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**Preliminary Design Review Report**

**FAMU-FSU College of Engineering**

**2525 Pottsdamer Street**

**Tallahassee, FL 32310**

**10/26/2023**

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# Summary of PDR Report

## Team Summary

### Team Name

Last year was this team's first excursion into the NASA Student Launch competition, and in honor of the path they paved for this year's team, our team's name was decided to be the Zenith Program.

### Mailing Address

The mailing address for the Florida Agricultural & Mechanical University – Florida State University Zenith Team is as follows:

FAMU-FSU AIAA

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### Team Information

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* **NAR Flyer Number:** 57205
* **TRA Flyer Number:** 01922
* **NAR/TRA Certification Level:** Level 2

### Travel Plans

The team plans to travel to Huntsville, Alabama from the FAMU-FSU College of Engineering in Tallahassee, Florida on April 10th, 2024, and be present for the launch readiness review, launch day, and all other events associated with and necessary activities and events on April 11th – April 14th. Funding for travel will be provided through the FAMU-FSU College of Mechanical Engineering and the FSU Student Government Association.

Travel specifics are currently undergoing review, as multiple methods of transportation are possible. Most ideally, the team can rent a van from any certified FSU vendor, including both Enterprise Reservations and National Rental car rental service companies. Another possible method of transportation is for the team to carpool and use one of our personal vehicles to travel from Tallahassee to Huntsville.

### Time Allotted to PDR

The team began working directly on the Preliminary Design Review (PDR) on October 9th, 2023. Since the initial creation of the document, each team member has allotted a minimum of 1 hour a day towards the assignment, with some members spending anywhere from 3-12 hours a day on the assignment, leading to a total of 220 hours spent on PDR.

### Social Media Presence

The team has decided to use Instagram as the primary platform for social media presence and engagement. Instagram offers the largest user base and is likely the most used social media platform for those the Zenith program aims to reach. In the previous year of this program, social media such as Facebook and Twitter were created and engaged but did not yield interaction on their platforms. To gain traffic more efficiently, the two Instagram accounts below will be utilized.

Table 1: The Zenith Program Social Media Accounts

|  |  |
| --- | --- |
| **Instagram Handle** | **Link** |
| @thezenithprogram | <https://www.instagram.com/thezenithprogram/> |
| @aiaa\_famu\_fsu | <https://www.instagram.com/aiaa_famu_fsu/> |

The first account, @thezenithprogram, is the main account for the FAMU-FSU Zenith Program. This account will be used to document team meetings, project progress, and generate a growth in engagement for the project, aiming to reach students across the university and beyond. This account was used last year, and using the momentum built last year, we can continue to grow this account to be far larger in follower count, engagement, and update frequency than the previous year.

The second account, @aiaa\_famu\_fsu, is the official Instagram for the AIAA chapter at the FAMU-FSU College of Engineering. This club “houses” the Zenith program and will be utilized as a general way to stay updated on all things related to the AIAA chapter at the FAMU-FSU College of Engineering, including the activities of the Zenith Program.

## Launch Vehicle Summary

### Official Target Altitude

The official target altitude proposed by The Zenith Program is 4940 feet (ft).

### Preliminary Motor Choice(s)

The leading choice for a motor is the AeroTech L850W.

### Size and Mass of Individual Sections

The current design of the vehicle is 8.13 ft from tip of nosecone to end of tail cone, while the diameter is 6.17 inches (in.). The masses calculated are using a non-specified fiberglass body tube and polyethylene terephthalate glycol (PETG) 3D printing filament for the nosecone, fins, and tail cone. The total mass of the rocket is designed to be 33.45 pounds (lbs.). The vehicle will separate into 3 sections. Section 1, the top section with the payload, weighs 15.4 lbs. Section 2, the middle section, weighs 2.03 lbs. Section 3, the bottom section fully loaded, weighs 16.01 lbs. Section 3 without the propellant, on descent, weighs 11.47 lbs.

### Recovery System

The team plans to deploy a drogue parachute at apogee and a main chute at 550ft. The drogue parachute is the Fruity Chute 18” Classic Elliptical, and the main chute is the Fruity Chute 84” Iris Ultra Standard. Chute deployment is controlled by a redundant altimeter setup using an Altus Metrum TeleMetrum and Entacore AIM 3. The altimeters are powered by separate 3.7V LiPo batteries and send signals to a Raptor CO2 ejection system to separate the vehicle.

## Payload Summary

The payload for the 2024 NASA Student Launch competition is ATLAS (Autonomous Transit and Landing for Airdropped Singlecopter). ATLAS is an autonomously controlled singlecopter that will safely and independently return the STEMnauts from the launch vehicle to the ground. ATLAS uses an RF receiver and line cutter to receive the team’s deployment signal and separate from the launch vehicle.

# Changes Made Since Proposal

The following tables highlight changes made since the proposal and the reason for those changes.

## Vehicle Criteria

Table 2: Changes made to vehicle criteria.

|  |  |
| --- | --- |
| Description of Change | Reason for the Change |
| Changed from an elliptical nosecone to an ogive nosecone | To make manufacturing easier |
| Changed the primary motor choice to the Aerotech L850 W | Because the team has access to extra reloads |
| Redesigned the thrust structure | To increase ease of assembly |
| Added a tail cone | To increase stability and apogee |
| Changed body material to fiberglass | To increase the structural integrity |

## Payload Criteria

Table 3: Changes made to payload criteria.

|  |  |
| --- | --- |
| Description of Change | Reason for the Change |
| Changed from a gas-thruster design to a single electric-powered ducted fan (EDF). | The EDF can provide significant thrust for a much longer period of time than the gas thruster. |
| Thrust-vectoring fins were introduced to the payload design. | Heightened control is needed to negate torque from the single motor, and to account for environmental disturbances during descent. |
| STEMnauts are now housed in individual capsules rather than a singular housing container. | Separate capsules are more modular and can improve mass distribution throughout the vehicle. |
| Landing legs are retractable instead of static. | Retractable landing legs allow the payload to fit in the launch vehicle better. |
| Landing legs are located higher up on payload body. | Having legs higher up on the payload body decreases probability of tipping during landing. |

## Project Plan

There were no changes made to the project plan.

# Vehicle Criteria

## Launch Vehicle Mission Statement and Mission Criteria

### Mission Statement

The mission is to design and launch a vehicle with the engineered payload to an apogee of 4892 feet. The deployment of the payload needs to be between 400 and 800 feet on descent. NASA’s Range Safety Officer (RSO) will grant permission to deploy the payload. The goal is that the rocket and payload are recovered safely on the ground, and that the payload lands in the designated orientation. The team is committed to the work conducted to deliver this and showcase STEM education and teamwork, while contributing to the advancement of space exploration.

### Mission Criteria

Table 4: Mission Criteria.

|  |  |  |
| --- | --- | --- |
| **Success level** | **Vehicle and Payload** | **Safety** |
| **Complete Success** | * Vehicle and payload complete full flight and recovery. * No damages. * Vehicle reaches ±300 feet of declared apogee. * Payload deploys after main parachute and permission is granted by NASA’s RSO. | * No personnel hazards created. * No vehicle hazards created. * No environmental hazards created. * No injuries |
| **Partial Success** | * Vehicle and payload complete full flight and recovery. * Possible damages that can be repaired at site. * Vehicle reaches ±600 feet of declared apogee. * Payload deploys ±100 feet of declared descent. | * Slight personnel hazards created. * Slight vehicle hazards created. * Slight environmental hazards created. * No injuries. |
| **Partial Failure** | * Vehicle and payload complete full flight and recovery. * Flight and/or recovery are not deemed safe. * Payload does not land in desired orientation. * Damages require more than a week to repair. * Vehicle does not reach apogee within the 4000-6000 feet margin. * Payload does not reach apogee within the 400-800 feet margin. | * Personnel hazards created. * Vehicle hazards created. * Environmental hazards created. * Some injuries. |
| **Complete Failure** | * Vehicle and payload did not complete full flight and recovery. * Flight and recovery are not deemed safe. * Damages are unrepairable. * Vehicle does not reach apogee within the 4000-6000 feet margin. * Payload does not reach apogee within the 400-800 feet margin. * Payload violates STEMnaut survivability metrics. | * High personnel hazards created. * High vehicle hazards created. * High environmental hazards created. * Many injuries. |

## Selection, Design, and Rationale of Launch Vehicle

### Thrust Structure

The rocket's thrust structure must be able to transfer the motor’s reaction force to the vehicle structure while not deforming under the immense load. There we many different iterations of this design. The parameters that the team decided to focus on for this aspect for the design was minimizing mass, how well the structure secured the fins to the rocket, how durable the structure was, and that it could adequately transfer the reaction force of the thrust of the engine to the vehicle body.

#### Alternative Designs

The team considered whether the thrust structure should be removable or if it should be fixed into place into the rocket. Extensive research was conducted, and it was determined that most of the time the thrust structure is fixed into place. The team in the past has had trouble with assembling the rocket on launch days because it is difficult to navigate tools in the thrust structure when it is fixed in the rocket. Because of workability, the team decided to generate a thrust structure that could be removed to easily work on and assemble.

The next design consideration was how to keep the motors line of action in line with the geometric center of the vehicle. Without this, a moment would be induced on the vehicle during powered ascent that could have catastrophic consequences. Research and experience determined that centering rings were the best way to achieve this goal. The team produced two design considerations for this parameter. The first was to use spruce centering rings. These centering rings are used commonly and are readily available. The next option was to design and 3D print centering rings. The problem with the 3D printing approaching is that filament has a low melting point, would not be as durable as the spruce, and they would have to be designed and manufactured instead of just being ordered. Because of these reasons, the team decided to use spruce centering rings.

Next it needed to be determined how to make the structure durable. The ideas the team developed were using threaded rods to prevent buckling failure, using aluminum framing to support the thrust loads, using no extra structuring, and 3D printing scaffolding.

The fins needed to be connected and secured to the thrust structure. They could be fastened to the outside of the vehicle body, they could be fastened to the vehicle with a slot cut into the vehicle and the fins sliding in, or some sort of internal fastening. The force of the motor's thrust also needed to be transferred to the vehicle body. The team produced the ideas of using a thrust plate and motor retainer system or using threaded rods.

#### Feasibility Study

The workability of the rocket was especially important to the team, so the removable thrust structure was deemed more feasible than the fixed thrust structure. The only downfall of the removable structure was that it may add more hardware which would increase the mass, but this was a sacrifice the team was willing to make. To keep the motors line of action in line with the center of mass spruce and filament materials were investigated, the spruce was determined to be capable of handling temperatures up to 700 C while filament was only capable of handling temperatures up to 150 C, the filament would also require more time and effort to produce. Aluminum framing was determined to be the best decision because it can withstand large loads but is still relatively compared to steel threaded rods.

### Fins and Nosecone Material Selection

The fins and nosecone will most likely be 3D printed in-house with our printers from the College. The final material choice alternatives are between Acrylonitrile Styrene Acrylate (ASA) filament, Polyethylene Terephthalate Glycol (PETG) filament, and birch plywood. Each material has been assessed at different angles and at different wind speeds from the launch site.

#### Acrylonitrile Styrene Acrylate (ASA) Filament

ASA is a thermoplastic that is often used in 3D printing. It is being considered as a material to use for the rocket’s fins for multiple reasons. ASA is known for its excellent durability and high resistance to temperature, UV rays, and weathering. Due to the nature of the rocket, it will reach a high apogee, so heat and UV resistance are of top priority. Since it is highly resistant to heat, printing with the material will not be difficult as it will not warp, deform, nor shrink as much. Also, it will ensure stability of the rocket upon its ascendance. It is also resistant to many chemicals which is best as design and testing progresses. The filament can be easily sanded and painted, which will ensure smoothness of the fins and nosecone, therefore decreasing potential drag that can be caused by it. ASA can be slightly more expensive than other 3D printing materials, but it still is within the budget, and it is widely available. The team will need to carefully design the fins and nosecone and take weight into consideration while designing to ensure that the added strength of ASA does not also add excessive weight. Simulations and testing will be done to verify the use of this material.

On the other hand, ASA typically prints at lower speeds which can potentially delay certain project milestones but to mitigate this, we intend to begin testing as soon as the material is available to the team. Proper ventilation and Personal Protection Equipment (PPE) will be required since ASA releases potentially dangerous fumes while printing. Even with this, ASA looks like a promising material to use for the fin structure.

#### Polyethylene Terephthalate Glycol (PETG) Filament

PETG is another thermoplastic that is commonly used from 3D printing. This material is known for its excellent strength and durability, which is essential for flying a high-powered rocket. It is a material that is flexible enough, making it virtually unbreakable in the direction of the layer. This becomes beneficial, especially during testing, because it can reduce the number of repairs in case of free fall or other impacts. There is excellent adhesion throughout the layer, which provides improved surfaces. PETG is a material that is fairly easy to print with so it can be handled by those in the team that are less experienced with 3D printing. Though not as heat resistant as ASA, it can withstand moderately high temperatures, but it is chemically resistant.

This filament is denser than other common materials, so this can potentially add weight onto the rocket. PETG does not have a very high heat resistance which may not be suitable for rockets that experience extremely high temperatures, but since this vehicle is not projected to experience that, it is still a good material to consider.

#### Birch Plywood for Fins Only

Birch plywood is a common material to use for constructing the fins. This type of plywood is high in strength and durability. It is relatively lightweight while still providing sufficient strength. The birch plywood can maintain is shape well and it is easy to work with. There are certain tools that may be necessary to cut and shape the wood, but these skills can be taught with simple instruction. Wood is susceptible to changes in humidity and temperature and this can result in deformations or changes in density. Extra caution will need to be taken because higher levels of moisture can greatly affect the wood and its strength. Finishes and other smoothing may need to be done with specific products and this can effectively adjust the budget.

### Fins Shape Selection

#### Fins Alternative Designs

The three fin shapes explored for this design were the trapezoidal, clipped delta, and elliptical fins. Each design has its advantages and disadvantages. To determine the best fin shape, ease of manufacturability, drag, fin flutter, and stability were the factors considered. The advantage of the clipped delta fins include that it has moderate stability, and they are very easy to manufacture regardless of the material due to their simple geometry. The disadvantages include that while the stability is good it is not great, and the drag force of these fins is larger relative to other designs.

Trapezoidal fins are a good compromise between stability and drag forces. They are also quite easy to manufacture and mount onto the vehicle. The drag force on these fins is larger than a clipped delta fin of comparable dimensions. These fins are not great for adverse weather conditions. The elliptical fins have a substantially smaller drag than the other fin shapes and are stable. Elliptical fins are very hard to manufacture and have a higher input cost.

#### Fins Feasibility Study

The fin flutter of a given fin can be calculated using the equation:

Where a is the speed of sound, is the ratio of the tip cord to the root cord, AR is the aspect ratio, G is the shear modulus, c is the rood cord length, t is the thickness of the wing, and P is static pressure. The fin flutter is a result of resonance and can occur at any speed. It is mostly due to the shape of the fin.

Because the rocket doesn’t need to increase speed and reach extreme altitudes and the team is operating on a modest budget, the team decided to not go with elliptical fins. The team decided that clipped delta fins would provide the amount of stability necessary. They also calculated the fin flutter speed to be around 700 mph whereas the projected max speed of the rocket is 445 mph.

### Nosecone Shape Selection

#### Nosecone Alternative Designs

The three nosecone designs that the team considered were a Haack series nosecone elliptical nosecone, and an ogive nosecone. The factors that influenced the selection of the nosecone were the aerodynamic efficiency, the drag, and the manufacturability. The Haack series nose cone is based on a special series that optimizes drag reduction. Because of this they are optimal for minimal drag. The Haack nosecone is very effective in high-speed applications. This nosecone also has a good balance of volume to drag reduction, making it mass efficient. The Haack series nosecone has a very complex design and therefore is very difficult to manufacture. It is also only optimal in a specific range of speeds, outside of these speeds its effects are not prevalent.

A close up of a grey object

Description automatically generated

Figure 1: Haack Series Nosecone.

A black object with a pointy tip

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Figure 2: Ogive Nosecone.

A close up of a black object

Description automatically generated

Figure 3: Elliptical Nosecone.

The elliptical nose cone also has a streamlined form and offers low drag. It is also fairly complex, so it offers a manufacturing challenge. The ogive nosecone is very commonly used so its characteristics and performance are widely known. The manufacturing of this nosecone is very simple. This nosecone also has low drag. It is not as volume efficient as other designs, meaning it is high volume compared to the drag reduction it provides.

#### Nosecone Feasibility Study

All the above factors were considered into the feasibility study of which nosecone to use. The team decided that the best nosecone for this vehicle would be the ogive nosecone. This is because is simpler to manufacture compared to the other two designs and provides an adequate amount of drag reduction. The ogive nosecone does provide is less mass efficient by about 22% (This was calculated by take two nosecones one ogive and one Haack and for keeping the drag force constant, calculating the volume of the two nosecones) but the team is willing to make this sacrifice at the expense of manufacturability. The team decided in addition they would lessen the sharp tip of this nosecone design, as this is a area that will fracture easily under aerodynamic stress.

### Tail Cone Shape Selection

#### Tail Cone Alternative Designs

The tail cone must be designed to minimize the vortices created from flow separation of the rocket. A few different shapes were explored for this year’s rocket. The first was the conical tail cone. A pro of this design is that it is very simple and easy to manufacture. The aerodynamics of this design are stable and give a good margin of stability. The problem is this shape is not optimal and can lead to increased drag compared to other designs.

The elliptical tail cone really helps to reduce drag because of its deal shape, and it provides a large amount of stability. This design is very difficult to manufacture. The parabolic tail cone provides stability and reduced drag and is less complex to manufacture than the elliptical tail cone.

#### Tail Cone Feasibility Study

The team decided to use the parabolic tail cone design because it has all the benefits of a tail cone and is not very difficult to manufacture. Its geometry is complicated but not as complicated as other designs. The team also placed an emphasis on integrating the tail cone with the thrust structure. This is because last year, the tail cone was placed on the rocket at the end and the motor burned it off. The length of the tail cone was optimized through OpenRocket algorithms, it was set to optimize apogee and stability by varying length.

### Body Tube

#### Body Tube Material Selection

The body tube will be purchased from an online retailer. The final material choice alternatives are between Blue Tube and G12 Fiberglass. Both materials are common in high-powered rocketry. The body tube airframe is necessary to withstand the forces it will experience throughout the flight and separation stages.

##### G12 Fiberglass

G12 fiberglass is a material that is used my many aerospace and engineering applications. This material is often used for rocketry airframes. It is a material known for its high strength to weight ratio, meaning it is lightweight while being significantly strong. Along with it being high in strength, it is highly durable, and it can withstand forces experienced during flight. It can resist high heat, moisture, and impact. G12 fiberglass is a body tube manufactured with a smooth surface, enhancing its aerodynamic capabilities. This material is also resistant to chemicals and other environmental factors. Although working with G12 fiberglass can be easy, specialized equipment and PPE is required. The cost of this material is higher than others, but it is higher quality and has better characteristics than other materials. The coupler will be used of the same material also. Using the online retailer of Madcow Rocketry, the density was calculated using the dimensions of the body tube given by them and the weight in ounce per foot (oz/ft). The dimensions are illustrated in the following table:

Table 5: Dimensions for G12 fiberglass from madcowrocketry.com

|  |  |
| --- | --- |
| Givens | Values |
| Inner diameter, r (in.) | 6 |
| Outer diameter, R (in.) | 6.17 |
| Weight (oz/ft) | 24 |
| Height, h (in.) | 60 |

The weight was multiplied with the given weight of 24 oz/ft to determine the weight of the entire body tube, and the result was . The following equations were worked through to determine the density.

The density resulted to be 1.23 oz/in3, which converts to 2.13 g/cm3. This makes this the higher density material from the other choice presented.

##### Blue Tube 2.0

Blue Tube 2.0 is airframe material created by Always Ready Rocketry, LLC. This material used for Blue Tube is vulcanized fiber. It is lightweight, which will aid in rocket weight reduction. It is more durable and rigid than other materials similar to it. The rigidity and durability make it a good choice since it will be able to withstand the forces experienced in the overall flight. Blue Tube has a higher resistance to moisture so this can reduce risks of degradation. With this material, there is a high degree con manufacturing consistency so there will also be less risks to structural integrity. Blue Tube is easy to cut, smooth, and work with using common tools. Blue Tube is not as economical as other materials, like cardboard or phenolic. There is also limited sizing, so if it is used, design will need to be restricted to the sizes of the Blue Tube. The coupler will be used of the same material also. Using the manufacturer’s website, the dimensions and density were found. The dimensions and density are illustrated in the following table:

Table 6: Dimensions of Blue Tube 2.0 from alwaysrocketry.com

|  |  |
| --- | --- |
| Givens | Values |
| Inner diameter, r (in.) | 6 |
| Outer diameter, R (in.) | 6.16 |
| Height, h (in.) | 48 |
| Density (g/cm3) | 1.25 |

### Layout

#### Alternative Designs

The rocket needed to have an overall layout that evenly distributed the mass to keep the rocket stable and a layout that was effective for separation events. The team wanted to keep the avionics bay in the middle of the rocket to protect the equipment from the ejection charges and so that there could be two separation events. The team has experience with this configuration. The next decision was where to put the drogue parachute, the main parachute, and the payload. These three components could either go in the bow or aft compartments.

#### Feasibility Study

Because the motor is so heavy and adding mass to the bow increases stability, the team decided to put the payload in the front bay. Next, it was decided that in order to deploy the payload at the appropriate altitude as defined by the competition rules, the main parachute needed to go in the bow compartment so that it could be attached to the payload. This meant that the drogue parachute had to go in the aft compartment.

### Motors

#### Alternative Designs

The three motors that the team is currently considering are the Aerotech L850W, the Animal Motor Works L1080BB, and the Cesaroni L800-P. All three motors have similar burn times and thrust profiles.

Table 7: Alternate motors considered.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Motor** | **Manufacturer** | **Total Impulse (Ns)** | **Average Thrust**  **(N)** | **Max Thrust**  **(N)** | **Burn Time (s)** | **Weight (g)** |
| L850W | Aerotech | 3,646.2 | 1,00.9 | 1,866.2 | 4.4 | 3,742 |
| L1080BB | Animal Motor Works | 3,686 | 1,112 | 1258 | 3.31 | 3,592 |
| L800-P | Cesaroni | 3731 | 805 | 1024 | 4.63 | 3,510 |

#### Feasibility Study

##### AeroTech L850W

The AeroTech L850 W is a very good option and currently the leading design for our team. It has a modest burn time and a maximum thrust of 1866.2 N which means aerodynamic stresses won’t be unbearable on the vehicle. This motor is the heaviest of the three so if mass becomes a problem the other two alternatives will be considered further. The only concerning aspect of this motor is that its maximum thrust value is 1,866 N which could present a problem for the structural integrity of the vehicle but that thrust will be necessary to navigate the large payload to the desired altitude.

Table 8: L850W performance.

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **Units** |
| Total Vehicle Weight | 15004 | grams |
| Stability Margin | 2.71 |  |
| Velocity off Rod | 11.1 | m/s |
| Apogee | 1506 | m |
| Max. Velocity | 189 | m/s |
| Time to Apogee | 17.5 | seconds |
| Flight Time | 37.9 | seconds |
| Descent Time | 20.4 | seconds |

A graph of a motor thrust curves

Description automatically generated

Figure 4: AeroTech L850W thrust curve.

##### Animal Motor Works L1080BB

The Animal Motor Works L1080BB motor is the shortest burning motor the team has selected to analyze. This has its advantages and its disadvantages. The advantages are that the heat transfer to the motor casing and the tail cone will be minimized. This motor will optimize the time it takes to get to altitude and descend back down. However, because this motor has to have a higher sustained force over a short time to have the same energy as the other motors, the aerodynamic stress on the vehicle will be a maximum for this motor.

Table 9: L1080BB performance.

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **Units** |
| Total Vehicle Weight | 14923 | grams |
| Stability Margin | 2.72 |  |
| Velocity off Rod | 20.4 | m/s |
| Apogee | 1489 | m |
| Max. Velocity | 205 | m/s |
| Time to Apogee | 17.3 | seconds |
| Flight Time | 38.1 | seconds |
| Descent Time | 20.8 | seconds |

A graph of a motor thrust curves

Description automatically generated

##### Cesaroni L800-P

The Cesaroni L800-P motor has the lowest average thrust and the longest burn time. This means it is a great option to minimize aerodynamic load. However, this also means it will take longer to get to altitude, therefore the drift might be maximized. This is the lightest motor so if the team needs to save mass it can swap the current design choice for this motor.

Table 10: L800-P performance

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **Units** |
| Total Vehicle Weight | 14841 | grams |
| Stability Margin | 2.74 |  |
| Velocity off Rod | 20.9 | m/s |
| Apogee | 1531 | m |
| Max. Velocity | 186 | m/s |
| Time to Apogee | 17.8 | seconds |
| Flight Time | 38.7 | seconds |
| Descent Time | 20.9 | seconds |

A graph of a motor thrust curves

Description automatically generated

Figure : Cesaroni L800-P thrust curve.

## Current Vehicle Design

The following figures display the current leading design for the team. They feature two bays for the payload and the parachutes. The middle section features an avionics bay that is 40 cm in length. The rocket will have two separation events. As discussed previously, the payload was chosen to be placed in the front bay to increase the stability margin.

A blue and grey cylindrical object

Description automatically generated

Figure : Leading Vehicle Design

A close-up of a pen

Description automatically generated

Figure : Leading Vehicle Design

**Figure 7** demonstrates the dimensions of the vehicle. The overall length is approximately 248 cm. The avionics bay will be a blue tube coupler. This choice was made because it will not undergo the aerodynamic stresses that the outside of the vehicle will experience during powered ascent. The blue tube choice was made to save weight. The avionics bay is also held together by ¼-20 threaded rods. These rods were chosen because they are a common size and the team felt that more security was needed to hold the avionics bay together during the rip forces of the separation events.

A blue and silver pipe with measurements

Description automatically generated

Figure : Vehicle Dimensions

The Open Rocket layout diagram can also be seen below. The avionics bay will also feature two bulkheads with U bolts that the shock chords will connect the two when separation events occur. The bulkheads were chosen to be spruce wood because of its ability to withstand forces. The U bolts were chosen over eye bolts because they can distribute the load of the shock cord pull during deployment better than the eyebolts. There will be a CO2 black powder system to initiate the separation events.

A diagram of a pipe

Description automatically generated

A drawing of a battery

Description automatically generated

The energetics on board will be the black powder charges used for deployment events. The team chose black powder because it is a common energetic used in this application. It is readily available, fairly easy to work with, and reliable. The separation points are also indicated in the above figure. These points were chosen because they separate the total mass of the vehicle evenly between the top and bottom sections.

The team chose the Ogive nosecone because it reduces drag forces and makes the rocket more stable. This was determined through open rocket simulations. The Ogive nose cone is less mass efficient than the other designs, but the team decided that because the shape is easy to manufacture then it would proceed with the ogive nose cone. The team decided to add a bluntness to the nose tip to decrease the possibility of cracking stresses under stress conditions.

The fins were changed many times very recently and probably will continue to change. The elliptical fins are really for applications involving relatively high speeds and this rocket was designed to achieve a maximum speed of about 0.6 Mach as to decrease the aerodynamic load on the vehicle. The fins were chosen to be the clipped delta design. This design was chosen because they are easy to design and manufacture while still providing decent stability and drag reduction. The fins were designed to have a simple 2D profile with a thickness. The team did not want to have a complicated 3D fin geometry due to complications in past years.

A drawing of a red object with measurements

Description automatically generated

Figure : Fin

Fin flutter was originally a large concern but as it was calculated in the previous section, this design has a factor of safety of about 1.5. The team is trying to optimize simplicity and workability for this year's competition which has led to many of the design decisions in the thrust structure. First, the team wanted a structure that could be assembled outside of the vehicle then easily placed in the vehicle. This will allow for quick assembly on launch days. The fins are bolted into the aluminum brackets and placed within the wood bulkheads. This assembly is placed into the aft end of the vehicle and a motor retainer is used to keep it from falling out. The team also wanted to combine the tail cone into the thrust structure because last year it was added behind the plume of the motor and the hot exhaust jet destroyed the tail cone.

The team also saw an opportunity to solve two challenges with one design decision. There were structural concerns and a reliable way to mount the fins was needed. So the team decided to mount the fins by squeezing them between two aluminum plates and bolting it all together. This also allows for the aluminum brackets to provide structural integrity. This design is simple and effective.

Originally the team wanted to use long bolts to fasten the entire structure together and to aid with structure but the team’s mentor, Tom, advised against this because he said it was unnecessary. The upward thrust of the motor would prevent the motor from falling out during powered ascent so the only downward force on the motor would essentially be the weight of the motor which could be overcome with a simple motor retainer system. This means that the threaded rods would have been overkill and would have only been added weight.

The current motor that the team has chosen is the Aerotech L850 W. This motor provides a thrust profile that is optimal, and the team currently has extra reloads in its possession from last year. So, to save money, this is the team’s current design choice.

A red and grey object with a round object

Description automatically generated with medium confidence

Figure : Tailcone and fins

A drawing of a red object with a grey ball

Description automatically generated

Figure : Tail cone and fin dimensions

The overall mass of the vehicle full and empty are presented below with a breakdown of the subsection masses and individual component masses. The mass of the vehicle right now does not inhibit the vehicle from reaching its desired altitude.

Table 11: Launch vehicle mass.

|  |  |
| --- | --- |
| **Component** | **Mass (g)** |
| Total mass with propellant | 15105 |
| Total mass without propellant | 13040 |
| Upper section Total | 6986.7 |
| Nosecone | 2267 |
| Ballast Mass | 500 |
| Bulkhead | 105 |
| Eyebolt | 70 |
| Body tube | 1552 |
| Payload | 2300 |
| Shock Cord | 13.7 |
| Main Parachute | 179 |
| Eyebolt | 70 |
| Avionics Bay Total | 921.5 |
| Body Tube | 71.9 |
| Coupler | 176 |
| Bulkhead | 98.3 |
| Bulkhead | 98.8 |
| Main Ejection Charge | 25 |
| Main Ejection Charge | 25 |
| Apogee Ejection Charge | 25 |
| Apogee Ejection Charge | 25 |
| Altimeter 1 | 85 |
| Altimeter 2 | 85 |
| Arduino Flight Computer | 37 |
| Battery 1 | 50 |
| Battery 2 | 50 |
| Bottom Section Total | 7265.8 |
| Body Tube | 1977 |
| Centering Ring | 74.1 |
| Centering Ring | 74.1 |
| Shock Cord | 13.7 |
| Drogue Parachute | 22.8 |
| Fins | 709 |
| Centering Ring | 76.8 |
| Eyebolt | 70 |
| Eyebolt | 70 |
| Centering Ring | 104 |
| GPS Tracker | 20 |
| Tail Cone | 46.1 |
| 75mm Motor Tube | 159 |
| Centering Ring | 23.8 |
| 75 mm Motor Retainer | 72.2 |
| Launch Mass of Motor | 3673 |
| Empty Mass | 1608 |

## Recovery Subsystem

### Description of Recovery Events

The launch vehicle will utilize two dual-deployment altimeters to control both stages of parachute deployment. The altimeters will be thoroughly tested before launch to ensure that accurate altitude can be determined from its barometric data and that the ejection signal fires as intended. Altimeters will not be armed until the vehicle is in launch configuration, to reduce any risk of charges firing in vicinity of people. After the vehicle is launched, the barometric sensors on the altimeters will detect when the pressure stops changing and determine apogee, signaling for the drogue ejection. This signal will utilize CO2 gas to pressurize enough to shear the pins holding the drogue bay. A similar operation will occur at 500 ft above ground level (AGL) to deploy the main. The two-stage separation allows for a safe recovery of the launch vehicle while minimizing drift from deploying a large parachute close to apogee.

Shock cords will be used to connect each section of the vehicle after separation. Parachutes will be attached to the cords with links, and carefully packed into their respective bays in a manner that will not tangle or otherwise hinder recovery. These shock cords hold each section of the vehicle together as the launch vehicle separates and descends.

### Recovery Alternative Designs

#### Altimeter Alternatives

Table 12: Altimeter alternatives.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | TeleMega | TeleMetrum | Aim 3 | RRC3 |
| Manufacturer | Altus Metrum | Altus Metrum | Entacore | Missile Works |
| Dimensions (L\*W\*H) (mm) | 88x32x16 | 27x70x16 | 65x25x15 | 100x23x4 |
| Pyro Channels | 6 | 2 | 2 | 2 |
| Field Output | Beeps, AltOS | Beeps, AltOS | Beeps | Beeps, LCD |
| Weight (g) | 24.95 | 20.13 | 12.81 | 17.01 |
| Sampling Rate (Hz) | 100 | 100 | 10 | 20 |
| Battery (V) | 3.7 | 3.7 | 3.7 | 3.7 |
| Price | $508.85 | $381.63 | $121.15 | $101.33 |
|  |  |  |  |  |

Every altimeter listed supports dual deployment, making them suitable for the project. The highest-end altimeters are the TeleMega and TeleMetrum from Altus Metrum. The advantage to these components is the live telemetry data, which can better characterize flight success and provide the team with a holistic view of the launch. The primary difference between the two Altus Metrum systems are the additional pyro channels included in the TeleMega, which could be used for additional ejection events. Both products contain a 1-axis 102G accelerometer and a barometric altitude sensor. These altimeters can also be armed remotely, allowing for a safer launch setup as people do not have to be close to the rocket when it is on the pad.

A downside of the Altus Metrum altimeters is the additional components needed to take full advantage of their capabilities. Both the TeleMega and TeleMetrum require the TeleBT and an external antenna to take advantage of the live telemetry.



Figure : The two considered Altus Metrum altimeters. The TeleMega offers four more pyro channels than its counterpart.

The Entacore AIM 3 altimeters have been used in previous years and offer a simple interface to program ejection charges. The AIM 3 also communicates apogee through a series of beeps, allowing for immediate feedback from the field. Data is easily transferred from the altimeter to a PC with a micro-USB, where the software can export as an Excel file for easy data processing.



Figure : The Entacore Aim 3 altimeter.

Another potential altimeter is the Missile Works RRC3. This altimeter provides very similar functionality to the Aim 3, coming preprogrammed with a drogue event at apogee and the main event at 500ft. However, the RRC3 requires a separate USB interface to change the default event configurations and download flight data. The Aim 3 can transfer data to a PC without a separate module, giving it an advantage over the RRC3 in this application.

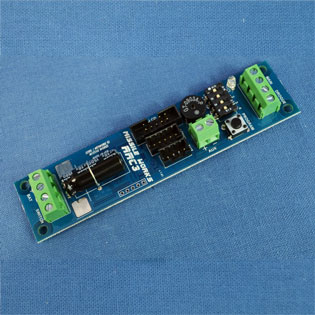


Figure : The Missile Works RRC3 Dual Deployment Altimeter.

#### Tracking Alternatives

In addition to sending ejection signals as altimeters, the TeleMega and TeleMetrum also have an integrated GPS sensor, the TeleGPS, which would eliminate the need for a separate system. Lists of potential GPS units are given below.

Table 13: Alternatives for tracking devices.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | TeleGPS | GPS Tracker | EggTimer | AirTag |
| Manufacturer | Altus Metrum | Featherweight | TX Transmitter | Apple |
| Dimensions (L\*W\*H) (mm) | 38 x 25 x 6 | 31 x 20 x 3 | 23 x 76 x 6 | 32 x 32 x 8 |
| Weight (g) | 12.3 | 15.0 | 12.0 | 11.0 |
| Range (km) | 100 | 85 | 9 | N/A |
| Transmitter Frequency (MHz) | 433 | 915 | 900 | 13.56 |
| Battery | 3.7 | 3.4 – 4.5 | 7.4 | 3 |
| Price | $254.43 | $365 | $110 | $30 |
|  |  |  |  |  |

The TeleGPS is available separately from the altimeters, making it a viable option for any altimeter choice. It requires a ground station and a separate antenna but is highly rated as a reliable GPS unit for high-powered rocketry. It boasts a range of over 100km, however, that value is known to vary based on configuration and environment. The Featherweight GPS tracker is another popular option, featuring an easy-to-use tracking system for finding the rocket after it lands.

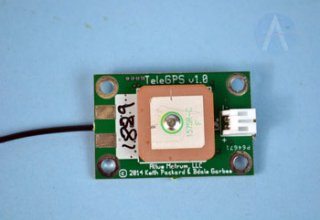


Figure : The independent GPS unit. The Altus Metrum altimeters have this unit integrated on the board.

The EggTimer TX is one of the most cost-efficient GPS modules on the market, however it requires moderately complicated assembly upon arrival. This assembly could risk the functionality of the module if not done correctly. The EggTimer has mixed reviews online, but customer service is said to be helpful during the assembly process. The EggTimer TX is the base model of the EggTimer GPS units and reliable for the scope of this project.

A green circuit board with a black wire and other components

Description automatically generated

Figure : The EggTimer TX transmitter, before assembly.

While initially drawn to the Apple AirTag due to its low price point and convenience, it was found that the AirTag uses Bluetooth from other iOS devices to locate itself rather than GPS. Therefore, the AirTag is unable to communicate vehicle location if the rocket lands in a rural area, which is likely due to the nature of launch locations. It would also not technically satisfy the competition requirements as a GPS on the launch vehicle and any independent sections that land separately. While this may prevent the AirTag from being the primary tracking device, having an AirTag on board could serve as a useful backup should failure occur. Searching for the vehicle in tall grass or other obstructive environments would be much easier with the help of an AirTag and iOS device.

#### Drogue Parachute Alternatives

The drogue parachute serves to decrease the velocity of the rocket prior to the deployment of the main parachute. Without this decrease in terminal velocity, the resultant forces from the rapid deceleration by the main parachute would overload the components at the points of attachment of the shock cord. Additionally, the drogue must not slow the rocket down too drastically such that the total descent time and drift distance exceed 90 seconds and 2500 feet, respectively. The rocket descent velocity was calculated for each drogue parachute alternative using the equation below.

In this equation, is the velocity with the parachute, is the burnout mass of the rocket, is the acceleration due to gravity, is the projected area of the parachute, is the drag coefficient, and is the density of air.

After each drogue parachute alternative’s velocity was calculated, the resultant value was used to calculate the descent times from apogee to the main parachute’s deployment altitude. The resultant descent times were used to calculate the drift distance under 20-mph during that time interval. These calculations are shown in depth in section [YO].

Table 14: Alternatives for drogue parachutes.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Parachute** | **Drag Coefficient** | **Projected Area (ft^2)** | **Descent Speed (ft/s)** | **Descent Time: Apogee to Main Deployment (s)** | **Wind Drift: Apogee to Main Deployment at 20-mph (ft)** |
| **Fruity Chute 15" Classic Elliptical** | 1.5 | 1.178 | 117.434 | 37.391 | 1096.810 |
| **Fruity Chute 18" Classic Elliptical** | 1.5 | 1.696 | 97.861 | 44.870 | 1316.185 |
| **Fruity Chute 24" Classic Elliptical** | 1.5 | 3.016 | 73.397 | 59.826 | 1754.885 |
| **Fruity Chute 30" Classic Elliptical** | 1.5 | 4.712 | 58.717 | 74.783 | 2193.619 |

The Fruity Chute 15-inch Classical Elliptical resulted in the largest velocity at 117.434 feet per second. This drogue parachute alternative was discarded as its descent velocity would result in too large of a force for the recovery components to withstand during main parachute deployment. Additionally, the Fruity Chute 30-inch Classical Elliptical had large values for descent time and wind drift, making it less viable than the 18-inch and 24-inch parachutes.

#### Main Parachute Alternatives

The main parachute is intended to bring the rocket to its desired landing velocity. This parachute deploys at a specified altitude that is reached after the drogue parachute is deployed. The main parachute is larger in size and has a larger drag coefficient than the drogue parachute. The descent speeds, descent times, and wind drifts of the main parachute alternatives were calculated with the same process used for the drogue parachute’s values. The results are shown in Table [YO] below.

Table 15: Alternatives for main parachutes.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Parachute** | **Drag Coefficient** | **Projected Area (ft^2)** | **Descent Speed (ft/s)** | **Descent Time from Main Deployment to Ground (s)** | **Wind Drift from Main Deployment to Ground at 20 MPH (ft)** | **Kinetic Energy of Heaviest Recovered Section (ft-lb)** |
| **Fruity Chute 60" Iris Ultra Standard** | 2.2 | 19.027 | 24.129 | 22.794 | 668.632 | 139.363 |
| **Fruity Chute 72" Iris Ultra Standard** | 2.2 | 27.399 | 20.107 | 27.353 | 802.359 | 96.779 |
| **Fruity Chute 84" Iris Ultra Standard** | 2.2 | 37.292 | 17.235 | 31.912 | 936.085 | 71.103 |
| **Fruity Chute 96" Iris Ultra Standard** | 2.2 | 48.708 | 15.081 | 36.471 | 1069.811 | 54.439 |

The Fruity Chute 60-inch and 72-inch Iris Ultra Standard parachutes had kinetic energies for the heaviest sections that exceeded the required 75 foot-pound force maximum. The resulting parachutes were judged based on which had smaller values for descent time and wind drift. The 84-inch parachute’s calculations resulted in the most adequate results for the parameters.

#### Shock Cord

The shock cord will attach the vehicle sections to the parachutes after deployment has occurred. The shock cord should be able to withstand the forces associated with deployment. The bets materials to use for shock cords are

#### Ejection

To avoid the inherent risk and legal concerns with traditional black powder ejection systems, the team will utilize a CO2 gas ejection system. These work through pressurizing the interior of the rocket bay until the shear pins break and the components inside are released. There are a variety of these available on the market, one that the team has experience with is the Raptor CO2 ejection system. Ejection sizing can come from the size of the gas canister attached.

### Recovery Leading Design

#### Avionics Bay

All avionics electronics will be contained in the avionics bay, which will protect sensitive components from corrosive gas during separation. The components will be arranged on a 3D printed sled, where they can be secured with zip ties to ensure vibrations during flight do not disrupt electronic connections.

#### Electronics

After considering the different alternatives for component selection, the team selected the TeleMetrum flight computer as the primary option for the project. This is due to its positive reviews and integrated GPS capabilities, which eliminates the need for a separate tracking system. The live telemetry data would also provide the team with valuable data to characterize flight data. As a backup the team will use an Entacore Aim 3 altimeter, which the team has access to and experience with. The altimeters will send the system to the Raptor CO2 gas ejection system to deploy the chutes.

Due to uncertainties around project budget, if the steep cost of the TeleMetrum and associated components is unable to be met then the team will use two Entacore Aim 3 altimeters, which will be wired completely independently and with a time delay. This will ensure deployment; however a separate tracking system will then be required to satisfy competition guidelines. Should this be the case, the team will use an EggFinder TX Transmitter as the GPS on the launch vehicle. While assembly introduces inherent risk to the system, a successful transmitter and receiver is feasible with documentation and customer support.

#### Parachutes

The Fruity Chutes 18-inch Classic Elliptical is the leading preliminary selection for the drogue parachute of the launch-vehicle. The shock load from the main parachute deployment with this selected drogue parachute is large, however, it should not lead to component failure. Ultimately, this parachute was selected due to its calculated values for descent time and wind drift being lower than the required values. Out of the drogue parachutes that resulted in adequate shock, this parachute offered the fastest descent time and lowest wind drift.

The Fruity Chute 84-inch Iris Ultra Standard is the leading preliminary selection for the main parachute of the launch-vehicle. This is because out of all the parachutes that satisfy the kinetic energy at landing requirement, the 84-inch provided the smallest total values for descent time and 20-mph wind drift at 76.8 seconds and 2252.3 feet, respectively.

#### Redundancy

For the recovery system, redundancy would be defined as implementing a backup system to ensure the deployment of the parachutes if the primary system fails. This backup should be completely independent of the primary system and utilize different hardware and software combinations to account for edge cases of a particular component. For the chosen recovery configuration, redundancy exists in the following form.

A diagram of a block diagram

Description automatically generated

***Figure 18:*** *Avionics Redundancy*

In this diagram there are two altimeters, of different makes and models, which can control both the drogue and main chutes. Each altimeter is attached to a separate battery. The primary system would be the more robust TeleMetrum altimeter, with the Aim 3 as a backup. For this system the Aim 3 would be programmed to deploy at a slight time delay after apogee and 500ft, so that simultaneous charges are not destructive to the vehicle.

## Mission Performance Prediction

### Launch Target Altitude

The mission target altitude is 4940 ft.

### Flight Profile Simulations

The below graphs show the flight profile, the vertical velocity, and the vertical acceleration of 3 flights with different wind conditions. The wind conditions are 5mph, 10 mph, and 15 mph. The fin cant angle is 5 degrees.

***A graph of a speed chart

Description automatically generated with medium confidenceFigure 19: 5 m/s Wind Speed Simulation***

A graph of a speed of a wind speed

Description automatically generated with medium confidenceA graph of a speed of a wind speed

Description automatically generated with medium confidence

### Stability Margin, Center of Pressure, and Center of Gravity

The below graphs show the stability margin, center of pressure, and the center of gravity of 3 flights with different wind conditions. The wind conditions are 5mph, 10 mph, and 15 mph. The fin can't angle is 5 degrees.

A graph of a speed test

Description automatically generated with medium confidenceA graph of a speed test

Description automatically generatedA graph of a speed test

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### Kinetic Energy at Landing

The kinetic energy of each tethered rocket section was calculated using the following equation:

Where is the mass of the section and is the velocity of the section. This equation was used in conjunction with the maximum allowable kinetic energy for an independently tethered section, 75 foot-pound force, to calculate the maximum allowable descent velocities for each tethered section. The results are shown in the table below.

Table 16: Alternatives for tracking devices.

|  |  |  |  |
| --- | --- | --- | --- |
| **Section** | **Mass (g)** | **Mass (slug)** | **Maximum Descent Velocity (ft/s)** |
| Nosecone + Upper Payload Bay + Payload | 6986.7 | 0.4787 | 17.701 |
| Nosecone + Upper Payload Bay | 4718.7 | 0.3233 | 21.539 |
| AV Bay | 921.5 | 0.0631 | 48.740 |
| Fin Can | 5200.8 | 0.3564 | 20.516 |

The velocity of each section was found using the velocity equation in section 3.4.2.3. for the selected main parachute. These velocities were used to calculate the impact kinetic energies for each tethered rocket section. These values are shown in the table below.

Table 17: Alternatives for tracking devices.

|  |  |  |  |
| --- | --- | --- | --- |
| **Section** | **Mass (g)** | **Mass (slug)** | **Kinetic Energy (ft-lb)** |
| Nosecone + Upper Payload Bay + Payload | 6986.7 | 0.4787 | 71.103 |
| Nosecone + Upper Payload Bay | 4718.7 | 0.3233 | 21.539 |
| AV Bay | 921.5 | 0.0631 | 48.740 |
| Fin Can | 5200.8 | 0.3564 | 20.516 |

### Descent Time

The descent time of the rocket varies with the size of parachute. The descent time was calculated by summing the descent time for each parachute type. Each individual descent time was calculated by multiplying the terminal velocity with the known altitude difference for each parachute. The distance for the drogue parachute is the difference between the target altitude and the main parachute deployment altitude. The distance for the main parachute is the difference between the main parachute deployment altitude and the altitude at the launch site. The resultant descent times for the drogue and main parachutes were calculated as 44.9 seconds and 31.9 seconds, respectively, combining for a total descent lasting 76.8 seconds.

### Drift Distance

The calculation of the drift distance for the rocket was calculated by multiplying the wind speed by the descent times. These calculations assume that the only component acting horizontally on the rocket is the counter wind, and that apogee is directly above the launch pad. Drift calculations for wind speeds of 0-mph, 5-mph, 10-mph, 15-mph, and 20-mph were 0 feet, 563 feet, 1126 feet, 1689 feet, and 2252 feet, respectively.

# Payload Criteria

## Payload Mission

### Payload Objective

The objective of the payload for the 2024 NASA Student Launch Competition is to design, fabricate, and successfully test a five-pound SAIL (STEMnaut Atmosphere Independent Lander) for safely retaining and transporting four figurines representing a human flight crew, called STEMnauts, from the descending launch vehicle to the ground. The payload will be deployed at an altitude between 400 to 800 feet AGL after real-time permission is given by the RSO. The SAIL will descend and land in a unique predetermined orientation while meeting safe landing parameters approved by NASA. The descent mode of the payload will not utilize parachutes and/or streamers, nor will it use chemical energetics below 500 feet.

### Payload Experiment and Success Criteria

The payload experiment payload will occur during a launch of the full-scale rocket. Prior to launch, the STEMnauts will be loaded and restrained within the SAIL. The SAIL will be loaded into the payload bay of the launch vehicle. Upon the descent of the launch vehicle between 400 and 800 feet AGL and after receiving real-time RSO permission, a signal will be sent to deploy the payload. After receiving the signal, the payload will separate from the launch vehicle and begin its independent controlled descent. The payload will safely descend to the ground and land in the prespecified and NASA-approved landing orientation. After landing, the STEMnauts will be removed from the payload and examined for damages.

Specific criteria have been outlined to qualify the payload experiment as a success. The criteria address two categories: STEMnaut survivability, and payload design/functionality. The STEMnauts are treated as living entities with their safety mirroring those of human astronauts. Thus, the payload experiment must ensure that a human would survive the payload’s landing and descent. Human survivability metrics were developed to encapsulate the inherent safety considerations of the payload experiment and must be met to qualify it as a success. The human survivability metrics are as follows:

* All STEMnauts remain within their designed restraints throughout the entirety of the payload experiment.
* No STEMnauts incur any significant physical damage or failure. This includes any crack/breakage, plastic deformation, burn/corrosion, and/or melting.
* No STEMnaut should experience an acceleration greater than 25 G for up to 150 milliseconds.
* A viable method of ingress/egress exists after the landing event

The payload design/functionality criteria are derived from the requirements from the 2024 NASA Student Launch Handbook. The documentation of these requirements constrains the avenues for design to a structured framework that aligns with the payload objective and technical specifications. The following payload design/functionality criteria are follows:

* Parachutes or streamers are not used to reduce descent speed.
* The SAIL weighs at least 5 lbs.
* The SAIL deploys between 400 and 800 feet AGL after real-time RSO permission is given.
* Chemical energetics are not used below 500 feet AGL.
* The SAIL lands in the predetermined orientation within the landing parameters, both accepted by NASA.
* The STEMnauts are retrievable through the designed method ingress/egress.
* The payload experiment flight data is recorded during and retrieved after the experiment.
* The SAIL meets all rules and regulations set forth by the FAA and NAR.

During the payload experiment, flight data will be recorded and stored using onboard sensors, flight computers, and memory storage. These metrics will be verified through post-flight data analyzation and physical examination of the payload vehicle and STEMnauts. After post-flight examinations and analyses, the payload experiment will be classified as successful if all criteria are met, and unsuccessful if any criterion is not met.

## Selection, Design, and Rationale of Payload

Successful completion of the payload mission requires a payload design with functional systems for deployment, retention, descent mode, flight control, data recording, and power. This section serves as a comprehensive exploration of the alternative designs for each system. All system design alternatives are judged based on their predicted reliability, price, ease of use, and ease of integration.

### Deployment

After receiving real-time permission from the RSO, the payload must deploy, meaning completely separating from the launch vehicle once user input is received. Functionally, the system must receive signals transmitted by the team, and have a method for separation that does not damage either the launch vehicle or the SAIL.

#### Electromagnetic Release

An electromagnetic release mechanism consists of strong electromagnets that hold and restrain the payload. Separate magnets are attached to both the payload and the launch vehicle. The electromagnets attract each other with a strong electromagnetic force, preventing movement of the payload within the body of the launch vehicle. When power is applied to the electromagnets, the electromagnetic force is canceled, and the payload is released.

There are a few notable advantages to this design. An electromagnetic release mechanism would be compact, meaning it would interface well between the payload and the launch vehicle. Regarding the nature of the payload release, an electromagnetic release mechanism would provide a gentle and instantaneous release between the payload and launch vehicle. Sensitive components of the payload would likely benefit from this alternative.

Several drawbacks for the electromagnetic release mechanism are its power demand, weight, commercial unavailability, the lack of ejection from the payload bay, and EMI (electromagnetic interference). Electromagnets capable of restraining a five-pound load require a large amount of power. This demand would require the inclusion of more batteries to an already space restricted area, increasing the complexity of the system. Additionally, capable electromagnets would add significant weight to the payload and launch vehicle, potentially giving rise to mass distribution issues. Also, there are very few commercially available electromagnetic payload release mechanisms, if any. The electromagnetic release mechanism would not be capable of forcefully ejecting the SAIL from the payload bay by itself. This would increase the complexity of the design as an ejection would be implemented in conjunction with the release. EMI could affect the communication and functionality of other onboard electronics and circuitry.

#### Tether and Line-Cutter

The tether and line-cutter design alternative involves a tether and a line-cutter used to sever the tether. The tether attaches to the payload and the main parachute of the launch vehicle, allowing for payload ejection from the payload bay during the main parachute deployment stage. The line-cutter is a commercially sourced component connected to the payload. The deployment and separation of the payload will occur after ejection. When the payload receives the deployment signal, the line-cutter will sever the attachment through cutting the tether between the parachute and the payload. Examples of these components are shown in Figure 18 below.

A close up of a tube

Description automatically generated

Figure : Commercially available line cutter

The advantages of the tether and line-cutter design include its smart integration, simplicity, and lightweight. This method uses smart integration through implementing an existing system to solve a separate functional need. The deployment of the main parachute serves to safely return the launch vehicle to the ground; however, it also pulls the payload out of the payload bay. Additionally, this design is comparatively simple to the other deployment alternatives. This is evident in that it utilizes an existing system and adds few extra components. The tether and line-cutter alternative is also lightweight given that the few required components are light.

There is the possibility of unintentional. In this case, the payload could deploy premature to RSO permission. This would cause immediate payload experiment failure. Additionally, the reliance on the recovery system could potentially cause two separate system failures instead of one or lead to the failure of the recovery system that was otherwise functional.

#### Spring-Loaded Ejection

Spring-loaded ejections are a method of payload deployment that involves the use of potential energy from compressed spring. The spring is held compressed by a latch that controls the release of energy of the spring. Upon deployment, the latch switches and the compressed spring is unconstrained, causing a rapid release of kinetic energy. The resultant spring force would jettison the payload out of the launch vehicle.

The spring-loaded ejection alternative has a few positive aspects. The mechanism has the potential to create a great distance between the payload and launch vehicle. An increase in distance between the two vehicles would lower the risk of collision between the payload and launch vehicle. This design is also incredibly straight forward and simple due to the small number of required components and moving parts.

There are numerous drawbacks for using a spring-loaded ejection for payload deployment. One issue is the lack of control with respect to the deployment conditions, like launch vehicle orientation at deployment. This degree of variability makes the direction deployment hard to predict and preserves the risk of payload-component collision. Another considerable factor is the risk of accidental ejection during flight. This poses a great risk to the structural integrity of the payload and launch vehicle, as both would certainly become damaged. Additionally, some larger complex payloads are unsuitable for spring-loaded ejections due to their mass and sensitive components. A five-pound payload could be too massive for effective ejection.

### STEMnaut Retention

#### One STEMnaut Capsule

A singular pod for the STEMnauts would allow for the payload design to focus on a specific area to maintain survivability metrics. This could be protected by other components as the most important section. However, one pod dedicates a large amount of space which can be hard to fit in certain designs.

#### Four Capsules

Separate STEMnaut capsules provide increased modularity into the payload design. This distribution could be used to more freely alter center of mass or other technical aspects of the design. However, it could potentially introduce multiple modes of failure for the STEMnauts, as each capsule now has to be retained separately, with one failed capsule ruining the entire payload experiment.

### Descent Mode

The descent mode of the payload is intended to decelerate the payload during its independent descent. The design alternatives for the descent mode may not utilize parachutes, streamers, or chemical energetics. The following design alternatives were evaluated based upon each’s thrust capability, fabrication feasibility, size, availability, and price.

#### Compressed CO2 Gas Thrust

Controlled descent by compressed CO2 involves downward expulsion of compressed gas to generate upward thrust. Compressed CO2 canisters would store the pressurized gas onboard and release with the actuation of a valve. Of all the alternative descent modes, compressed CO2 thrusting is the most atmosphere independent approach.

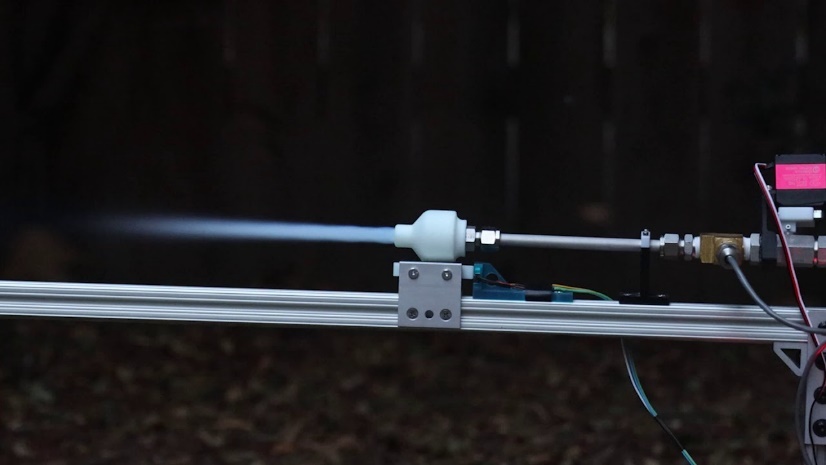


Figure 20: An experimental setup of a cold gas thruster by an enthusiast

There are few positives to using compressed CO2 gas thrusting. The main justification is the degree of its atmosphere independence with respect to other alternatives. Most other alternatives utilize the atmosphere through dependence on drag and air, whereas compressed CO2 gas thrusting uses the pressure differential between the gas container and exterior to expel high-speed gas. This mode of descent is applicable to a larger variety of environments, making it a more “on-theme” approach to the payload design.

This design alternative has significant drawbacks to the project, one being the complexity and difficulty of controlling the thrust. Fluid propulsion is difficult to model due to its unpredictable nature and complex governing equations. Additionally, compressed gas thrusters are not commercially available, meaning the method for gas expulsion would have to be designed. This method would also pose a greater financial burden than other alternatives as compressed gas is a limited resource, and a great amount of testing would be required, meaning the CO2 would have to be continuously purchased or refilled.

#### Glider

Descent by a glider involves a winged vehicle that glides through the air without the use of propulsion. The glider would use a fuselage to provide lift and stability during its descent. This design would likely have to be remote-controlled as autonomous control of this system would be outside of the team’s scope of capabilities. Thus, a camera would be included to aid with the control of the vehicle.



Figure 21: Image of a potential glider-based payload

The positive aspects of the glider include its cost effectiveness and precision control potential. Compared to powered thrust design alternatives, the glider would cost much less due to its small power demand. Additionally, the plane-based design for the glider would allow for a greater dynamic range of actuation. This is an optimal feature given the orientation requirement for landing the payload.

The negative aspects of this design include spatial concerns, range limitations, and lack of propulsion. Firstly, the payload would likely have difficulty interfacing within the payload bay. This is because a glider is long and wide due to its aerodynamic structure. Also, gliders have limited range for control, meaning another failure mode is introduced. Lastly, the lack of propulsion could be detrimental to the payload recovering from strong crosswinds.

#### Quadcopter

The quadcopter design closely resembles a common recreational drone. It contains four propellers, each accompanied by a motor. Two motors spin clockwise and the other two spin counterclockwise. This orientation cancels out the yaw induced by the spinning components. The quadcopter would be autonomously controlled using a flight controller.



Figure 22: Commercial quadcopter carrying payload

This design is advantageous as it has extremely precise control, it is widely documented, and is commercially available. Four sources of thrust allow for dynamic actuation and effective responses to flight disturbances. The documentation for drones is extensive and many required flight software is open source. This makes design and control much simpler than alternative methods for descent. Additionally, components for drones can be easily found online, making their fabrication more feasible.

There are severable disadvantages to designing a quadcopter for controlled descent. One issue is spatial concern. Typical drones are dimensionally wider than the available space within the payload bay. It is likely that using this design would require a foldable frame to fit within the payload space, increasing the complexity and risk of failure. Another issue is the risk associated with propellers near the recovery components. Incorrect deployment could lead to collision between the parachutes and the payload. This could lead to failures for recovery and payload.

#### Thrust-vectoring Singlecopter

The thrust-vectoring singlecopter is essentially a drone with one motor driven propeller. Without an even number of propellers, yaw rotation is induced due to the lack of a counterbalance. Thrust vectoring can be used to negate this. Thrust vectoring is essentially changing the direction of the thrust force to accomplish some desired actuation. Many thrust-vectoring singlecopters use fins to change the direction of air flow from the propellers. An example of this thrust-vectoring singlecopter design is shown below.

There are many positive qualities about this design alternative. These types of drones are typically compact, meaning that it would interface well within the space-limited payload bay. Also, much like the quadcopter, there is a vast amount of available documentation for designing and controlling this type of UAV (unmanned aerial vehicle). Many open-source flight control programs are available to use as well.

Like the quadcopter, the deployment of this design could cause failure to both payload and recovery systems if done improperly. In addition, testing the functionality of the controller requires the fabrication of a testing rig that restrains the device while allowing it to freely rotate. Otherwise, the device would likely destroy itself by crash landing.

### Landing Gear

The landing gear for the payload will allow it to hold itself securely in a specific orientation on the ground. It must be durable enough to withstand the loads exerted upon impact. The landing gear must not negatively interfere with the interface between the payload and launch vehicle. The criteria used to judge the landing gear alternatives are its volume, stability, complexity, ease of integration, and price.

#### Folding Mechanical Legs

Deployable folding mechanical legs are mechanical structures intended to absorb the shock from landing and keep the payload held in an upright position after landing. These legs are out of the way during most of the descent and deploy when the payload is closer to the ground. This alternative allows for compact storage of the payload in the launch vehicle and offers decent stability. Additionally, the design could be as simple as a four-bar linkage.

#### Inflatable Platform

An inflatable platform deploys close to the ground and is intended to absorb the shock from landing, much like the airbag in a car. The platform could be inflated using compressed gas or an onboard pump. Prior to landing, the control system of the payload triggers the platform to inflate. The platform cushions the impact of the payload with the ground, offering extra protection and care for sensitive components housed within the payload. One negative aspect of this is the instability introduced as the platform deploys. This instability could act as a major disturbance to the controlled descent and cause the payload to spiral out of control. Additionally, using any chemical energetics to inflate the platform below 500ft would be a violation of competition guidelines.

### Flight Control

The flight controller is crucial to the functionality of the payload as it is responsible for all the actuations. The flight controller commands the actuators to adjust for disturbances and errors between desired and actual values. Some flight controllers are equipped with an internal IMU and gyroscope.

#### Arduino

An Arduino is a popular microcontroller and open-source software used for controlling electronic devices. Arduinos interface with a vast variety of electronic components such as sensors, actuators, data recorders, computers, etcetera. Arduinos can be used for flight control applications and have community libraries for controlling actuators used in UAVs. On the other hand, Arduinos are inferior to other types of flight controllers in that they have greater power demands, more latency, and are relatively bulkier.

#### Raspberry Pi

A Raspberry Pi is a small, credit card sized computer commonly used in applications that require computing power that exceeds the capabilities of an ordinary microcontroller. Most drone applications can be accomplished using microcontrollers as the computational demands are relatively low. Additionally, like Arduinos and other similar microcontrollers, Raspberry Pis are less power efficient, have greater latency, and are bulkier than flight controllers.

#### Flight Controller

Dedicated flight controllers are the most used controller in drone and UAV applications. These devices are much smaller and less power demanding than ordinary microcontrollers. They are designed to make real-time adjustments to flight variables, such as altitude, orientation, and stability. Most are equipped with built-in sensors that monitor the mentioned variables. Additionally, there are many open-source programs and algorithms that are compatible with most flight controllers. There are a variety of different options for flight controllers based off of required builds, sensors, or tasks. Also, there is large amount of publicly available documentation that demonstrates how to design and control UAVs using flight controllers. This simplifies the design and control aspect of the payload design.



Figure 23: Popular PixHawk flight controller

### Data Storage

Flight data records must be stored for post flight analysis. This data is stored onto small storage devices that are compatible with common controllers. The data can be retrieved from these storage devices by connecting them to a computer.

#### Flash Chip

Flash chips are soldered directly onto an electronics board within the device. These allow for real-time data logging that is accessible both during and after the flight. They are practical in flights with harsh conditions due to their permanent contact with the board.

#### SD Card

SD cards are storage devices that are commonly used in flight data recording applications. Unlike flash chips, SD cards are portable and more user friendly. One drawback is that they can potentially disconnect under harsher flight conditions which results in lost or corrupted flight data.

During ideation, a variety of alternative designs were considered to meet the 2024 Payload objective. Each of these alternatives offers unique ways to achieve a successful payload experiment, however a final preliminary design was chosen after considering the pros and cons of each alternative.

## Preliminary Payload Design

### Autonomous Transit and Landing for Airdropped Singlecopter (ATLAS)

A grey robot with red and blue buttons

Description automatically generated

Figure 24: Rendering of preliminary payload design in desired landing orientation (left), and retracted (right).

A drawing of a machine

Description automatically generated

Figure 25: Annotated view of ATLAS components

The final preliminary payload design for the 2024 Student Launch competition was chosen to be Autonomous Transit and Landing for Airdropped Singlecopter (ATLAS). It was decided that this design presented the best path to successfully meet the competition requirements. The ATLAS will autonomously land the STEMnauts, represented as LEGO astronauts, in the specified desired orientation in an astronaut-survivable manner. For this design the desired orientation is defined as standing vertically with the landing legs extended.

After considering all alternatives, the primary mode of descent was chosen to be the singlecopter. Specifically, the main component of the ATLAS is the singular electric-powered ducted fan (EDF) it uses to reduce kinetic energy during descent. Using multiple 2S LiPo batteries, the EDF can generate over seven pounds of thrust for extended periods of time, allowing it to not only descend at a safe rate but also enter a hover mode near the ground to land as softly as possible. This extended duration of thrust was a major factor in choosing the EDF over a gas-thruster design, as controlling a single motor is more predictable than controlling multiple cold-gas canisters. The brushless motor used to turn the EDF requires an electronic speed controller (ESC) to control it. Another advantage of the singlecopter design is the shape of the craft; one rotor allows for a cylindrical-shaped vehicle which compliments the shape of the rocket nicely. Ultimately, this shape constraint was another reason the quadcopter was not chosen as there were concerns with fitting inside the rocket, as well damage to unducted propellors breaking during payload testing.

*A black motor with a yellow wheel

Description automatically generated*

Figure 26: The EDF chosen to control ATLAS descent, capable of over 7lbs of thrust.

However, selecting a singlecopter design introduces another complication into the payload, which is the torque from the single motor causing the payload to spin upon descent. This uncontrolled rotation would be harmful to the STEMnauts and could increase instability in the system. To counter this, and provide heightened control of the system, the design include four thrust-vectoring fins below the EDF. These fins, controlled by servo motors, alter the direction of the airflow, countering the torque of the motor and correcting for disturbances from wind and other environmental factors during descent. Overall, these fins will increase the robustness of the ATLAS design.

A black and blue objects

Description automatically generated with medium confidence

Figure 27: Thrust vectoring fins for ATLAS stabilization.

The ATLAS will be autonomously controlled using an Ardupilot-compatible flight controller to autonomously control descent. Armed with a nine-axis IMU, barometer, and servo outputs, the flight controller will be able to control the motor and servos based off its own sensors. Although an RF receiver will need to be implemented into the payload for to signal release, an autonomous descent would be preferred to remote-controlled piloting due to issues determining orientation from the ground. As an open-source software with singlecopter compatibility, Ardupilot is a great option to implement this autonomy due to its extensive documentation and use in the field of personal aircraft.

To satisfy competition requirements as a component landing untethered to the launch vehicle, the payload will also need to include a GPS tracking device. This will be stored in the central hub with the flight computer, ESC, and RF receiver.

The chosen system for landing was extendable legs with built-in suspension to dissipate energy upon landing. The legs utilize a four-bar linkage for retraction and extension, using servos as actuators. This design allows for a rigid extension of surface area for the vehicle, increasing the likelihood of a successful landing. For testing purposes, the leg-based landing system was more appealing than others which are less robust or reusable, such as an inflatable or disintegrating design.

A black metal object with a curved handle

Description automatically generated with medium confidence

Figure 28: Retractable four bar landing leg design, actuated with a servo on the top link.

STEMnauts will be housed in individual capsules spread around the body of the vehicle. These capsules will be snap-fit and fastened to the payload body, with padding on the inside to reduce vibrational energy experienced during launch and landing. The team will retrieve the STEMnauts manually from the vehicle after it has landed as the method of ingress and egress. Data from the flight computer and observations of structural integrity will be used to determine if survivability metrics were met.

As an emergency backup, the team plans to implement a small parachute on the payload body in case of failure. This will mitigate risk should the EDF fail to slow descent, and hopefully provide a safer environment during launch day. While not pictured in this design, the emergency parachute would be released when a certain velocity or angular velocity was reached. This threshold would mean that the vehicle is either in free fall or spinning uncontrollably, which both present a hazard to people near the launch.

### Drawings/Schematics

Table 18: Estimated Masses of Payload Components

|  |  |  |  |
| --- | --- | --- | --- |
| Component | Individual weight (g) | Quantity | Net Weight (g) |
| EDF/motor | 372 | 1 | 372 |
| 2S LiPo Batteries | 280 | 4 | 1120 |
| ESC | 122 | 1 | 122 |
| Receiver | 3 | 1 | 3 |
| GPS | 12 | 1 | 12 |
| Frame | 220 | 1 | 220 |
| Servo | 9 | 7 | 63 |
| Fin | 10 | 4 | 40 |
| Leg Assembly | 80 | 3 | 240 |
| Line Cutter | 22 | 1 | 22 |
| Wire | 50 | 1 | 50 |
| Tether | 5 | 1 | 5 |
| STEMnaut | 3 | 4 | 12 |
| TOTAL |  |  | 2,281.00 |

### Justification

The ATLAS features many design choices specifically implemented to adhere to the intent of the challenge. While exact parameters are subject to change as the design process continues, the motivation behind the design will allow for a successful payload experiment.

The first design choice is the shape of the main body of the vehicle. There is a seven-degree draft from the top of the payload body to the bottom, which was implemented to improve self-stabilization during flight as air travels around the vehicle during descent. To further stabilize the vehicle, heavier components such as LiPos and STEMnauts were distributed on the lower half of the payload body to encourage the vehicle to land in its desired orientation. The STEMnauts are stored in individual capsules housed around the payload body to allow for greater control over the center of mass of the vehicle.

Another design choice made to increase success probability was locating the legs higher up on the body, in conjunction with the lower center of mass on the payload. This heavily reduces the chance of tipping, as opposed to legs lower on the vehicle with mass concentrated upwards. Other design choices on the legs included the curved shape of the leg and the ridged ends of the end effectors. The curved leg shape increases the surface area for landing, while the ridges aim to reduce the chance of a leg slipping after contacting the ground.

A diagram of a device

Description automatically generated

Figure 29: Illustrated section view of design justifications in the body frame

A potential concern with the ATLAS design was the presence of boundary layer effects within the EDF duct. Flow stagnation during descent would reduce thrust levels and potentially result in unsafe landing of the STEMnauts. To mitigate this risk, the EDF duct has a very slight outward draft to ensure the air has enough space to flow through, without getting overcongested by the boundary layer. Another modification to the EDF duct is the presence of four crescent openings on the aft end of the body. The purpose of these openings is to allow for air to flow out of when being altered by fins, allowing for heightened maneuverability of the control system.

### Preliminary Interfaces between Payload and Launch Vehicle

Due to competition restraints, the payload must be released only after permission is granted from the NASA range safety officer. This means that the payload must stay attached to the main during both separation events, should they happen before permission is granted. To account for this, the team decided to store the payload in the forward bay, which separates with the main parachute. The payload will be attached to the shock cord, so if permission is not granted, it will safely land with the rest of the rocket. If the RSO does deem it safe to release, then the team will command a signal to release from the harness and begin the mission.

The preliminary release mechanism design involves securely fastening the payload body to the harness with zip ties, then utilizing a commercial line cutter to slice the ties after receiving a command, therefore allowing the payload to begin its descent. This design allows for the payload to descend with the main parachute if conditions are not conducive to running the payload experiment.

### Preliminary Design of Payload Retention System

The payload will be housed in the payload bay, which corresponds to the forward bay of the rocket. The interior diameter of the fullscale will allow for sufficient clearance of the ATLAS when the landing legs are retracted. To keep the payload from moving in the launch vehicle the payload will be placed on hollow metal rails which are rigidly attached to one side of the front bay, while not being attached to the other side. This will keep the payload stationary during flight, allow the payload vehicle to slide off after separation. This system will require minor adjustments to the main frame of the payload to accommodate the rail.

# Safety

The Range Safety Officer (RSO) for this year is Atzimba Avellaneda. Her duties as RSO are to implement safety standards and regulations during all phases of the project. She shall develop and enforce safety protocols that are to be followed by all subsystems and individuals. Safety briefings will be provided to all involved. She will develop and communicate emergency response plans that cover potential hazards and mitigate solutions so everyone is prepared in case of an emergency and in the rare occasion that the RSO is not present. She will inspect the vehicle before and after test launches and monitor the weather to ensure the launches safety. She will monitor activities such as design and construction of vehicle and payload, STEM engagement activities, and recovery. She will also manage, maintain, and assist in writing the hazards analyses failure mode analyses, procedures, and chemical inventory.

The safety of all individuals surrounding the progression of the project is of utmost importance. Ensuring the security of the students and the environment, and minimizing the risks is the foundation for a positive learning experience. This section provides comprehensive safety measures and guidelines that must be adhered to throughout the entire process, from design to final disassemble of the rocket. By respecting and strictly following these safety protocols, the team creates a safer and more rewarding environment as we move through the competition.

The following tables are the Risk Assessment Matrices that identify the likelihood and severity of the hazards for the Personnel Hazard Analysis (PHA) and the Failure Modes and Effects Analysis (FMEA). Each hazard has a grading labeled from the Risk Assessment Category (RAC) before and after the mitigation.

Table 19: Risk Assessment categories for PHA and FMEA.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Risk Assessment Matrix | | Likelihood | | | |
| A  Improbable | B  Occasional | C  Probable | D  Highly probable |
| Severity | 1  Marginal | 1A | 1B | 1C | 1D |
| 2  Significant | 2A | 2B | 2C | 2D |
| 3  Critical | 3A | 3B | 3C | 3D |
| 4  Catastrophic | 4A | 4B | 4C | 4D |

## Personnel Hazard Analysis (PHA)

A PHA is a crucial component of ensuring the safety of all participants involved in activities revolving the rocket's construction. The following tables outline the hazard risk to the personnel involved in this year’s NASA Student Launch. The PHA is used to identify potential hazards that can happen throughout the project's progression, how the team assesses the risks, and outlines the team's measures to mitigate them.

Table 20: Personnel Hazard Analysis.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Hazard** | **Cause** | **Effect** | **RAC (before)** | **Mitigation** | **RAC (after)** |
| Personnel Hazards due to Rocket Building Activities | | | | | |
| Inhalation of chemicals, such as propellant, epoxy, and fiberglass, or debris. | Improper or no use of PPE (face mask) and not handled in well ventilated area. | Mild to severe irritation in throat and/or lungs. | 3C | Proper application of PPE and maintain sufficient caution while handling. Person is trained to handle materials. | 3B |
| Ingestion of chemicals, such as propellant, epoxy, and fiberglass, or debris. | Improper or no use of PPE (face mask) and insufficient caution. | Mild to severe irritation in respiratory system and/or stomach. | 3A | Proper application of PPE and maintain sufficient caution while handling. Person is trained to handle materials. | 2A |
| Contact with chemicals, such as propellant, epoxy, and fiberglass, or debris. | Improper or no use of PPE (gloves, long sleeves, long pants, closed-toe shoes, etc.). | Mild to severe irritation or burn to skin. | 3D | Proper application of PPE and maintain sufficient caution while handling. Person is trained to handle materials. | 3B |
| Trips and falls. | Shop not clean, spill of liquid, or lack of attention to surroundings. | Cuts and scrapes. | 2D | Make sure shop is clean and always upkept and be aware of surroundings (especially around hazardous materials). | 2B |
| Contact with hot tools. | Improper or no use of PPE (gloves, long sleeves, long pants, closed-toe shoes, etc.), and not handling tool properly. | Mild to severe irritation or burn to skin. | 2D | Proper application of PPE and maintain sufficient caution while handling. Person is trained to handle tools. | 2A |
| Fumes from soldering. | Improper or no use of PPE (face mask) and not handled in well ventilated area. | Mild to severe irritation in respiratory system. | 3B | Proper application of PPE and maintain sufficient caution while handling. Person is trained to handle tools. | 2A |
| Carrying high load. | One or more person lifts too much load at once or throughout time. | Body soreness to muscle tear or hernia. | 4B | If object is too heavy, add more people to lift to lighten load. If many people are required to lift, use other methods, like rolling or sliding, to move. | 3A |
| Contact with sharp objects. | Improper or no use of PPE (gloves, long sleeves, long pants, closed-toe shoes, etc.), and not handling object properly. | Mild to severe cuts. | 3D | Proper application of PPE and maintain sufficient caution while handling. Person is trained to handle tools and/or materials. | 2A |
| Allergy to epoxy or resin. | Improper or no use of PPE (gloves, long sleeves, long pants, closed-toe shoes, etc.), and prolonged exposure to substances. | Itching and rashes, chemical burns, and/or irritation in respiratory system. | 3B | Proper application of PPE and maintain sufficient caution while handling. Person is trained to handle materials. | 2A |
| Injury from rocket debris. | Sections of rocket could break off and person is unaware of surroundings. | Bodily injury. | 3C | Maintain communication with events of launch and be cautious of surroundings. | 2B |
| Absence of proper first aid supplies. | Improper upkeep up first aid kit and other safety supplies while operating shop. | Injuries could get out of hand. | 3B | Properly restock first aid kit and other safety supplies. Also, maintain knowledge of how to address injuries. | 1A |
| Contact with electricity. | Improper or no use of PPE (gloves, long sleeves, long pants, closed-toe shoes, etc.), and not handling properly. Live electrical wiring. | Mild to severe irritation or burn to skin. | 2D | Proper application of PPE and maintain sufficient caution while handling. Person is trained to handle materials. | 2B |
| Proximity to high-pressure event. | Over-pressured vessel by product malfunction or human error. | Bodily injury, such as redness and burns, and/or ear damage. | 3B | Maintain high caution while handling. Person is trained to handle materials. Not overfilling vessels. | 3A |
| Proximity to explosive event. | Unaware of surroundings. Accidental initiation by product malfunction or human error. | Bodily injury, such as redness and burns, and/or ear damage. | 4B | Minimize people handling. Maintain high caution while handling. Person is trained to handle materials. Isolate firing mechanism until clear range. | 4A |
| Proximity to combustion event. | Intentional or unintentional ignition of motor. Product malfunction or human error. | Bodily injury, such as redness and burns, and/or ear damage. | 4B | Minimize people handling. Maintain high caution while handling. Person is trained to handle materials. Isolate firing mechanism until clear range. | 4A |
| Personnel Hazards due to Environmental Causes | | | | | |
| Allergies from outdoor activities, such as launch day. | Too much pollen or prolonged exposure. | Itching, rashes, and/or irritation in respiratory system. | 2B | Reduce long outdoor exposure. | 1A |
| Exposure to illness, such as cold or flu. | Near others in crowd who are sick. Improper or no use of face masks when feeling ill around others. | Cold or flu like symptoms. | 2B | If falling ill or near someone ill, communicate with team and wear face mask. | 1B |
| Eye sensitivity from sun or bright sky. | Observing rocket throughout launch during sunny day. | Temporary to permanent blindness and/or eye irritation. | 1C | Wear protective eyewear, and do not look into sky for prolonged periods of time. | 1B |
| Skin sensitivity from sun exposure. | Prolonged exposure outdoors on day with high UV index. | Skin redness, irritations, and/or burns. | 2C | Wear protective sun care and/or long sleeves and pants. Reduce sun exposure. | 1C |
| Bug bites or stings. | Prolonged exposure outdoors within wildlife. | Skin redness, irritations, and/or rash. Respiratory problems and bodily shock. | 3C | Use bug spray. Knowledge of allergies and proper use of allergy medication. | 3A |
| Falling into body of water, such as puddles or lakes. | Lack of attention to surroundings during tests and launch days. | Bodily injury. Wet clothes and/or shoes. | 2A | Aware of surroundings. | 1A |
| Trips or falls. | Lack of attention to surroundings during tests and launch days. | Cuts and scrapes. | 2B | Aware of surroundings. | 2A |

## Failure Modes and Effects Analysis (FMEA)

When conducting an FMEA, it is crucial to identify and assess potential failures, their causes, effects, and propose solutions. The following tables will outline the hazards that take part from designing the rocket until after the launch day.

### Payload FMEA

Table 21: Payload FMEA.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Hazard** | **Cause** | **Effect** | **RAC (before)** | **Mitigation** | **RAC (after)** |
| Fails to be manually deployed at designated altitude. | Faulty release mechanism or improper vehicle stage separation. | The payload does not detach from the rocket. | 2C | Failsafe mechanism that ensures payload is deployed. | 2A |
| Descent control malfunction. | Heavy environmental disturbances, failing thrust component(s). | Unstable or accelerated falling. | 4B | Avoid deployment in hazardous weather conditions, backup parachute. | 2A |
| Total lack of controlled descent. | Electronic malfunction, wiring issue, receiver failure. | Free fall. | 4C | Emergency parachute. | 2C |
| Component detachment from main vehicle. | Tethering issue, heavy external disturbances, contact with launch vehicle on release. | Free fall. | 4C | Ensure components are attached through detailed analysis and testing. | 4A |
| STEMnauts undergo lethal forces. | EDF does not function properly. Other electronic malfunctioning. | Free fall. | 4C | Ensure EDF functions properly through testing and fail-safe mechanisms. | 3B |
| Payload legs do not deploy. | Failure in leg release mechanism, vehicle hits ground too fast for legs to reach full deployment. | Energy not dissipated on descent, damage to payload or loss of payload. | 3B | Test leg deployment prior to launch and develop a reliable system. | 2A |
| Payload legs deploy too soon/too late. | Failure in leg release mechanism, vehicle hits ground too fast for legs to reach full deployment, adverse air drag on payload. | Energy not dissipated on descent, damage to payload or loss of payload, improper orientation on landing. | 3B | Test leg deployment prior to launch and develop a reliable system. | 2A |
| Payload breaks apart under wind shear. | Failure in materials, improper securement of components, poorly designed geometry. | Total loss of payload, hazardous debris in free fall. | 4B | Simulate stress analysis on payload body, test payload structure under stresses. | 4A |
| Power loss during flight | Batteries left uncharged or used, insecure wiring to batteries, severe electrical component malfunction. | Free fall. | 4B | Ensure charged batteries before flight. Test components under vibrations to ensure strong wire attachments. | 4A |

### Launch Vehicle FMEA

Table 22: Launch Vehicle FMEA.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Hazard** | **Cause** | **Effect** | **RAC (before)** | **Mitigation** | **RAC (after)** |
| Crack or break in body tube. | Material defect and/or improper handling of material. | Excessive vibrations. Damage to internal components. Vehicle loss due to body tube fracture. | 4A | Thorough inspection of material before, during, and after manufacturing. Limit cutting/drilling. Trained and knowledgeable personnel handles materials. | 2A |
| Cracks in bulkheads. | Strong or irregular forces and vibrations, improper material selection. | Instability in vehicle structure, loss of vehicle. | 4B | Material inspection, structural analysis simulation and analysis. | 3A |
| Chips or cracks in 3D printed parts. | Strong or irregular forces on parts, large pressure gradients, temperature fluctuations. | Alteration of vehicle flight path, failures in vehicle structure, loss of vehicle and failed flight. | 4B | 3D printing analysis in layering, good material selection, strong support designs, structural analysis, proper 3D print filament usage. | 3A |
| Melting of tail cone. | High motor temperatures, improper motor shielding, imperfections in solid propellant manufacturing. | Alteration of vehicle flight trajectory, vibrations in motor thrust forces, loss of vehicle and failed flight. | 4B | Proper motor casings used, temperatures & pressure simulations conducted, motor observation and analysis prior to launch. | 3A |
| Propellant does not burn for required duration. | Improper manufacturing methods of solid propellant, improper light. | Vehicle does not meet apogee or greatly exceeds apogee. | 3A | Inspect motor for material imperfections, ensure motor charges are properly hooked up. | 1A |
| Vehicle trajectory disturbed. | Adverse wind speeds, fins breaking off, nose or tail cone deformities. | Loss of vehicle, mid-flight vehicle disintegration, failed landing area requirement. | 4A | Ensure fins, nose and tail cones, and general vehicle body is strong and secure in high vibration and forces. Do not launch on windy days. | 2A |
| Vehicle airframe disassembles under propellant forces. | Vehicle structure unable to withstand forces produced by motor. | Rapid disassemble mid-flight, total loss of vehicle, dangerous falling debris. | 4A | Simulation and testing to ensure vehicle body can withstand motor forces. | 2A |
| Motor explodes. | Motor casing unable to withstand motor burn or motor casing not used. Manufacturing malfunction. | Loss of vehicle and payload, flying debris, fire hazards. | 4A | Ensure proper motor casing is utilized. Ensure motor capabilities through testing. | 3A |
| Launch rail fails upon vehicle takeoff. | Launch rail not secure on asphalt, large amounts of friction in rail. | Severely affected trajectory, possible horizontal flight path. | 3A | Check that launch rails meet required specs and are securely placed. | 2A |
| Fins shear off under air forces. | Fins not firmly secured to rocket body, material failure under high stress. | Altered flight trajectory, possible loss of vehicle and payload. | 4A | Ensure fins are securely placed on vehicle. Simulate FEA on fins and fin material(s) | 2A |
| Nose cone shears off upon landing. | Nose cone material fails under stress, impact forces higher than anticipated | Broken vehicle airframe upon recovery; possible failed flight | 2B | Run stress testing on nose cone, ensure good material selection, ensure vehicle descent meets team derived requirements. | 2A |

### Recovery Systems FMEA

Table 23: Recovery Systems FMEA.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Hazard** | **Cause** | **Effect** | **RAC (before)** | **Mitigation** | **PAC (after)** |
| Parachute deploys too early or too late. | Improperly calibrated altimeters, power loss, or altimeter malfunction. | High-velocity vehicle fall, not enough/no deceleration, vehicle body caught in parachutes, hazard to bystanders. | 3B | Test altimeters, batteries, and wiring setup prior to launch. Have back-up avionics in case one system fails. | 3A |
| Parachute does not deploy. | Improperly calibrated altimeters, power loss, altimeter malfunction, shear pin mis-sizing, CO2 cartridge malfunction. | Vehicle “Lawn Darts” into the ground. Total loss of vehicle, hazard to bystanders. | 4B | Test altimeters, batteries, CO2,and wiring setup prior to launch. Have back-up avionics in case one system fails. Analyze and simulate shear pin failure and function. | 4A |
| Parachutes rip or tear. | Early/late parachute deployment, irregular forces or vibrations on chutes and/or shock chords, collision with vehicle or other bodies | Vehicle does not slow enough on decent, total loss of vehicle and/or payload, hazard to bystanders. | 4A | Altimeter testing, shock chord testing, parachute testing, observation of parachute and shock chord integrity prior to launch. | 3A |
| Shock cord rips. | Late parachute deployment, inconsistencies in shock cord manufacturing, improper force analysis on shock cords. | Vehicle free fall from parachutes. | 4A | Shock cord failure analysis, shock cord testing, deployment at correct altitudes and times. | 3A |
| Shock cord disconnects. | Improper securement of shock cord to vehicle, failure of carabiner under force/vibration. | Vehicle free fall from shock cord(s). | 4B | Failure analysis on securing carabiner, proper securement of shock cord to vehicle and parachute. | 3A |
| Shock cord tangles at deployment of parachutes. | Improper packaging of shock cords in rocket body, adverse vibrations/forces on vehicle/cord at deployment. | Vehicle does not hang as low as intended upon descent, tangled parachutes, improper descent velocity. | 4C | Ensure that shock cord is packaged correctly in vehicle body. | 3A |
| Parachute gets entangled with rocket body section or another object. | Improper packaging of shock cords and/or parachute in rocket body, adverse vibrations/forces on vehicle/cord at deployment. | Free fall of vehicle and payload. | 4A | Ensure proper chute and cord packaging, avoid launching in high winds. | 3A |
| Shear pins shear prematurely or do not shear at all. | Improper shear pin sizing, CO2 cartridges deploy at the same time or do not supply enough force. | Rocket does not deploy parachutes or prematurely deploys both chutes at apogee, | 4A | Failure analysis on shear pins, simulation, and FEA on pins. CO2 force calculations and testing. | 2A |
| Late separations. | Improperly calibrated altimeters, delay in signaling. | Parachute tear, shock cord tear, connection failure between separation bodies. | 3B | Properly calibrated altimeters, testing of recovery systems and system components prior to flight. | 2A |
| Premature or late black powder detonation. | Improperly calibrated altimeters, power loss, or altimeter malfunction. | High-velocity vehicle fall, not enough/no deceleration, vehicle body caught in parachutes, hazard to bystanders. | 4B | Test altimeters, batteries, and wiring setup prior to launch. Have back-up avionics in case one system fails, including backup black powder charges. | 2A |
| Vehicle takes flight without altimeter and/or barometer functioning. | Battery death on launch pad, insecure wiring causing loss of power, neglect of team members to check systems prior to launch. | Free fall of vehicle. | 4A | Test altimeters, batteries, CO2, and wiring setup prior to launch. Ensure batteries are charged and working. | 3A |

### Environmental Safety FMEA

Table 24: Environmental Safety FMEA.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Hazard** | **Cause** | **Effect** | **RAC (before)** | **Mitigation** | **RAC (after)** |
| Environmental Risks to the Vehicle. | | | | | |
| Wind speeds are too high. | The bigger the difference between the pressures, the faster the air will move from the high to the low pressure. | Winds less than 20 miles per hour, can affect the trajectory of rocket/payload. Adjust launch parameters. Incorporate stabilizing fins. | 3A | Monitor the wind speeds. NASA has a designated backup launch date in case wind speeds exceed 20 miles per hour. | 2B |
| Inclement weather. | Excessive winds, lightning strikes, and/or storm fronts. | Winds less than 20 miles per hour can affect the trajectory of rocket/payload. Electrical damage, malfunction, or total loss of vehicle. | 3A | Monitor the weather. NASA has a designated backup launch date in case of bad weather. Not able to launch if the wind speeds exceed 20 miles per hour or if there is a storm. Postpone test launches if bad weather. | 2B |
| Wet grass around launch pad. | Rain or excess humidity. | Unsafe launch therefore will not be able to launch. | 3C | Ensure the rocket is launched from a stable device that provides rigid guidance and there is dry grass cleared around the launch pad, or rocket launches on asphalt | 1B |
| Low visibility. | Fog and/or heavy precipitation. Pollutants in the air. | Tracking rocket/payload throughout launch becomes more difficult. | 2D | Ensure tracking systems are functioning properly and monitor vehicle as closely as possible. | 1D |
| UV radiation. | Low cloud cover, high altitude at launch site, and/or high noon. Prolonged exposure to UV rays. | Potential damage to UV sensitive materials on rocket/payload causing degradation. | 2B | Ensure materials used on vehicle are UV and heat resistant or prepared to withstand these. | 1A |
| Air density variations. | Altitude, temperature, and humidity levels of the vehicle ascends and descends. | Alter vehicle performance that could affect thrust, trajectory, and deployments. | 2B | Account for density variations in vehicle design and launch calculations. | 1A |
| Extreme atmospheric conditions. | High humidity and moisture or heat is too dry. | Corrosion and degradation of materials. Electrical malfunctions. Reduced stability during flight. | 2B | Use moisture resistant materials, effectively protect electrical components. Store vehicle in cool, dry conditions. | 1A |
| Vehicle Risks to the Environment. | | | | | |
| Vehicle debris, wiring waste, and/or other littering on landscape. | Separation stages and deployment of parachutes and payload. | Soil contamination and potentials damage to flora and fauna. | 2C | Implement clean-up protocols and spill prevention measures; ensure launch site is cleaned post-launch. | 1B |
| Vehicle debris, wiring waste, and/or other littering in body of water. | Separation stages and deployment of parachutes and payload. | Water contamination and potentials damage to aquatic life. | 3A | Launch away from bodies of water. Implement spill prevention measures. | 2A |
| Vehicle or motor exhaust’s fumes, flames, and residue. | Residue left from vehicle propellant after ignition. Battery or other electrical explosions. | Contamination of the launch sites, the soil, and/or bodies of water. Potential harm to ozone layer. | 2C | Select launch sites with minimal environmental impact. Use motor casings with minimal residue. Ensure soil is not underneath the vehicle | 2A |
| Other fumes are released from the payload. | Payload descent mechanisms. | Contamination of the launch sites, the soil, and/or bodies of water. | 2A | Select launch sites with minimal environmental impact. | 1A |
| Vehicle components interact with flora and fauna. | Vehicle is launched in area with plenty of wildlife. | Disrupt local ecosystems and potential damage to habitat. | 4B | Select launch sites with minimal environmental impact. Adhere to local and federal regulations. | 4A |
| Vehicle lands in tree or large and is not recoverable. | Excessive wind speeds. Incorrect trajectory from human error. | Difficulty in recovering vehicle. Damage to vegetation. Damage to vehicle components. | 2C | Long and strong shock cord to maintain components and allow for retrieval. Ensure correct launch trajectory. | 1B |
| Vehicle lands in or near powerlines. | Excessive wind speeds. Incorrect trajectory from human error. | Difficulty in recovering vehicle. Damage to powerlines. Damage to vehicle and electrical components. Fire hazard. | 4B | Long and strong shock cord to maintain components closely together. Ensure launch is distanced from infrastructure. | 3A |
| Parachute(s) get stuck high up on tree. | Excessive wind speeds. Incorrect trajectory from human error. | Difficulty in recovering vehicle. Damage to vehicle components. | 2C | Long and strong shock cord to maintain components closely together. Ensure launch is distanced from vegetation. | 1B |
| Forceful impact of vehicle onto ground. | Late or no function of recovery system. | Detrimental damage to vehicle. Damage to field and potential infertility of soil. | 4C | Ensure avionics and recovery systems are working properly before launch. | 3B |
| Creation of corrosive hydrochloric acid. | Hydrogen chloride in ammonium perchlorate composite propellant comes in contact with water. | Condensation of atmospheric moisture in the plume and this enhances the visibility of the contrail. Contributes to air pollution. | 3B | Maintain launch away from water, ensure design burns all motor propellant before descent. | 2A |
| Transport of chemical hazards. | Transportation of certain materials and propellant could spill. | Release of chemicals to area. Soil or water contamination. | 4A | Implement clean-up protocols and spill prevention measures. Properly handle and dispose of chemicals. | 2A |
| Noise pollution. | Loud rocket noise from propulsion and deployment of parachutes and payload. | Disrupt wildlife in surrounding area and/or nearby residents. | 1D | Choose launch sites that will minimize noise impact. Schedule at appropriate date and times. | 1B |
| Resource consumption. | Excess resource use of materials and launches. | Depletion of resources. Potential delay of progression in project. High environmental impact due to resource consumption. | 1C | Plan testing and material usage during manufacturing. Explore recycling options to reduce waste. | 1B |

## Project Risk Assessment (PRA)

The PRA is conducted like the PHA and the FMEA tables. The PRA is ranked from highest likelihood and impact to the lowest. This risk assessment will be categorized with the new Risk Assessment Matrix below.

Table 25: Risk Assessment Categories for Project Risk Assessment.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Risk Assessment Matrix | | Likelihood | | |
| A  Low | B  Medium | C  High |
| Impact | 1  Low | 1A | 1B | 1C |
| 2  Medium | 2A | 2B | 2C |
| 3  High | 3A | 3B | 3C |

Table 26: Project Risk Assessment FMEA.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Risk Item** | **Effect** | **RAC (before)** | **Mitigation** | **RAC (after)** |
| Lack of team coordination | Poor communication among team members which leads to misunderstanding and inefficient workflow. Delay in progression of project. There could also be role overlap and confusion on tasks to be completed. | 3C | Establish clear responsibilities withing team. Hold “scrum” sessions (each member discussing daily tasks), weekly, and monthly meetings. Encourage open communication among team. Clearly define member responsibilities and roles. | 2A |
| Shop injuries. | Review of safety standards in shop. Delay in progression of project. Potential problems with stakeholders. | 3B | Provide proper safety training and include warning signs around the shop. Maintain shop clean and organized. | 2B |
| Poor time management. | Delay in progression of project. Potentially NASA deadlines and launch dates. | 3B | Create detailed project schedule and add in buffer time for unexpected delays. Regularly monitor work that needs to be completed and progress. | 2B |
| Forgetting components and testing failures. | Delays since additional test launches need to be scheduled. Loss of vehicle and additional costs to repair. | 3B | Each member maintains checklist of all materials and equipment. All members ensure no missing components. Checklists to ensure all components are wired and attached correctly. Record potential reasons for failure and discuss. Have backups of certain components to prevent delays. | 3A |
| Functionality issues. | Rocket and/or payload does not perform as expected. Delay in progression of project. | 3B | Extensive CAD simulations, and test rocket and payload together and separately to ensure compatibility and proper functionality. Ensure designs align with objectives and requirements. | 3A |
| Resource shortages. | Low stock of commercially sourced products. Build and/or testing delays. Higher fees for expedited shipping. | 2C | Maintain comprehensive inventory of necessary materials. Have contingency plans for acquiring resources and allow time for items shipped from farther locations. Order parts well before deadlines. | 2B |
| Conflict and disagreements. | Delay progression of project. Harm team morale. | 3B | Establish conflict resolution process to address disputes. Encourage a collaborative and respectful team environment. Effectively communicate goals and values to aide in team and project progression. | 3A |
| Team member availability. | Scheduling conflicts between members and NASA deadlines. Increased schoolwork, extracurricular activities, and/or job-relates activities. Delay progression of project. | 2C | Plan and communicate for potential scheduling conflicts in beforehand. Establish contingency plans for members’ unavailability. Use “When2Meet”, Microsoft Teams, and/or other shared calendar options to plan schedules. | 1B |
| Weather dependencies. | Adverse weather conditions that can result in postponed or canceled launch dates. | 2B | Monitor weather forecasts. Have backup dates. | 1B |
| Skills and/or knowledge gaps. | Team members may lack certain skills needed to complete aspects of the project. Delay in progression of project. | 2B | Identify and address skill gaps and address them accordingly. Allow for learning, share knowledge across the entire team. Talk with experts and mentors for guidance. | 2A |
| Design complexity. | Overly complex rocket and/or payload design. Leads to design or construction errors. | 2B | Speak with mentors and other professionals for guidance on design and construction, perform systems engineering. | 2A |
| Scope expansion. | Project expands beyond initial plans. Potential delay in progression of project. | 3A | Clearly define objectives and boundaries. Implement a change-control process that will assess any changes. | 2A |
| Regulatory non-compliance. | Non-compliance with local and federal regulations that result in certain legal issues, additional fees, and/or stoppage of project. | 3A | Familiarize with laws and regulation standards. Ensure all necessary waivers and permits are signed. Conduct pre-launch safety checks to ensure compliance with all laws. | 2A |
| Budget overruns. | Costs exceeds allocated budget. Financial strain. Lower quality materials sourced for remaining components. | 2B | Develop detailed budget plan. Keep track on all expenses and adjust the budget throughout the progression of project. | 1A |

# Project Plan

## Requirements Verification

### Vehicle Requirements Verification

***Figure 30:*** *Vehicle Requirements Verification*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Requirement #** | **Description** | **Rationale** | **Verification** | **Verification State** |
| **Vehicle** | | | | |
| 1.1 | Vehicle Shall Use a single, solid propellant motor | USLI Requirements | Design, subscale launch, full scale launch | Ongoing Verification |
| 1.2 | Vehicle must be reusable | USLI Requirements | Design consideration, tested independently and during launches | Ongoing Verification |
| 1.3 | Must be designed, constructed, and tested by student team | USLI Requirements | Ongoing general consideration | Ongoing Verification |
| 1.4 | Must be equipped with a tracking device that allows for location | USLI Requirements | Design consideration, tested independently and during launches | Ongoing Verification |
| 1.5 | Shall be capable of being launched by standard 12-volt DC firing system | USLI Requirements | Launch for subscale and full scale | Verified |
| 1.6 | Vehicle shall deliver payload to apogee between 4,000 and 6,000 feet | USLI Requirements | Design consideration, tested independently and during launches | Ongoing Verification |
| 1.7 | Nosecone shoulders which are located at in-flight separation points shall be at least 1⁄2 body diameter in length. | USLI Requirements | General design consideration | Verified |
| 1.8 | Vehicle shall have a maximum of four (4) independent sections | USLI Requirements | General design consideration | Verified |
| 1.9 | Coupler/airframe shoulders which are located at in-flight separation points shall be at least 2 airframe diameters in length | USLI Requirements | General design consideration | Verified |
| 1.10 | Coupler/airframe shoulders which are located at non-in-flight separation points shall be at least 1.5 airframe diameters in length. | USLI Requirements | General design consideration | Verified |
| 1.11 | Shall be capable of remaining in launch-ready configuration on pad for minimum of 3 hours without losing functionality | USLI Requirements | Design consideration, tested independently and during launches | Ongoing Verification |
| 1.12 | shall require no external circuitry or special ground support equipment to initiate launch | USLI Requirements | General design consideration | Ongoing Verification |
| 1.13 | Shall use commercially available ematches or igniters | USLI Requirements | General design consideration | Verified |
| 1.14 | Shall use commercially available solid motor propulsion system | USLI Requirements | General design consideration | Verified |
| 1.15 | Total impulse shall not exceed 5,120 Newton- seconds (L-class) | USLI Requirements | Design Consideration, tested in simulation and in full-scale launch | Ongoing Verification |
| 1.16 | Shall have a minimum static stability margin of 2.0 at the point of rail exit | USLI Requirements | Design Consideration, tested in simulation and in subscale, full-scale launch | Ongoing Verification |
| 1.17 | Shall have a minimum thrust to weight ratio of 5.0:1.0 | USLI Requirements | Design Consideration, tested in simulation and in subscale, full-scale launch | Ongoing Verification |
| 1.18 | Vehicle shall accelerate to a minimum velocity of 52 fps at rail exit | USLI Requirements | Design Consideration, tested in simulation and in subscale, full-scale launch | Ongoing Verification |
| 1.19 | Vehicle shall reach 1506 meters (4941 ft) apogee | Team derived requirements | Design consideration, tested during launches | Ongoing Verification |
| 1.20 | The launch vehicle shall have symmetrical fins | Team derived requirements | General design consideration | Ongoing Verification |
| 1.21 | Shall be able to launch in temperatures between 40ºF and 100ºF | Team derived requirements | Design Consideration, tested in simulation and in subscale, full-scale launch | Ongoing Verification |
| 1.22 | The launch vehicle shall use at least 2 centering rings to support the motor tube | Team derived requirements | General design consideration | Ongoing Verification |
| 1.23 | The launch vehicle shall be able to be disassembled and assembled for transport | Team derived requirements | General design consideration | Ongoing Verification |

### Recovery Requirements Verification

***Figure 31:*** *Recovery System Requirements Verification*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Recovery** | | | | |
| **Requirement #** | **Description** | **Rationale** | **Verification** | **Verification State** |
| 2.1 | Main parachute shall be deployed no lower than 500 feet | USLI Requirements | Design consideration, tested independently and during launches | Ongoing Verification |
| 2.2 | Apogee event shall contain a delay of no more than 2 seconds | USLI Requirements | Design consideration, tested independently and during launches | Ongoing Verification |
| 2.3 | Shall be capable of remaining in launch-ready configuration on pad for minimum of 3 hours without losing functionality | USLI Requirements | Design consideration, tested independently and during launches | Ongoing Verification |
| 2.4 | Each section of the vehicle shall have maximum kinetic energy of 75 ft-lbf at landing | USLI Requirements | Design consideration, tested independently and during launches | Ongoing Verification |
| 2.5 | Shall contain redundant, commercially available barometric altimeters specifically designed for initiation of rocketry recovery | USLI Requirements | General design consideration | Verified |
| 2.6 | Each altimeter shall have a dedicated power supply | USLI Requirements | General design consideration | Verified |
| 2.7 | All recovery electronics shall be powered by commercially available batteries | USLI Requirements | General design consideration | Verified |
| 2.8 | Each altimeter shall be armed by a dedicated mechanical arming switch accessible from the exterior of the rocket airframe when the rocket is on the launch pad | USLI Requirements | Design consideration, tested independently and during launches | Ongoing Verification |
| 2.9 | Arming switches shall be capable of being locked in the ON position | USLI Requirements | General design consideration | Not Verified |
| 2.1 | Recovery system, GPS, altimeters, electrical circuits shall be independent of payload electrical circuits | USLI Requirements | Design consideration, tested independently and during launches | Ongoing Verification |
| 2.11 | Removable shear pins shall be used for main parachute compartment and drogue parachute compartment | USLI Requirements | General design consideration | Verified |
| 2.12 | Recovery area shall be limited to 2,500 ft. radius from launch pads | USLI Requirements | Testing consideration, verified at launch & independent testing | Not Verified |
| 2.13 | Descent time of launch vehicle shall be limited to 90 seconds | USLI Requirements | Testing consideration, verified at launch & independent testing | Ongoing Verification |
| 2.14 | Electronic GPS tracking device shall be installed in launch vehicle and transmit the position of tethered vehicle | USLI Requirements | Design consideration, tested independently and during launches | Ongoing Verification |
| 2.15 | The first main chute charge will fire at 600ft | Team derived requirements, testable independently and at launch | Design consideration, tested independently and during launches | Ongoing Verification |
| 2.16 | Backup main chute charge will fire at 550ft | Team derived requirements, testable independently and at launch | Design consideration, tested independently and during launches | Ongoing Verification |
| 2.17 | Avionics components in the vehicle will be removable | Team derived requirements | General design consideration | Ongoing Verification |
| 2.18 | U-bolts will be utilized for shock cord connections | Team derived requirements | General design consideration | Ongoing Verification |
| 2.19 | All batteries shall be fully charged before every flight | Team derived requirements | General design consideration | Ongoing Verification |
| 2.20 | Avionics components shall be securely fashioned into the AV bay | Team derived requirements | General design consideration | Ongoing Verification |

### Payload Requirements Verification

***Figure 32:*** *Payload Requirements Verification*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Requirement #** | **Description** | **Rationale** | **Verification** | **Verification State** |
| **Payload** | | | | |
| 3.1 | Must be designed, constructed, and tested by the student team | USLI Requirements | Design, payload testing, full scale launch | Ongoing Verification |
| 3.2 | Must include DAQ that records and stores data including altitude, velocity, acceleration | USLI Requirements | Design, payload testing, full scale launch | Ongoing Verification |
| 3.3 | Must not use parachutes or streamers, "atmosphere independent" | USLI Requirements | Design, payload testing, full scale launch | Ongoing Verification |
| 3.4 | Payload shall remotely eject manually from vehicle | USLI Requirements | Design consideration, tested independently and during launches | Not Verified |
| 3.5 | Shall be fully retained until the intended point of deployment | USLI Requirements | Design, payload testing, full scale launch | Ongoing Verification |
| 3.6 | Shall be a minimum of 5lbs including landing capsule and the 4 STEMnauts | USLI Requirements | General design consideration | Ongoing Verification |
| 3.7 | Deployment of the SAIL shall occur between 400 and 800 feet AGL | USLI Requirements | Design, payload testing, full scale launch | Ongoing Verification |
| 3.8 | Payload Shall land in a unique landing orientation | USLI Requirements | Design, payload testing, full scale launch | Ongoing Verification |
| 3.9 | EDF motor produces enough thrust to efficiently decelerate payload | Team derived requirements | Design, payload testing, full scale launch | Ongoing Verification |
| 3.10 | Deployable legs counter and balance payload landing forces upon landing | Team derived requirements | Design, testing, and full-scale flight | Ongoing Verification |
| 3.11 | Payload shall fit into rocket body without damage to rocket or payload | Team derived requirements | Design, fabrication, testing | Not Verified |
| 3.12 | Payload shall have a battery life that exceeds the total flight duration and launch pad wait time | Team derived requirements | Design, testing, and full-scale flight | Ongoing Verification |
| 3.13 | Payload batteries will be off the shelf, commercially available | Team derived requirements | General design consideration | Verified |
| 3.14 | All STEMnauts remain in their restraints throughout the entirety of the flight duration | Team derived requirements, survivability metrics | Design consideration, tested independently and during launches | Not Verified |
| 3.15 | No STEMnauts incur any significant physical damage or failure | Team derived requirements, survivability metrics | Design consideration, tested independently and during launches | Not Verified |
| 3.16 | No STEMnaut should experience an acceleration greater than 25 G for up to 150 milliseconds | Team derived requirements, survivability metrics | Design consideration, tested independently and during launches | Not Verified |

## Budgeting, Funding, & Timeline

### Budget





Figure 33: Fall 2023 Expenditures.





Figure 34: Spring 2024 Expenditures.



Figure 35: Total Estimated Project Cost.

### Funding Plan

#### Funding Acquisition Routes

Funding for this project is being sourced from a few different areas. First, the academic sponsor for this project, Dr. Chiang Shih. Dr. Shih is a professor of aeronautics, fluids, and topics alike at the FAMU-FSU College of Engineering and has promised to provide financial support since before the project began. Discussions with Dr. Shih are ongoing as to the amount of contribution currently.

The next source of financial support for the project is provided by Dr. William Oates, Dean of Mechanical Engineering at the FAMU-FSU College of Engineering. Dr. Oates has provided financial support for previous years’ Zenith team. Discussions of financial aid with Dr. Oates have only recently begun, and a specific amount has yet to be decided.

The Student Government Association (SGA) of Florida State University is another source of funding for the Zenith program. SGA routinely provides funding for travel, parts, tools, materials, and events for an assortment of organizations across all things that FSU may be affiliated with, including the Zenith program.

Branches of SGA include the Resource for Travel Allocations Committee (RTAC), which focuses its efforts on travel expenses. This will be used to aid the Zenith team in their travels for sub-scale and full-scale launches and travel to Huntsville, AL for competition. The Programming Allocations Committee (PAC) branch of the FSU student government focuses its efforts on providing student organizations with funding for tools, parts, materials, food, beverages, and more. This will be used to allocate funding for all the aforementioned tools, parts, and materials for the project.

The Florida Space Grant Consortium (FSGC) will also be supporting the project, coordinated by Dr. McConomy. Dr. McConomy is the senior design/senior capstone project coordinator for the FAMU-FSU College of Engineering. The FSGC is an association in the state of Florida that funds student research and student projects associated with all things space. The estimated financial support from FSGC is roughly $2000, however, more precise figures will be determined as more discussions with the FSGC and Dr. McConomy are coordinated.

#### Material Acquisition Plan

Material acquisition will be done through the FAMU-FSU College of Engineering for parts that must be specially ordered, customized, or otherwise require specialized care and attention (aside from hazardous materials).

General purpose parts will be purchased locally to save time, as options are plentiful and readily available. Hazardous materials will be purchased by the Zenith team but only handled by those with proper certification. In our cause, this is our mentor, Tom McKeown, with an NAR/TRA Certification Level of 2.

Table 26: Material Acquistion Types

|  |  |  |
| --- | --- | --- |
| Material Type | Component(s) | Description |
| Specialized Boutique | Avionics unit, recovery systems, telemetry transmission, airframe, shear pins | Uncommon items, often from small distributors. Can be difficult to find, little optionality. |
| Specialized | Actuators, EDF motors, 3D-print material, chute bags | Common items but are found in fewer places than general purpose materials. |
| General Purpose | Shock cord, links, bolts, glues, tools, etc. | Readily available. Can be purchased easily and with plentiful optionality. |
| Hazardous | Solid propellant motor | Special order. Mentor certification needed. Special storage considerations. Does not get handled by students |

### Timeline

The project timeline is broken down into days from being accepted into the competition until the day of the final deliverable due date. Weekends are omitted from the calendar to allow the team time to focus on other classes, obligations, or cushion time for when Murphy’s law takes effect on the project timeline.

Noted in the legend below the figure, weeks are denoted in black at the top of the figure. Days of the week are in blue, shown directly below the week. The overall duration of a set of deliverables is in light green while specific tasks are shown in dark green. Important deadlines are shown in red, and public holidays and breaks are blocked out in grey.



Figure 36: Project Timeline Legend.



Figure 37: Fall 2023 Project Timeline



Figure 38: Spring 2024 Timeline



***Figure 39:*** *Timeline Dates*