Critical Design Review

NASA Student Launch

2014-2015

Modular Autonomous Launch Platform for a Martian Ascent Vehicle Analogue Mission

Icarus Rocketry

Arizona State University

Contents

1 Summary of Critical Design Review Report

1.1 Team Summary

Team Name
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School
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Contact Information

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Project Title
Modular Autonomous Launch Platform for a Martian Ascent Vehicle Analogue Mission

1.1.1 NAR/TRA Mentor

Roy Polmanteer
NAR #83979
TRA #11283

Qualifications
Level 3 Certified
TRA Technical Advisory Panel Member

1.1.2 Launch Vehicle Summary

Length: 103”
Diameter: 4.02”
Mass: 13.8 lbs
Rail Size: 1515

Motor: Aerotech J800T
Recovery System: 18” drogue
60” mains

1.1.2.1 Milestone Review Flysheet

See end of document attachment.

1.1.3 AGSE Summary – Modular Autonomous Launch Platform

The AGSE system that was designed has been name MALP. Key components of MALP include the support system, servo motors to the pivot rod so that rocket can erect, pivot rod, and the counter balance weights to keep the rocket steady. The support system is a connected two tower system that is raised off of the ground. The height is to give the main rod, which the rocket is attached to, room to erect without hitting the ground, it also allows room to insert the ignition wire to a lunch the rocket. The extended rod is there to allow counter weights, which is another key component, to help assist the servo motors to turn the pivot rod that is connect to the rocket rod, in order to erect the rocket into launch position. The towers also allow a place to put the servo motors and attached the pivot rod to allow twisting motion.

The payload key components include the Arm to pick up and insert payload into the payload bay, the door system inside rocket to keep payload from falling out, and the funnel inside the payload bay that allows to stable the payload so that the payload does not shake while rocket is being launched. The Arm is the robot component that picks up the payload with a claw rising on a central beam that then slides back to position claw over open payload bay doors and drops payload safely. The payload door system is composed of two sections, the outer doors and inner doors. The inner doors have a trigger that once the payload passes through they flip the outer doors shut with the momentum of the falling payload. Once the payload is inside the payload bay it waits until the rocket begins to erect. As the rocket erects the payload slides into a funnel at the bottom of the payload bay allowing the payload to keep steady during launch.

The MALP and payload systems will work together similar to a computer program. The systems are given set of instruction to follow in a particular order, however if one component of the system line fails the project is a failure. By working together the system can achieve the means of a relevant and cost effective research and development of a self-sustaining system to retrieve, accept, and fly a "Mars sample" to an altitude of 3,000 feet about ground level.

2 Summary of Changes Since Proposal

2.1 Changes Made to Vehicle Criteria

The nosecone was changed from a Shockwave Rocketry model to one from Wildman Rocketry since Shockwave Rocketry has closed their business due to ongoing health issues.

Moreover, the BigRedBee BRB9000 GPS system was replaced in favor of the much cheaper Eggfinder GPS system, which still has similar capabilities.

2.2 Changes Made to AGSE

The MALP itself has seen some robust changes, including but not limited to an additional support beam between the two main towers, the introduction of a third separate support tower, and the change from 1010 railing to 1030 railing. It also has some added safety measures such as the locking mechanism at the pivot beam should the power fail and the motors cannot hold the rocket in launch position. The ARM has changed from the entire beam sliding to only the grabbing mechanism moving along the main beam, and the up down motion has been changed to a pulley/conveyor belt system with dual motors powering the lift. Finally, the MIIS has been simplified to a platform being moved along the center slot of the 1030 launch rail by a similar conveyor belt method, with the igniter cable being attached to a dowel for support and to ensure that the cable can enter the bottom of the rocket to begin the launch sequence. While being minute changes individually, the sum total of these changes increased the effectiveness of the design immensely.

2.3 Changes Made to the Project Plan

In regards to the project plan, changes have been made to the funding plans. A corporate funding packet has been created to distribute to corporate sponsors. In addition, steps have been taken to launch the PitchFunder campaign including attending training sessions, video planning, and business logistics research regarding online funding campaigns. Icarus has also been in contact with the undergraduate student government to obtain funding for club merchandise.

3 Vehicle Criteria

3.1 Selection, Design, and Verification

3.1.1 Mission Statement

"To successfully launch a simulated Mars sample return mission payload to an altitude of 3000 ft AGL, deploy the payload bay containing the payload at 1000 ft AGL, and recover all launch vehicle components."

3.1.2 Requirements

The following are mission requirements as prescribed by the NASA Student Launch Handbook. They serve as our baseline requirements for the launch vehicle.

1. Vehicle Requirements

1.1. The vehicle shall deliver the payload to, but not exceeding, an apogee altitude of 3,000 feet above ground level (AGL).

1.2. The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in the competition scoring. The altitude score will account for 10% of the team's overall competition score. Teams will receive the maximum number of altitude points (3,000) by fully reaching the 3,000 feet AGL mark. For every foot of deviation above or below the target altitude, the team will lose 1 altitude point. The team's altitude points will be divided by 3,000 to determine the altitude score for the competition.

1.2.1. The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight.

1.2.2. Teams may have additional altimeters to control vehicle electronics and payload experiment(s).

1.2.2.1. At the Launch Readiness Review, a NASA official will mark the altimeter that will be used for the official scoring.

1.2.2.2. At the launch field, a NASA official will obtain the altitude by listening to the audible beeps reported by the official competition, marked altimeter.

1.2.2.3. At the launch field, to aid in determination of the vehicle's apogee, all audible electronics, except for the official altitude-determining altimeter shall be capable of being turned off.

1.2.3. The following circumstances will warrant a score of zero for the altitude portion of the competition:

1.2.3.1. The official, marked altimeter is damaged and/or does not report an altitude via a series of beeps after the team's competition flight.

1.2.3.2. The team does not report to the NASA official designated to record the altitude with their official, marked altimeter on the day of the launch.

1.2.3.3. The altimeter reports an apogee altitude over 5,000 feet AGL.

1.2.3.4. The rocket is not flown at the competition launch site.

1.3. The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.

1.4. The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.

1.5. The launch vehicle shall be limited to a single stage.

1.6. The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the Federal Aviation Administration flight waiver opens.

1.7. The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.

1.8. The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.

1.9. The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).

1.9.1.Final motor choices must be made by the Critical Design Review (CDR).

1.9.2.Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO), and will only be approved if the change is for the sole purpose of increasing the safety margin.

1.10. The total impulse provided by a launch vehicle shall not exceed 5,120 Newton-seconds (L-class).

1.11. Any team participating in Maxi-MAV will be required to provide an inert or replicated version of their motor matching in both size and weight to their launch day motor. This motor will be used during the LRR to ensure the igniter installer will work with the competition motor on launch day.

1.12. Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria:

1.12.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) shall be 4:1 with supporting design documentation included in all milestone reviews.

1.12.2. The low-cycle fatigue life shall be a minimum of 4:1.

1.12.3. Each pressure vessel shall include a solenoid pressure relief valve that sees the full pressure of the tank.

1.12.4. Full pedigree of the tank shall be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.

1.13. All teams shall successfully launch and recover a subscale model of their full-scale rocket prior to CDR. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model.

1.14. All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full scale demonstration flight:

1.14.1. The vehicle and recovery system shall have functioned as designed.

1.14.2. The payload does not have to be flown during the full-scale test flight. The following requirements still apply:

1.14.2.1. If the payload is not flown, mass simulators shall be used to simulate the payload mass.

1.14.2.2. The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.

1.14.2.3. If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems shall be active during the full-scale demonstration flight.

1.14.3. The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulate, as closely as possible, the predicted maximum velocity and maximum acceleration of the competition flight.

1.14.4. The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the competition flight.

1.14.5. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO).

1.15. Each team will have a maximum budget they may spend on the rocket and the Autonomous Ground Support Equipment (AGSE). Teams who are participating in the Maxi-MAV competition are limited to a $10,000 budget while teams participating in Mini-MAV are limited to $5,000. The cost is for the competition rocket and AGSE as it sits on the pad, including all purchased components. The fair market value of all donated items or materials shall be included in the cost analysis. The following items may be omitted from the total cost of the vehicle:

- Shipping costs
- Team labor costs

1.16. Vehicle Prohibitions

1.16.1. The launch vehicle shall not utilize forward canards.

1.16.2. The launch vehicle shall not utilize forward firing motors.

1.16.3. The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.).

1.16.4. The launch vehicle shall not utilize hybrid motors.

1.16.5. The launch vehicle shall not utilize a cluster of motors.

2. Recovery System Requirements

2.1. The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude. Tumble recovery or streamer recovery from apogee to main parachute deployment is also permissible, provided the kinetic energy during drogue-stage descent is reasonable, as deemed by the Range Safety Officer.

2.2. Teams must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.

2.3. At landing, each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.

2.4. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.

2.5. The recovery system shall contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers. One of these altimeters may be chosen as the competition altimeter.

2.6. A dedicated arming switch shall arm each altimeter, which is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.

2.7. Each altimeter shall have a dedicated power supply.

2.8. Each arming switch shall be capable of being locked in the ON position for launch.

2.9. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.

2.10. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.

2.10.1. Any rocket section, or payload component, which lands untethered to the launch vehicle shall also carry an active electronic tracking device.

2.10.2. The electronic tracking device shall be fully functional during the official flight at the competition launch site.

2.11. The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).
- 2.11.1. The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.
- 2.11.2. The recovery system electronics shall be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.
- 2.11.3. The recovery system electronics shall be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.
- 2.11.4. The recovery system electronics shall be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.

3.1.3 Mission Success Criteria

The following are the necessary criteria our launch vehicle must attain to be declared a success:

- Successfully launch and maintain and stable flight trajectory to apogee.
- Attain an apogee between 2,800 and 3,200 ft AGL.
- Eject and deploy a drogue parachute within 1 to 2 seconds after reaching apogee.
- Eject and separate the nosecone/sample bay from the rest of the launch vehicle at 1,000 ft AGL and:
  - Deploy the nosecone/sample bay parachute.
  - Deploy the launch vehicle's main parachute.
- Successfully recover the launch vehicle and sample bay.
- Minimal damage to the launch vehicle or sample bay post-flight.

3.1.4 Major Milestone Schedule

Please see section 5.3.

3.1.5 System Level Review

Our team's launch vehicle is comprised of multiple sub-systems that will enable it to accomplish the required mission objectives. The Structures Subsystem provides the airframe support structure that contains the other subsystems, the aerodynamic shape that allows it to successfully travel at the required velocities and the payload bay sub-assembly that contains the sample capsule during the flight. The Propulsion Subsystem provides the thrust for the vehicle to reach the required altitude given the vehicle's mass. The Flight Dynamics Subsystem ensures that the vehicle is stable throughout its flight and that the structural loading occurs as expected. The Electronics Subsystem provides altimeters for verifying the vehicle reaches the required altitude, altimeters for correctly deploying the recovery system components and GPS tracking systems for each of the independent vehicle segments. And the Recovery Subsystem provides the parachutes and related recovery equipment for each of the vehicle segments. If each of the subsystems performs as designed, our team's vehicle will successfully complete the mission objectives.

3.1.5.1 Airframe and Structures

3.1.5.1.1 Sample Payload Bay

The sample payload bay is the component of our launch vehicle which includes the payload bay doors that open to the external environment to accept the sample tube, and a sample retention system in the rocket that will help minimize motion and rattling of the sample tube in the rocket airframe.

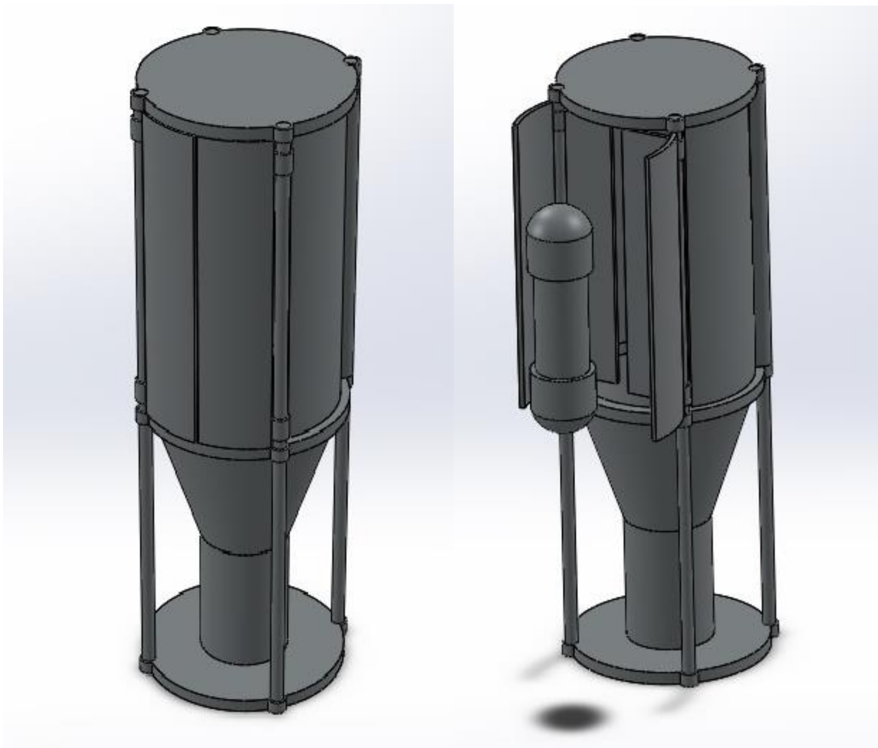


Figure 1 – SolidWorks Design of the Sample Payload Bay. (L) The sample bay with doors closed. (R) The sample bay with doors open and sample tube for scale, and to show the internal flaps which serve as lever arms to close the doors once the sample tube is dropped in.

Our payload bay will utilize dual payload bay doors which open out with a flap attached along the hinge. When open, these flaps on the payload bay doors will effectively close off the opening of the payload bay door, such that when the sample tube is dropped onto these flaps, they will act as levers closing the payload bay doors. The inspiration for this design comes from mail drop boxes which utilize a similar flap mechanism (albeit, in these instances it is for security reasons). The doors themselves will have a small spring along their hinges to ensure that the doors do not accidentally close from a gust of wind. Neodymium rare earth magnets along inside of the flap, and along the sidewalls of the payload bay will ensure that once the payload bay doors are closed, they remain firmly closed throughout the stresses of flight.

The aft end of this internal payload bay is a 3in long conical section which terminates in a 3in long section of 1.25in diameter tube. When the rocket is raised, the gravity will funnel the sample tube into this smaller diameter tube which will serve to reduce any rattling or movement of the sample tube in the airframe so as to not affect the aerodynamic performance of the rocket.

The lower 4 inches of the payload bay assembly will be enclosed in a BlueTube coupler tube 8 inches long. This will serve as an auxiliary payload bay. Contained inside mounted to a plywood sled will be our GPS transmitter, the Eggfinder.

At the top and bottom of the assembly are machined 6061 aluminum bulkheads, and all the components are connected together with 4 all-thread rods for structural support. Each of the aluminum bulkheads will have four screw holes arranged along their circumference. For final assembly, this entire assembly will be sled into the rocket's upper airframe tube. The assembly will we secured in place by driving screws through the outer airframe into the aluminum bulkheads.53951

3.1.5.2 Propulsion

Our launch vehicle will utilize a commercially available **Aerotech J800T** motor. This is an 91% J reloadable composite motor which utilizes Aerotech's Blue Thunder formulation of a ammonium perchlorate composite propellant. This yields a **thrust-to-weight ratio of 13.03** for the launch vehicle, and velocity of our ***10ft rail*** of

To minimize costs, the team is using an already available Rouse-Tech 54/2560 reload casing with the Aerotech 54mm Reload Adapter System.

Additional motor options that would have resulted in performance within our altitude window included either the K185W, J401FJ, J415W, J540R, J1799N, or J800T. The K185W was ruled out as it only produced a thrust-to-weight ratio of 2.52. Similarly, the J401FJ and J415W were ruled out for having velocities off a 10ft launch rail of <70ft/s. The J540R yields better performance, and came in a close second, but only yielded a thrust-to-weight ratio of 8.79. The J1799N was ruled out as it uses Aerotech's Warp-9 propellant – their fastest burning propellant, which would have resulted in a max acceleration of the launch vehicle of 30.3G's. Use of this motor would require additional strengthening of the rocket airframe beyond the current design, and was therefore eliminated.

3.1.5.3 Flight Dynamics

Stability of the rocket flight is crucial to mission success as well as ensuring safety of any nearby spectators. Our rocket is designed with a **static stability margin of 1.98**. The static stability margin is a dimensionless number which is computed by taking the difference in the center of gravity and center of pressure of the rocket divided by the body tube diameter. With this margin, our rocket is stable, **statically stable**.

3.1.5.4 Electronics

The electronics payload of our rocket is relatively basic. All electronics are limited to flight mission critical hardware, since we are not flying any additional science payloads on this launch vehicle. All electronics in the launch vehicle will be contained on electronics bay, with the exception of the GPS radio telemetry system, which will fly in a separate dedicated electronics bay the base of the nosecone/sample bay assembly.

3.1.5.4.1 Electronics Bay

Electronics in the main electronics bay or (E-bay) are necessary for the function of the recovery system, and also the competition altitude verification. For redundancy, there will be two altimeters to be flown in the E-bay. Each altimeter will be wired in independent circuits with their own power supplies. In addition to account for any possible manufacturer issues, the two altimeters will be of different makes and models. The altimeters selected for flight are a **PerfectFlite Stratologger**, and a **MissileWorks RRC3**.

3.1.5.4.2 GPS Tracking

Due to the way our rocket is designed, a separate ejection charge will not be necessary to deploy the parachute of the sample bay. As a result the only electronics required on-board will be the GPS tracking unit. For our purposes, because we did not want to use a system which operates on radio bands that require the use of a HAM license, we selected the **Eggfinder GPS Tracking System**. It is a complete system for GPS telemetry that includes a receiver and transmitter. This differs from our original selection of the Big Red Bee BRB9000. The choice was made due to budget constraints. The Eggfinder offers similar performance, however is at lower cost at the expense of having to solder the components to the board ourselves.

The transmitter unit uses RF modules in the 902-928 MHz ISM band from Hope RF, model HM-TRP-915. This offers an 8,000' range line-of-sight which should easily cover any requirements necessary for the performance window of our rocket system. The receiver includes a USB link to connect to any computer to download the NMEA data stream as it is received from the transmitter on-board the rocket.

Both the Electronics Bay and Sample Bay will have an Eggfinder GPS. The altimeters in the bay will be shielded from GPS transmitter using aluminum foil tape.

3.1.5.5 Sample Payload Bay

The sample payload bay is the component of our launch vehicle that will accept the sample tube from the AGSE and automatically secure it for launch. SolidWorks models of the sample payload bay are shown in Figure 3.

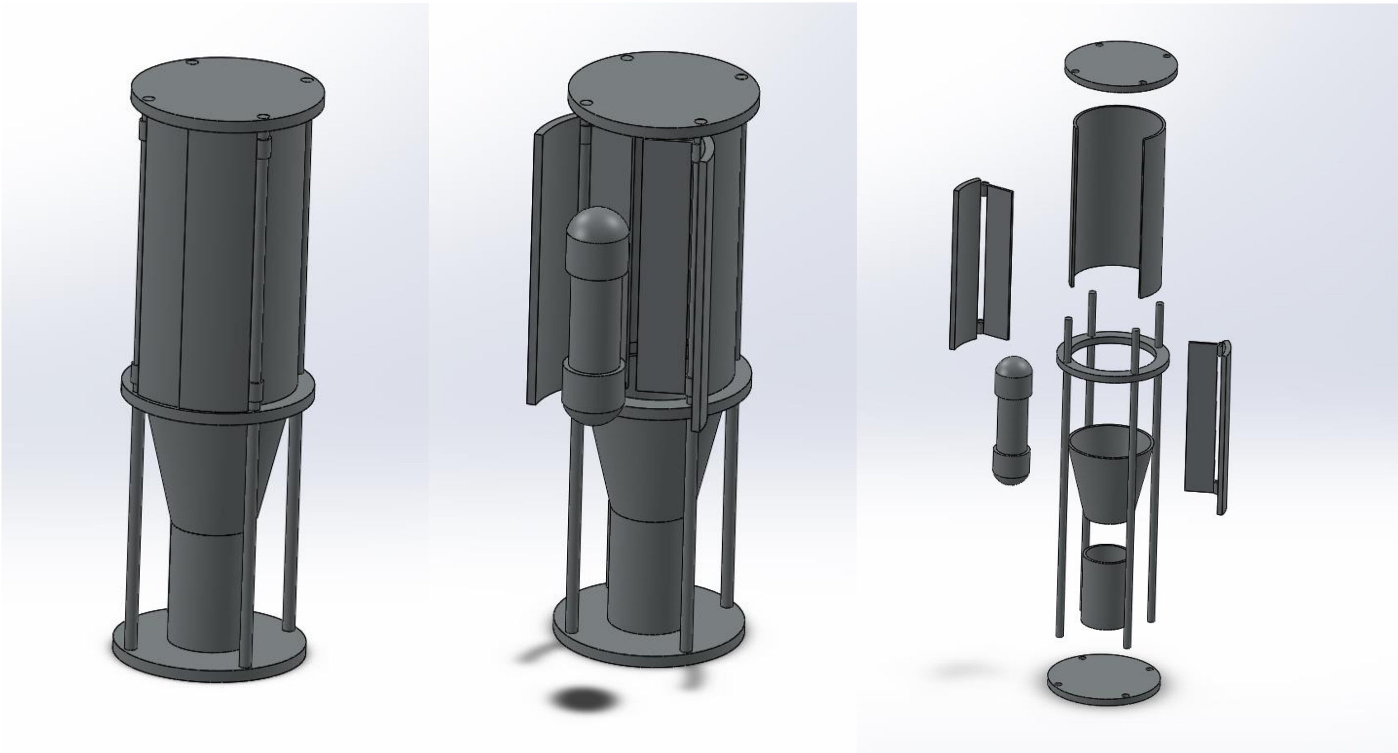


Figure 2 – SolidWorks Design of the Sample Payload Bay. (L) The sample bay with doors closed. (C) The sample bay with doors open and sample tube for scale. R) Component View of the sample bay.

Our payload bay will utilize dual bay doors, which open upward when the launch vehicle is in its pre-launch horizontal configuration and will be left open prior to our automated sample loading procedures. While the outer doors are open, the inner flaps on the doors will mostly close off the payload bay opening. During the sample loading procedure, the AGSE will drop the sample tube onto these inner flaps, which will act as levers and use the weight of the tube to rotate the outer doors to their closed position. The inspiration for this design comes from mail drop boxes, which utilize a similar flap mechanism (albeit, in these instances it is for security reasons). The doors will have small springs along their hinges that will prevent them from accidently closing due to wind or vibrations caused by the AGSE. Once closed, small neodymium magnets on the inner flaps will secure themselves to identical magnets along the inner sidewalls of the payload bay to ensure that the payload bay doors remain firmly closed throughout the launch and recovery process.

The aft half of the payload bay includes a 3in long conical section that terminates in a 3 inch long section of 1.25 inch diameter tube. When the rocket is raised, gravity will funnel the sample tube into this smaller diameter tube, which will serve to reduce movement of the sample tube in the airframe during launch.

The lower 4 inches of the payload bay assembly will be enclosed in an 8 inch long BlueTube coupler tube. This will serve as an auxiliary payload bay. Our GPS transmitter (Eggfinder GPS) will be mounted to a plywood sled in this section.

At the top and bottom of the payload bay assembly are machined 6061 aluminum bulkheads, and the major components are connected together with 4 all-thread rods for structural support. Each of the aluminum bulkheads will have four pre-threaded screw holes arranged around their circumference. After the payload bay has been constructed, the entire assembly will be inserted into the rocket's upper airframe tube. The assembly will then be secured in place by driving screws through the outer airframe into the pre-threaded holes in the aluminum bulkheads and center ring.

3.1.5.6 Mission Performance Predictions

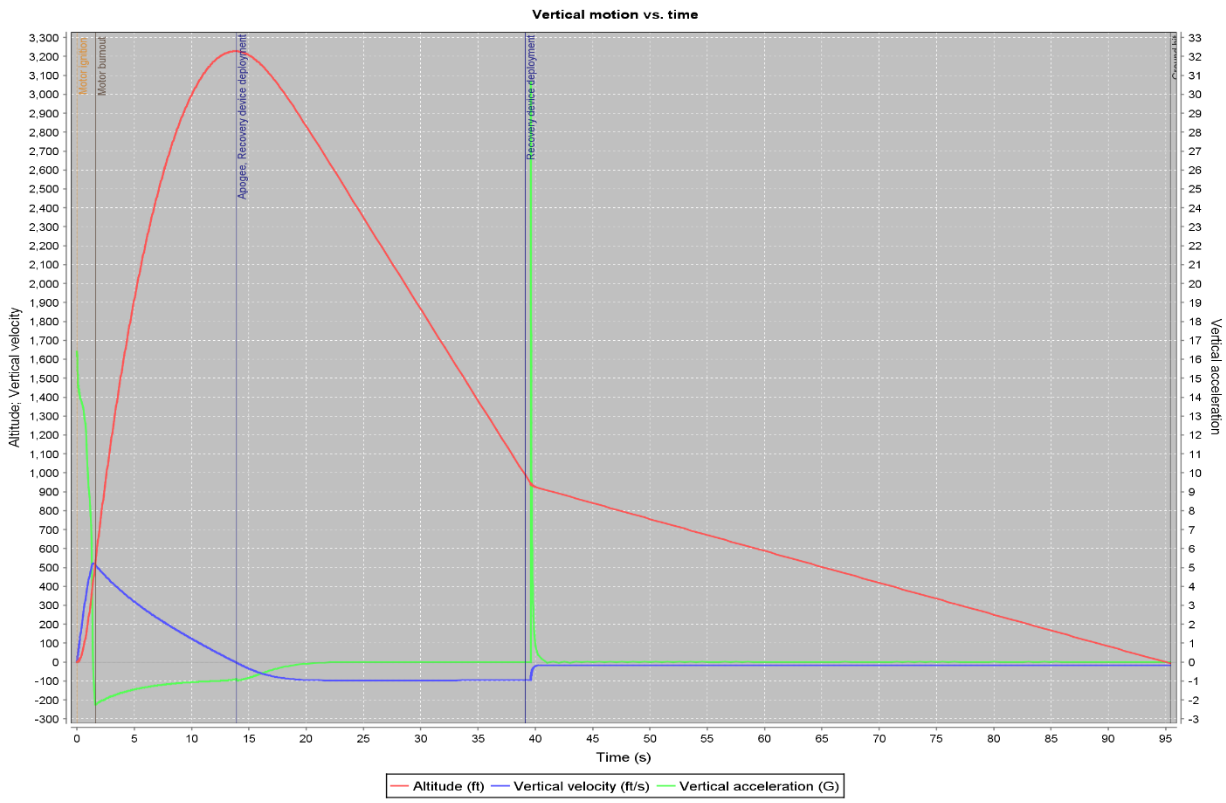
3.1.5.6.1 Mission Performance Criteria

- The launch vehicle must successfully launch and attain an apogee of 3,000 ft AGL.
- The launch vehicle must deploy a drogue parachute at apogee; and eject the sample bay and main parachute at 1,000 ft AGL during descent.
    - This recovery system must successfully land the rocket with minimal damage (ready to fly with minimal labor)
    - This recover system must arrest the terminal velocity of the rocket and sample bay such that each section that lands has less than 75 ft-lbf of energy.

3.1.5.6.2 Flight Profile Simulations

Flight simulations were conducted using OpenRocket. The launch conditions were set roughly to the location of Huntsville, Alabama, with an elevation of 600ft. Atmospheric conditions were set to the averages for April. The launch rod was set to 10ft and an angle of 5 degrees off vertical.

Our predicted altitude is 3,657 ft AGL.


Vertical motion vs. time
Altitude; Vertical velocity
Vertical acceleration
Time (s)
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Altitude (ft)
Vertical velocity (ft/s)
Vertical acceleration (G)

3.1.6 Thrust Curve

The selected motor is an Aerotech J800T, which produces a peak thrust of just under 850N.

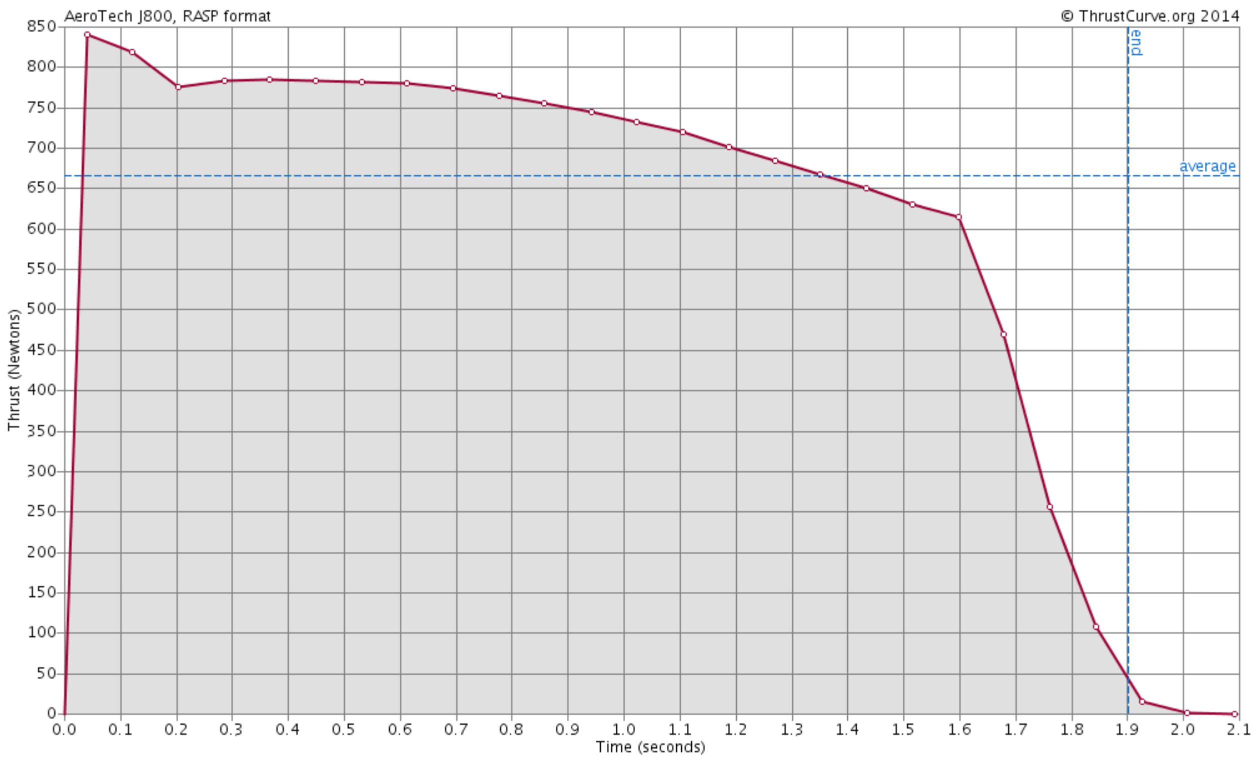
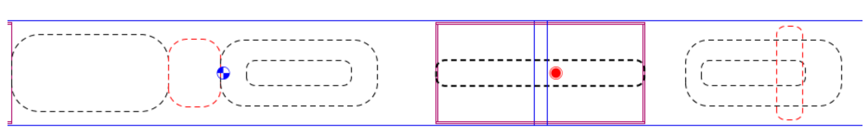


Figure 5 - Thrust curve for Aerotech J800T. Provided by http://www.thrustcurve.org/

3.1.7 Stability Margin

The stability margin of the rocket is computed to be 1.98 with the Center of Pressure and Center of Gravity at 63.088 inches, and 55.057 inches from the tip of the nosecone, respectively.



3.1.7.1 Schematics

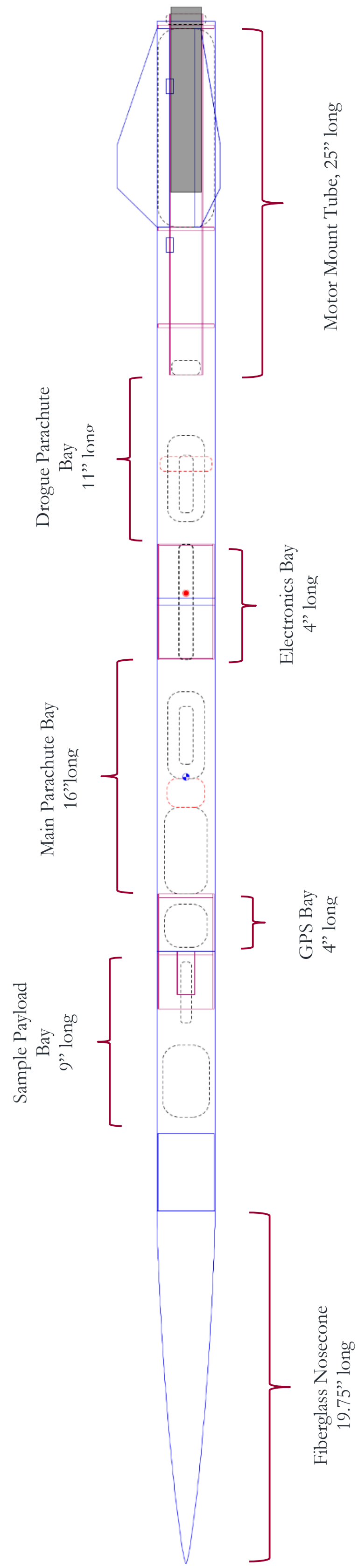


Figure 7 - Schematic of the Rocket

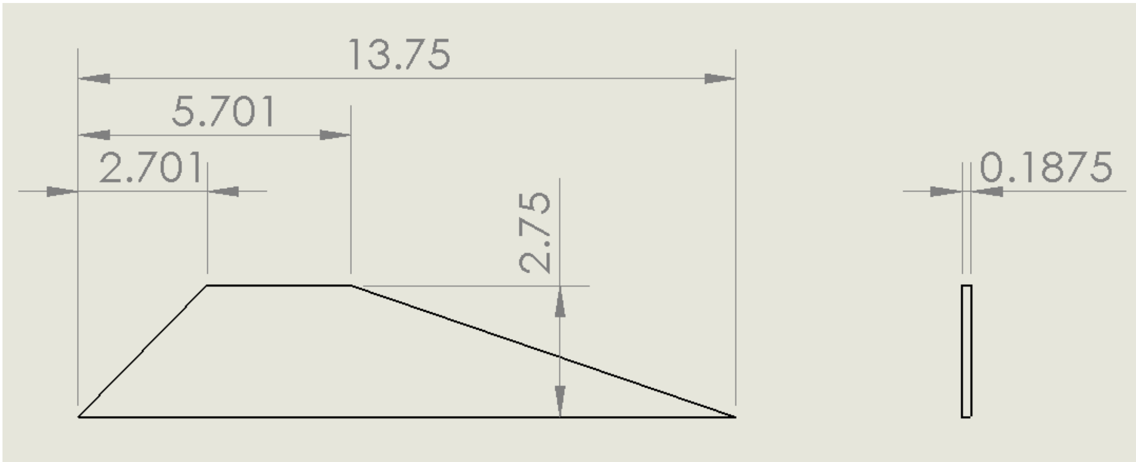


Figure 8 - Schematic of the Fins.

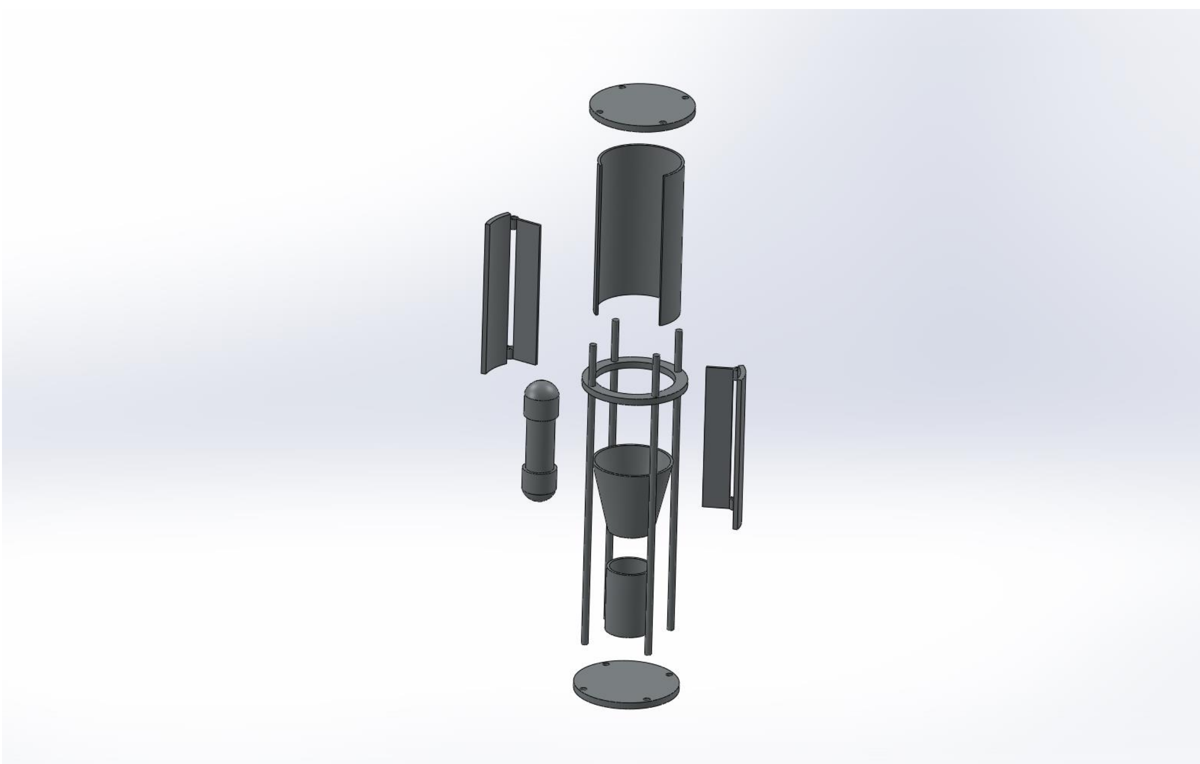


Figure 9 - Blow apart diagram of the Sample Payload Bay Assembly

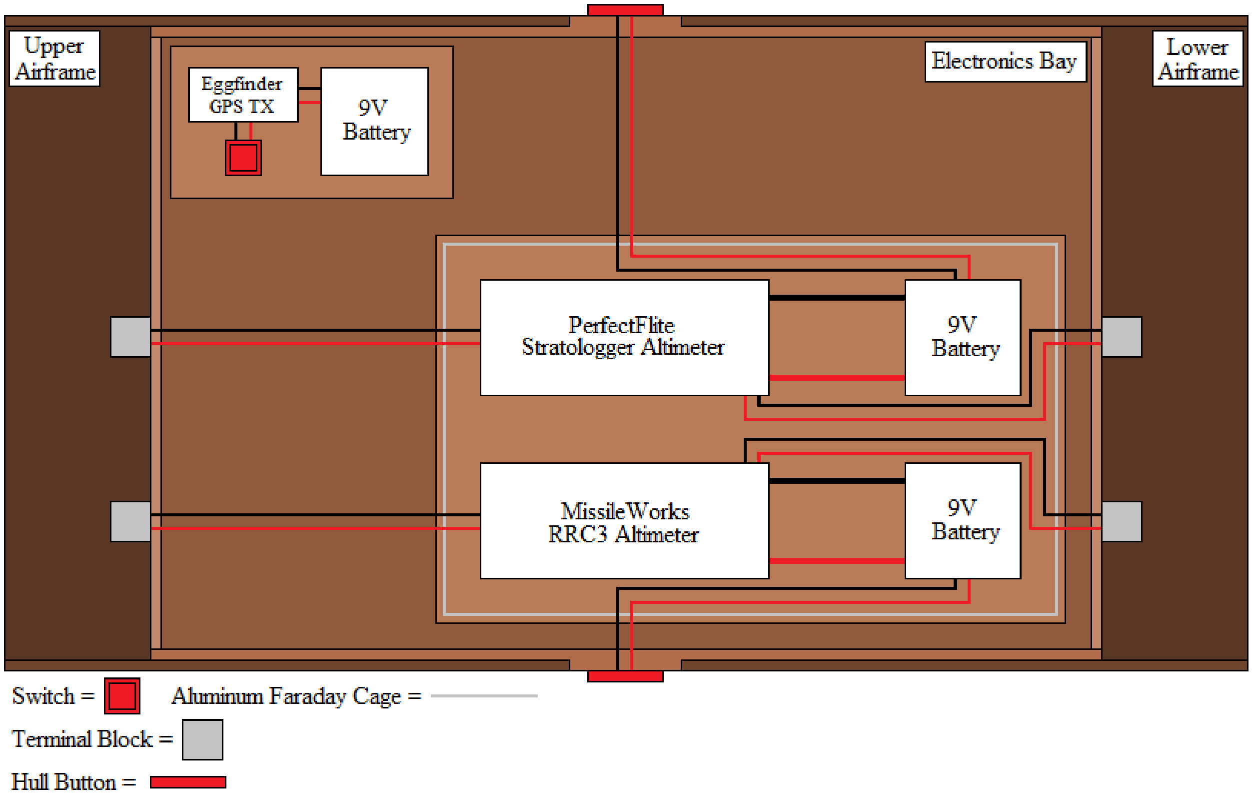


Figure 10 - Electronics Bay Wiring Schematic

3.1.8 Performance Characteristics and Evaluation

The performance of the Propulsion Subsystem is integral to the completion of our vehicle's mission objectives. It utilizes a commercially available J-class APCP motor with a peak thrust of 248lb, which will propel the vehicle to a **maximum velocity of 587 ft/s** and an apogee of 3,424 ft. Although the OpenRocket simulations estimate an apogee greater than the required altitude, our team's experience with these simulations suggest that this is an overestimate, which we will verify with our full-scale test flight.

The performance of the Recovery Subsystem is also key to the successful completion of our team's objectives. The main vehicle will deploy a drogue parachute to slow and stabilize its descent and a main parachute to slow it sufficiently for touchdown. This will result in a ground impact speed of ***16.5 ft/s*** and an impact force less than the required value of 75 lbf. The sample payload section of the vehicle will descend on a single parachute after being ejected at 1,000ft AGL. This will result in a ground impact speed of ***16.5 ft/s*** and an impact force less than the required value of 75lbf.

3.1.9 Workmanship

The approach to workmanship taken was to play to everyone strengths and likes. The Icarus team has a wide variety of skills and levels of knowledge. A portion of the team has never been involved with a project of this magnitude. In order to have everyone fully able to help with the workload, more inexperienced members where given the choice of what they would like to be apart of so that they could learn from the experienced team leaders. The team leaders were chosen for their skills in specific areas. The Project Director and Safety Officer have the most experience with projects such as the Student Launch and give their experience and help to newer members to make the project run smoother. The project has been broken up into separate teams including the electronics, AGSE, launch vehicle, and safety. These teams were broken down into sub teams, each with team leaders. The success of the project requires all teams to correlate with one other, in order to make sure all the teams work together weekly meetings attended.

3.1.10 Testing

The simulations done for the launch vehicle was in OpenRocket and real time subscale testing. All components of the full-scale launch vehicle performed as expected in the OpenRocket simulations. The final test result after the subscale launch concluded that the through-the-wall fins with expanding foam, birch plywood center rings and fins, dual deploying system, and the Rouse-tech 54/2560 with 54mm reloadable adaptor system are all tested and approved for the the full-scale launch vehicle, as they all tested perfectly. Since both the OpenRocket simulations and subscale testing performed as expected the team has full confidence of the abilities of the full-scale launch vehicle.

3.1.10.1 Future Test Plans

Given the successes of our subscale flight, we do not foresee the need for any future test of materials or structural testing.

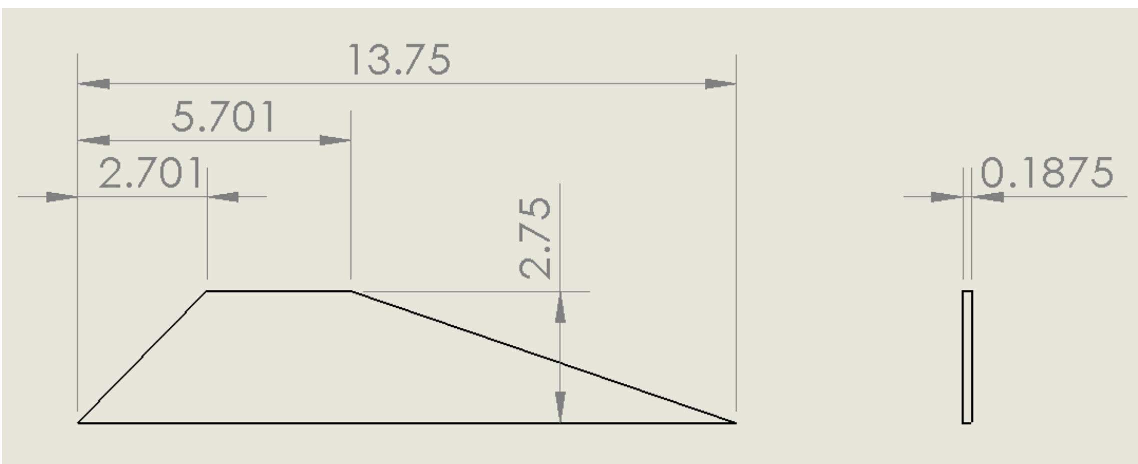
3.1.11 Status of Manufacturing and Assembly

At the point of writing, all major construction of the final full-scale rocket still needs to be started. Acquisition of minor components and parts (quick-links, swivels, shockcords, hardpoint anchor, parachutes, etc.) has been completed. Major build materials such as nose cones, birch plywood, and airframe tube still need to be purchased. A setback was encountered with the loss of Shockwave Rocketry as our original supplier of filament wound fiberglass nosecones. However, with the selection of Wildman Rocketry as a replacement source, we can move ahead with construction following successful completion of the Critical Design Review.

3.1.12 Design Integrity

3.1.12.1 Fin Design

The aspect ratio of a fin is the square of the fin semispan divided by the fin area. Higher aspect ratio fins are more aerodynamically efficient. In terms of actual fin planform shape, this is generally only a second or third order consideration on the performance of the fin compared to the aspect ratio of the fin. With this in mind, the team chose a relatively non-traditional fin design, which has been dubbed the "aggressor," for the missile-like imagery that it elicits. The forward-swept clipped delta was designed specifically to minimize fin damage in the event of a recovery system failure. This design was developed by the team for a previous high power rocketry competition, and shown to have exemplary aerodynamic performance, as well as performing its intended design function of minimize fin damage.



For fin retention and maximum structural support, the fins will through-the-wall mounted. The fin tabs which extend in through the outer airframe tube will extend all the way to the motor mount tube, and there will be centering rings that abut the upper and lower edges of the fins. The fins will be mounted with epoxy, and all parts of the airframe that meet the fin will be epoxied as well. Further, after the aft centering ring is epoxied in place, two holes in the centering ring will be used to pour expanding 4lb density closed-cell polyurethane expanding foam. This will add additional structural support to the fin area.

3.1.12.2 Structural Materials

The airframe of the rocket is one of the most essential and critical aspects of the launch vehicle, serving as the backbone upon which additional components, electronics, and payloads are mounted. Structural integrity is of vital concern to ensure that the launch vehicle is not only capable of withstanding the forces at launch, recovery system deployment, and ground impact, but also protecting the onboard equipment and payloads.

3.1.12.2.1 Airframe Material – BlueTube 2.0

The expansion of high power rocketry as yielded a vast variety of airframe materials. Generally, airframe materials can be separated into two classes: paper-based, and composite. In the paper-based category is the traditional phenolic tube, MagnaFrame, and BlueTube 2.0. Composites consist of either G12 filament wound fiberglass, or carbon fiber.

For consistency, our team established a requirement that all airframe tube components of the launch vehicle be constructed of the same material for consistency. The requirement for a GPS or radio locator in the payload container eliminated carbon fiber as an airframe material since it blocks all RF signals.

The strongest and most durable airframe material is certainly G12 fiberglass; however, it suffers from much higher cost and weight compared to the other airframe material options. The relatively low altitude requirements of the launch vehicle mean that the launch vehicle will not be subjected to excess high stress forces, either from launch or ground impact (in the event of a recovery system failure). As a result, fiberglass was also eliminated as an airframe material.

Figure 12 – BlueTube 2.0

Paper-based airframes were therefore the only remaining options. As an airframe, phenolic is the weakest in terms of peak load and is the most brittle of airframe materials. MagnaFrame and BlueTube 2.0 are similar in that they both utilize vulcanized fibers in their construction. MagnaFrame is composed of interlaced layers of vulcanized fiber and phenolic. BlueTube made primarily out of vulcanized fiber, and withstands the highest peak loads of the paper-based airframe materials. Although it has a lower modulus than MagnaFrame, this lends to its inherent durability against impact, and resistance to abrasion. Moreover, as a lower-cost material than MagnaFrame, this made BlueTube the optimal airframe material for our launch vehicle.

3.1.12.2.2 Centering Rings and Fin Material – Aircraft Birch Plywood

For their ease of manufacturability and strength, birch plywood was selected as the airframe material for constructing centering rings and fins. Plywood can be easily CNC'ed with machines available in student machine shops on our campus. In addition, plywood can be easily sanded and shaped – important for cutting the fins and shaping their leading and trailing edges to reduce drag.

And alternative considered was G10 fiberglass, which has a higher strength to weight ratio compared to birch plywood. However, concerns about cutting and sanding such an abrasive material – both toward our cutting tools, as well respiratory and skin safety ruled out G10 fiberglass for this particular launch vehicle. The difficulties of handling the material was not justified given the design and necessary performance parameters of the launch vehicle.

3.1.12.2.3 Interface Bonding and Composites

To minimize external protuberances that result in additional drag, the majority of airframe structural components will be attached to each other using high-strength epoxy. This includes centering rings, and fin attachments. In the cases of bonding metallic components to the airframe, a metal-impregnated epoxy, JB-Weld will be utilized to ensure a better bond than regular epoxy. These instances include attaching the Acme conformal launch rail guides, Aeropack Motor Retainer, and Giant Leap Hardpoint anchor. The only instance where an epoxy will not be used in the rocket is to attach the sample bay assembly into the rocket. In this case, the upper and lower bulkheads of the sample bay will have mount points for the team to screw through the outer airframe into to secure the bay in the launch vehicle.

3.1.12.3 Assembly Procedures

In order to assemble the rocket from scratch, you must first create the universe. This will take 13.8 billion years. Insert an apple pie in the oven while waiting.

Then assemble the hardpoint anchor to the motor. Dry fit both centering rings into the airframe and over the motor mount tube. Spread a bead of epoxy around the circumference of one end of the motor tube leaving a gap in the bead for the notch in the centering ring. Slip the notched centering ring over the motor tube with the notch aligned with the gap in the epoxy bead. Locate the ring from the end of the motor tube and allow the epoxy to set. Apply an epoxy fillet to each side of the ring still keeping the notch clear. Slide the standard centering ring over the motor tube until of the motor tube is protruding beyond the ring. Spread a layer of epoxy on the motor tube just below the notch in the upper centering ring. Pull strap through the notch and press it firmly into the epoxy on the side of the motor tube. Hold the strap in place against the tube with masking tape until the epoxy cures. Remove the masking tape. Fill the entire centering ring notch with epoxy. All fins should be sanded to assure smooth consistent surfaces, especially the one that connects to the body tube. Apply a bead of epoxy to the root edge of a fin. Push the fin through the slot in the airframe and against the motor mount tube. Repeat this process for all fins. Apply an epoxy fillet to both sides of each fin. Once the center ring is in place after finishing the fins, drill two small holes on both the top and bottom of the motor inside the center rings. Mix 1:1 part of expanding foam and pour into cavities around fins of rocket. Now check that the apple pie is done.

The payload bay assembly will be structurally supported by four lateral rods secured to two end plates and a middle ring. The top half includes a set of inner doors connected to a set of outer doors. The act of dropping the sample capsule onto the inner doors while the vehicle is positioned horizontally will cause them to open, allowing the capsule to drop into the payload bay, and simultaneously close the outer doors, which will be secured in the closed position by small neodymium magnets. The bottom half includes a funnel and tube that will automatically position the sample capsule for launch when the vehicle is raised into a vertical position for launch and will prevent the capsule from shifting during the ascent portion of the flight. The design of the payload bay assembly only includes two moving parts (the two independently hinged doors) in an effort to simply the design.

The three components of the launch vehicle are joined by two coupler tubes. Each coupler tube's fore section will be secured to the airframe by way of four ¼ inch removable nylon rivets, symmetrically set about the circumference of the launch vehicle while the aft section will be secured by two 2-56 x ¼ inch nylon screws also symmetrically set about the launch vehicle's circumference, serving as shear pins. Using four rivets will sufficiently secure the fore section of each coupler tube to the airframe while the two screws will provide enough leverage for the launch vehicle to remain linked without creating an excessive level of resistance to overcome when setting off the ejection charges, thus avoiding significant issues of over-pressurizing the airframe without separation. Within the lower airframe is the motor, set at the aft portion of the launch vehicle. The fore section of the motor tube is epoxied to a hardpoint anchor from Giant Leap Rocketry. The shock cord—½ inch in width and composed of tubular braided Kevlar—will be connected to the hardpoint anchor using a ¼ inch quick link. The shock cord will be 31.25 feet in length, or approximately 3.5 times the length of the launch vehicle, which will allow the launch vehicle components to descend without potential collisions with one another. The other end of the shock cord will be secured by another quick link to a ¼ inch eyebolt in the bulkhead of the electronics bay. Along the length of the shock cord will be a knotted portion that creates a small loop that will serve as a linking point for a drogue parachute. The upper airframe will contain two primary parachutes that are appended to separate lengths of shock cord. This is due to the upper airframe and nosecone/sample bay sections becoming individual entities upon deploying the second ejection charge. Since the two portions cleanly separate, the shock cords will not have to absorb the resulting shock of two airframe segments—only one; therefore, the shock cord will not have to be as long as the one used within the lower airframe. The two shock cords within the upper airframe will be 13.5 feet in length—approximately 1.5 times the length of the launch vehicle. One end of each shock cord will be knotted to form a loop for the parachute while the other end will be connected to a ¼ inch eyebolt in the bulkhead of their respective airframe component by way of a ¼ inch quick link.

3.1.12.4 Motor Mount

Our motor mount is a 25" long, 54mm diameter BlueTube2.0 tube. The aft end of the motor mount will have n 54mm Aeropack Quick Change Motor Retainer epoxied to it using JB Weld. From team experience with other rockets as well on our subscale rocket, this method of motor retention has been shown to withstand not only powerful K motors, but also hard impacts on the desert floor without any significant damage or loss of motor.
The team has developed a plan for verifying compliance with the requirements stated in the NASA Student Launch Project Statement of Work (SOW). The requirements, the design features that address them, the methods of verifying compliance and the status of the verifications are summarized in Table 1.

3.1.13 Verification Plan

The status of each verification is shown using a color-coded system: verified requirements are listed in green, requirements that have not yet been verified are listed in yellow and requirements that failed verification are listed in red. (There are currently no requirements that have failed verification.)

Table 1 - Vehicle Requirement Verification Plan

Req #	Requirement	Relevant Design Feature	Verification Method
1.1	The vehicle shall deliver the payload to, but not exceeding, an apogee altitude of 3,000 feet above ground level (AGL).	OpenRocket will be used to simulate the launch and select an appropriate motor.	Testing: The sub-scale and full-scale test flights will be used to verify the accuracy of the OpenRocket simulations.
1.2	The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in the competition scoring.	Redundant barometric altimeters are included in the design.	Design: The Recovery Team lead will ensure the proper altimeters are included in the design.
1.2.1	The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight.	Both altimeters shall report the altitude via a series of beeps.	Design: The Recovery Team lead will ensure the proper altimeters are included in the design.
1.2.2	Teams may have additional altimeters to control vehicle electronics and payload experiment(s).	Additional altimeters will be used for the ejection of the payload section.	Design: The Electronics Team lead will ensure that appropriate altimeters are selected for non-scoring purposes.
1.3	The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The launch vehicle is designed to be recoverable and reusable.	Design: The full-scale test flight will verify that the vehicle is recoverable and reusable.
1.4	The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	The launch vehicle design only includes three independent sections.	Design: The Project Manager will ensure the vehicle includes the proper number of independent sections.
1.5	The launch vehicle shall be limited to a single stage.	Only a single motor stage will be used.	Design: The Project Manager will ensure the vehicle includes only one propulsive stage.
1.6	The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the Federal Aviation Administration flight waiver opens.	The vehicle is designed to be prepared for launch in less than 1 hour, in order to provide sufficient margin.	Testing: The full-scale test flight will verify the preparation timeline is accurate.

1.7	The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	The vehicle will be designed to remain launch-ready for over 2 hours, in order to provide sufficient margin.	Testing: Tests of the electronic systems prior to the test flights will verify their power consumption rates.
1.8	The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.	The vehicle uses a commercially-available APCP J-class motor capable of being launched by a standard 12 volt DC firing system.	Testing: The sub-scale and full-scale test launches will verify the motor ignites as designed.
1.9	The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	The vehicle uses a commercially-available APCP J-class motor.	Design: The Propulsion Team lead will ensure the motor uses only APCP propellant and is properly certified.
1.10	The total impulse provided by a launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	The vehicle uses a commercially-available APCP J-class motor.	Testing: The full-scale test launch will verify the motor provides the designed total impulse.
1.11	Any team participating in Maxi-MAV will be required to provide an inert or replicated version of their motor matching in both size and weight to their launch day motor. This motor will be used during the LRR to ensure the igniter installer will work with the competition motor on launch day.	A simulated motor will be constructed for use throughout the project.	Design: The Propulsion Team lead will ensure the simulated motor is an accurate inert representation of the J-class motor that will be used.
1.12	Pressure vessels on the vehicle shall be approved by the RSO	No pressure vessels will be used in the launch vehicle.	Design: The Project Manager will ensure that no pressure vessels are added to the vehicle design.
1.13	All teams shall successfully launch and recover a subscale model of their full-scale rocket prior to CDR. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the sub-scale model.	A sub-scale model will be built based on the full-scale design.	Schedule: The Project Manager will have primary responsibility for ensuring the sub-scale model is flown prior to CDR.

1.14	All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day.	The full-scale launch vehicle will be launches on a test flight prior to FRR.	Schedule: The Project Manager will have primary responsibility for ensuring the full-scale model is flown prior to FRR.
1.14.1	The vehicle and recovery system shall function as designed.	OpenRocket simulations and ground tests will be used to verify systems before being installed in the vehicle for final testing during the full-scale test flight.	Testing: The sub-scale and full-scale test flights will verify that all vehicle systems function as designed.
1.14.2	The payload does not have to be flown during the full-scale test flight.	The payload will be flown in the full-scale test flight.	Design: The payload will be flown in the full-scale test flight.
1.14.3	The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification.	The full-scale motor will be used for the full-scale test flight.	Design: The full-scale motor will be used for the full-scale test flight.
1.14.4	The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the competition flight.	The vehicle will be flown in a fully-ballasted configuration during the full-scale test flight.	Design: The Project Manager will ensure that the vehicle is fully-ballasted for the full-scale test flight.
1.14.5	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO).	The full-scale flight will be performed with the vehicle in its competition-ready configuration.	Inspection: The Project Manager will ensure that no modifications are made to the vehicle after the full-scale test flight.
1.15	Teams who are participating in the Maxi-MAV competition are limited to a $10,000 budget.	The budget for the entire project is below the budget cap.	Inspection: The Chief Financial Officer will ensure the budget cap is not exceeded.
1.16	The launch vehicle shall not utilize forward canards, forward firing motors, motors that expel titanium sponges, hybrid motors or clusters of motors.	The vehicle design does not include any of the prohibited design elements.	Design: The Project Manager will ensure none of the prohibited design elements are added to the vehicle design.

Table 2 - Recovery System Requirement Verification Plan

Req #	Requirement	Relevant Design Feature	Verification Method
2.1	The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.	The recovery design includes staged recovery including both a drogue and main parachute.	Design: The Recovery Team lead will ensure this aspect of the design is maintained.
2.2	Teams must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial sub-scale and full-scale launches.	A ground ejection test is planned before the sub-scale launch.	Schedule: The Recovery Team lead will ensure the ground ejection test is performed properly.
2.3	At landing, each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	The recovery system is designed such that no component has a landing kinetic energy greater than 70 ft-lbf.	Testing: The full-scale test flight will verify the kinetic energy of each component at landing is within the designed range.
2.4	The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	The recovery system electrical components are isolated from all other electrical circuits.	Design: The Recovery Team lead will ensure all electrical components are properly isolated.
2.5	The recovery system shall contain redundant, commercially available altimeters.	The recovery system includes redundant commercially available altimeters.	Design: The Recovery Team lead will ensure the appropriate altimeters are used in the recovery system.
2.6	A dedicated arming switch shall arm each altimeter, which is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Each altimeter has a dedicated arming switch on the exterior of the vehicle.	Design: The Recovery Team lead will ensure that each altimeter has a dedicated external arming switch.
2.7	Each altimeter shall have a dedicated power supply.	Each altimeter has an independent, dedicated power supply.	Design: The Recovery Team lead will ensure that all altimeters have a dedicated power supply.
2.8	Each arming switch shall be capable of being locked in the ON position for launch.	All altimeter arming switches are capable of being locked "ON".	Design: The Recovery Team lead will ensure that all altimeter arming switches can be locked in the "ON" position.
2.9	Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	Removable nylon shear pins will be used for both parachutes.	Design: The Recovery Team lead will ensure that the appropriate shear pins are used.

2.10	An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.	Each independent section will include a GPS tracking device, which will be used solely for locating vehicle sections after landing.	Design: The Recovery Team lead will ensure all vehicle sections include appropriate GPS tracking devices.
2.10.1	Any rocket section, or payload component, which lands untethered to the launch vehicle shall also carry an active electronic tracking device.	Each independent section will include a GPS tracking device, which will be used solely for locating vehicle sections after landing.	Design: The Recovery Team lead will ensure all vehicle sections include appropriate GPS tracking devices.
2.10.2	The electronic tracking device shall be fully functional during the official flight at the competition launch site.	All tracking devices will be active during the competition launch.	Inspection: The Recovery Team lead will ensure all tracking devices are operating properly prior to the competition launch.
2.11	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight.	The recovery system electronics are isolated from all other electrical systems on the vehicle.	Testing: Ground testing and the full-scale test flight will ensure the recovery electronics function properly without interference.
2.11.1	The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The recovery system altimeters will be physically isolated within the vehicle.	Design: The Recovery Team lead will ensure the recovery system altimeters are properly isolated.
2.11.2	The recovery system electronics shall be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.	The recovery system electronics will be shielded to prevent external interference.	Testing: Ground testing and the full-scale test flight will ensure the recovery electronics function properly without interference.
2.11.3	The recovery system electronics shall be shielded from all onboard devices which may generate magnetic waves to avoid inadvertent excitation of the recovery system.	There are no onboard devices that generate magnetic waves strong enough to interfere with the recovery electronics.	Testing: Ground testing and the full-scale test flight will ensure the recovery electronics function properly without interference.
2.11.4	The recovery system electronics shall be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The recovery system electronics will be shielded to prevent external interference.	Testing: Ground testing and the full-scale test flight will ensure the recovery electronics function properly without interference.

Table 3 - Maxi-MAV Competition Requirement Verification Plan

Req #	Requirement	Relevant Design Feature	Verification Method
3.2.1.1	Teams will position their launch vehicle horizontally on the AGSE.	The vehicle is designed to be loaded onto the AGSE horizontally.	Design: The Project Manager will ensure this design aspect is maintained.
3.2.1.2	A master switch will be activated to power on all autonomous procedures and subroutines.	The AGSE design includes a master power switch.	Testing: Ground testing will verify the master switch operates as designed.
3.2.1.3	After the master switch is turned on, a pause switch will be activated, temporarily halting all AGSE procedure and subroutines. This will allow the other teams at the pads to set up, and do the same.	The AGSE design includes a pause switch.	Testing: Ground testing will verify the pause switch operates as designed.
3.2.1.4	After setup, one judge, one launch services official, and one member of the team will remain at the pad. The rest of the team must evacuate the area. The one team member is only there to answer questions the launch services official may have, and is not permitted to interact with the AGSE in any way.	The Safety Officer will brief the team members on launch day procedures.	Inspection: The Safety Officer will ensure all launch day procedures are followed.
3.2.1.5	After all nonessential personnel have evacuated, the pause switch will be deactivated.	The Safety Officer will brief the team members on launch day procedures.	Inspection: The Safety Officer will ensure all launch day procedures are followed.
3.2.1.6	Once the pause switch is deactivated, the AGSE will progress through all subroutines including containment of the payload and erection of the launch pad. The launch services official may re-enable the pause switch at any time. If the pause switch is re-enabled all systems and actions shall cease immediately.	The AGSE design includes a pause switch.	Testing: Ground testing will verify the pause switch operates as designed.
3.2.1.7	The team member at the launch pad will arm all recovery electronics.	The pre-launch checklist will include steps for arming the recovery electronics.	Inspection: The Project Manager will ensure the recovery electronics are properly armed before flight.
3.2.1.8	Once the launch services official has inspected the launch vehicle and declares that the system is eligible for launch, he/she will	The AGSE design will include a master arming switch for the ignition procedures.	Testing: Ground testing and the full-scale test flight will verify the ignition arming switch operates as designed.

	activate a master arming switch to enable ignition procedures.		
3.2.1.9	All personnel at the launch pad will evacuate the area.	The Safety Officer will brief the team members on launch day procedures.	Inspection: The Safety Officer will ensure all launch day procedures are followed.
3.2.1.10	The Launch Control Officer (LCO) will activate a hard switch, and then provide a 5-second countdown.	The AGSE design includes a hard switch for arming the ignition system.	Testing: Ground testing and the full-scale test flight will verify that the ignition arming switch operates as designed.
3.2.1.11	At the end of the countdown, the LCO will push the final launch button to initiate launch.	The AGSE design includes a hard-wired remote launch button.	Testing: The full-scale test flight will verify that the launch button operates as designed.
3.2.1.12	The rocket will launch and jettison the payload at 1,000 feet AGL during descent.	The vehicle flight profile includes the ejection of the payload at 1,000 ft AGL during the descent.	Testing: The full-scale test flight will verify that the payload ejection system functions as designed.

Table 4 - Safety Requirement Verification Plan

Req #	Requirement	Relevant Design Feature	Verification Method
4.1	Each team shall use a launch and safety checklist. The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and launch day operations.	The Safety Officer will develop a launch and safety checklist.	Testing: The launch and safety checklist will be validated during the full-scale test launch.
4.2	A student safety officer shall be identified, and shall be responsible for all safety procedures throughout the project.	A Safety Officer has been designated.	Inspection: The Project Manager will oversee the performance of the Safety Officer.
4.3	The safety officer will monitor team activities for safety, develop safety procedures and manage hazards documentation.	The Safety Officer will develop safety training and checklists for all hazardous team activities.	Inspection: The Project Manager will oversee the performance of the Safety Officer.
4.4	Each team shall identify an adult mentor certified by NRA or TRA for the motor class being used and have a minimum of two flights at that certification level.	An adult mentor has been designated.	Inspection: The Project Manager will oversee the team's interactions with the adult mentor.
4.5	During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO.	The team will abide by all rules and guidance provided by the local RSOs.	Inspection: The Safety Officer will ensure compliance with the local RSOs.
4.6	Teams shall abide by all rules and regulations set forth by the FAA.	The team will abide by all applicable FAA regulations.	Inspection: The Safety Officer will ensure compliance with all applicable FAA regulations.

Table 5 - General Requirement Verification Plan

Req #	Requirement	Relevant Design Feature	Verification Method
5.1	Student team members shall so 100% of the project, except for handling black powder, ejection charges and installing electric matches.	The team only includes Arizona State University students.	Inspection: The Project Manager will ensure that all team members are students and complete all work, with the exception of handling the prohibited items.
5.2	The team shall maintain a project plan that includes project milestones, budgets, checklists, personnel assignments, educational engagement events and risks and mitigations.	The team has developed a project plan with the necessary sections.	Inspection: The Project Manager will ensure that the project plan sections are properly maintained by the appropriate team leads.
5.3	Each team shall successfully complete and pass a review in order to move onto the next phase of the competition.	The team will participate in all required reviews.	Inspection: The Project Manager and Safety Officer will ensure work does not progress until the appropriate reviews are completed.
5.4	Foreign national team members shall be identified by the PDR.	All foreign national team members will be identified in the PRR documentation.	Inspection: The Project Manager will ensure all foreign national team members are properly identified.
5.5	The team shall identify all team members attending launch week activities by the CDR.	All team members attending the launch activities will be identified in the CDR documentation.	Inspection: The Project Manager will ensure all team members attending the launch activities are properly identified.
5.6	The team shall engage a minimum of 200 participants in education activities.	The team's Education and Public Outreach (EPO) plan includes activities that will engage more than 200 participants.	Inspection: The Education Outreach Director will ensure that more than the necessary number of participants are engaged.
5.7	The team shall develop and host a website for project documentation.	The team has deployed a website where all required documentation will be posted.	Inspection: The Project Manager will oversee future work on the website.
5.8	The teams shall post the required deliverables to the team website by the due dates specified in the project timeline.	The team has deployed a website where all required documentation will be posted.	Inspection: The Project Manager will ensure all documentation is properly posted to the website.
5.9	All deliverables must be in PDF format.	All deliverable will be posted in PDF format.	Inspection: The Project Manager will ensure all deliverables are posted in the proper format.
5.10	All reports shall include a table of contents.	All reports shall include a table of contents.	Inspection: The Project Manager will ensure all deliverables are properly formatted.

5.11	All report pages shall be numbered.	All report pages will be numbered.	Inspection: The Project Manager will ensure all deliverables are properly formatted.
5.12	The team must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194) Subpart B-Technical Standards.	The team will implement all the requirements of 36 CFR Part 1194 Subpart B.	Inspection: The Project Manager and Safety Officer will ensure compliance with the CFR Part 1194 Subpart B technical standards.

3.1.13.1 Risk Assessment

There are a number of potential risks inherent to this project that could cause significant delays or prevent us from completing milestones before the necessary deadlines. The most likely risks regarding time, resources and budget are summarized in Table 6 and summarized in the risk matrix in Figure 13.

The risks listed in Table 6 that were successfully avoided or mitigated and are no longer a concern at the time of the CDR are listed in green, the risks that are still a concern are listed in yellow and the risks that were unsuccessfully mitigated are listed in red. There are currently no risks that have not been successfully mitigated.

The risks listed in Figure 13 that have been successfully avoided or mitigated are greyed out to represent the fact that they are no longer a concern at the time of the CDR.

Table 6 - Risk Summary

Risk ID	Risk	Impact	Mitigation Plan
R1	Not Enough Time to Complete Fundraising Before Sub-Scale Test Flight	May not be able to purchase vehicle components in time to fly before CDR.	- Multiple members turning their attention to fundraising campaign after PDR
R2	Not Enough Time to Complete Sub-Scale Flight Before Holidays	May not be able to complete sub-scale flight before CDR	- All members are finalizing/rescheduling holiday plans so we can make a planned launch
R3	Fundraising Campaign May Raise Less Money Than Planned	May not be able to purchase necessary components and/or materials.	- Team members are reaching out to multiple local aerospace companies to investigate additional funding sources.
R4	Components or Materials Cost Significantly More Than Anticipated	Budget resources are depleted before all components/materials are purchased.	- Subsystem leads are working to front-load all major purchases so there is time to adjust the budget for any unanticipated cost increases.
R5	Payload Retrieval System Does Not Perform Accurately or Reliably.	The major objective of the flight cannot be completed.	- This subsystem will be subjected to repeated ground testing to identify any potential weaknesses in the design.
R6	Vehicle Erector System Does Not Perform Reliably	The launch cannot be completed as planned.	- This subsystem will be subjected to repeated ground testing to identify any potential weaknesses in the design.
R7	Igniter Insertion System Does Not Perform Reliably	The launch cannot be completed as planned.	- This subsystem will be subjected to repeated ground testing using the inert replica motor to identify any potential weaknesses in the design.

R8	Actual Vehicle Performance is Significantly Different Than Designed	Work on project must be suspended until a suitable investigation and mitigation plan is in place.	- The sub-scale test flight will verify the accuracy of the OpenRocket simulations. - The full-scale test flight will verify vehicle performance characteristics.

Likelihood						
	Almost Certain					
	Likely					
	Moderate		**R3**	**R1,R2**		
	Unlikely		**R4**	**R8**	**R5,R6,R7**	
	Very Unlikely					
		Insignificant	**Minor**	**Moderate**	**Major**	**Catastrophic**
		Consequence				

Figure 13 - Risk Matrix for the Vehicle Systems

3.1.13.2 Test and Verification Plan

3.1.13.2.1 Manufacturing and Verification Plan

With the vast majority of the design work completed for CDR, the team's attention will focus on manufacturing the vehicle and AGSE components and verifying that the components are manufactured within the necessary tolerances. The vehicle component manufacturing process will be organized according to subsystem, with the subsystem leads organizing the manufacturing efforts for their subsystem components. All subsystem leads have experience building the components within their subsystem and will oversee the manufacturing work performed by their team members. The AGSE-related component manufacturing process will be organized by major subsystems (launch structure, payload retrieval mechanism and vehicle payload bay), with the subsystem leads organizing the manufacturing efforts for their system's components. The work will be performed by members of the established vehicle and AGSE subsystem teams who have the necessary manufacturing training and experience.

Prior to any manufacturing activities, all team members will receive a general safety briefing by the Safety Officer. The briefing will cover general best practices for handing common manufacturing tools and materials, the proper use of material safety data sheets (MSDSs) and basic first aid. Team members who will be involved in more advanced manufacturing processes (machining, welding, etc) will undergo safety training conducted by the ASU Student Machine Shop and will provide evidence of their training to the Safety Officer before beginning manufacturing and/or assembly work on the vehicle or AGSE components. They will then perform the advanced manufacturing activities under the supervision of the Safety Officer and/or machine shop managers.

As the vehicle and AGSE components are being manufactured, the subsystem leads will be responsible for verifying that they are manufactured to the expected quality and to within the necessary tolerances. They will then be stored by the subsystem leads until they are ready for integration into the vehicle or AGSE.

3.1.13.2.2 Integration Plan

As components are completed and verified, the subsystem leads will plan their integration into the relevant subassemblies, which will provide further verification that the components were manufactured to the necessary specifications. As the subassemblies are completed, they will be integrated into either the launch vehicle or the AGSE.

In the event that problems are detected with any components that prevent their integration into the subassemblies or into the vehicle/AGSE, the subsystem lead who oversaw the manufacture of the given component will be assigned to either correct the component or to re-manufacture it, which they can delegate to their subsystem team members as appropriate. Manufacturing issues such as these will be reported to both the Project Manager and the Safety Officer so they can track potential issues with the various subsystems and provide additional oversight if necessary.

3.1.13.2.3 Testing Plan

As the various vehicle and AGSE subassemblies are completed, they will undergo initial testing to ensure they perform as designed to within the necessary tolerances. They will then undergo additional testing once they have been integrated into either the vehicle or the AGSE to ensure that they were properly integrated into their respective systems.

As critical subassemblies are completed (ie: parachute ejection system), they will undergo full functional ground tests to ensure their critical functions will be performed accurately and reliably. These tests will be overseen by the Project Manager and Safety Officer to ensure that they are accurate and safe tests of the systems. In the case of systems including items that teams members are prohibited from handling (ie: black powder), the Project Manager and Safety Officer will organize the tests in collaboration with the team mentor, who will handle all the prohibited items and materials.

3.1.13.2.4 Operations Plan

The Safety Officer will be responsible for developing pre-launch operational checklists for the test launches and the competition launch, including details for properly handling the motor, the black powder charges and other hazardous materials. The checklists will also include detailed steps for properly preparing the AGSE for its autonomous operations, especially verifying the proper functioning of the “Pause” switch on the AGSE.

The subsystem leads will be responsible for developing pre-launch checklists for their subsystems, which will be compiled by the Safety Officer and reviewed by the Project Manager. Prior to launches the subsystem leads will be responsible for completing all the preparations included in their checklists under the supervision of the Project Manager and Safety Officer.

In order to avoid confusion, all checklists will be compiled into a single document maintained by the Safety Officer, who will verify that all the necessary checklists have been completed before proceeding to subsequent steps during the launch preparations. The Safety Officer will then be responsible for giving the final “Go” for launch after all checklist items have been verified as completed.

3.1.13.3 Mass Statement

The estimated mass of the launch vehicle including motors is 13.8lbs. The estimated mass of the rocket without motors is 13.3lbs.

The sample payload bay including door and mechanisms to be constructed has an estimated mass from SolidWorks of 1.45lbs based on the use of 6061 aluminum.

The estimated masses for the minor components of our rocket have been input into OpenRocket with as much manufacturer information as possible to ensure the most accurate mass estimate of the entire system. However, we were unable to get mass estimates for all of the components. In these cases, we made our best liberal estimate for the mass of the component based on density and size as possible. We decided it would be better to overestimate mass, rather than underestimating it – especially with respect to such important things as determining the thrust-to-weight ratio. Because of this overestimation, the accuracy of the mass estimation is within 10% of actuality.

Future mass growth will not be tolerated. Growth of mass will be met with a swift asymmetric response and excess mass will be eliminated with extreme prejudice. We do; however, expect and 8-10% increase in mass due to the epoxy and miscellaneous hardware fasteners such as nuts and quick links.

Even with a thrust-to-weight ratio of 11.3, we have a considerable margin for mass increase before our launch vehicle becomes unsafe to launch with our current motor. However, given the design mass of our rocket, and the flexibility of motor options with our 54/2560 motor case and the Aerotech Reload Adaptor System, our team actually has a number of different motor options that we could select from to ensure that we still meet our altitude target.

Nose cone	G10 Fiberglass Filament Wound Tube (1.82 g/cm^3)	Haack series	Len: 19.75 in	Mass: 0.824 lb
MAV Payload	Vulcanized Fiber (1.25 g/cm^3)	Dia_{in} 3.906 in Dia_{out} 4.02 in	Len: 18 in	Mass: 0.577 lb
Tube coupler	Blue tube (1.3 g/cm^3)	Dia_{in} 3.764 in Dia_{out} 3.888 in	Len: 8 in	Mass: 0.28 lb
Bulkhead	Plywood (birch) (0.63 g/cm^3)	Dia_{out} 3.764 in	Len: 0.25 in	Mass: 0.063 lb
Sample Retention Tube Always Ready Rocketry BT20-29A	Vulcanized Fiber (1.25 g/cm^3)	Dia_{in} 1.141 in Dia_{out} 1.265 in	Len: 3 in	Mass: 0.032 lb
Bulkhead	Plywood (birch) (0.63 g/cm^3)	Dia_{out} 3.764 in	Len: 0.25 in	Mass: 0.063 lb
GPS Tracker		Dia_{out} 2.984 in		Mass: 0.15 lb
Sample Tube		Dia_{out} 0.754 in		Mass: 0.25 lb
MAV Parachute/Shockcord		Dia_{out} 2.984 in		Mass: 1 lb
Door Mech		Dia_{out} 3.25 in		Mass: 1.45 lb
Upper Frame	Blue tube (1.3 g/cm^3)	Dia_{in} 3.9 in Dia_{out} 4.02 in	Len: 24 in	Mass: 0.841 lb
Main Parachute	Rip stop nylon (66.8 g/m^2)	Dia_{out} 60 in	Len: 1.984 in	Mass: 0.687 lb
Shroud Lines	Tubular nylon (11 mm, 7/16 in) (13 g/m)	Lines: 12	Len: 42 in	
Shock cord	Tubular nylon (11 mm, 7/16 in) (13 g/m)		Len: 324 in	Mass: 0.236 lb
Siren		Dia_{out} 0.984 in		Mass: 0.15 lb
Payload Bay	Blue tube (1.3 g/cm^3)	Dia_{in} 3.9 in Dia_{out} 4.02 in	Len: 0.5 in	Mass: 0.018 lb
Tube coupler	Vulcanized Fiber (1.25 g/cm^3)	Dia_{in} 3.764 in Dia_{out} 3.9 in	Len: 8 in	Mass: 0.296 lb
Bulkhead	Plywood (birch) (0.63 g/cm^3)	Dia_{out} 3.764 in	Len: 0.079 in	Mass: 0.02 lb
Bulkhead	Plywood (birch) (0.63 g/cm^3)	Dia_{out} 3.764 in	Len: 0.079 in	Mass: 0.02 lb
Payload Sled		Dia_{out} 0.984 in		Mass: 1.06 lb
Blue Tube Body Tube	Blue tube (1.3 g/cm^3)	Dia_{in} 3.9 in Dia_{out} 4.02 in	Len: 40 in	Mass: 0.796 lb
Siren		Dia_{out} 0.984 in		Mass: 0.15 lb
Drogue Chute Public Missiles, Ltd. PML PAR-18-F111	Rip stop nylon (66.8 g/m^2)	Dia_{out} 18 in	Len: 0.984 in	Mass: 0.337 lb
Shroud Lines Public Missiles, Ltd. PML PAR-18-F111	Thin poly (0 g/m)	Lines: 8	Len: 13 in	
Shock cord	Tubular nylon (11 mm, 7/16 in) (13 g/m)		Len: 324 in	Mass: 0.236 lb
Blue Tube 54mm MMT	Kraft phenolic (0.959 g/cm^3)	Dia_{in} 2.15 in Dia_{out} 2.28 in	Len: 25 in	Mass: 0.099 lb
Aeropack Motor Retainer		Dia_{out} 2.75 in		Mass: 0.089 lb
Hardpoint Adaptor		Dia_{out} 1.984 in		Mass: 0.169 lb
Top Centering Ring	Aircraft plywood (Birch) (0.725 g/cm^3)	Dia_{in} 2.28 in Dia_{out} 3.9 in	Len: 0.25 in	Mass: 0.052 lb
Middle Centering Ring	Aircraft plywood (Birch) (0.725 g/cm^3)	Dia_{in} 2.28 in Dia_{out} 3.9 in	Len: 0.25 in	Mass: 0.052 lb
Bottom Centering Ring	Aircraft plywood (LOC) (0.725 g/cm^3)	Dia_{in} 2.28 in Dia_{out} 3.9 in	Len: 0.25 in	Mass: 0.052 lb
Launch lug Giant Leap RG	Cardboard (0.68 g/cm^3)	Dia_{in} 0.4 in Dia_{out} 0.5 in	Len: 1 in	Mass: 0.002 lb
Launch lug Giant Leap RG	Cardboard (0.68 g/cm^3)	Dia_{in} 0.4 in Dia_{out} 0.5 in	Len: 1 in	Mass: 0.002 lb
Foam		Dia_{out} 3.9 in		Mass: 0.5 lb
Fin set (3)	Aircraft plywood (Birch) (0.725 g/cm^3)	Thick: 0.188 in		Mass: 0.749 lb

3.2 Subscale Flight

3.2.1 Subscale Rocket

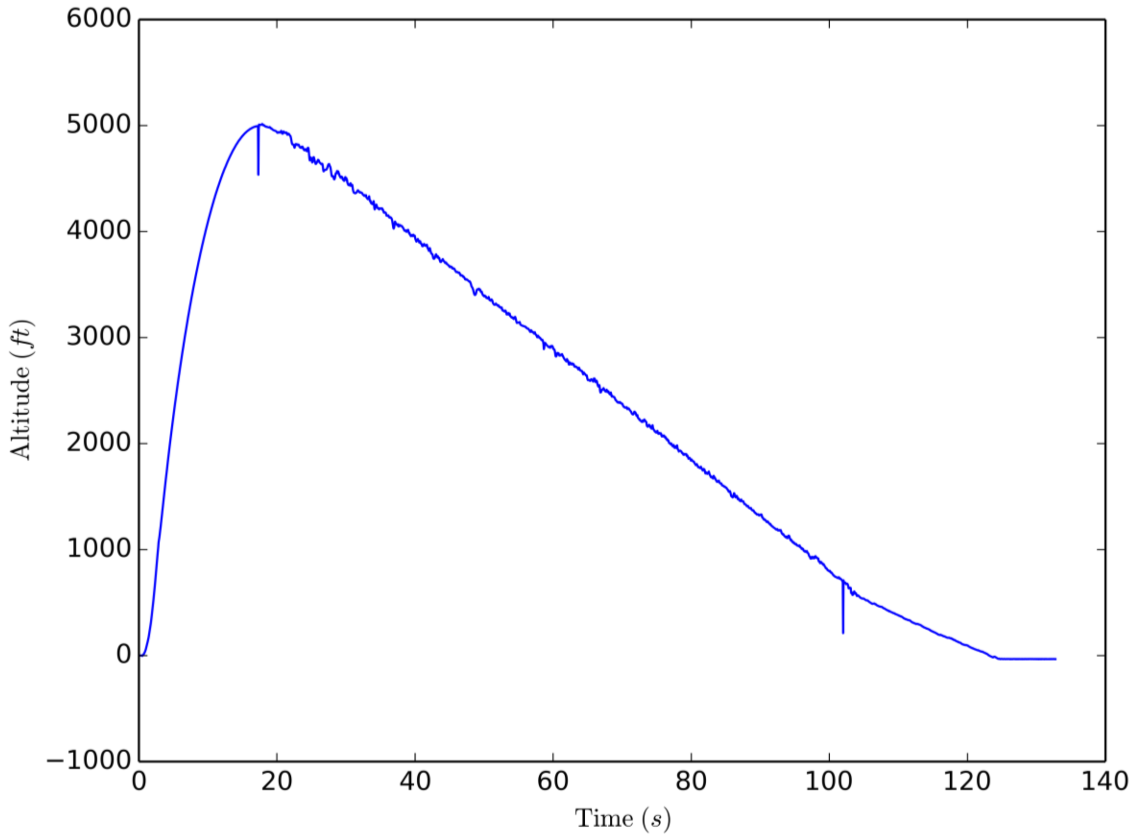
Due to cost limitations our team's focus on the subscale flight was to demonstrate solid engineering techniques and to prove the materials and construction techniques that would ultimately be used on the full scale launch vehicle. Our focus was largely on proving:

- Through-the-wall fin mount system with expanding foam to fill the cavity
- Use of Birch plywood centering rings and fins
- Use of Giant Leap Rocketry's hardpoint anchor for the shock cord mount
- Dual-Deploy systems using the Perfectflite Stratologger
- Aeropack motor retention system
- Verifying use of a Rouse-Tech 54/2560 motor casing with Aerotech 54mm Reloadable Adaptor System

As a result, a 4" diameter, 90.75" long rocket was constructed out of BlueTube 2.0 with the above characteristics. The rocket was properly ballasted to yield similar stability margins to our full-scale rocket. The bays for the main and drogue parachutes were also the same size as on our full-scale rocket. As a result, this sub-scale rocket was also used for our ejection charge testing.

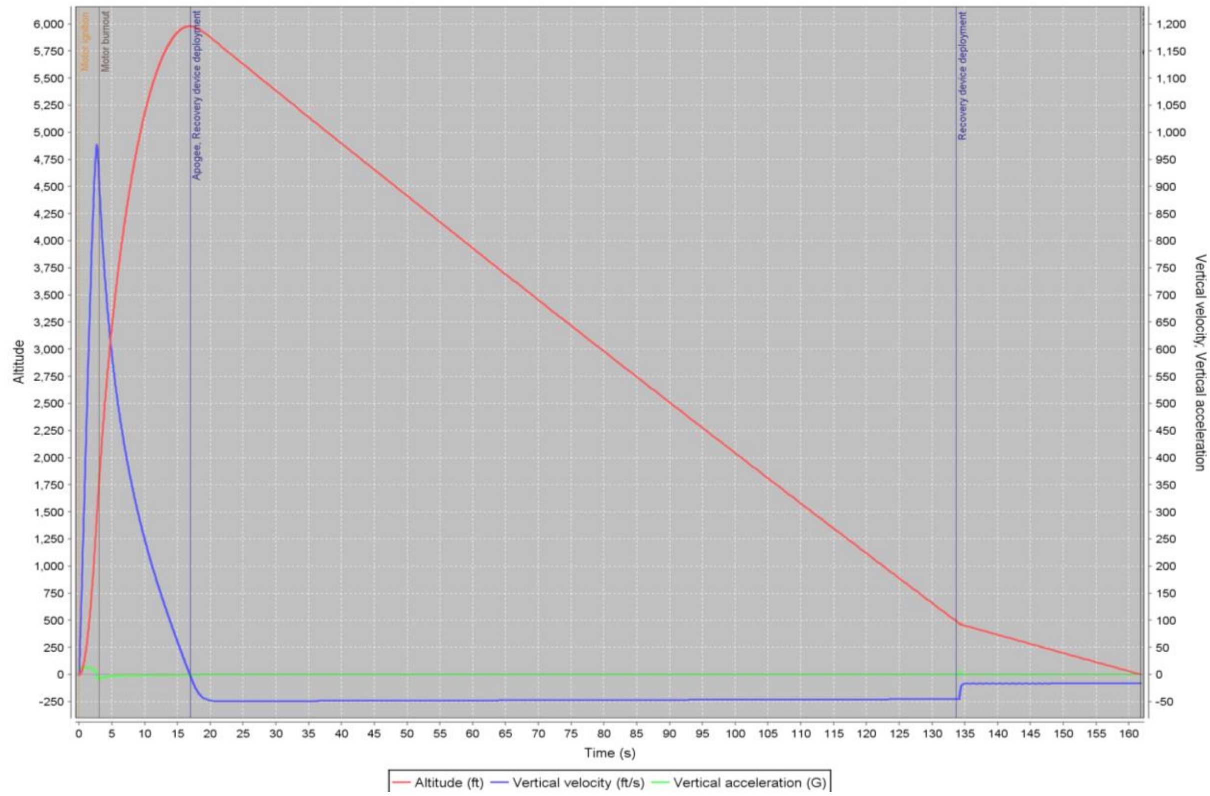
The subscale rocket was flown at a launch with the Superstition Spacemodeling Society at a launch site outside of Hope, AZ. The rocket was flown with an Aerotech K456DM motor that was on hand to minimize costs.

Using OpenRocket simulations of the rocket, and comparing the flight results to those from the on-board Stratologger, we were able to determine how to fine tune the drag measurements of the simulations to match real life results.



Our original simulations predicted a flight up to 6,020 ft AGL with all environment data for our particular launch site. Actual data from the altimeter show that the rocket only reached a max altitude of 5,977 ft AGL.

From the results of this subscale flight test, we verified that most of our primary construction methods yields a strong and stable rocket test, and assures us that our plans for the full-scale rocket are sound.



Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Altitude
Vertical velocity, Vertical acceleration
Time (s)
Altitude (ft)
Vertical velocity (ft/s)
Vertical acceleration (G)

3.3 Recovery Subsystem

Due to the complexity of the launch vehicle, the recovery subsystem must be equally intricate and redundant to ensure the safety of all components and spectators. The launch vehicle itself is composed of three primary components: the nosecone/sample bay, the upper airframe, and the lower airframe.

3.3.1 Parachutes

The main parachutes for both the sample bay and the launch vehicle will be a Fruity Chutes Classic Elliptical Parachute which will 60 inches in diameter. The coefficient of drag, Cd, of the parachute is 1.55.

Figure 17: Example of the Fruity Chutes Classic Elliptical Parachute to be used as the main parachute.

The drogue parachute will be a Public Missiles 18" parachute with a 4" spill hole.

3.3.2 Recovery System Design

The three components of the launch vehicle are joined by two coupler tubes. Each coupler tube's fore section will be secured to the airframe by way of four ¼ inch removable nylon rivets, symmetrically set about the circumference of the launch vehicle while the aft section will be secured by two 2-56 x ¼ inch nylon screws also symmetrically set about the launch vehicle's circumference, serving as shear pins. Using four rivets will sufficiently secure the fore section of each coupler tube to the airframe while the two screws will provide enough leverage for the launch vehicle to remain linked without creating an excessive level of resistance to overcome when setting off the ejection charges, thus avoiding significant issues of over-pressurizing the airframe without separation.

Within the lower airframe is the motor, set at the aft portion of the launch vehicle. The fore section of the motor tube is epoxied to a hardpoint anchor from Giant Leap Rocketry. The shock cord—½ inch in width and composed of tubular braided Kevlar—will be connected to the hardpoint anchor using a ¼ inch quick link. The shock cord will be 31.25 feet in length, or approximately 3.5 times the length of the launch vehicle, which will allow the launch vehicle components to descend without potential collisions with one another. The other end of the shock cord will be secured by another quick link to a ¼ inch eyebolt in the bulkhead of the electronics bay. Along the length of the shock cord will be a knotted portion that creates a small loop that will serve as a linking point for a drogue parachute.

The upper airframe will contain two primary parachutes that are appended to separate lengths of shock cord. This is due to the upper airframe and nosecone/sample bay sections becoming individual entities upon deploying the second ejection charge. Since the two portions cleanly separate, the shock cords will not have to absorb the resulting shock of two airframe segments—only one; therefore, the shock cord will not have to be as long as the one used within the lower airframe. The two shock cords within the upper airframe will be 13.5 feet in length—approximately 1.5 times the length of the launch vehicle. One end of each shock cord will be knotted to form a loop for the parachute while the other end will be connected to a ¼ inch eyebolt in the bulkhead of their respective airframe component by way of a ¼ inch quick link.

Tests will be conducted to determine if the equipment used will be able to withstand the forces exerted upon them during launch and descent; however, theoretical values have been noted in the chart below. Quick links have been tested by many rocketeers as well as mountain hikers and a general consensus has been reached that the breaking point of a quick link that has been reliably manufactured—deep, distinct threads and uniform, durable metal—is on average approximately five times the working load limit (WLL) designated by the manufacturing company. Similar conditions apply to other hardware components with notes on specific exceptions.

Component:	**Size: (inches)**	**Working Load Limit (WLL): (lbs)**	**Breaking Point: (lbs)**
Quick Links	¼	880	4400
Swivels	2.25	1500	7500
Eyebolts	¼	650	3250
Shock Cord	½	1000	5000

Table 7 - Stress Limits of Recovery System Hardware

Special notes will be made for the eyebolts, which are not designed to have forces exerted upon them beyond 45° from vertical in the plane perpendicular to the circular face of the bolt. The only instance where this will be a concern is upon deployment when the airframe components place tension upon the shock cord. The instant of shock absorption may create enough impulse to damage the eyebolt; however, after the initial instant, the angular momentum of the airframe components will lead to the eyebolt adjusting itself such that the shock cord will be approximately 0° from vertical with respect to the eyebolt as the airframe components spin about the pivot provided by a swivel.

In order to prevent damage to the launch vehicle components upon landing, three parachutes are necessary: two primary parachutes and a single drogue parachute. The primary parachutes will both be a Fruity Chutes Classic Elliptical Parachute 60 inches in diameter. The parachutes have a drag coefficient, Cd, of approximately 1.55 and are composed of notably light material that can be effectively packed compared to other parachutes. The drogue parachute will be a Public Missiles parachute 18 inches in diameter with a 4 inch spill hole to allow the launch vehicle to reduce its decent velocity without being carried away from the original launch site.

Furthermore, to avoid potential sabotage due to the shock cord and parachute lines becoming twisted during decent, the parachutes are linked to their corresponding shock cord loop segments by way of two ¼ inch quick links and a 2.25 inch swivel. During decent, the launch vehicle will be subject to angular momentum that may be fueled by wind conditions, which would normally cause the shock cord and parachute lines to get twisted and cause the parachute to gradually become less effective and eventually collapse; however, the swivel will absorb the angular momentum, allowing the launch vehicle to spin about the swivel's pivot point and negate any twisting of the shock cord and parachute lines.

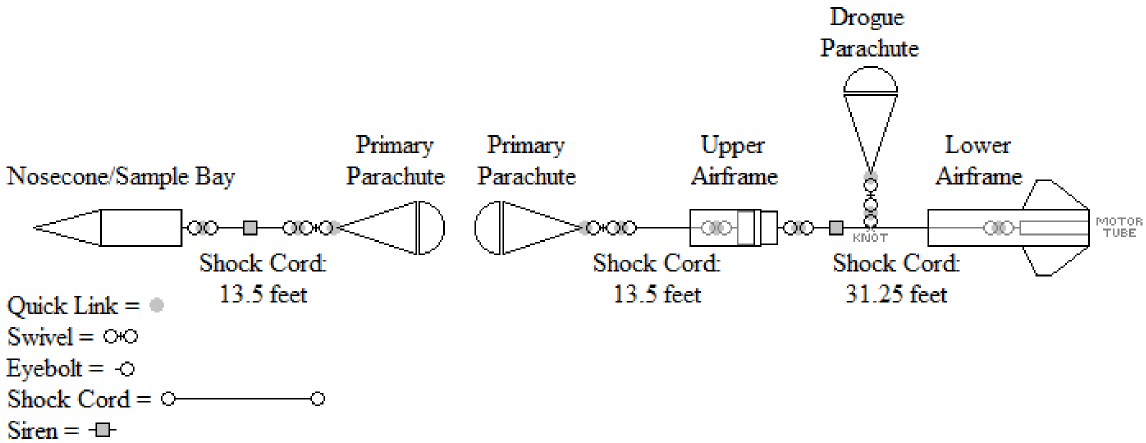


Figure 18 - Diagram of Recovery System Connections

The electrical components involved in the recovery subsystem are diverse in nature. Two altimeters will be situated within the electronics bay: a PerfectFlite Stratologger and a MissileWorks RRC3 altimeter. The Stratologger altimeter is a notably reliable unit that has seen use in past dual-deploy configurations and successfully completed its task while the RRC3 altimeter is highly recommended by experienced high-power rocketeers at local club launches. Two altimeters are used in order to provide a redundant system in the case the primary altimeter fails due to defects or manufacturing flaws in the model's batch produced by the company.

Each altimeter will be wired to an independent power source using 20-22 gauge wire and situated upon a board. Furthermore, the altimeters will be wired to buttons attached to the hull of the launch vehicle near the electronics bay and four terminal blocks located at the bulkheads—two terminal blocks at each bulkhead. The buttons will be used to prepare the altimeters for launch while the terminal blocks will be used to send electrical charges to the ejection charges when the launch vehicle reaches certain altitudes.

The Stratologger altimeter will serve as the primary altimeter for deploying the parachutes. It will be programmed to deploy the first charge between the upper and lower airframes at apogee, releasing the drogue parachute which will ensure that the launch vehicle reaches a terminal velocity of 71.6 feet/second during the main portion of its descent. The RRC3 altimeter will serve as a backup unit for the Stratologger, and it will be programmed to deploy the same ejection charge 1 second after apogee. The delay avoids any chance of over-pressurization in the case both altimeters were to deploy at apogee; furthermore, the delay is within a sufficient margin that the launch vehicle will remain safe in case the Stratologger altimeter fails. The altimeters will be further programmed to deploy the second ejection charge at an altitude of 1000 feet and 950 feet, respectively. This height will allow the launch vehicle to reduce its impact velocity upon landing while minimizing potential drift effects.

Along with the altimeters in the electronics bay is an Eggfinder GPS TX system that will keep track of the launch vehicle's position via satellite. The GPS unit will be wired to an individual power source as well as a switch that will be pressed prior to launch to initialize the GPS unit. The switch will be activated by way of a small hole within the launch vehicle through which the switch can be pressed using a thin rod. Furthermore, to ensure that the GPS unit will not interfere with the altimeters, the altimeters' board will be encased in a thin aluminum shield—with designated holes for wiring purposes—that will serve as a Faraday cage and protect the altimeters from the effects of any exterior electric fields. Another Eggfinder GPS TX system will be situated within the sample bay since the sample bay will eventually be deployed as an individual unit from the primary airframe components during launch, thus ensuring that there is a method of tracking for each landing entity.

To aid in recovering the launch vehicle and sample bay, two sirens will be attached to the shock cords: one will be attached to the sample bay's cord while the other will be on the cord upon which the drogue parachute is mounted. The sirens will be mounted such that the body component is attached to one end of the cord while the pin for the siren is attached to the other end; therefore, while the shock cord is packed into the airframes, the pin can be inserted into the siren. Upon deployment, the shock cord will be stretched taught, pulling the pin from the siren in the process and setting the unit off. The sirens were tested during the subscale launch and have proven helpful in locating the launch vehicle after it has landed.

3.3.3 Ejection Charge

FFFFg black powder will be used for ejection charges. The amount of black powder used will be computed to generate the optimal amount of pressure in the chambers to break the 2-56 x ¼" nylon screws used as shear pins.

The ejection charge used to deploy the drogue chute will be 2.1 grams. The ejection charge to deploy the main parachutes will be 1.26 grams. Ground tests of the ejection charges will be completed to ensure that the size of the charges are sufficient to break the shear pins without overpressurizing the chambers.

3.3.4 Landing Kinetic Energy

The launch vehicle is designed such that two independent portions will land—the primary airframe components and the nosecone/sample bay. Since the two components are independent, their individual landing kinetic energies will be lower than the entire launch vehicle landing as a whole. Furthermore, flight simulations using Open Rocket showed that the impact velocity for the launch vehicle components will be approximately 4.6 meters/second. Given the impact velocity, the kinetic energy of the primary airframe components and the nosecone/sample bay can be determined provided the mass of each individual landing entity. The primary airframe components—minus the solid motor (now burned)—totals to a mass of 5.452 kilograms while the nosecone/sample bay has a mass of 0.609 kilograms. From these values and a few conversion factors, the kinetic energies are as follows:

$$KE_{Primary\ \mathrm{Airframe}} = 0.7376\ \mathrm{ft\cdot lbf\cdot J^{-1}}[\tfrac{1}{2}(5.452\ \mathrm{kg})(4.6\ \mathrm{m\cdot s^{-1}})^2]$$
$$KE_{Primary\ \mathrm{Airframe}} = 42.55\ \mathrm{ft\cdot lbf}$$

$$KE_{Sample\ Bay} = 0.7376\ \mathrm{ft\cdot lbf\cdot J^{-1}}[\tfrac{1}{2}(0.609\ \mathrm{kg})(4.6\ \mathrm{m\cdot s^{-1}})^2]$$
$$KE_{Sample\ Bay} = 4.75\ \mathrm{ft\cdot lbf}$$

These impact kinetic energy values are well below the limit stipulated—75 ft·lbf; therefore, the launch vehicle is theoretically in good standing as far as landing is concerned.

3.3.5 Airframe Drift

Using the simulations from Open Rocket and assuming that the recovery systems properly deploy based on the programming of the Stratologger alone, the following tables summarize the predicted areas within which the launch vehicle and sample bay will land due to drift caused by a varying wind speed (holding that there is 10% turbulence).

Table 8 - Table of Landing Predictions

Wind Speed:	Angle (°):	Position Upwind (ft):
0 mph	0	694.1
	30	600.8
	60	345.5
	90	-3.4
	120	-352.4
	150	-608
	180	-701.7
5 mph	0	102.5
	30	3.8
	60	-251
	90	-590.5
	120	-939.3
	150	-1218.4
	180	-1316.8
10 mph	0	-465.4
	30	-596.8
	60	-881.8
	90	-1206.5
	120	-1540
	150	-1846
	180	-1941.9
15 mph	0	-1097.4
	30	-1218.7
	60	-1363.4
	90	-1754.4
	120	-2243.2
	150	-2443.1
	180	-2531.7
20 mph	0	-1628.3
	30	-1880.6
	60	-2055
	90	-2480.1
	120	-2726.8
	150	-3085
	180	-3120.9

3.4 Safety

3.4.1 Final Checkout and Assembly Procedure Checklist

Section 1: Final AGSE Checkout		
1.1	Verify Power to AGSE	
1.2	Test Autonomous Retrieval Mechanism (ARM) Motion	
1.3	Test Pause Switch Operation	
1.4	Test Launch Rail Servo Motion	
1.5	Test Motor Igniter Insertion System (MIIS) Motion	
1.6	Verify Launch Button Power	
1.7	Reset AGSE to "Power OFF"	
1.8	Reset Autonomous Retrieval Mechanism (ARM) to Starting Position	
1.9	Reset Launch Rail to Starting (Horizontal) Position	
1.10	Reset Motor Igniter Insertion System (MIIS) to Starting Position	
1.11	GO/NOGO Poll of AGSE Subsystem Leads	
	AGSE Structure Subsystem	
	Autonomous Retrieval Mechanism (ARM) Subsystem	
	Motor Igniter Insertion System (MIIS) Subsystem	
Safety Officer Signature		
Project Director Signature		
Section 2: Final Launch Vehicle Checkout		
2.1	Secure Launch Vehicle in Launch Rail	
2.2	Test Launch Vehicle Motion Along Launch Rail	
2.3	Test Payload Bay Door Motion	
2.4	Verify GPS Locator Signals Are Being Received	
2.5	Lock External Altimeter Switches 1 & 2 to "ON"	
2.6	Visually Inspect Launch Vehicle Airframe for Damage	
2.7	GO/NOGO Poll of Launch Vehicle Subsystem Leads	
	Flight Dynamics Subsystem	
	Propulsion Subsystem	
	Recovery Subsystem	
	Electronics Subsystem	
	Payload Bay Assembly Subsystem	
Safety Officer Signature		
Project Director Signature		

Section 3: AGSE Launch Preparations		
3.1	Move All Non-Required Personnel to the Observation Area	
3.2	Set Launch Button Safety Switch to "ON"	
3.3	Load and Secure Motor in the Launch Vehicle	
3.4	Load Motor Igniter in the Motor Igniter Insertion System (MIIS)	
3.5	Connect Launch Controller to the Motor Igniter	
3.6	GO/NOGO Decision from Safety Officer	
3.7	GO/NOGO Decision from Project Manager	
Safety Officer Signature		
Project Director Signature		
Section 4: Competition Flight Preparations		
4.1	Set AGSE Power Switch to "ON" **(Proceed quickly to Step 4.2)**	
4.2	Set AGSE Pause Switch to "ON"	
4.3	Receive Range Safety Officer's Clearance to Proceed	
4.4	Switch AGSE Pause Switch to "OFF"	
4.5	Successful Completion of Automated Launch Preparation Sequence	
4.6	Receive Safety Officer's Final Clearance to Launch	
4.7	Receive Range Safety Officer's Clearance to Launch	
Safety Officer Signature		
Project Director Signature		
Proceed with Launch		

3.4.2 Safety Officer

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3.4.3 Preliminary Hazard Analysis

3.4.3.1 Personnel Hazards

The process of constructing, launching and recovering of our rockets will include a number of tools and materials that could potentially harm our team members or bystanders if they are used improperly. The most common hazards are presented in

Table 9 along with their potential injury risks and the steps we have taken to mitigate those risks.

Table 9 - Personnel Hazards

Hazard	Potential Risks/Injuries	Mitigation Plan
Power Tool Use	- mild to severe cuts - mild to severe burns - eye injury - blunt force trauma - damage to tools/property	- tools are only to be operated by those with the proper training - eye protection is required - close-toed shoes are required - no food or drink allowed in the work areas
Welding	- mild to severe burns - eye injury - damage to tools/property	- welding masks and gloves are required - close-toed shoes are required - long pants and long-sleeve shirts required - only those with aluminum-specific welding training and/or experience may be involved in any aluminum welding operations
General Adhesive & Paint Use	- mild to severe chemical burns - skin injury - eye injury - inhalation of toxic fumes - damage to property	- MSDS information must be available whenever chemicals are in use - gloves and eye protection are required for all chemical use - chemicals must be used in well-ventilated areas - protective work surface coverings must be used
Epoxy Use	- skin injury - eye injury - inhalation of toxic fumes - damage to property	- MSDS information must be available whenever epoxies are in use - gloves and eye protection are required for all chemical use - epoxies must be used in well-ventilated areas - protective work surface coverings must be used - all work with epoxies must be supervised a team member who has experience using epoxies in the construction of high-powered rockets

3.4.3.2 Failure Mode Analysis

With any complex system, there are numerous potential failures that could result in the loss of the vehicle and/or failure to achieve our project's stated objectives. For organizational purposes, the potential failure modes have been divided into three categories, Vehicle Design and Construction (

Table 10), AGSE Operations (Table 11) and Launch Operations (Table 12), and are presented below along with their likely effects and mitigation strategies. The likelihood of their occurrence and their potential overall impact on the success of our team's project are summarized in the Failure Mode Risk Matrix in Figure 19.

Table 10 - Failure Mode Analysis – Vehicle Design and Construction

Failure Mode ID #	Failure Mode	Effect	Mitigation Plan
A.1	Vehicle Instability	Possible loss of vehicle, possible failure to deploy payload	- make OpenRocket simulations as accurate as possible - perform sub-scale test flight - perform full-scale test flight
A.2	In-flight Structural Failure	Loss of vehicle, possible failure to deploy payload	- all structural assembly procedures will be overseen by NAR and/or Tripoli certified team members
A.3	Recovery System Failure (attachment points, shock cords, etc)	Drogue and/or main parachutes do not deploy properly, loss of vehicle	- the team's mentor will be consulted regarding the recovery system design, since no team members have recovered a vehicle this large before - the design will be tested in both sub-scale and full-scale flights
A.4	Budget Exceeded	Unable to purchase components for test flights and/or competition flight	- The Chief Financial Officer will oversee all purchases to ensure we remain on-budget - The subsystem team leads will be responsible for providing cost estimates and searching for the best prices for their subsystems' components
A.5	Material/Equipment Unavailable	Unable to complete construction tasks	- Subsystem leads will front-load purchases and major equipment use so time will be available to deal with any availability issues
A.6	Personnel Unavailable	Unable to complete tasks	- Subsystem leads will ensure multiple team members are sufficiently trained for all activities.

Table 11 - Failure Mode Analysis – AGSE Operations

Failure Mode ID #	Failure Mode	Effect	Mitigation Plan
B.1	AGSE Fails to Properly Load the Payload	Vehicle is unable to launch, disqualified from competition	- Repeated ground tests will be performed, in addition to the full-scale test flight.
B.2	AGSE Fails to Properly Erect the Vehicle for Launch	Vehicle is unable to launch, disqualified from competition	- Repeated ground tests will be performed, in addition to the full-scale test flight.
B.3	AGSE Pause Switch Does Not Successfully Pause AGSE Operations	Vehicle is unable to launch, disqualified from competition	- Repeated ground tests will be performed, in addition to the full-scale test flight.
B.4	AGSE Fails to Properly Insert the Igniter	Vehicle is unable to launch, disqualified from competition	- Repeated ground tests will be performed, in addition to the full-scale test flight.

Table 12 - Failure Mode Analysis – Launch Operations

Failure Mode ID #	Failure Mode	Effect	Mitigation Plan
C.1	Motor Failure	Loss of vehicle, possible failure to deploy research payloads	- the mentor will oversee all activities involving the motor - motor grains will be inspected after transportation
C.2	Parachute Entanglement	Possible loss of vehicle (Depending on degree of entanglement)	- Recovery Team lead will supervise the packing of the parachutes prior to all launches
C.3	Recovery System Deployment Failure	Loss of vehicle	- wiring to the ejection charges and the altimeters will be verified by the Recovery Team lead prior to all launches
C.4	Recovery System Elements Deploy Early/Late	Loss of vehicle (if deployment failed in-flight), personal injury (if deployment occurs on the ground)	- wiring to the ejection charges and the altimeters will be verified by the Recovery Team lead prior to all launches - once motors and/or ejection charges have been installed on the vehicle, any team members working on the vehicle must wear appropriate skin and eye protection
C.5	Failure to Reach Design Altitude	Loss of points towards the competition	- make OpenRocket simulations as accurate as possible - perform sub-scale test flight - perform full-scale test flight

Likelihood		Insignificant	Minor	Moderate	Major	Catastrophic
	Almost Certain					
	Likely			**A.6**		
	Moderate			**A.5, C.2, C.5**	**A.1, A.4, B.1**	
	Unlikely			**A.3**	**B.2, B.4, C.3**	**A.2**
	Very Unlikely				**C.4, B.3**	**C.1**
				Consequence		

Figure 19 - Failure Mode Risk Matrix for the Vehicle Systems

3.5.3.3 Failure Mode Analysis NAR Safety Code Compliance

The National Association of Rocketry's (NAR's) Safety Code will serve as the basis for our team's overall safety plan. The Safety Code specifies best practices for the design, construction, launch and recovery of high-powered rockets. Table 13 lists the 13 points of the NAR Safety Code along with our team's plan for ensuring compliance with each point.

3.5.3.3 Failure Mode Analysis FAA, NFPA, ATF, and State Law Compliance

The operation of high-powered rockets in the United States is subject to both Federal Aviation Administration (FAA) and National Fire Protection Association (NFPA) regulations, which our team will need to comply with in addition to the NAR Safety Code. Our team has reviewed these regulations and the Safety Officer will be responsible for ensuring the team's compliance. The relevant regulations and our compliance plans for each are summarized below.

3.5.3.4 Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C

The primary purpose of these regulations is to prevent high-powered rockets from posing a threat to aircraft, particularly general aviation aircraft flying at low altitudes. The regulations require that high-powered rockets be constructed of breakable or compactable materials, that they be launched in areas that are verifiably-free of air traffic and can be safely recovered. By adhering to the NAR Safety Code we will ensure compliance with these regulations.

3.5.3.5 NFPA Code 1127

This set of regulations more clearly defines what qualifies a rocket as "high-powered', what propellants may be used in the motor and what materials may be used to construct the vehicle. They also define classes of motors based on impulse and set requirements for purchasing and operating motors from various classes. By adhering to the NAR Safety Code we will ensure compliance with these regulations.

3.4.3.6 Code of Federal Regulation 27 Part 55: Commerce in Explosives

These regulations control the sale, transportation and storage of explosive materials, which include high-powered rocket motors. They require that the motor manufacturer only sell and ship motors to those with the appropriate certification. In our case, the motor will have to be sold and shipped to our group's mentor since no one else in the group has either NAR or TRA Level 3 certification. These regulations also require that explosive materials only be stored by those with appropriate certifications, which means our mentor will also need to be responsible for storing our motors prior to launch. By adhering to the NAR Safety Code we will ensure compliance with these regulations.

3.4.3.7 State Laws

Both the states of Arizona and Utah have based their local laws regarding the operation of high-powered rockets on the FAA, NFPA and ATF regulations cited above. By maintaining compliance with those regulations and the NAR Safety Code we can ensure compliance with all applicable local laws.

3.5.3.8 Compliance with the Range Safety Officer

In addition to the NAR Safety Code and the relevant federal and state laws, our team will comply with any and all instructions given by the range safety officer at the launch events where we participate.

3.4.3.8 NAR Safety Code Compliance Plan

The design, construction and operation of the team's launch vehicle will be conducted in accordance with the National Association of Rocketry's (NAR's) Safety Code. Our team's plan for complying with the NAR Safety Code is presented in Table 11.

Table 13 - NAR Safety Code Compliance Plan

Section	Code	Compliance Plan
1. Certification	I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.	All flight operations will be performed under the supervision of the team's mentor. Team members will only be allowed to handle motors above their qualification level under his DIRECT supervision.
2. Materials	I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	The design of our vehicle only includes approved materials. The Safety Officer will be responsible for ensuring no unapproved materials are used during construction.
3. Motors	I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	The team will be using an Aerotech N-1000 motor, which will be purchased, stored and transported by the team's mentor. Any team members without the proper NAR or TRA qualifications will only be allowed to handle the motor under his DIRECT supervision.
4. Ignition System	I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. If my rocket has onboard ignition systems for motors or recovery devices, these will have safety interlocks that interrupt the	Only an approved electrical launch system will be used for the primary motor. The launch abort motor, which will be ignited by the flight computer during flight, will include a safety interlock that will only be removed once the vehicle is on the pad and prepared for flight.

	current path until the rocket is at the launch pad.	
5. Misfires	If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The Safety Officer will be responsible for enforcing the misfire protocols. In addition, if it is necessary to re-approach the vehicle after a misfire, the launch abort motor safety interlock will be replaced before any additional work is performed.
6. Launch Safety	I will use a 5-second countdown before launch. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table, and that a means is available to warn participants and spectators in the event of a problem. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable.	The team's mentor and Safety Officer will be responsible for ensuring proper countdown procedures. The Project Director and the Safety Officer will be responsible for jointly verifying the stability of the vehicle prior to all launches.
7. Launcher	I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 if the rocket motor being launched uses titanium sponge in the propellant.	All launches will be performed at NAR and/or TRA certified events using proper launch pad equipment. The Safety Officer will be responsible for verifying the compliance of launch pad conditions. The team will NOT be using a motor containing titanium sponge material.
8. Size	My rocket will not contain any combination of motors that total more than 40,960 N-sec (9,208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	The design of the main vehicle complies with the total impulse requirements. The Propulsion System Lead will be responsible for verifying the launch abort component of the vehicle complies with the average thrust requirement during design and prior to launch.
9. Flight Safety	I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if	The Safety Officer will be responsible for verifying compliance with all flight safety requirements prior to any launches.

	wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	
10. Launch Site	I will launch my rocket outdoors, in an open area where trees, power lines, buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater.	All launches will be performed at NAR and/or TRA certified events using properly-size launch sites.
11. Launcher Location	My launcher will be at least one half the minimum launch site dimension, or 1,500 feet (whichever is greater) from any inhabited building, or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	All launches will be performed at NAR and/or TRA certified events using launches properly-placed within the boundaries of the launch site.
12. Recovery System	I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	The primary vehicle and the launch abort component will both use parachutes and fire-proof materials in their recovery systems. The Recovery Systems Lead will be responsible for verifying compliance.
13. Recovery Safety	I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	Only trained members of the Recovery Systems group will be allowed to recover the vehicle components.

3.4.3.9 Material Safety Data Sheets

There are a number of materials that will be used during the construction of our vehicle that we have identified as being potentially hazardous. They include:
Aluminum Perchlorate Composite Propellant
Black Powder
U.S. Composites 150 Epoxy *
U.S. Composites 150 Epoxy Hardener *
Fiberglass
Kevlar
Spray Paint Primer **
Spray Paint **

* At the time of this report, U.S. Composites has not yet responded to our request for MSDSs specific to their 150 Epoxy kit, so equivalent MSDSs will be used until they are received.
** At the time of this report, our team has not yet decided on an exact brand and color of paint, so these equivalent MSDSs will be used until that decision is made.

Material Safety Data Sheets (MSDSs) for each of these materials have been collected and are included at the end of this presentation. Printed versions have been placed in a binder that will be kept with our construction materials, ensuring easy access to the MSDSs in the event they are needed.

3.4.4 Environmental Concerns

Our team must also ensure that all hazardous materials used in the construction and operation of our vehicle are properly stored and disposed of in order to prevent any environmental contamination. Therefore, the team's Safety Officer will be responsible for verifying that:

1) All hazardous materials are stored according to the instructions on their MSDS
2) Any work materials (gloves, table coverings, etc) that have been contaminated by a hazardous material are disposed of according to the instructions on the appropriate MSDS
3) Any remaining, and un-usable, hazardous materials (ie: epoxies, etc) will be disposed of according to the instructions on the appropriate MSDS and in coordination with the Arizona State University Environmental Health and Safety (EH&S) department, if necessary.

4 Modular Autonomous Launch Platform (AGSE)

4.1 Selection, Design, and Verification

4.1.1 System Level Review

The first design for the MALP system was a simple tripod stand, with the base of the ASGE consisting of aluminum tubing and joints, covered with aluminum sheet metal to help protect the inside components from the rocket's ignition once it launches. Inside is the servo to raise the launch railing, as well as all the electronics to facilitate the automated launch sequence, and the power source for all the electronic components. The rocket would have been laid on the 80/20 1010 railing, with the payload opening facing upwards in the upper half of the rocket body. The doors would have rested on hinges with plates inside that would give way under the weight of the payload capsule, swinging them down and sealing them shut with neodymium magnets for stability. After reviewing the idea it was found that the motor would have had to use substantial power in order to create the necessary torque in order to erect the rocket. The idea was changed to a robust design that would be more mechanically sound.

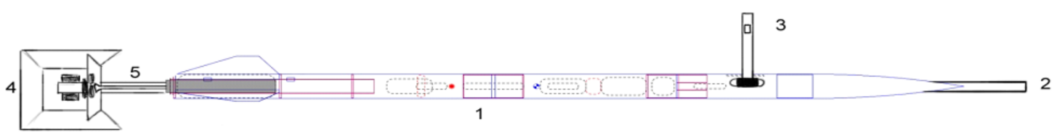


Figure 20 - Top-down view of MALP 1.0

The second design for the MALP system was more intricate, but ultimately unwieldy and unnecessary. The system structure consisted of a large launch platform and a separate smaller rocket support platform. The main launch pad was going to be an "L" shape with a base and upper tower attached to the base. At the bottom on the tower, there were going to be two motors controlling two pulley systems that were leading up into the tower connecting to the rocket rod. When the motors were activated the pulley system would allow the rocket to erect to the desired position. The pulley system was also going to have a fail-safe such that if one of the motors failed, the system could function with only one if needed. The smaller platform was to be placed away from the main structure to help alleviate some of the stress caused to the launch railing of the 9' rocket. It was connected to the larger launch pad by metal rods that resembled a train track. The idea was to have the metal connection so that the robotic arm could have been attached easily to the entire system, and also to make sure that the support platform would always be the same distance and orientation from the main launch pad. The design was thought to be too complicated, intricate, and time consuming. The design was scrapped before sketches could be provided. This time the design performed too much. The idea was once again changed to a more efficient design.

The design that had been presented in the PDR essentially took the best of both previous iterations. The goldilocks design took the motor erection idea from the first and added the stability support and help of two towers and two motors from the second. In this design there was to be two identical towers apart from each other connected by a 1" steel rod that would pivot, powered by two motors housed on each tower. The rocket launch railing is attached to this steel rod, and it is the turning of this rod that erects the rocket. On the opposite end of the rocket rod are going to be two ten pound weights to help offset the rocket weight. This will demand less torque of the motors to fully raise the rocket. The design allowed the ability to keep everything efficient and still be able to function without requiring unreasonable amounts of power.

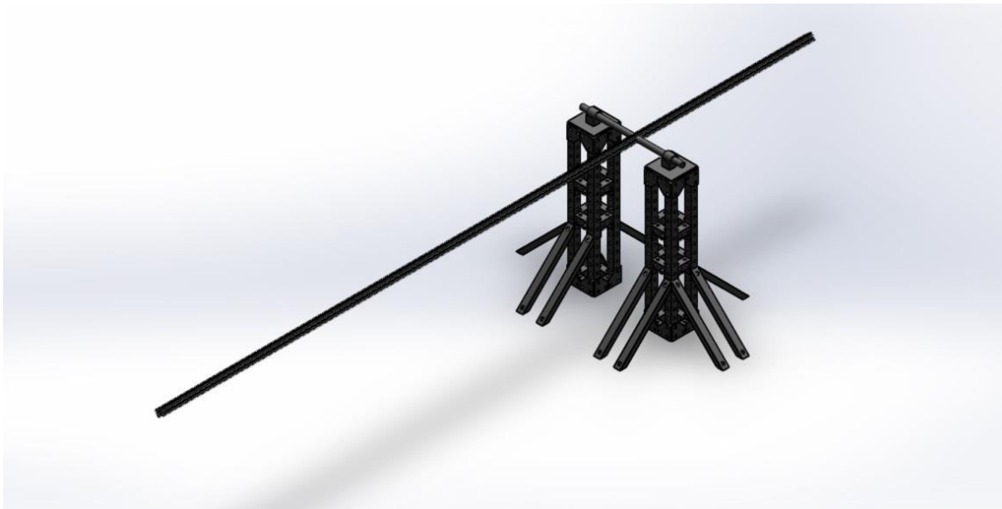
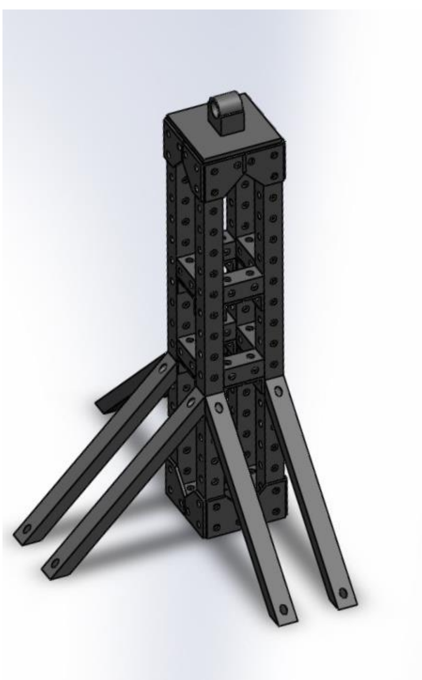


Figure 21 - SolidWorks Model of MALP 3.0

Figure 22 - Model of one of the towers of the MALP 3.0.



However, during the PDR presentation there were some concerns brought up, mostly in regards to the safety and mechanical viability of the design. Taking these critiques, modifications were made to the semi-final design to fully satisfy any concerns about the AGSE. To ensure that the railing will be able to sustain suspension, the 1030 triple railing was chosen to help increase the strength of the railing. The small platform from the second design has also been reintroduced to the design so that the ARM can be attached to it, and that the rocket's length will not pose a problem to the stability of the launch system. Also being added are locking gears along the pivot beam that will hold the launch railing once it has been raised so that the motors alone are not the only things holding to launch position, in the case of a power failure or other unforeseeable complication. The MIIS and the ARM have also undergone several iterations before being satisfactory. These alterations to the third design make up the finalized version that is presented in further detail here.

4.1.2 Mission Critical Systems Review

The success of this mission is reliant upon three subsystems working in tandem: the autonomous retrieval mechanism (ARM), the MALP to raise the rocket to the specified angle, and the motor igniter insertion system (MIIS).

4.1.2.1 Autonomous Retrieval Mechanism (ARM)

The payload arm has the ability to retrieve the designated payload when placed within reach of the arm but outside the bodyline of the rocket. The design is a modified crane. The bottom of the crane being stable and mounted to the ground dimensions of 16" wide and 15.61" high will serve as the base. A secondary smaller block will sit upon the base with the ability to turn itself 360 degrees, having a width of 8" and a height of 4.5". An arm with the ability to pivot up and down has a length of 21.86" and a width of 3.04. This allows the ARM to extend out and the secondary smaller arm attached to that has a length of 13". Together the two arms form something similar to a human arm with the connection point acting like an elbow. On the smaller secondary arm the claw is attached to allow payload pick up. The claw is a simple design similar to a stuffed animal claw but with more accuracy. The tips of the claw will be covered with rubber to allow more friction between the payload and the claw fingers.

4.1.2.2 Modular Autonomous Launch Platform (MALP)

The raising of the rocket will be done with two motors at the pivot point that is supported by the two-tower base structure. The motors will be housed in the towers to be protected from the ignition of the rocket, and the pivot point is on the 80/20 1015 railing between the rocket and the counter balance at the end. The two-tower base structure is constructed out of perforated P900 Unistrut Telestrut 1-⅝" square telescopic tubing material.

The tubing dimensions are 1⅝" width, 1⅝" length, and ¼" thick. The holes in the Telestrut dimensions are 9/16" diameter, 13/16" from edge to center of first hole, and 1-⅞" from center of hole to center of hole. Each tower has a height of 2.79' and a square width of 6.47". The tower is supported by four beams that are 2.79' in height connected together by four smaller beams 6.47" in height to form a hollow box with two sub-levels for extra support. The height was chosen to give the rod that the rocket is attached to room so that a counter side with weights could be attached to the end. Also a factor of choosing height was the holes in the Telestrut, as the hole distances are constrained the height was chosen to allow a whole number of full holes and an even gap at each end. The counter rod is 2.5' in length resulting in the tower at minimum being that height. The towers being 2.79' gave room from the ground to the bottom of the launch rod when the rocket is fully erected, and the ability to use a larger counterweight should it ultimately be needed.

To mount the Telestrut together two different fitting pieces were chosen. P1326 Unistrut 3-hole 90 degree Fitting is used to the brace the underside corner of the smaller beam to the larger beam, 16 pieces are used to connect all eight corners to the two sub-level braces. P1334 Unistrut 3-hole corner flat plate fitting is used to connect the base and top of the structure mounting to the sides of the larger and smaller beams, also 16 pieces in total. This fitting piece has an extra connecting plate on one corner for more stability. By choosing the extra connecting plate for the fitting piece allows more stability in the structure. All of the Telestrut and fitting pieces have a Perma Green III finish. This finish is a factory applied, electro-deposition acrylic coating with superior rust protection and fade-resistance. The acrylic coating is a proprietary formulation and is essentially "heavy-metal" free. The electrodeposition coating process provides a smooth, hard, durable surface which is completely cured.

4.1.2.3 Motor Igniter Insertion System (MIIS)

This subsystem is located on the lower end of the launch railing, secured into the center beam of the triple rail. The means of motion relies on a conveyor belt and pulley system, with the pulleys anchored into the far side of the triple-rail, and the motor mounted below the railing. The main platform is attached to the conveyor, so as the motor moves the cable slides the platform along the T-slot. The platform is a simple semi-box, with the head of it pushing along the igniter cable into the bottom of the rocket. To increase the stability of the cable itself, a small dowel will be attached the cable to ensure that the cable does in fact go into the rocket instead of kinking to the side and failing to properly ignite when the launch command is given. The top of the platform will also ensure that the small hole in the blast plate, which is necessary to allow the igniter cable access to the rocket, is completely closed off once ignition begins.

4.1.3 Performance Characteristics and Evaluation

The overall success of the mission is dependent on the general effectiveness of all the subsystems working together, and the redundancy of certain systems in place to ensure all possible complications are accounted for and do not interfere with the final acquisition, deposit, and launching of the payload.

4.1.3.1 ARM

The performance of this subsystem will be measured not only on the accuracy of its deposit of the payload, but also the speed and the control with which it executes it main mission. The ARM must be adaptable enough the capture the payload should it roll out of its initial placement, and also be able to make adjustments for deposit using the imaging system to ensure that the payload is properly inserted. The ARM must also function at the base in order for the rocket to be raised, once the ARM has been repositioned to the side; else it would be obstructing the railing's path and the launch angle would be impossible to achieve.

4.1.3.2 MALP

The MALP utilizes a mixed redundancy of both mechanical and electric systems to ensure the rocket is raised to its full launch height. The counterweight is used to ease the work needed by the dual motors at the base of the pivot, and each motor will be able to raise the rocket on its own should the other motor fail or become unresponsive at any time during the mission; there will also be interlocking gears at the motors to mechanically lock the railing in launch position should power fail after it has been raised. The MALP will also maintain constant communication with the ARM to ensure the payload has been deposited before the rocket begins the raising sequence. The success will be dependent on how well the two subsystems remain in communication and the effectiveness of all the integrated redundancies, as well as the ease and accuracy with which the rocket is raised to its final launching position.

4.1.3.3 MIIS

Being the final stage of the launch sequence, the success of the MIIS is a very high priority. It must remain in constant communication with the rest of the ground system so as to not begin early, but also remain in standby until the final signal to launch has been given. The major points of measuring the success of this subsystem is how well it can maintain contact with the other subsystems and how easily it can complete the task of inserting the igniter cable into the rocket without any mission-ending complications occurring.

4.1.4 Preliminary Integration Plan

The two towers are to be assembled on site, and then staked into the ground to ensure the stability of the structure. These towers are connected by a support beam between the two, and above that beam is the pivoting rod attached to motors at either end. This rod supports the launch railing that that rocket is to be locked into, and beneath the rocket and the blast plate is the MIIS system, attached to the same railing. The MIIS will use the railing to line up with the ignition opening at the bottom of the rocket, and close the blast plate to allow for ignition and launch. Prior to the activation of the MIIS, however, the ARM must pick up the payload and have a successful delivery. The ARM is placed during assembly a designated distance away from the main structure. It possesses the grabbing mechanism for the payload retrieval, as well as an extension to the rocket railing to provide additional support to the 10' beam suspended away from the towers. This extra structure is also staked into the ground for support. The ARM will deposit the payload into the designated bay, which will then close once the payload is dropped in. The payload door system is composed of two sections, the outer doors and inner doors. The inner doors have a trigger that once the payload passes through they flip the outer doors shut with the momentum of the falling payload. Once the payload is inside the payload bay it will wait until the rocket begins to erect. When the rocket erects the payload will slide into a funnel at the bottom of the payload bay allowing the payload to keep steady during launch. First the ARM must clear the path of the rocket railing to be raised, and the MIIS will be in standby at the base of the railing until the rocket is in the ready position. All sections of the structure will be in constant communication so as to not begin the next stage in the launch sequence until the prior has been completed. The rocket will not raise until the ARM has given the clearance to do so, and the MIIS will not activate until the rocket has signaled that it is ready in the upright position.

4.1.5 Key Component Analysis

The design for the AGSE has been dubbed the MALP, and several of the key components include the support structure, the motors connected to the pivot rod so that rocket can erect, pivot rod, and the widened launch railing. The support system is a connected two tower system that is raised off of the ground, along with a separate tower at the far end of the rocket to give support to the 10' beam extending from the main structure. The height is to give the main rod, which the rocket is attached to, room to erect without hitting the ground; it also allows room for the MIIS to complete its function. The extended rod is there to allow counter weights, another key component, to help assist the motors to turn the pivot rod that is connect to the launch railing, in order to erect the rocket into launch position. The towers also allow a place to put the motors and attach to the pivot rod to initiate the raising of the railing.

The payload key components include the ARM to pick up and insert payload into the payload bay, the door system inside rocket to keep the payload from falling out, and the funnel inside the payload bay that stabilizes the payload so that it does not shake while rocket is being launched. The ARM is the crane component that picks up the payload with a grabbing mechanism that slides along the main horizontal beam using a conveyor belt system to position the payload over the open bay doors and deposits it safely. The payload door system is composed of two sections, the outer doors and inner doors. The inner doors have a trigger that once the payload passes through they flip the outer doors shut with the momentum of the falling payload. Once the payload is inside the payload bay it waits until the rocket begins to erect. As the rocket erects the payload slides into a funnel at the bottom of the payload bay that is more constrained, allowing the payload to keep steady during launch.

The largest components of the MIIS subsystem include the platform powered by a pulley system, and the dowel the igniter cable is attached to that will ensure the cable makes it into the rocket. The pulley system is anchored into the T-slots of the 1030 launch railing, and is in place to guarantee that the igniter cable takes a direct path into the motor ignition system of the rocket, and the dowel is to reinforce the cable to prevent any obstacles or slips of the cable that could bend or completely derail it in a manner that could be detrimental to the success of the mission. The platform that propels the cable into the rocket will also complete the blast shield to deflect the blat of the ignition once the rocket has been launched.

The MALP and payload systems will work together in a linear progression of programming. The systems are given a set of implicit instruction to follow, preceded by a signal to come from a designated subsystem; however if one component of the system line fails the project is a failure. By working together the system can achieve the means of a relevant and cost effective research and development of a self-sustaining system to retrieve, accept, and fly a "Mars sample" to an altitude of 3,000 feet about ground level.

4.2 MALP Concept Features and Definition

There was a certain uniqueness brought to the mission project by the wide variety of students drawn to the project. It became an interesting mixture of engineering and science interests that motivated the designs of previous iterations of the MALP before the final design came out victorious. The team became more than aerospace and mechanical students crafting an overly elaborate machine to launch a toy rocket or a handful of astrophysics students attempting to juggle an unnecessarily large number of servos to shoot off a lovingly crafted piece of art.

The significance became apparent when the opposing viewpoints stopped competing against each other and began competing with each other. The importance of involvement on a mission as detailed and multi-faceted as this brought an understanding to the team that not one specific methodology is best. It has enabled the interaction of members at levels that had not been expected.

And this interaction is what brings the true challenge to the project. Rather than simply building the biggest rocket that can fly the highest or the robot that can hit the hardest, multiple groups have to combine knowledge and expertise in a way that is not only logical but also functional and even competitive. Previous years, Icarus Rocketry had been focusing solely on the launching of rockets to higher and higher limits. This is the practical application of what has been learned in classrooms along with the cooperation with those outside the typical range of knowledge reserved for rocketry enthusiast clubs.

4.2.1 Test and Verification Plan

Table 14 - Autonomous Ground Support Equipment (AGSE) Requirement Verification Plan

Req #	Requirement	Relevant Design Feature	Verification Method
3.2.2.2	All AGSE systems shall be fully autonomous. The only human interaction will be when the launch services official pauses or arms any equipment, when the team arms the recovery electronics, and when the LCO initiates launch.	The AGSE systems are designed to be fully autonomous with the exception of the required hard switches.	Design: The Project Manager will ensure that the final AGSE meets all autonomy requirements.
3.2.2.3	Any pressure vessel used in the AGSE will follow all regulations set by requirement 1.12 in the Vehicle Requirements section.	No pressure vessels will be used in the launch vehicle.	Design: The Project Manager will ensure that no pressure vessels are added to the vehicle design.
3.2.3.1	The AGSE may not employ any equipment that would not function in a Martian environment.	The AGSE design does not include any of the prohibited equipment.	Design: The Project Manager will ensure that no prohibited equipment is added to the vehicle design.

Table 15 - Payload Requirement Verification Plan

Req #	Requirement	Relevant Design Feature	Verification Method
3.2.4.1	Each launch vehicle must have the space to contain a cylindrical payload approximately 3/4 inch in diameter and 4.75 inches in length, and must be able to seal the payload containment area autonomously prior to launch.	The vehicle design includes a payload bay that will hold a payload of the required dimensions.	Testing: Ground testing and the full-scale test launch will verify the payload fits into the payload bay as designed and properly closes before launch.
3.2.4.2	Each team will be required to use a regulation payload provided to them on launch day.	The vehicle design includes a payload bay that will hold a payload of the required dimensions.	Testing: Ground testing and the full-scale test launch will verify the payload fits into the payload bay as designed.
3.2.4.3	The payload will not contain any hooks or other means to grab it.	The AGSE systems assume the payload will not be modified from the provided specifications.	Design: The AGSE is designed to handle and load an unmodified payload capsule.
3.2.4.4	The payload may be placed anywhere in the launch area for insertion, as long as it is outside the mold line of the launch vehicle when placed in the horizontal position on the AGSE.	The payload will be placed on the ground at the base of the AGSE outside the mold line of the vehicle.	Inspection: The Project Manager will ensure that the payload is properly placed during the test launch and during the competition launch.
3.2.4.5	The payload container must utilize a parachute for recovery and contain a GPS or radio locator.	The payload section of the vehicle contains an independent parachute and GPS locator.	Design: The Recovery Team lead will ensure that the payload section of the vehicle is built as designed.
3.2.4.6	Each team will be given 10 minutes to autonomously capture, place, and seal the payload within their rocket, and erect the rocket to a vertical launch position five degrees off vertical. Insertion of igniter and activation for launch are also included in this time.	The AGSE will be designed to carry out all launch preparations in less than 8 minutes, in order to provide some margin.	Testing: The full-scale test launch will verify that the AGSE can carry out all launch preparations within the allotted timeframe.
3.2.5	Each team must provide the following switches and indicators for their AGSE: a master power switch, a pause switch, a safety light and a "Systems Go" light.	The AGSE design includes all of the required switches and lights.	Design: The AGSE Subsystem lead will ensure the AGSE design includes all of the required switches.

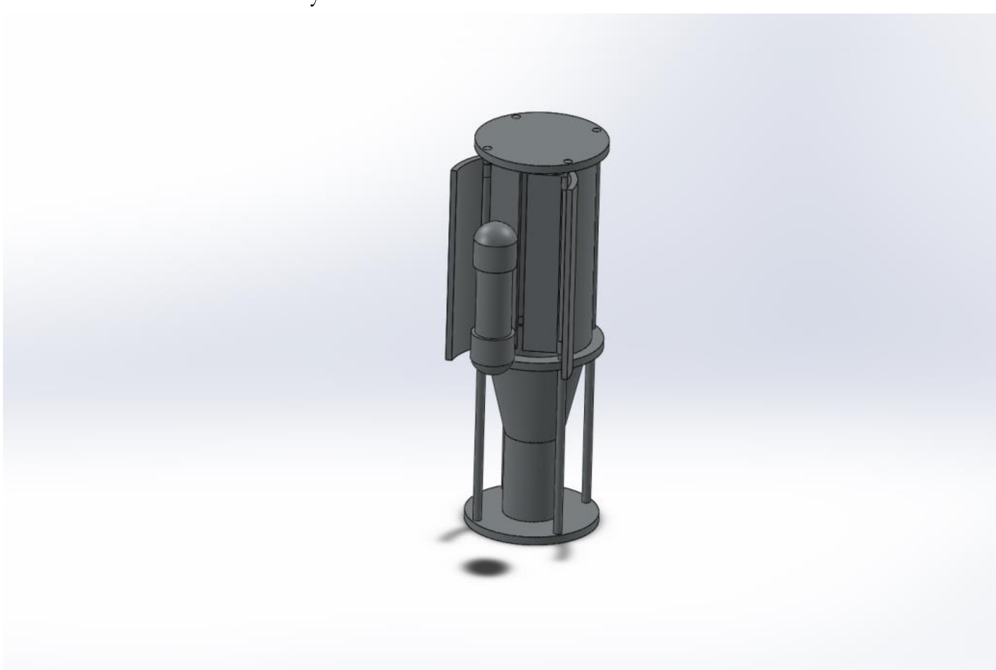
4.2.2 Payload Integration Plan

The launch vehicle's payload bay assembly has been designed to accept the sample capsule from the Automatic Retrieval Mechanism, secure it for launch and protect it during descent. In order to simplify the manufacturing and assembly process, the entire payload bay assembly will be built outside of the launch vehicle airframe and then inserted into the vehicle and secured with screws through the external walls of the vehicle.

A model of the payload assembly, including a model of the sample capsule, is presented in Figure 23.

The payload bay assembly will be structurally supported by four lateral rods secured to two end plates and a middle ring. The top half includes a set of inner doors connected to a set of outer doors. The act of dropping the sample capsule onto the inner doors while the vehicle is positioned horizontally will cause them to open, allowing the capsule to drop into the payload bay, and simultaneously close the outer doors, which will be secured in the closed position by small neodymium magnets. The bottom half includes a funnel and tube that will automatically position the sample capsule for launch when the vehicle is raised into a vertical position for launch and will prevent the capsule from shifting during the ascent portion of the flight. The design of the payload bay assembly only includes two moving parts (the two independently hinged doors) in an effort to simply the design.

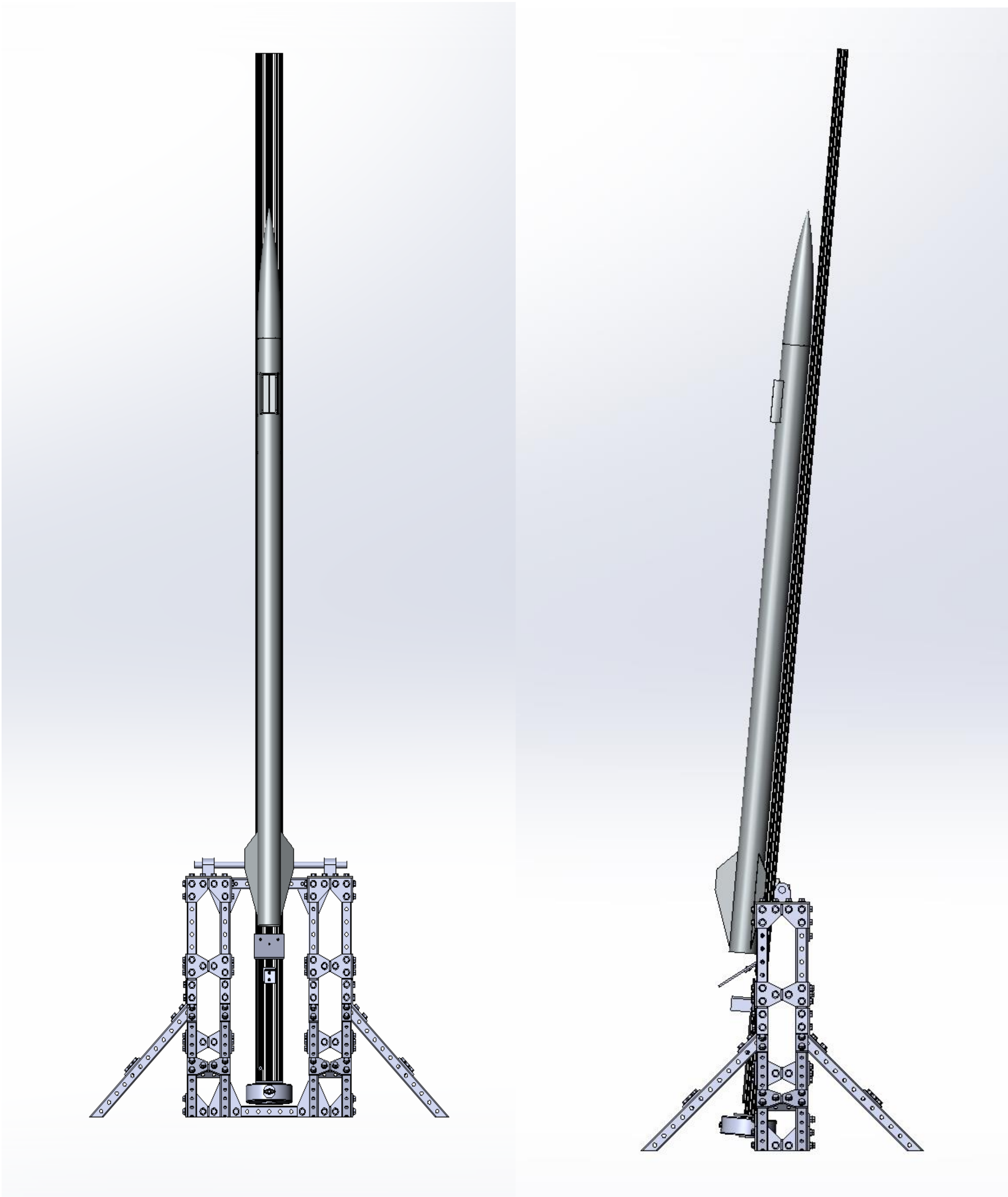
The payload bay assembly was developed in close collaboration with the launch vehicle subsystem teams in order to ensure that the mass and volume were properly accounted for in the launch vehicle design drawings and flight simulations. As the payload bay assembly is manufactured, the launch vehicle flight dynamics team will be informed of any changes in the expected mass of the assembly.

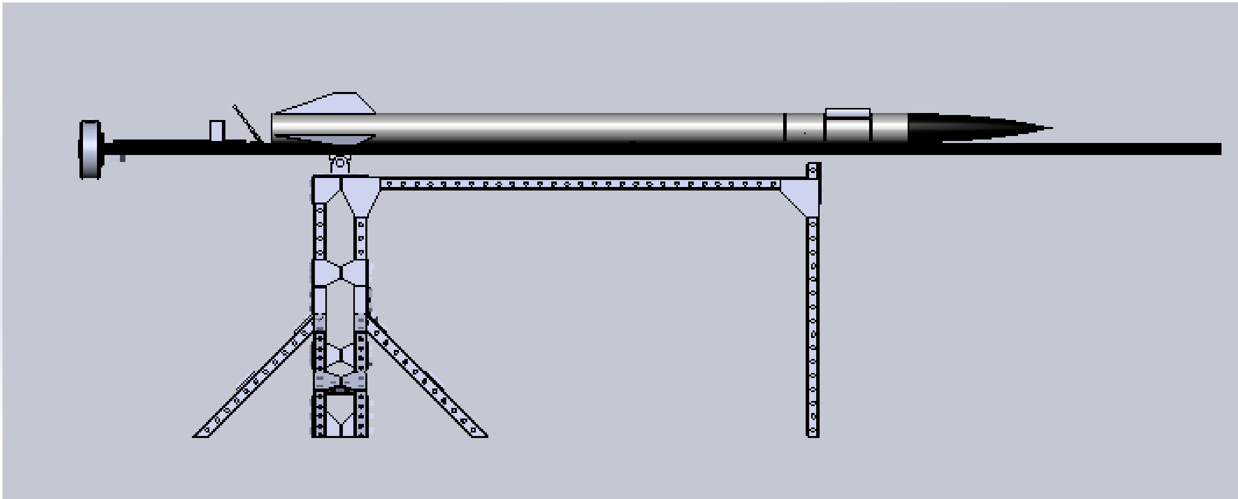


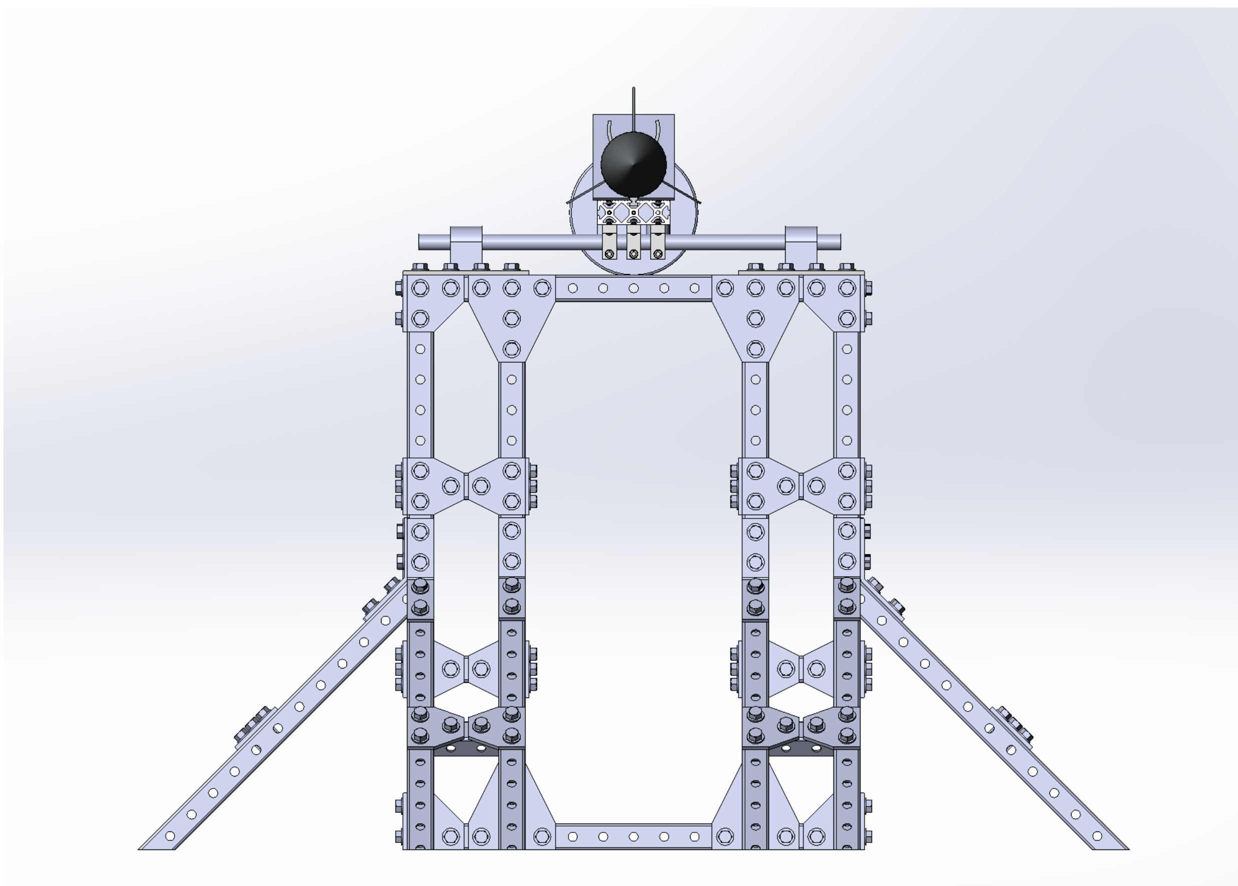
The sub-scale test flight did not include a sub-scale version of the payload bay assembly due to the cost and complexity it would have unnecessarily added to the sub-scale test flight effort. However, the sub-scale test flight did have a mass distribution similar to the mass distribution of the full-scale vehicle design, resulting in roughly similar static stability margins. The sub-scale vehicle had a stability margin of 2.314 and the full-scale vehicle has a designed stability margin of 2.692.

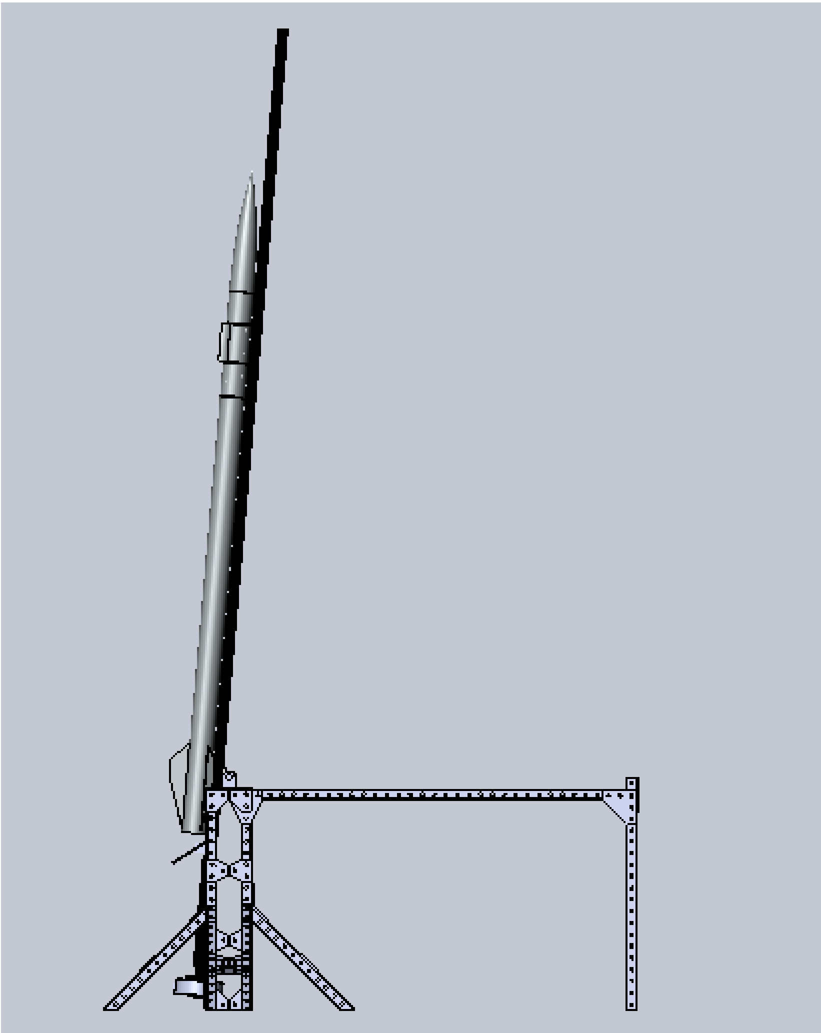
The sub-scale test flight vehicle performed as expected from OpenRocket simulations of the design, which gives the team confidence in the OpenRocket simulations of the full-scale vehicle design. Since the simulated full-scale vehicle design includes mass and volume models for the payload bay assembly, the team believes the sub-scale test flight sufficiently tested the . As a result of this, the design of the payload bay has not been changed based on data from the sub-scale flight test.

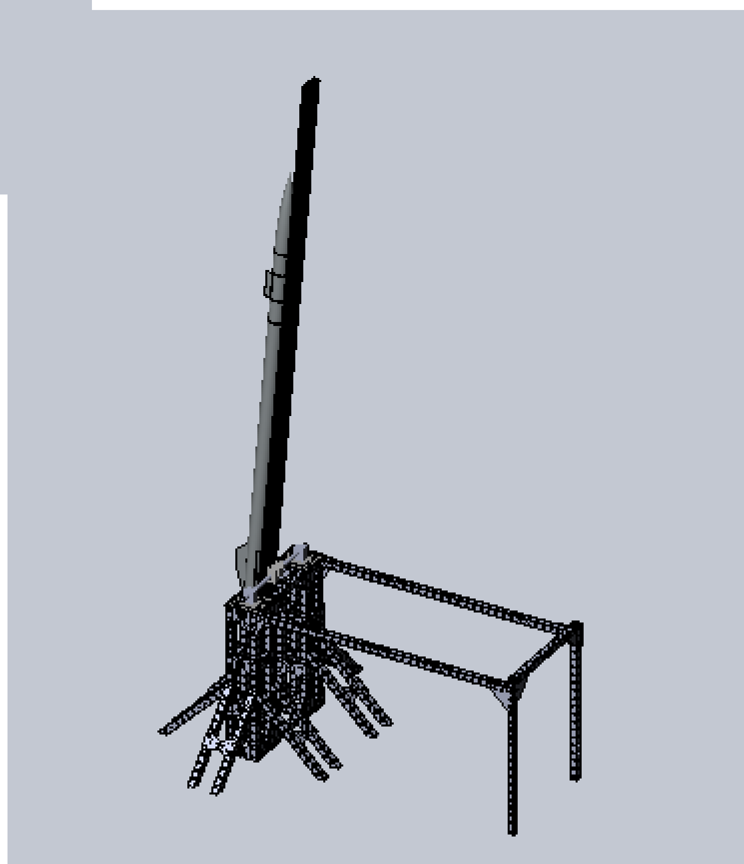
4.2.3 Schematics

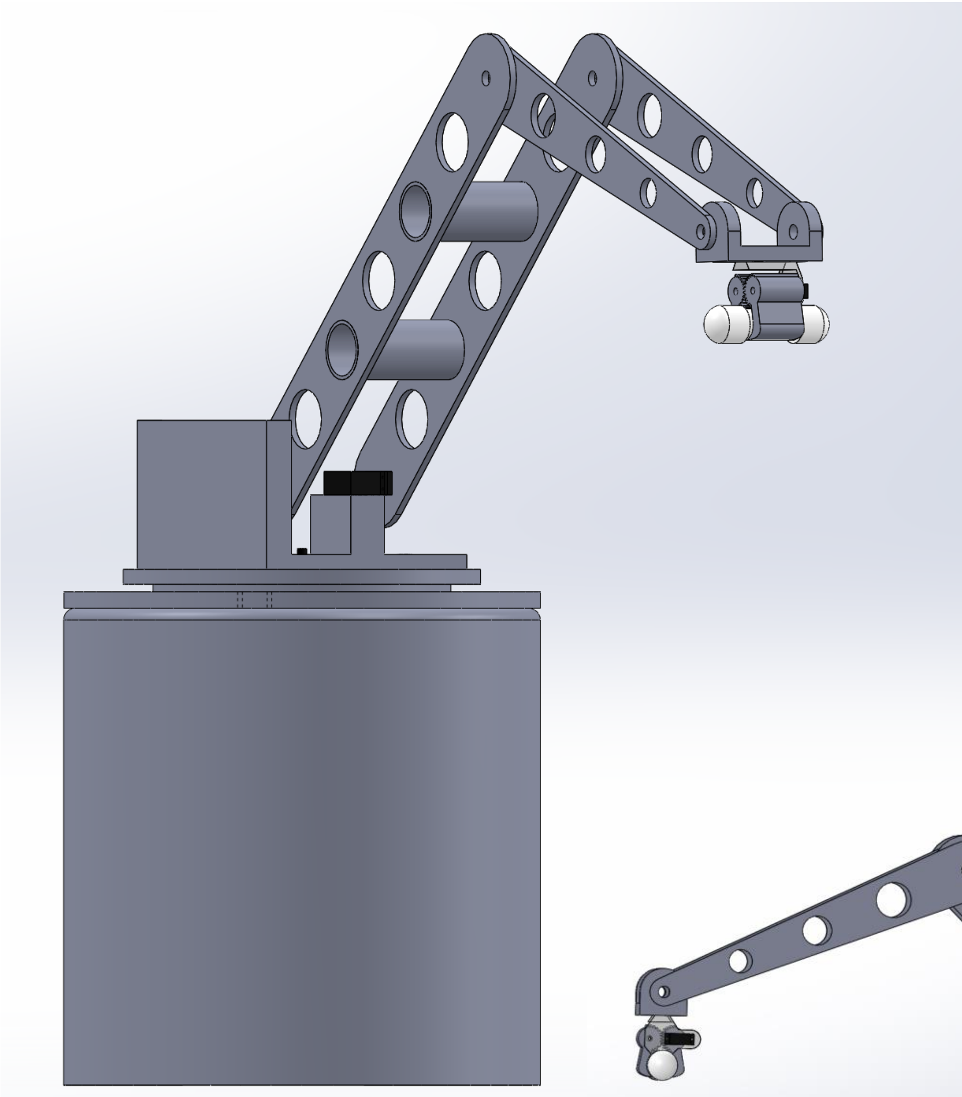


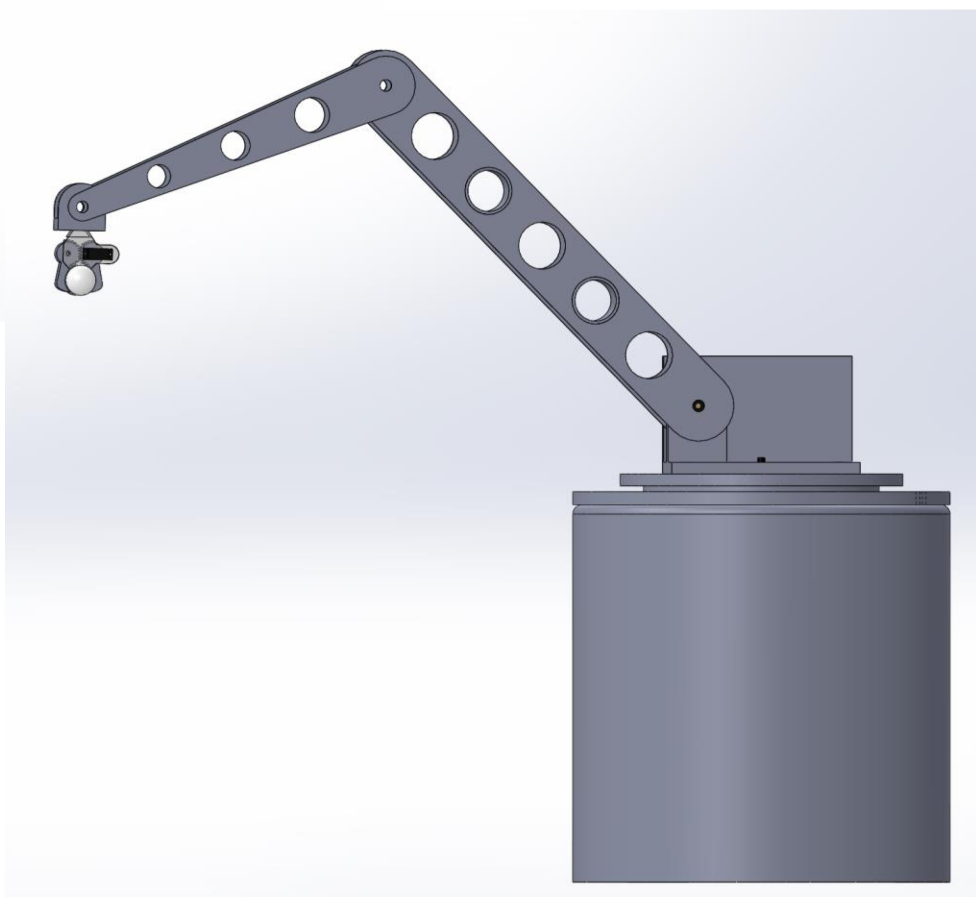












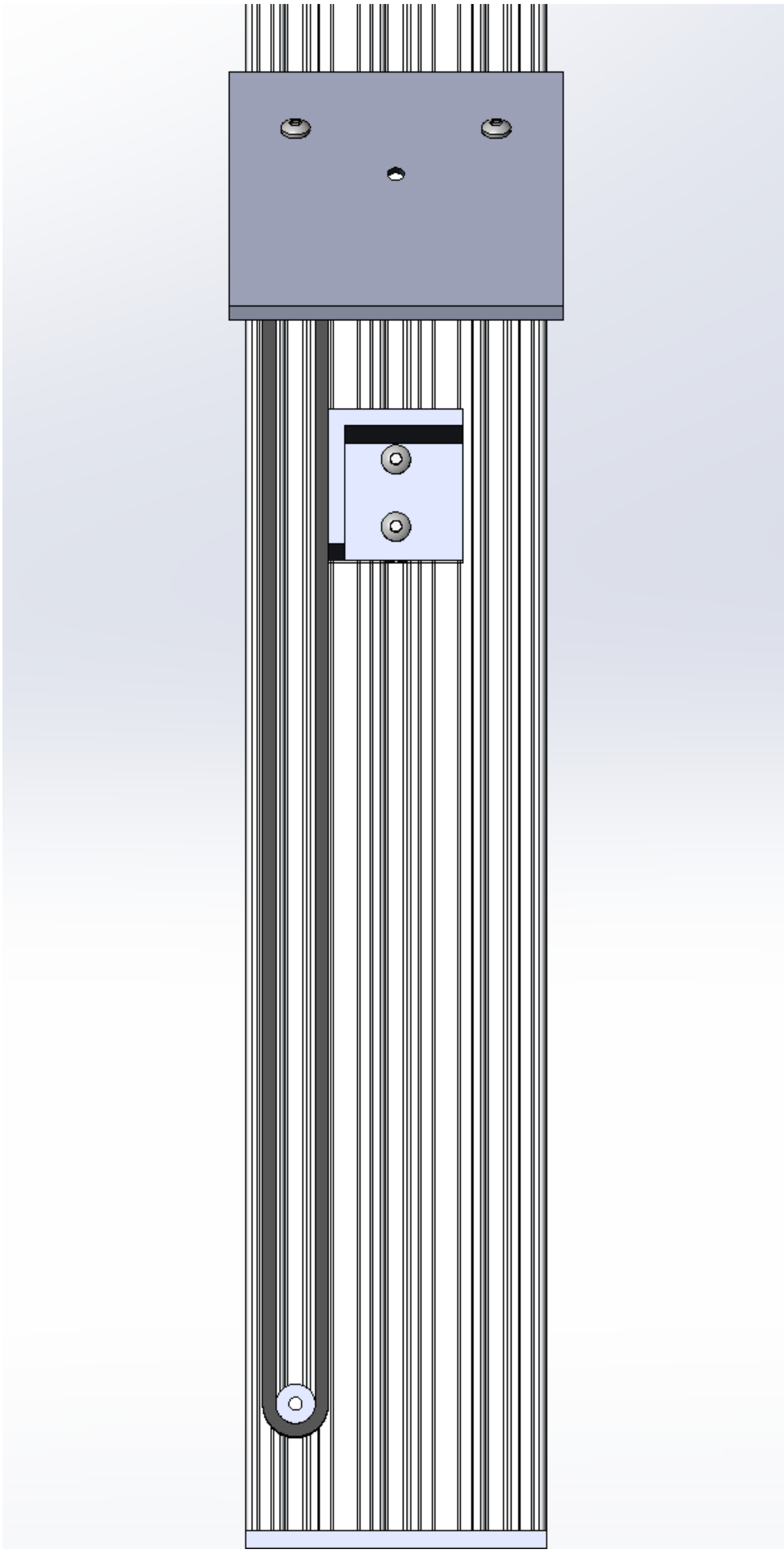


Figure 28- MIIS

- Blast plate
- Conveyor belt
- Pushing plate

5 Project Plan

5.1 Budget Plan

Table 16 - Electronics Budget

Description	Quantity	Price	Subtotal
PerfectFlite Stratologger	2	67.96	$135.92
PerfectFlite USB Data Transfer Kit	1	$26.96	$26.96
PerfectFlite miniTimer4	2	$35.96	$71.92
HD Wing Camera 1280x720p 30fps 5MP CMOS	2	$37.18	$74.36
Push-Hold Switch Trigger	3	$20.00	$60.00
Eggfinder GPS	1	$70	$78.00
Shipping			$150.00
		TOTAL	$589.16

Table 17 – MALP

Description	Quantity	Price	Subtotal
P9000 Unistrut Telestrut 1.625"x1/625"x10' Square Telescopic Tubing	4	$104.99	419.96
P1026 Unistrut 2-hole 90 degree angle fitting	32	$1.07	34.24
P1334 Unistrut 3 hole Corner flat plate fitting	32	$10.40	332.8
Steel Rod 4'x1"	1	$16	16
1515 80/20 Railing (97"x1.5")	2	$91.50	183
20lb torq servo motor	2	$250	500
MissileWorks RRC3 Altimeter System	2	$79.96	$159.92
		TOTAL	1645.92

Table 18 - Build Materials Budget

Item Number	Description	Quantity	Price	Subtotal
EPOX-150315	US Composites 150 Epoxy, 2 Gallon, Medium	1	$128	$128.00
	Blue Tube 2.0 3.9"x0.062 wall x 48"	4	$38.95	$155.80
	Blue Tube 2.0 54mm x 0.062 wall x 48" MMT	2	$23.95	$47.90
	Blue Tube Electronics Bay 4.0" x 8"	2	$41.95	$83.90
	3.9" 5-1 Von Karman Fiberglass Nose Cone	1	$69	$69
	Hardpoint Anchor	2	$6.51	$13.02
98mm	Hardpoint Motortube Adapter	2	$10.49	$20.98
	Acme Conformal Launch Rail	2	$3.66	$7.32
13076	Removable Rivets (x10)	3	$2.58	$7.74
13082	Brass Screws (x4)	6	$1.00	$6.00
H530-ND	2-56 1/4" Nylon Screw (x100)	1	$8.86	$8.86
	2 Quart Kit Mega Foam	1	$22.50	$22.50
	G10 Fins	6	$30	$180.00
	Shipping			$150.00
			TOTAL	$849.o

Table 19 - Propulsion Budget

Description	Quantity	Price
Aerotech J800	3	$74.99

Table 20 - Sample Containment Bay

Description	Quantity	Price	Subtotal
(1/8"x36") Threaded T6061 Aluminum Rod	2	$14.89	$29.78
(8"x8"x0.25") Aluminum Plate	1	$9.93	$9.93
1.5" Diameter Cardboard Tube	1	$1.49	$1.49
3" Diameter Cardboard Tube	1	$2.79	$2.79
(12"x12"x0.125") Cardboard Sheet	2	$0.99	$1.98
		TOTAL	44.98

Table 21 - MIIS Budget

Description	Quantity	Price	Subtotal
Linear Motor	2	$330.95	661.9
Galvanized Flat Steel Sheet	1	$9.34	$9.34
GT2 Belt and Pulley Set	1	$12.99	$12.99
U-style clip-on nut	1	$10.00	$10.00
		TOTAL	693.51

Table 22 - Travel Budget

Description	Quantity	Price	Subtotal
4 nights at Huntsville Embassy Suites Hotel and Spa (Queen Rooms for 5)	4	$1856	1856
SUV Rental	2	$627.98	1255.96
Gasoline (gallons)	78	$257	257
		TOTAL	3368.78

Table 23 - Outreach Budget

Description	Quantity	Price	Subtotal
Wix - Unlimited 1 Yr Hosting	1	$150	$150.00
Team Patches	25	$7.50	$187.50
Team Polos	15	$30	$450.00
Generic E2X Model Rockets Educator Pack (12)	10	$72.59	$725.90
Estes Blast Off Pack 24 asst motors	6	$47	$279.54
Additional Materials, Giveaways	1	$700	$700.00
		TOTAL	$2,492.94

Table 24 - Tool Budget

Description	Quantity	Price	Subtotal
Misc Tools	1	$300	$300.00
Shipping Costs	1	$100	$100.00
		TOTAL	$400.00

Table 25 – Recovery

Description	Quantity	Price	Subtotal
Classic Elliptical 36" Parachute - 112lbs @ 20fps	2	$78	$156.00
PML 18" Parachute	2	$18.95	$37.90
1/2" Tubular Kevlar Shock Cord /yd	30	$3.75	$112.50
1500 lb test 2.25" 23g Swivel	16	$6	$96.00
1/4" 880 lb test Quick Link	24	$1.35	$32.40
Medium Blastcap (Pair)	6	$24.00	$144.00
FFFFg Black Powder (1lb)	1	$15	$15.00
Firewall 18"x18" Nomex Chute Protector	2	$10.95	$21.90
Firewall 6"x6" Nomex Chute Protector	1	$4.95	$4.95
Shipping			100.00
		TOTAL	$720.65

Table 24 – Autonomous Control

Component	Quantity	Price
Arduino Processor Board	2	$23.83
Ada fruit Motor Shield	2	$21.90
Indicator Lights	5	$0.27
SPST Switch	3	(5 Switch) $6.69
Photoelectric Sensor	4(Pair)	(5 LDR) $5.84
ArduCAM shield Rev.C	1	$29.99
Connecting Wires		(40 Strip)$3.95
Battery 12V, 7.2Ah	1	$35
Polycase (Safety – to cover Electronic Kit)	2	$5
Wireless SD Shield	1	$25.95
Miscellaneous		$30
	TOTAL	$95.95

Table 25 – ARM

Item	Price	QTY
SS3306	39.99	3
spg5685a-45 (6.53 ft lb torque)	119.99	1
CanaKit Stepper Motor with Cable	$23.95	1
36x36 acyrlic sheet	43.62	1
Machine Time (24Hours) Change this if necessary)	$600	1
Claw (Dead Link)	$54	2

5.2 Funding Plan

Our team intends to pursue a number of different funding sources for our participating in NASA SLP. Among the more traditional route, the team is pursuing possible sponsorship opportunities from Orbital Sciences, Raytheon, Microchip, Moog, and other aerospace and technology companies in the greater Phoenix Metropolitan area. A corporate funding campaign and informative packet have undergone developing since the Preliminary Design Review and are at 75% completion.

The team expects to receive support from the Undergraduate Student Government appropriations for student organizations, and the School of Earth and Space Organization – our host department. The support that the USG would provide cover food and other club related merchandise to help promote the ambitions of Icarus Rocketry.

In addition to these more traditional sources of funding, our team will also be pursuing crowdfunding through the PitchFunder organization. PitchFunder is a new program from the ASU Foundation designed to empower the ASU community to raise the funds they need for the projects, events, and organizations they are passionate about. Their program provides groups the training, tools, and technology necessary to raise charitable funds in partnership with the ASU Foundation. To date, Icarus has reached out to PitchFunder, and is in the process of training with PitchFunder to begin our crowdfunding campaign. The expected launch date of the PitchFunder campaign is February 1st, and funds from the campaign are expected to be available on March 14th, in time to fund the transportation costs from Tempe to Huntsville.

5.3 Timeline: Major Milestone Map

Task Name	Duration	Start	Finish	% Complete
Proposal Submission	26 days	Mon 9/1/14	Mon 10/6/14	100%
Team Web Presence	35 days	Mon 9/1/14	Fri 10/17/14	100%
Corporate Funding Campaign	76 days	Mon 11/17/14	Sat 2/28/15	50%
PitchFunder Campaign	**87 days**	**Mon 11/17/14**	**Tue 3/17/15**	**50%**
PitchFunder Training Period	56 days	Mon 11/17/14	Sat 1/31/15	71%
PF Online Campaign	23 days	Sun 2/1/15	Tue 3/3/15	0%
PF Funds Available	0 days	Tue 3/17/15	Tue 3/17/15	0%
Design Period	**131 days**	**Mon 9/1/14**	**Sat 2/28/15**	**99%**
Preliminary Design Review	**23 days**	**Fri 10/17/14**	**Tue 11/18/14**	**100%**
PDR Writing Process	22 days	Fri 10/17/14	Mon 11/17/14	100%
PDR Video Teleconference	1 day	Tue 11/18/14	Tue 11/18/14	100%
Subscale Model Launch, December SARA Club Launch	1 day	Sat 12/13/14	Sat 12/13/14	100%
Ejection Charge Test, December SARA Club Launch	1 day	Sat 12/13/14	Sat 12/13/14	100%
Critical Design Review	**52 days**	**Wed 11/19/14**	**Thu 1/29/15**	**100%**
CDR Writing Process	42 days	Wed 11/19/14	Thu 1/15/15	100%
CDR Teleconference	1 day	Thu 1/29/15	Thu 1/29/15	100%
Fullscale Model launch	1 day	Sat 2/28/15	Sat 2/28/15	100%
Flight Readiness Review	**1 day**	**Mon 3/16/15**	**Mon 3/16/15**	**0%**
FRR Video Teleconference	1 day	Wed 3/18/15	Wed 3/18/15	0%
Travel to Alabama and Marshall Space Flight Center	2 days	Sun 4/5/15	Mon 4/6/15	0%
Launch Readiness Reviews	1 day	Tue 4/7/15	Tue 4/7/15	0%
LRR and Safety Briefing	1 day	Wed 4/8/15	Wed 4/8/15	0%
Rocket Fair and MSFC Tours	1 day	Thu 4/9/15	Thu 4/9/15	0%
Maxi/Mini MAV Launch	1 day	Fri 4/10/15	Fri 4/10/15	0%
Backup Launch Day	1 day	Sat 4/11/15	Sat 4/11/15	0%
Post Launch Assessment Review	1 day	Wed 4/29/15	Wed 4/29/15	0%
Winning Team Announced	1 day	Mon 5/11/15	Mon 5/11/15	0%

5.4 Education Engagement Plan

Icarus Rocketry works closely with the School of Earth and Space Exploration (SESE) in education and public outreach (EPO). EPO has been a main component and a focus of SESE since the beginning of the department. As a group mainly comprised of SESE students, Icarus

Rocketry can utilize the EPO infrastructure created by SESE in the past years. Icarus' educational engagement plan relies on the connections and partnerships already in place within the department – primarily with middle schools in the metro Phoenix area.

On October 25th, 2014, Icarus Rocketry provided a day of science and engineering fun to 300 school-age students, with approximately half of those being middle school students. Icarus Rocketry set up two large tables with which to teach students the science behind straw rockets and how to make them. In addition to making straw rockets, the team also taught inquisitive students about the science of rocketry as well as the importance of rocket science in our day to day lives.

In November, SESE hosted an Open House event at their ISTB4 building where clubs, organizations, graduate students, and professors would share general Earth and space knowledge to the general public. This event is held monthly, and Icarus had the privilege to take part in the Open House. Approximately 35 middle school children and their teachers were interacted with, not including older students and their families. SESE will be hosting monthly Open Houses monthly in 2015 starting in February, where Icarus expects to be present.

On December 9th, the Akimel A-al middle school in the Kyrene school district hosted an astronomy night for their students where they invited science clubs from ASU and other organizations to showcase their projects. Approximately 80 middle school students were interacted with, not including their parents and teachers.

In mid-February, the BASIS Mesa Middle and High Schools will be hosting a science night and are inviting local science related organizations to present their projects and provide informal lessons for their students and families. Approximately 100 students are expected to be interacted with at this event.

In March, ASU will be hosting the Night of the Open Door, where all of the buildings on all of ASU's campuses will be open for the general public. During this event, Icarus plans to have a couple of tables set up to provide informal rocketry related outreach to the guests of ASU.

6 Conclusion

In conclusion, we hope to create a launch vehicle whose success comes from the synchrony of its ground subsystems. The ingenuity and creativity of our team has allowed us to design powerful, efficient, and cost-effective means of delivering a successful launch vehicle. The NASA Student Launch is an excellent platform for the team to create innovative solutions while solving exciting challenges involved with the contest.

The two-tower system of our MALP provides a strong and efficient means of raising and reorienting our launch vehicle. Our ARM successfully loads the payload into the launch vehicle in an uncomplicated and straightforward so as not to hinder the other subsystems. The sample bay's elegant construction utilizes basic laws of physics to lock the sample into the payload bay as well as keep the sample still while the launch vehicle is in motion.

New edits added to the AGSE streamlined and refined the goals of our mission. In more solid detail, our designs reflect an efficient system that will safely and effectively launch our vehicle.

The team feels confident that this final design will perform well as designed, and allow us to collect meaningful information. After careful refinement, only the best designs for our subsystems and launch vehicle have been provided. In doing so, the components of the AGSE will be able to load and reorient the launch vehicle efficiently and without unnecessary complications. The team looks forward to finalizing the designs of our launch vehicle and its related subsystems, come the subscale model launch.

Now enjoy your apple pie.