We hope to return the favor to Boston's youth community. Moreover, we want to help grow our community's passion for aerospace and rocketry. We believe there is a bright future in the aero/astro sector as more private companies seek to partner with government agencies. Not only do we want to be a part of this movement in the present, we also want to help sustain it. This can only be accomplished by inspiring Boston's next generation of scientists and engineers. These two motives are the heart and soul of our outreach program.

Our team has a full schedule of STEM outreach events. In planning most of these events, we have worked closely with Northeastern University's Center for STEM Education. Dr. Christos Zahopoulos, Executive Director of Northeastern's STEM department, and the STEM Center organize several annual field trips for Boston Public School students to visit the Northeastern University campus. A list of both past and future activities can be seen below.

5.3.1. Activities Past and Future:

October 24: STEM field trip involved over 40 young students from the Boston School District. After we displayed our rockets and gave a background on the basics of rockets, we worked with the kids in small groups to build paper rockets. Each student had the opportunity to to fly their rocket in Northeastern's Centennial quad using a 'stomp rocket' mechanism. Watching all the excitement wash over each student was a rewarding experience.

October 25 and November 1: Team members taught a class to high school students as part of Northeastern's NEPTUN program. Classes of 9-10 students used SolidWorks 3D design software to virtually assemble the components of a car jack, a fan, a robot arm, and some other interesting machines. Students were also taught the basics component patterns, mating, and photo rendering. After designing some basic shapes, the kids played around with a photo rendering of King Kong fighting a 747. Needless to say, it was crowd pleaser (image below). Students also learned how to perform a motion simulation and were able to create their own double pendulum animation.

Figure 5.2

November 22: This event was a middle school field trip of 40 students. They visited Northeastern University to participate in an in-depth science and mathematics event. Team members presented Newton's Three Laws with demonstrations that related these fundamental laws to rocketry. The students were very intrigued by the rockets.

December 5th: We hosted an activity and tour through our club’s laboratory for high school students. Students were able to handle past rocket and weather balloon projects and see our workspace. This field trip also included a demonstration by our team and an hour-long project. This project was centered around the basic principles of rocket science, specifically Newton's Third Law and conservation of momentum.

February 13th: There will be a STEM field trip for 5th graders at Northeastern University. We will help with activities and present our work with high-powered rockets and some of the scientific principles behind them.

March 7th: We will assist in judging a 5th grade science fair. We will also have an exhibit displaying what we do as a club as well as details about high-powered rockets for any interested students.

March 21st: We will attend an event held through the Science Club for Girls (SCFG), in which we talk about our work with rocketry and exhibit what we do as a club.

March 28th: Team members will teach another SolidWorks class in which young students will virtually create their own assemblies.

April 2nd: There will be a STEM field trip for elementary students at Northeastern. We will help with activities and present our work with high-powered rockets and some of the scientific principles behind them.

Post-competition: We are working with NU's STEM Center to plan a summer science camp for Boston middle school students. This activity will take place after the competition, but we are committed to the long-term sustainability of our outreach efforts. The science camp is hosted by Northeastern University and looks to further the education of young students who are interested in science.

Our outreach program is something we hold in high regard, something we emphasize year-round. We revel in teaching young students about science and look forward to sharing our passion. We will post photos of these events in the outreach section of our new website: http://www.northeastern.edu/aiaa/.

6. Conclusion

On Earth, to perform complex analysis on samples, they must be collected and brought to a lab. Currently, billions of dollars have been spent to bring the lab to Mars. We have outlined our solution for the opposite: bring the sample of Martian terrain to be analyzed in the labs on Earth. Every system has been designed with the application of an extraterrestrial mission in mind. We begin by placing a single sealed container on a surface next to a sample as if it were dropped by a sky crane, like the one used for the Curiosity Rover. We incorporated multispectral imaging into a vision system to isolate our prospective payload based on its optical characteristics. A conveyor belt has been proposed as a straight-forward solution to acquire the payload. From that point forward, a series with a minimum number of mechanical actions will lift the payload into a capsule in the launch vehicle. The system will then erect the launch vehicle, while rotating the base of the launch vehicle into an isolated compartment of the initial system containment. Our scale model will launch the payload to 3,000 feet, simulating the complexity of sending the sample back to Earth. In either case our payload will be jettisoned from the vehicle as it approaches Earth's surface. A soft landing will be provided by a parachute and a GPS tracker will send the position of the payload capsule to the awaiting mission members.