By:

Georgia Institute of Technology Team Autonomous Rocket Equipment System (A.R.E.S.)

Georgia Institute of Technology

North Avenue NW

Atlanta GA, 30332

Project Name: Hermes

MAXI-MAV Competition

Friday, September 11th, 2015

Table of Contents

1. Introduction

1.1. School Information & NAR Contacts

Table 1: Team Summary

Team Summary	
School Name	Georgia Institute of Technology
Mailing Address	North Avenue NW, Atlanta GA 30332
Team Name	Team Autonomous Rocket Equipment System (A.R.E.S.)
Project Title	Simple Complexity
Launch Vehicle Name	Skeiron
Project Lead	Victor R.
Safety Officer	Stephen K.
Team Advisors	Dr. Eric Feron
NAR Section	Primary: Southern Area Launch vehiclery (SoAR) #571
NAR Contact, Number & Certification Level	Primary Contact: Joseph Mattingly NAR/TRA Number: 92646 Certification Level: Level 2 Secondary: Jorge Blanco

1.2. Student Participation

Team Autonomous Rocket Erector System (A.R.E.S.) is composed of twenty-one students studying varying fields of engineering. Our team is composed of less than 50% Foreign Nationals (FN) per NASA competition requirements. To work more effectively, the team is broken down into groups that focus on special tasks. Each sub-team has a general manager supported by several technical leads and subordinate members. Team memberships were selected based on each individual's area of expertise and personal interest. Figure 1 shows the work breakdown structure of Team A.R.E.S.

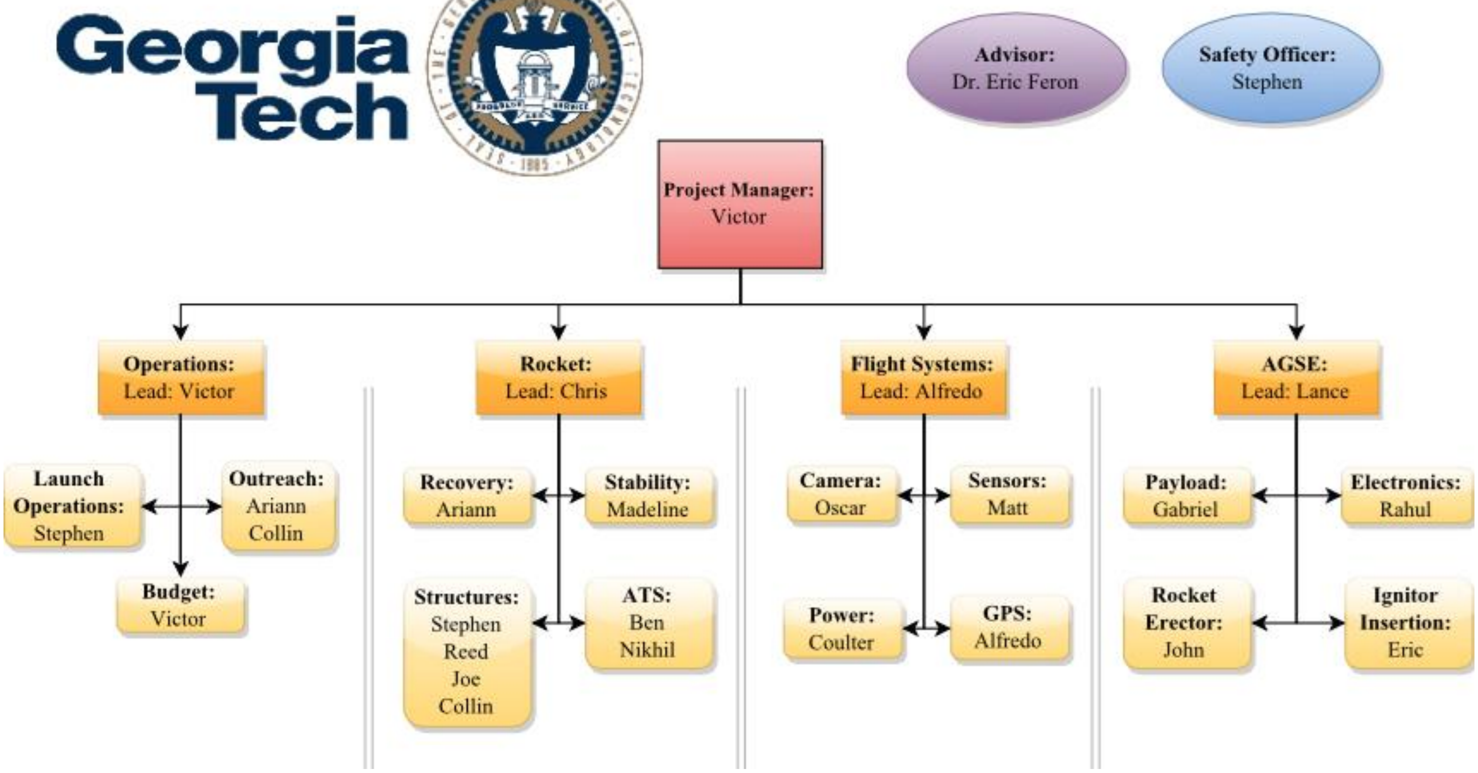


Figure 1: Team Breakdown Structure

1.3. Facilities and Equipment

This section will detail and list all applicable facilities, equipment, and software that Team A.R.E.S. will have access to in the design and testing of Project Hermes.

1.3.1. Facilities

For manufacturing and fabrication of the rocket system and AGSE system, the Georgia Tech Invention Studio has tremendous capabilities for enabling a NASA SL team to construct innovative and creative projects. Team A.R.E.S. will have access to the Invention Studio from 10AM-5PM, Monday through Friday. These facilities will be useful for the team to build structural and electrical components. Under supervision of a University Lab Instructor (ULI), team members will be able to learn how to operate these:

- Laser Cutter
- CNC Mill & Lathe
- Water Jet Cutter
- Mills, Lathes, & Drill Presses
- Basic Power Tools
- Basic Hand Tools
- Oscilloscope
- Soldering Station
- Multimeter
- LCR Meter
- 3D Printers

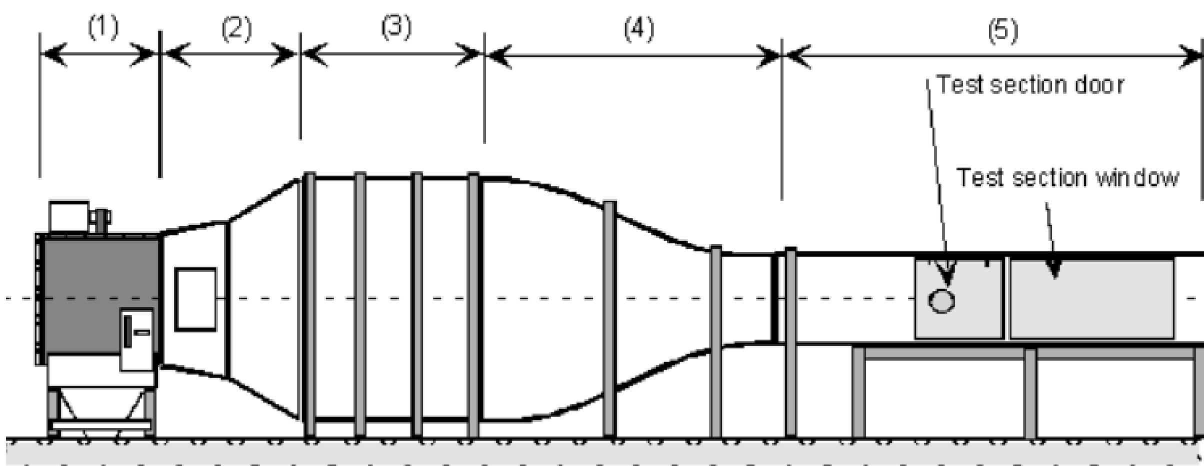


Figure 2: Open Return, Low Speed Aerocontrols Wind Tunnel Schematic

The Georgia Tech campus is equipped with an open-return, Low Speed Aerocontrols Wind Tunnel (Figure 2), which will be available for use pending graduate student supervision from 9AM-6PM, Monday through Friday. This will enable Team A.R.E.S. to learn the aerodynamic characteristics of their rocket, and understand how to optimize parameters for the desired performance. The wind tunnel comes equipped with a 42” x 42” x 42” test section, Barocel pressure transducers, strain gage force-moment balance, high speed, multi-channel signal filtering, and computer data acquisition systems. Although the wind tunnel has only a maximum mean velocity of 78 ft/s, useful data can still be gathered through the use of flow similarity transformations. Telepresence Systems (CTS 1000), as well as POLYCOM HDX video teleconferencing capabilities through the Georgia Tech Vertically Integrated Projects (VIP) program, with a T3 broadband connection. Team A.R.E.S. will maintain a dedicated website, and will include project documentation, current team information, team pictures, and other pertinent information. Compliance with all facets of the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194) Subpart B-Technical Standards will be implemented by Team A.R.E.S.

1.3.2. Software

Georgia Tech allows 24/7 access to all team members standard of industry-standard software suites. A number of engineering software packages are available on personal and campus computers, such as:

• SolidWorks, AutoCAD (FEA and CAD)

• OpenRocket

• Ansys Fluent(CFD)

• NX7, Abaqus(FEA)

• MATLAB, Simulink

• Autocoders(control algorithms)

• COSMOL(Multi-physics Modeling and Simulation)

• JMP(Data Analysis/Statistical Software)

These software capabilities are enhanced with standard software packages, such as various internet access capabilities, and Microsoft Office 2010.

2. Safety

2.1. Mission Assurance

The goal of the Safety Team will be to develop and implement a safety plan that will encompass all aspects of the team's designs, construction and launch techniques. Technical knowledge and experience of our Graduate students, faculty and NAR mentors will be utilized. The safety plan will include sections on how to use Personal Protective Equipment (PPE) when operating with possibly hazardous equipment. All NAR/TRA personnel involved with Team A.R.E.S. will enforce compliance with NAR high power safety code regarding the rocket operation, rocket flight, rocket materials, and launch site activities.

2.2. Material Handling

The Safety Team will brief all team members on the procedure of how to properly handle and store hazardous materials. Some of the materials requiring specific safety protocols and procedures include: ammonium perchlorate composite propellant, rocket motor igniters, and black powder. The Safety Brief will include knowledge and close proximity access to Material Safety Data Sheets (MSDS) for all potentially hazardous substances. The safety plan will ensure use of proper Personal Protective Equipment when handling hazardous materials.

2.3. Vehicle Safety

Vehicle safety will be ensured through repeated testing. Ground testing will be performed to ensure the reliability of the team's design and construction efforts. Various methods of loading, including impulsive- representative of parachute deployment- as well as static loading-representing constant thrust- will be performed multiple times to repeatability and veracity of the data gathered for analysis. Wind tunnel testing will be able to evaluate the effects of aerodynamics on the design. The experimental data will be used to validate the theoretical models (FEA, CFD) to ensure safe operation of the rocket. The results of this experimental testing will be used to create a Pre-Flight Inspection Checklist of rocket system components.

2.4. Purchase, Shipping, Storing, and Transporting of Rocket Motors

Currently, there are no members of Team A.R.E.S. who currently hold a Low Explosives User Permit (LEUP). As a result, all rocket motors will be acquired from vendors at the launches we attend. Furthermore, for the Competition launch site in April 2016, Team A.R.E.S. will plan to order motors in advance from a specialized vendor.

2.5. Launch Site Safety

The Safety Officer (SO) will create a safety checklist and brief the team of safety requirements imposed therein. The SO will be in charge of ensuring all the requirements on the safety checklist are met. The safety checklist and briefing will include details of compliance with federal, state, and local laws regarding motor handling and unmanned rocket launches. Specifically, Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, NFPA1127 "Code for High Power Rocket Motors." Additionally, the SO will provide a pre-launch safety briefing covering all the specific hazards for the launch, which will include the safety rules in place by the local NAR section. Launches will only occur at NAR sponsored launch events at high power fields.

2.6. High Power Rocket Certifications

Currently, no members of Team A.R.E.S. have any NAR or TRA certifications. The certification process is designed to allow the candidate to demonstrate their understanding of the basic physics and safety guidelines that govern the use of high power rockets. Level 2 certification requires one to construct, fly, and recover a high power rocket in a condition that it can be immediately flown again, as well as pass a written exam that test the knowledge of rocket aerodynamics and safety.

3. Technical Design – Launch Vehicle

3.1. Launch Vehicle Requirements & Overview

Table 2: Launch Vehicle Requirements

Requirement	*Design Feature to Satisfy Requirement*
The vehicle will deliver the payload at its peak altitude of 5,280 feet above ground level (AGL).	Payload bay located inside the rocket; payload secured once inside
Vehicle altimeter will report an apogee altitude of most nearly 5,280 feet AGL.	Low-mounted electric-controlled fins will be extended and retracted in reaction to altimeter readings to control drag and limit altitude.
Launch vehicle will be designed to be recoverable and reusable within the day of initial launch.	Vehicle will be constructed of (carbon fiber or fiberglass) to resist fractures and ensure stability. Motor will...
Vehicle will be prepared within 2 hours and will be able to maintain launch-ready position for at least 1 hour.	Simple-to-assemble Design
The launch vehicle shall have a maximum of four (4) independent sections.	Three (3) sections include: nosecone, payload, motor
The vehicle will be limited to a single stage, solid motor propulsion system, delivering an impulse of no more than 5,120 Newton-seconds.	Design using one motor
Team must launch and recover both a subscale and full scale model prior to each CDR and FRR respectively.	Efficient Recovery System
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.	Efficient Recovery System
At landing, the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	Maximization of parachute size.
The recovery system will contain redundant altimeters, each with their own power supply and	Have an easy access switch

dedicated arming switch located on the exterior of the rocket airframe	
Each detachable section of the vehicle and payload must contain an electronic tracking device and continue transmission to the ground throughout flight and landing.	Efficient and tested GPS system

3.2. General Vehicle Dimensions and Mass Breakdown

The general vehicle layout is shown in Figure 3. As shown, the launch vehicle will consist of three physically independent sections that are connected with smaller diameter tube segments which are attached to the intermediate section. The design, from aft to front, include the booster and control section, avionics section, and the payload retention section. The components distributed on the inside are labeled in Figure 3, with the exception of relatively smaller components such as bulkheads, U-bolts, and shock-cords.

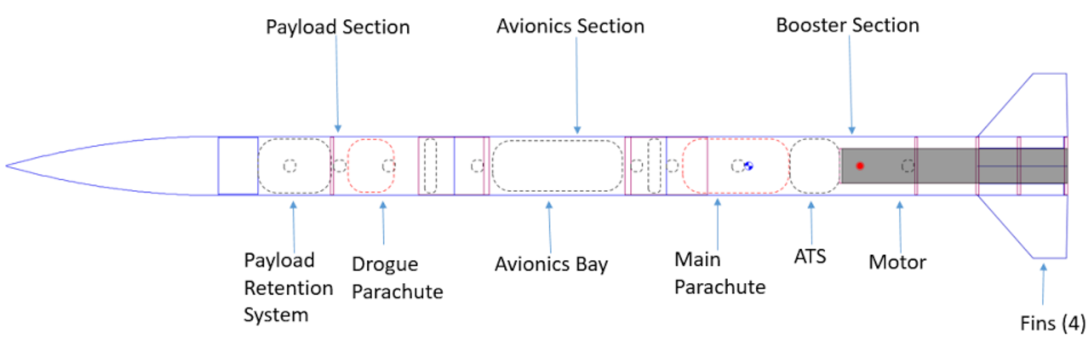


Figure 3: General Layout of Rocket Components

The dimensions of the launch vehicle were specifically determined in order to be able to achieve the mission requirements detailed in the previous section, and also to accommodate the various systems efficiently and effectively, while still maintaining a high stability margin to ensure the safety of the operation. The specific dimensions are as follows in Table 3.

Table 3: Overall Dimensions

Parameter	Value
Overall Length	90 in
Booster Section	34 in
Avionics Section	18 in
Payload Section	20 in
Body Diameter	5 in
Nose Cone Length	18 in
Fin Height	5.3 in
Fin Root Chord	7.5 in
Fin tip Chord	3.1 in

The dimensions for the systems that are categorized as inner components of the launch system are detailed below.

Table 4: Internal Component Dimensions

Parameter	Value
Payload Bay	6.2 in
Avionics Bay	11 in
ATS	4.2 in
Motor Casing	20.4 in
Couplers	7 in
Bulkheads & Centering Rings (Thickness)	0.25 in

The clipped delta fin planform is an ideal shape for the fins. The fins are large enough to stabilize all rockets adequately if certain design formulas are followed. The clipped delta fin also creates little drag. Once the general shape of the fins is produced, it must be sanded down to create a symmetrical airfoil. This will reduce drag due to the fact that the most efficient part of the fins is at the tips. At the tips, airflow is smooth because it is outside the turbulent region caused by air flowing over the nose cone.

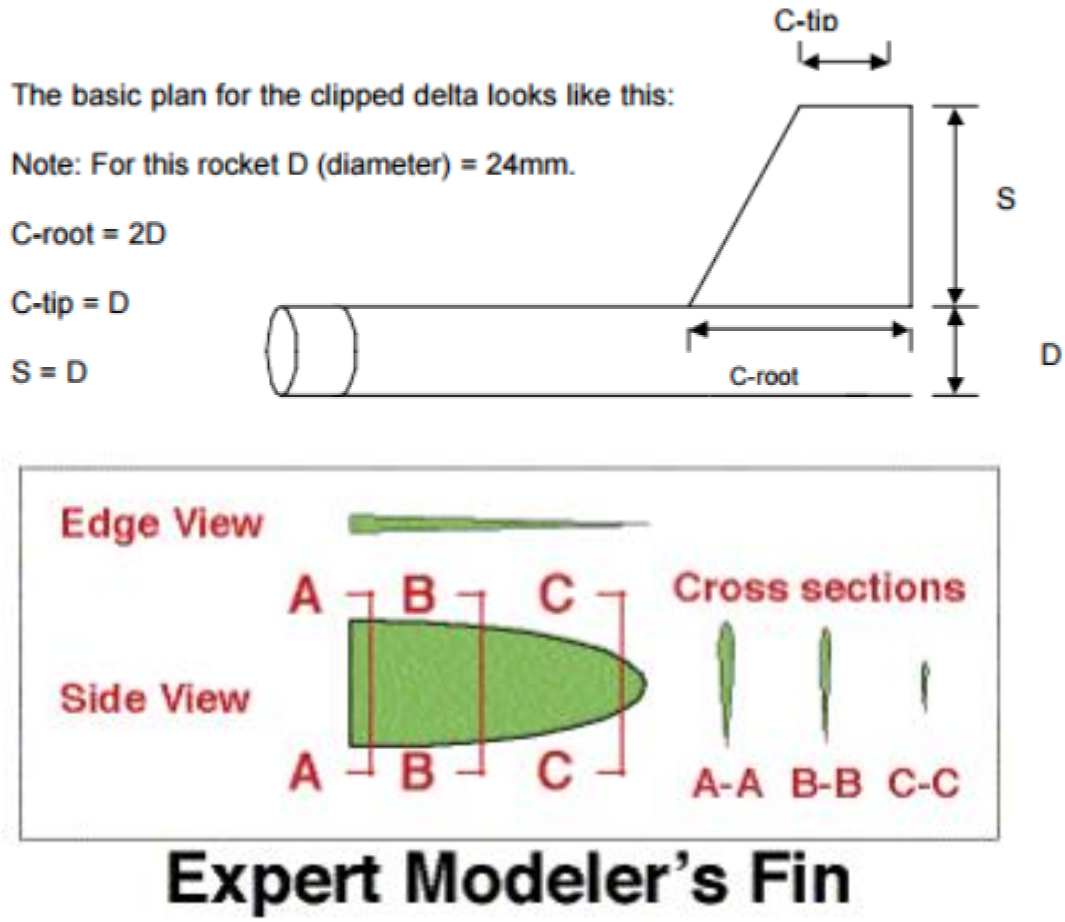


Figure 4: Ideal Fin Property Guidelines

A configuration of four such fins, as opposed to three, is proposed to increase stability. The driving factor behind the desire for increased stability, afforded by a four fin arrangement, is the decision to implement a variable Apogee Targeting System which may lead to an increasingly complex tendency toward instability. This choice is estimated to increase stability by slightly over 50%. Other benefits include increased design symmetry and the associated manufacturing costs, and a reduction in material required per fin, allowing for lower cost replacement fins. The Figure below, extracted directly from OpenRocket, depicts the estimated locations of the center of gravity and the center of pressure, and based on this information it derives the stability of 1.85 cal. The typical values utilized by high powered rocketry enthusiasts range anywhere between 2 cal and 1 cal. Evidently this value is on the high end of the spectrum, which gives us a very high stability so that the disturbances and separated flow created as a result of the ATS don't present a risk to the rocket's flight direction and consequently to the launch vehicle's safety.

Figure 5: Stability Profile

To improve the process by which fins may be replaced in the event of fin failure, particularly during the recovery and landing phase of a rocket test launch, it is proposed to design circular brackets to be attached around the exterior of the engine housing tube to which the fins may be inserted and secured with lightweight metallic hardware. The circular brackets will have small tabs that extend from the motor housing towards the exterior of the rocket about half an inch, and on such tabs there will be small perforations through which screws can be inserted and secured with nuts. The fins will have small perforations at locations that match those of the circular bracket's perforations, and will be reinforced with a small amount of epoxy coating to reduce the possibility of delamination of the system and to ensure that the stress generated at these locations won't create a crack along the fiberglass fins that would compromise the structural integrity and safety of the rocket.

The mass of the launch vehicle is depicted in Figure 6. The different categories are defined by what purpose they serve in the launch vehicle's performance. Combined, all the components of the vehicle have a total mass of 8930 grams.

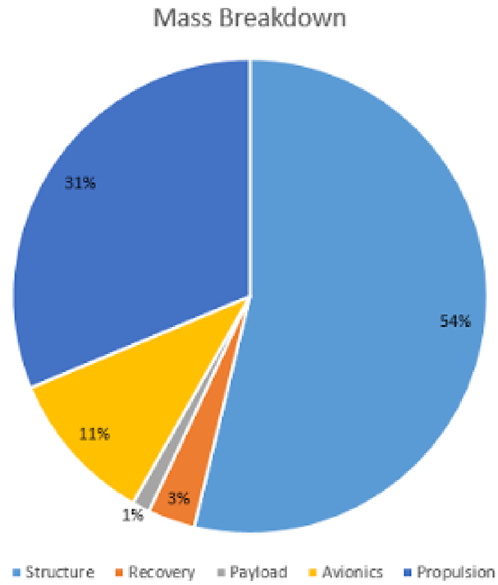


Figure 6: Mass Breakdown

3.3. Material Selection and Justification

The airframe of the rocket, including the nose cone and body tube, will be made with G10 fiberglass. Fiberglass was chosen for this competition mainly for its reliability in the last competition and because it is much more cost effective than carbon fiber. Though carbon fiber has a much higher tensile strength and is more rigid, fiberglass has a higher ultimate breaking point and is more ductile. This means that carbon fiber will crack easily, while fiberglass allows for more flexibility and multiple uses. Other benefits of using fiberglass over carbon fiber for the rocket include the material being lighter, having a higher strength-to-weight ratio, and having a weather-resistant finish, which will help greatly in random weather occurrences. The fiberglass will be bought locally and commercially. A design possibility presented during the preliminary design discussions was utilizing regular cardboard body tubes which provide the general shape and length while maintaining a very low mass profile, and furthermore coating the cardboard with a carbon fiber "sock" which would be adhered to the surface using epoxy resin. The drawbacks from this option were the fact that the mass of the epoxy that would be utilized is very unpredictable and reduces the ability to predetermine what the total mass of the rocket and thus leaves some of the stability characteristics undetermined, which would present a safety risk. Given this uncertainty, it is also possible that the amount of epoxy used would surpass the difference in weight of the fiberglass body tubes; thus it would be much more inefficient and expensive to follow this approach of manufacturing.

The fins can be made with either balsa wood or ULTEM 9085. Balsa wood weighs approximately 8 to 14 pounds per cubic foot, depending on the density of the wood. Balsa wood would have to be handmade each time the rocket is launched. One problem that seems to occur is that the Balsa wood fins would break when the rocket lands. To combat the problem, other materials such as ULTEM 9085 can be utilized. ULTEM 9085 is a high-performance thermoplastic suited for parts that need superior durability. ULTEM is FST rated and one of the only 3D printing plastics certified for aircraft components. A group of students from the University of Arizona successfully launched a rocket with fins that were 3D printed using ULTEM 9085. The UoA students worked with a 3D printing company, Solid Concepts, to help with the cost of ULTEM 9085.

As mentioned above, the nose cone would be constructed of fiberglass; the strength of the material is satisfactory for the demands of the rocket. According to flight simulation data provided by our Open Rocket model, as well as the efficiency measurement chart below, it was determined that the Von Karman nose cone shape would best serve the rocket. This decision was made in confidence given the fact that our rocket will not exceed Mach 1, and need only ascend to 1 mile in altitude.

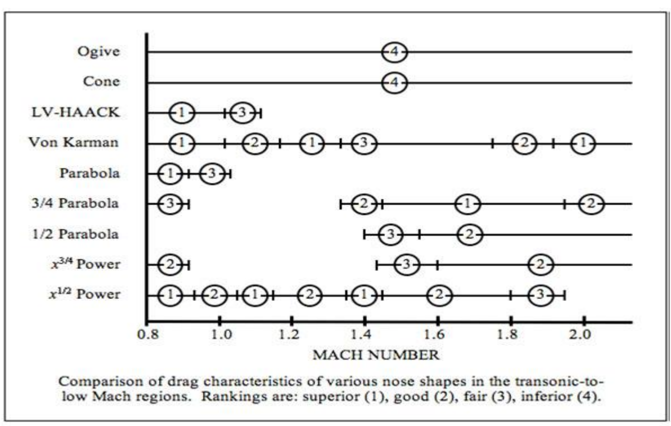


Figure 7: Drag Ranking for Various Nosecones

Balsa wood Properties Guide

Density	163 ± 10 kg/m³
Compressive Strength¤ low density medium density high density	4.7 MPa 12.1 MPa 19.5 MPa
Tensile Strength¤ low density medium density high density	7.6 MPa 19.9 MPa 32.2 MPa
Elastic Modulus - Compression **Elastic Modulus - Tension**	460 ± 71 MPa 1280 ± 450 MPa

¤ Low Density = 75 kg/m³ (0.0027 lb/in³); Medium Density = 150 kg/m³ (0.0054 lb/in³); High Density = 225 kg/m³ (0.0081 lb/in³)

Figure 8: Balsa Wood Property Guide

Laminated 1-ply custom balsa sheet price	
Thickness inches	Price per square foot
1/64	$60.00
1/32	$60.00
1/20	$60.00
1/16	$30.00
3/32	$30.00
1/8	$10.00
5/32	$10.00
3/16	$10.00
1/4	$5.63
5/16	$6.33
3/8	$7.03
1/2	$8.44
5/8	$9.84
3/4	$11.25
1	$14.06
2	$25.31
3	$36.56

Figure 9: Pricing for Balsa Sheet

ULTEM 9085 Properties Guide

Mechanical Properties[1]	Test Method	English		Metric	
		XZ Orientation	ZX Orientation	XZ Orientation	ZX Orientation
Tensile Strength, Yield (Type 1, 0.125", 0.2"/min)	ASTM D638	6,800 psi	4,800 psi	47 MPa	33 MPa
Tensile Strength, Ultimate (Type 1, 0.125", 0.2"/min)	ASTM D638	9,950 psi	6,100 psi	69 MPa	42 MPa
Tensile Modulus (Type 1, 0.125", 0.2"/min)	ASTM D638	312,000 psi	329,000 psi	2,150 MPa	2,270 MPa
Tensile Elongation at Break (Type 1, 0.125", 0.2"/min)	ASTM D638	5.8%	2.2%	5.8%	2.2%
Tensile Elongation at Yield (Type 1, 0.125", 0.2"/min)	ASTM D638	2.2%	1.7%	2.2%	1.7%
Flexural Strength (Method 1, 0.05"/min)	ASTM D790	16,200 psi	9,900 psi	112 MPa	68 MPa
Flexural Modulus (Method 1, 0.05"/min)	ASTM D790	331,000 psi	297,000 psi	2,300 MPa	2,050 MPa
Flexural Strain at Break (Method 1, 0.05"/min)	ASTM D790	No break	3.7%	No break	3.7%
IZOD Impact, notched (Method A, 23°C)	ASTM D256	2.2 ft-lb/in	0.9 ft-lb/in	120 J/m	48 J/m
IZOD Impact, un-notched (Method A, 23°C)	ASTM D256	14.6 ft-lb/in	3.2 ft-lb/in	781 J/m	172 J/m
Compressive Strength, Yield (Method 1, 0.05"/min)	ASTM D695	14,500 psi	12,700 psi	100 MPa	87 MPa
Compressive Strength, Ultimate (Method 1, 0.05"/min)	ASTM D695	26,200 psi	13,100 psi	181 MPa	90 MPa
Compressive Modulus (Method 1, 0.05"/min)	ASTM D695	1,030,000 psi	251,000 psi	7,012 MPa	1,731 MPa

Price: $685.00

Manufacturer: Stratasys, Inc.
MFG. PN: 312-20000

ULTEM 9085 Filament Canister for FORTUS 400mc & 900mc

- FST (flame, smoke, toxicity) certified thermoplastic
- High heat and chemical resistance; highest tensile and flexural strenght
- Ideal for commerical transportation applications in airplanes, buses, trains, boats, etc.

Product comes in Beige or Black

Figure 10: ULTEM 9085 Properties

3.4. Apogee Targeting System

The rocket will include the Apogee Targeting System (ATS), a variable drag control system to improve the accuracy upon reaching the target apogee. The ATS will coincide with a flat plate air brake system which includes an array of pins near the fin section and horizontally extending and retracting tabs out of the body of the rocket. The extending distance will be determined by the flight computer to create additional drag. The flight computer will contain pre-calculated scenarios in the onboard memory bank to be compared with the actual rocket values of velocity and apogee altitude after motor burnout. The aerodynamic effects caused by the airbrake system will be recorded and analyzed prior to launch. The wind tunnel data in combination with validated CFD results will construct the rocket guidance database for the flight computer.

The airbrake system will be located as far down the rocket body as possible, as the pins create turbulent air flow. The location will be nine inches above the bottom to avoid disrupting the airflow over the rocket fins in the wake of the pins. Furthermore, the pin and flat plate system was chosen as it is compact and will not utilize much vertical space inside the rocket body. The airbrake system will include a pin hub, which rotates to extend and retract the tabs, a drive shaft to transfer rotation from a servo motor. Only one servo motor located above the engine block will be used to prevent aerodynamic asymmetry.

The airbrake fins in the ATS will consist of a four fin system located in the inner tube housings in between the four main rocket fins. The design of the airbrake fins are a modification of the tabs used in the last competition with more sanded edges to decrease unsteady flow before the rocket fin section which leads to a more aerodynamic efficiency than a flat plate. Additionally, the shape has been chosen so as to provide maximum surface area for drag force but at the same time allow for the fin system to operate smoothly within the inner rocket tube without any interference with the rocket fin housings and inner walls of the tube.

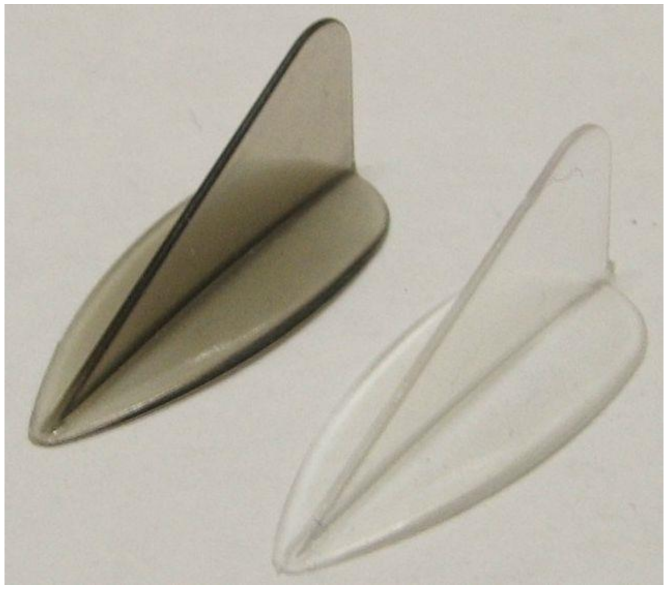
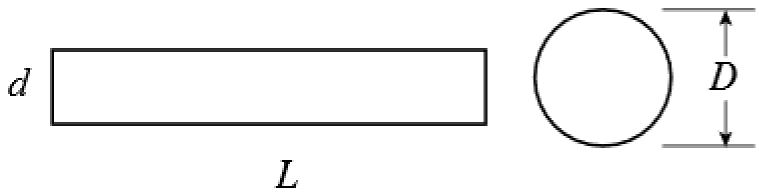


Figure 11: Concept Airbrake Fin Design with sanded edges for improved drag and maximum usable surface area

3.5. Recovery System & Vehicle Performance

The main parachute will be housed in the avionics section, while the drogue parachute will be located just below the avionics section (using the nosecone as reference location). All chutes are made of rip-stop nylon to support the weight of the rocket, and will be protected by insulator material to prevent the ignition of the nylon due to the explosive charges that will separate the different rocket sections during descent deployed from the blasting caps that are attached to the bulkheads which seal the avionics bay from the rest of the launch vehicle's compartments. The parachutes are secured to the rocket with the assistance of shock-cord that is attached to U-bolts secured to the bulkheads/centering rings insulating each section of the rocket from the pressurization. Sizing for the drogue chute was done using the formulae shown in Figure 12. L is defined as the length of the body tube and d, the diameter. From this, it was found that a 24" diameter drogue parachute would be most effective. An 80'' main parachute was used in order to support the weight of the rocket. Parachutes were also sized such that the impact kinetic energy of each independent section is below the 75 ft-lbf limit, listed in Table 6.



$$Area = L\,d \qquad Area = \frac{\pi}{4}D^2 \qquad D = \sqrt{\frac{4\,L\,d}{\pi}}$$

Figure 12: Parachute Sizing Formulae

Table 5: Parachute Overview

Parachute	Description	Cd	Carrying Capacity	Cost
Main	CERT-3 Large 80"	1.6	**16.2-35lb**	$27.50
Drogue	CERT-3 Drogue 24"	1.6	**2.2lb**	$145.00

Table 6: Average Kinetic Energy for Launch Vehicle Sections

Section	*Impact KE (lbf-ft)*
Booster	30.97
Avionics	16.96
Upper Coupler	3.79
Nose Cone	7.0

Flight simulations were conducted with OpenRocket software. Figure 13 shows the predicted, mean ascent, and descent profile of the rocket (altitude, vertical velocity, and acceleration). Expected launch conditions in Huntsville, Alabama for April were included in Table 7.

Table 7: Predicted Conditions in Huntsville, AL

Conditions	Values
Wind speed	13.5ft/s
Temperature	60.8 °F
Latitude	34° N
Pressure	1013 mbar

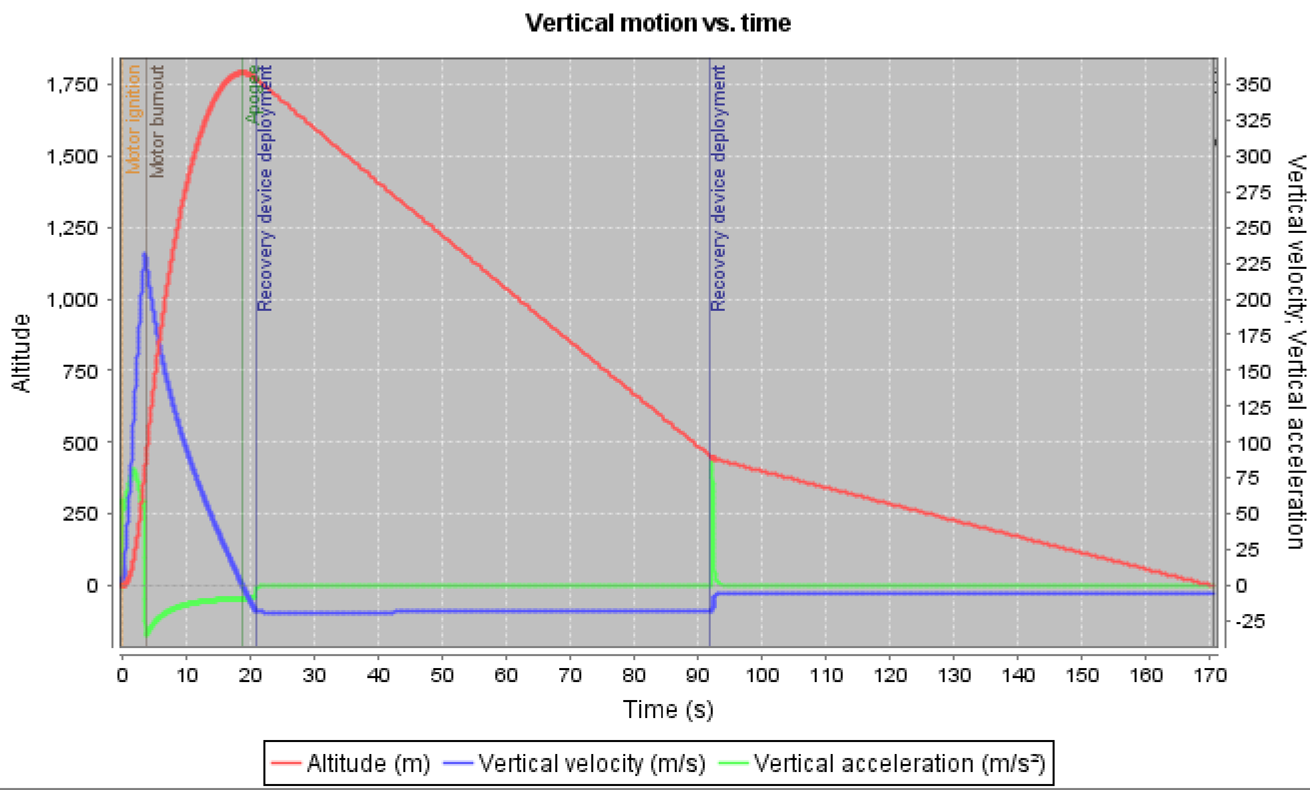


Figure 13: Flight Profile Altitude vs Time

After burnout the apogee targeting system will adjust the drag on the rocket. Further experimentation and simulation will be carried out to quantify the effect of this system on apogee. Figure 13 demonstrates that the rocket reaches apogee at approximates 19s where the apogee projected to be 5,885.83 ft (without assistance from the ATS). At apogee, the ejection charges for the drogue parachute will activate. Deployment of the main parachute will occur between 1500 and 1000 ft AGL to further decelerate the rocket so that the impact force is below 75 ft-lbf and still prevent the considerable amount of horizontal displacement that occurs as a result of wind gusts and the general direction of the wind flow.

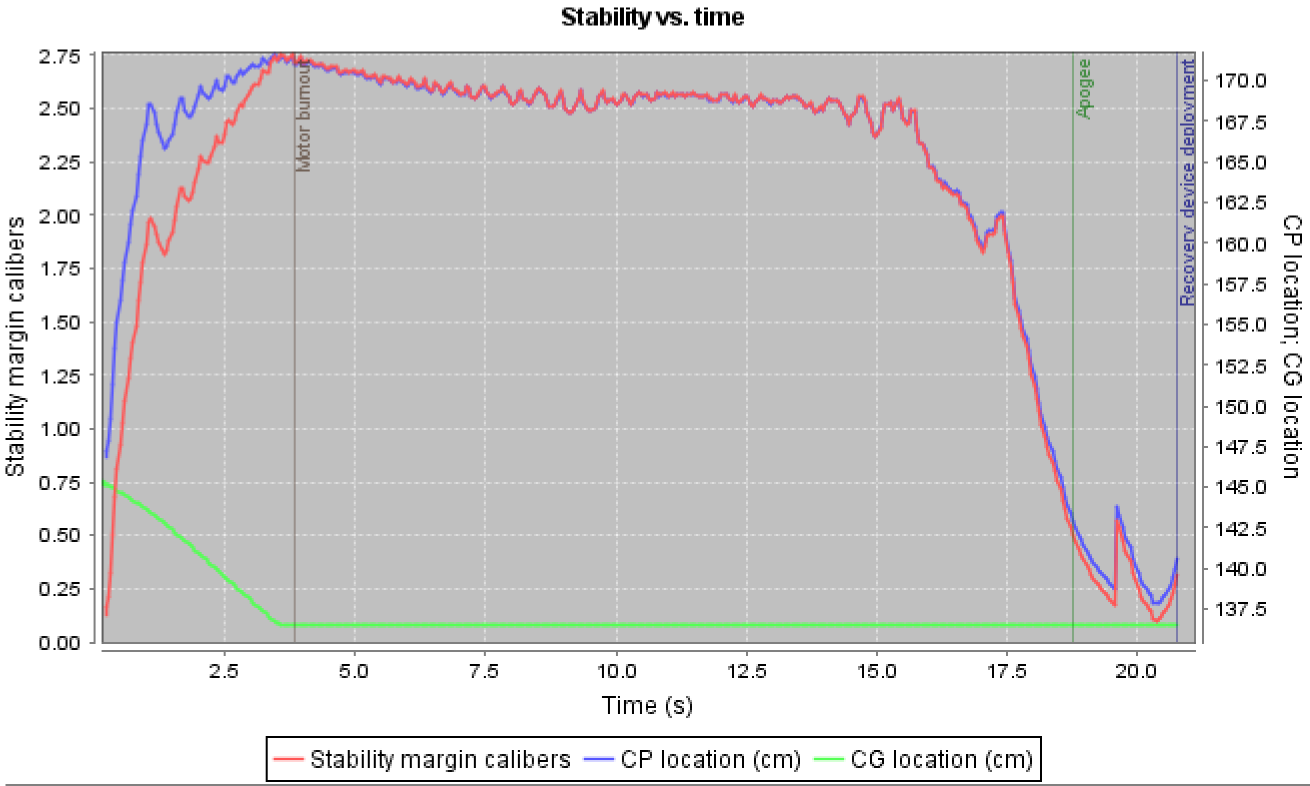


Figure 14: Stability Analysis

Stability analysis was performed to ensure a safe flight profile as shown in Figure 14. The stability margin of our rocket during most of the flight is 2.5 calibers, where one caliber is the maximum body diameter of the rocket. This is close to the general rule that the CP should be 1-2 calibers aft of the CG. Motor burnout will occur at approximately T+3.75s.

Ultimately, the launch vehicle's mission is to attain an apogee of 1 mile (5,280 feet / 1,610 meters), as precisely as possible. Several performance parameters are implicit in this objective: most importantly, a controlled ascent and a survivable descent velocity (such that the ground impact does not compromise any component's structural integrity). Given the Student Launch competition's mission requirements, the success of the launch vehicle's performance can be quantified by the difference between its intended apogee and its real, experimentally measured apogee. Much of this final apogee will be determined by thrust, which will be determined by the motor's performance, and will be determined by which motor is selected for the launch. Thus, careful analysis during motor selection was essential.

In the motor selection process, it was essential to keep in mind: performance and affordability. In terms of affordability, since the team was starting out with a limited budget, the logical path to take was an economically conscious one; the team could not afford to ignore cost-effectiveness. In terms of performance, the team actually sought a motor that (if left alone) would overshoot the mission requirement of a 1-mile apogee. This intentional overshooting owed itself to the fact that the vehicle's Apogee Targeting System will increase the drag force on the vehicle, thus acting directly against the motor's performance, and allowing the vehicle to reach its intended apogee far more accurately.

With those two factors in mind, OpenRocket simulations led the team to the conclusion that the desirable total impulse delivered by the motor (for an approximate apogee of a 1 mile) would be 2,750 Newton-seconds. The closest commercial motor to this performance value is the Cesaroni L910, which also happened to meet the two needed constraints: a diameter of 75mm, and an expected performance slightly above what is needed for a 1-mile apogee. (For reference, the standalone L910 delivers a total impulse of 2,869 Newton-seconds, which would ascend a rocket without an ATS to an altitude of 1.15 miles.)

According to its website, Bay Area Rocketry sells the Cesaroni L910 propellant kit for $133. Since a Cesaroni 75mm casing can have a price in excess of $400, the selected motor seems to have both saved the team money and met all appropriate performance requirements.

3.6. Major Technical Challenges and Solutions

Table 8: Major Technical Challenges and Solutions for Launch Vehicle

Major Technical Challenges	*Solutions*
Full Software Implementation for the ATS	Full system test prior to every launch
Successful ATS Deployment	Ground testing & Wind tunnel testing

Stability Margin Consistency	Proper measurements of mass distribution and center of pressure. Ground testing of ATS flow discrepancies
Structurally Sound Design	Structural testing before full assembly
Full Recovery of Launch Vehicle	Effective recovery system design
Efficient Manufacturing	Proper training of manufacturing techniques

4. Technical Design – AGSE

4.1. AGSE Overview

The Autonomous Ground Support Equipment (AGSE) will have a 10 ft length, 4 ft width and 10 ft height at full extension. The total weight will be 130 lbs. It will feature a robotic arm that will pick up the payload and secure it in the rocket. The rocket will be supported by a rail that will be able to raise the rocket 85 degrees off the horizontal axis. The rocket's motor will be ignited via an electronic match inserted by the AGSE.

4.2. AGSE Requirements

Table 9: AGSE Requirements

Requirements	Design Feature	Verification
Under 150 lb	Lightweight aluminum frame	Scale
No more than 12 ft length, 12 ft height, 10 ft width	Compact placement of various mechanisms	Measuring tool
Operate autonomously	Starts with one switch	Trial runs
Master switch to start all procedures	Appropriate wiring & design	Trial runs
Pause switch that will halt all procedures temporarily	Appropriate wiring & design	Trial runs
Capture and contain the payload, without gravity-assist	Robotic arm and snap locks inside payload bay	Individual testing
Erect the rocket to 5 degrees off the vertical	DC motorized actuators underneath the rocket rail	Individual testing

Insertion of the motor igniter	Rack system beneath rocket motor	Individual testing
Payload must be placed 12 in. away	Robotic arm reaches off of AGSE, to 12 in.	Individual testing
Payload is correct size and weight	The payload will be 0.75 in. diameter and 4.75 in length, made of PVC pipe. It will weight 4 oz, and be capped with domed PVC end caps	Inspection

4.3. AGSE Design

4.3.1. Payload Recovery/Capture

A robotic arm will be used to pick up the payload and secure it in the payload bay in the rocket. The arm will have 4 joints. The payload bay will be just below the nose cone of the rocket and accessible through a door on the side of the rocket. The payload will be locked in place by two snap locks, shown in Figure 15 to prevent it from becoming dislodged during flight. After the payload is secured, the robotic arm closes the door which is locked in place with magnets. Once the door is closed, the robotic arm will move out of the way to let the rocket rise.

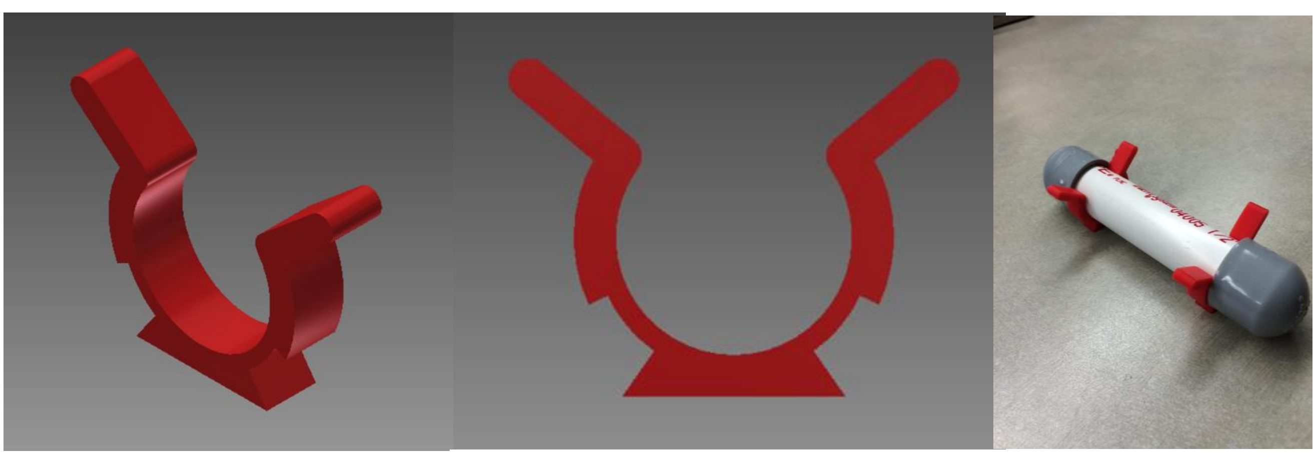


Figure 15: Proposed Payload Holding

4.3.2. Rocket Erector Mechanism (REM)

The rocket will be raised into launch position via the Rocket Erection Mechanism (REM). The REM will raise the rocket 85 degrees off the horizontal axis. It will do this by using a linear motorized actuator (Figure 16) to lift the structure holding the rocket. The actuator will be placed towards the base of the rocket to allow the rocket to raise to 85 degrees with less actuator height. The REM will be equipped with an Erection Step Lock (ESL) for safety. As the actuator raises the rocket, the ESL will frequently lock the rocket into the current height using the weight of the rocket. It will prevent the rocket from falling back down towards the horizontal axis while not inhibiting the progression towards the vertical axis.

Figure 16: Linear Actuator

Table 10: Linear Actuator Overview

Actuator Specifications	
Movement	Linear
Technology	Motorized, Stepper
Max Force	3000 N
Max Velocity	250 mm/s

4.3.3. Motor Ignition System

Once the rocket is raised, the AGSE activates the Motor Ignition System (MIS). This mechanical system is located exactly below the rocket and is also attached to the support that raises the rocket. The MIS is mainly composed by a rack and gear system. The rack, pointed to the bottom of rocket, is moved with a rotating gear, thus raising the platform up and inserting the igniter into the rocket's motor. Having completed this stage, the rocket is ready to be launched.

4.4. General Dimensions

The AGSE will be approximately 10 ft by 4 ft at the starting position. The RPDS will be located 15 inches below the rocket. The REM will be located underneath the rocket. The MIS will be placed behind the rocket.

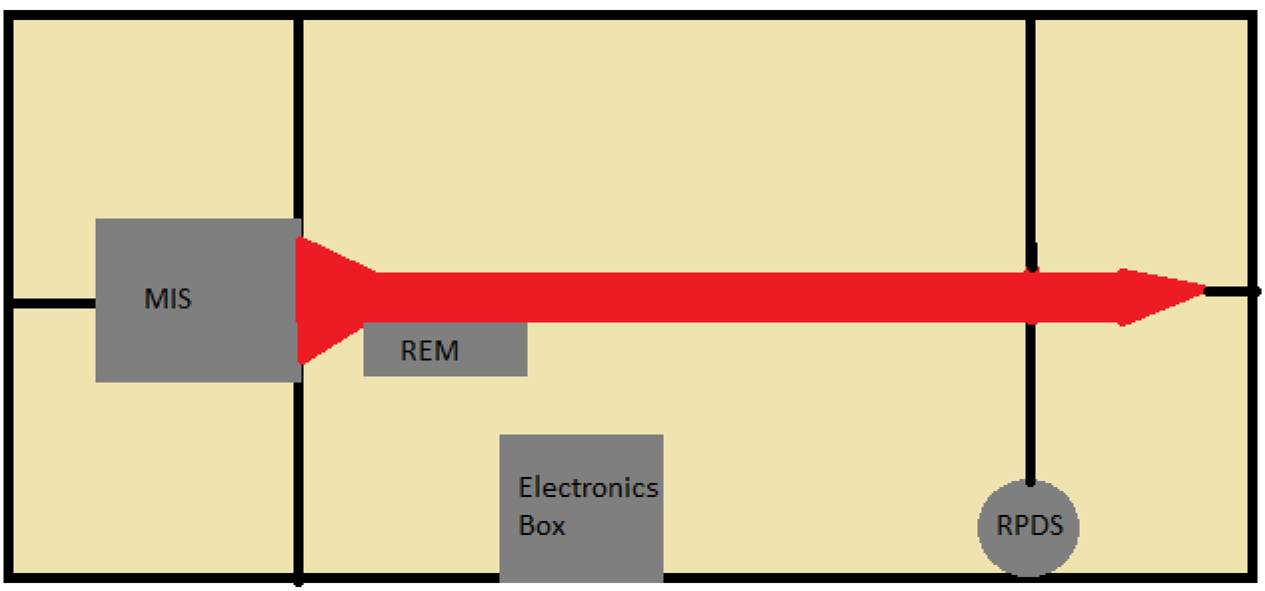


Figure 17: General Layout of AGSE Systems

4.5. Electronics

For the electronics, an Arduino Uno-R3 will be used for the motors because this is the most efficient Arduino that also supplies the necessary 5V to the servo motors. The Arduino will power the robotic arm, the REM, and the MIS, in that order. The Arduino-Uno has 14 digital inputs/outputs, more than enough to satisfy the control requirements of our proposed systems. All the wiring and electronics will be housed in a large blast-proof box for organization and safety purposes. Also, this will keep all the circuitry from being damaged from debris.

Board	*System Voltage*	*Clock Speed*	*Digital I/O*	*Analog I/O*	*Microcontroller*	*Cost ($)*
Arduino Uno-D3	5V	16MHz	14	6	ATmega328P	29.95

Figure 18: Arduino Properties

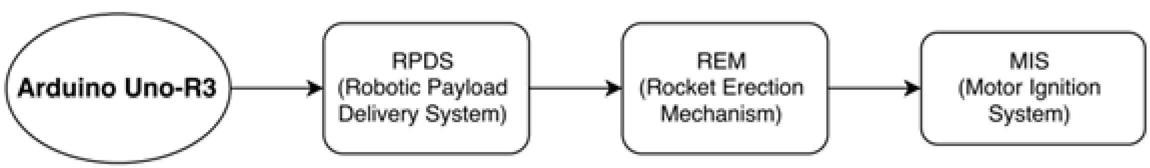


Figure 19: Arduino Diagram

4.6. Major Technical Challenges and Solutions

Table 11: Technical Challenges and Solutions

Challenge	Solution
Accurately grabbing the payload	Trial runs and mechanical movement optimization
Raising the rocket in a stable manner	Optimize the ESL and REM mechanism
Manufacturing parts needed	Use of standardized parts and simple designs
Organization of components	All electronics will be organized and housed together
Circuitry failure/short circuit	Predetermine allotted voltage/power for each component

Completing all tasks in 10 minutes	Pre Planning and rehearsing tasks

5. Avionics

5.1. Avionics Overview

Various sensors will be used to feed information to the controller in order to store the information, and use it to ensure it will reach apogee. The heart of the avionics will be the microcontroller. We will use the Arduino Uno. The sensors will communicate serially with the Arduino. The Arduino will run computations to store correct values and use those values to make flight adjustments. The operation of the avionics will be separated into two sections: telemetry and recovery. The following table shows how the sensors will be used:

Table 12: Avionics Requirements

Requirement Number	Requirement Definition
2.1	The launch vehicle shall stage the deployment of its recovery devices in the following order, drogue parachute, main parachute
2.2	Teams must perform a successful ground ejection test for both the drogue and main parachute
2.3	At landing, each independent section’s kinetic energy shall not exceed 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
2.6	A arming switch shall arm each altimeter, which is accessible from the exterior of the rocket airframe
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 transmit the position of the rocket

2.11	The recovery system will by shielded from magnetic waves and all onboard devices, and placed in separate compartments within the vehicle

5.2. Recovery

The recovery system will use two PerfectFlite miniAlt/WD (MAWD) altimeters, which collect flight data (altitude, temperature, and battery voltage) at a rate of 20 samples per second. One altimeter will be used as the main altimeter and the other will be used for redundancy purposes. The recovery system will be shielded from the GPS to avoid any interference and noise. Faraday shielding will be implemented using aluminum.

5.3. GPS

The GPS will be the telemetry system's most important sensor. We will use CookingHack's GPS module to gather information on position, speed, and altitude on Universal Time Coordinated. Additionally, the module runs on the National Marine Electronics Association (NMEA) protocol. The module will communicate with the Arduino serially as well as transmitting to a ground station.

5.4. Power

To maximize efficiency and conserve weight, an 11.1V, 1300 mAh lithium ion battery will be used to power an Arduino microcontroller with various outputs, the PerfectFlite miniAlt/WD (MAWD) altimeter, as well as the ATS braking system. Unless the power consumption of the braking system significantly exceeds expectations, this battery should easily be able to power the total avionics of the rocket for the allotted flight time (roughly 10 minutes). Additionally, the 11.1V voltage reading falls within the Arduino's desired range of nine to twelve volts and provides a higher voltage option for the braking system. Ideally we will have several batteries and be able to change them out with minimal time and disassembly in order to decrease the chances of power failure.

5.5. Camera Module

The HackHD camera model is the camera of choice for live video recording. The HackHD is a 1080p video recorder that can be easily integrated with any microcontroller. Which is perfectly suited for the avionics portion of the rocket because in case the Arduino Uno doesn't fit all future needs, the HackHD is compatible with any microcontrollers or simple sensors. The Hack HD is lightweight, easy to mount, and trigger to record. The camera itself records at 30 frames per second and only requires any power source that can supply 3.7 Volts and a push button. The HackHD also comes with micro SD card capability for video storing capabilities in order to store all flights. However, the most important capabilities are its composite video output and external audio input. The composite video output option allows the user to experience live video recording while the camera is storing the video on the micro SD card. The main purpose of the Camera Module is to provide visual confirmation of our new airbrake system is functioning properly.

6. Project Plan

6.1. Timeline

The Hermes project is driven by the design deadlines set forth by the NASA SL Program office. These deadlines are listed in Table 13.

Table 13: Important Milestones

Deadline	Date
Proposal	11 SEPT
Web Presence Established	23 OCT
PDR Documentation	6 NOV
PDR Teleconference	9-20 NOV
CDR Documentation	15 JAN
CDR Teleconference	19-29 JAN
FRR Documentation	14 MAR
FRR Teleconference	17-30 MAR
Competition	13-16 APR
PLAR Documentation	29 APR

To meet these deadlines, sufficient planning and hindsight must be employed. In addition to the deadlines set by the NASA SL program office, we have set our own preliminary deadlines, which can be found below:

Table 14: Important Dates

Sub team	Milestone	Date
Rocket	Finalized Parts List - Subscale	18 SEPT
	Internal Design Review	23 SEPT
	Finalized Parts List Full-scale	15 OCT
	Structural Testing – Fins, Bulkheads, Airbrakes	20 OCT
	Recovery System Testing	6 NOV
	Subscale & Full Scale Design Review	8 NOV
	Subscale Launch	16 NOV

	Full Scale Construction	20 NOV
	Recovery System Testing	3 DEC
	Airbrake Wind tunnel Testing	3 DEC
	Full Scale Design Review	5 JAN
	Full Scale Test Launch	15 FEB
	Competition	13-16 APR
AGSE	Finalized Design	18 SEPT
	Finalized Parts List	22 SEPT
	AGSE Design Review	6 OCT
	RDPS Construction	20 OCT
	REM Construction	21 OCT
	MIS Construction	21OCT
	Testing – RDPS, REM, MIS	22-30 OCT
	Full Frame Construction	8 NOV
	Entire Systems test with fully integrated electronics	18 JAN
	Test with Full Scale	15 FEB
	Competition	13 APR
Avionics	Finalized Parts List	20 SEPT
	Avionics Bay Construction - Subscale	18 OCT
	Finished Software - Airbrakes	16 NOV
	Testing - GPS, Altimeters, and sensors	21 NOV
	Avionics Bay Construction – Full Scale	12 FEB
	Full Scale Integration Testing	13 FEB
	Full Scale Launch	15 FEB
	Competition	13-16 APR
Operations	Secure All of Budget Funding	6 NOV
	Set up Outreach Events for the rest of the life cycle	20 NOV
	Secure transportation and housing for competition	20 JAN
	Competition	13-16 APR

6.2. Education Engagement

An important part of the 2015-2016 Georgia Tech Team A.R.E.S. mission is to build support in the Georgia Tech community. The USLI competition has been made into a highly integrated, class-based, team project through Georgia Tech's Vertically Integrated Program (VIP). The VIP Program unites undergraduate education and faculty research in a team-based context. VIP extends the academic design experience beyond a single semester, with students participating for up to three years. It provides the time and context to learn and practice professional skills, to make substantial contributions, and experience different roles on large multidisciplinary design/discovery teams. As part of this experience, the USLI team takes on the responsibility to contribute in turn to the community and promote scientific and engineering knowledge to high school students through educational outreach.

6.3. Community Support

In order to gain support from the community, Team A.R.E.S. will pursue advertising opportunities through on-campus events. This will allow the Team A.R.E.S. to gain exposure to local businesses and organizations that could help support the Team throughout the project. In addition to this, Team A.R.E.S will also manage and produce content for a YouTube channel and Facebook page in order to increase our reach to the community and promote STEM.

6.4. Educational Outreach

The goal of Georgia Tech's outreach program is to promote interest in the Science, Technology, Engineering, and Mathematics (STEM) fields. Team A.R.E.S. intends to conduct various outreach programs targeting middle school Students and Educators. Team A.R.E.S. will have an outreach request form on their webpage for Educators to request presentations or hands-on activities for their classroom. The team plans to particularly encourage requests from schools in disadvantaged areas of Atlanta, with the goal of encouraging students there to seek careers in STEM fields.

6.4.1. FIRST Lego League

FIRST Lego League is an engineering competition designed for middle school children in which they build and compete with an autonomous MINDSTORMS robot. Annual competitions are held centered on a theme exploring a real-world problem. Team A.R.E.S. plans to have a booth at the Georgia Tech FIRST Lego League Tournament, with the goal of illustrating how the skills and ideas utilized in the competition translate to real world applications; in particular, a rocket with autonomous capabilities. The team also plans to help judge the tournament.

6.4.2. Georgia Tech NSBE

The Georgia Tech chapter of the National Society of Black Engineers (NSBE) is one of the largest student-governed organizations at Georgia Tech. NSBE's mission is to increase the number of culturally responsible black engineers who excel academically, succeed professionally and positively impact the community. Team A.R.E.S. plans to engage the chapter throughout the year, coordinating with them on high-profile engineering outreach-related events to further both organizations' outreach goals.

6.5. Budget

In order to ensure we have a successful project, our team will be receiving donations in the form of financial donations or in material donations. Figure 20 and Table 15 illustrate the breakdown of the estimated budget across all of our sections.

Table 15: Cost Analysis

Section	Cost
Avionics	$1,300.00
AGSE	$2,500.00
Rocket	$1,200.00
Testing	$900.00
Travel	$1,000.00
Outreach	$800.00
Total Budget	$7,700.00

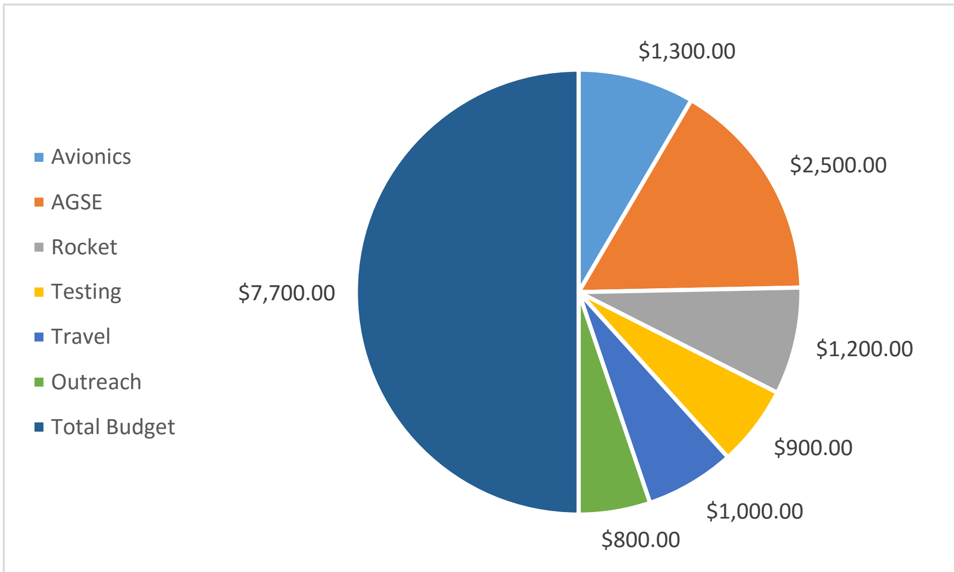


Figure 20: Cost Analysis

Currently our only source of funding is from the Georgia Space Grant Consortium that is providing the team with $2,200. The team is actively looking for more sponsorships in the Georgia Tech Community and local Atlanta Companies as well as corporate sponsors, SpaceX, Boeing, etc.

6.5.1. Funding Plan

In order to achieve the maximum goal of raising $10,000 for the rocket and the AGSE and other supports for 2014-2015 Student Launch competition, Team A.R.E.S. have sought sponsorships through three major channels

- Georgia Tech Alumni
- Companies that team members have interned
- Local Companies in Atlanta area

The fund raising actions were started with the connections that can be reached on campus. Operation sub-team talked to several professors separately and obtained the contact information of Georgia Tech Alumni working in the Aerospace field. At the same time, all Team A.R.E.S. members were working together to provide contact information of past companies. After compiling this information, the Outreach and Budget managers reached out to potential sponsors via phone calls and email. In order to explain the project further, either in-person meetings or virtual meetings via Skype are scheduled to speak with these potential sponsors. Lastly, the Team has also received a dedicated room at Georgia Tech in which the Team can construct and store their launch vehicle, payload, and other non-explosive components.

6.5.2. Additional Community Support

Team A.R.E.S. will have the opportunity to recruit more fellow Yellow Jackets once the spring semester arrives in January 2015. Moreover, Team A.R.E.S. has developed a plan to outreach as many students in metro-Atlanta as possible. The plan will include teaming up with a local high school to develop their engineering, math, and science curriculum. The idea is to present the local schools with the lifestyle of being an engineer is like, for example, in the academic field by coming up with lesson plans to present engineering courses.

6.5.3. Plan for Sustainability (VIP)

Recognizing the opportunities and experience gains offered by the NASA SL competition, the Georgia Tech Team A.R.E.S. has worked with Georgia Tech to offer the SL competition as a highly integrated team project through the Vertical Integrated Program (VIP). The VIP program provides the necessary infrastructure and environment that allows for a highly integrated design utilizing inputs from the aerospace, mechanical, and electrical engineering disciplines. Additionally, the VIP program provides technical elective credit for all students – both undergraduate and graduate.

7. Appendix I – Safety Sheets

I understand and will abide by the following safety regulations:

- 1.6.1. Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.
- 1.6.2. The RSO has the final say on all rocket safety issues. Therefore, the RSO has the right to deny the launch of any rocket for safety reasons.
- 1.6.3. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

NAME	DATE
Sung Kim	09-10-15
Ariana Duncan	09-10-15
J. Collin Garnett	9/10/15
Benjamin Sumner	9/10/15
Joseph Elkins	9-10-2015
Madeline Landman	9/10/15
Reed Coker	9/10/15
NIKHIL VENKATESH	09/10/15
VICTOR RODRIGUEZ	09/10/15
Matt Allen	9/10/15
Alfredo Monzalvo	9/10/15
[illegible]	9/10/15
Eric Alu	9/10/15
John Butchko	9/10/15
Gabriel Nakajima An	9/10/15
Rahul Maran	9/10/15
Lance Li	9/10/15
Kyle Zeitler	9/10/15