AUBURN UNIVERSITY STUDENT LAUNCH

Project Tigris

211 Davis Hall

AUBURN, AL 36849

Proposal

September 14, 2018

Contents

List of Tables 6

List of Figures..7

1. General Information 9

1.1: Team summary 9

1.2: Adult Educators 9

1.3: Team Mentor 10

1.4: Student Team Leader..11

1.5: Student Safety Officer 11

1.6: Project Organization..12

1.7: NAR/TRA Sections 12

2. Facilities 14

2.1: Aerospace Computational Lab 14

2.2: Aerodynamics Laboratory 14

2.3: Advanced Laser Diagnostics Laboratory 15

2.4: Composites and UAV Laboratory 16

2.5: Design and Manufacturing Laboratory..17

2.6: Flow Visualization Laboratory 18

2.7: GKN Aerospace Tallassee, Alabama 19

2.8: Machine Tool Laboratory and the Aerospace Wood Shop 20

2.9: Structures Laboratory 20

3. Safety..21

3.1: Personnel and Responsibilities 21

3.2: Hazard Analyses 22
3.3: Checklists 25
3.4: Team Briefings and Checks 25
3.5: Energetic Device Handling 26
3.6: Law Compliance 27
3.6.1: FAA Regulations: 27
3.6.2: Alabama, Tennessee, and NFPA Codes: 28
3.7: NAR/TRA Safety Codes 31
3.8: Caution Statements 33
3.9: Team Safety Statement 35
3.10: Risk Assessments 35
4. Technical Design 36
4.1: Vehicle Design 36
4.2: Projected Altitude 40
4.3: Recovery System Design 41
4.3.1: Structural Elements 41
4.3.2: Materials 43
4.3.3: Ejection System 44
4.3.4: Parachutes 45
4.3.5: Parachute Construction 49
4.3.6: Drift 50
4.3.7: Electronics 51
4.4: Motor Selection 56

4.5: Payload Design (Rover)....57
4.5.1: Rover Orientation System (ROS)....57
4.5.2: Rover....57
4.5.3: Electronics....58
4.6: Altitude Control....59
4.6.1: Structure....62
4.6.2: Electronics....62
4.7: Requirements Verification....66
4.7.1: General Requirements....66
4.7.2: Vehicle Requirements....69
4.7.3: Vehicle Prohibitions....76
4.7.4: Recovery Requirements....77
4.7.5: Rover Requirements....80
4.7.6: Safety Requirements....81
4.8: Major Technical Challenges and Solutions....82
5. STEM Engagement....84
5.1: General Statement....84
5.2: Drake Middle School 6th Grade Rocket Week....84
5.2.1: Rocket Week Plan of Action....85
5.3: Samuel Ginn College of Engineering E-Day....86
5.4: Boy Scouts of America: Space Exploration Badge....87
5.5: Girl Scouts of America....88
5.6: GRAND Engineering Showcase....89

5.7: Auburn Junior High School Engineering Day....89

6. Project Plan 90

6.1: Systems Engineering 90

6.1.1: CFD....90

6.1.2: Rover....90

6.1.3: Embedded 91

6.1.4: Recovery 92

6.1.5: Vehicle Body 93

6.2: Development Timeline 94

6.3: Budget....95

6.3.1: Budget Summary 100

6.4: Funding Plan....101

6.5: Sustainability 102

6.5.1: Aeropalooza....102

6.5.2: Organization Week 103

6.5.3: Auburn University Rocketry Association....104

Appendix A. Risk Assessment Tables....105

List of Tables

Table 1: Severity Levels 23

Table 2: Probability Levels 24

Table 3: Risk Assessment Matrix 24

Table 4: Fin Dimensions and Fin 39

Table 5: Parachute Size Pugh Chart 46

Table 6: Parachute Sizing Details 49

Table 7: Altimeter Specifications 55

Table 8: Motor Specifications 56

Table 9: Microcontroller Trade Study 63

Table 10: DC Motor Trade Study 64

Table 11: Vehicle Expected Costs 95

Table 12: Recovery Expected Budget 96

Table 13: Rover Expense Summary 97

Table 14: Research and Development Projected Expenses 98

Table 15: Altitude Control Expense Summary 98

Table 16: Outreach Expenses 99

Table 17: Budget Summary 100

Table 18: Funding Sources 101

List of Figures

Figure 1: Organizational Chart 13

Figure 2: Organizational chart 13

Figure 3: Subsonic Wind Tunnel 15

Figure 4: Advanced Laser Diagnostics Laboratory 16

Figure 5: Composites and UAV Laboratory 17

Figure 6: Flow Visualization Laboratory 18

Figure 7: Autoclave at GKN 19

Figure 8: Vehicle Rendering 36

Figure 9: Open Rocket Model 36

Figure 10: Braided Section Sample 37

Figure 11: Projected Altitude 40

Figure 12: BAE 3D Printed Housing 42

Figure 13: Nosecone Diagram 45

Figure 14: 6 Gore Template 47

Figure 15: 8 Gore Template 47

Figure 16: Hemispherical Parachute 48

Figure 17: TeleMega 52

Figure 18: TeleMetrum 52

Figure 19: PerfectFlite StratoLogger 53

Figure 20: Adafruit Trinket 54

Figure 21: Nosecone Wiring Diagram 54

Figure 22: Motor Thrust Curve ... 57

Figure 23: Left: Rover in closed, transport configuration. Right: Rover in extended, working configuation. ... 58

Figure 24: Controller Block Diagram ... 61

Figure 25: Rocket with drag plates extended ... 61

Figure 26: Conceptual Rendering ... 62

Figure 27: STM32F103C8 (“Blue Pill”) ... 63

Figure 28: Planetary Gear Motor with Encoder. The 26 RPM model is depicted; however, the 280 RPM has the same dimensions. ... 64

Figure 29: Picture of sixth graders on Launch day for Rocket Week for spring 2018. ... 85

Figure 30: USLI team members talking to E-Day visitors of spring 2018. ... 86

Figure 31: AUSL members setting up rockets for the Boy Scouts to launch for the Boy Scout event in spring 2018. ... 87

Figure 32: AUSL pose with Girl Scouts and their rockets after launching in spring 2018 ... 88

Figure 33: Gannt Chart ... 94

Figure 34: The USLI team at Aeropalooza 2018 talking to Aerospace Department faculty and recruiting new members. ... 103

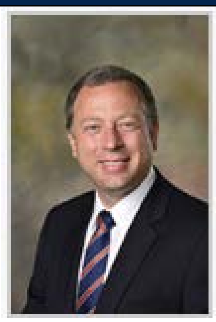
Figure 35: An AURA build group in Fall 2017 preparing their rocket engines for launching to attempt their Level 1 certifications. ... 104

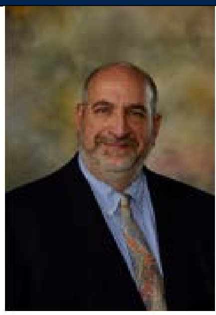
1. General Information

1.1: Team summary

General Team Information	
University Affiliation	Auburn University
Mailing Address	211 Davis Hall Auburn, AL 36849
Title of Project	Tigris
Date of Proposal	September 12, 2018
Experiment	Option 2: Deployable Rover

1.2: Adult Educators

Adult Educator		
	Name	Dr. Brian Thurow
	Title	Aerospace Engineering Department Chair
	Email	thurobs@auburn.edu
	Phone	344-844-6827
	Address	211 Davis Hall Auburn, AL 36849

Adult Educator		
	Name	Robert Kulick
	Title	Aerospace Engineering Faculty Advisor
	Email	kulicro@auburn.edu
	Phone	344-844-6869
	Address	220 Davis Hall Auburn, AL 36849

1.3: Team Mentor

Mentor		
	Name	Dr. Eldon Triggs
	Title	Lecturer, Aerospace Engineering, Mentor
	Certification	Tripoli Rocketry Association Level 2
	Email	trigged@auburn.edu
	Phone	344-844-6809
	Address	336 Davis Hall Auburn, AL 36849

1.4: Student Team Leader

Student Project Lead		
	Name	Bryce Gardner
	Title	Senior in Aerospace Engineering
	Email	blg0010@auburn.edu
	Phone	719-930-1445
	Address	215 South Gay St Apt. 106 Auburn, AL 36830

1.5: Student Safety Officer

Student Safety Officer		
	Name	Jackson Treese
	Title	Junior in Aerospace Engineering
	Email	jbt0022@auburn.edu
	Phone	334-275-6378
	Address	2260 E University Dr. Apt 8D Auburn, AL 36830

1.6: Project Organization

This year, the team will have four technical development teams and four operations support teams. All students that are not in a leadership position are a member of a technical team. The technical teams are vehicle body, recovery, payload, and altitude control. They are responsible for the design and fabrication of major sections of the rocket. The support teams are systems engineering, educational engagement, safety, and paper editing. Members of the support teams are embedded in the other teams. This is essential for the systems engineering and safety teams to perform their roles by engaging them at the lowest level of organization. This arrangement also provides additional experience for members of support teams, especially educational engagement and paper editing, which may otherwise not have the opportunity to work in a technical role. During educational events, members of the outreach team organize and coordinate while members of all teams volunteer. An organizational chart of the team can be seen in Figure 1.

1.7: NAR/TRA Sections

The Auburn Student Launch team is planning to attend launches hosted by Phoenix Missile Works (PMW) and the South Eastern Alabama Rocket Society (SEARS). PMW (Tripoli Section #81) will be hosting a new launch event called Bama Blastoff in Aliceville, Alabama on October 27-28. SEARS (NAR Section #572) will host a launch on the first Saturday of every month during the competition season in Samson, Alabama. In addition to providing the majority of the team's launch opportunities, the team will be partnering with Christopher Short of SEARS, who will provide further technical expertise and serve as a rocketry vendor.

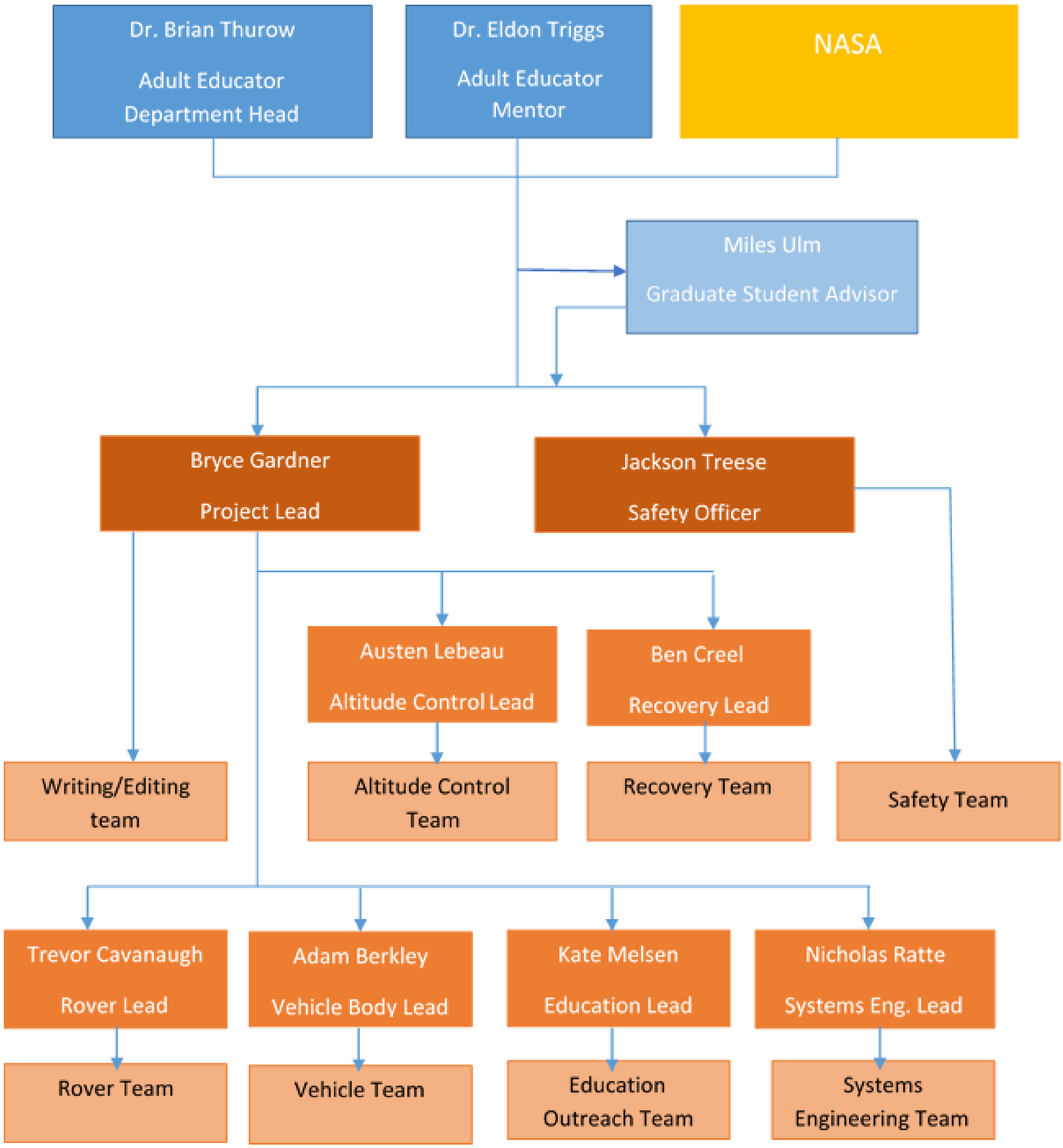


Figure 1: Organizational Chart

2. Facilities

2.1: Aerospace Computational Lab

The Aerospace Computational Lab, located in Davis 330, provides sixteen Windows PC workstations for students to use while on campus. Software packages such as MATLAB, NASTRAN, PATRAN, ANSYS, etc., are available and will be used to analyze the technical aspects of the launch vehicle, such as drag data and altitude projections. Student also have access to a variety of CAD programs such as Solid Edge, AutoCAD, Autodesk Inventor, SmartDraw, and SolidWorks, which will aid in the design of various launch vehicle components. Team members also have access to the CES EDU Pack, a materials database which provides a comprehensive database of materials and process information and can be used to perform various parametric trade studies with materials.

2.2: Aerodynamics Laboratory

The aerodynamics laboratory is located near campus in the Auburn Research Park. It includes two subsonic and three supersonic wind tunnels, as well as a low-speed smoke tunnel for flow visualization. An open-circuit, low-speed wind tunnel with a 2-ft by 2-ft test section is available for testing (see Figure 3). The flow speed may be varied from 0 to approximately 120 mph. Different types of mounting hardware and balances are available, including a six degree-of-freedom floor mounted balance and angle of attack control along with a three degree-of-freedom sting-mounted balance. This represents the primary wind tunnel that will be used for the project's parachute testing. The aerodynamics lab is also equipped with a 4 in. by 4 in. supersonic wind tunnel which is capable of flow testing at Mach numbers from 1.5 to 3.5. A Schlieren system is used to detect shock waves optically. Recently, a new converging and test section were designed and fabricated to provide transonic flow in this tunnel. The wind tunnel may be used to study the effects on the launch vehicle as it approaches supersonic speeds. Furthermore, inserts can be used to change the geometry of the inlet of the test section of the 7-inch by 7-inch in-draft supersonic wind tunnel and produce discrete test section Mach numbers between 1.4 and 3.28. This wind tunnel can be used for additional data collection on the proposed launch vehicle configuration at supersonic speeds if needed.

Figure 3: Subsonic Wind Tunnel

2.3: Advanced Laser Diagnostics Laboratory

The Advanced Laser Diagnostics Laboratory (ALDL) located in the Woltosz Engineering Research Laboratory specializes in the development and application of laser diagnostics for aerodynamic measurements (see Figure 2.2). The laboratory is equipped with the following advanced instrumentation:

• MHz rate Nd:YAG pulse burst laser system.

• Ultra-high speed intensified camera capable of imaging at up to 500,000 fps.

• Galvanometric scanning mirrors.

• High QE CCD cameras.

Areas of specialization include high-repetition rate flow visualization and high-speed three-dimensional imaging. The centerpiece of the laboratory is a custom-built pulse burst laser system with the ability to produce a burst of high-energy laser pulses at repetition rates up to 10 MHz and an ultra-high speed camera capable of imaging at up to 500,000 frames per second. The laser is an Nd:YAG base laser system and has been used in the past to make high-repetition rate planar flow visualization, particle image velocimetry (PIV), and planar Doppler velocimetry (PDV) measurements in supersonic flow fields. This laboratory may be used for flow visualization purposes in order to accurately characterize the flow around the launch vehicle including the hot plume trailing behind the motor.

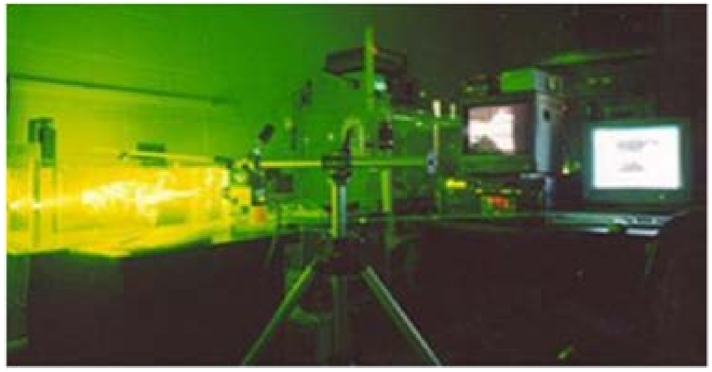


Figure 4: Advanced Laser Diagnostics Laboratory

2.4: Composites and UAV Laboratory

The Composites Laboratory located in Davis Hall 222 serves as the main lab space for the Auburn Student Launch team. This lab provides equipment and workspace for the construction of adaptive aerospace structures using composite materials and additive manufacturing. The Auburn Student Launch team primarily uses this lab for design prototyping construction of the main vehicle body. The laboratory houses a CNC Router, 3D printer, filament winder, composites oven, and many additional pieces of equipment utilized in the construction of the main vehicle body. The Rockler CNC Shark brand CNC router has a 25-in by 25-in by 7-in work area and is capable of accurately machining wood, composite materials, plastics, and soft metals. This machine can produce high quality, precision milled components and is typically used by the vehicle body team to produce fins, bulkheads, and other flat components of the launch vehicle. The LulzBot TAZ 4 3D printer is used in the production of a wide range of launch vehicle elements, ranging from custom ribbed nosecones to single-use black powder charge caps. The printer has an 11.7-in by 10.8-in by 9.8-in print bed with a print tolerance of 0.003 in. This printer has the capability to make components out of ABS, PLA, HIPS, PVA and wood filaments. The team is expanding its additive manufacturing capabilities by printing structures and overlaying composite materials for more control over the shape and strength. To accompany the 3D printer, the lab is equipped with a material reclaimer that allows the manufacturing of custom 1.75 mm to 3 mm diameter ABS, PLA and HIPS filaments. As part of the composites capabilities of the lab, a microprocessor-controlled, floor model, Blue-M convection oven is employed to cure composite parts. The oven has internal dimensions of 48-in by 48-in by 36-in. Cold storage equipment is available in the lab for long-term, thermoset prepreg carbon fiber storage.

Figure 5: Composites and UAV Laboratory

2.5: Design and Manufacturing Laboratory

The Auburn University Design and Manufacturing Laboratory (DML) aids in the manufacturing of large metal parts required for the fabrication process. The DML is a machine shop that provides various work areas for machining metal. The machine shop tools include lathes, mills, drill presses, saws, a CNC milling machine, a metrology section, and various sanders. The DML specializes in making high precision metal parts that can be machined with tolerances as low as 0.001 in.

2.6: Flow Visualization Laboratory

The Flow Visualization Laboratory utilizes a 45-cm by 45-cm test section water tunnel for flow visualization, shown in Figure 6: Flow Visualization Laboratory. The water tunnel has a maximum speed of 1.2 meters per second and is equipped with the latest instrumentation for visualization and flow measurements. This includes a planar and stereoscopic particle image velocimeter, hot film anemometer, high speed imager, pulsed and continuous wave front lasers for laser-induced fluorescence, and a multiple color dye injection system. Specially designed flow tanks and channels are also available to study the evolution of vortex dominated flows and vortex filaments. This facility will be extensively used for visualizing the flow field around the launch vehicle structure.

Figure 6: Flow Visualization Laboratory

2.7: GKN Aerospace Tallassee, Alabama

GKN Aerospace's facility in Tallassee, Alabama has 380,000 sq. ft. of manufacturing space. Their facility includes clean rooms and laser ply projections for composite assembly, Gerber cutting

Figure 7: Autoclave at GKN

systems for precision fabrication, and autoclaves for curing and consolidation of composite materials. Their largest autoclave is 15-ft by 50-ft (shown in Figure 2.4). Additionally, GKN has CNC milling capabilities for a wide range of part sizes as well as Honeycomb machining. For composite curing and consolidation of the airframe, GKN has kindly allowed the use of their facilities.

2.8: Machine Tool Laboratory and the Aerospace Wood Shop

The Machine Tool Laboratory and the Aerospace Wood Shop will both be used for the fabrication of the internal components of the launch vehicle. The Machine Lab has a CNC milling machine that may be used to fabricate precision parts. The Wood Shop has multiple tools such as drill presses, lathes, belt sanders, band saws, and pneumatic rotary tools for the fabrication of parts, especially the cutting of composites.

2.9: Structures Laboratory

Auburn's Structures Laboratory, located in Woltosz 1568, is equipped with a variety of testing equipment suitable for materials testing on launch vehicle components. These include a pair of screw-driven universal testing machines for tensile, compression, and 3-point bend testing. Additional facilities can measure dynamic loadings as well. Structural test data may be obtained from the manufactured composite specimens in the Composites Laboratory by using the servo-hydraulic testing machine and the data acquisition equipment that are available in the Structures Laboratory (Figure 2.5). Two new pieces of equipment in the Structures Laboratory that will be useful for the team this year are a Universal Testing Machine and a Split Hopkinson Pressure Bar Apparatus. The Universal testing machine can perform a wide variety of quasi-static loading configurations, such as tension, compression, and three-point bend testing. The Split Hopkinson Bar can provide high strain rate testing on materials samples, similar to what would be experienced during impacts with the ground or other rapid changes in acceleration.

3. Safety

3.1: Personnel and Responsibilities

The Auburn Student Launch organization has a team in place to ensure that all activities and property of the organization is prepared, handled, and operated in a safe manner while still achieving the organization's goals. The role of safety officer will be fulfilled by Jackson Treese. Jackson is a sophomore in aerospace engineering and is entering his second year working with Auburn Student Launch. He was previously a member of the recovery team. He will oversee a safety team consisting of liaisons from each Auburn Student Launch team. This group will facilitate frequent interaction, communication, and documentation of safety practices for every aspect of Auburn Student Launch. This organizational strategy will improve every member's awareness and knowledge of safety procedures and allow quick access to a safety expert for each team.

In accordance with the NASA Student Launch handbook, the Safety team will:

1. Monitor team activities with an emphasis on Safety during:

    a. Design of the vehicle and payload

    b. Construction of the vehicle and payload

    c. Assembly of the vehicle and payload

    d. Ground testing of the vehicle and payload

    e. Sub-scale launch test(s)

    f. Full-scale launch test(s)

    g. Launch Day

    h. Recovery activities

    i. STEM Engagement Activities

2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities.

3. Manage and maintain current revisions of the team's hazard analyses, failure mode analyses, procedures, and MSDS/chemical inventory data.

4. Assist in the writing and development of the team's hazard analyses, failure mode analyses, and procedures.

The Auburn Student Launch organization will adhere strictly to all NAR and TRA regulations. The team's mentor is Dr. Eldon Triggs, a professor at Auburn University who holds a Level 2 high power rocket certification. This certification allows him to handle up to class L rocket motors, which is sufficient for this project. Dr. Eldon Triggs will be primarily responsible for overseeing the transportation and handling of rocket motors and of launch procedures. He will review the design of the rocket at each stage of the design process and ensure that it is within the safety requirements set by NAR and TRA. He will travel with the team on launch day and collaborate with the safety officer to produce a launch checklist that the safety officer will be responsible for adhering to and ensuring other members adhere to. This checklist will include ensuring safe weather conditions, clearing and preparing the launch area, locating observers a safe distance from the launch pad, and meeting all NAR and TRA launch safety requirements. The handling of any hazardous material will be the responsibility of the mentor, the safety officer, or another certified member of the team with permission from either the mentor or the safety officer.

The team website will serve as an online archive for safety materials. In addition, physical copies of MSDS sheets, hazard analyses, risk mitigation procedures, and NAR and TRA regulations will be printed and available in the lab where construction will take place.

3.2: Hazard Analyses

The safety team's responsibilities will include the identification and analysis of the hazards involved with every step of the project. This will include hazards to personnel, hazards to the rocket, and hazards to the environment.

A risk assessment matrix has been prepared to unambiguously categorize hazards that the team identifies. The matrix can be found below in Table 3.3: Risk Assessment Matrix.

Severity levels ranging from 1 (Catastrophic) to 4 (Negligible) and Probability levels ranging from A (Frequent) to E (Improbable) will be utilized. These quantities have been provided with a qualifying descriptor to help classify hazards as they are determined.

Severity Level	Descriptor	Example
1	Catastrophic: Immediate loss of mission or loss of rocket or significant safety risk to one or multiple personnel or the environment.	A rocket motor is improperly constructed or assembled in such a way to cause a misfire.
2	Critical: Immediate threat to mission completion or likely harm to personnel or environmental destruction.	The rocket must be recovered from power lines, an active roadway, or another active hazard.
3	Marginal: Immediate or delayed threat to partial or total mission completion or moderate threat to personnel or environmental concerns requiring attention.	Sparks or exhaust from the rocket motor ignite a small brush fire on launch.
4	Negligible: Delayed threat to partial mission completion or minor environmental concerns; Minor or no threat to personnel.	One nylon screw on the nose cone requires replacement.

Table 1: Severity Levels

Probability Level	Descriptor	Likelihood
A	Frequent	>85% chance of occurring.
B	Probable	50% to 85% chance of occurring.
C	Occasional	15% to 50% chance of occurring.
D	Remote	1% to 15% chance of occurring.
E	Improbable	<1% chance of occurring.

Table 2: Probability Levels

Probability Level	Severity Level			
	1	2	3	4
A	1A	2A	3A	4A
B	1B	2B	3B	4B
C	1C	2C	3C	4C
D	1D	2D	3D	4D
E	1E	2E	3E	4E

Table 3: Risk Assessment Matrix

3.3: Checklists

The safety officer will work closely with the other team leads and safety liaisons to compose a thorough list of procedures that team members will follow prior to the launch of any sub-scale or full-scale rocket as well as safety lists for the construction process and day-to-day lab work. The purpose of these checklists is to centralize the preparation process and unambiguously detail the actions the team should take and in what order they should be taken.

Checklists will be created for each of the rocket's subsystems, final assembly, and for launch. Team leads will be responsible for checklists that cover the subsystem they have authority over and will see to it that they are followed closely. Upon completion of the subsystem checklists, they will sign the checklist and report the checklist to the safety officer. The safety officer will have the authority over the final signature for the overall assembly checklist, and the team mentor will have authority to sign off on the final launch time checklist. In the event that a team member deviates from the checklist, the team lead or safety officer will immediately determine what actions were taken and what actions can be further taken to return to following the checklist as closely as possible.

3.4: Team Briefings and Checks

Before lab work begins on the project, a meeting will be held with the entire membership of Auburn Student Launch to inform members of the risks and responsibilities they will encounter in the lab, during testing, and on launch day. The material used in these briefings will be made available online, and the safety liaisons for each team will be available to team leads and team members during general construction and testing for questions. The briefing will include machine and tool hazards, chemical and material handling procedures, and instruction regarding the use of personal protection equipment (PPE). Team members will be required to attend this meeting and to acknowledge they understand this information and will comply with it at all times by signing a waiver that will be available at the briefing and kept on file.

Materials and chemicals in the laboratory will be stored properly per their hazard level. Flammable and toxic chemicals will be stored in specifically labeled flammable cabinets to protect them from accidentally being released. One of the major roles of the safety team is to keep an accurate and complete inventory of all materials and chemicals in the laboratory areas. Clear and readable labels will be in place to identify hazard levels and make them easier to locate. Team members will be briefed on the proper disposal of materials and chemicals per the hazard level of each material and chemical.

All machinery must be used exclusively by properly trained and briefed members. Before using a machine, team members must demonstrate to the safety officer or another member of the safety team that he or she can properly and safely use the equipment. Members will be briefed on different hazards that could occur and what to be aware of while operating machines to avoid accidents. Team members will keep a safe distance from a machine making sure that hands and bodies are clear before starting the machine to avoid accidents. Machines will not be operated alone; there will always be at least two people present when machinery is being used. Before operating a machine, team members will check to make sure that safety shields are in place and secure (if applicable). Team members will be briefed on the use of proper personal protective equipment (PPE) to wear when operating machines.

3.5: Energetic Device Handling

The purchase of rocket motors will be done only by a certified NAR/TRA instructor. Motors purchased will be limited to a total impulse of 5,120 Newton-seconds (Class L), as regulated by the 2018 NASA Student Launch Handbook (Vehicle Requirement 2.15). Rocket motors will be stored in a designated casing designed to keep the motor secure, prevent damage to the propellant and motor casing, and to avoid sparks or any dangerous complications. The motor will be kept at least 25 feet away from any heat sources or flammable liquids.

A no-smoking policy will always be strictly enforced within 25 feet of the rocket motor and its components. Transportation of the rocket motor will be accomplished independently of other rocket components, and it will be securely immobilized and padded to prevent damage. The rocket will include some small energetic systems that will also be purchased by the NAR/TRA mentor. The energetic systems will be securely stored and padded to prevent damage independently of the rocket motors. The electrical systems will also be transported and installed on the rocket only in the designated assembly area. All the components of this system will be inhibited except when the rocket will be in the launching position and all personnel are at the minimum safe distance and the NRA/TRA mentor can confirm so. During the use of the rocket motors and energetic devices, specific requirements will be followed per the regulations set forth by NAR. Also per team requirements, specific guidelines and documentation will be followed to ensure the safety of all team members and observers present at either the launches or tests for specific systems.

3.6: Law Compliance

The regulations imposed nationally by the FAA and within the state of Alabama, due to the adoption of the National Fire Protection Agency (NFPA) codes, are relevant and will be complied with for the purposes of this project.

3.6.1: **FAA Regulations:**

FAA Regulation	Compliance
No member shall operate an unmanned rocket in a manner that creates a collision hazard with other aircraft.	The team will ensure that the immediate airspace is clear of all aircraft before launching. If an aircraft is in the airspace, the team will not launch the rocket.
No member shall operate an unmanned rocket in controlled airspace.	The team will work with the RSO to ensure that the launch site is within uncontrolled airspace.
No member shall operate an unmanned rocket within five miles of the boundary of any airport.	The team will review a map of the launch site to guarantee that no airports are within five miles.
No member shall operate an unmanned rocket at any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails.	The team will delay the launch of the rocket until the appropriate weather conditions are active.
No member shall operate an unmanned rocket at any altitude where the horizontal visibility is less than five miles.	The team will review the launch site to ensure no objects obscure horizontal visibility out to five miles.
No member shall operate an unmanned rocket into any cloud.	The team will delay the launch until the immediate skies are clear.
No member shall operate an unmanned rocket within 1,500 feet of any person or property that is not associated with the operations or between sunset and sunrise.	The team will only use launch sites that have been approved with the owner of the property and will not launch the rocket between sunset and sunrise.

3.6.2: **Alabama, Tennessee, and NFPA Codes:**

Alabama 2013 NFPA Codes	Compliance
Only a certified user shall be permitted to launch a high power rocket.	Dr. Eldon Triggs is the team's mentor and has a level 2 certification. He will be the only person to launch the rocket.
Only certified high power rocket motors or motor reloading kits or motor components shall be used in a high power rocket.	Per competition rules, the launch vehicle will 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).
A single-use high power rocket shall not be dismantled, reloaded, or altered.	The team will be using a multi-use rocket.
A reloadable high power rocket motor shall not be altered except as allowed by the manufacturer and certified by a recognized testing organization acceptable to the authority having jurisdiction to meet the certification requirements set forth in NFPA 1125.	The team will not alter any reloadable rocket motors that may be used.
The stability of a high power rocket shall be checked by its user prior to launch.	A launch checklist will be used to ensure the rocket is fully prepared to launch which includes checking the stability of the rocket.
If requested by the RSO, the user shall provide documentation of the location of the center of pressure and the center of gravity of the high power rocket.	The rocket will have marks at the location of both the center of pressure and the center of gravity and documentation will be on hand at launch.
The maximum liftoff weight of a high power rocket shall not exceed one-third (1/3) of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	Calculations have been made by the team and double checked to ensure the rocket weight is below the required limit.
A high power rocket shall be launched only if it contains a recovery system that is designed to return all parts of the rocket to the ground intact and at a landing speed at which the rocket does not present a hazard.	All sections of the rocket will be under a parachute calculated to slow the decent of the rocket to which the total kinetic energy is less than 75 ft-lbf.
The person who prepares the high power rocket for flight shall install only flame	Flame resistant recovery wadding will be used only if necessitated by the design

resistant recovery wadding if the design of the rocket necessitates the use of wadding.	
No attempt shall be made to catch a high power rocket as it approaches the ground.	All personnel will be made to stand a safe distance away from the launch pad and will not leave this area until the rocket has touched down.
No attempt shall be made to retrieve a high power rocket from a power line or other life-threatening area.	If a rocket lands on a power line or other life-threatening area, all team members will be instructed to stay clear and the appropriate authorities will be contacted.
A high power rocket shall be launched using an ignition system that is remotely controlled, is electrically operated, and contains a launching switch that returns to the "off" position when released.	The RSO will be consulted to ensure the ignition system is within regulation standards.
The ignition system shall contain a removable safety interlock device in series with the launch switch.	The RSO will be consulted to ensure the ignition system is within regulation standards.
The launch system and igniter combination shall be designed, installed, and operated so that liftoff of the rocket occurs within 3 seconds of actuation of the launch system.	The RSO will be consulted to ensure the launch system and igniter combination is within regulation standards.
An ignition device shall be installed in a high power rocket motor only at the launcher or within the prepping area.	An ignition device will only be installed at the launcher by the RSO.
A high power rocket shall be pointed away from the spectator area and other groups of people during and after the installation of the ignition device.	The rocket will be pointed away from all personnel once the ignition device is installed and will only be taken down after the ignition device has been removed.
A high power rocket shall be launched in an outdoor area where tall trees, power lines, buildings, and persons not involved in the rocket launch do not present a hazard.	The launch site will be surveyed beforehand to ensure no obstacles are in the immediate vicinity.
Fire suppression devices and first aid kits shall be located at the launch site during the launch of a high power rocket.	The appropriate safety equipment will be brought to every launch and will be included on a pre-launch to ensure they are present at launch.
No person shall ignite and launch a high power rocket horizontally, at a target, or so that a rocket's flightpath during ascent phase is	The team will consider the predicted flight path of the rocket to ensure it does not leave

intended to go into clouds, directly over the heads of spectators, or beyond the boundaries of the launch site, or so that the rocket's recovery is likely to occur in spectator areas or outside the boundaries of the launch site.	the launch area. The launch will only occur under the appropriate weather conditions.
No person shall launch a high power rocket if the surface wind at the launcher is more than 32 km/h (20 mph).	An anemometer will be kept on hand at every launch to ensure the wind speed does not exceed 32 km/h (20 mph).
No person shall operate a high power rocket in a manner that is hazardous to aircraft.	The rocket will not be launched if any aircraft are in the area.
A high power rocket shall be launched only with the knowledge, permission, and attention of the RSO, and only under conditions where all requirements of this code have been met.	The RSO will be consulted before launching to ensure all conditions of this code have been met. Once compliance has been established, with the permission of the RSO, the team will launch the rocket.
High power rocket motors, motor reloading kits, and pyrotechnic modules shall be stored at least 7.6 m (25 ft) from smoking, open flames, and other sources of heat.	The crates that the rocket motor and other flammable items are stored in will be marked with appropriate warning signs and a team member will be responsible for watching over them at launch.
Not more than 23 kg (50 lb) of net rocket propellant weight of high power rocket motors, motor reloading kits, or pyrotechnic modules subject to the storage requirements of 27 CFR 555, "Commerce in Explosives," shall be stored in a Type 2 or Type 4 indoor magazine.	The team will not be using more than 23 kg (50 lb) of net rocket propellant weight.
A high power rocket motor shall not be stored with an ignition element installed.	The high power rocket motor will be stored by itself away from any ignition sources.

The Auburn University Student Launch team and all of its members have fully read and agree to abide by all rules and regulations set forth by the FAA.

3.7: NAR/TRA Safety Codes

NRA/TRA Code Topic	Details	Additional Information or Precautions
Materials	I will use only lightweight, non-metal parts for the nose, body, and fins of my rocket.	Carbon fiber and fiberglass will be used for the body and flight stabilization systems of the rocket. 3D printed plastics will be used for the nose. These materials are nonmetal, extremely lightweight, and very durable.
Motors	I will use only certified, commercially-made model rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer.	We will stay within the limitation of the motors and inspect the quality of the motor before use.
Ignition System	I will launch my rockets with an electrical launch system and electrical motor igniters. My launch system will have a safety interlock in series with the launch switch and will use a launch switch that returns to the "off" position when released.	After following these guidelines, A Range Safety Officer certified by NAR or the TRA will have ultimate authority regarding launches and will be the person to launch the rocket.
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.	Following the 60 second period of inactivity, the rocket will be approached by either the safety officer or the team mentor and all other team members will remain a safe distance from the rocket. Safety devices will be on hand for any circumstance.
Launch Safety	I will use a countdown before launch, and will ensure that everyone is paying attention and is a safe distance of at least 15 feet away when I launch rockets	A highly visible object will be used to mark the minimum distance team members should be away from the rocket. The visible object will be in the form of a

	with D motors or smaller, and 30 feet when I launch larger rockets. If I am uncertain about the safety or stability of an untested rocket, I will check the stability before flight and will fly it only after warning spectators and clearing them away to a safe distance. When conducting a simultaneous launch of more than ten. rockets I will observe a safe distance of 1.5 times the maximum expected altitude of any launched rocket.	bright line on the ground created by tape or paint and a vertical object that the safety officer will hold. All team members and observers will remain soundly behind this line.
Launcher	I will launch my rocket from a launch rod, tower, or rail that is pointed to within 30 degrees of the vertical to ensure that the rocket flies nearly straight up, and I will use a blast deflector to prevent the motor's exhaust from hitting the ground. To prevent accidental eye injury, I will place launchers so that the end of the launch rod is above eye level or will cap the end of the rod when it is not in use.	Beyond this guideline, only safety personnel, team leads, and the team mentor will be allowed to approach the launch rod and to prep the rocket for launch. This is to minimize the number of people around the rocket immediately prior to launch, helping to prevent accidents to either personnel or the launch system.
Size	My model rocket will not weigh more than 1,500 grams (53 ounces) at liftoff and will not contain more than 125 grams (4.4 ounces) of propellant or 320 N-sec (71.9 pound-seconds) of total impulse.	Each system of the rocket and section of the body will be weighed independently before transportation and directly prior to assembly. The assembled weight will be known prior to launch.
Flight Safety	I will not launch my rocket at targets, into clouds, or near aircraft, and will not put any flammable or explosive payload in my rocket.	During a rocket launch and prior to launch, all team members will be required to remain together and be vigilant of impeding objects as well as a recovery failure in case

		the rocket returns at a dangerous speed in the direction of personnel.
Launch Site	I will launch my rocket outdoors, in an open area at least as large as shown in the accompanying table, and in safe weather conditions with wind speeds no greater than 20 miles per hour. I will ensure that there is no dry grass close to the launch pad, and that the launch site does not present risk of grass fires.	All launches will take place at certified NAR or TRA events and locations. Currently, our only launch site is the SEARS launch site in Samson, AL.
Recovery System	I will use a recovery system such as a streamer or parachute in my rocket so that it returns safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	The team will calculate the optimum heights at which to deploy the drogue and main parachutes to maximize drag and minimize drift. This will aid in a safe and undamaged recovery. The parachutes will also be made of flame resistant material to avoid heat related failures of the system.
Recovery Safety	I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places.	In the event that the rocket does land in a dangerous place, appropriate help will be consulted immediately to avoid danger to any other peoples or infrastructure.

3.8:Caution Statements

Safety is of the highest importance in all aspects of the competition and critical to the design philosophy of Auburn Student Launch. To ensure that this is kept as the first priority of all the team members, before any procedures are undertaken there will be a safety briefing led by the safety officer and safety liaisons of each team lead. The briefing will cover all the important procedural and safety acknowledgements necessary to construction, assembly, and launch day activities. The safety liaison members will be responsible for reporting back changes to the design that affect safety considerations and providing an accessible and knowledgeable voice for safety concerns.

Team members will be briefed on the proper personal protection equipment (PPE) to wear while working in the laboratory. This includes hand, foot, ear, eye, and respiratory protection. Loose clothing must be secure, and jewelry must be removed before operating machinery. Members will be required to wear long pants, closed toed shoes, safety glasses, and gloves while working in the laboratory. Respiratory protection will also be used when toxic chemicals or small particle forming machines are in use. Team members will be required to wear lab coats when handling chemicals along with proper skin protection and respiratory protection as appropriate.

To avoid accidents, listening to music with earbuds or headphones will be prohibited while operating machines. Team members will look over machines before operating to ensure the machine is in proper condition. Ventilation systems will be checked prior to work to make sure they are also in proper working condition. An inventory of all materials and chemicals in the laboratory will be maintained along with labels to identify the hazard levels and what precautions to take with each of them. A waiver has been created for all team members to sign prior to entry to the lab that states their knowledge and understanding of these statements, the hazards they may encounter and their responsibilities to keep a safe work environment, and their intent to follow them closely.

3.9: Team Safety Statement

All members of the Auburn University Student Launch team have read and will abide by all of the rules as set forth by NASA. Before each flight a safety inspection will be completed by the Range Safety Officer (RSO). If any changes need to be made as per request of the RSO, they will be completed immediately. Auburn University Student Launch will comply with the safety decisions of the RSO to ensure the flight capability of the rocket and continued participation in the competition. The team members of Auburn University Student Launch understand that the RSO has ultimate authority of the flight readiness of any rocket to be flown by the team. Members of the team understand that this means the RSO has the authority to deny the launch of a rocket for any safety issue that is determined to be risky or of concern. The team will comply with all safety requirements of the competition, NASA, NAR, local and federal agencies, and the RSO in order to ensure the safety of all persons at the launch event.

All team members present at assembly and launch will sign a safety waiver that acknowledges their complete understanding of these safety statements and their intent to comply.

3.10: Risk Assessments

The risk assessment tables are located in Appendix A: Risk Assessment Tables.

4. Technical Design

4.1: Vehicle Design

Figure 8: Vehicle Rendering

The launch vehicle body will be composed of six major structural elements: the nose cone, the rover bay, the avionics section, the main parachute compartment, the drogue chute compartment, and the booster section. The preliminary model in Figure 9 shows the general layout of the rocket.

The outer diameter of our rocket will be 6.25 inches, while the inner diameter will be 6 inches. This will give a wall thickness of 0.25 inches. Finite element analysis will be performed to ensure that the wall thickness will be adequate for a successful and safe flight. The inner diameter was chosen to maximize the amount of usable space without increasing the weight too much. Work will also be done to limit the lengths of each section to further decrease the weight.

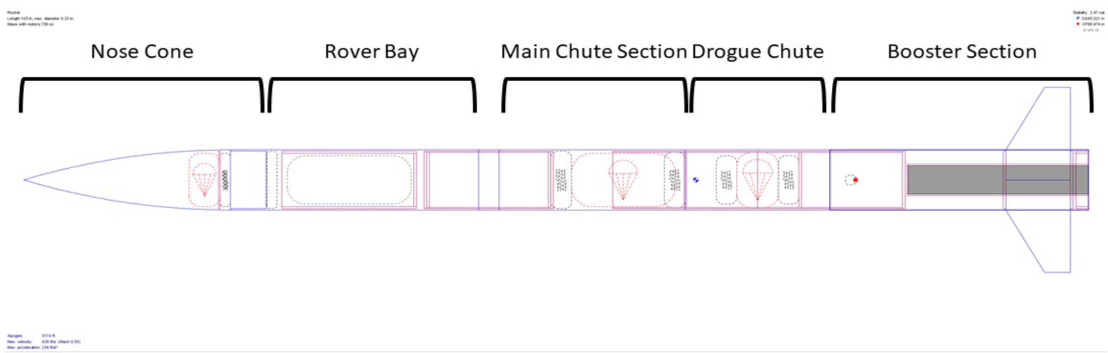


Figure 9: Open Rocket Model

The main body of the rocket will be constructed using composite materials. The body tubes will be constructed using two methods: carbon fiber braiding and filament winding. The carbon fiber

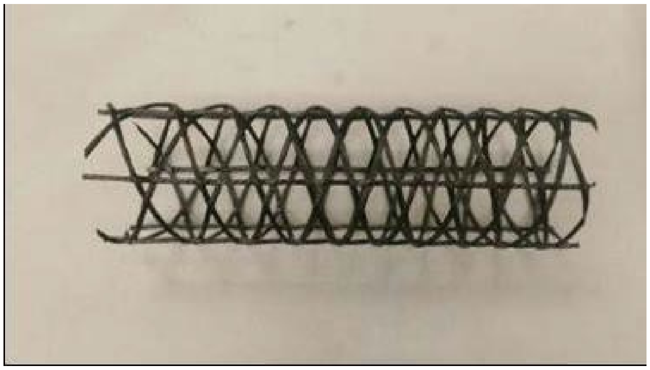


Figure 10: Braided Section Sample

braiding process weaves cords of carbon fiber into a braid which is then turned into an open-architecture composite isogrid structure using filament winding. Isogrid structures are a lighter alternative when compared to solid tubes. Using current samples of the isogrid structure, the body tube will potentially be 20 to 30 percent lighter than using a solid carbon fiber structure. In previous years, there was initial success using this method, so the team has a high level of confidence in incorporating this unique structure into the airframe. A sample of the isogrid structure is displayed in Figure 10.

A thin sheet of fiberglass will be secured inside the structure to create a smooth surface to allow for incorporation of the subsystem components. Additionally, the outside will be covered in a thin layer of filament wound carbon fiber to create a smooth surface to decrease aerodynamic drag. The thickness of these sections will be minimal, as they are not going to be carrying the structural load during launch. The team also has access to a filament winder which will be used for manufacturing carbon fiber tubes. Filament winding is a fabrication technique used mainly for manufacturing a cylindrical hollow product. Filament winding is highly beneficial because it is automated and precise, creating lightweight, strong composite parts, with minimal labor required. The different variables when winding are fiber type, resin content, wind angle, tow, and thickness of the fiber bundle. The filament winder will use a 6-inch diameter aluminum mandrel. Using an aluminum mandrel allows the team to produce very accurate body tubes. As filament winding is highly repeatable and has a high degree of accuracy, several spare body tubes could be created and tested to help the team eliminate undesirable configurations before proceeding to full-scale testing.

Finally, the last few primary pieces of the rocket will be constructed by utilizing a much different form of composite layup. Since bulk-plates and fins require very little special geometric variance from a flat plate, several plates of varying thickness composites will be made using a compaction method. This approach will significantly reduce the cost and difficulty of composites manufacturing, since vacuum bagging is not required in a compaction method. An added benefit will be the ability to achieve effective ply consolidation while remaining relatively easy to layup. Once post-cured the flat plates of cured composites will be milled and machined into the final shape required.

The stability of the rocket will be controlled by the fins. The fin's primary purpose is to locate the center of pressure aft of the center of gravity. The greater drag on the fins will keep them behind the upper segments of the vehicle, allowing the rocket to fly straight along the intended flight path while minimizing the chances of weather-cocking. A trapezoidal planform has been selected for the fins. Trapezoidal fins provide an easily machinable avenue for achieving a large section of wetted surface area. In addition, the trapezoidal design produces a large, easily machinable surface area to bond and secure the fin to the structural assembly beneath it. Four trapezoidal fins will be machined from .25-inch-thick carbon fiber plates. The trailing edge of the fins will be located one inch forward of the end of the body tube. This design feature will provide some impact protection for the fins when the rocket hits the ground. Carbon fiber of 1.03 oz./in^3 density has been selected due to its stiffness, strength, and light weight. Each fin will have a surface area of 56.88 in^2 respectively (summing both sides), making the fin surface area total to 227.52 in^2. These dimensions provide the vehicle with a projected stability of 2.53 calibers. This level of stability is ideal, as it is well above stable but below over-stable. Detailed dimensions of the fins are provided in Table 4: Fin Dimensions.

Section	Lengths
Nose Cone	20 in
Rover Bay	24 in
Avionics Section	12 in(2 in externally)
Main Parachute Section	18 in
Drogue Chute Section	14 in
Booster Section	25 in
Total Length	103 in

Trapezoidal Fin Dimensions	
Root Chord	6.25 in
Tip Chord	2.5 in
Height	6.5 in
Sweep	3.677 in
Sweep Angle	29.5°

Table 4: Fin Dimensions and Fin

4.2: Projected Altitude

In order to create an initial, fairly accurate projection of the altitude, the team used OpenRocket, a freeware program designed to calculate various parameters in rocket flight. Given the team's experience with this software in the previous years, the team is confident in the ability of OpenRocket to produce accurate estimates of the altitude. With the current motor selection, discussed in section 4.4: Motor Selection, the current projected apogee for the vehicle is 5111 ft. In addition, a chart of the altitude over time is provided in Figure 11: Projected Altitude.

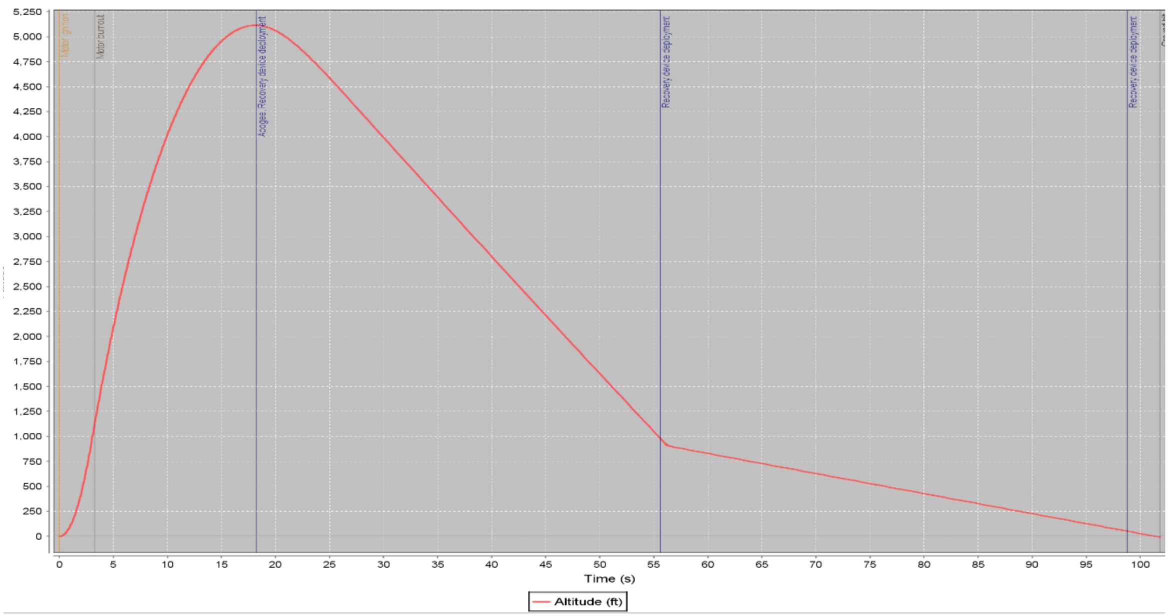


Figure 11: Projected Altitude

4.3: Recovery System Design

The 2018-2019 Auburn Student Launch team is planning on employing a dual-stage, dual-system recovery approach this year. The lower recovery system will consist of two parachutes, a drogue and a main, contained within their own separate housings. The housing for the drogue chute will be placed just above the embedded systems portion of the rocket with the main parachute housing and BAE respectively being stacked on top of that. The drogue chute will be deployed at apogee at a height of 5111 ft. followed by a main parachute deployment at 600 ft. Both parachutes will be deployed from their own individual compartments with redundant black powder charges and shear pins. These black powder charges will be ignited by electronic matches connected to redundant altimeters housed within the Barometric Avionics Enclosure (BAE).

The upper recovery system will be housed in the nosecone and will consist of a single parachute, two altimeters, a microcontroller, and a servo. These components will be assembled in such a manner as to create a redundant mechanical release. At 700 ft., the altimeters will send a signal to the microcontroller causing it to turn the servo, retracting the tabs holding the nosecone in place. A spring system will be in place to push the nosecone and parachute out of the rocket once the mechanical release is activated. The nosecone will then drift the rest of the way to the ground separately with its own parachute.

4.3.1: **Structural Elements**

The centerpiece of Auburn's lower recovery system will be the BAE. The BAE will be formed by an 8-inch-long cylindrical fiberglass coupler. Within the coupler, there will be a 3D printed housing for both the altimeters and their bulk plates to make efficient use of the space as seen in Figure 12. There will be three holes through the length of the housing to run charge wires and threaded rods. The hole for the wires will be in the center of the housing and half an inch in diameter. The holes for the two threaded rods will be half an inch in diameter and two inches away from either side of the hole for the wires. The coupler forming the outside of the BAE will be sealed off with bulk plate caps on both ends. The aforementioned rod holes will continue through both bulk plate caps. Rods will be fitted through these holes and secured with lock nuts on either side to hold the BAE together for the duration of the flight. The hole for the charge wires will continue down through the bottom bulk plate cap exclusively. After the wires have been pulled through it, this hole will be sealed with epoxy to help eliminate the chance of back pressure causing damage to the altimeters or forces from parachute deployment pulling on the charge wires and damaging altimeter terminals. The BAE will serve as the coupler between the lower parachute housings and the payload section. Neither of these sections will separate once the rocket is assembled.

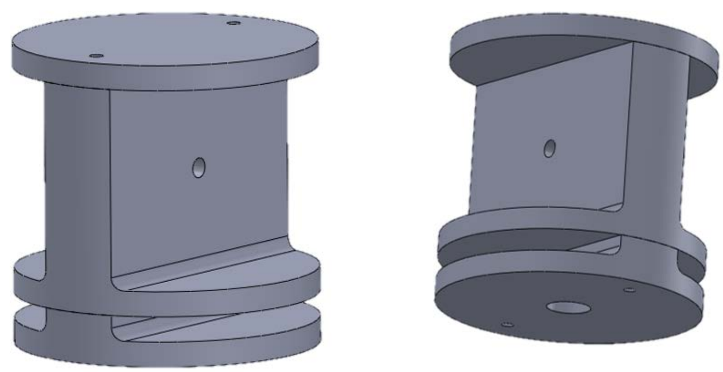


Figure 12: BAE 3D Printed Housing

Two additional holes will be drilled in the bottom bulk plate cap of the BAE for a U-bolt. This U-bolt will be the anchor point for the main parachute and will be attached with lock nuts on either side of the bulk plate to keep it from moving during parachute deployment.

Centered on the outside of the BAE there will be a two-inch-wide ring of fiberglass that is the same diameter as the outside of the rocket. The switches and pressure holes for the altimeters will be located on this ring. The key switches located on the ring will allow the team to externally arm the altimeters while the rocket is assembled. This will be done so the tube connections between the payload section, the BAE, and the main parachute housing are continuous and smooth, minimizing the impact on the aerodynamic performance of the rocket due to these connections.

In between the drogue and main parachute housings will be a 12-inch fiberglass coupler with a bulk plate fixed inside to separate the two compartments. The bulk plate will be fixed six inches from either end of the coupler to separate the two sections evenly and give both separation points a 6-inch shoulder. In this bulk plate there will be five holes, four of which will be used for U-bolts on either side of the plate secured in the same fashion as the one below the BAE. The fifth hole will be used for the e-match wire for the drogue charge. Separation points on both sides of the coupler will use three shear pins each.

Located in the nosecone will be a second altimeter bay to control the mechanical release of the nosecone. A housing similar to the one seen in Figure 12: BAE 3D Printed Housing will be used to secure the altimeters, microcontroller, servo and batteries. The top of the housing will be tapered to reflect the taper of the nosecone, and an additional hole will be placed in the bottom of the housing to secure the servo. The servo will be placed radially in the center of the rocket with three arms attached to it. This single servo approach is being used because it eliminates the possibility of asymmetrical actuation and creating a loosely attached nosecone. There will be three slots drilled in the nose cone and outer body of the rocket for the arms to slide into in order to lock the nosecone to the body. The arms, when locked into place, will be flushed with the outer surface of the rocket as to not to create unnecessary drag during ascent. The arms will have a ring of support structure around them to reduce the moment on the arms themselves and strain on the servo. On the bottom of the nosecone shoulder there will be a bulk plate with U-bolt for the parachute to attach to. Three threaded rods will pass through the bulk plate, arm support structure, bottom level and middle level of the altimeter housing with lock nuts on either side of each piece, totaling six lock nuts per rod. This will be done to ensure that each of these components stay in the same relative position to each other throughout the duration of the flight. The entire assembly will be fixed to the nosecone via four machine screws. These four screws will be screwed into the middle level of the altimeter housing through the top of the shoulder of the nosecone. In order to keep the screws from causing part of the nosecone shoulder to be exposed, the end of the airframe tube will be notched. This will be done to allow the screws, switches, and pressure holes to slide down to where the nosecone is fully seated against the top of the rocket. This is also done to relieve any undue stress from boost on the locking arms by transferring those forces directly to the airframe.

4.3.2: **Materials**

The materials chosen to create the team's recovery subsystems are of the utmost importance. They must work properly for the team’s payload, a rover that cannot be damaged when it returns to Earth. The materials must be both strong and lightweight in order to be effective, as well as not adding unnecessary weight to the rocket. The parachutes will be made from ripstop nylon. Ripstop nylon is an ideal material for this application; the fabric is thin and lightweight, but its reinforced woven composition makes it resistant to tearing. The 70 denier ripstop nylon fabric has been chosen for the parachutes because it has a tensile strength of 1500 psi, which is more than sufficient for the needs of this project. The drogue and nosecone shroud lines will be made of paracord, unlike the main parachutes shroud lines, which will both be made of tubular nylon. Tubular nylon was chosen for the main parachute due to its high strength and ability to stretch slightly, absorbing some of the shock from deployment without failing. Tubular nylon will be used for the shock cord connecting the shroud lines to the rocket for the same reasons, with sections being reinforced with tubular Kevlar as needed as determined after testing. Kevlar was chosen for the reinforcing material because it is even stronger and able to withstand more impact than tubular nylon. Nylon shear pins will be used to attach both the main parachute housing and drogue parachute housing to the parachute coupler section of the rocket to prevent drag separation. In the proposed configuration, #4-40 nylon screws will be used to secure these sections together. These machine screws each have a double shear strength of 50 lbs. This shear strength will be verified via ground testing to ensure safety. For all 3-D printed materials, the team will be using a Markforged 3-D printer and their patented material, Onyx. Onyx is a product consisting of nylon and chopped carbon fiber that is 1.4 times stronger than traditional ABS. This product offers high strength and low weight which will help ensure that the rockets overall weight stays low while not sacrificing safety. U-bolts will be used for all parachute anchor points in the rocket. All bulk plates used in both recovery sections will be made out of 1/8th inch perpendicularly layered carbon fiber.

4.3.3: **Ejection System**

The Auburn University Student Launch team will be using two different recovery systems within this year's rocket. The lower recovery system will be using black powder charges for separation and lower parachute deployment. Prior to each separation, the drogue and main parachutes will both be stored in their own compartments with two black powder charges with their own independent altimeter. Two charges are included in each compartment to make the system doubly redundant. The exact amount of black powder per charge will be determined once components have been assembled and testing can be performed. The drogue charge will deploy at apogee and the main charge will deploy at 600 ft. Both redundant charges will have a one-second delay on ignition so as not to over pressurize a section and compromise the structural integrity of the airframe. The separation points for the lower recovery system will be above and below the parachute coupler. The black powder charges for the drogue parachute will be located directly aft of the parachute coupler bulk plate and the main parachute black powder charges will be located directly aft of the BAE bottom bulk plate cap.

The upper recovery system will be using a mechanical release to separate the nosecone at 700 ft in a non-energetic event. The team elected to use a mechanical release for the nosecone due to the pressurizing nature of a black powder event. The embedded payload section is located directly below the nosecone and a pressurizing event would damage the sensitive electronics of the rover payload. The mechanical release will consist of two altimeters, a microcontroller and a servo motor. Each altimeter will be connected to its own microcontroller. The two microcontrollers will be wired in tandem in an open circuit containing the servo and a power source. When the altimeters reach the target altitude, they will send a pulse of electricity to the microcontrollers and prompt them to close the circuit for a predetermined amount of time to fully retract the locking arms. A spring positioned between the payload and nosecone parachute will then push the parachute and nosecone out of the rocket allowing it to drift the rest of the way to the ground. A diagram detailing the nosecone recovery system can be seen below in Figure 13: Nosecone Diagram.

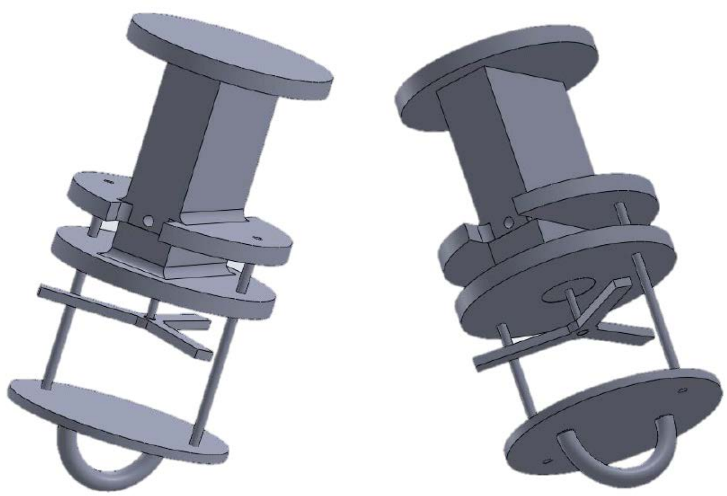


Figure 13: Nosecone Diagram

4.3.4: **Parachutes**

Auburn's double system recovery approach will make use of three separate parachutes designed and constructed in house by the Auburn Student Launch team. The team has been making its own parachutes for six years and has refined its manufacturing process to produce quality, custom parachutes that produce the desired drag and drift for all sections of the rocket. The drogue parachute will be a small, circular parachute constructed of ripstop nylon with paracord shroud lines. Following the first event at apogee, the drogue will be deployed from the middle of the rocket with both halves still connected. This will stabilize descent until main deployment at the second event at 600 feet. Slightly prior to this event the mechanical release will activate, and the nose cone parachute will deploy. When the rocket reaches 600 feet in altitude, a second charge will push off the coupler to release the main parachute. A spill hole will be added to the main parachute. In accordance with the general rule of thumb, the spill holes will be close to 20% of the total base diameters of the chutes. The 20% diameters of the spill holes are chosen because it only reduces the areas of the parachutes by about 4%, allowing enough air to go through the spill hole to stabilize the rocket without drastically altering the descent rate.

A drogue parachute size can be estimated by the following calculation based on the length and diameter of the rocket body.

$$D_{Drouge} = \sqrt{\frac{4 \times L_{Tube} \times D_{Tube}}{\pi}}$$

The team's rocket will have a length of approximately 106 in and a diameter of 6 in, yielding a drogue chute diameter of 28.5 in. The recovery system will have two main parachutes constructed of ripstop nylon with 0.5-inch tubular nylon shroud lines. The main parachute and nosecone parachute will be hemispherical in shape. The hemispherical design can be more difficult to manufacture, but will produce the most drag, allowing the rocket to have maximum drag with minimum weight. A Pugh chart can be seen below comparing different parachute shapes. The shape of the main parachutes and their gores for both 8 and 6 gore configurations can be seen in Figure 14: 6 Gore Template, Figure 15: 8 Gore Template, and Figure 16: Hemispherical Parachute.

	Baseline	Square	Circular	Hemispherical
Drag Produced	3	1	1	2
Ease of Manufacturing	2	1	2	1
Stability	1	2	1	1
Total		7	8	9

Table 5: Parachute Size Pugh Chart

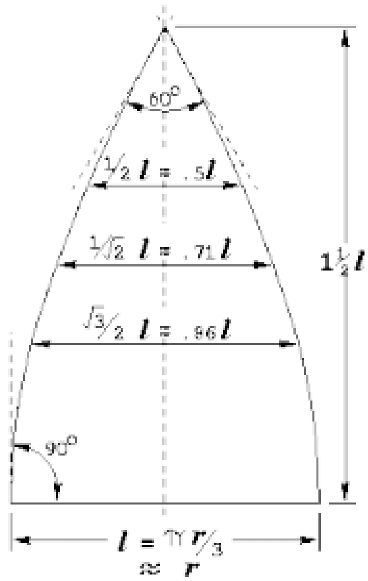


Figure 14: 6 Gore Template

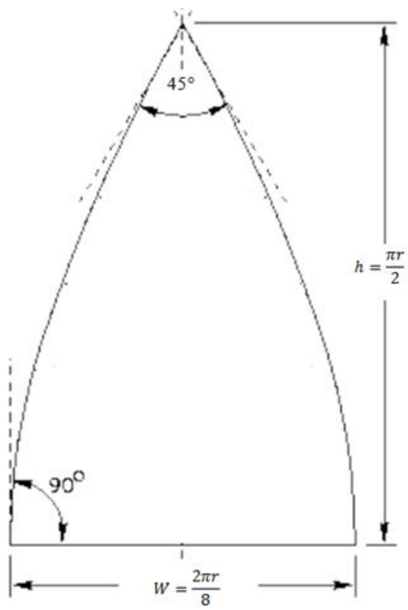


Figure 15: 8 Gore Template

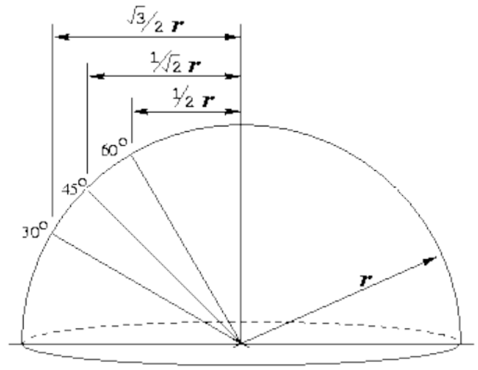


Figure 16: Hemispherical Parachute

The kinetic energy for the rocket upon impact can be calculated using the following formula:

$$KE = \frac{1}{2} m \times V^2$$

Where *m* is mass and *V* is descent velocity. The team will use this equation to solve for descent velocity to determine the size of the parachute. Solving the above equation for *V* yields:

$$V = \sqrt{\frac{2 \times KE}{m}}$$

Auburn Student Launch will apply a factor of safety of 1.5 to the competition kinetic energy requirement of 75 ft-lbs of force upon impact for a target kinetic energy of 50 ft-lbs upon landing. Using this value and an initial mass estimate of 29.7 lbm for the rocket body, the equation above yields:

$$V = \sqrt{\frac{2 \times 50 ft \cdot lb \times 32.2 \frac{ft}{s^2}}{29.7 lb_m}} = 10.4 \frac{ft}{s}$$

Applying the same technique to the nosecone with an initial mass estimate of 8 lbm, the descent velocity equation shows:

$$V = \sqrt{\frac{2 \times 50 ft \cdot lb \times 32.2 \frac{ft}{s^2}}{8 lb_m}} = 20.0 \frac{ft}{s}$$

Parachute areas for hemispherical shaped chutes are determined using the following equation:

$$A = \frac{2 \times F}{\rho \times C_D \times V^2}$$

Where F is force, ρ is density of the air, C_D is the drag coefficient and V is descent velocity. The team will use this equation to calculate an appropriate area for the main parachute so that the kinetic energy of the rocket does not exceed 75 ft-lbs during recovery and remains within safe limits. Testing on hemispherical parachutes done in prior years by Auburn Student Launch has concluded that hemispherical parachutes have a drag coefficient of 1.31. Using this data, estimated mass of 37.3 lbs after burnout with 8 lbs of that being in the nosecone, and descent velocities of 10.4 and 20.0 ft/s calculated above, the team has used the following formula to determine the initial estimate of the size of the main and nosecone parachutes.

$$A_{Main} = \frac{2 \times 29.7_{lbm} \times 32.2 \frac{ft}{s^2}}{0.076474 \frac{lb_m}{ft^3} \times 1.31 \times \left(10.4 \frac{ft}{s}\right)^2} = 176.52\ ft^2$$

$$A_{Nosecone} = \frac{2 \times 8.0_{lbm} \times 32.2 \frac{ft}{s^2}}{0.076474 \frac{lb_m}{ft^3} \times 1.31 \times \left(20.0 \frac{ft}{s}\right)^2} = 12.86\ ft^2$$

	Main Chute	Nosecone Chute
Area	176.5 ft^2	12.9 ft^2
Diameter	127.2 in	17.2 in
Diameter of Spill hole	25.4 in	3.4 in
Number of Gore	8	6
Width of Each Gore at Base	50.0 in	9.0 in
Height of Each Gore	99.9 in	13.5 in
Circumference at Base	33.3 ft	4.5 ft

Table 6: Parachute Sizing Details

4.3.5: **Parachute Construction**

The parachutes will be manufactured at Auburn University by the Auburn Student Launch team members. The drogue parachute will be created by cutting an appropriately sized circle out of orange ripstop nylon. Sizing for the drogue can be seen in Table 6: Parachute Sizing Details. Orange ripstop nylon will be chosen because it is easier to see whether or not the drogue has deployed when compared to blue ripstop nylon. Shroud lines will be attached in four evenly spaced intervals around the drogue with four inches of the paracord being sewn on at each point. Once they are designed, 1:1 gore templates will be made for the main parachutes using SolidWorks. These templates will include an extra inch around the perimeter of the gore for sewing and hemming purposes. Once they are cut out, templates will be lain over the team's stock of orange and blue ripstop nylon and will be used for cutting out all of the gores from the team's stock of orange and blue ripstop nylon. The main and nosecone parachute for the 2018-2019 rocket will consist of 8 and 6 gores respectively. The gores will be sewn together with a butterfly stitch; wherein, the gores will be pinned along the edges and sewn together using strong nylon thread and a straight stitch. These seams will then be inverted and a new seam will be added to encase the first seam. This process will be repeated for all the gores until the parachute is fully assembled and reinforced to ensure safety. After the assembly is completed, the spill-hole will be traced onto the top of the parachute and the excess fabric will be removed. Next the spill-hole edges and the outer circumference of the parachute will be hemmed utilizing a straight stitch. Finally, the shroud lines will be added around the circumference of the parachute. Due to the thickness of the shroud lines, two parallel zigzag stitches – one on each edge of the shroud lines – will be used to attach them firmly to the parachute. Once the parachute is completed, it will be inspected for any flaws in the workmanship or materials that could lead to failure in the recovery system.

4.3.6: **Drift**

The distance the rocket will drift during descent can be estimated with the following equation.

$$Drift = Wind\ Speed \times \frac{Altitude\ Change}{Descent\ Velocity}$$

However, this drift estimation assumes wind speed and descent velocity are constant and does not account for the horizontal distance the rocket travels during ascent. There will be two stages of descent. First, the rocket will descend under the drogue parachute from an altitude of 5111 ft. to 700 ft. At 700 ft. the second event will occur, and the nose cone will separate from the rocket body, continuing the rest of the way to the ground under a separate main parachute. A third event will occur at 600 ft. when a charge will separate the parachute coupler and push the main parachute out. The rate of descent under drogue can be calculated with the following equation:

$$Descent\ Velocity = \sqrt{\frac{2 \times Force}{Air\ Density \times Drag\ Coefficient \times Parachute\ Area}}$$

Using this information and weight of the rocket, the team will be able to calculate an estimated descent velocity. This descent velocity will then be used to ensure drift is kept to a maximum of 2,500 feet away from the launch pad.

4.3.7: **Electronics**

The lower recovery system BAE will house two altimeters to satisfy redundant system requirements. Both altimeters will fire an initial charge at apogee (target altitude: 5111 feet) to separate the rocket at the drogue section and eject the drogue parachute. Then both altimeters will fire main deployment charges at an altitude of 600 ft, separating the parachute coupler from the upper rocket body and releasing the main parachute. At both of these separation points, the separated pieces will still remain attached to one another via shock cord. The altimeters will have a one second firing delay at both apogee and main deployment to avoid compromising the structural integrity of the airframe while still providing redundancy.

The team will use an Altus Metrum TeleMega (Figure 17: TeleMega) as the primary altimeter and an Altus Metrum TeleMetrum (Figure 18: TeleMetrum) as the secondary altimeter in the BAE. Both Altus Metrum altimeters gather flight data via a barometric pressure sensor and an onboard accelerometer. The TeleMega has an advanced accelerometer for more detailed flight data acquisition. Additionally, using two Altus Metrum altimeters will make programming quicker and easier, as they share an interface program. This will ensure that any last minute or on-site changes are more efficient and less prone to error. Altus Metrum altimeters are capable of tracking in flight data, apogee and main ignition, GPS tracking, and accurate altitude measurement up to a maximum of 25,000 feet. This height is much higher than the team's anticipated maximum altitude of 5111 feet. They are also capable of being armed from outside the rocket using a key switch, which is their intended purpose.

Figure 17: TeleMega

Figure 18: TeleMetrum

Another reason that the Altus Metrum altimeters are preferred are their radio frequency (RF) communication capabilities. Both TeleMega and TeleMetrum are capable of communicating with a Yagi-Uda antenna operated by the team at a safe distance during the launch. It can be monitored while idle on the ground or while in flight. While on the ground, referred to as “idle mode,” the team can use the computer interface to ensure that all ejection charges are making proper connections. The main and apogee charges can be fired via the RF link to verify functionality, which will be used to perform ground testing. The voltage level of the battery can also be monitored, and, should the battery dip below 3.8V, the launch can be aborted in order to charge the battery to a safer level. Additionally, the apogee delay, main deploy height, and other pyro events can be configured to almost any custom configuration. The altimeter can even be rebooted remotely. Furthermore, while in flight, referred to as “flight mode,” the team can be constantly updated on the status of the rocket via the RF transceiver. It reports altitude, battery voltage, igniter status, and GPS status. However, in flight mode, settings cannot be configured and the communication is one way from the altimeter to the RF receiver. Both Altus Metrum altimeters transmit on one of ten channels with frequencies ranging from 434.550 MHz to 435.450 MHz.

The nosecone electronics will feature a different set of altimeters. The mechanical release in the nosecone will employ two StratoLogger PerfectFlite altimeters pictured in Figure 19: PerfectFlite StratoLogger. StratoLogger altimeters were chosen for the nosecone for several reasons. StraoLogger altimeters cost less and have a smaller footprint than AltusMetrum altimeters without comprising critical functionality. StratoLogger altimeters are also able to use commercially available 9V batteries. The PerfectFlite model works up to an altitude of 100,000 ft and audibly reports peak altitude and maximum velocity at the end of the flight. When the altimeters reach their predetermined altitude of 700 ft, a one-second-long pulse will be sent to the microcontroller. The team does not plan on putting a delay between firings of the two nosecone altimeters due to the non-energetic nature of the event. The two altimeters will use a pull-pin power switch with the external holes being located on the shoulder of the nosecone.

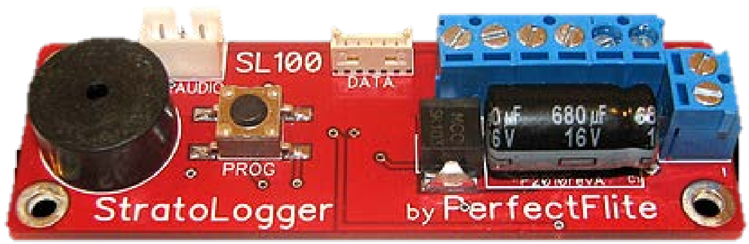


Figure 19: PerfectFlite StratoLogger

The microcontroller that the team has chosen to use for the nosecone electronics is the Adafruit Trinket pictured in Figure 20: Adafruit Trinket. The team will be using this microcontroller because it can accomplish the task that the team needs it to while also being cost, space and weight effective. Once the microcontroller receives a signal from one of the altimeters, it will activate the servo motor and move the locking arms to the open position. A circuit diagram for the nosecone electronics is pictured below in Figure 21: Nosecone Wiring Diagram.

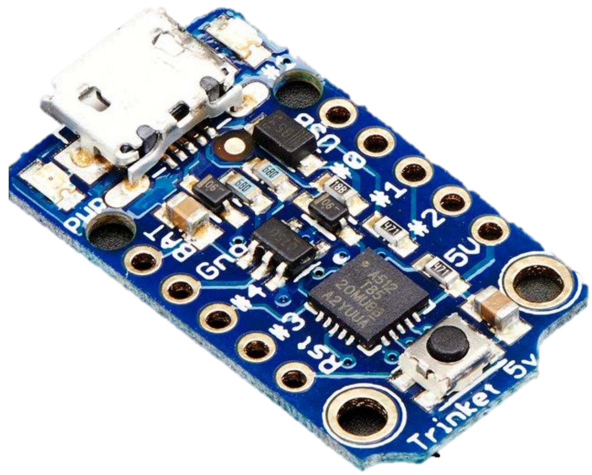


Figure 20: Adafruit Trinket

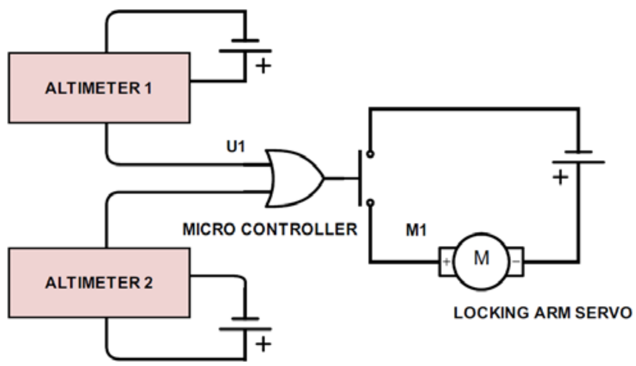


Figure 21: Nosecone Wiring Diagram

In past years, this radio frequency communication has caused trouble due to signal strength. Communication could intermittently be established with the rocket while on the ground, and settings could be configured. Once launched however, connection with the onboard altimeters was soon lost due to weak signal strength. This is likely due to several causes such as the antenna not being straight inside the rocket, the conductive carbon fiber body blocking the signal, or low power output of the altimeter's whip antenna. To prevent these issues, the team will replace the altimeters' default antennae with new antennae. Isolating one altimeter system (altimeter, battery, and wires) from the other will help prevent any form of coupling or cross-talk of signals. Isolation will be realized via distancing the two systems, avoiding parallel wires, and twisting wires within the same circuit. Additionally, the most apparent form of radio-frequency interference (the antennae) will resonate on wires any multiple of ¼ λ (1/4 of ~70cm). Avoiding resonant lengths of wire will be done wherever possible. Within the BAE, the altimeters and batteries will be mounted on opposing sides of the carbon fiber avionics board, with one battery and altimeter per side. Since carbon fiber is an effective shielding material (50dB attenuation), this board will act as shielding between the two altimeters and will minimize cross-talk as well as nearfield coupling. This board will also be easily removable for connecting the altimeters to computers for configuration and for charging the altimeters' batteries. A table comparing the different altimeters and detailing the specifications within the two recovery systems can be seen below in Table 7: Altimeter Specifications

Model	Altus Metrum TeleMega	Altus Metrum TeleMetrum	Stratologger
Dual Deployment	Yes	Yes	No
Telemetry Downlink	70cm ham-band transceiver	70cm ham-band transceiver	-
Barometric Pressure Sensor	Good to 100k ft. MSL	Good to 100k ft. MSL	Good to 100k ft. MSL
Accelerometer	1-axis, 105g, motor characterization/3-axis, 16g, gyro calibration	1-axis, 105g, motor characterization	-
Gyro	3-axis, 200dps,	No	No
On-board GPS	Yes	Yes	No
On-board nonvolatile memory for flight storage data	Yes	Yes	Yes (31 flights)
Power, configuration, data recovery interface	USB	USB	USB
Board size	3.25" x 1.25"	2.75" x 1"	2.75" x 0.9" x 0.5"
Weight	-	-	12.8 grams
Microcontroller	STM32L151 ARM Cortex M3	STM32L151 ARM Cortex M3	-
Regulator	STM32L151 ARM Cortex M3	STM32L151 ARM Cortex M3	-
Range	120kPa to 1kPa	120kPa to 1kPa	-
Precision	2.4Pa	2.4Pa	+/- 0.1%
Inertial Sensor	SPI Interface, +- 105g, on-chip 12-bit digitizer	SPI Interface, +- 105g, on-chip 12-bit digitizer	None
Magnetometer	3-axis	None	None

Table 7: Altimeter Specifications

4.4: Motor Selection

The rocket motor initially selected for the competition is the Aerotech L1420R. The L1420's specifications are listed below in Table 8: Motor Specifications. Additionally, the thrust curve for this motor is shown in Figure 22: Motor Thrust Curve below:

Motor Specifications	
Manufacturer	AeroTech
Motor Designation	L1420R
Diameter	2.95 in
Length	17.44 in
Impulse	4616.31 N-s
Total Motor Weight	160.92 oz
Propellant Weight	90.30 oz
Propellant Type	APCP
Average Thrust	320.31 lb_f
Maximum Thrust	373.76 lb_f
Burn Time	3.24 s

Table 8: Motor Specifications

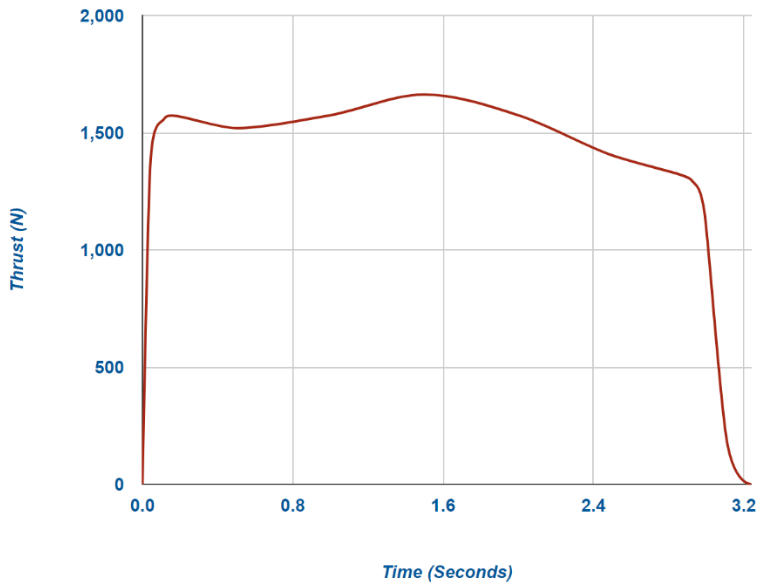


Figure 22: Motor Thrust Curve

4.5: Payload Design (Rover)

4.5.1: **Rover Orientation System (ROS)**

The orientation of the rover upon its departure from the launch vehicle was a driving factor in its design. A trade study was conducted to decide between a rover that could operate on both sides and one that required an orientation system to deploy the rover in the correct orientation. This Rover Orientation System was decided to be the best option.

The ROS will utilize a turntable bearing at the rear and three press fit type ball transfer units to support the front end of the sled used to carry the rover. The ROS will correct the rover's position using a passive weight driven orientation correction. The sled will be kept from rotating during ascent by a pin tethered to the nose cone. The pin will be released when the nose cone falls away during descent, allowing the ROS to freely spin upon landing.

4.5.2: **Rover**

The rover will deploy 3D printed tracks to facilitate movement. Tracked vehicles have continuously proven that they provide the most traction across all possible terrains that our rover may encounter. The rover will be powered by two contained motors, one for each track to allow for possible navigation. All the required electronics will be contained between these tracks in a 3D printed body in a low lying configuration. A retention system that anchors the rover to the ROS will be housed in the rear of the rover. This device will use a motor that raises an arm to unhook the rover from the ROS after the signal has been sent to begin operations. To complete the experiment of collecting a 10 mL soil sample, an arm will deploy from the inside of the rover once it has reached its final destination. This arm will consist of an inch wide belt with multiple buckets placed at equal intervals. This belt will rotate for a predetermined time along the length of the arm scooping up soil at the far end of the rover and depositing the sample into a container within the rover. The sample will then be covered by a sliding cover to contain it safely. The arm will utilize a servomotor to deploy and keep the arm at a constant force against the ground. A separate stepper motor will rotate the belt.

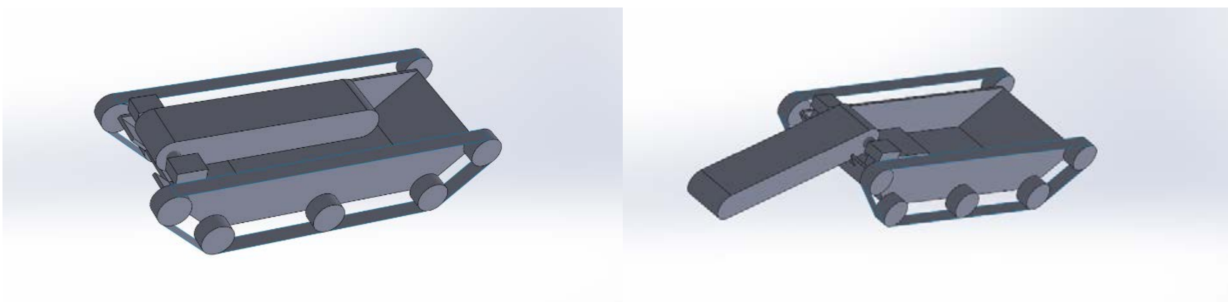


Figure 23: Left: Rover in closed, transport configuration. Right: Rover in extended, working configuation.

4.5.3: **Electronics**

The rover requires 6 motors. Four "1000:1 12V Pololu Micro Metal Gearmotors" will be used to turn the tracks, turn the soil collection belt, and close the soil containment system. This motor proved to provide the required torque to move the rover in a small package. The rover retention system will use an "Adafruit TowerPro SG-501" servomotor to hold the rover in place during launch until landing. The final motor will pivot the soil collection belt. A servomotor with a control area up to 270 degrees was required and a "LewanSoul LD-3015MG" servomotor fulfills this requirement. For controlling the rover, the team has decided to use an Arduino Uno as they are simple to code and the team has previous experience with them. An Adafruit 10-DOF IMU Breakout will be used to calculate the acceleration and orientation of the rover. The IMU Breakout consists of a 3-DOF accelerometer, a 3-DOF gyroscopic sensor, a 3-DOF compass and barometric pressure/temperature gauge. To activate the rover, an SMS text message will be sent to an Arduino

GSM Shield attached to the rover body. The accelerometer will be used to ensure the rover moves more than 10 feet from the launch vehicle. When this requirement is met, the rover will be at its final destination and deploy the soil collection device.

4.6: Altitude Control

To ensure the vehicle reaches its target altitude, a drag system will be utilized again this year. This year's design will be similar to last year's system. Drag plates will be embedded inside the body of the vehicle and will be actuated out by a single motor, perpendicular to the airflow. The team prefers to use a single motor to reduce the complexity of the system while increasing safety. However, two plates will be used instead of three, since this allows more effective surface area due to the size constraints of the vehicle. Rudimentary CFD analysis showed that two plates with an effective frontal surface area of 6.5 in^2 each increases the total drag force of the vehicle by roughly 80%, providing sufficient stopping power. A PID controller will be used to control the position of the drag plates. The projected altitude of the vehicle is calculated and compared with the target altitude to determine the position the plates should be set to. The projected equation can be calculated by using the following equation:

$$y_{max} = \frac{{v_t}^2}{2g} ln(\frac{{v_0}^2 + {v_t}^2}{{v_t}^2}),$$

where,

$$v_t = \sqrt{\frac{2mg}{C_d A\rho}}$$

C_d is not a known quantity, however, we also have the following equation:

$$a = -g - \frac{C_d A\rho v^2}{2m}$$

Solving for C_d results in:

$$C_d = -\frac{2m}{A\rho v^2}(a + g)$$

Plugging this back into the equation for v_t and simplifying gives us the following equation:

$$v_t = \sqrt{\frac{v^2 g}{-(a + g)}}$$

This eliminates the need for C_d, as well as ρ. We now have an equation for v_t as a function of acceleration and velocity, which can be calculated using sensors. Plugging this new equation for v_t into the equation for y_{max} and simplifying results in the following equation:

$$y_{max} = -\frac{v^2}{2(a + g)} \ln\left(-\frac{a}{g}\right)$$

The projected altitude can then be calculated using this equation and adding it to the current altitude of the vehicle. In addition, a Kalman filter will be applied to each sensor's signal to filter the output, yielding a more accurate projected altitude calculation. The block diagram in Figure 20: Controller Block Diagram outlines the current setup of the controller.

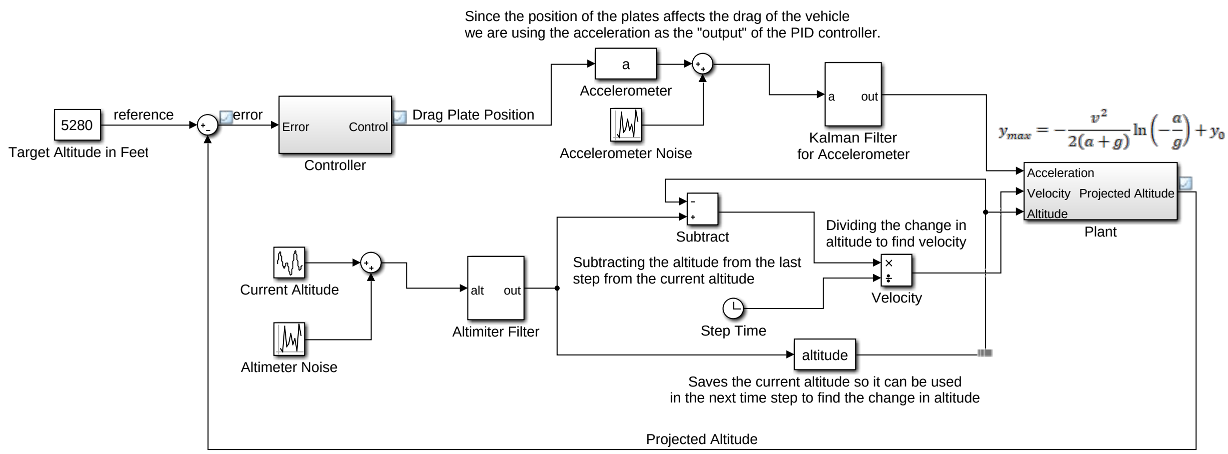


Figure 24: Controller Block Diagram

Figure 25: Rocket with drag plates extended

4.6.1: **Structure**

The drag plates and the internal structure of the drag plate assembly will primarily be 3D printed with onyx, a mixture of carbon fiber and nylon. The entire structure will be attached to a coupler that sits between the booster section and the recovery section, which will allow the team to have its own section while optimizing space. The drag plates will be mounted to aluminum rods and will be actuated by the motor via a rack and pinion. The electrical components will be attached to printed trays, which can be taken out separate from the rest of the assembly. This gives the team the ability to work on the electrical components separately.

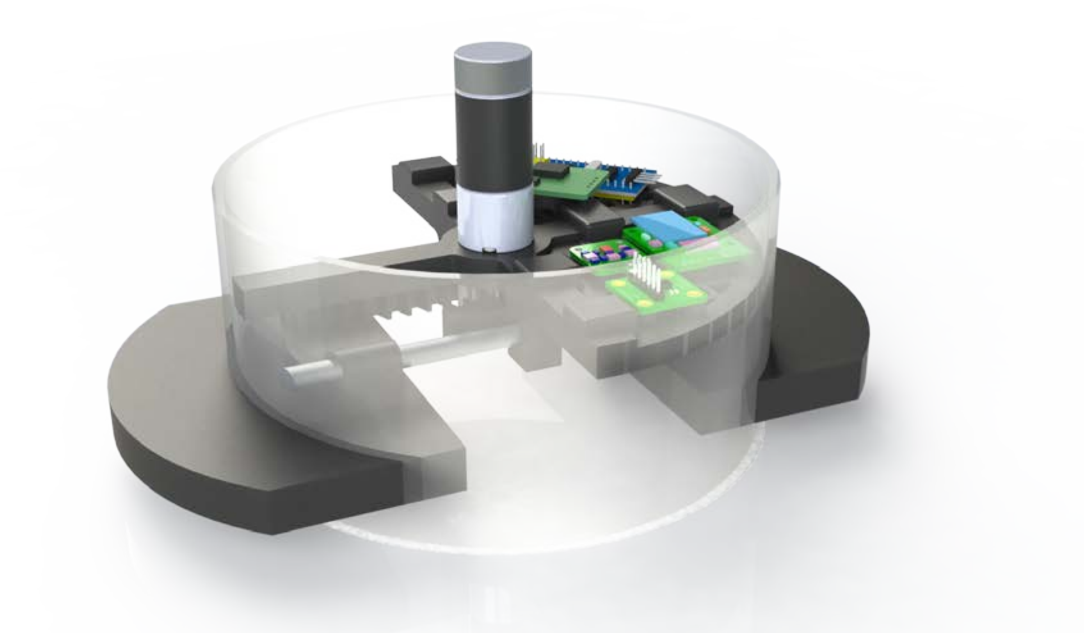


Figure 26: Conceptual Rendering

4.6.2: **Electronics**

This year the team will be using a STM32F103C8 microcontroller (commonly known as "Blue Pill") instead of an Arduino Uno. Last year the team had issues with the Uno as there was not enough memory to handle the size of the code. A quick trade study was done to weigh the pros and cons of each microcontroller, which can be seen in Table 9: Microcontroller Trade Study.

The Blue Pill has more RAM as well as increased computational power. It consists of a 32-bit processor running at 72 MHz with 64 KB of flash memory and 20 KB of RAM. This is opposed to the Uno’s 8-bit processor running at 16 MHz, with 32 KB of memory and 2 KB of ram. In addition, the Blue Pill is much smaller than the Uno, which gives the team more space to work with inside the vehicle. However, the Blue Pill is not as easy to use as the Uno and requires additional setup and configuration to work with other electrical devices.

Microcontroller Trade Study		
Categories	STM32F103C8	Arduino Uno
Processing Power	5	2
Memory	4	1
Size	4	2
Integration	1	5
Total	14	10

Table 9: Microcontroller Trade Study

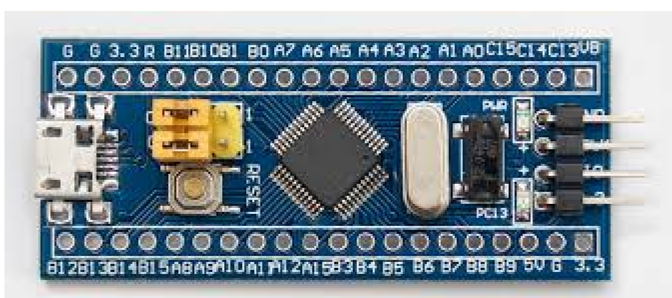


Figure 27: STM32F103C8 (“Blue Pill”)

The team also plans to use a different DC motor. Last year the team used a NeveRest 40 Gear motor, which was very heavy and large. The team decided that the NeveRest was overkill for the current assembly and opted for a smaller motor. The team is currently looking at the 280 RPM gear motor offered by ServoCity, outlined in the trade study in Table 10: DC Motor Trade Study. An image of the ServoCity motor can be seen in Figure 24.

DC Motor Trade Study		
Categories	NeveRest 40 Gear Motor	Robotzone 280 RPM Planetary Gear Motor
Weight	2	5
Power	4	2
Size	2	4
Total	8	11

Table 10: DC Motor Trade Study

The projected altitude calculation requires knowing the acceleration and velocity of the vehicle. The acceleration can be calculated by simply using an accelerometer. However, the velocity of the vehicle cannot be calculated accurately using the accelerometer alone. A real time clock module will be used to measure the velocity of the vehicle by dividing the change in altitude per unit time.

Figure 28: Planetary Gear Motor with Encoder. The 26 RPM model is depicted; however, the 280 RPM has the same dimensions.

The team has decided to use the DS3231 module from Adafruit to measure time accurately. The rest of the components the team plans to use is provided as components listed in Table 15: Altitude Control Expense Summary.

4.7: Requirements Verification

4.7.1: **General Requirements**

Requirement Number	Description	Verification Method
1.1	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	Demonstration: During the course of the competition, the team's mentor will only assemble the motor and handle the ejection charges and electronic matches, with all other tasks performed by students on the team.
1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	Inspection: The team will include a detailed project timeline, educational engagement plan, and safety risk and mitigations with proposal, and release additional documentation as early as possible.
1.3	Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during certain activities.	Demonstration: Foreign National team members will be identified by PDR and will understand that they may be separated from the team during certain launch week activities.
1.4	The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include: 1.4.1. Students actively engaged in the project throughout the entire year. 1.4.2. One mentor (see requirement 1.13). 1.4.3. No more than two adult educators.	Demonstration: The team will identify all team members attending launch week activities by CDR. Members attending launch week will be students, one mentor, and two adult educators
1.5	The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering,	Demonstration: The team will engage far more than 200 participants in educational STEM activities prior to FRR. All events

	and mathematics (STEM) activities, as defined in the STEM Engagement Activity Report, by FRR. To satisfy this requirement, all events must occur between project acceptance and the FRR due date and the STEM Engagement Activity Report must be submitted via email within two weeks of the completion of the event.	will have their Educational Activity Report submitted via email within two weeks of the event.
1.6	The team will establish a social media presence to inform the public about team activities.	Demonstration/ Inspection: The team has an Instagram and Facebook account and will update both regularly.
1.7	Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient.	Demonstration: The team will email all deliverables to the NASA project team prior to the specified deadlines, utilizing a link to download if the deliverable is too large.
1.8	All deliverables must be in PDF format.	Demonstration: All deliverables will be in PDF format.
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Demonstration: All reports will include a table of contents.
1.10	In every report, the team will include the page number at the bottom of the page.	Demonstration: All reports will include a page number at the bottom of the page.
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	Demonstration: The team will utilize a conference room within the Aerospace Engineering building that will provide a video camera, speaker telephone and internet connection, while a team member will provide the computer.
1.12	All teams will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted on the launch field. Eight foot 1010 rails and 12 foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on launch day. The exact cant will depend on launch day wind conditions	Test: The rocket will be designed to fit on either 1010 or 1515 launch rails. During construction it will be verified to fit on the planned type of launch rails using a test segment of the same type of launch rail.

1.13	Each team must identify a “mentor.” A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend launch week in April.	Demonstration: The team has already identified its mentor as Dr. Eldon Triggs. Dr. Triggs has a current level 2 certification from the Tripoli Rocketry Association and is in good standing.

4.7.2: **Vehicle Requirements**

Requirement Number	Requirement Statement	Verification Method and Execution of Method
2.1	The vehicle will deliver the payload to an apogee altitude between 4,000 and 5,500 feet above ground level (AGL).	Analysis, Demonstration, Testing - Launch vehicle and check altimeters
2.2	Teams shall identify their target altitude goal at the PDR milestone.	Demonstration- Launch vehicle and check altimeters
2.3	The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner.	Inspection, Demonstration- Purchase and calibrate one commercially available altimeter.
2.4	Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Demonstration - Test the altimeter arming switch to verify it works
2.4	Teams may have additional altimeters to control vehicles electronics and payload experiment(s).	Demonstration- The team may use additional altimeters
2.5	Each altimeter will have a dedicated power supply.	Inspection, Demonstration- The team will design altimeters with separate power supplies.
2.6	Each arming switch will be capable of being locked in the ON position for launch	Inspection, Demonstration- Ensure arming switch can be locked in the ON position.
2.7	The launch vehicle shall be designed to be recoverable and reusable. Reusable defined as being able to launch again on the same day without repairs or modifications.	Testing, Analysis, Demonstration, Inspection - Trajectory simulations and testing will ensure the launch vehicle is recoverable and reusable
2.8	The launch vehicle shall have a maximum of four (4) independent sections.	Demonstration - Team will design and build launch vehicle that can have, but does not require, four independent sections

2.8.1	The official, marked altimeter is damaged and/or does not report an altitude via a series of beeps after the team's competition flight.	Inspection, Analysis, Testing - Design the electronics housing to prevent damage to altimeter
2.8.2	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.	Demonstration - The team is timely and organized in gathering data and reporting to NASA official
2.9	The launch vehicle shall be limited to a single stage.	Demonstration - Team will design and build a single-stage launch vehicle
2.10	The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal Aviation Administration flight waiver opens.	Demonstration - Team will be timely and organized to ensure vehicle is prepared on time
2.11	The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 2 hours without losing the functionality of any critical on-board component.	Demonstration - Team will design vehicle with ability to remain launch-ready for at least one hour.
2.12	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.	Testing - Batteries shall be tested with full electronics to verify their life
2.13	The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by launch services provider).	Demonstration - The team will design a vehicle requiring no external circuitry or special ground support equipment
2.14	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and	Demonstration Vehicle will be designed around commercially available, certified motors

	certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	
2.14.1	Final motor choices must be made by the Critical Design Review (CDR).	Demonstration - CDR will determine which motor the team will use for competition
2.14.2	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.	Demonstration - If the change is made to increase safety margin, NASA RSO will allow the change
2.15	Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria:	Analysis, Testing - Inspection of pressure vessel by RSO standards by testing.
2.15.1	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.	Inspection, Analysis, Testing- Team will design the pressure vessels to have a factor of safety of 4:1.
2.15.2	Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	Inspection, Analysis, Testing - Inspection of each pressure vessel and testing of the pressure relief valve to see that it works correctly
2.15.3	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.	Inspection, Demonstration- The team will inspect the tank along with documentation of testing and history
2.16	The total impulse provided by a College and/or University launch	Demonstration, Analysis-

	vehicle shall not exceed 5,120 Newton-seconds (L-class).	The team will choose a motor with a total impulse that does not exceed 5,120 Newton-seconds (L-class).
2.17	The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	Testing, Demonstration, Analysis- The team will design and test the vehicle to ensure that it has a stability margin of 2.0 at the point of rail exit
2.18	The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	Demonstration, Analysis, Testing - The team will design the and test the vehicle to ensure that it's minimum velocity at rail exit is at least 52 fps.
2.19	All teams shall successfully launch and recover a subscale model of their rocket prior to CDR.	Demonstration, Testing - A demonstration of the launch will be exhibited through testing.
2.19.1	The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used at the subscale model.	Demonstration - The subscale model will be designed to resemble and perform similarly to the full-scale model.
2.19.2	The subscale model will carry an altimeter capable of reporting the model's apogee altitude.	Demonstration - An altimeter capable of reporting the model's apogee altitude will be implemented on the subscale model.
2.19.3	The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	Demonstration - The team will construct a subscale specifically for this year's vehicle.
2.19.4	Proof of a successful flight shall be supplied in the CDR report.	Testing, Demonstration - The team will send use altimeter data to proof a successful flight.
2.20	All teams will complete demonstration flights as outlined below.	
2.20.1	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	Testing, Demonstration, Analysis - A test of the rocket will be exhibited, demonstrating all hardware functions properly.

	flown of launch day. The following criteria must be met during the full-scale demonstration flight:	
2.20.1.1	The vehicle and recovery system shall have functioned as designed	Testing - Testing of vehicle will show how recovery system functions.
2.20.1.2	The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	Demonstration - The team will build a vehicle specifically for this year's competition.
2.20.1.3	The payload does not have to be flown during the full-scale test flight. The following requirements still apply:	
2.20.1.3.1	If the payload is not flown, mass simulators shall be used to simulate the payload mass.	Testing, Demonstration, Analysis- Payload will be flown
2.20.1.3.2	The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.	Inspection- Inspection of the rocket payload will be done by the team to ensure it is properly placed.
2.20.1.4	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 activated during the full-scale demonstration of flight	Demonstration, Testing- Demonstration of the adaptability of the systems notice to payload changes of the external surfaces through testing.
2.20.1.5	Teams shall fly the launch day motor for the Vehicle Demonstration Flight.	Inspection- The team will ensure that the motor will be the one used on launch day.
2.20.1.6	The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight.	Testing, Demonstration- Testing of the ballast systems to ensure proper mass locations.
2.20.1.7	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the	Demonstration- The team will demonstrate that it did not alter any components or vehicle after demonstration flight.

	concurrence of the NASA Range Safety Officer (RSO).	
2.20.1.8	Proof of a successful flight shall be supplied in the FRR report.	Demonstration, Testing- The team will use altimeters to verify a successful flight
2.20.1.9	Vehicle Demonstration flights must be completed by the FRR submission deadline (March 4, 2019).	Demonstration- The full-scale flight will be completed by March 4th, 2019,
2.20.2	Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline (March 25, 2019).	Demonstration - The payload demonstration flight will be completed by the FRR submission (March 4th, 2019).
2.20.2.1	The payload must be fully retained throughout the entirety of the flight, all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair.	Demonstration, Testing- The team will demonstrate the payload being fully secured during flight.
2.20.2.2	The payload flown must be the final, active version.	Demonstration, Testing- The team will use the final active payload during flight.
2.20.2.3	If the above criteria is met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.	Demonstration- The additional flight will not be flown, if the above criteria is met.
2.20.2.4	Payload Demonstration Flights must be completed by the FRR Addendum deadline.	Demonstration- The payload demonstration flight will be completed by March 25th, 2019.
2.21	An FRR Addendum will be required for any team completing a Payload	Analysis- The FRR Addendum will be finished if a re-flight is required.

	Demonstration Flight or NASA-required Vehicle Demonstration Re-flight after the submission of the FRR Report.	
2.21.1	Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly the vehicle at launch week.	Analysis- We will abide by the rules and not fly.
2.21.2	Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly the payload at launch week.	Analysis- We will abide by the rules and not fly with the payload.
2.21.3	Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week.	Analysis- The team will listen to the NASA RSO on permission for flying with the payload.
2.22	Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	Demonstration - Team will design all structural protuberances on the vehicle to be aft of the burnout center of gravity.
2.23	The team’s name and launch day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe.	Demonstration - The team will design the vehicle as to have contact information and the team’s name on the airframe of each piece of the rockets.

4.7.3: **Vehicle Prohibitions**

Requirement Number	Requirement Statement	Verification Method and Execution of Method
2.24.1	The launch vehicles shall not utilize forward canards.	Demonstration - The team will demonstrate how the launch vehicle does not utilize canards.
2.24.2	The launch vehicle shall not utilize forward firing motors.	Demonstration - The team will design the vehicle so that it does not utilize forward firing motors.
2.24.3	The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	Demonstration- The team will not utilize a motor that expels titanium sponges.
2.24.4	The launch vehicle shall not utilize hybrid motors.	Demonstration - The team will not utilize a hybrid motor.
2.24.5	The launch vehicles shall not utilize a cluster of motors.	Demonstration - A demonstration and inspection of the launch vehicle shall be carried out to validate it does not use a cluster of motors.
2.24.6	The launch vehicle shall not utilize friction fitting for motors.	Demonstration - The team will design the vehicle so that it does not utilize friction fitting for the motor.
2.24.7	The launch vehicle shall not exceed Mach 1 at any point during flight.	Demonstration ,Testing, Analysis - The team will test and demonstrate to ensure that the vehicle does not exceed Mach 1 at any point during the flight.
2.24.8	Vehicle Ballast shall not exceed 10% of the total weight of the rocket.	Demonstration, Testing ,Analysis- The team will design ballast so that it does not exceed 10% of the total weight of the rocket.
2.24.9	Transmissions from onboard transmitters will not exceed 250 mW of power.	Demonstration, Testing- The team will design transmitters that will not exceed 250 mW of power.
2.24.10	Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	Demonstration- The team will design the vehicle to ensure it does not use dense metals.

4.7.4: **Recovery Requirements**

Requirement Number	Description	Verification Method
3.1	The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.	The team will stage the deployment of our recovery devices with a drogue parachute deployed at apogee, currently specified at 5111 ft. before altitude control.
3.1.1	The main parachute shall be deployed no lower than 500 feet.	The team will stage the deployment of our recovery devices with the main parachute at 600 ft.
3.1.2	The apogee event may contain a delay of no more than 2 seconds.	A redundant altimeter will be in place with an apogee delay of 1 second.
3.2	Each team 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.	Prior to the initial subscale and full scale launches the team will perform a ground ejection test for both the drogue and main parachute.
3.3	At landing, each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	The team will calculate and test both sections of our launch vehicle to ensure that a maximum kinetic energy of 75 ft-lbf at landing is not exceeded.
3.4	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	The team will create independent circuits for our recovery system so that they are independent of any payload electrical circuits.

3.5	All recovery electronics will be powered by commercially available batteries.	All recovery electronics included in the recovery systems will be powered by commercially available batteries.
3.6	The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple and more sophisticated flight computers.	The recovery systems will contain TeleMetrum and TeleMega altimeters for the BAE, and two Stratologger altimeters for the nose cone.
3.7	Motor ejection is not a permissible form of primary or secondary deployment.	The recovery system will not use motor ejection as a form of primary or secondary deployment.
3.8	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Removable shear pins will be used for both the main parachute and drogue parachute compartments.
3.9	Recovery area will be limited to a 2,500 ft. radius from the launch pads.	The team will ensure recovery area will be less than a 2,500 ft. radius from the launch pads.
3.10	Descent time will be limited to 90 seconds (apogee to touch down).	The team will limit the descent time to under 90 seconds.
3.11	An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	The team will install an electronic tracking device in the launch vehicle that will transmit the position of both independent sections to a ground receiver.
3.11.1	Any rocket section or payload component which lands untethered to the launch vehicle will contain an active electronic tracking device.	Both independent sections of the launch vehicle will contain and active electronic tracking device.
3.11.2	The electronic tracking device(s) will be fully functional during the official flight on launch day.	The team will test the electronic tracking devices to ensure their functionality for the official flight on launch day.

3.12	The recovery system electronic will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The team will test the recovery system electronic to ensure it is not affected by any other on-board electronic devices.
3.12.1	The recovery system altimeters will 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 located in separate compartments within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.
3.12.2	The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The team will ensure that the recovery system electronics will be shielded from any and all transmitting devices to avoid any excitation of said electronics.
3.12.3	The recovery system electronics will 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.	The recovery electronics will be sealed in their own separate compartment separate from all other magnetic wave including devices in the rocket.
3.12.4	The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The recovery electronics will be sealed in their own separate compartment from all other magnetic wave inducing devices in the rocket.

4.7.5: **Rover Requirements**

Requirement Number	Description	Verification Method
4.3.1	Teams will design a custom rover that will deploy from the internal structure of the launch vehicle.	Design: Tracked rover and orientation system will be completely housed inside the body of the rocket.
4.3.2	The rover will be retained within the vehicle utilizing a fail-safe active retention system. The retention system will be robust enough to retain the rover if atypical flight forces are experienced.	Testing: A servomotor held within the rover will hold onto an anchor point.
4.3.3	At landing, and under the supervision of the Remote Deployment Officer, the team will remotely activate a trigger to deploy the rover from the rocket.	Testing: Communicate via SMS message to rover to activate deployment.
4.3.4	After deployment, the rover will autonomously move at least 10 ft. (in any direction) from the launch vehicle. Once the rover has reached its final destination, it will recover a soil sample.	Testing: A 3-axis accelerometer will be used to determine distance from launch vehicle. At final destination soil recovery device will activate.
4.3.5	The soil sample will be a minimum of 10 milliliters (mL).	Testing: Soil recovery device will run for a designated amount of time.
4.3.6	The soil sample will be contained in an onboard container or compartment. The container or compartment will be closed or sealed to protect the sample after collection.	Testing: An integrated container will hold the sample, and a motor will extend a cover to contain the sample.
4.3.7	Teams will ensure the rover's batteries are sufficiently protected from impact with the ground.	Testing: A slot for the batteries will be a priority when designing the rover so they will be integrated seamlessly in a safe, padded location.
4.3.8	The batteries powering the rover will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other rover parts	Design: All hazardous elements of the rover will be marked with a bright red color and be visible from the outside without moving parts to access them.

4.7.6: **Safety Requirements**

Requirement Number	Description	Verification
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	Demonstration - The team will develop and utilize their launch and safety checklists at all flights (testing and at competition) and at LRR
5.2	Each team must identify a student safety officer who will be responsible for all items in section 5.3.	The team has identified Jackson Treese as the student safety officer
5.3.1	Monitor team activities with an emphasis on Safety during: 1. Design of the vehicle and payload 2. Construction of the vehicle and payload 3. Assembly of the vehicle and payload 4. Ground testing of the vehicle and payload 5. Sub-scale launch test(s) 6. Full-scale launch test(s) 7. Launch Day 8. Recovery activities 9. STEM Engagement Activities	Demonstration- The Safety team will be present during all activities by virtue of being embedded within every team, and will monitor all activities to ensure that they are performed safely
5.3.2	Implement procedures developed by the team for construction, assembly, launch and recovery activities	Demonstration – During their duties while embedded in the other teams, safety liaisons will record the procedures that their teams follow, recording best practices and ensuring that safety checks are implemented.
5.3.3	Manage and maintain current revisions of the team's hazard analysis, failure analysis, and procedures and MSDS/inventory data	Demonstration – The safety team will maintain current revisions of all required documents
5.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Demonstration – The safety team will assist in writing all required documents
5.4	During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	Analysis, Demonstration – During test flights and design, the team will ensure that all aspects of the rocket are compliant with launch site requirements.
5.5	Teams will abide by all rules set forth by the FAA.	Demonstration – The team will abide by all rules set forth by the FAA

4.8: Major Technical Challenges and Solutions

As the Auburn team continues to mature its design, it has identified the major technical challenges ahead and potential solutions to them.

Team	Design Challenges Faced	Potential Solutions
Vehicle Body	Need to create a smooth surface around the iso-grid for aerodynamic efficiency	Wrapping a single layer of pre-preg carbon fiber around the isogrid structure could provide a relatively low weight and easily applicable outer coating to the main body tube
		Filling the iso-grid tube with a dissolvable foam and sanding the foam such that it was flush with the outer edge of the iso-grid would provide a relatively smooth and level surface for filament winding
Recovery	Nose cone release cannot use a black powder charge	Some form of mechanical ejection system could be designed to more effectively and safely separate the nose cone from the rest of the launch vehicle, as described in 4.3.3: Ejection System
	Need a more reliable altimeter system	A trade study into different altimeter bay layouts could be conducted in order to determine a more efficient and reliable system
	Ensure the black powder charges used in main separation generate sufficient pressure	Ensure the amount of black powder used for successful separation test is documented and used for all further vehicle launches
	Ensure the main parachute is always loaded properly	Establish a procedure for packing both the drogue and main parachute, and ensure it is followed during all launches
	Phase out Jolly Logic parachute release system	The parachute release could be paired with the main separation programming
Embedded Systems	Instruments create too much data noise for the altitude control system to sort through	The PID controller could be set to accept the average value of small data sets rather than every piece of data in order to streamline the flow of data being analyzed
Rover	Need to increase effective battery life	A more robust power system needs to be designed in order to ensure the rover can stay powered on the launch pad for the required two hours and still remain effective. A trade study into

		different batteries and power sources could be conducted to determine the most effective and efficient option
	Rover will require new motors for propulsion	A trade study into various motors will need to be conducted in order to select a motor capable of propelling the rover over any terrain it might encounter
	Rover bay design was not robust enough to successfully deliver the rover	Rover bay will be redesigned with a new release mechanism, a new deployment system, and a new method of ensuring the rover remains right way up

5. STEM Engagement

5.1: General Statement

The Auburn University Student Launch (AUSL) team is entering an exciting new era of growth, influence and leadership, as devotion for the future advancement of aeronautical and astronautical engineering swells throughout the department. The team truly aspires to instill a passion for science, technology, engineering, mathematics (STEM) and rocketry in young students here on the Plains.

There are many middle school, high school, and college students that possess talents in math and science, and they may aspire to pursue STEM careers in the future. Auburn University students have great influence in the Auburn community. AUSL plans to use its influence to enrich the minds of young students in Auburn and enable them to realize their full potential for STEM careers.

5.2: Drake Middle School 6th Grade Rocket Week

Date: Spring 2019, exact week TBD

This year, the team's primary plans begin with its venture in engaging young students by bringing a hands-on learning experience for the sixth-grade class of J.F. Drake Middle School (DMS). The program is entitled DMS 6th Grade Rocket Week, and the goal of the program is to encourage interests in STEM and rocketry through an interactive three-day teaching curriculum that will reach approximately 700 middle school students.

The sixth-grade science curriculum at DMS has a space unit during the school year. Therefore, the rocketry unit curriculum will include lessons about rocketry and the forces that cause a rocket to fly. Then, students will be divided into teams of 2-3 and provided a small alpha rocket to construct and launch under the supervision of AUSL and certified professionals. This program was successfully implemented during the 2013-2014 school year, and we have continued our relationship every year since then.

5.2.1: **Rocket Week Plan of Action**

Day 1: AUSL members will come to each sixth-grade science classroom and present a presentation on rocketry and how it works. The members will engage the students during the presentations with questions and answering their questions. If the presentation finishes before the end of class, the students will begin on their rockets.

Day 2: The students will be split into teams of 2-3 and given a small alpha rocket assembly kit and the required materials to build and decorate the rocket. AUSL members and the teachers will lead the students in building and answers any questions that occur from the rocket building. All the rocket building should finish on this day.

Day 3: All science classes will head to the P.E. field on DMS's campus during each period throughout the day. Students will also be informed of all safety and launch procedures for the event when they first arrive on the field. A summary of what will take place at the launch and a launching order will be announced on this day.

The launch day will be held on the DMS P.E. field on the third and final day of the program. Each period of the school day, four or five science classes will proceed to the launch field. There will be multiple launch rails set up in sanctioned safe zones in different parts of the field, meeting all

Figure 29: Picture of sixth graders on Launch day for Rocket Week for spring 2018.

NAR Safety Guidelines for launching model rockets. After the rockets are inspected to ensure they are safe to launch, one student per launch rail will be sent to the launch location where an AUSL member will help each student set up and launch the rocket. A permission slip will require parental permissions for students to launch rockets.

5.3: Samuel Ginn College of Engineering E-Day

Date: February 22, 2019

E-Day is an annual open house event during which middle and high school students and teachers from all over the southeast are invited to tour Auburn University's campus. AUSL will be participating in the event to promote aerospace engineering, rocketry, the organization, and NASA's Student Launch competition. Students will be informed of the current activities that AUSL is involved in, and they can learn how they, too, could join organizations like AUSL while at Auburn. At least 3,000 students and teachers attended E-Day in the past. More than half of the attendees were exposed to the work and activities that AUSL performs and learned about the Auburn rocket team's accomplishments in the NASA Student Launch competition. The same results are expected for E-Day 2019 in February.

Figure 30: USLI team members talking to E-Day visitors of spring 2018.

5.4: Boy Scouts of America: Space Exploration Badge

Date: TBD

Through AUSL, scouts from Boy Scouts of America can receive the Space Exploration Badge. The Space Exploration Badge is meant to persuade young scouts to explore the mysteries of the universe and build rockets. The boy scouts will be led by students in AUSL to learn about rocketry and build rockets. After the rocketry are inspected, they will be launched at the small rocket launch fields south of Auburn University's campus. This event began in 2016, and AUSL plans on continuing working with the Boy Scouts this year. There is a Boy Scouts Engineering event during the school year that scouts come to earn many badges, such as the Space Exploration Badge. AUSL plans on coordinating with this event to set up a day to lead scouts in earning this Badge with rocketry.

This event is planned to take up a single day on a weekend. The scouts will arrive to the Davis Aerospace Engineering Building on Auburn University's Campus where they will learn about rocketry. Afterwards, they will be lead in building model rockets by AUSL members. AUSL members will inspect the rockets for checking the integrity of the build. Then the scouts and AUSL members will travel to the launch fields south of campus to help the scouts launch the rockets.

Figure 31: AUSL members setting up rockets for the Boy Scouts to launch for the Boy Scout event in spring 2018.

5.5: Girl Scouts of America

Date: TBD

Figure 32: AUSL pose with Girl Scouts and their rockets after launching in spring 2018

AUSL worked with other organizations in Auburn last spring to host an Engineering Day with the Girl Scouts. AUSL plans on participating with the Girl Scout Engineering Day this year. The team will present on aerospace concepts to the scouts. AUSL has two experiments members will run. One experiment floats a ping pong ball that represents lift and the balance of forces on an object in space. The second experiment launches straw rockets to show the dynamic forces in ballistic trajectories. The AUSL team also plans on incorporating rocket builds and launches with the scouts, as has been done in the past.

5.6: GRAND Engineering Showcase

Date: September 11th, 2018

This is an outreach event for 4-8th graders which has demonstrations about different areas of Engineering. This is the first year AUSL participated in this event. AUSL presented on aerospace concepts with two experiments. One experiment floats a ping pong ball that represents lift and the balance of forces on an object in space. The second experiment launches straw rockets to show the dynamic forces in ballistic trajectories. Members interacted with the children and answered any questions they may have. This allows the team to continue its ongoing engagement with the local community.

5.7: Auburn Junior High School Engineering Day

Date: Fall 2018

The Auburn Junior High School Engineering Day was created to encourage student interest in engineering and to create an opportunity for students to gain firsthand experience as to what it is like to be an engineer. AUSL will participate in the event to promote aerospace engineering, rocketry, and the AUSL Competition. The team will bring example rockets and rocket components to present to the students so that they can get an up close and hands on view of what AUSL does. Last year the team presented to 1,000 students, many of whom expressed interest in engineering and rocketry, and the team hopes to reach similar numbers this year.

6. Project Plan

6.1: Systems Engineering

This year, the Auburn University Student Launch testing team is being reformatted into a Systems Engineering team. This shift will serve to expand the team's responsibilities from assisting the more traditional design teams with verification and testing of launch vehicle components to ensuring each team's work is compatible with every other teams. It is crucial that communication and co-operation be constantly maintained between the teams. Proper inter-team communication can prevent last minute inconsistencies in dimensions or general designs, leading to a much higher rate of success at launch. This team's new responsibilities are designed to ensure consistency in all aspects of the launch vehicle. The team will still maintain its original purpose of assisting in all testing activities and will be responsible for ensuring all components on the launch vehicle function properly and meet or exceed design requirement criteria. The combination of these two duties should ensure quality control in all aspects of the design and construction process and contribute to a safer and more consistent launch vehicle.

6.1.1: **CFD**

The team will be using computational fluid dynamics (CFD) to analyze this year's launch vehicle. CFD is a process which uses finite element analysis to model how fluid flow will interact with a solid body. The team will insert a CAD model of the launch vehicle into the simulated flow field to test the total drag of the rocket body and the effectiveness of the altitude control system. This data will allow the team to more accurately predict the final altitude of the launch vehicle and to calibrate the altitude control system more precisely.

6.1.2: **Rover**

The rover team will be using a revolving rover bay with gravity-based stabilization in order to ensure the rover can deploy right side up upon vehicle landing. This system will receive extensive drop, vibration and rotation testing in order to ensure proper function when mounted on the launch vehicle. The rover capsule will have two locking mechanisms, one that is released by a pin with the parachute when it deploys, and one released by remote control. The first system will allow the gravity-based system of the capsule to activate and keep the rover upright. The second system will detach the rover after confirmed touchdown. Only after these mechanisms both are unlocked will the rover be able to exit the rocket body. Both systems will be tested to ensure they only function when needed for the safety of both the payload and potential bystanders. After the rover deploys, it will use its tracked drive system to drive up to ten feet away from the vehicle body. Subsequently, it will use a trenching mechanism to collect a large sample of soil into its soil bay. Thorough testing will be done to ensure the rover is well engineered to do its task and that there are no soil conditions on which the rover cannot complete its mission. Electronic systems will be tested for battery life and capability from long distances. All systems mentioned above will undergo vibration and centrifuge testing, to ensure they are ready for the forces of flight and deployment.

6.1.3: **Embedded**

One of the primary performance requirements for this year's competition is for the rocket to be able to reach a predetermined altitude. To ensure the rocket does not over shoot this target, variable flat plates on the rocket will need to be able to generate controllable drag force. The team will conduct both CFD simulation and wind tunnel testing to determine how much drag is produced by the plates. This data will be fed into a PID controller on the rocket which will constantly determine the projected altitude. When that value is determined, the rocket will be able to adjust position of the plates and therefore drag accordingly. Determining how much drag this system produces and how it will affect the final altitude of the rocket will be an essential part of testing.

The rocket will have multiple electrical components such as batteries, controllers, and their respective circuitry. These devices will have to be verified to be able to function after being left on for over two hours on the launch pad. Additionally, the altimeter(s) and accelerometers used will have to be verified to be accurate, since they are managing the energy of the rocket. These will be tested by the team to ensure they are safe and will accomplish their designed function. Additionally, they will be tested ensure the forces applied by launch and main chute deployment do not disrupt their function. Another concern for the electrical and software components will be environmental challenges – the main concern being humidity. The electrical and software components will be tested to ensure there are no potential hazards which could result from humidity damage or other environmental causes.

6.1.4: **Recovery**

The Recovery system will have to undergo intensive testing to ensure the successful final recovery of the rocket. Testing will follow similar, however slightly augmented, methods as previous years. The team will be manufacturing both the drogue and main parachutes in house. In order to test the parachutes, the team will construct a scaled hemispherical main parachute, which will then be tested in the Auburn University wind tunnels in similar flow conditions to what the full sized parachute will experience at launch. Drag data from the tests will be averaged and used to compute a coefficient of drag for the hemispherical parachute with a spill hole. The data will be compared to the coefficients of drag obtained via research and last year’s data to confirm accurate sizing and performance of the team's parachutes. With this data, the team will be able to more accurately size the parachute to ensure a safe descent for the vehicle. Finally, when the parachutes are completed, the team will analytically determine an efficient packing style for the parachute and conduct drop tests to ensure the recovery system deploys properly. The team will be conducting extensive ground testing of the black powder ejection system, as proper deployment is essential and in need of optimization from previous years. Brainstorming and testing of a mechanical release for the nosecone separation will be conducted to determine whether the mechanical release is more reliable than black powder. These tests will be performed by assembling the avionics bay along with the sections of the rocket that separate; the sections will be fixed in a testing rig oriented horizontally. The nose cone will be aimed at a backstop so as to prevent injury and damage. The altimeters will be connected to a ground computer, from which the charges are triggered. Safety equipment will be on site, including fire extinguishers. For the black powder system, testing will begin with the smallest black powder charge from a calculated range. The testing will iterate with increasing black powder charges until the minimum charge is reached that safely separates each rocket section.

6.1.5: **Vehicle Body**

The body team will be conducting various material, structural, and aerodynamic tests to ensure the launch vehicle can withstand the forces of launch and maintain a controlled and predictable ascent. Material and structural testing of the body will consist of electronic simulation, followed by physical testing to verify models and highlight necessary changes. Finite element analysis within computer aided design software will be used to model the effects of launch forces on individual components of the vehicle to ensure they are robust enough to support the launch vehicle. Additionally, material samples of carbon fiber, 3D-printed Onyx, and fiberglass will be tested to ensure these models provide accurate data. The entire launch vehicle will also be modelled in CFD software to gather expected drag data and determine a maximum altitude prediction. As construction progresses, complete flat plates and sections of the open architecture structure will be tested to ensure their structural properties are still sufficient. Wind and water tunnel testing of the body and fins will be performed to gather real world data on drag characteristics.

6.2: Development Timeline

This year, the Auburn team plans to pursue an aggressive testing and construction schedule in order to ensure that our timeline can absorb delays. A high level overview of team activities that contribute to the mission can be seen in Figure 33: Gannt Chart. Dates for team educational engagement events and specific launches that will be attended are not yet available, and will be added to the timeline as they become known.

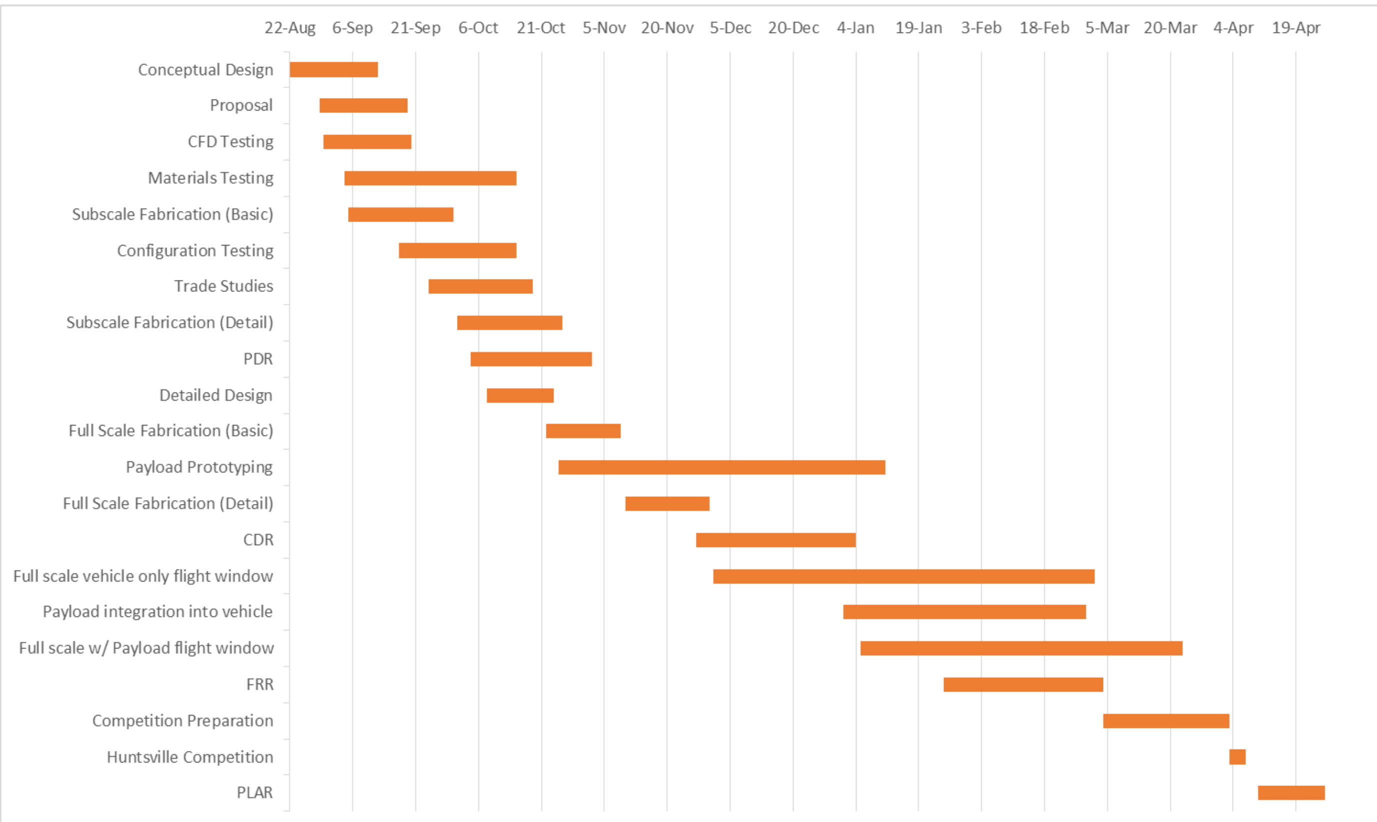


Figure 33: Gannt Chart

6.3: Budget

The projected budget for the 2018-2019 competition can be seen in the tables that follow. Since this is the planning stage of the competition, specific component costs were used when available, but otherwise intentionally over estimated when not available. For example, the price of the planned full scale motor (an Aerotech L1520T) is already known to be $259.99, but the exact quantity of Onyx printer material that will be used over the course of the competition is not, so each section is assumed to use an entire roll on their own. Of course, in actual manufacturing this resource will be shared between teams and should not exceed that level, especially with material left over from previous years. Similarly, costs for all sections of the project are greatly reduced through the team's built up stockpile of extra attachment hardware, parachute and structural material, electronics and tooling.

Vehicle (Full Scale and Subscale)				
Item	Cost Per Unit	Unit	Quantity	Total
Prepreg Carbon Fiber	$0 (Donated by GKN Aerospace)	Per square yard	9	$0
Aerotech L1520T	$199.99	Per unit	1	$199.99
RMS 75/3840 Motor Case and Associated Hardware	$385	Per unit	1	$385
Aerotech L1420R	$259.99	Per unit	1	$259.99
RMS 75/5120 Motor Case and Associated Hardware	$390	Per unit	1	$390
Fiberglass Coupler	$69	Per unit	6	$414
Rail Buttons	$3	Per unit	4	$12
Total				**$1,661**

Table 11: Vehicle Expected Costs

Recovery (Full Scale and Subscale)				
Item	Cost Per Unit	Unit	Quantity	Total
Ripstop Nylon	$8	Per yard	25	$200
Nylon Thread	$8	Per spool	3	$24
Tubular Nylon	$1	Per foot	50	$50
Paracord	$5	Per roll	1	$5
Telemetrum	$200	Per unit	1	$200
Telemega	$400	Per unit	1	$400
Adafruit Trinket	$14	Per unit	1	$14
Total				**$893**

Table 12: Recovery Expected Budget

Rover (Full Scale)				
Item	Cost Per Unit	Unit	Quantity	Total
LewanSoul LD-3015MG 270 degree servo	$16.49	Per Unit	1	16.49
BRUPS-15-S-NBK Press Fit Type Ball Transfer Unit	$15	Per Unit	3	$45
4.5" Inch (120mm) Aluminum Lazy Susan Bearing Turntable Bearings	$10	Per Unit	1	$10
Roll of Onyx	$189.00	Per Roll	1	$189.00
TRENDnet Low Loss Reverse SMA Connector Cable (8M, 26.2ft.) TEW-L208	$22.99	Per Unit	1	$22.99
U.FL Mini PCI to RP-SMA Pigtail Antenna WiFi Cable Pack of 2	$4.99	Per Unit	1	$4.99
Xbee Explorer dongle	$24.95	Per Unit	2	$49.90
Xbee Pro 60 mW Wire Antenna	$37.95	Per Unit	2	$75.90
Total				**$414.27**

Table 13: Rover Expense Summary

Research and Development Costs				
Item	Cost Per Unit	Unit	Quantity	Total
Carbon fiber and resin for open weave structure.	$284	Per tube	2	$568
Fiber glass sleeve	$33	Per tube	2	$66
Pre-preg Carbon Fiber	$118	Per yard	3	$354
Stratologger CF	$55	Per unit	2	$110
Roll of Onyx	$189.00	Per Roll	2	$189.00
Total				**$1,287**

Table 14: Research and Development Projected Expenses

Altitude Control		
Items	Name	Price
Accelerometer	ADXL345	$17.50
SD Card Datalogger	MicroSD card breakout board+	$7.50
Premium Planetary Gear Motor w/Encoder	280 RPM Premium	$49.99
Altimeter/Pressure Sensor	MPL3115A2	$9.95
Display	2x16 Character Display	$4.95
RTC	DS3231	$13.95
Motor Driver	Adafruit DRV8833	$4.95
2 9V Batteries	Duracell	$10.00
Onyx Structure (one roll of material)	MarkForged	$189.00
Microcontroller	STM32F103C8T6 “Blue Pill”	$2.50
Total		**$310.29**

Table 15: Altitude Control Expense Summary

Education Outreach	
Item	Cost
Estes Educator Rockets	$ 2040
Glue for Rockets	$ 50
Estes A8-3 Motors	$ 805
Straw Rockets	$ 20
Launch Controller Batteries	$ 30
Rocket Building Supplies (X-acto Knives, Sandpaper)	$ 20
Total Cost	**$ 2965**

Table 16: Outreach Expenses

6.3.1: **Budget Summary**

The total costs for each segment of the team can be seen below in Table 17: Budget Summary, in addition to the total cost for the year based on current projections. To provide further robustness and ensure that unforeseen expenses are accounted for, the total projected costs were multiplied by twenty percent. This second number is the one that the team feels is a more accurate prediction of the final project cost based off of previous experience.

Budget Summary	
Vehicle	$1661
Recovery	$893
Rover	$414.27
Research and Development	$1287
Altitude Control	$310.29
Education/ Outreach	$2965
Hotel and Travel	$2500
Promotional Materials	$1250
Total	**$11,280.56**
Total plus 20% growth	**$13,536.67**

Table 17: Budget Summary

6.4: Funding Plan

The teams current expected funding level is in Table 18: Funding Sources. For our corporate sponsors, these numbers are based off of last year's contributions, and are expected to remain constant. The team must also thank GKN Aerospace in Tallassee, Alabama for their support. Instead of providing monetary support, GKN donates surplus composites to Auburn University, which the team is in turn able to use to manufacture our airframe. Additionally, over the previous year the Auburn team was able to maintain a budget surplus, and these funds have been rolled over to the current year's resources as well. As already mentioned in Section 6.3: Budget, the current costs are all conservative overestimations for materials quantities when not related to specific new components that will be ordered. Even with a hefty twenty percent further increase in expenses, the team's current projections expect a budget surplus of almost two thousand dollars.

Source	Amount
Alabama Space Consortium	$12,000
Dynetics	$2,500
Team Savings	$1003.02
Total Funding	**$15,503.02**
Total plus 20% growth	**$13,536.67**
Expected Savings	**$1966.35**

Table 18: Funding Sources

6.5: Sustainability

In order to maintain the AUSL team, AUSL must recruit every year to train and maintain the technical skills needed for running the team. Multiple events in the fall semester of school are used to outreach to college students to introduce them to AUSL. These new members are brought into the teams and taught the technical skills so that the level of quality rocket production is kept the same. All members are required to participate in Education outreach activities to not only train them in outreach, but also to maintain the relationships created for outreach events in the area. The coordinators that work with AUSL gain familiarity with members they see each year, developing a relationship between the team and the educational opportunities.

As far as the community presence, the team has now been in regular contact with many local organizations and businesses for over two years. The team has established programs for educational engagement that it can improve every year with experience and the addition of a larger, better trained workforce. The team's partnerships with Drake Middle School, Auburn Junior High School, and Auburn High School are well developed and it hopes to maintain its relationship through the continuation of successful educational engagement events.

As for financial stability, both of the primary sources of funding, the Alabama Space Consortium and Auburn University College of Engineering, are renewable in that the team does not foresee issues obtaining relatively similar amounts of money for future years assuming the continued success of the organization. If for any reason the team receives reduced funding from either source, budget gaps can be made up with department funding, club dues, and other smaller fundraising opportunities.

6.5.1: **Aeropalooza**

Date: August 28, 2018

Aeropalooza is a yearly gathering at the beginning of the fall semester that seeks to bring together the entirety of the Auburn Aerospace community. One of the main purposes of the event is to help students find a student organization that occupies their interests. To this end, AUSL set up a table and several rockets from previous years. As students came by members explained the competition to them and answered any questions they had. The team also answered many questions from faculty members about the teams' plan for the upcoming year and how they could help. Aeropalooza allows AUSL to bring in a large cadre of potential new members each year from both the freshman and returning upper classmen students in Auburn University's Aerospace program.

Figure 34: The USLI team at Aeropalooza 2018 talking to Aerospace Department faculty and recruiting new members.

6.5.2: **Organization Week**

Date: August 29-30, 2018

Organization Week, also known as O-Week, is a campus event that occurs during the second week of classes. During this event, organizations set up tables to recruit new members, bringing in a variety of different majors and diversity to AUSL. AUSL set up a table with several rockets from previous years to represent the team. As students came by, members explained the competition, answered any questions, and took down their contact information if the students were interested.

6.5.3: **Auburn University Rocketry Association**

The Auburn University Rocket Association (AURA) is a sister organization parallel to AUSL and operates with the Education Outreach team. The goal of AURA is simple: it instructs students in how to construct a rocket with which they can secure their Tripoli level one certification. To achieve this, students are first taught how to model their rockets in the OpenRocket design software, and some of the strengths and limitations of that program. Next, members construct their rockets in the lab, gaining familiarity with the machines and tools within and the techniques involved. Finally, the students' rockets are launched at the same launch day as a AUSL subscale or full-scale launch, to allow for sharing rides and save time. AURA serves a dual purpose for AUSL. First, it allows current-but-newer AUSL members to gain experience and appreciation for the design of an entire rocket and valuable hands-on lab experience. Secondly, it provides a gateway in rocketry for those initially daunted by the scale of the AUSL competition, who after developing their skills feel confident enough to take the plunge and join AUSL

Figure 35: An AURA build group in Fall 2017 preparing their rocket engines for launching to attempt their Level 1 certifications.

Appendix A. Risk Assessment Tables

Construction & Assembly				
Hazard	Cause	Result	Risk Assessment	Mitigation
Use of power tools such as dremels, drills, etc.	Improper use and /or improper protection such as lack of gloves or safety glasses.	Mild to severe cuts, scrapes, and other injuries. Additionally, reactions can result in harm to rocket components being worked upon.	3D	Demonstration of proper use by experienced team members, easily accessible safety materials and protective wear, and securely fastening the object being worked upon.
Particles of carbon fiber	Sanding carbon fiber or other fibrous material without using a mask or filter.	Mild coughing and difficulty breathing, irritation in the eyes and skin.	3C	When sanding or cutting tools are used on carbon fiber all members in the lab, regardless if they are working on the carbon fiber or not, are required to utilize a mask to prevent the breathing in of excessive particles.
Insecure tools in the Workspace.	Tools are left out in the lab workspace and not returned to a storage space there they belong.	Cuts, pricks, or tears when members sort through items or knock loose tools around or off tables.	4C	The storage spaces for all tools are clearly marked and easy to find. Members are instructed to return tools they find left out to their storage spaces.

Construction & Assembly				
Hazard	Cause	Result	Risk Assessment	Mitigation
Use of soldering tool	Failure to pay proper attention to the soldering tool.	Mild to severe burns on the fingers or hands of the team member using it. Additionally, could result in excessive heat and damage to the component being worked on.	3D	Members that use the soldering iron are required to give it their full attention for the duration of their work. They must turn off and stow the tool somewhere away from the object being worked on if they must attend to something else before work is finished.
Fumes from soldering Tool.	Improper ventilation of the workstation where soldering is taking place.	Excessive exposure to toxic fumes results in nausea and irritation. Reactions could potentially damage the component(s) being worked upon.	3D	The workstation will be properly vented and members using it are required to confirm ventilation is functioning periodically. Additionally, team members will not be allowed to continue soldering for an extended period of time and must take a break to let any buildup of fumes disperse.
Use of the belt sander, band saw, or drill press.	Failure to pay attention, aggressive use of the tools, lack of proper protective equipment	Severe cuts, burns, rashes, bruises, or other harm to fingers, hands, and/or arms.	2D	Experienced team members will instruct inexperienced team members before they are allowed to use the tools, protective equipment will be easily accessible.

Construction & Assembly				
Hazard	Cause	Result	Risk Assessment	Mitigation
Use of tools.	Improper maintenance of tools used in the lab and workspace.	Damage to sections of the rocket or to team members, or delays to the project to get replacement parts.	3E	All tools are maintained regularly. Any tools deemed beyond repair are disposed of and replaced immediately.
Use of electrical Equipment.	a) Improperly maintained equipment. b) Improper use of equipment.	Electric shocks could occur to team members handling the equipment.	1E	Electrical equipment will be maintained regularly. Electrical equipment will only be plugged in when ready for immediate use and will be promptly unplugged afterward.
Carbon fiber splinters.	Handling of carbon fiber components with bare hands.	Slivers of carbon fiber break off and become stuck in the skin of fingers and hands handling it.	4B	Members are encouraged to handle carbon fiber components with gloves. In the event that gloves are unavailable, gentle handling is enough to avoid splinters.
Structural integrity of the rocket is compromised by buckling during flight.	Excessive aerodynamic loading on the airframe of the rocket.	The mission is lost, the rocket becomes unstable during flight and may be a danger to personnel or the environment.	1E	Extensive testing of the materials and structural architecture of the rocket body will be done before subscale and full-scale launches to confirm that the design will withstand forces that it will encounter.
Sections of the rocket are poorly coupled together.	The use of weak bolts or poorly designed couplers between sections.	Sections of the rocket may wobble and the trajectory of the rocket could be affected during ascent or during recovery.	2D	Extensive testing of the coupler will be done prior to subscale and full-scale launches. The coupler will be visually inspected before and after assembly.

Vehicle Structure				
Hazard	Cause	Result	Risk Assessment	Mitigation
The airframe is dropped or hits against a hard surface during construction, assembly, or in transport.	Distracted or clumsy handlers that are not aware of their surroundings.	The body or nose cone may be damaged by the impact and may require replacement.	3D	Great care will be taken when working on components under all conditions. During transportation multiple personnel will carry the rocket slowly and carefully while an additional team member removes obstacles or opens doors as necessary. Replaceable parts such as pins, screws, and the nose cone will have duplicate parts available during assembly.
Holes in the airframe leading to the inside of the rocket body.	Insufficient communication in addition to excessive drilling or work on components or failure to notice missing pins or screws	The hole could result in an improper reading of air pressure by the altimeter and result in premature activation of the recovery system.	1D	All sections of the rocket will be visually inspected immediately after construction, before transport to the launch site, and on assembly. Duplicates of objects such as pins, screws, etc. will be available to replace any missing ones.
Cracks in the airframe.	Excessive physical or thermal loading to the rocket body during storage or transport.	The rocket body fractures on launch or on ascent releasing debris in the immediate area.	1E	Sections of the rocket body will be kept in a dry location at room temperature. The rocket body will be visually inspected before and after transport, during assembly, and immediately prior to launch to confirm that there are no cracks.

Vehicle Structure				
Hazard	Cause	Result	Risk Assessment	Mitigation
A segment of the airframe is misplaced or lost.	A messy or disorganized work environment leads to poor tracking and storage of pertinent rocket segments.	An incomplete rocket body is transported or ready for assembly on launch day. Segments may need to be remanufactured if they cannot be located.	2E	Once segments of the rocket body are completed they will be immediately stored in a location exclusively for launch-ready components. For subscale launches, some components will be manufactured twice so that one may serve as a backup.
Stability and Propulsion				
Hazard	Cause	Result	Risk Assessment	Mitigation
Motor explodes on Launch.	Manufacturing defect from supplier	The rocket is destroyed on the launch pad or shortly after launch.	1E	Rocket motors will only be purchased from a certified source and will be handled with extreme care exclusively by the team mentor or by someone with permission of the team mentor.
The rocket exceeds Mach 1 on ascent.	The rocket motor utilized in the design is too powerful for the mass of the rocket.	Vehicle requirement 1.19.7 is violated, compromising the validity of the mission.	2E	Team members will analytically evaluate the expected speed of the rocket prior to testing and will confirm these results in sub-scale and full-scale testing. In the event that the mass of the rocket is too low, additional mass will be added to the inside of the rocket to ensure it does not exceed Mach 1.

Stability and Propulsion				
Hazard	Cause	Result	Risk Assessment	Mitigation
Motor fails to ignite.	a) Defect in Manufacturing b) Failure of the ignition system. c) Delayed ignition.	a) and b) The motor will not fire and the rocket will not launch. c) The motor will fire and the rocket will launch an unknown amount of time after the button is pressed.	3D	In accordance with the NAR Safety Code, the safety interlock will be removed or the battery will be disconnected and no team member will approach the rocket for 60 seconds. After 60 seconds without activity the safety officer will approach and check the ignition systems. In the event that the ignition systems are not at fault the motor will be removed and replaced with a spare. A second launch will be attempted if there is time to do so.
Motor is physically Damaged.	Motor was damaged during handling or transport.	The motor will be primarily handled by the team mentor or another member certified to do so with the permission of the mentor or safety officer.	2E	The mentor will oversee the design of a carrying case for the motors that they will be safely stored in during transport and will be the one to stow and remove them from this case.
Epoxy used is insufficient to stabilize fins on rocket body.	a) The epoxy was mixed or cured improperly. b) The epoxy used was not strong enough to withstand forces encounter in flight.	Fins may vibrate and cause unexpected or erratic changes to the course of the rocket. This could endanger personnel on ascent or recovery.	2D	Proper procedures regarding the mixing and curing of epoxy will be strictly followed during construction of the rocket. During assembly team members will apply pressure to the fins to confirm they do not move and will not during flight.

Stability and Propulsion				
Hazard	Cause	Result	Risk Assessment	Mitigation
Rocket center of gravity and center of pressure are improperly placed.	Rocket property calculations were made incorrectly.	The rocket's ascent will be unstable and potentially dangerous.	1E	Calculations will be checked multiple times prior to launch. Subscale launches will provide an opportunity to confirm these calculations prior to full scale launch. Additionally, the center of gravity will be physically checked prior to launch.

Scientific Payload				
Hazard	Cause	Result	Risk Assessment	Mitigation
Improper soldering.	Too much or too little solder is used when constructing the electrical equipment to control the science payload.	Electrical malfunctions and a loss of system integrity.	2D	The electrical equipment will be visually inspected by multiple team members and tests run to ensure that it carries electrical signals as intended.
Improper wiring.	Electrical signals are transmitted improperly resulting in unexpected behavior.	The science payload does not behave as expected or does not function at all.	2D	Wires will be color-coded to communicate their function and a specific checklist will be created to ensure the system is wired correctly. Extensive ground testing will confirm payload functionality

Scientific Payload				
Hazard	Cause	Result	Risk Assessment	Mitigation
The servos utilized by the science payload jitter or do not actuate smoothly.	a) Internal electrical failure. b) Worn or malfunctioning gears.	The science payload may not respond as accurately as expected.	3D	The servos that will be used for flight will be purchased at the beginning of the project and will be stored in a space away from any chemicals or excessive humidity. The servos will be tested before transport, before and after assembly to confirm that they actuate properly.

Recovery				
Hazard	Cause	Result	Risk Assessment	Mitigation
Parachute failure on deployment.	The parachute is not packed properly.	The parachute becomes tangled on descent resulting in an erratic and fast moving projectile that endangers personnel and property below.	1C	Packing of the parachute will be performed by dedicated members of the recovery team who will have practiced previously.

Recovery				
Hazard	Cause	Result	Risk Assessment	Mitigation
The parachute fails to deploy in any capacity.	a) A faulty altimeter fails to detect the altitude at which the parachute should deploy. b) Not enough black powder is used in the recovery system.	The rocket descends chaotically at a speed that his extremely dangerous to both the rocket and personnel.	1D	a) A reliable altimeter will be selected during the PDR phase and will be tested prior to launch in a full-scale capacity. b) The amount of black powder that will be used will be calculated by team members beforehand. Calculations will include the amount necessary and the amount allowable with the final amount used lying somewhere within the range.
The parachute deploys early.	A faulty altimeter fails to detect the altitude at which the parachute should deploy.	The rocket's ascent will be compromised and its descent will result in the rocket drifting for a very long distance.	2D	The altimeter will be thoroughly tested prior to its use in a full-scale capacity to confirm that it will function as intended.
The parachute tears after deployment.	Defects in the parachute occurred during construction.	The rocket's descent will not be slowed as effectively and could endanger the rocket or personnel.	2D	The parachute will be visually inspected and tested prior to its utilization in a full-scale capacity and upon assembly on launch day. The container holding parachute will be smoothed to not contain any sharp edges. All parachutes will be reinforced at any potential tear location.

Recovery				
Hazard	Cause	Result	Risk Assessment	Mitigation
The rocket falls too quickly.	Design oversight causes the rocket to fall faster than desired.	The body of the rocket will be damaged and potentially the internal components damaged as well. This could violate vehicle requirement 1.4 and jeopardize mission success.	2C	The exact size of the parachute needed to slow down the descent of the rocket and the timing of its release will be calculated and sufficient leeway given to ensure that recovery will not threaten the rocket or personnel.
Wind blows the rocket off course.	a) Strong winds on the day of the launch affect descent more than expected. b) A premature parachute deployment causes the rocket to be subject to more drift.	Rocket could become lost, damaged, or could endanger observers.	3C	The rocket will not be launched if weather conditions are considered dangerous by either the team or the range safety officer. All parts of the rocket will have a GPS locater device securely attached to facilitate tracking during and after descent.

Recovery				
Hazard	Cause	Result	Risk Assessment	Mitigation
The parachute or chords catch fire upon deployment.	Excessive black powder and insufficient flame retardant wadding.	The descent of the rocket is accelerated and the external and internal structure of the rocket is jeopardized. Upon landing, a flaming parachute or chords could ignite brush.	2C	Testing will be done to determine the exact amount of black powder and wadding needed to safely deploy the parachute. No more than is needed will be used. A fire extinguisher will be available to combat any fires that may occur once the rocket lands. If the fire spreads or is significantly large, authorities will be contacted.