Project Hrafn

Preliminary Design Report

Cedar Falls High School
1015 Division Street, Cedar Falls, IA 50613
October 26th, 2022

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I) Summary of PDR Report

1.1 Team Summary

- Team name and mailing address
    - Cedar Falls High School Rocket Club
    - 1015 S Division St. Cedar Falls, Iowa, 50613
- Name of mentor, NAR/TRA number and certification level, contact information
    - Tyler Sorensen, NAR #: 99437, TRA #: 16311, Level Two certified, tylersorensen3@gmail.com
- Documentation of hours spent working on the CDR milestone
    - The team has spent 295 hours working on the PDR milestone. Hours include brainstorming/research, vehicle design/development, payload design/development, PDR writing, PDR proofreading, and PDR presentation creation.
- Team social media handles

@CFHSRocketClub (Twitter)	cfhsrocketclub (Instagram)

1.2 Launch Vehicle Summary

- Official target altitude (ft.)

Target Altitude - 4500 feet

- Preliminary Motor Choice(s)

Preliminary motor choice - K1440

- Size and mass of individual sections

30” Nose Cone - 3.362 lbs Payload (Inside Payload Coupler) - 1.472 lbs 20” Payload Coupler - 1.977 lbs

32” Recovery Section - 2.875 lbs 12” Electronics Bay Coupler (With 2-inch Switchband) - 3.81 lbs 40” Booster Section - 9.951 lbs

- Recovery system

18” Elliptical Drogue chute by Fruity Chutes 72” Iris Main chute by Fruity Chutes

1.3 Payload Summary

- Payload Experiment

Executive Summary
The team’s payload is the Deployable Rocketry Operational Navigation Equipment or D.R.O.N.E, consisting of two primary parts. The deployment mechanism is the first of the two and is responsible for removing the UAV from inside the payload section of the vehicle and preparing it to launch. The second part of the payload is a UAV, which will autonomously fly from the vehicle to a team member wearing a controller. It will then fly back to the vehicle, showing the way, at the same rate the controller is walking.
Deployment Mechanism
The deployment mechanism is a self-leveling sled that separates the nose cone and payload section/coupler apart. It self-levels using two bearings on either side of the main sled that the UAV is placed on. The CG is carefully placed slightly under the center so that the bearings always rotate toward the lowest point (level). The separation of the nose cone and payload section is done by 3 threaded rods. One threaded rod is attached one way, and two in the other direction. These threaded rods act as a linear actuator, shearing two shear pins, and making enough clearance for the UAV to take off. There are two locks on the deployment mechanism. One lock holds the rotational axis of the sled while the other holds the UAV in place until deployment.
The deployment mechanism shares a majority of its electronics with the UAV, where the only two different parts are the motors and their respective controllers. All other UAV-focused components like the lidar, ultrasonic sensor, and more, aren’t included. The computer used is a Teensy 4.0, paired with a NEMA 17 motor and A4988 motor controller. These components are powered by an 11.4V 6200mAh battery. This battery will last more than two hours on the launch pad in accordance with the NASA SLI Handbook rules.
UAV

The UAV will be a quadcopter with vertically folding wings. The quadcopter will be equipped with a multitude of sensors including range finding and gyroscopic sensors. The computer will be a Teensy 4.0 paired with “2S” sized motors and controllers for the flight of the UAV. It will be coded in C++.

II) Changes Made Since Proposal

2.1 Changes Made to Vehicle Criteria

There have been a few changes made to the vehicle since the Proposal. To start, the projected apogee is now 4500 feet instead of 4775 feet. As the mass is being finalized, the altitude predictions have been modified accordingly. The recovery section, which is between the payload coupler and the electronics bay, is now attached to the payload coupler. The electronics bay will have no other sections of the vehicle attached to it directly. The electronics bay will be tethered to the rest of the vehicle, having the drogue and main parachute on opposite sides. The vehicle mass has also changed from 23.5 lbs to a slightly heavier 24.1 lbs.

2.2 Changes Made to Payload Criteria

Some minor changes have been made to the payload criteria previously not listed. First, the deployment system is no longer active, but rather passive. We are using gravity to level the UAV instead of additional motors and electronics. Two main modifications were made to the UAV design. First, there will no longer be a camera mounted on the UAV but rather on the deployment mechanism, which captures the separation event and take-off of the UAV. The second modification is the way the arms fold. The arms will now fold vertically instead of horizontally and be held in place through the thrust of the motors, not by a locking mechanism.

2.3 Changes Made to Project Plan

No changes have been made to the project plan.

III) Vehicle Criteria

3.1 Selection, Design, and Rationale of Launch Vehicle

- Unique mission statement and mission success criteria.

The CFHS Rocket Club’s mission is to design, manufacture, and launch a vehicle that, after landing, deploys a small autonomous UAV, flying from the vehicle to a team member, and then back. Mission success can be divided into two main events that occur after the vehicle landing: the successful deployment of the UAV and the successful take-off, navigation, and guidance of team members through the use of the UAV.

- Design reviewed at a system level, going through each system’s alternative designs, and evaluating the pros and cons of each alternative.

Nose Cone
Shape ● Conical ○ The nose cone would come to a sharper point in a conical shape. This would result in higher drag, making it harder to reach a higher altitude with more drag acting against the vehicle thrust. ● Elliptical ○ The elliptical shape has a more rounded and blunt point at the tip of the nose cone. This has a low coefficient of drag for lower-powered rocketry with rounded edges. The higher velocity means that a more pointed nose cone with rounded edges would be more beneficial for a high-powered vehicle. ● Ogive ○ The ogive shape has a rounded shape with no corners to be caught, reducing overall drag. It also has a sharp point that comes to the top of the vehicle. This allows for a higher altitude than the other nose cone shapes with its higher efficiency and lower drag.
Size Ratio ● 4:1 ○ A nose cone with a 4:1 ratio has the benefit of lower mass in comparison to a 5:1 due to its shorter nature. Due to its shorter nature, it “cuts” the air over a shorter period making it less aerodynamic. ● 5:1 ○ A nose cone with a 5:1 ratio has the benefit of being more aerodynamic due to it “cutting” the air over a longer period. Since the nose cone is longer though, the overall mass will be greater.

Body Tube
Material ● Blue Tube ○ Blue Tube provides the cheapest and lightest material option for body tube construction. This cost and mass benefit is negated due to the other qualities of Blue Tube. This includes a lower strength-to-mass ratio, non-fire resistance, and non-moisture resistance. ● Fiberglass ○ Fiberglass provides a balance between cost and durability/strength. It has s directionless grain which provides optimal strength and durability. Fiberglass is also fire and moisture-resistant. However, fiberglass is more expensive than Blue Tube, making it more costly for the team. It's also weaker than carbon fiber, with a small potential of having cracks or fractures. ● Carbon Fiber ○ Carbon Fiber is the strongest of the three materials. It is also fire and moisture-resistant, making it more durable. Unfortunately, Carbon Fiber has a very high cost per pound which is not offset by the strength benefits.
Vehicle Overall Length ● 104 inches ○ A 104-inch long vehicle would provide additional space for the payload section. This allows more flexibility in the design of the payload and more room for the UAV. Increased surface area results in more parasitic drag and a higher mass, causing the overall altitude of the vehicle to be lower. ● 96 inches ○ A 96-inch long vehicle is the minimum viable length that provides room for a 10-inch payload section. This follows SLI handbook rule 2.4.1 having a coupler twice as long as the vehicle diameter. The surface area and mass of the vehicle would be minimized, allowing for a higher overall altitude. The minimal size of the payload section results in a much greater or incapable challenge to fit the UAV and deployment mechanism into the payload coupler. This makes the total vehicle length of 104 inches to be much more favorable.
Diameter ● 6 inches ○ A body tube diameter of 6 inches would provide the most space for the UAV payload. Conversely, it would have a higher mass, air resistance, and cost. The UAV can fit in a smaller body tube diameter though, making this larger body tube diameter unnecessary. ● 5 inches ○ A body tube diameter of 5 inches provides just enough room for the UAV payload and deployment mechanism. It has a lower mass, air resistance, and cost. This body tube diameter provides a good compromise between cost, mass, and air resistance. ● 4 inches

○ A body tube diameter of 4 inches provides the lowest mass, air resistance, and cost. This would provide the least amount of space for the payload, potentially making it impossible to put a UAV and deployment mechanism into the vehicle.

Bulkheads
Material ● Plywood ○ Plywood is the cheaper and lighter bulkhead option. It is weaker and has lower durability, resulting in it not being able to withstand some impact forces. ● Fiberglass ○ Fiberglass provides higher strength and durability in comparison to plywood. Fiberglass is fire and moisture-resistant with the added benefit of withstanding higher impact forces.

Electronics Bay
GPS ● AIM XTRA GPS ○ The AIM XTRA GPS can track the vehicle up to 20 miles away with an accuracy of 3 feet. It will aid in the tracking and recovery of the vehicle. It will also be a better option because we can use two previous GPS units that our team already owns. One downside of this brand is its greater price. ● TeleMetrum v3.0 ○ The TeleMetrum v3.0 is a flight computer that is capable of dual deployment, tracking the vehicle, and many other useful functions. However, some of these functions are not necessary for this vehicle. A primary drawback of this flight computer is the elevated cost of the components and that the team doesn't have any available. ● Featherweight GPS Tracker ○ The Featherweight GPS Tracker has the longest radio range at over 164,000 feet. It uses a GPS system that pairs with a phone app to track the vehicle. It has an incredibly small footprint and can run for 16 hours. Features of this tracker include 3D Data logging, Multi-stage Flights, an Over-the-Horizon relay, and Estimated Landing Points.
Altimeter ● Perfectflite StratoLoggerCF ○ The Perfectflite StratoLoggerCF is the best altimeter from Perfectflite. It has a compact footprint, high versatility, and high accuracy. The downside is that it is more expensive than other options on the market. ● Perfectflite StratoLogger SL100 logging deployment altimeter ○ The Perfectflite StratoLogger SL100 is larger than the StratoLoggerCF. It has lower accuracy and a much larger form factor. It costs similar to the

StratoLoggerCF.

Fins
Material ● Plywood ○ Plywood is the lightest and cheapest fin option. Its lower durability and strength make it not favorable. This coincides with its lack of fire resistance and water resistance. Plywood fins are very likely to be damaged at impact with the ground or during the vehicle's flight due to high acceleration. ● Fiberglass ○ Fiberglass provides a balance between cost, durability, and strength. It has directionless grain, making it better able to handle impact and drag forces experienced in flight. The fire and water resistance of fiberglass fins are important with the nearby flames and high heat due to the close proximity to the motor. Fiberglass fins are more expensive than plywood and weaker than Carbon Fiber. ● Carbon Fiber ○ Carbon Fiber fins would be extremely strong and durable alongside their moisture and fire resistance. This is important with the vehicle's high acceleration, drag, and impact forces. The proportional cost of carbon fiber is significantly more than fiberglass for higher strength and durability.
Shape ● Clipped Delta ○ A clipped delta fin shape is easy to construct and commonly used. It sits flush with the bottom of the vehicle, making fin damage when impacting the ground very likely. ● Elliptical ○ An elliptical fin shape provides the most aerodynamic design with the lowest drag. It can be difficult to size and modify if needed. It has a smaller size which raises the center of gravity. ● Trapezoidal ○ A trapezoidal fin shape provides lower drag and less mass compared to a clipped delta. In addition, due to its shape, it does not sit flush with the end of the vehicle, preventing damage to the fin upon impact. It is still less aerodynamic than an elliptical fin.
Root ● 14 inch ○ This root size allows for a lower stability margin without sacrificing too much mass in the design. It will have less surface area than some of the other options which makes it less steady during flight. There is not as much material as the other options which could be beneficial where there could be too much surface area and drag on the vehicle.

● 16 inch ○ This option would have a higher stability margin which could allow for more stability during flight and a higher altitude reached, however, it has more mass as there is more material as well as more surface area which can cause more drag on the vehicle, potentially bringing the altitude down.
Span ● 4.5 inch ○ The span size of 4.5 inches would allow a compromise between surface area, center of gravity changes, and the modification of the center of pressure. The smaller or larger span is less impactful to the overall height or performance of the vehicle. The smaller span allows the fins to fit into smaller sheets of fiberglass, making production costs lower for the team. ● 6 inch ○ A 6-inch span would provide more surface area, a lower center of gravity, and a lower center of pressure. While the larger span has its benefits, they are minimal, which makes it unnecessary and creates a higher cost of production.
Number of Fins ● 3 Fins ○ Three fins provide optimal stability with reduced drag due to a minimum number of protrusions on the vehicle. three fins provide a lower cost and higher altitude when compared to four fins. ● 4 Fins ○ A total of four fins provides more than enough stability but has a higher drag due to the increased number of protrusions on the vehicle. Four fins would move the center of pressure closer to the vehicle's rear. Conversely, it would cost and weigh more than a three-fin configuration.

- Research presented on why each alternative should or should not be chosen.

Nose Cone
Shape ● Conical ○ A conical nose cone shape should be chosen for its lighter mass with less overall volume. ○ A conical nose cone shape should not be chosen because it comes to a sharp angle causing the drag to have more effect on the ascent of the vehicle, affecting the overall altitude of the vehicle. ● Elliptical ○ The elliptical nose cone shape should be chosen because of its easier-to-manufacture tip, making the overall cost lower. ○ Elliptical nose cone shape should not be chosen because it is too rounded with too blunt of a tip which would not be ideal for the drag of a high-powered

vehicle, causing the altitude to be lower than desired. ● Ogive ○ Ogive nose shape should be chosen because it has rounded edges with no sharp corners but a pointed tip which would cause less drag in the high-powered vehicle as it could slice through the air better with its higher velocity, thus allowing it to have a higher altitude. ○ The ogive shape shouldn't be chosen due to its harder-to-manufacture design, making it more expensive.
Size Ratio ● 4:1 ○ The 4:1 ratio should be chosen due to the lower overall mass of the nose cone. ○ The 4:1 should not be chosen due to it being less aerodynamic, thereby leading to a lower launch altitude. ● 5:1 ○ The 5:1 nose cone ratio should be chosen due to it being more aerodynamic and thereby having a higher launch altitude. ○ The 5:1 nose cone should not be chosen due to its higher mass.

Body Tube
Material ● Blue Tube ○ Blue Tube remains the cheapest material to build with, making it beneficial to use for the team's budget. ○ Blue Tube should not be chosen due to it being relatively weak and less durable compared to the other materials. ● Fiberglass ○ Fiberglass should be chosen due to its compromise between strength/durability and lower cost than carbon fiber. ○ Fiberglass should not be chosen because it is not as strong as carbon fiber, and is more expensive than Blue Tube. ● Carbon Fiber ○ Carbon fiber should be chosen because it has the highest strength and durability than any other option. ○ Carbon fiber should not be chosen as the proportionally added strength and durability do not cover the proportionally added cost.
Length ● 104 inches ○ This length should be chosen because it allows more room to work within the vehicle which would cause less room for error in the construction of the vehicle, its payload, and its components. ○ This length should not be chosen because while it allows more room for the payload, the additional mass and drag make the target altitude lower, and the

vehicle heavier.

- 96 inches
  - This length should be chosen because it is the most compact and lightweight design with the least air resistance.
  - This length should not be chosen because it would be more compact with less room to work with, which could cause problems with the design of the payload being too large.

Diameter

- 6 inches
  - A 6-inch diameter should be chosen because of the added payload space allowing our UAV to be larger.
  - The 6-inch diameter should not be chosen due to the added mass and unnecessary extra payload space. The added mass will lead to a lower overall launch altitude.
- 5 inches
  - A diameter of 5 inches should be chosen due to nominal payload and recovery space alongside reduced drag and mass compared to a 6-inch diameter. This leads to a higher launch altitude.
  - A 5-inch diameter vehicle still weighs more than a 4-inch diameter vehicle, making it less reasonable to be chosen.
- 4 inches
  - The 4-inch diameter vehicle should be chosen because of its lighter mass, making the target altitude higher.
  - A diameter of 4 inches should not be chosen due to its limited payload space.

Bulkheads

Material

- Plywood
  - Plywood should be chosen because of its low cost.
  - Plywood should not be chosen due to limited strength/durability
- Fiberglass
  - Fiberglass should be chosen due to its strength/durability.
  - Fiberglass should not be chosen because of its higher cost.

Electronics Bay

GPS

- AIM XTRA GPS
  - The AIM XTRA GPS can track the vehicle for extremely long distances making it very favorable.
  - The AIM XTRA GPS has a very high price making it less favorable.
- TeleMetrum v3.0

- The TeleMetrum v3.0 should be used, as it is capable of dual deployment, tracking vehicle, and a few other functions.
- The TeleMetrum v3.0 should not be used because of the high price also found on this GPS.

- Featherweight GPS Tracker
    - The Featherweight GPS Tracker should be chosen because of its superior long-distance range, connected phone app, and multitude of features.
    - The Featherweight GPS Tracker should not be included because of its incapability for dual deployment and separate battery location.

Altimeter

- Perfectflite StratoLoggerCF
    - The Perfectflite StratoLoggerCF should be chosen because of its smaller size, high accuracy, and large storage.
    - The Perfectflite StratoLoggerCF shouldn't be chosen because of its extremely high cost.
- Perfectflite StratoLogger SL100
    - The Perfectflite StratoLogger SL100 should be chosen because of its reliability, being older than the StratoLoggerCF.
    - The Perfectflite StratoLogger SL100 should not be chosen for a variety of reasons including its lower accuracy and larger form factor.

Fins

Material

- Plywood
    - Plywood should be chosen because of the massively lower cost.
    - Plywood should not be chosen due to its limited strength and durability.
- Fiberglass
    - Fiberglass should be chosen due to its compromise between cost and strength/durability
    - Fiberglass should not be chosen because it has a high cost for its strength, making it less favorable.
- Carbon Fiber
    - Carbon Fiber should be chosen because it has the highest strength and durability over everything else.
    - Carbon Fiber should not be chosen because the proportionally increased costs do not match the proportionally increased strength and durability. It costs more for a slight improvement in strength.

Shape

- Clipped Delta
    - The clipped delta shape should be chosen because of its much easier construction and common use.
    - A clipped delta fin should not be chosen due to the added mass and the fact that

the fin is flush with the bottom of the vehicle, increasing the risk of damage to the fin.

- Elliptical
  - The elliptical-shaped fin should be chosen because of its highly aerodynamic design with the lowest amount of drag.
  - An elliptical fin should not be chosen due to the difficulty in constructing and altering its shape.
- Trapezoidal
  - Trapezoidal fins should be selected due to their compromise in mass and aerodynamics. They do not sit flush with the bottom of the vehicle, preventing any additional damage to the fin.
  - The trapezoidal fin shape should not be selected because of its lower aerodynamics compared to the elliptical fin shape.

Root

- 14 inch
  - The 14-inch root length should be chosen for its lower stability margin without large mass sacrifice or gain.
  - 14-inch root length fins should not be chosen because of their lower surface area making them less stable.
- 16 inch
  - A 16-inch fin root length should be chosen because it creates a higher stability margin, making the vehicle more stable.
  - The vehicle's 16-inch fin root length should not be chosen because of the higher surface area, and therefore higher drag on the vehicle.

Span

- 4.5 inch
  - This 4.5-inch span should be chosen for our vehicle because it balances mass with a surface area much better than a 6-inch span. Air resistance/drag isn't as high.
  - The 4.5-inch span should not be chosen because of the higher center of gravity and center of pressure resulting in the smaller span.
- 6 inch
  - The 6-inch span should be chosen because the higher surface area gives it a lower center of gravity and lower center of pressure.
  - The 6-inch span should not be chosen because the benefits are minimal due to the higher surface area and higher drag.

Number of Fins

- 3 Fins
  - Having three fins should be chosen due to the lower mass and lower number of protrusions on the vehicle, producing lower drag/air resistance and therefore a higher altitude. It also has the added benefit of costing less than adding a fourth fin.
  - Three fins should not be chosen because the stability would be lower than with

4 fins. ● 4 Fins ○ The four fin configuration should be chosen because it allows much higher stability for the vehicle, moving the center of pressure closer to the vehicle's rear. ○ Having four fins should not be chosen due to the increased drag, mass, cost, and protrusions on the vehicle, causing a lower total altitude.

- A feasibility study was conducted for each alternative.

Nose Cone
Shape ● Conical ○ The conical-shaped nose cone provides less room for the payload to be put into. This makes it less favorable for use because of the larger payload sled design. ● Elliptical ○ The elliptical shape is a good shape, but is extremely difficult to find from a manufacturer, making it not favorable for the team. ● Ogive ○ The Ogive shape is the most feasible for the rocketry team as it is the only commercially available nose cone sold by wildman rocketry, our supplier for fiberglass parts.
Size Ratio ● 4:1 ○ A nose cone with a ratio of 4:1 would cost less due to the shortened length. The effort to assemble the 4:1 or 5:1 nose cone is negligible compared to each other. ● 5:1 ○ A nose cone with a ratio of 5:1 would cost more due to its longer length. The effort to assemble the 5:1 or 4:1 nose cone is almost identical, if not identical.

Body Tube
Material ● Blue Tube ○ Blue Tube would be very feasible to build a vehicle out of due to the availability of material, cost, and ease of manufacture. BlueTube can be found in large quantities in most places. Additionally, Blue Tube is the cheapest material to build from. Lastly, Blue Tube is very easy to work with, needing a minimal amount of work to be used, shaping, and working with it. ● Fiberglass ○ The team can competently work with fiberglass. It is less feasible to work with than Blue Tube, but still possible. Proper PPE has to be worn to handle

fiberglass due to the fibers that can get in the air or on an individual when handled. Fiberglass has a lower cost than carbon fiber with significantly more strength than Blue Tube. The cutting process is more difficult, but the team has access to the proper tools to complete cutting. ● Carbon Fiber ○ Carbon fiber would be the least feasible due to its high expense. It is also harder to obtain compared to all of the other materials. Working with Carbon Fiber is more difficult than fiberglass, and the team has little to no knowledge of handling or cutting carbon fiber.
Length ● 104 inches ○ A length of 104 inches provides the most space for all internal components, but would require a higher cost of materials and increase the mass of the vehicle. ● 96 inches ○ A length of 96 inches would be cheaper with fewer materials needed for it, but could severely limit space for the internal components.
Diameter ● 6 inches ○ A diameter of 6 inches would cost more and weigh more, but as a result, provide ample space to work with for the payload. ● 5 inches ○ A diameter of 5 inches weighs and costs less while providing ample space for the payload. Cutting is easier on a smaller diameter tube because there is less “wiggle room” in the cutting tools. ● 4 inches ○ A diameter of 4 inches would weigh less, cost less, and take the least amount of time to cut, but would not provide enough space for the payload.

Bulkheads
Material ● Plywood ○ Plywood is very cheap and is available everywhere. Additionally, it is very easy to work with in its manufacture. ● Fiberglass ○ Fiberglass is more expensive than plywood but is still only around $2.00-$3.00 per pound of fiberglass. It isn’t too hard to acquire and isn’t too difficult to cut.

Electronics Bay
GPS ● AIM XTRA GPS

- The high distance for vehicle tracking makes this GPS a good competitor. Our team is in the possession of two of these GPS' already, making it not have an impact on our budget.
- TeleMetrum v3.0
    - The TeleMetrum v3.0 is as capable as the other two GPS systems but is more expensive. It comes with a dual deployment system but we do not need that as our altimeters are being used for this. Our team also doesn't have any that we already own, making it more costly for our budget.
- Featherweight GPS
    - The Featherweight GPS Tracker has many benefits, including the longest radio tracking range. The phone app makes it more applicable to the rocketry team composed of high school students. Our team is able to take the 3D telemetry and analyze the flight later. On top of all of this, our team already owns one of these GPS' which we can use at no additional cost.

Altimeter

- Perfectflite StratoLoggerCF
    - Our team finds that the Perfectflite StratoLogger is better for our team to use. Its smaller size and high accuracy make it more favorable. While it is more expensive, our team already has two that we can use as our primary and secondary (backup) flight altimeters, making no impact on our budget.
- Perfectflite StratoLogger SL100 logging deployment altimeter
    - The reliability and older StratoLogger 100 is similar in cost to the other stratoLogger. It is now out of stock and is not worthwhile waiting to purchase one, as we already have a StratoLoggerCF.

Fins

Material

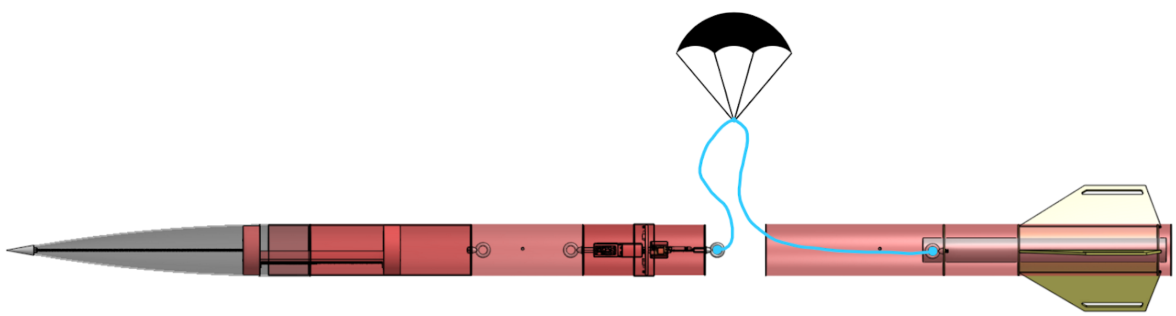
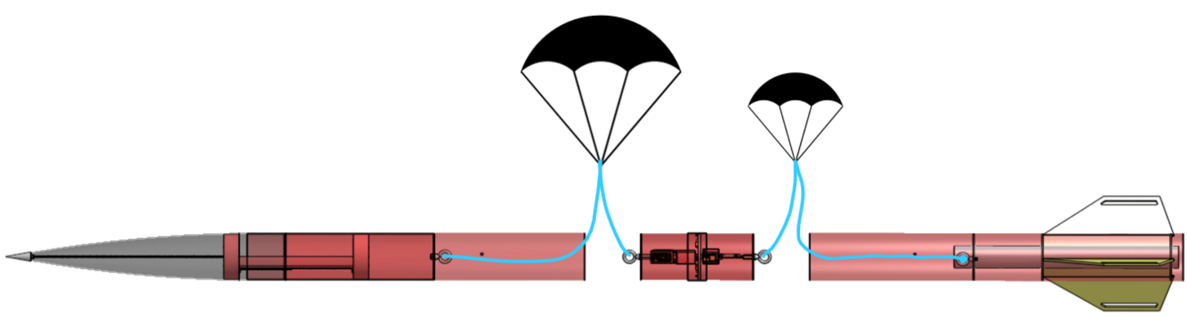
- Plywood
    - Plywood is the most readily available fin material and the easiest to manufacture and assemble. Additionally, it is the cheapest option, making our budget lower.
- Fiberglass
    - Fiberglass is less accessible than plywood. It is only commercially available in a few places. It requires additional protocols and PPE for manufacturing and assembling it. It is more expensive than plywood but cheaper than carbon fiber.
- Carbon Fiber
    - Carbon fiber is the most expensive of the three materials in consideration. It is the hardest to find and purchase commercially. Handling carbon fiber is complex and requires the most amount of work to be put into manufacturing and assembling it.

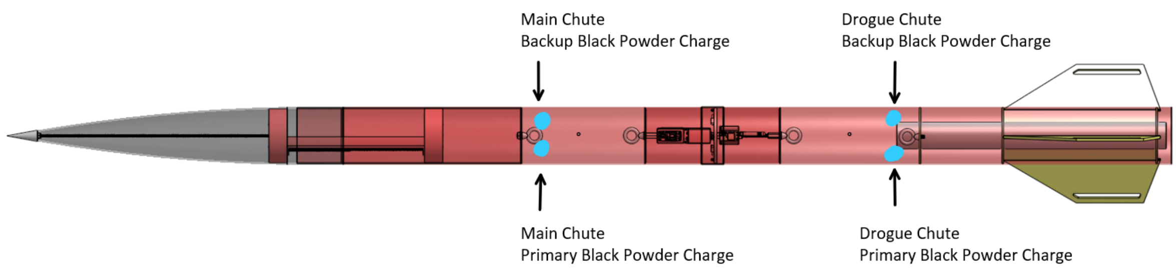
Shape

- Clipped Delta

○ Clipped delta fins are the easiest to manufacture as they have a simple shape that is easy to cut. Our team gets the fiberglass fins cut from the same fiberglass tubing supplier, making it not difficult to cut different fin shapes. ● Elliptical ○ The elliptical shape is the most aerodynamic but also smaller. This makes it more difficult to change the center of gravity and center of pressure for the vehicle. ● Trapezoidal ○ Trapezoidal fins are easier to manufacture compared to elliptical fins, but slightly more difficult because of the more complex shape to cut out. Their benefits come in the capability to manipulate the center of gravity and center of pressure in the vehicle.
Root ● 14 inch ○ The 14-inch root length has a lower stability margin and less surface area. If the stability margin is within reason, that's perfectly fine. The lower surface area is nice because it costs less for the team to manufacture. ● 16 inch ○ A 16-inch root length has a higher stability margin and higher surface area. This allows a more stable flight but results in a higher cost and drag.
Span ● 4.5 inch ○ The 4.5-inch span allows the fin to fit onto a smaller sheet of fiberglass, making expenses lower on the team. It also is lighter, making a higher center of gravity for the overall vehicle. ● 6 inch ○ A 6-inch span is larger, requiring larger sheets of fiberglass and a higher overall cost. It provides a lower center of gravity and a lower center of pressure. The vehicle is heavier and drag is higher with a 6-inch span, making the altitude lower.
Number of Fins ● 3 Fins ○ Due to less material being used, 3 fins would cost less and require less time for manufacturing and assembly. ● 4 Fins ○ An additional fin has more materials that are required, making the cost higher. It then takes more time and costs more to add the fourth fin to the vehicle.

- Points of separation located on the design with the corresponding location of energetic materials.

Points of Separation
Regardless of the material, length, diameter, or modification of fins, the points of separation are identical. The vehicle will separate twice during its descent. The first separation event will be at apogee with the backup at apogee + 1 second. This separation will be between the electronics bay coupler and the booster section. The 18" Fruity Chutes drogue chute will deploy here. The vehicle will descend at ~88.79 ft/sec until the second separation event. The configuration of the vehicle during the first stage of descent is shown in figure 3.1.1. The second separation event will be at 600ft with a backup at 600ft + 1 second (~500 ft). This event will separate the other side of the electronics bay coupler from the recovery section which is connected to the payload coupler and nose cone. At this time is when a 72” Fruity Chutes iris chute will deploy. The vehicle will descend at a much slower ~18.23 ft/sec until it touches down / lands on the ground. The second stage descent configuration is shown in figure 3.1.2.
 *Figure 3.1.1 - First Stage Separation (Drogue)*
 *Figure 3.1.2 - Second Stage Separation (Main)*

Energetic Material Locations
The team will be using 2 sets of black powder charges for energetic materials. The first, for the first stage (drogue chute) deployment, will be two black powder charges. One of the charges will be for the primary, and one for the secondary. The second will be two more black powder charges for the secondary (main) chute deployment. The first black powder charges (primary) for each separation event will be 3g for the drogue chute and 4g for the main chute. The secondary (backup) black powder charges for each separation event will be 5g for the drogue chute and 6g for the main chute. The black powder will be on the opposite side of the electronics bay coupler on both sides. This is so that when the black powder ignites, it pushes each parachute out of the vehicle while separating it at the same time. Figure 3.1.3 shows the location of all black powder charges in the system.
 *Figure 3.1.3 - Energetic Material Locations*

- After evaluating all alternatives, present a vehicle design with the current leading alternatives, and explain why they are the leading choices.
    - Describe each subsystem and the components within those subsystems
    - Provide a dimensional drawing using the leading design
    - Provide estimated masses for each subsystem
    - Provide sufficient justification for design selections

Nose Cone |3.362 lbs|
We will be using an ogive nose cone with a 5:1 ratio composed of fiberglass. An ogive nose cone is one of the more aerodynamic nose cones for high-powered rocketry with its rounded edges, allowing for a higher launch altitude. Moreover, a 5:1 ratio was selected due to it being more aerodynamic due to its increased length and “cutting” the air over a longer period of time, once again leading to a higher launch altitude. Fiberglass was chosen as the material due to its durability and strength, as well as being utilized for the other body tubes of the vehicle.

Payload Coupler |3.449 lbs|
The payload coupler is 4.998 in. outside diameter and 4.822 inside diameter. The payload section is unique compared to other vehicles as there is no bulk plate between the nose cone and payload coupler. The 20-inch long payload coupler itself is attached to the nose cone by two shear pins. These two shear pins will break when the payload sled separates. There is a threaded rod attached to either side of the payload sled, from the lower bulk plate all the way to the nose cone. It allows the sled to expand and retract after the vehicle has landed, but doesn't affect the vehicles' strength and performance during flight.

Recovery Section |2.875 lbs|
A 5-inch diameter and 32-inch long fiberglass body tube was chosen. Fiberglass was chosen due to its strong and durable nature, such as being fire and moisture-resistant which is important for vehicle design in general, as well as being less costly than carbon fiber. Strength and durability are important due to the strong forces the vehicle will be subjected to. The recovery section will be attached to the payload coupler by 4 evenly spaced rivets. The recovery section will also be coupled with the electronics bay coupler on the other side with 2 shear pins. The main 72" parachute will be placed inside the recovery section.

Electronics Bay (Coupler) |3.81 lbs|
The electronics bay coupler is 12 inches long with a 2-inch wide switchband. It holds two altimeters, a primary and a backup. The altimeters are Perfectflite StratoLoggerCF's. The electronics bay also contains a Featherweight GPS Tracker. The altimeters and GPS are separated by a piece of plywood and chicken wire for signal shielding. The plywood has 3 lock-on buttons. There are 3 holes on the outside of the vehicle that let a small screwdriver reach in and activate these buttons, turning on the GPS and altimeters after the vehicle is on the launch pad. Either side of the coupler has two shear pins connecting the recovery section on one side and the booster section on the other side. The Perfectflite StratoLoggerCF was chosen as the main altimeter(s) because of the stock that the team already had for it, without any beneficial improvements over the other altimeter(s). Similarly, the team already had a Featherweight GPS Tracker. The other GPS trackers provided no significant improvement over the Featherweight GPS tracker, so we will be using it.

Booster Section & Fins |9.951 lbs|
The booster section will continue to use a fiberglass body tube with a diameter of 5 inches which will be 40 inches long. This provides ample room for the motor/motor housing, and recovery system. Additionally, trapezoidal fiberglass fins with a root length of 14 inches, a 4.5-inch span, and a width of 3/16 inches will be used. This fin shape was chosen because of its better aerodynamics and lower mass compared to the other fin shapes. Additionally, it is higher up on the booster section, not sitting flush with the floor, causing unnecessary damage.

Fiberglass was chosen as the material because of the high durability, strength, fire resistance, and water resistance that was provided. This is extremely beneficial in close proximity to the high-powered motor and any potential exhaust. The root length of 14 inches and a 4.5-inch span were chosen to optimize vehicle stability and reduce drag, allowing for a stable, safe flight, to a higher launch altitude. The fin thickness of 3/16 of an inch was chosen due to it providing optimal strength and reduced drag. Additionally, the team added a slot to a portion of the fin. This slot was originally for aesthetics but has two important applications that we ended up using it for. This slot can be increased or decreased, affecting the height of the center of gravity and the location of the center of pressure.

Executive Summary |27.083 lbs|

The CFHS Rocket Club will be creating a 104-inch (8ft, 8in.) tall vehicle for the NASA SLI Competition. It will house a payload with a deployment mechanism and a UAV. The vehicle will be 5.15 inches outside diameter (referred to as 5-inch). It will use trapezoidal fins and a dual deployment system split into 3 sections, the nosecone/payload section, electronics bay, and booster section. The vehicle with the payload will weigh 27.083 lbs and reach a target altitude of 4500 feet. It will use two Perfectflite StratoLoggerCF altimeters alongside a Featherweight GPS Tracker. Fiberglass will be the main material of the vehicle because of its high strength and durability for an affordable price for the team compared to other options including carbon fiber. The specific dimensions of each section can be found in each section above. These dimensions can also be found in figure 3.1.6 and figure 3.1.9.

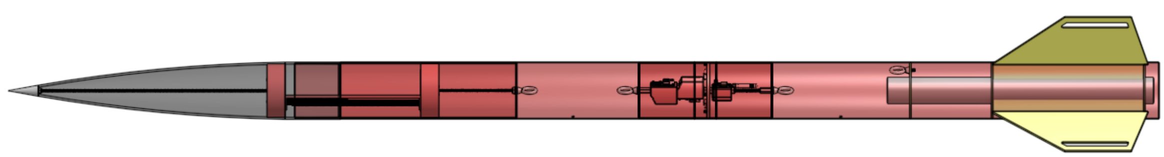


Figure 3.1.4 - Full Vehicle Assembly, Translucent

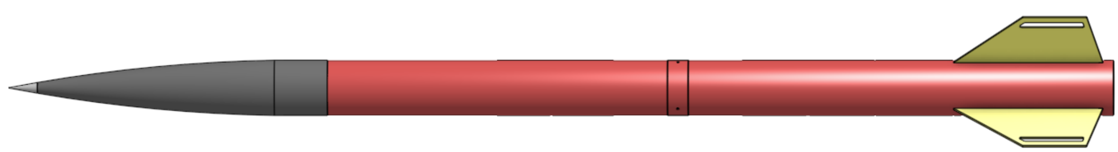


Figure 3.1.5 - Full Vehicle Assembly, Non-Translucent

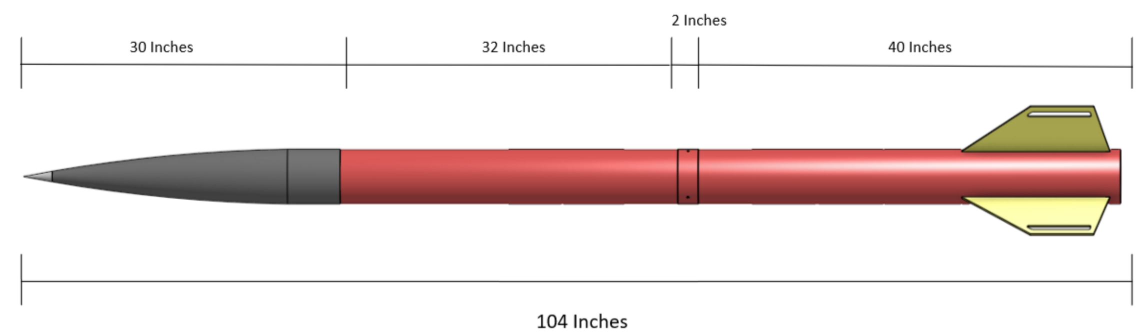


Figure 3.1.6 - Dimensioned Full Vehicle Assembly, Non-Translucent

Figure 3.1.7 - Exploded Vehicle Assembly, Translucent

Figure 3.1.8 - Exploded Vehicle Assembly, Non-Translucent

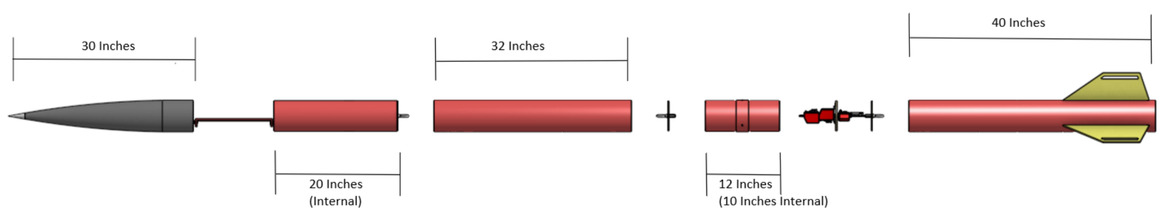


Figure 3.1.9 - Dimensioned Exploded Vehicle Assembly, Non-Translucent

- A Review of different motor alternatives and some data on each alternative.

Motor Alternatives
Sizes ● K1440 ○ The K1440 motor gave the vehicle a projected altitude of 4678 feet which is well above our goal altitude. If any mass changes impact the altitude of the vehicle, this will work well. ● K660 ○ The K660 motor gave the vehicle a projected altitude of 4682 feet which is well

above our goal and slightly higher than the K1440. It has a burn time of 3.7 seconds as opposed to the K1440’s 1.7-second burn time which is crucial for stability exiting the rail. ● K820 ○ The K820 gave the vehicle a projected altitude of 4572 feet which is much closer to the altitude goal which poses some concerns if there are mass changes. It also has a 2.9-second burn time which causes less velocity immediately upon rail exit.

3.2 Recovery Subsystem

- Design reviewed at a component level, going through each component’s alternative designs, and evaluating the pros and cons of each alternative.

Drogue Parachute
Sizes ● 15” Fruity Chutes Drogue Chute ○ A drogue chute of 15” would allow for a quicker initial descent and/or be used if the overall mass of the vehicle is lighter than expected. Of the drogue chute options, this is the cheapest. It is also made of ripstop nylon, a very durable material. In contrast, if the vehicle's mass is too large, the descent could be too quick. ● 18” Fruity Chutes Drogue Chute ○ A drogue chute of 18” would allow for a compromise between the quicker descent rate of 15” and a slower descent rate of 24” and should be used if the vehicle's mass is not deemed as heavy overall. It is also made of ripstop nylon, a very durable material. This chute’s price is also a compromise between 15” and 24”. In contrast, if the vehicle's mass is too large or little, this would result in a descent rate that is too quick or slow, leading to drift that is too far, or deployment of the main chute at a too quick descent velocity. ● 24” Fruity Chute Drogue Chute ○ A drogue chute of 24” would provide the slowest descent rate and be used if the vehicle's mass is deemed heavy. It is also made of ripstop nylon, a very durable material. In contrast, this chute’s price is the most expensive of the three options and could provide a too-slow descent rate, leading to a large amount of drift.

Main Parachute

Sizes

- 60” Fruity Chutes Iris Ultra Parachute
    - The main parachute of 60” would provide a quicker descent rate than that of 72” (given the mass of the vehicle is the same) reducing the amount of drift. It is also made of ripstop nylon, a very durable material, and is the cheaper option of the two parachutes. Although, if the vehicle is heavy in mass, the descent rate could be too quick, leading to a too-high kinetic energy impact amount.
- 72” Fruity Chutes Iris Ultra Parachute
    - The main parachute of 72” would provide a slower descent rate than that of 60” (given the mass of the vehicle is the same), allowing for more drift. It is also made of ripstop nylon, a very durable material. If the vehicle’s mass is too light, it will result in a descent rate that is too slow, leading to excessive drift.

Shock Cord

Type

- ⅜” Kevlar Cord
    - ⅜" kevlar is cheaper than 1" Nylon cord, and also has a very high breaking strength. Kevlar is also flame resistant. However, kevlar can cause damage to the vehicle on ejection due to the kevlar's hardness.
- ½” or 1” Tubular Nylon Cord
    - Nylon cord is much softer which in turn means a much lower chance of vehicle damage compared to kevlar. The ½" size of the cord also has a lower cost per foot of it. On the other side, different manufacturers make different products which in turn could mean ground testing to find the effectiveness, size, and viability of the different nylon cords. Nylon is also flammable.

Protective Wadding

Type

- Disposable Recovery Wadding
    - It is cheaper per pack of wadding and can have a variable amount used for it. It needs new wadding each time with the wadding needing to be repacked on each use.
- 18” Parachute Protector
    - It is reusable and it stays connected to the vehicle, with the ability to be cleaned due to soot buildup. The parachute protector, however, cannot have its size changed, and it costs more.

Ejection Charges
Type ● Black Powder Ejection Charges ○ Black Powder would provide a simpler and cheaper deployment option, but have a greater environmental impact and be more dangerous to work around. It would also cause residue inside the vehicle. ● RAPTOR CO_2 Ejection System ○ The RAPTOR CO_2 Ejection System would provide a more precise ejection charge and be cleaner for the environment. In contrast, it is a more complex system and requires more equipment to implement.

- Research presented on why each alternative should or should not be chosen.

Drogue Parachute
Sizes ● 15” Fruity Chutes Drogue Chute ○ This chute should be chosen because it allows for a quicker initial descent. ○ This chute should not be chosen because it could drop the vehicle to fast if the vehicle is too heavy. ● 18” Fruity Chutes Drogue Chute ○ This chute should be chosen as the drogue chute because it has an optimal descent rate when paired with the 72” main chute on the vehicle. ○ This chute should not be chosen if the vehicle’s mass is too large, resulting in too fast of descent and too high of kinetic energy. ● 24” Fruity Chutes Drogue Chute ○ This chute should be chosen because it can provide the slowest descent rate if the vehicle’s mass is too heavy. ○ This chute should not be chosen as the 24” diameter chute with the 72” diameter main chute would cause a slower descent rate than desired in the vehicle.

Main Parachute
Sizes ● 60” Fruity Chutes Iris Ultra Parachute ○ This chute should be chosen because it could provide less drift and land faster if the vehicle is too heavy. ○ This chute should not be chosen as the main chute as it would have a quicker descent rate that could result in uncontrolled descent and complications during the descent of the vehicle. ● 72” Fruity Chutes Iris Ultra Parachute ○ This chute should be chosen as the main chute as it provides a slower and more

controlled descent rate with more drift.
    - This chute should not be chosen if the vehicle is too lightweight. It will result in more drift and going past the landing time limit.

Shock Cord

Type

- ⅜” Tubular Kevlar Cord
    - The Kevlar cord should be used because of its superior strength and flame-resistance.
    - The Kevlar cord has drawbacks with the damage it can cause to the vehicle on ejection.
- ½” or 1” Tubular Nylon Cord
    - The Nylon cord should be used because of the lower cost and lower likelihood to cause damage.
    - Nylon cord shouldn’t be used because it is flammable and has a lot more variability in manufacture, requiring a lot of testing.

Protective Wadding

Type

- Disposable Recovery Wadding
    - Disposable Recovery Wadding should be used because of the lower cost and variable amount that can be customized for each launch.
    - The Disposable Wadding should not be used because of the high time consumption when the team needs to repack the wadding after every launch.
- 18” Nomex Parachute Protector
    - The Nomex Parachute Protector should be used because of its reusability and ability to be cleaned.
    - This Parachute Protector shouldn’t be used because of the non-customizability in size and the extra overhead costs.

Ejection Charges

Type

- Black Powder Ejection Charges
    - Black Powder Ejection Charges should be used due to their simplicity and the fact that less can go wrong during recovery, ensuring successful parachute deployment.
    - Black Powder Ejection Charges shouldn’t be used because of their environmental impact and higher risk to work around.
- RAPTOR CO_2 Ejection System
    - The RAPTOR CO_2 Ejection System should be used because of the more precise

ejection and cleanliness to the environment. ○ The RAPTOR CO_2 Ejection System should not be used due to the complexity as it would require more payload design to house it, and the fact that the complexity adds opportunity for something to go wrong, adding risk that the recovery stage does not go as expected.

- Preliminary analysis on parachute sizing, determining the sizes required for a safe descent based on estimated masses.

Main Parachute
Nosecone, Payload, and Recovery Section |10.322 lbs| 1 lb = 0.453592 kg 1 Joule = 1.35582 ft-lb 1 Foot = 0.3048 m 1 m/s = 3.28084 ft/s $10.322\ lb \bullet 0.45392 = 4.6820\ kg$ 75 ft-lb • $1.35582 = 101.6865$ joules KE = $\frac{1}{2}mv^2$ 101.6865 j = $\frac{1}{2}(4.6820)v^2$ $43.4372 = v^2$ $\sqrt{43.4372} = v$ $6.5907\ m/s = v$ $6.5907 \bullet 3.28084 = 21.6230$ ft/s
The **nose cone, payload, and recovery section** shall not descend at a rate faster than **21.6230 ft/s** in order to stay at or under the 75 ft-lbs KE limit.
Electronics Bay |3.81 lbs| 1 lb = 0.453592 kg 1 Joule = 1.35582 ft-lb 1 Foot = 0.3048 m 1 m/s = 3.28084 ft/s $3.81\ lb \bullet 0.45392 = 1.7294\ kg$ 75 ft-lb • $1.35582 = 101.6865$ joules KE = $\frac{1}{2}mv^2$ 101.6865 j = $\frac{1}{2}(1.7294)v^2$ $117.5974 = v^2$ $\sqrt{117.5974} = v$

$10.8442\ m/s = v$ $10.8442 \bullet 3.28084 = 35.5781$ ft/s
The **electronics bay section** shall not descend at a rate faster than **35.5781 ft/s** in order to stay at or under the 75 ft-lbs KE limit.
Booster |9.951 lbs| 1 lb = 0.453592 kg 1 Joule = 1.35582 ft-lb 1 Foot = 0.3048 m 1 m/s = 3.28084 ft/s $9.951\ lb \bullet 0.45392 = 4.5170\ kg$ 75 ft-lb • $1.35582 = 101.6865$ joules KE = $\frac{1}{2}mv^2$ 101.6865 j = $\frac{1}{2}(4.5170)v^2$ $45.0239 = v^2$ $\sqrt{45.0239} = v$ $6.7100\ m/s = v$ $6.7100 \bullet 3.28084 = 22.0144$ ft/s
The **booster section** shall not descend at a rate faster than **22.0144 ft/s** in order to stay at or under the 75 ft-lbs KE limit.

Based on the calculations above, the **main parachute** providing a decent rate of **21.6230 ft/s** or less is required to not exceed the maximum KE energy upon impact limit. Since all the vehicle sections are tethered together, the **lowest decent rate from the calculation will be used.** The following calculations were used to determine the descent rate of the vehicle on the main parachute options:

60” Fruity Chutes Iris Ultra Parachute	72” Fruity Chutes Iris Ultra Parachute
F_g = Force of gravity (weight, in N) ρ = Density of air C_d = Parachute’s Coefficient of Drag A = Area of parachute Total Mass: 27.083 lb or 12.2846 kg 1 m/s = 3.28084 ft/s	F_g = Force of gravity (weight, in N) ρ = Density of air C_d = Parachute’s Coefficient of Drag A = Area of parachute Total Mass: 24.083 lb or 10.9239kg 1 m/s = 3.28084 ft/s

$v = \sqrt{\frac{2F_g}{\rho \bullet C_d \bullet A}}$ $F_g = 10.9239 \bullet 9.8$ $F_g = 107.05422\ N$ $v = \sqrt{\frac{2(107.05422)}{1.2 \bullet 2.2 \bullet 1.8241}}$ $v = 6.6679\ m/s$ $5.4764 \bullet 3.28084 = 21.8764\ ft/s$ 21.8764 ft/s > 21.6230 ft/s	$v = \sqrt{\frac{2F_g}{\rho \bullet C_d \bullet A}}$ $F_g = 10.9239 \bullet 9.8$ $F_g = 107.05422\ N$ $v = \sqrt{\frac{2(107.05422)}{1.2 \bullet 2.2 \bullet 2.6268}}$ $v = 5.556501378\ m/s$ $5.556501378 \bullet 3.28084 = 18.2300\ ft/s$ 18.2300 ft/s < 21.6230 ft/s

Only a 72” or larger parachute is satisfactory for a safe descent according to the KE requirement.

- Drawings/sketches, wiring diagrams, and electrical schematics.

Electrical schematics are not included as all recovery electronics are available commercially. Refer to Figures 3.1.1 and 3.1.2 for recovery system sketches.

- Leading components amongst the alternatives and explanation for their lead.

Drogue Parachute
For the drogue parachute, an 18” Fruity Chutes Drogue Chute will be used. This was chosen due to its descent rate and time when paired with a 72” main parachute.

Main Parachute
A 72” Fruity Chutes Iris Ultra Parachute will be used for the main parachute. This option was chosen as it provides a safe kinetic energy for all vehicle sections within the requirements. The alternative 60” parachute does not provide a low enough kinetic energy to be considered safe.

Shock Cord
For the shock cord, ⅜ inch tubular Kevlar was chosen. Its high strength and non-flammable properties offer the most durable and reliable shock cord option for recovery.

Protective Wadding
A combination of disposable recovery wadding and an 18-inch Nomex parachute protector will be used. The 18-inch Nomex parachute protector is reusable, durable, and has proven to be reliable in the past. Additionally, with protective wadding in as well, any space missed by the chute protector will be covered, providing more redundancy in protecting our parachutes.

Ejection Charges
For the ejection charges, black powder will be used. Due to their reliability and ease of use/lack of additional components, black powder provides the simplest and most reliable recovery ejection charge.

- Proof that redundancy exists within the system.

Black Powder (Material Energetics)
At each separation point, drogue, and main parachute deployment, there are two black powder charges. The backup (secondary) charges are controlled by a separate altimeter and are larger. The secondary charges are larger to clear any obstruction and effectively separate in case of any failure where the smaller black powder size was not effective. This adds redundancy to the system in case of failure of the primary charges.

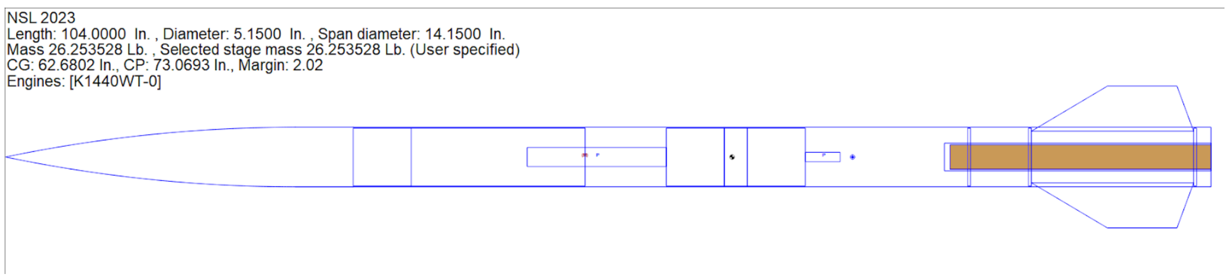
Altimeters
The vehicle design includes two separate altimeters. One of the altimeters is the "main," while the other is the "backup." The "main" altimeter will fire its black powder charges at apogee & 600 feet above ground level. The "backup" altimeter will fire its black powder charges at apogee + 1 second & 600 feet above ground level + 1 second, or ~500 feet. This redundancy ensures that even with the failure of an altimeter, the vehicle will still safely be recovered.

3.3 Mission Performance Prediction

- The team's official competition launch target altitude (ft.).

4500 Feet

- Flight profile simulations including altitude, velocity, and acceleration versus time predictions. Additionally uses simulated vehicle data, component weights, and simulated motor thrust curves. The vehicle is verified to be robust enough to withstand the expected loads.



Simulation	Results	Engines loaded	Optimal delay	Max. altitude Feet	Max. velocity Miles / Hour	Max. acceleration Gees	ocity at deployme Miles / Hour	Velocity at launch guide departure Miles / Hour	WeatherCocking
0		[K1440WT-P]	15.11	4678.25	417.27	17.57	9.28	58.57	Safe

Figure 3.3.1

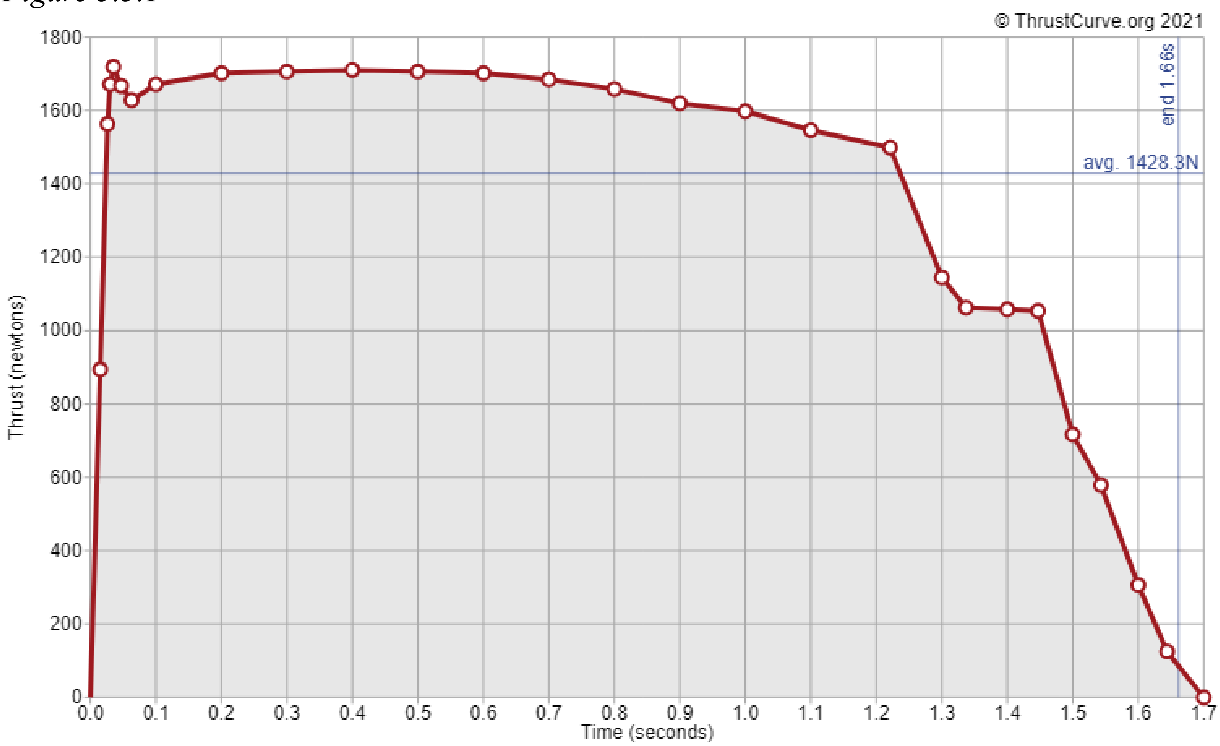


Figure 3.3.2 - Thrust Curve of Cesaroni K-1440

- Stability margin and simulated Center of Pressure (CP)/Center of Gravity (CG) relationships and locations.

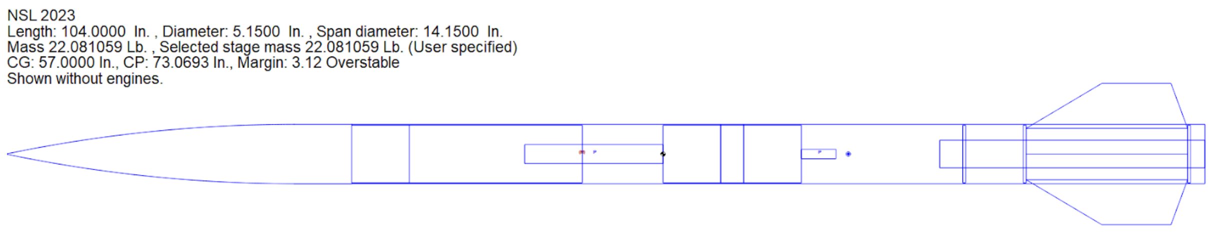


Figure 3.3.3. - Without Motor

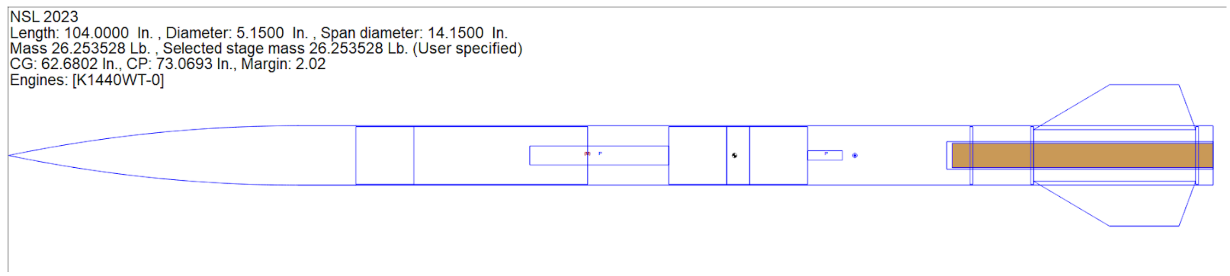


Figure 3.3.4 - With Motor

- Kinetic energy at landing for each independent and tethered section of the launch vehicle.

Nosecone, Payload, and Recovery Section - 10.322 lb or 4.6820 kg

1 Joule = 1.35582 ft-lb
1 Foot = 0.3048 m
1 m/s = 3.28084 ft/s

$$KE = \frac{1}{2}mv^2$$

$v = 5.5565\ m/s$
$m = 4.6820\ kg$

$KE = \frac{1}{2} \bullet 4.6820 \bullet 5.5565^2$
$KE = 72.27765456\ J$
$72.27765456\ J \bullet \frac{1\ ft-lb}{1.35582\ J} = 53.3092$ ft-lbs

The kinetic energy of the nose cone, payload, and recovery section is 53.3092 ft-lbs, which is less than the 75 ft-lb maximum, meeting the kinetic energy requirements.

Electronics Bay - 3.81 lb or 1.7294 kg

1 Joule = 1.35582 ft-lb
1 Foot = 0.3048 m

1 m/s = 3.28084 ft/s $KE = \frac{1}{2}mv^2$ $v = 5.5565\ m/s$ $m = 1.7294\ kg$ $KE = \frac{1}{2} \bullet 1.7294 \bullet 5.5565^2$ $KE = 26.69734639\ J$ $26.69734639\ J \bullet \frac{1\ ft-lb}{1.35582\ J} = 19.6909$ ft-lbs The kinetic energy of the Electronics Bay section is 19.6909 ft-lbs, which is less than the 75 ft-lb limit, meeting the kinetic energy requirements.
Booster - 9.951 lb or 4.5170 kg 1 Joule = 1.35582 ft-lb 1 Foot = 0.3048 m 1 m/s = 3.28084 ft/s $KE = \frac{1}{2}mv^2$ $v = 5.5565\ m/s$ $m = 4.5170\ kg$ $KE = \frac{1}{2} \bullet 4.5170 \bullet 5.5565^2$ $KE = 69.73049245\ J$ $69.73049245\ J \bullet \frac{1\ ft-lb}{1.35582\ J} = 51.4305$ ft-lbs The kinetic energy of the Booster section is 51.4305 ft-lbs, which is less than the 75 ft-lb limit, meeting the kinetic energy requirements.

- Expected descent time for the rocket and any section that descends untethered from the rest of the vehicle.

Drogue Descent Rate F_g = Force of gravity (weight, in N) ρ = Density of air C_d = Parachute's Coefficient of Drag A = Area of parachute Total Mass: 27.083 lb or 12.2846 kg 1 m/s = 3.28084 ft/s

$v = \sqrt{\frac{2F_g}{\rho \bullet C_d \bullet A}}$
$F_g = 10.9239 \bullet 9.8$
$F_g = 107.05422\ N$
$v = \sqrt{\frac{2(107.05422)}{1.2 \bullet 1.5 \bullet 0.1642}}$
$v = 27.06372854\ m/s$
$27.06372854 \bullet 3.28084 = 88.79176314\ ft/s$

Descent Time

Drogue:
t = time (seconds)
v = descent velocity (feet per second)
d = descent distance/altitude (feet)

$t = \frac{d}{v}$

$d = 4500\ ft - 600\ ft$

$v = 88.79176314\ ft/s$

$t = \frac{3900}{88.79176314}$
$t = 43.9229931$ seconds

Main:
t = time (seconds)
v = descent velocity (feet per second)
d = descent distance/altitude (feet)

$t = \frac{d}{v}$

$d = 600\ ft$

$v = 18.2300\ ft/s$

$t = \frac{600}{18.2300}$
$t = 32.91278113$ seconds

Total Descent Time:
$t = 32.91278113 + 43.9229931$
$t = 76.8358$ sec

The total descent time is 76.8 seconds, which is less than the 90 second maximum.

- Calculated drift for each independent section of the launch vehicle from the launch pad for five different cases: no wind, 5-mph wind, 10-mph wind, 15-mph wind, and 20-mph wind. Drift calculations performed with the assumption that apogee is reached directly above the launch pad.

No wind: 1 mph = 1.46667 ft/s $0\ mph\ \bullet 1.46667\ ft/s = 0\ ft/s$ $0\ ft/s \bullet\ 76.8358\ seconds\ =\ 0$ ft drift
5-mph Wind 1 mph = 1.46667 ft/s $5\ mph\ \bullet 1.46667\ ft/s = 7.3334\ ft/s$ $7.3334\ ft/s \bullet\ 76.8358\ seconds\ = 563.4675$ ft drift
10-mph Wind 1 mph = 1.46667 ft/s $10\ mph\ \bullet 1.46667\ ft/s = 14.6667\ ft/s$ $14.6667\ ft/s \bullet\ 76.8358\ seconds\ = 1126.9273$ ft drift
15-mph Wind 1 mph = 1.46667 ft/s $15\ mph\ \bullet 1.46667\ ft/s = 22.0001\ ft/s$ $22.0001\ ft/s \bullet\ 76.8358\ =\ 1690.3947$ ft drift
20-mph Wind 1 mph = 1.46667 ft/s $20\ mph\ \bullet 1.46667\ ft/s = 29.3334\ ft/s$ $29.3334\ ft/s \bullet\ 76.8358\ seconds\ =\ 2253.8545$ ft drift

Drift calculations estimate that all drift scenarios given will result in the recovery area being less than the required 2,500 ft recovery area radius.

- Data from a different calculation method to verify that original results are accurate.

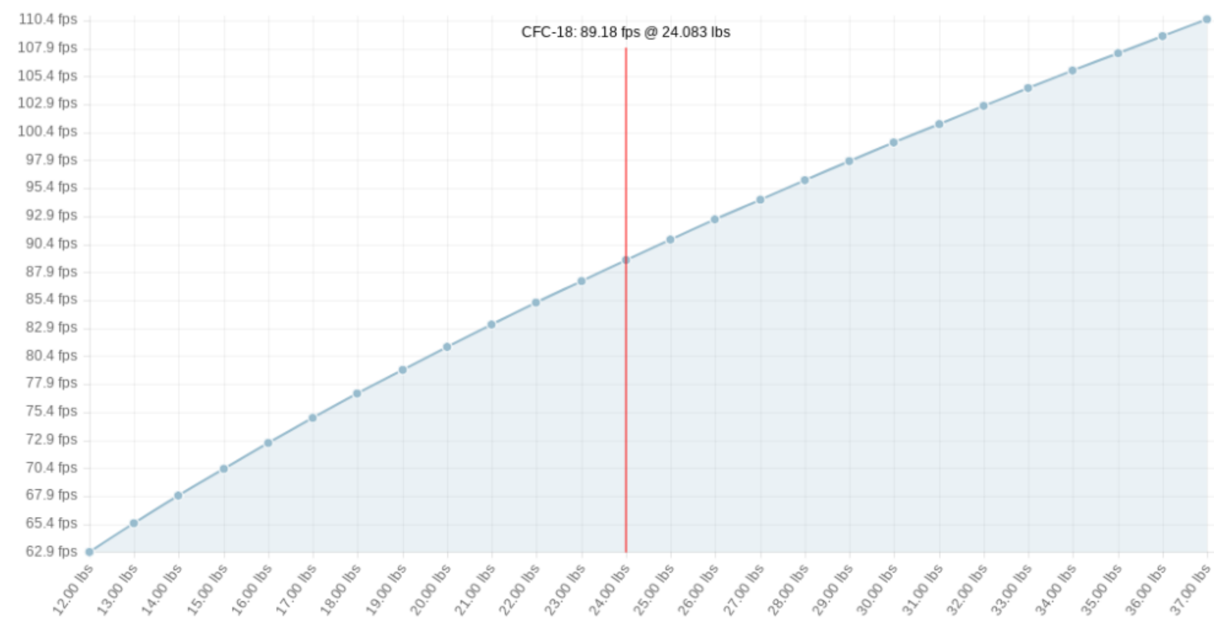


Figure 3.3.5 - Drogue Parachute Descent Velocity from fruitychutes.com

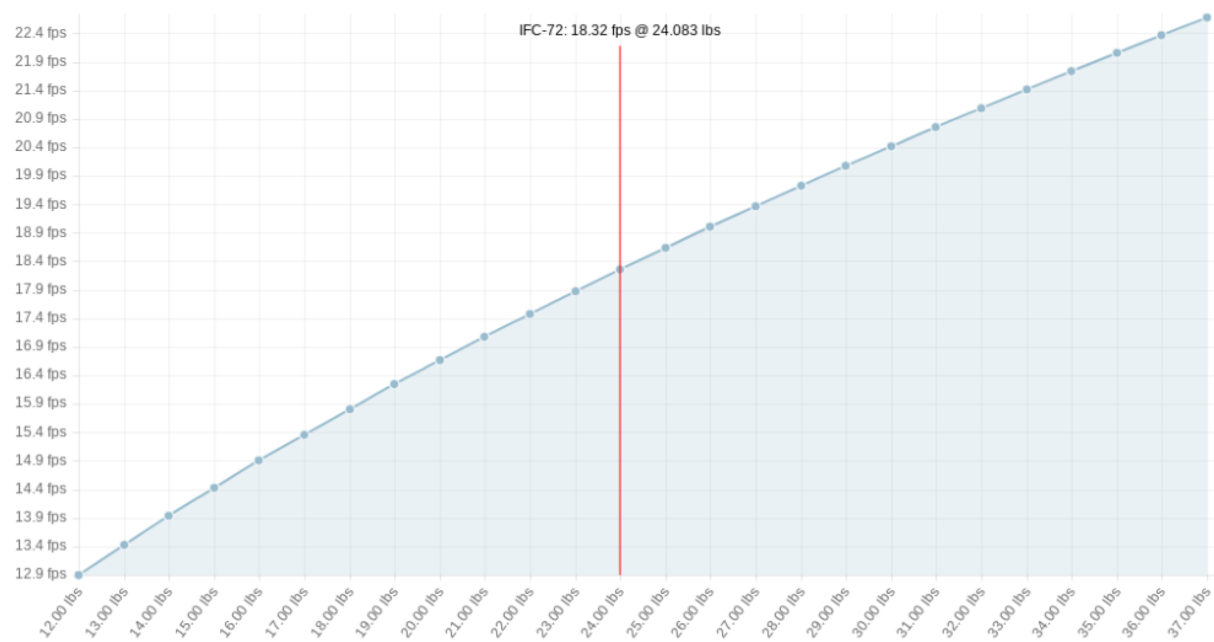


Figure 3.3.6 - Main Parachute Descent Velocity from fruitychutes.com

Mass	10.322	lb
Velocity	18.32	ft/s
Kinetic energy	53.8368	ft-lbs

Figure 3.3.7 - Kinetic Energy Calculation (Nosecone, Payload, and Recovery) from omnicalculator.com

Mass	3.81	lb
Velocity	18.32	ft/s
Kinetic energy	19.87194	ft-lbs

Figure 3.3.8 - Kinetic Energy Calculation (Electronics Bay) from omnicalculator.com

Mass	9.951	lb
Velocity	18.32	ft/s
Kinetic energy	51.9017	ft-lbs

Figure 3.3.9 - Kinetic Energy Calculation (Booster) from omnicalculator.com

- Discussion of differences between the different calculations.

Values for descent rates are within 0.5 ft/sec between the two calculation methods. The differences are likely due to intermediate rounding errors. The difference between these values is small enough to be considered insignificant.

Values for kinetic energy are within 0.6 foot pounds between the two calculation methods. These differences are likely due to errors caused by intermediate rounding. These differences are minor enough to be considered insignificant, especially as all sections are more than twenty foot pounds under the kinetic energy limit.

- Multiple simulations verify that results are precise.

Recovery system data as seen on Rocksim with K1440:

- Time from launch to landing with 15.0 mph winds: 95.09 seconds
- Time from launch to landing in ideal conditions: 95.35 seconds
- Time from launch to landing with 30 mph winds: 94.41 seconds

Corrected for ascent time, the descent time will be less than the maximum of 90 seconds.

IV) Payload Criteria

4.1 Selection, Design, and Rationale of Payload

- Objective of the payload and what experiment it will perform as well as the results that will qualify it as a successful experiment.

The objective of the payload is to autonomously deploy, fly, and navigate an Unmanned Aerial Vehicle (UAV). This will be used to test methods of securing and deploying a payload within a launch vehicle, as well as control and data retrieval of a UAV system.
After the vehicle has landed, the UAV will be deployed only after confirmation provided by the RSO has been given that it is safe to begin and the vehicle is confirmed to be in a safe location for deployment. The UAV will travel to a team member who has an override controller with a GPS on it. It will then guide the team member back to the vehicle. This design is intended to be implemented on other launches outside of NASA SLI for larger-scale vehicles to guide individuals back to their vehicle.
If successful, the UAV will safely attain sustained flight and navigate the team member back to the vehicle's landing point.

- Design at a system level, going through each system's alternative designs and evaluating the pros and cons of each alternative.

Deployment Mechanism
Leveling ● Automatic (Electronic) ○ An electronically controlled system would level the UAV during the deployment process. The system would result in additional mass and a rotational limit. An additional set of batteries and control systems that are activated only after landing would be necessary for this system to work effectively. This creates an issue if the vehicle were to continue rolling or rotating after landing. ● Manual (Human-Input) ○ The manual leveling option is the simplest method available, as no mechanical systems are required. Instead, a team member would physically rotate the payload section into the correct orientation for UAV deployment. ● Gravitational ○ A gravitationally leveled system is simple, yet automatic. It uses bearings and utilizes a specific center of gravity slightly off of the actual center, resulting in a payload that stays level regardless of external or rotational forces applied to it. The system's incremental cost is minimal with a very small increase in mass

due to the bearings.

Deployment/Separation

- Threaded Rod
  - A threaded rod provides a high mechanical advantage such that very little force is required to move or secure the payload sled. This allows for a smaller motor to be used to drive the deployment system.
  - Threaded rods can be used in both directions to create a telescoping effect, doubling the amount of usable space for deployment of the UAV.
- Belt Drive with Linear Rails
  - A belt drive with linear rails is the heaviest method. It requires the attachment of the sled that holds the UAV to the bulk plate. This puts many extra forces during the separation events of the vehicle into the UAV and its sled. This method is also the most costly and complicated to implement the method as linear rails need to maintain perfect vertical/horizontal alignment.
- Manual (Human-Input)
  - This method is simplest, requiring the unlocking of and separation of the vehicle by hand. The UAV would be able to take off, clear of the vehicle, and fully prepared. This is also the lightest method requiring only locks for the UAV during flight and nothing else.

Unmanned Aerial Vehicle (UAV)

Styles

- Quadcopter
  - The Quadcopter UAV design utilizes four folding wings with attached motors and propellers providing upwards thrust. This allows the UAV to hover, and its orientation can be controlled by varying the output from each motor. This quadcopter is non-standard in that it uses passive folding arms. The arms curl around the sides of the quadcopter to stay in the dimensions of the vehicle.
- Tricopter
  - The Tricopter design consists of one fixed wing and one folding tail. It also has a propeller to pull it through the air more efficiently. It uses a long wing to give it extra lift allowing it to glide and use less battery power.
- Gull-Wing
  - The Gull-Wing design is unique and has attributes that have been adapted to other designs. It uses a passive vertical folding mechanism. No actuation is required to unfold the UAV, leaving less room for failure points to occur during deployment. The aerodynamics of the UAV behave like a tri-copter even with the unique design.

In addition to the three above designs, other options were considered during brainstorming, and others were determined to be unsuitable for further development due to concerns of safety, difficulty, or feasibility. These ideas included a tri-copter idea with multiple folding wings and no forward propeller as well as a design inspired by real-world vertical takeoff and landing aircraft which rotate their propulsion systems to transition from vertical to horizontal flight.

Electronics
Shared Electronics (Same on both components) ● Main Computer ○ Teensy 4.0 ■ The Teensy 4.0 offers both a 600MHz processor and a small form factor compared to the Teensy 4.1 and Arduino Nano. It costs slightly more than the Arduino, while still retaining a good price for its value. ○ Teensy 4.1 ■ The Teensy 4.1 is the most expensive option, especially compared to the 4.0. It has a 2048K flash memory, which is 4 times larger than that of the Teensy 4.0 - one of the only upgrades from the 4.0 as the processing speed is the same. ○ Arduino Nano ■ The Arduino Nano is the least expensive option, but only runs at 20MHz - much less than either of the Teensy's. It also only offers 32KB of flash memory. ● GPS ○ "Ultimate GPS" 1616S ■ The 1616S is a solid GPS that offers 66 channels and only 20 mA current draw. ○ "Ultimate GPS" 1616D ■ The 1616D is the newer version of the 1616S, but still comes at the same price. It provides 99 channels (including GLONASS) and only a 10mA increase in the current draw. ○ "Ultimate GPS" 1616D, SMD Version ■ This is identical to the "Ultimate GPS" 1616D above, but in a smaller, cheaper, and lighter form factor. This makes it favorable over the above option. ● Radio ○ Adafruit RFM95W LoRa Radio Transceiver Breakout - 868 or 915 MHz - RadioFruit ■ This radio operates on the license-free 915 MHz band, and supports a 2km range with simple antennas, or further if thought is put into the antenna design. The board is a small breakout board that would interface with the microcontroller. ○ Adafruit RFM96W LoRa Radio Transceiver Breakout - 433 MHz - RadioFruit ■ This board is exactly the same as the above, but operates at the license-free 433 MHz band. ○ Adafruit Feather M0 with RFM95 LoRa Radio - 900 MHz - RadioFruit ■ This Radio module uses a separate microcontroller to communicate on the 915 MHz band. It is similar to the first option but would require communication between the two microcontrollers.

- Battery
    - 1S 520 mAh
        - This battery has the most limited capacity and can only power 1S motors. This is the least expensive option and has the least mass and volume. This battery is sold in packs of four.
    - 2S 1500 mAh
        - The 2S 1500 mAh battery is the smallest battery capable of powering 2S motors. This has the most limited capacity of the 2S batteries and is the least expensive and massive of these. This battery is sold in packs of two.
    - 2S 5200 mAh
        - The 2S 5200 mAh battery is a larger 2S battery with a much greater capacity than the 1500 mAh. This is the second most expensive option and is the second greatest in size and mass. This battery is sold in packs of two.
    - 2S 6200 mAh
        - The 2S 6200 mAh battery is the largest battery option available. This battery is capable of powering 2S motors and has the highest capacity. This is the greatest in size and mass and the most expensive option. This battery is sold in packs of two.

Deployment Mechanism

- Motors
    - NEMA 17 Stepper Motor
        - The NEMA 17 Stepper motor is comparable in cost to the 12V DC motor but is less than half the mass at only 6.7 ounces. It runs at the same speeds, however, with a max speed of 150 rpm. It's also a 12 V motor with 59 N/cm holding torque.
    - 5V DC Motor
        - These 5V DC Motors come in a pack of 6, making it the cheapest option per motor. They're supposed to run up to speeds of 16000 rpm and weigh only 3.98 ounces - making it the quickest and lightest option as well. However, as reflected in the low cost and light build, they may be less durable and have less torque than other motor options.
    - 12V DC Motor
        - The 12V DC Motor is the most expensive and heaviest option, weighing in at 14.08 ounces. It's significantly slower than the 5V DC motor, with a max speed of 150 rpm. However, it likely has much greater force, with a rated torque of 147.1 N/cm.
- Motor Controllers
    - A4988 Stepper Motor Driver Carrier
        - The A4988 motor controller has median pricing and an 8 to 36V operating range. It also provides up to 2 A current with sufficient cooling and is smaller than the largest option.
    - TB6612FNG Dual Motor Driver Carrier
        - The TB6612FNG motor controller is the cheapest option and has a 4.5

to 13.5V range. It's also identical in size to the TB6612FNG motor controller and provides a 1-3 A current.

- Telesky MOS Module Controller
  - The Telesky motor controller is the most expensive option with a 5 - 36V operating range. It also provides a 15 A current and is larger than both of the other options.

UAV

- Distance Measuring Equipment (DME)
  - Gyro
    - Adafruit LSM6DSO32
      - The Adafruit LSM6DSO32 has 6 degrees of freedom, acceleration measuring up to 32G's, and rotation up to 2000 degrees per second. It can interface with I2C and SPI with 3-5V. It is the cheapest option.
    - Adafruit L3GD20H Triple-Axis Breakout Board
      - The L3GD20H gyro handles up to 2000 degrees per second sensitivity, a 3.3 V power draw, and I2C or SPI interface. This option is also the same price as the LSM6DSO32 as the cheapest.
    - Adafruit BNO055
      - The BNO055 features a wide variety of measurement capabilities, including Absolute Orientation, Angular Velocity Vector Measurement, and Acceleration Vector Measurement. It is compatible with I2C connections and runs on 3-5 V. This option is the most expensive, despite having notably fewer features. The biggest difference is this sensor's higher G force rating.
    - Adafruit BNO085/080
      - The BNO085 contains all the measurements of the BNO055, as well as a variety of sensors to maintain accurate and unaltered data. This option is cheaper than its predecessor but more expensive than the other possible solutions.
  - (Lidar/Ultrasonic) Range Finder
    - Garmin LIDAR-Lite V4
      - The Garmin V4 is the most expensive option as it's a true lidar sensor. Its price point is almost four times as much as the Adafruit sensor, but it also comes with 10 meters of range and increased reliability.
    - Adafruit VL53L1X
      - The Adafruit is not a true lidar or ultrasonic sensor, but rather a "time of flight sensor" - as reflected in its low price. This sensor only has a 4-meter range, but it's the cheapest option by a lot.
    - Maxbotix Ultrasonic Rangefinder EZ4
      - The Maxbotix Ultrasonic EZ4 is an ultrasonic sensor with a lower price point than the lidar option. It has a range of up to 5

meters and still has the reliability and precision of a true lidar sensor.

- Altimeter
    - BMP 388
        - The BMP 388 is a pretty standard altimeter and the older version of the BMP 390 is reflected in its slightly cheaper price. It has a relative accuracy of 8 pascals (± 0.5 meters of altitude).
    - BMP 390
        - The BMP 390 is the newer version of the BMP 388. It's slightly more expensive, but also offers more precision than the BMP 388. It has a relative accuracy of 3 pascals (± 0.25 meters of altitude).

- Motors
    - iFlight XING Nano 0803 17000 kV
        - The iFlight XING Nano is a 1S motor with a 17000 kV motor, and is also the most expensive.
    - HAPPYMODEL SE0802-19000kv
        - This 1S-2S Motor is 19000 kV output and is the cheapest motor on the list.
    - HAPPYMODEL SE0802 1-2S Brushless Motor
        - The 1S-2S Motor has a 22000 kV, or an optional 25000 kV, motor, and is cheaper than the iFlight option, but more expensive than the SE0802-19000kV.
- Motor Controllers
    - AGFRC Mini 4A ESC Brushless DSHOT600
        - This is the lightest and most compact motor controller option, however, it only allows for use with 1S-powered motors. In addition, this option is slightly more expensive than the 2S controller and significantly less expensive than the 2-6S controller.
    - XSD7A Micro Speed Control
        - The 2S Motor Controller allows for 1S or 2S motors to be used and is slightly more massive than the 1S controller, and significantly less massive than the 2-6S controller. This is also the cheapest option available.
    - ESC 2S-6S Lipo Electronic Speed Controller
        - This motor controller is the largest and most versatile, as it allows for the use of 2S through 6S powered motors. It is also the heaviest and most expensive of the options.

- Research presented on why each alternative should or should not be chosen.

Deployment Mechanism
Leveling ● Automatic ○ This design should be chosen due to its ability to actively level the UAV at a precisely determined position. ○ This design shouldn't be chosen due to its higher mass, cost, and complexity. ● Manual ○ This design should be chosen due to its simplicity, low complexity, and lack of risks. ○ This Manual leveling/release shouldn't be chosen because it takes a large amount of time to do and doesn't meet part of our payload goals to deploy unmanned. ● Gravitational ○ The gravitational leveling should be chosen because of its simplicity, effectiveness, and minimal mass. It allows the UAV to be leveled without any complex electronics or systems. ○ This leveling system should not be chosen because the bearings have a risk of slipping or the payload has a risk of rocking too much.
Deployment ● Threaded Rod ○ The threaded rod should be chosen due to its simple concept and straightforward application. ○ The threaded rod should not be chosen due to its heavier mass compared to manual deployment, alongside its large volume consumption. ● Belt Drive ○ The belt drive mechanism should be used because of its reliable accuracy. ○ The belt drive mechanism should not be used because of its high cost and high mass. ● Manual ○ The manual method should be chosen because of the lighter mass with only a locking mechanism. ○ The manual method should not be chosen because it doesn't meet part of our payload goals to deploy unmanned.

UAV Design
Styles ● Quadcopter ○ The Quadcopter design should be chosen due to its simpler design while remaining just as effective. ○ The quadcopter design should not be chosen because of the higher number of motors and lower energy efficiency. ● Tricopter

- The tri-copter design should be chosen due to its energy efficiency with its bigger wing.
- The tri-copter design should not be chosen because of the moving tail that needs to be locked in place alongside the long wingspan that needs clearance to take off.

- Gull Wing
  - The gull wing should be chosen because of the passive folding system, fewer motors, and compact packaging.
  - The gull wing should not be chosen due to the complexity of coding tri-copters and the length of the design.

Electronics

Shared Electronics (Same on both components)

- Main Computer
  - Teensy 4.0
    - The Teensy 4.0 should be chosen because of the small form factor benefitting aerodynamics.
    - The Teensy 4.0 should not be chosen because it contains a relatively low capacity, leading to fewer additions.
  - Teensy 4.1
    - The Teensy 4.1 should be chosen because it contains the most memory, allowing for more complex additions.
    - The Teensy 4.1 should not be chosen because it limits our budget for other materials.
  - Arduino Nano
    - The Arduino Nano should be chosen because it allows for higher spending on other components.
    - The Arduino Nano should not be chosen because it contains much lower capacity and lower processing speed, leading to inferior ability.
- GPS
  - “Ultimate GPS” 1616S
    - The 1616S GPS should be chosen because it has a low power draw, allowing for use of higher draw components.
    - The 1616S GPS should not be chosen because there are superior-performance versions for the same price.
  - “Ultimate GPS” 1616D
    - The 1616D GPS should be chosen because it offers increased performance at the same price as the 1616S.
    - The 1616D GPS should not be chosen because it has a higher relative power draw, constricting other components.
  - “Ultimate GPS” 1616D, SMD version
    - The 1616D SMD should be chosen because it offers the same performance as previous versions but is smaller and more aerodynamic.
    - The 1616D SMD should not be chosen because it shares the issue of

power draw constraining other components.

- Radio
    - Adafruit RFM95W LoRa Radio Transceiver Breakout - 868 or 915 MHz - RadioFruit
        - This radio should be used because of its very long range and compact size. It also doesn't require additional code with a second microcontroller.
        - The radio shouldn't be used because without a second microcontroller it's much more challenging to code and has the radio listening for other signals.
    - Adafruit RFM96W LoRa Radio Transceiver Breakout - 433 MHz - RadioFruit
        - This doesn't have any serious pros and cons besides operating on the 433 MHz band. 868-915 MHz is the US public signal standard, which makes the others more favorable than this one.
    - Adafruit Feather M0 with RFM95 LoRa Radio - 900 MHz - RadioFruit
        - This radio module should be used because it separates the rest of the complex program for flying the UAV from the GPS coordination between the two other radios.
        - This radio module shouldn't be used because the separate GPS coordination can cause interruptions in the ability to communicate between the main computer.
- Battery
    - 1S 520 mAh
        - The 1S 520 mAh battery should be chosen because of its low price point and mass.
        - The 1S 520 mAh battery should not be chosen because of its limited capacity and ability to only power 1S motors.
    - 2S 1500 mAh
        - The 2S 1500 mAh battery should be chosen because it's the smallest battery that is capable of powering 2S motors, while still having the least expensive price point and smallest mass.
        - The 2S 1500 mAh battery should not be chosen because it has the most limited capacity of the 2S batteries.
    - 2S 5200 mAh
        - The 2S 5200 mAh battery should be chosen because it has a much greater capacity than the 1500 mAh battery.
        - The 2S 5200 mAh battery should not be chosen because of its higher price point, size, and mass.
    - 2S 6200 mAh
        - The 2S 6200 mAh battery should be chosen because of its highest capacity and ability to power 2S motors.
        - The 2S 6200 mAh battery should not be chosen because of its large size, mass, and price.

Deployment Mechanism

- Motors

- NEMA 17 Stepper Motor
    - The NEMA 17 Motor should be chosen because of its relatively low mass and high torque.
    - The NEMA 17 Motor should not be chosen because of its high price point and low RPM.
- 5V DC
    - The 5V DC Motor should be chosen because of its cheap price point, low mass per motor, and high RPM.
    - The 5V DC Motor should not be chosen because of its decreased torque and possible lack of durability.
- 12V DC Motor
    - The 12V DC Motor should be chosen because of its high torque.
    - The 12V DC Motor should not be chosen because of its high price point, low RPM, and high mass.

- Motor Controllers
    - A4988 Stepper Motor Driver Carrier
        - The A4988 motor controller should be chosen because of its median price point, sufficient cooling, high voltage range, and small size.
        - The A4988 motor controller should not be chosen because of its low amperage and incompatibility with DC motors.
    - TB6612FNG DC Dual Motor Driver Carrier
        - The TB6612FNG motor controller should be chosen because of its low price point, small size, and compatibility with DC motors.
        - The TB6612FNG motor controller should not be chosen because of its lower voltage range and amperage.
    - Telesky MOS Module Controller
        - The Telesky motor controller should be chosen because of its high voltage range and 15 A current.
        - The Telesky motor controller should not be chosen because of its expensive price point and large size.

UAV

- Distance Measuring Equipment (DME)
    - Gyro
        - Adafruit LSM6DSO32
            - The Adafruit LSM6DSO32 should be chosen because of the cost savings it presents, as well as the acceleration capabilities.
            - The Adafruit LSM6DSO32 should not be chosen because it offers a limited list of functions compared to other options.
        - Adafruit L3GD20H Triple-Axis Breakout Board
            - The Adafruit L3GD20H should be chosen because of the relative cost savings for what it provides, such as safety features and accuracy.
            - The Adafruit L3GD20H should not be chosen because of the lack of certain features which could prove useful in certain situations.

            - Adafruit BNO055
                - The Adafruit BNO055 should be chosen because it provides a wide variety of measurements that could be incredibly useful in more complex and reaction-based situations.
                - The Adafruit BNO055 should not be chosen because of the expensiveness of the hardware, compared to the cheaper and more advanced BNO085.
            - Adafruit BNO085/080
                - The Adafruit BNO085 should be chosen because it offers a variety of protective features as well as the variety of measurements of the BNO055 for a cheaper price.
                - The Adafruit BNO085 should not be chosen because it is more expensive than other options and less flexible with connections, which is an unwanted constraint.
        - (Lidar/Ultrasonic) Range Finder
            - Garmin LIDAR-Lite V4
                - The Garmin V4 Lidar Sensor should be chosen due to its large range of detection and increased precision.
                - The Garmin V4 Lidar Sensor should not be chosen due to its high price point, as that money could be better spent on other components.
            - Adafruit VL53L1X
                - The Adafruit sensor should be chosen due to its low price point.
                - The Adafruit should not be chosen due to its short range and possible lack of reliability.
            - Maxbotix Ultrasonic Rangefinder EZ4
                - The Maxbotix Ultrasonic sensor should be chosen due to its large target detection and narrow beam width.
                - The Maxbotix Ultrasonic sensor should not be chosen due to its relatively higher price point.
        - Altimeter
            - BMP 388
                - The BMP 388 should be chosen because of the cost savings it offers.
                - The BMP 388 should not be chosen because of the lack of accuracy compared to the BMP 390.
            - BMP 390
                - The BMP 390 should be chosen because of the improved accuracy, which will be important for our mission to succeed.
                - The BMP 390 should not be chosen because of the increased cost, which will put constraints on other components.
- Motors
    - iFlight XING Nano 0803 17000 kV
        - The iFlight XING Nano should be chosen because it can run efficiently at full speed on less power than other options.

        - The iFlight XING Nano should not be chosen because it has no outstanding upsides, and is the most expensive option.
    - HAPPYMODEL SE0802-19000kV
        - The SE0802-19000kV should be chosen because they are the most cost-effective option while offering more performance than the previous option.
        - The SE0802-19000kV should not be chosen because there are higher output options that use the same amount of power.
    - HAPPYMODEL SE0802 1-2S Brushless Motor
        - The SE0802 1-2S Brushless Motor should be chosen because they offer the highest output for a similar power draw.
        - The SE0802 1-2S Brushless Motor should not be chosen because they are more expensive and possibly excessive for the stated goal.
- Motor Controllers
    - AGFRC Mini 4A ESC Brushless DSHOT600
        - The AGFRC Mini should be chosen because of the aerodynamic capabilities that it provides.
        - The AGFRC Mini controller should not be chosen due to it only working on 1s motors and the fact that it is relatively more expensive than other options.
    - XSD7A Micro Speed Control
        - The XSD7A Micro should be chosen because it is the cheapest and most flexible controller, allowing for use on all the motors we have suggested while still remaining feasible.
        - The XSD7A Micro should not be chosen because of the added mass possibly causing problems.
    - ESC 2S-6S Lipo Electronic Speed Controller
        - The ESC 2S-6S Lipo should be chosen because of the flexibility it offers for motor choices.
        - The ESC 2S-6S Lipo should not be chosen because of mass constraints and the fact that current motor choices do not require the flexibility it offers.

- A feasibility study was conducted for each alternative.

Deployment Mechanism
Leveling ● Automatic ○ Automatic leveling is the most complex option out of the three, as it requires active electronics, additional power usage, and a more complicated design. ● Manual ○ Manually leveling the UAV is the least complex method as it requires no mechanisms or electronics, reducing the mass, power usage, and difficulty. However, this option does not meet team objectives for the payload which include a mechanical deployment system. This causes the manual leveling option to be considered primarily as a fallback method, rather than a leading option. ● Gravitational ○ Using gravity is the simplest way to autonomously level the UAV because no extra power will be needed to ensure that the UAV is upright. This allows the UAV to deploy upright in any vehicle orientation as the deployment system will be free to rotate once released. This method requires no calculations to determine when the sled is level, reducing the power used by the system. **Deployment** ● Threaded Rod ○ The Threaded Rod design is a feasible option due to its simple nature and mechanical properties. The threaded rod design only requires a simple electric motor connected to the rod, which can be locked or rotated throughout flight and deployment. Of the two mechanical designs, the threaded rod is the simplest, and offers the best mechanical advantage, requiring less energy usage. ● Belt Drive ○ The Belt Drive option is the least feasible as it has the highest complexity and mass of the designs. This design requires a carefully aligned rail along with motors capable of providing force sufficient to resist the acceleration during launch and separation of the vehicle as a belt drive provides relatively little advantage. Additionally, the system uses significantly more space and mass, restricting the size of the UAV as well as increasing the mass of the launch vehicle. ● Manual ○ Manually deploying the UAV is the simplest method available as no mechanical or electronic systems are needed, thus limiting the necessary mass and power. Unfortunately, this method fails to meet the goal of an autonomous deployment, relegating this option to the role of a failsafe.

UAV Design

- Quadcopter
    - The Quadcopter design is the most feasible UAV option as the majority of commercial and hobby UAVs follow a similar design. The symmetric positioning of the upwards motors allows for precise hovering and maneuvering with already existing control systems. This would reduce the effort needed to program the UAV. This will allow more effort to be spent on accomplishing our objectives with the UAV rather than on the challenge of creating a working flight system.
- Tricopter
    - The Tricopter design is a moderately feasible UAV option due to its limited number of folding sections. However, this has the drawback of requiring a longer payload bay and deployment system to take off. In addition, the use of three upwards motors necessitates a higher thrust to be provided by each, such that more wear will be sustained by each motor during vertical flight or hovering. On the contrary, in horizontal flight, the larger wing will allow for minimal thrust usage to maintain altitude. This design is also susceptible to the problem of torque created by rotating motors as the Tricopter does not have any motor countering the force of the rear propeller.
- Gull Wing
    - The Gull Wing design is the least feasible UAV option since larger propellers would be needed in order to lift it. Larger motors use more energy which is inconvenient when designing a compact UAV. Since only three upwards-facing motors are used, each must provide more of the total thrust required. Additionally, the primary reason why a Gull Wing would not be a reasonable design to pursue is that the UAV is hard to stabilize during flight because the tail motor provides torque in one direction.

Electronics

Shared Electronics (Same on both components)

- Main Computer
    - Teensy 4.0
        - The Teensy 4.0 is feasible and recommended for the current system, as it fulfills all requirements without constraining other hardware needlessly. It offers everything we need and nothing that we don’t, as well as being cost-effective to an extent. It is doable and the most likely path forward from now on.
    - Teensy 4.1
        - The Teensy 4.0 is most likely feasible, but not recommended, as it has certain excesses that we don’t need in our system. It also causes some cost constraints, which we are trying to avoid. The system will certainly work with it, but it may be more than we need.
    - Arduino Nano
        - The Arduino Nano may not be feasible, as the limits of the technology can have negative outcomes on the performance of the system as a

whole. The low processing power and storage might make this incompatible with the rest of the system as a whole, and could greatly diminish the capacity for success of the system.

- GPS
  - "Ultimate GPS" 1616S
    - The Ultimate GPS 1616S is the least feasible and least recommended option, as it is the most lacking in terms of channels and GPS capabilities. It could be possible to complete our project with this option as it does have the benefit of a low price, but it could greatly diminish our success in terms of GPS capability.
  - "Ultimate GPS" 1616D
    - The Ultimate GPS 1616D is feasible, but not recommended. It has all the capabilities of the SMD version, but with a higher price, larger size, and greater form factor.
  - "Ultimate GPS" 1616D, SMD Version
    - The Ultimate GPS 1616D, SMD Version is the most feasible and recommended solution, as it incorporates the best of the GPS systems, with the only drawback being the price. It doesn't constrain physical UAV systems and offers more flexibility to the system.
- Radio
  - Adafruit RFM95W LoRa Radio Transceiver Breakout -868 or 915 Mhz - RadioFruit
    - This option is very simple in design, and has very reliable components. This makes it a highly feasible option for implementation into the design, and this radio operates on the desired frequencies for use in this project.
  - Adafruit RFM96W LoRa Radio Transceiver Breakout - 433 Mhz - RadioFruit
    - The 433 Mhz radio is not a feasible option because, while it has identical components to the 915 Mhz radio, it does not operate on the frequencies expected for use in this project.
  - Adafruit Feather M0 with RFM95 LoRa Radio - 900 MHZ - RadioFruit
    - This may be a feasible option for the project, as it clearly separates different components for simpler use. However, this may also cause disruption in communications between components.
- Batteries
  - 1S 520 mAh
    - The 1S 520 mAh battery is not feasible or recommended because it does not have the capacity or ability required to complete our project. It does have a low mass and price, but nothing the other options can't provide as well in addition to sufficient battery capacity.
  - 2S 1500 mAh
    - The 2S 1500 mAh battery is feasible, but not recommended as it is the smallest battery that is technically capable of powering 2S motors. However, this capacity is limited and we could get a much better battery for a slightly higher price.
  - 2S 5200 mAh

■ The 2S 5200 mAh battery is feasible and recommended because it has a sufficient capacity to complete our project while still retaining an acceptable price point. It has a much greater capacity than the 1500 mAh battery and only a slightly higher price. ○ 2S 6200 mAh ■ The 2S 6200 mAh battery is feasible, but not recommended as it costs more than the 5200 mAh battery for only slightly more capacity which may prove to be unnecessary. It does have the highest capacity and ability to power 2S motors, but it also has the largest mass and highest price.
Deployment Mechanism ● Motors ○ NEMA 17 Stepper Motor ■ The NEMA 17 Stepper Motor is feasible and recommended bcause of its relatively low mass and high torque. Even with its high price point, it is still recommended as the high level of torque on this motor is not offered in the other options. ○ 5V DC Motor ■ The 5V DC Motor is not feasible or recommended as it lacks the torque and durability that our project requires. Its low price and mass is overshadowed by the lack of capability. Choosing this option could result in a failure of our deployment mechanism. ○ 12V DC Motor ■ The 12V DC Motor is feasible and recommended because of its high torque and compatibility with motor controllers as a DC motor. This motor does have a high price and mass, which may be necessary factors to account for in order to get a motor with the proper capabilities. ● Motor Controllers ○ A4988 Stepper Motor Driver Carrier ■ The A4988 Stepper motor controller is potentially feasible and recommended as it has a median price point, sufficient cooling, high voltage range, and small size. However, this motor controller is only compatible with stepper motors - a factor to consider after choosing a motor. ○ TB6612FNG Dual Motor Driver Carrier ■ The TB6612FNG DC Dual motor controller is potentially feasible, but not recommended as it has low amperage. It may not be enough to for the deployment mechanism to run effectively, even though it has a low price point and small size. ○ Telesky DC MOS Module Controller ■ The Telesky motor controller is feasible and recommended as it provides sufficient amperage and voltage range for out project. While it is is the most expensive option and larger than ideal, our project may not be feasible without this motor controller.

UAV

- Distance Measuring Equipment (DME)
    - Gyro
        - Adafruit LSM6DSO32
            - The Adafruit LSM6DSO32 is feasible, saving us money and time by simplifying the process as well as being flexible to possible changes to design. There are a few minor issues with this system, including the lack of exemplary accuracy that could affect system performance, but overall, this option is feasible to complete in the time and constraints we have.
        - L3GD20H Triple-Axis Breakout Board
            - The L3GD20H is feasible and recommended, as it is cost-effective while completing all the major objectives set out for it. However, the lack of extra measuring capabilities and lack of an accelerometer might cause issues that could affect the performance of the UAV. Overall, this is a good option, but not necessarily the best option.
        - BNO055
            - The BNO055 is potentially feasible, but may cause issues, as it is more expensive than all the other options. It also lacks the safety and accuracy features that would be preferred in our system.
        - BNO085/080
            - The BNO085/080 is feasible and recommended, as it contains the features that we would prefer to have incorporated in our system, but the price of the component might still pose an issue. However, this is not a difficult obstacle, and this option is preferable to others on this list.
    - (Lidar/Ultrasonic) Range Finder
        - Garmin LIDAR-Lite V4
            - The Garmin LIDAR-Lite V4, although expensive, is feasible and recommended as it is light-weight, compact, and requires low power. These properties save mass, power, and space, which are important when designing our UAV which will have limited power and space to be stored. This option also has an exemplary update rate.
        - Adafruit VL53L1X
            - The Adafruit VL53L1X is not feasible or recommended as its precision is much lower than other options. This option does have an astoundingly low price, which may be an accurate reflection of the precision and durability of this sensor. Just like the Garmin, it is compact and lightweight, but it has half the range.
        - Maxbotix Ultrasonic Rangefinder EZ4
            - The Maxbotix Ultrasonic Rangefinder EZ4 is also feasible and recommended. Its price and range fall between that of the

Garmin and Adafruit, and this option is also compact and lightweight.

- Altimeter
  - BMP 388
    - The BMP 388 is feasible, as it is a cheap and quick solution to the problem, but not recommended, as it lacks accuracy, which can affect crucial parts of our mission.
  - BMP 390
    - The BMP 390 is feasible and recommended, as it achieves the level of accuracy we need to successfully complete our mission, and the price difference does not cause a large problem.

- Motors
  - iFlight XING Nano 0803 17000 kV
    - The iFlight XING Nano is potentially feasible, but not recommended as it has no outstanding upsides for a high cost. However, if the cost wasn't a consideration, it could be feasible as it can run efficiently at full speed on less power than other options.
  - HAPPYMODEL SE0802-19000kV
    - The SE0802-19000kV is feasible and recommended as it is the most cost-effective option and also offers more performance than the previous option. It provides everything we need out of a motor for our UAV while still having an acceptable price point.
  - HAPPYMODEL SE0802 1-2S Brushless Motor
    - The SE0802 1-2S Brushless Motor is potentially feasible, but not recommended as it is the most expensive and also weaker than the 19000kV motor. This option does provide the highest output for a similar power draw. If cost wasn't a consideration, this option would be a good choice.
- Motor Controllers
  - AGFRC Mini 4A ESC Brushless DSHOT600
    - The AGFRC Mini motor controller is likely not feasible or recommended as it only works on 1S motors and is relatively more expensive than other options. This motor controller does provide aerodynamic capabilities, but the beneficial and likely possibility of utilizing 2S motors on our UAV makes this option potentially infeasible.
  - XSD7A Micro Speed Control
    - The XSD7A Micro Speed Control is feasible and recommended as it is the most cost-effective and flexible controller. It's compatible with any of the motor options listed above, making it an all-around solid choice and likely the one we'll choose, even with a higher mass than the AGFRC mini.
  - ESC 2S-6S Lipo Electronic Speed Controller
    - The ESC 2S-6S Lipo is not feasible or recommended as it provides potential mass constraints. Even though it offers flexibility in our motor choice, this flexibility may not be necessary as the XSD7A Micro offers the same flexibility for a much lower price.

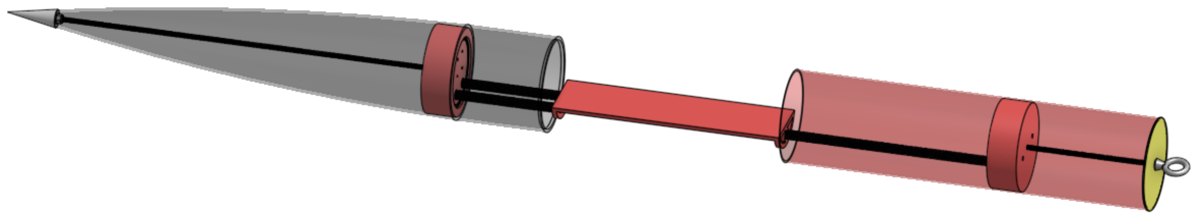
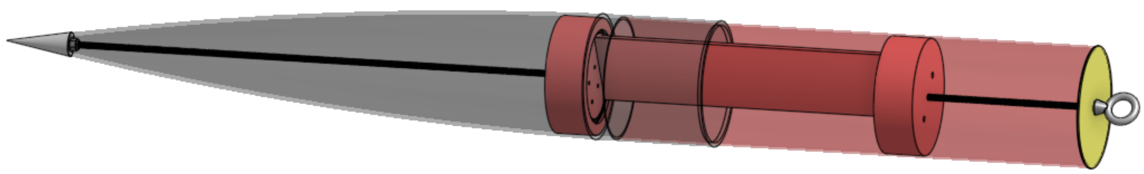
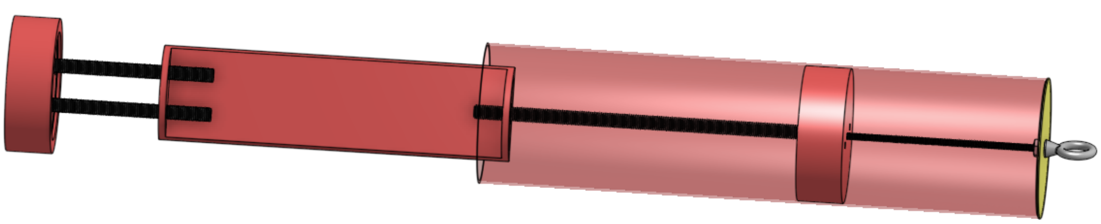
- The payload design with current leading alternatives and explanations on why they are the leading choices.

Deployment Mechanism (With Related Electronics)
The team intends to design a deployment mechanism using gravitational leveling and threaded rod deployment. The gravitational leveling reduces the amount of work needed to level the UAV, and by using a carbon fiber threaded rod, telescoping in both directions creates a large workspace to develop a UAV. The electronics used will be the Teensy 4.0, Ultimate GPS 1616D SMD Version, Adafruit RFM95W LoRa Radio Transceiver, 2S 5200 mAh battery, NEMA 17 Stepper Motor, and the TB6612FNG Dual Motor Driver Carrier. The deployment mechanism will lock the bearings in place for flight by using a servo with a metal arm. The current leading alternatives are backups in case of a failure in the original or modified design(s) for any reason. These would be the manual leveling and releasing of the UAV.

UAV (With Related Electronics)
The team intends to design a UAV using a modified quadcopter design with vertically folding wings. (Figure 4.1.2) These vertically folding wings allow the folding mechanism to be completely passive, reducing mass and unnecessary complexity. The release/locking mechanism holding on to the deployment mechanism will be a servo motor with an attached arm to prevent movement. The electronics used in this design are the Teensy 4.0, Ultimate GPS 1616D SMD Version, Adafruit RFM95W LoRa Radio Transceiver, 2S 1500 mAh battery, Adafruit LSM6DSO32 gyro, Garmin LIDAR-Lite V4, BMP 390 altimeter, the HAPPYMODEL SE0802-19000kV motor, and ESC 2S-6S Lipo Electronic Speed Controller.

Handheld Controller
The handheld controller will be 3D Printed with PLA. It will use the same GPS, radio module, and microcontroller as used in the UAV and deployment mechanism. The controller will include buttons to deploy the UAV, force the UAV to hover, and force a landing of the UAV. The leading alternative and backup to this design is a standard UAV control system with full manual operation.

- Drawings and electrical schematics for all elements of the preliminary payload as well as estimated masses for components.

Deployment Mechanism |0.852 lbs|
 *Figure 4.1.2 - Deployment Mechanism Extended*
 *Figure 4.1.3 - Deployment Mechanism Retracted*
 *Figure 4.1.4 - Deployment Mechanism Extended from Underside*

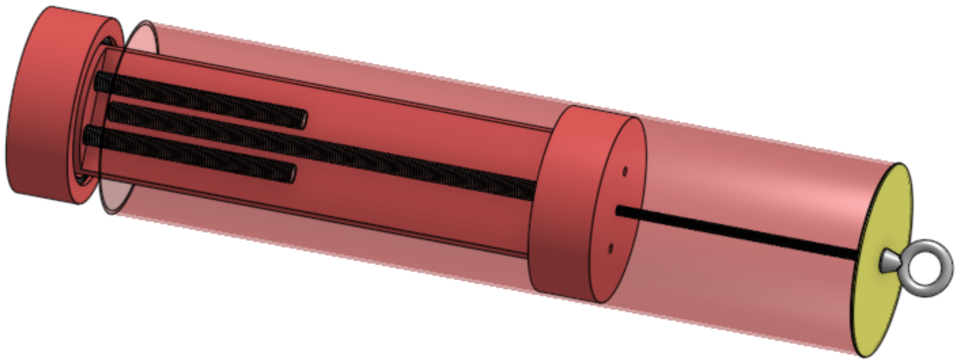


Figure 4.1.5 - Deployment Mechanism Retracted from Underside

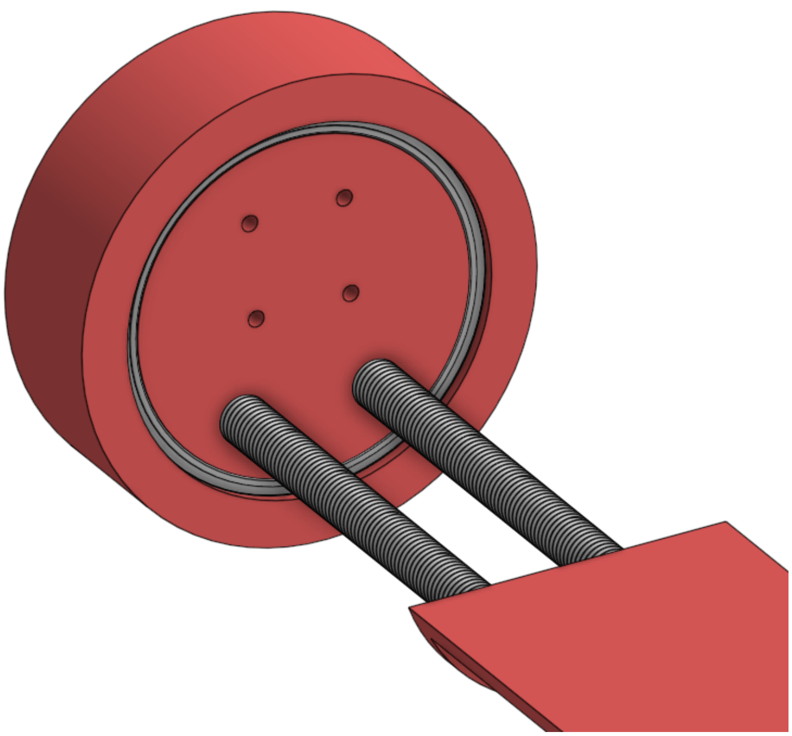
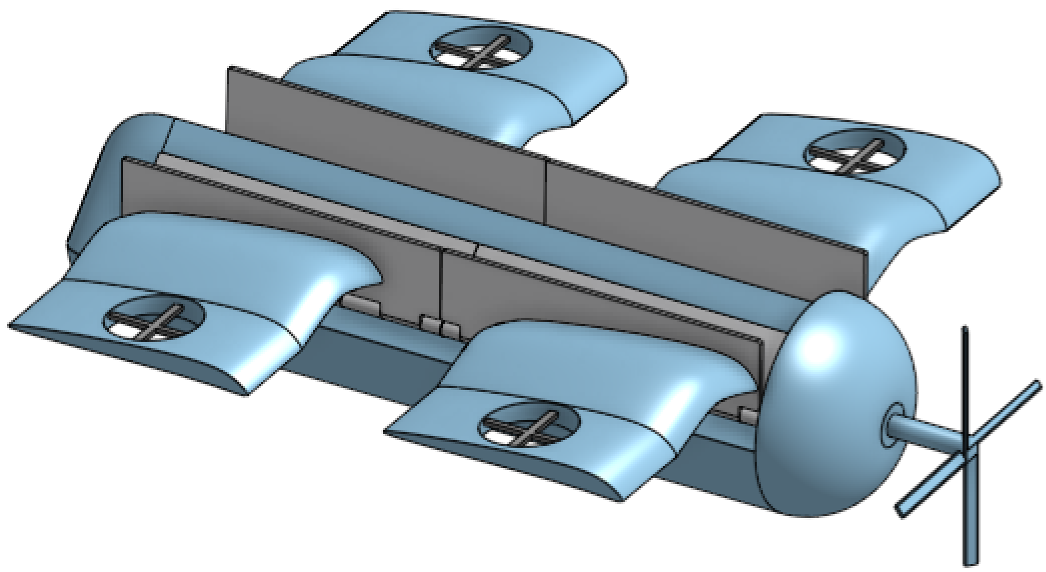


Figure 4.1.6 - Deployment Mechanism Bearing Closeup

UAV |0.62 lbs|
 *Figure 4.1.7 - UAV Design*

- Justification used when making design selections.

Deployment Mechanism
Simplicity and mechanical properties were the two primary factors in the decision to use a threaded rod deployment mechanism. The threaded rod design is not complex, as it only requires a motor to directly turn the rod. Additionally, the only electronic component of the leveling system is a servo to lock the system during flight. The mechanical properties include the high mechanical advantage of the threaded rod, which allows a very small force output from a motor to exert a much larger force on the parts it must move.

UAV
Familiarity and simplicity were the foremost factors in determining that a quadcopter design should be used. Most commercial and hobby UAVs utilize some form of quadcopter system, and the quadcopter is the best-proven design available. Additionally, the most common mechanical and programming challenges have already been solved for a quadcopter, allowing the team to focus on the objectives of the payload rather than on the process of making it operate. Additionally, the design is the simplest as it can be operated successfully without utilizing the airfoils or forward propeller if needed, and only requires hinges to operate the wing deployment mechanisms.

Handheld Controller
Manufacturability and the ability to program were the two primary considerations in determining the handheld controller system design. Creating the unit with 3D-printed parts allows for prototyping and modification as needed throughout the design process. The use of common electronics for the GPS, radio, and controller allows for familiarity with the components and their usage. Including controls for the necessary functions of the UAV allows for simplified programming and a smaller unit, as only three buttons are essential to operate the UAV while maintaining control over the system.

4.2 Payload System Interfaces

- Preliminary interfaces between the payload and launch vehicle.

Deployment Mechanism
The deployment mechanism creates no adverse design changes to the outside components of the vehicle compared to a standard vehicle. The nose cone and payload coupler will be held together using two shear pins. After the vehicle has landed, the deployment mechanism will use its strong separation to break the shear pins, separating the two sections by about 12 inches. No other interfaces between the payload and launch vehicle are made, including by the UAV.

- Preliminary design of the payload retention system.

Deployment Mechanism
The top portion of the deployment mechanism, inside the nose cone, will be retained by using the steel threaded rod that ties to the top of the metal nose cone tip. The lower portion of the deployment mechanism will be held in place by the fiberglass bulk plate attached to the end of the coupler. The coupler and nose cone will be held together by two, shear pins. When the payload is deployed, the shear pins will break, separating the sections. The rotational portion of the deployment system will be locked in using a servo.

UAV
The UAV is only directly secured to the Deployment Mechanism using a separate servo on the sled. This locks all degrees of freedom and will hold the UAV in place until the vehicle has landed and the UAV is ready for lift-off.

V) Safety

5.1 Project Understanding

- Demonstrated understanding of all components needed to complete the project and how risks/delays impact the project.

Given the understanding that NASA SLI is an intricate project with many working components, from outreach to vehicle design and construction, there are a variety of safety concerns that have hazardous potential. The Cedar Falls High School rocketry team ranks safety above all else and takes all relevant precautions in order to mitigate hazardous situations. With our main concern being safety, below details potential hazardous situations, tools, or activities along with controls and mitigations for said hazards. Outlining the significance of each potential hazard illustrates the amount of risk and potential delay to the project timeline involved.

5.2 Personnel Hazard Analysis

Preliminary Personnel Hazard Analysis provided. The focus of the Hazard Analysis at PDR was identification of hazards, their causes, and the resulting effects. Preliminary mitigations and controls were identified, but not implemented at this point unless they were specific to the construction and launching of the subscale rocket or are hazards to the success of the SL program (i.e. cost, schedule, personnel availability). The risk of each hazard was ranked for both likelihood and severity.
○ Data was included indicating that the hazards have been researched (especially personnel). Examples: NAR regulations, operator's manuals, MSDS, etc.

Hazard	*Cause*	*Effect*	*Preliminary Mitigation*	*Hazard Ranking: Likelihood and Severity* (1 = least likely/severe, 5 = most likely/severe)
Failure to raise funds	Inadequate outreach or volunteering to work for funds	Overall failure of project; not enough money for construction or travel.	Limiting our budget to only completely necessary expenses. Commitment	S: 5 L: 2

			and dedication by members of our fundraising team.	
Missing submission deadline of milestone documents.	Poor planning, laziness of team members.	Consequences from NASA.	Communication between team members regarding meetings and deadlines. Commitment of team members to put in work.	S: 3 L: 2
Forgetting recovery wadding which can subsequently destroy the parachute, leading to catastrophic landing.	Forgetting recovery wadding/Nomex in the vehicle for the black powder charge at apogee.	Catastrophic and uncontrolled landing which can result in injury with a high altitude vehicle traveling towards the ground at a high velocity.	Have a step by step procedure put in place to prevent forgetting to put the recovery wadding/Nomex into the vehicle before launch of the vehicle.	S: 5 L: 1
Injury while cutting fiberglass	Ignorance of machine operators, inadequate training or preparation.	Extreme bodily injury	Presentations made by Safety Officer to educate team members on how to safely operate machinery.	S: 5 L: 2
Dust/fiberglass particle accumulation	Inadequate PPE and poor ventilation area whilst sanding	Excessive inhalation of foreign substances, mild-severe lung respiratory damage	Utilize readily accessible PPE and IT rooms. Safety Officer informs the team by presentation of PPE available and proper sanding procedures.	S: 1 L: 4
Car accident	Lack of	Mild to life	Basic awareness	S: 5

	awareness by team members when fundraising through manning parking lots, driving to and from launches/outreach events/team meetings	threatening bodily damage	of surroundings and informational meeting on rules and expectations of fundraising events	L: 2
Getting hit by paper rockets/outreach experiments	Unclear launch area for students, lack of instruction and guidance when presenting	Mild bodily harm	Clear instructions from student leaders to younger students on safety expectations, as well as adequate enforcement of said rules	S: 1 L: 3
Sub scale launch				
Launch site lights on fire	Launch site ground too dry, inadequate mitigation equipment (fire extinguisher) on hand	Decimation of launch site, spectators and team members lives put in danger	Proper safety checklist and kit including tools necessary to mitigate potential scenarios. Saturate launch area and have proper launch pad.	S: 5 L: 3
Parachute fails to deploy	Ejection charges fail to cause the body tubes to separate, contingency charges fails, chute releases and backup chute do not	Vehicle has an uncontrolled descent, leading to potential spectator and team member bodily harm as the velocity is well above	Ensure sufficient amounts of black powder, check through simulations to make sure launch should go successfully.	S: 3 L: 2

	activate	safety guidelines.		
Vehicle components break upon landing	Inadequate construction and assembly of sub scale vehicle	Failed sub scale launch	Stick to a detailed schedule so construction is not rushed, apply vital components, such as epoxy, with special care.	S: 3 L: 2

5.3 Failure Modes and Effects Analysis

Provide preliminary Failure Modes and Effects Analysis (FMEA) of the proposed design of the rocket, payload, payload integration, launch support equipment, and launch operations. Again, the focus for PDR is identification of hazards, causes, effects, and proposed mitigations. Cach hazards were ranked for both likelihood and severity.

Hazard	*Cause*	*Effect*	*Preliminary Mitigation*	*Hazard Ranking: Likelihood and Severity* (1 = least likely/severe, 5 = most likely/severe)
Parachute gets tangled	Failure to package correctly, freak accident	Vehicle has an uncontrolled descent	Take time to correctly pack parachute	S: 4 L: 2
Parachute does not deploy	Ejection charges fail to cause the body tubes to separate, contingency charges fails, chute releases and backup	Vehicle has an uncontrolled descent	Ensure sufficient amounts of black powder, check through simulations to make sure launch should go successfully.	S: 4 L: 2

	chutes do not activate			
Motor fails to ignite	Faulty motor, ignitor not set up correctly, launch box issues	Vehicle does not launch	Ensure clips are properly attached and not touching launch pad	S: 1 L: 3
Inclimate weather on launch day	Bad luck	Vehicle launch is postponed	Plan launch date accordingly	S: 1 L: 2
Motor explodes on launchpad	Malfunctioned motor	Potential fire, vehicle and launchpad unusable	Store and transport motor appropriately	S: 5 L: 1
Fins break upon landing	Poor application of fins, flaw in fin material	Failed sub scale launch	Assemble and construct vehicle without rushing, taking special care to filleting fins and allowing proper bonding time	S: 2 L: 2
Vehicle lands in hazardous area	Weather conditions, imperfect flight	Potential injury recovering vehicle, potential property damage, vehicle damage	Don’t fly with winds of over 20 mph, ensure launch site is clear of surrounding trees, debris, or bodies of water that the vehicle could land in	S: 2 L: 2
UAV crashes upon release from vehicle	Rotors have damage during flight, caught on deployment mechanism, control system malfunction	UAV destruction, project failure, potential property and person damage	Pad UAV during flight, provide back up plans for control system and deployment mechanism, such as manual release of UAV	S: 3 L: 2

			for imperfect flights	
UAV crashes during flight	Control system malfunction, loss of battery life, collision with surroundings, sticky bearings	Project failure, potential collision with objects or personnel, loss of data	Proper testing of UAV before launch, address any issues beforehand	S: 3 L: 2
UAV fails to avoid obstacles	Control system malfunction	Collision with obstacle, destruction to property and UAV	Significant testing beforehand, recording malfunctions and adjusting after each test	S: 3 L: 2
UAV fails to release from vehicle	Damage to deployment mechanism, parachute interference, surrounding debris interference	UAV unable to complete project	Provide a manual release as a backup method	S: 1 L: 2
Data from UAV fails to be collected	Control system malfunction, failure to set up correctly, battery life runs out	UAV unable to fly to target and back to the vehicle's location	Significant testing beforehand, recording malfunctions and adjusting after each test	S: 2 L: 2
Data collection system runs out of battery	Failure to charge before launch, the vehicle travels farther than UAV can travel on current battery life.	No data is collected, UAV is unable to fly to target and complete project goal	Follow launch day checklist and preparation. Charge battery.	S: 5 L: 2
Emergency-Stop fails	Control system malfunction, out of range	UAV crashes, UAV releases from vehicle	Understand max range of E-Stop controllers and	S: 4 L: 2

		uncontrolled/unsafely	stay well within bounds. Test E-Stop before launch repeatedly	
UAV wings fail to extend	Not protected well enough during flight, surrounding debris catches on UAV	UAV crashes	Provide E-Stop to ensure UAV is operating safely, have clear launch zone/site	S: 3 L: 2
Launch rail falls over	Inclimate weather, Uneven ground	Dangerous launch, too hazardous of a launch angle, potential severe harm of spectators and buildings	Ensure a level launch site, don't fly with winds of over 20 mph	S: 5 L: 1
Spectator injury	Too close to launchpad, lack of proper launch day procedures	Spectator harm, lawsuits	Enforce NAR safety code and mandatory distance table	S: 5 L: 2
Parachute opens too early	Ejection charges failed to deploy properly	Vehicle drifts out of range, lands in unauthorized zones	Ensure sufficient amounts of black powder, check through simulations to make sure launch should go successfully.	S: 3 L: 2
Collision between UAV and person	Strong wind, ignorance of people, poor programming of UAV.	Severe personal injury, destruction of UAV.	Launching only in safe weather, sufficient UAV flight testing, making sure all flight spectators are attentive.	S: 5 L: 2
Collision between UAV and object	Strong wind, poor programming of	Destruction of UAV, damage to surrounding	Sufficient flight testing, accounting for	S: 5 L: 2

	UAV, failure to account for obstacles.	private property and subsequent financial liability.	all possible objects that may interfere with flight.	
Sticky Bearings	Clogged up, not greased enough	UAV crashes	Use UAV efficiently, regrease when necessary and clean out before testing	S: 4 L: 2
UAV catches on billowing parachute and crashes	Team deploys UAV while vehicle is still in motion and doesn't accelerate vertically fast enough	UAV crashes, damage to parachute	Deploy UAV when vehicle comes to rest, or under a safe velocity of the vehicle, tested prior to launch date	S: 3 L: 5

5.4 Environmental Concerns

Environmental concerns using the same format as the Personnel Hazard Analysis and FMEA.
○ Includes how the vehicle affects the environment and how the environment can affect the vehicle.

Hazard	*Cause*	*Effect*	*Preliminary Mitigation*	*Hazard Ranking: Likelihood and Severity* (1 = least likely/severe, 5 = most likely/severe)
Unpredictable weather during launch	Temperature changes, air pressures changes, weather patterns, seasonal change, cloud patterns, etc.	Unsafe wind gusts, launch delayed, unsafe flight due to sudden weather shifts	Check the forecast beforehand. Practice caution over getting the launch in, plan for multiple launch dates	S: 3 L: 2

Uneven landing ground/excessive foliage on landing area	Vehicle drifted outside of target landing zone, windy	Harm to environment as vehicle lands, harm to payload and vehicle	Check the forecast beforehand, and launch within a safe wind speed of 20mph or less. Launch in a large flat area with least possible variables involved	S: 2 L: 2
Contamination of ground by vehicle motor during launch	Insufficient, or lack of, pad underneath vehicle	Damage to soil and Earth, residue and contamination of environment possible with contents of motor	Follow the preflight checklist and ensure the vehicle and launch pad is positioned correctly.	S: 2 L: 2

5.5 Risk, Mitigation, and Impact

Defined risks (time, resource, budget, scope/functionality, etc.) associated with the project. Likelihood and impact value was assigned to each risk. This part was kept simple (i.e. low, medium, high likelihood, and low, medium, high impact). Mitigation techniques were developed for each risk, starting with the risks with higher likelihood and impact, and working down from there. If possible, the mitigation and impact were quantified. For example, including extra hardware to increase safety will have a quantifiable impact on budget. This type of information was included in the table.

Risk	*Likelihood*	*Impact*	*Mitigation Effort*
Time	High	High	Including elaborate detail in deliverables will increase the functionality of the project, but will have a large impact on the amount of time necessary to submit. We will utilize a

			schedule detailing when to work on each section of a deliverable, and when to move onto the next section. This will provide a controlled balance of depth of content while managing time.
Budget	High	High	The more we spend, the more creative we can be with our payload, as well as increase the bandwidth of our project. This comes with a decrease of our budget, meaning we will map out every expense we will have over the duration of the project. After referencing past year's fundraising efforts and total money used, we will cut down on planned expenses to within a reasonable scope and build the project from there.
Welfare	Medium	High	The more elaborate the payload, the more variables that can potentially go wrong. In order to proceed safely, we cut down on unnecessary sections of the payload, down to one focal point of UAV tracking. Checklists and safety

			presentations will also be implemented to ensure each risk is known and accounted for.
Functionality	Medium	Medium	The functionality and scope of the project is limited as the budget is fixed, leaving risk for a loss in functionality due to not enough money/time/resources. Given that the functionality is an effect of the amount of time, money, and resources put into the project, we will increase fundraising efforts and work with the community to receive more resources in order to increase the functionality
Resources	Low	Medium	In order to ensure our resources are sufficient, several locations for paperwork, brainstorming, construction, and assembly of the vehicle have been planned and are ready to use within the community.

VI) Project Plan

6.1 Requirements Verification

Team-derived requirements in the following categories: Vehicle, Recovery, and Payload. These are requirements for mission success that are beyond the minimum success requirements presented in this handbook. These requirements are not arbitrary and are required for our team's unique project.

Vehicle:
The inner diameter of the body must be 5 inches to support the materials and payload. This is important due to the lifeline hardware needing to be housed well to allow the vehicle to have a flight that follows NASA's requirements. Also, our payload must fit inside the vehicle, which is important to complete the mission.

Recovery:
The descent rate of the vehicle must be at or under 19.0328 ft/s. In order to comply with the Kinetic Energy requirements outlined in the Handbook, as well as prevent damage to the vehicle/payload upon impact with the ground, from the calculations the team has determined the descent rate must fall at or below this value.

Payload:
Our payload must automatically deploy (after RSO permission is received) from the vehicle and fly at a safe speed and safe distance from obstacles and spectators. It must return to the team member with the controller and then guide itself to the recovered vehicle at a safe distance from obstacles and spectators. It must travel at a speed and altitude adequate for team members to follow.

6.2 Budgeting and Funding

- A line item budget for all aspects of the project with market values for individual components, material vendors, and applicable taxes or shipping/handling fees.

Item:	**Cost:**	**Quantity:**	**Total Cost:**	**Vendor**
Motors & ESCs (comes in pack of 4)	$45.00	1	$45.00	Amazon
Propellers (custom)	$15.00	4	$60.00	Various

				Locations
Microcontroller	$25.00	2	$50.00	Best Buy
Radio (for Remote Override) (Custom Built)	$100.00	1	$100.00	Various Locations
GPS Module	$18.00	1	$18.00	Amazon
Altimeter	$16.00	1	$16.00	PerfectFliteDirect
Gyro	$30.00	1	$30.00	Apogee Components
Battery	$45.00	2	$90.00	Best Buy
Camera	$150.00	1	$150.00	GoPro Website
Lidar/Ultrasonic	$26.00	1	$26.00	Amazon
Interior Cameras	$150.00	1	$150.00	GoPro Website
Cesaroni K1440 Motor	$196.26	3	$588.78	Off We Go Rocketry
5" Fiberglass body tube (per ft)	$39.60	8	$316.80	Wildman Rocketry
Cesaroni 54mm 6-Grain Hardware Set	$135.00	1	$135.00	Apogee Components
5:1 Ogive Filament Wound Fiberglass 5" nosecone	$141.90	1	$141.90	Wildman Rocketry
72" Parachute	$265.71	1	$265.71	Fruity Chutes
18" Drogue Parachute	$70.95	1	$70.95	Fruity Chutes
5" Fiberglass body tube coupler	$56.89	2	$113.78	Wildman Rocketry
RocketPoxy structural adhesive	$65.00	1	$65.00	Wildman Rocketry
G10 Fiberglass 12"x12"x0.125" sheet (for fins)	$18.00	3	$54.00	Wildman Rocketry
Kevlar Shock Cord - 1500#- Main Chute (per ft.)	$0.97	40	$38.80	Wildman Rocketry
Kevlar Shock Cord - 1500#- Drogue Chute (per ft.)	$0.97	40	$38.80	Wildman Rocketry
Tube Bulkhead - 5"	$7.70	4	$30.80	Home Depot
3/8" U-bolts	$5.49	4	$21.96	Home Depot
Motor Mount Tubing - 54mm fiberglass	$27.00	1	$27.00	Wildman Rocketry

Centering Ring - 5" x 54mm inner dia. Fiberglass	$8.80	4	$35.20	Apogee Components
AeroPack Retainer - 54mm	$31.00	1	$31.00	Wildman Rocketry
1/4" quick links	$0.99	6	$5.94	Home Depot
4-40 Nylon shear pins (20-pack)	$1.00	6	$6.00	Home Depot
Removable Plastic Rivets (10-pack)	$5.00	5	$25.00	Home Depot
1/4" threaded steel rod (3ft. each)	$1.75	2	$3.50	Fastenal
PerfectFlight StrattologgerCF altimeter	$54.95	2	$109.90	PerfectFliteDirect
Scale Model	$500.00	1	$500.00	Various Locations
Cesaroni Motor for Scale Model	$50.00	2	$100.00	Apogee Components
Vehicle Tracker Transmitter	$150.00	1	$150.00	Off We Go Rocketry
Vehicle Tracker Receiver	$190.00	1	$190.00	Off We Go Rocketry
1/4" threaded steel rod (3ft. each)	$1.75	1	$1.75	Fastenal
12V DC Stepper Motor	$13.99	1	$13.99	Amazon
Deluxe Servo	$15.99	2	$31.98	Amazon
Coupler Bulkhead - 5"	$11.50	3	$34.50	Wildman Rocketry
Tax:	$271.81			
Shipping and Handling	$200.00			
Total Cost:	$4,309.85			

2023 NSL Budget - Travel					
Hotel:	**Cost per room**	**Number of Rooms**	**Number of nights**		**Total Cost**
Embassy Suites	$166.00	6	4		$3,984.00

Gas:	Cost per Gallon	Number of gallons for one-way trip	Number of Vehicles	Trips	Total Cost
	$3.50	50	3	2	$1,050.00
Travel Tax:	**$278.88**		**Total Travel Budget:**		**$5,312.88**

Total Overall Cost/Budget: $9,622.73

- A funding plan describing sources of funding, allocation of funds, and material acquisition plan.

The team's funding plan will incorporate a combination of "work for donations," local business contributions, and large company sponsorships and grants. The "work for donations" could include, but isn't limited to, working in concession stands, event parking, and stadium cleaning for the local universities sporting events, as well as working with local restaurants, such as Pizza Ranch, to collect donations while bussing tables. Local business donations will occur through the efforts of students going to different local businesses and educating them on what the NASA project entails and what their money will go towards, before asking them for a donation. Other large company sponsorships and grants, such as John Deere and the Iowa Space Grant will be pursued in order to further push us toward our funding goal. Furthermore, the team will use the previous year's "surplus funds" to cover any initial costs incurred at the beginning of the year.

6.3 Timeline

A timeline including all team activities and expected activity durations. This schedule is complete and encompasses the full term of the project. Deliverables are defined with reasonable activity duration.

October 2022

Sunday	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*
						1
2	3	4 Team meeting, Awarded	5	6 Team meeting Kickoff	7	8

		proposals announced		and PDR Q&A		
9	10	11 Team meeting, start ordering materials	12	13 Team meeting	14	15 Outreach event dates scheduled
16	17	18 Team meeting 1 hour	19 Sections I-III of PDR completed	20 Team meeting 1 hour	21	22
23	24 Sections IV-VI of PDR completed 4 hours	25 Team meeting 1 hour	26 **PDR DUE at 8 a.m. CDT**	27 Team meeting PDR presentation run through	28	29
30	31 PDR presentation run through 30 min			PDR presentation run through 30 min		

November 2022

Sunday	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*
		1 PDR Video Teleconfer-ences begin and Team meeting	2	3 Team meeting 1 hour	4	5
6	7	8 Team	9 PDR	10 Team	11	12

		meeting 1 hr	Presentatio n 12 pm - 1 pm	meeting 1 hr		
13	14	15 Team meeting 1 hr	16	17 Team meeting 1 hr	18	19
20	21 PDR Video Teleconfer- ences end	22 Team meeting 1 hr	23	24	25	26
27	28	29 Team meeting 1 hr	30			

<u>December 2022</u>

Sunday	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*
				1 CDR Q&A 2 hr (discuss after)	2	3
4	5 Deadline to order subscale materials Deadline to plan subscale launch dates	6 Team meeting 1 hr	7 Subscale planning 30 min	8 Team meeting 1 hr	9 Subscale planning 30 min	10
11	12 Subscale planning 30 min	13 Team meeting 1 hr	14	15 Team Meeting 1 hr	16 Subscale planning 30 min	17

18	19 Subscale constructio n 30 min	20 Team meeting 1 hr	21 Subscale constructio n 30 min	22	23 Subscale constructio n 30 min	24
25	26	27	28	29 CDR Work Time 2 hr	30 CDR Work Time 3 hr	31

January 2023

Sunday	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*
1	2 CDR Work Time 1 hr (in school meeting) 2 hr (after school meeting	3	4	5 Team meeting and Check over CDR and make final edits 30 min	6	7 CDR Work Time (final revisions)
8 CDR Proofread and Submitted	*9* **Subscale Flight deadline** **Submit CDR, presentati on slides, and flysheet report by 8am**	10 Team meeting 1 hr	11 CDR presentatio n practice and run through (30 min)	12 Team meeting 1 hr	13	14
15	16 CDR presentatio n practice and run through	17 Team meeting	18 CDR presentatio n practice and run through	19 Team meeting	20	21

	(30 min)		(30 min)			
22	23	24 Team meeting 1 hr	25	26 Team meeting 1 hr	27	28
29	30	31 Team meeting 1 hr				

February 2023

Sunday	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*
			1	2 Team Meeting 1 hr	3	4
5	6 1 hr FRR Work Time 1 hr	7 Team meeting 1 hr	8	9 Team meeting *and* FRR Q&A	10	11
12	13	14 Team meeting 1 hr FRR Work Time 1 hr	15	16 Team meeting Sections V-VII of FRR completed	17	18 Full scale launch completed
19	20	21 Team meeting FRR presentatio n complete	22	23 Team meeting 1 hr	24	25 FRR Work Time 3 hr
26	27	28				FRR Work

	Outreach interactions completed by now	Team Meeting 1 hr				Time 3 hr

March 2023

Sunday	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*
			1	2 Team Meeting 1 hr	3	4 FRR Work Time 3 hr
5 Check over FRR presentation and report	6 **Vehicle Demonstrati-on Flight deadline *and* Flight Readiness Review (FRR) report, presentation slides, and flysheet submitted to NASA project management team by 8:00 a.m. CST.**	7 Team meeting 1 hr FRR Presentation Practice (30 min)	8 FRR Presentation Practice (30 min)	9 Team meeting 1 hr	10 FRR Presentation Practice (30 min)	11
12 FRR video teleconferen-ces **start**	13	14 Team meeting 1 hr	15	16 Team meeting 1 hr	17	18
19	20	21	22	23	24	25

		Team meeting 1 hr		Team meeting 1 hr		
26	27	28 Team meeting 1 hr	29	30 Team meeting 1 hr	31 FRR video teleconfere n-ces **end**	

April 2023

Sunday	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*
						1 Launch window opens for teams not traveling to Launch Week. PLAR must be submitted within 14 days of Launch.
2	3 **Payload Demonstr ation Flight and Vehicle Demonstr ati-on Re-flight deadlines,** ***and*** **FRR**	4 Team meeting 1 hr	5	6 Launch Week Q&A Team meeting 30 min	7	8

	Addendum submitted to NASA project management team by 8:00 a.m CDT. (Teams completing additional Payload Demonstration Flights and Vehicle Demonstrati-on Re-flights only)					
9	10	11 Team meeting	12 Teams travel to Huntsville, AL, Launch Readiness Review (LRR) for teams arriving early	13 Official Launch Week Kickoff, LRRs, Launch Week activities	14 Launch Week activities	15 Launch Day and Awards Ceremony
16 Backup Launch Day	17	18 Team meeting 1 hr	19	20 Team meeting 1 hr	21	22
23	24	25 Team meeting 1 hr PLAR	26	27 Team meeting 1 hr PLAR	28	29

		work time (1 hr)		work time (30 min)		
30 <u>Launch window closes for teams not traveling to Launch Week. PLAR must be submitted within 14 days of launch.</u>	PLAR work time (1 hr)		PLAR work time (1 hr)		PLAR work time (1 hr)	

<u>May 2023</u>

Sunday	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*
Final revisions, submit PLAR 3 hr	1 **<u>Teams travelling to Launch Week: Post-Launch Assessment Review (PLAR) submitted to the NASA project management team by 8:00 a.m. CDT</u>**	2		4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20

21	22	23	24	25	26	27
28	29	30	31			