M-3 Concept Design Report

USSF 2k Rocket Launch Black Team

Sponsor: United States Space Force (USSF)

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Executive Summary

The team's goal for the United States Space Force (USSF) 2k Rocket Launch competition is to effectively deliver and recover sensitive payloads from a high-suborbital parabolic launch. This competition is an effort to simulate and solve the challenges regarding the launch and recovery of critical payloads that may be sensitive to high g-forces in order to deliver crucial and life saving payloads to US troops abroad.

The proposed project involves launching chicken eggs to an altitude of 2000 feet, using a high powered rocket and implementing a robust recovery system to ensure the safe return of the sensitive payload. The primary objectives are to design a protective payload capsule to shield the sensitive payload from vibrations, acceleration forces and impacts, secure them within the rocket, and deploy a reliable parachute system for a gentle descent. Inside of the 3-D printed payload capsule, the eggs will be nested within EVA foam for protection. The exterior of the payload capsule will be lined with damping pucks or springs, to further mitigate damaging forces. A dual deployment parachute system will be utilized for recovery, ensuring a controlled, stabilized descent while minimizing impact forces upon landing. Through meticulous testing and iterative adjustments, this project aims to achieve a successful launch and recovery, demonstrating the feasibility of safely transporting fragile payloads in high-altitude rocketry. This endeavor not only showcases engineering ingenuity but also explores the application of mechanical and aerospace technology in unconventional contexts.

In the result of a successful mission the team will contribute in the effort to solve the challenges with launching critical payloads; Therein minimizing casualties as well as cost, while maximizing American troops effectiveness overseas.

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Terms And Abbreviations

Acronyms/Technical Terms	
USSF	United States Space Force
CFD	Computational Fluid Dynamics
FEA	Finite Element Analysis
RIN	Requirement Identification Number
LRS	Launch Recovery System
AGL	Above Ground Level
PDR	Preliminary Design Review
Apogee	Max height rocket will reach
FOS	Factor of Safety
FMEA	Failure Modes and Effects Analysis
FDM	Fused Deposition Modeling
PLA	Polylactic Acid
ABS	Acrylonitrile Butadiene Styrene

1 Introduction

This project will play an integral role in the U.S.S.F quest to design, build and operate a rocket based delivery system that will provide much needed cargo and supplies to remote areas around the world, in less than an hour. To simulate this on a much smaller scale, a project has been implemented to launch a high powered rocket loaded with eggs to an altitude of 2000 feet and safely return them to Earth unharmed. In order for this to be achieved a team effort has been put in place to research, design and engineer a rocket that can perform this task.

The purpose of this report is to illustrate the design and decision making process that goes into creating, testing, launching and recovering a rocket and its payload carrying multiple eggs. It is no easy feat to successfully perform this task. Many of the obstacles encountered during this project will be the same obstacles encountered by the U.S.S.F during their journey to create the world's first rocket powered delivery system. This report will highlight the needs of such a service, including all those who would benefit. It will break down the different components that will be utilized to pull off such a challenge. This report will break down the requirements needed to successfully perform this task as well as the concepts generated during the design phase. It will also provide engineering analysis on the structure of eggs and the testing that was performed. A Gantt chart with deliverables will be provided of tasks completed and tasks still incomplete. Finally, a Failure Modes and Effects Analysis will be provided to illustrate all the possibilities of potential events that could sideline a project of this magnitude.

The history of logistics can be traced back to ancient civilizations where the organization and the coordination of resources were essential for military campaigns, trade and construction. As troops conquered parts of the world, logistical concepts were evident in the Roman, Greek and Egyptian armies. They learned to coordinate the movement of supplies and equipment over vast distances. During the Middle Ages, there was a rise of merchant guilds and trade routes. The Silk Road for example, became a complex logistical network, connecting the East and West. During the Industrial Revolution of the 18th and 19th centuries, mass production and the rise of factories, the demand for more sophisticated logistics were required to manage raw materials, production processes and distribution. Both World War I and World War II were characterized as massive logistical efforts. The scale and magnitude of these conflicts required huge supply chains to sustain armies and coordinate global movements of troops and materials. After World War II, logistics became a distinct field, leading to the establishment of supply chain management principles. The development of the cargo aircraft was a major game changer for logistics, moving goods around the globe faster than boats, trains or vehicles could. During the latter half of the 20th century, there was a widespread adoption of technology in logistics. Computers and advanced software revolutionized inventory management and order fulfillment. With the rise of e-commerce, logistics has further been transformed, utilizing sophisticated technologies, data analytics and automation to optimize supply chains and meet the demands of a rapidly changing global market. Today, logistics continues to adapt to new challenges and opportunities in our interconnected world.

The problem that has always plagued logistics is time. In order for logistics operations to be efficient, timing is everything. Logistics is a fundamental component of the broader supply chain. This involves the coordination and movement of goods and resources to ensure a timely delivery and minimize delays. If something takes too long to get delivered, stock runs out, costing money and in some cases, lives. Delays in any aspect of logistics can lead to customer dissatisfaction and impact the overall success of a business. In an interconnected global economy, timing becomes even more critical because of factors like varying time zones and international regulations. In summary, effective timing is a linchpin for efficient logistics. Whether it's synchronizing a supply chain, managing inventory, resupplying a military or providing humanitarian aid, timing is essential for logistics to thrive in today's interconnected world.

Time is the nemesis of logistics. The only way to deal with that nemesis, is to create a system that can remove time, completely from the equation. What is the motivation to do that? Because every second that ticks by, is costing someone either their money or their life. Trains, trucks and cargo planes take too long to get to their destination. By implementing a rocket based delivery system, a huge chunk of time has been removed from the actual delivery. Today's world has an insatiable demand for faster, more efficient delivery solutions and the prospect of a one hour delivery service to anywhere in the world, is a force to be reckoned with. A rocket based delivery service is a concept that has the potential to redefine the boundaries of what's possible and what is not. With the integration of this program, the efficiency of the supply chain will be enhanced, and economic growth will be fostered by the increased accessibility to goods and services worldwide. Life Saving medical supplies and humanitarian aid will save lives everywhere. As we embark on this exploration, envision a future where low orbit space is the gateway to a more connected and accessible global community.

2 Needs Analysis

The concept of being able to launch a rocket into low orbit and safely deliver vital and sensitive supplies to the other side of the world, in under an hour, is an interesting subject of analysis. However, to make this concept come to fruition it is important to identify the stakeholders, decision makers, end-users and other relevant parties with which low orbit resupply will impact. Currently, to deploy humanitarian aid or military support thousands of miles away supplies must be flown via aircraft, offloaded, reloaded onto trucks or helicopters and finally delivered. This concept, although logical, takes many hours to complete. Implementing a low orbit rocket to supply a region in much need can save lives and time.

There are many users and scenarios where a low orbit delivery service would be extremely beneficial. For instance: people living in remote or isolated areas facing natural disasters, or conflict zones, or places with a lack of infrastructure. These groups could receive rapid assistance that would improve the quality of life in their area and potentially save lives. U.S. soldiers and their allies fighting in war torn regions, facing logistical challenges, could receive quick and direct support. During medical emergencies where supplies like vaccines, medications, and medical equipment are urgently needed, a rocket based delivery system could be a swift and efficient solution. To aid their relief efforts, humanitarian organizations such as the Red Cross, Doctors Without Borders and the United Nations could greatly appreciate receiving their supplies within the hour of making a call. Research and development teams would benefit greatly by attracting scientists who are developing cutting edge technologies to enhance global advancement. Finally, a low orbit rapid delivery system would greatly help with global supply chain issues, such as what the world saw following the Covid-19 pandemic. These are just a few of the users that would benefit from this concept, although there are many more.

The ability to not only launch a payload at a low orbit but to protect an extremely sensitive payload can be utilized in many fields. In a military application there are often times when supplies being delivered are sensitive and need to be treated as such. In a resupply service more often than not the supply being shipped is going to be sensitive and needs to be protected when delivered. While most shipments are not going to contain a payload as sensitive as an egg, there are still payloads that are extremely sensitive and using similar protection measures that are being utilized here can be very useful to other applications.

As there are many humanitarian and private organizations who would benefit and welcome this idea, there are many stakeholders who would love to see a new, rapid delivery service become available. Some of these stakeholders include global logistics and shipping companies, giving them options for time sensitive or high-value cargo delivery. These companies could revolutionize their services by offering incredibly fast and efficient global delivery options, reducing transit times and operational costs. This would help retail companies by allowing ultra-fast delivery capabilities, rapid order fulfillment and enhancing customer satisfaction. Manufacturers and suppliers, especially those with time sensitive or perishable goods could leverage this system to ensure quick and reliable distribution of their product. Stakeholders involved in global supply chain networks, including raw material suppliers, could optimize their operations by reducing lead times and improving overall supply chain efficiency. Overall, consumers would experience the direct benefits of high speed deliveries, with the convenience of receiving their goods in a timely fashion. Other stakeholders involved in this project include Aerospace and Technology companies such as NASA, SpaceX, and Microsoft to name a few. These companies involved in the development and manufacturing of a rocket based delivery system, would directly benefit from the creation, deployment, services and maintenance of such systems. Professionals in these industries, including engineers and scientists would be involved in the designing, developing and maintaining this delivery system. Investors and financial institutions would be key stakeholders as they would benefit greatly from the growth and profitability of companies involved in this sector. Telecommunication companies involved in providing communications services and real time tracking capabilities for all involved, would also see profit and growth as these services became more available.

As the idea of a low orbit rocket based delivery system begins to grow, so does the list of potential businesses and investors who would like to purchase such a system. However, the list may not be as big as one might think. To purchase a low orbit delivery system with rockets, facilities and personnel, it would require a significant financial investment. The level of technical expertise to keep a company of this caliber successful, is extremely high. Other components that are required to purchase a rocket delivery company include a launch and maintenance facility, payload integration, launch operations with fuel and maintenance overhead, upgrades, R&D investments, liability insurance, risk management, emergency response teams as well as many more key considerations. Likely purchasers of a rocket delivery service would include most national governments who already have a space administration, or an existing space company such as SpaceX, Blue Origin, or Virgin Galactic who already have experience and investment capital to move forward with such a venture.

3 Technology Assessment

3.1 Avionics

Avionics refers to all the electronic systems in an aircraft. Avionics can include flight computers, data monitoring, flight control etc. The avionics needed for this rocket are data acquisition, and chute control. The three methods that satisfy these needs are a combination of a simple altimeter and chute release, a dual deployment altimeter, or a full flight computer.

Simple altimeter and chute release:

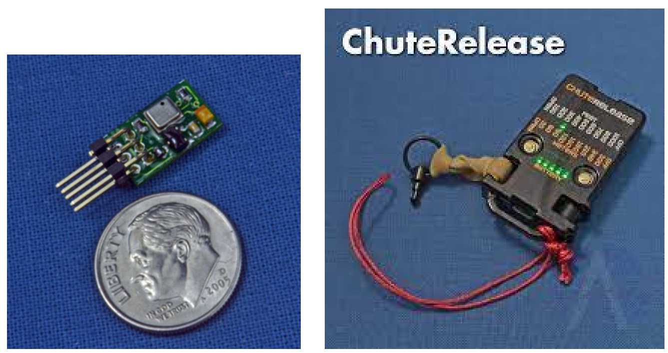

Figure 3.1.1 Altimeter and chute release [4] [5]

The combination of a simple altimeter and chute release is the simplest form of avionics that can be used to perform the necessary tasks for this application. The simple altimeter does not offer many features or acquire much data, however it does record the maximum altitude reached using a barometric pressure sensor which is the only data we have to have to have a successful launch. The chute release controls the parachute(s). Chute releases sense when the vessel begins to descend from apogee and releases one or more chutes utilizing black powder charges.

Flight Computer: Flight computers are at the opposite end of the avionics spectrum. Flight computers record altitude typically with a barometric pressure sensor and control one or more chutes same

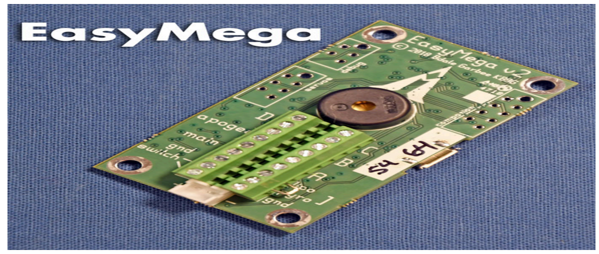

Figure 3.1.2 Flight computer [6]

as the combination of the simple altimeter and chute release but include more data acquisition and advanced features. The data acquisition abilities include recording maximum velocity and acceleration, flight time, and time to apogee. Flight computers provide more advanced options for releasing chutes, such as time delayed releases. Some advanced features found in flight computers are the ability to add servo motors to the vessel and utilization of telemetry for manual flight controls.

Dual Deployment Altimeter: Dual deployment altimeters are the happy medium between the previous two avionics methods. This variation of altimeter combines the features of a simple altimeter and a chute release into

Figure 3.1.3 Dual deployment altimeter [10]

one unit. Dual deployment altimeters record maximum height as well as maximum velocity and acceleration and provide the ability to control multiple chute releases. Many of these altimeters include features to release chutes at different points of the flight, similar to flight computers. In general, dual deployment altimeters don't provide as many advanced features as flight computers but still offer more than a simple altimeter.

Black Powder Charges and E-Matches: Black powder charges are small pouches filled with black powder. These pouches, when ignited, generate a small pyro event creating a pressure build up inside the rocket until a designated portion of the rocket separates. This separation is when the parachute is released. In order to ignite the black powder charges electronic matches or e-matches are used. E-matches are a system of two wires that carry electric current from an altimeter to an igniter to initiate the black powder pyro sequence.

3.2 Additive Manufacturing

3-D Printing: 3-D printing is split into many categories that include powder bed fusion, material extrusion, sheet lamination, etc. Fused deposition modeling (FDM) is a type of material extrusion 3-D printing that is most relevant to the presented project challenges due to its high accessibility, low costs, and low complexity.

Figure 3.2.1 3D Printer [26]

Filaments: There are many 3-D printing filaments that can be utilized for all sorts of specialized projects. Using 3-D printed material would be perfect for the nose cone and fins of the rocket. Filaments can be broken down into two categories: polymers and composites.

Polymers: The most used filaments in regards to polymers are Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), and Nylon. Nylon has a high heat resistance, is very abrasive resistant, and has very good impact strength. The only drawback is that it absorbs moisture very easily and is not biodegradable. ABS is mainly used in injection molds and is also not biodegradable. ABS is also toxic when printing which requires lots of area circulation. PLA is the cheaper option of the three and is made from corn starch, so it is biodegradable. It is very easy to use, has a low density, and can be printed at higher speeds than most other materials which can allow for more flexibility when making last minute changes to prototypes. This material would be perfect for the nose cone, fins, and other needed parts on the rocket. Polyethylene terephthalate glycol (PETG) is more heat resistant and stronger but is heavier and brittle.

Composites: Composite materials such as nylon carbon fibers and PETCF have many advantages but can only be printed by selective laser sintering printers (SLS). SLS printers are not as accessible as FDM printers and more expensive.

Specialized: A more specialized filament called PLA-Aero is commonly used for aeromodelling due to its controllable foaming ratio at specific heats which allows for massive weight reduction. This filament would be a perfect substitute for a high infill value of the rocket fins which would reduce the weight of the rocket by a significant margin and can be printed with FDM printers. The only drawback to PLA-Aero is its high cost.

3.3 Aerodynamic Body Structure & Materials

Single Stage Rocket: The single stage rocket will be the most flexible and least complex option for the presented challenge. The body tube will make up a large portion of the rocket as can be seen in figure 2. It is very important that a high integrity structural material is chosen that also has attributes that allow for flexibility in the design so that changes can be made when needed.

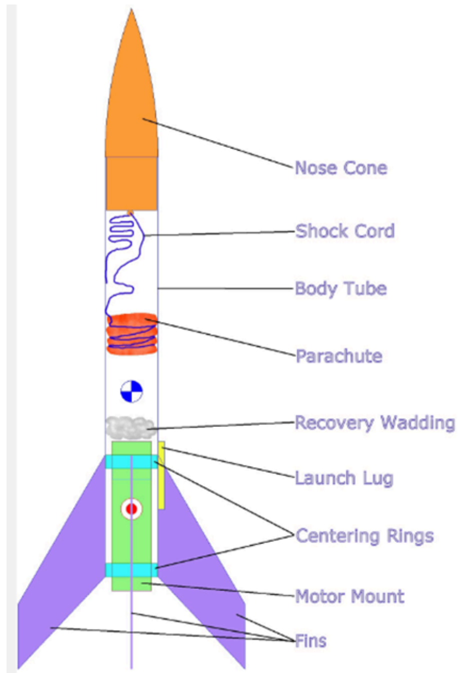

Figure 3.3.1 Model Rocket Configuration [28]

<u>Body Tube Materials</u>: The most commonly used body tube materials are tightly wound kraft paper tubes, fiberglass tubes, phenolic tubes, blue tubes, and carbon fiber tubes.

Body Tubes: Tightly wound paper body tubes have a very low weight, cost, and are very design flexible. The only problem with them is their very low availability across all suppliers and lower durability as compared to other materials. With lots of different mass components being integrated within the rocket, warping of the body tube is a strong concern with paper tubes. Phenolic tubing is pre-impregnated with resin, spiral wrapped and then heat cured. It has a much higher compression strength than paper tubes and weighs about a half a pound more. The downside to phenolic tubing is its brittleness if its compressive limits are exceeded and is a lot less design flexible. Gluing parts to it would require epoxy and any kind of manipulation to the tubing could risk it shattering. This also means that it would not be a good option if multiple launches with the same tubing is planned. Blue tube is made from a vulcanized cellulose fiber and has a way higher impact resistance than phenolic tubing. Its strength is a little bit lower than phenolic tubing but it is much more flexible. Since it is made from paper fiber it is also much more design flexible than phenolic tubing. You can shape blue tubes like paper tubes and can also use wood glue. Fiberglass tubing is made of fiberglass roving and wound in many layers. It is super strong but also super heavy. It is also a lot less design flexible than other tubing options and costs significantly more with lower availability. Carbon fiber is made of thin strands of organic polymers that are held together by carbon and then heated to extreme temperatures to perform carbonization. What’s left are long and very strong strands of carbon fiber which are wound in layers to make rocket tubes. It weighs less than fiberglass but more than the other material options. It also costs significantly more than all other material choices.

Fin Materials: The main function of the fins is to act as a stabilizer for the rocket during launch. This is done via the Bernoulli effect and the forces caused by pressure differentials on either side of the fin. The fin design and geometry also play a significant factor in determining the location of the aerodynamic center of the rocket. Because of the fins' large importance on stability the material chosen in return plays an equally large part. Different materials available have different weight and mechanical properties that will allow the use of different design shapes.

Some of the most common materials used are fin or Birch plywood for its cheap and easy machine ability. G-10 fiberglass can provide all the same characteristics as Birch plywood with the added bonus of being much stronger in tensile strength and resistance to impact forces. However this does come at an increased cost as well as increase in density per unit of materials. The increase in weight can possibly be negated depending on creative designs for fins allowing the use of thinner walls and more efficient geometry. Other possible options are 3-D printed materials such as PLA, Nylon -12, and PETG. Each material has its own benefits and mechanical properties that can be used for stable flight. The large benefit of 3-D printed material is the ease of manufacturing and low cost of each design. This could be a great advantage given a long enough build time to run multiple interactions of tests and fine tune the best possible design for each fin. Metals can also be used for fin design, however due to limited motor sizes research in metal fins was not conducted.

Figure 3.3.2 Tube Testing [3]

Criteria	**Paper**	**Phenolic**	**Blue**	**Fiberglass**	**Carbon Fiber**
Cost	$23.32	$35.53	$43.95	$115.5	> $200
Weight	1.0294	1.438	1.967	2.803	2.698
Strength	3	2	4	4	4
* Values collected at an estimated tube length of 48 inches and diameter of 98 millimeters * Weight in lbs ** 1-4 Rating system.*					

Table 3.3.1 Material comparisons for rocket body tube

3.4 Rocket and Payload Recovery System

The safe recovery of a high powered rocket carrying a payload of chicken eggs, is critical for the success of this project. In Milestone one's Technology Memo, many different mechanisms and tactics were displayed, illustrating the many different ways to safely recover a rocket from apogee. However, with a sensitive payload of chicken eggs involved, only two were deemed logical.

Separation of Payload and Rocket: Separating the payload from the rocket at apogee is a method that would greatly reduce impact forces on the eggs during landing. By separating the rocket from the payload, there would be two independent bodies descending to Earth. The payload would be void of the extra weight created by the rocket, allowing for a lower descent rate. Other benefits include more precise control over the descent trajectory, which is important when aiming for a specific landing area. Separation also ensures that no flailing rocket parts, such as a swinging nose cone or chassis, collide with the payload during descent. This method of recovery, however, comes with challenges. Keeping the payload connected to the rocket can simplify the design and deployment logistics. Complexity for this project should be minimal. Also, keeping the cargo attached to the rocket maintains a streamlined descent profile.

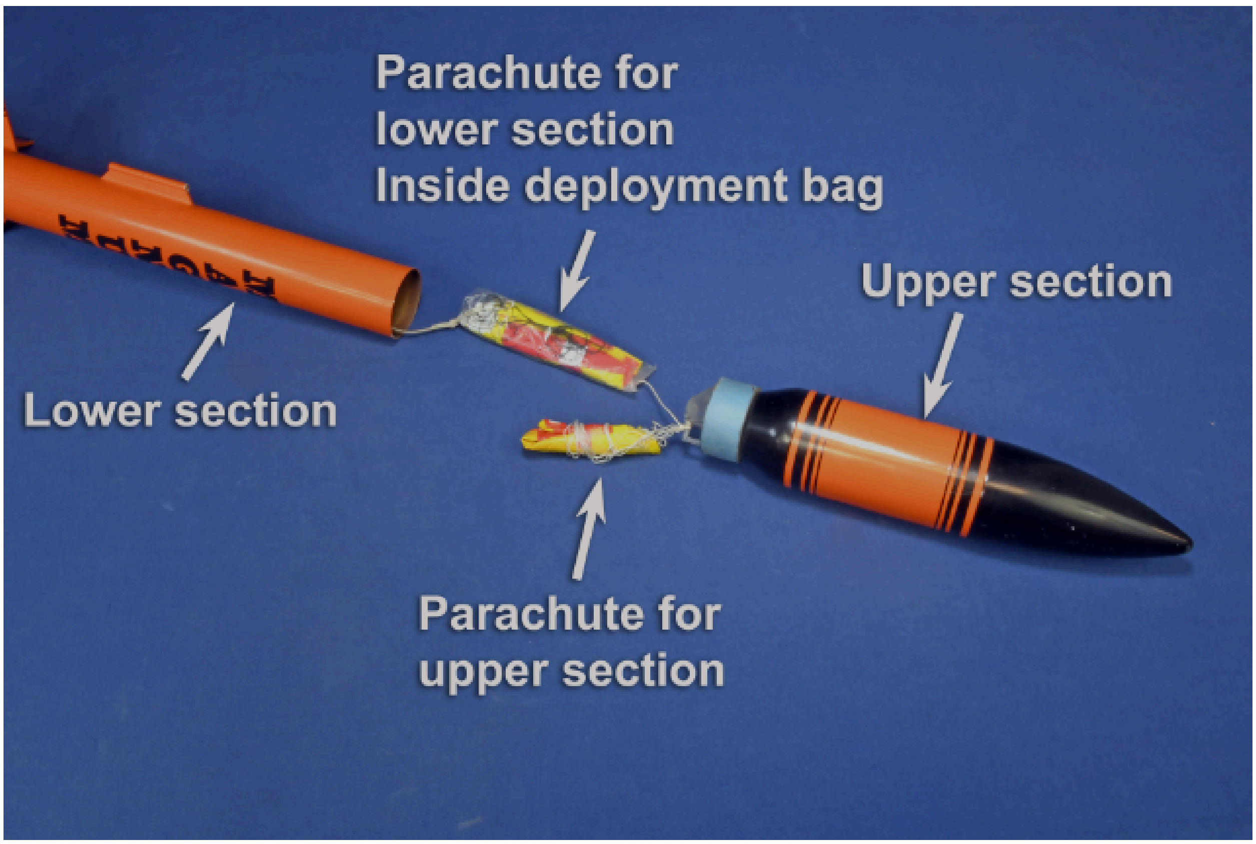

Figure 3.4.1 Parachute Assembly [8]

Dual Deployment Parachute System: Currently, the rocket for this project, with payload, weighs 5.67 lbs as per the mass properties table. According to Apogee Rockets, a 16” drogue parachute would slow the rocket to a tolerable descent rate before main parachute deployment. However, with the sensitive payload of chicken eggs onboard, a 24” drogue chute will be used. The added 8” of canopy will provide substantial drag, contributing to effective stabilization during the initial descent stage. During the final descent stage, the drogue chute will also provide added drag to aid the main chute for a softer landing. The 24” drogue parachute will give added latitude to the weight of the rocket, in the event more cargo should be included.

The main parachute for this project will serve a crucial role in the safe recovery of the eggs. A 36” canopy is an optimal size parachute that can provide a substantial amount of drag force, distributing deceleration over a greater area. The increased drag will promote a stable descent trajectory which will ensure a controlled and predictable landing for the rocket and its payload. A larger, 36” parachute is a great candidate for battling elevated winds at higher altitudes.

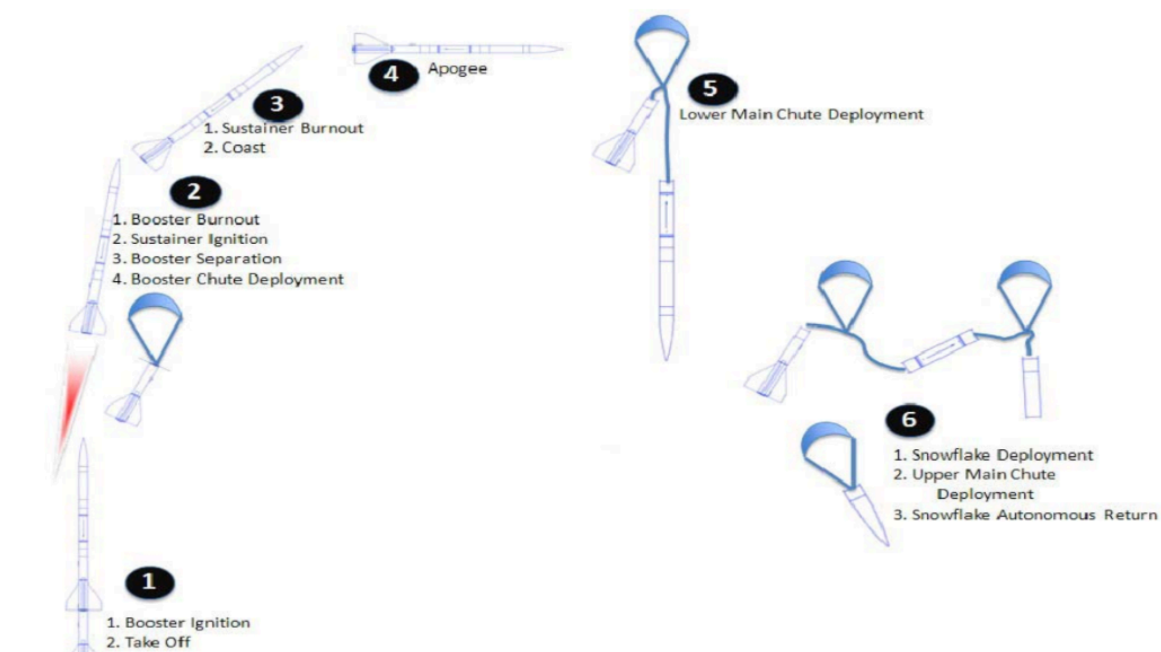

Figure 3.4.2 Launch and Recovery Path [23]

Apex Venting: Apex venting is a technique used in parachute design to modify the airflow around a parachute's apex or top. The primary purpose of apex venting, is to reduce the oscillations or swinging motions during descent and improve the parachute's stability. Here's how it works: A small vent, or opening, is placed in the center of the parachute's canopy. This vent allows air to pass through, altering the pressure distribution across the parachute. This releases pressure on the sides of the canopy, which are ultimately what are creating the oscillating motion that is affecting the stability of the rocket and its cargo during descent. This vent is especially critical when carrying sensitive payloads. Excessive swinging could lead to instability and potential damage upon landing.

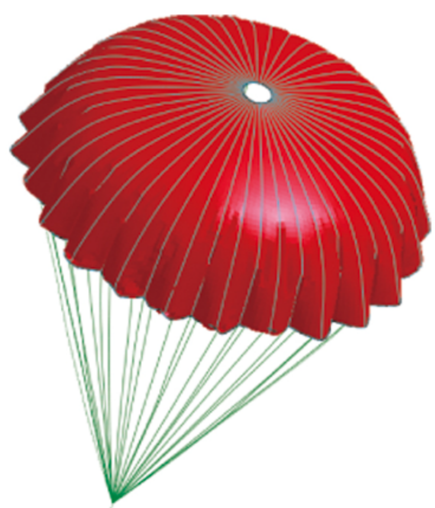

Figure 3.4.3 Apex Vent [20]

Parachute Material: Parachutes can be made out of many different materials. Certain criteria play a role in deciding what to use. This can include cost, durability, availability and practicality. When researching materials, one stood out above all of the others. Ripstop Nylon. Ripstop nylon is a fabric that is woven using a special reinforcing technique. The term ‘Ripstop’ refers to the grid pattern created by the thicker threads woven into the fabric at regular intervals. These thicker threads have higher tensile strength. Ripstop Nylon is known for its integrity and durability. It is lightweight, but also has a high resistance to tearing. This provides resilience against potential damage during takeoff, deployment or descent. Nylon has a high resistance to heat, making it a prime choice for this project. Nylon is also flexible and has good elasticity, allowing the parachute to deform under high stress and return to its original formation or shape as the stress is abated. This is crucial for landing performance. Nylon parachutes are easy to maintain, as they can be cleaned, dried and stored with relative ease, ensuring that the parachute remains in good condition when not in use. Above all, nylon is cost effective, making availability abundant. The combination of strength, durability and affordability make it a popular choice for this application.

Shock Chords: There are many different kinds of shock chords in the world of rocketry, including tubular nylon, and elastic. For this project, Kevlar will be the material of choice. Although it has less elasticity, kevlar is extremely resistant to heat and abrasions. With its exceptional tensile strength, it is a good choice for the forces that will be placed on it during parachute deployment. Kevlar shock cords are lightweight, affordable, available and will contribute greatly to the overall efficiency of the rocket.

Shroud Lines: Shroud lines play a crucial role in the deployment and stability of a parachute during descent. Shroud lines are attached to the parachute canopy at multiple points around the perimeter. These lines are also connected to the rocket's shock cord. These lines facilitate the controlled deployment of the parachute, by allowing it to unfold and inflate. They are responsible for distributing the load or forces across the parachute, evenly. This even distribution helps prevent stress concentrations on any one specific point on the parachute, contributing to structural integrity during descent. The number and length of the shroud lines influence a parachute's stability. Properly configured shroud lines contribute to a controlled descent without excessive swinging or oscillations. Having multiple lines provides redundancy in case one or more fail. This enhances the reliability of the parachute system, reducing the risk of failure during descent.

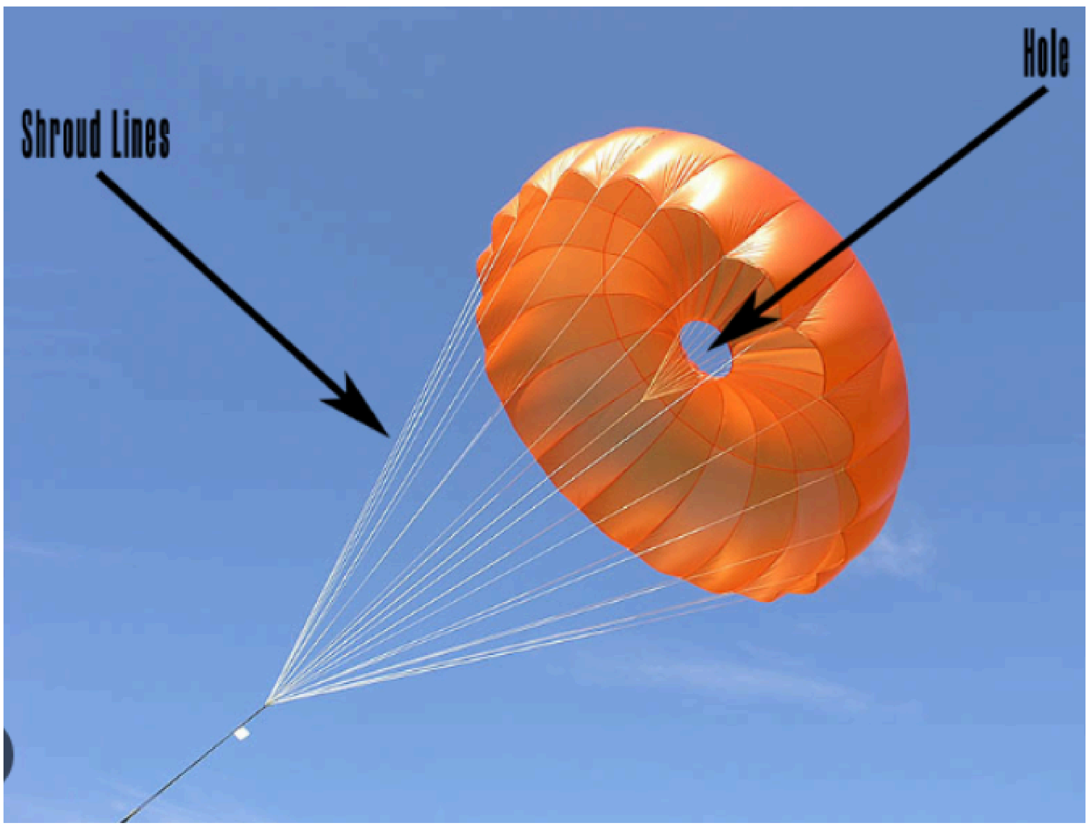

Figure 3.4.4 Shroud Lines [29]

4 System Requirements

The object of the 2k Egg drop is the simulation of delivering critical payloads across the planet. For this competition the focus will be on suborbital launch with a goal of 2000 ft AGL. The product in design is being built to effectively and efficiently deliver sensitive payload without damage to cargo and major expenses to the customers. Unlike current transportation used for goods, such as airplanes, boats, trains, and semi trucks the team's scaled model will represent the possibility that delivery by rocket is both effective but efficient. Current methods of shipment may have difficulty reaching certain regions such as mountain tops or dense jungles where medical supplies can be life saving. Methods of shipment may also take days to travel across the globe and even with planes they are limited in weight and restricted by weather or hostile conditions. Whereas a reliable rocket delivery system won't be restricted to specific weather conditions or climates and the longest time span for delivery may be only a few hours once a payload is fully loaded.

Other notable conceptions of this build can be found in the NAR "S2P Precision Payload" competition held annually. This competition encourages model rocket enthusiasts and young children to build rockets with motors limited to 60 N-sec. This only allows those rockets to be flown roughly 1000 ft and with a max lift of mass of 650g. Although much smaller than the requirements set by USSF competition the basic builds and similar techniques are used. The following are some common standards whenever launching sensitive payloads.

- Two parachutes (1- At apogee, 1- At lower predetermine alt)

- Foam/padding between eggs and rocket body
- Forward placement of payload
- 4 fins
- Elliptical nose cone

Out of these past competitions many of the same failures occurred due to less than optimal build design. Listed below are some key takeaways from past failed attempts.

- Insufficient padding between eggs and rocket body
- Lack of spacing between payload and other internal compartments
- Ineffective parachute sizing
- Non vertical flight due to lack of thrust
- Materials breaking during flight due to insufficient durability or strength

The following is the theory of operation to take place during test launch and Milestone 6.

1. LRS is attached to launch pad with corrected angle of departure for weathercocking and safety regulations
2. Launch is initiated with sufficient thrust to stabilize rocket once free of guide rails
3. During climb to 2000 ft AGL the payload will be protected by foam padding, springs, and damping pucks to minimize vibrations
4. Seconds after apogee the first drogue chute will deploy to slow terminal velocity and minimize drift from launch site
5. Once at 500 ft AGL Main parachute will deploy and bring the impact velocity at or below 25 ft/s.

6. Team will locate payload, via GPS tracker
7. Payload will then be removed from LRS and inspected for integrity

The overall function and goal of the LRS is to add a viable option as a means to deliver and transport goods to locations anywhere and anytime around the globe. This means the ease of packaging will not be drastically complicated or sensitive. The payload design will be made as such that it is not much more difficult, if at all, than shipping product across the country in an airplane or vehicle. The difference and benefit will be the versatile and timely delivery of the goods if full scale production is ever to be reproduced.

Requirements were set in order to ensure the USSF and the team had clear goals and understandings of engineering tasks to be completed in order to provide an effective product to customer standards. A few of the most crucial requirements for success are laid out below with an explanation of the importance as to why these requirements were set.

The LRS -03 requirement is one of the few directly outlined in the competition handout. This requirement must be achieved to meet the minimum standards set by the USSF.

[LRS - 03] The LRS shall be capable of flight and reach a minimum altitude of 2000 ft above ground level (AGL).

LRS - 04 exists to ensure that not only the safety of the payload but of the operators around the launch pad. Without a stable rocket flight no successful delivery of a payload will be possible.

> ***[LRS - 04] The LRS shall engage in stable flight.***

LRS - 07 and LRS - 09 are requirements made to directly address the delivery stages (2-7) previously mentioned in the theory of operation. The most critical requirement is the safety of the payload. The entire build of the LRS is designed around the optimal payload configuration. The importance of the payload success can not be stressed enough as the number 1 requirements to successfully achieve.

> ***[LRS - 07] The LRS shall have a subsystem capable of transporting the cargo from launch to recovery phases.***
> ***[LRS - 9] The LRS shall contain a specialized cargo bay within the chassis that will house at least 1 chicken egg.***

The LRS will need to comply with local laws and standards established for both safety and legal reasons. LRS - 15 will ensure design and analysis will ensure that the team’s product is one built with ethics and morality involved in its production.

[LRS - 15] The LRS shall comply with all FAA, NAR, TRA and local gov't guidelines to ensure appropriate steps are taken to mitigate risk. Effective October 17, 2023

The design of the LRS must be compatible with the customers standard launch interface. In the case of the competition Requirement 16 will include a hearing to the guided rail system TRA has set at their local launch site in Palm Bay.

[LRS- 16] The LRS shall be capable of being armed on a launch pad and guide rail provided by the Tripoli Rocketry Association (TRA) Effective October 17, 2023

In order to make a realistic and useful product the LRS must be usable in the environments that it will be deployed to and launched from. Requirement 17 will ensure the construction and materials being selected are capable of flight in the predetermined location of Palm Bay.

[LRS - 17] The LRS shall be capable of launching in clear weather conditions that are standard at the Palm Bay launch site during the month of Apr.

5 Concept Generation and Selection

5.1 Concept Generation

The primary problem being addressed is the handling and protection of a sensitive payload via rocket transportation. The solution to solve this issue will be the combination of seven main subcomponents. Given the team's limits from the USSF competition the scope of solution is enclosed by the limitations of a level 1 High Powered Rocketry License. Meaning rocket motors of H and I impulsive levels and the use of a traditional rocket design. Basic functional requirements the product will achieve is stable flight, solid motor propelled, a payload capable of carrying and transporting chicken eggs and a height of 2000 ft AGL is achieved. Outside of these customer given requirements the team has conducted research for components that will ensure the previous functionalities are met. Past launch attempts of eggs in rockets usually fail due to inadequate padding and protection for the eggs. As well as failure to properly predict the impact velocity in which the rocket descended pack to earth. This failure is related directly to the parachute size and deployment.

Learning from past efforts the LRS in development will be designed to ensure sufficient protection and spacing is given between eggs and other crucial components. Extra attention to parachute configuration and sizing has also been highly emphasized throughout early development to ensure a safe landing for the payload.

5.2 Concept Selection

Each subcomponent will play a crucial job to ensure the mission objective of the competition and the requirements set between the team and customer are met. Several different criteria went into selecting and categorizing each subcomponent, such as cost, weight, durability and others that specifically addressed concerns with each subcomponent. Modified Pugh selection matrices were made in order to more clearly organize and compare the team's findings of alternative solutions.

Below are the top 3 subcomponent solutions that each team member had found to best fit the team's conceptual design. Every subcomponent is unique in its task of functionality. Therefore different criteria were established to rate each component. However, weight ratings for each component's criteria were discussed in detail among the team as a whole to ensure time and focus was being spent solving the biggest issues each component will encounter. The weights seen in Figure xx used in the Pugh Matrices are percentages out of 100%, divided between each criteria with the most important having the highest percentage

Criteria	**Weighted Importance %**
Reliability	15%
Accuracy	10%
Cost	20%
Weight	20%
Dimensions	5%
Availability	15%
Features	15%
Totals	100%

T*able 5.2.1 Weighted Importance Example*

The percentage is then multiplied by a given rating, seen in Figure xx, that comes from the component's effectiveness in the criterias selected for the component to be evaluated by.

Rating	Value
Unsatisfactory	0
Tolerable	1
Fair	2
Good	3
Great	4

Table 5.2.2 Rating Example

The resulting sum of all multiplied values is a number that represents the overall effectiveness the component will have in successfully fulfilling all build requirements for the product.

5.3 Alternate subcomponent solutions

5.3.1 Avionics

The main functions of the avionics system are to verify that the requirement of 2000 ft AGL was achieved during flight and to release the parachutes at and/or after apogee is reached. There are other methods other than avionics to complete this requirement however as a team it was decided that an avionics system is the best method to achieve a successful flight.

EasyMega Flight Computer:

		EasyMega Flight Computer	
Criteria	Weight Importance	Rating	Weighted Rating
Reliability	15%	4	0.6
Accuracy	10%	4	0.4
Cost	20%	1	0.2
Weight	20%	4	0.8
Dimensions	5%	1	0.05
Availability	15%	2	0.3
Features	15%	4	0.6
Totals	100%		2.95

Table 5.3.1.1 EasyMega FLight Computer

The EasyMega flight computer is the top option for flight computers. The EasyMega is incredibly accurate and reliable. It has the team's required features such as maximum altitude data and chute control. It also has the most advanced features of any avionics unit we considered. The EasyMega includes an event timer, accelerometer, gyro tilt sensors, and active telemetry. The accelerometer provides data on maximum velocity and acceleration. The gyro tilt sensors provide location information of the rocket in 3D space. The telemetry capabilities allows the team to view data wirelessly from the ground and make live adjustments mid-flight. These additional advanced features and data acquisition are very useful however the cost to get these functions is too great as the EasyMega costs approximately $360.00. In addition to the high cost there are very few available units to purchase because they are a niche avionics system intended for larger, more sophisticated vessels such as L3 level rockets.

Pros:

- Extremely accurate
- Extremely reliable
- Low weight
- Advanced data recording
- Many Advance Features

Cons:

- Cost
- Unnecessary features
- Size

Chute Release (Jolly Logic) + Adrel Altimeter

		Chute and Altimeter	
		Chute Release (Jolly Logic) +	
Criteria	**Weight**	**Rating**	**Weighted Rating**
Reliability	15%	4	0.6
Accuracy	10%	3	0.3
Cost	20%	2	0.4
Weight	20%	3	0.6
Dimensions	5%	1	0.05
Availability	15%	3	0.45
Features	15%	1	0.15
Totals	100%	**2.55**	

Table 5.3.1.2 Chute Release (Jolly Logic) + Adrel Altimeter

The next alternative solution for the avionics component is a chute release and altimeter combination. These devices in combination allow us to meet the requirements of maximum altitude verification and parachute release to aid in recovery. The simple altimeter calculates the altitude using a barometric pressure sensor. The chute release utilizes an accelerometer to release one or more chutes when it begins to descend from apogee. These systems are incredibly simple in comparison to the other avionics methods which makes them accurate and incredibly reliable. The trade off is that the simple altimeter lacks some of the more advanced data acquisition and features that will be useful during testing. Although the systems are simple they do not reduce cost by a dramatic amount and the size of the chute release is large creating a more difficult fitment compatibility.

Pros

- Reliability
- More Fail safes
- Availability

Cons

- Large space needed within design
- Lack of advanced data acquisition
- Lack of advanced features

Blue Raven

		Blue Raven	
Criteria	Weight	Rating	Weighted Rating
Reliability	15%	4	0.6
Accuracy	10%	4	0.4
Cost	20%	3	0.6
Weight	20%	4	0.8
Dimensions	5%	4	0.2
Availability	15%	4	0.6
Features	15%	4	0.6
Totals	100%		3.8

Table 5.3.1.3 Blue Raven

The Blue Raven system is a dual deployment altimeter. The Blue Raven altimeter provides accurate and reliable flight data. It provides the required altitude data as well as velocity, acceleration, and time of flight that will be useful during testing. The dual deployment function of this altimeter allows for more advanced chute release options compared to the chute release previously discussed. These options include ejection at descent, timed ejection, and manual ejection allowing the team to actively stage more precise chute release for multiple chutes. The Blue Raven uses telemetry to communicate with a mobile phone app allowing the team to track live flight data and manually eject chutes if needed. The Blue Raven is affordable, however it can be difficult to obtain if it is needed to be purchased via commerce. (We have access to a Blue Raven altimeter)

Pros

- Accurate
- Easily available
- Light weight

- Mobile phone app
- Advance data acquisition
- Advanced features

Cons

- Fewer features than a flight computer

RRC3 “Sport”

		RRC3 "Sport" Dual Deployment Altimeter	
Criteria	Weight Importance	Rating	Weighted Rating
Reliability	15%	3	0.45
Accuracy	10%	3	0.3
Cost	20%	4	0.8
Weight	20%	3	0.6
Dimensions	5%	3	0.15
Availability	15%	4	0.6
Features	15%	3	0.45
Totals	100%		3.35

Table 5.3.1.4 RRC3 “Sport”

The RRC3 “Sport” is a dual deployment altimeter similar to the blue raven. It is reliable, accurate, affordable, and available. Similar to the Blue Raven it records peak altitude, and velocity. While other information like acceleration and flight time can be derived. The RRC3 has similar dual deployment capabilities as well. It will allow chutes to be ejected at apogee and on a delayed timer allowing the team to manage multiple chute releases. The RRC3 has many optional add-ons available to purchase such as telemetry units and gps. However these units would be an additional expense on the budget and increase the weight of the unit.

Pros

- Cost
- Availability
- Data acquisition

Cons

- Advanced features require add-ons

After compiling a weighted importance chart for several avionics methods the team concluded that a dual deployment altimeter is the best option. A dual deployment altimeter provides the team with the means to stage a successful flight and gives the team access to some advanced features and data acquisition that will be useful during testing. The RRC3 is a good option, however the Blue Raven is the best option. The data acquisition and chute control is similar in both altimeters but the mobile phone app feature of the Blue Raven sets it apart from the rest.

5.3.2 Body Tube Materials

The main characteristics of the material used for the body needed for a successful launch are durability, machinability, and lightweight. One goal for the LRS is that it can be launched multiple times. Therefore decreases overall cost with every successful launch and can increase the speed at which more sensitive payloads can be launched.

Fiberglass Tube

		Fiberglass Tube	
Criteria	Weight Importance	Rating	Weighted Rating
Low Cost	15%	2	0.3
Strength	30%	4	1.2
Availability	15%	1	0.15
Low Weight	30%	0	0
Design Flexible	10%	0	0
Totals	100%		**1.65**

Table 5.3.2.1 Fiberglass Tube

A body tube made of fiberglass offers superior strength that it had to be matched by most other materials available for model rocketry. Fiberglasses' massive yield strength would allow for many reuses and decrease the likelihood of structural failure. However due to its heavy body and difficult machinability it is not an ideal material to work with given time restraints.

Pros

- Large yield strength
- High useability

Cons

- Difficult to machine
- Heavy
- expensive

Wound Kraft Paper Tube

		Wound Kraft Paper Tube	
Criteria	**Weight Importance**	**Rating**	**Weighted Rating**
Low Cost	15%	4	0.6
Strength	30%	3	0.9
Availability	15%	1	0.15
Low Weight	30%	4	1.2
Design Flexible	10%	4	0.4
Totals	100%		**3.25**

Table 5.3.2.2 Wound Kraft Paper Tube

Wound Kraft is the standard material to make a level 1 model rocket body from. The materials provide sufficient strength while still remaining lightweight at a low cost per unit. Due to its popularity though, it may be difficult to acquire in time necessary to proceed forward given time restraints. Another major concern with Wound Kraft is it is made of condensed cardboard. Meaning the structural integrity can be easily compromised if exposed to high levels of moisture. This greatly affects its reusability and the ability to be used in multiple locations.

Pros

- Light weight
- Sturdy
- Easily machined

Cons

- Low availability
- Easily compromised with water

Blue Tube

		Blue Tube	
Criteria	Weight Importance	Rating	Weighted Rating
Low Cost	15%	4	0.6
Strength	30%	4	1.2
Availability	15%	4	0.6
Low Weight	30%	2	0.6
Design Flexible	10%	3	0.3
Totals	100%		**3.3**

Table 5.3.2.3 Blue Tube

Blue tube originally started in military applications used for tank ammunition due to its durable material properties. Blue tube is a type of vulcanized cellulose fiber that offers more resistance to abrasion and has no cracking or brittleness. At a lower cost than carbon fiber and a strength that rivals fiberglass, Blue tube offers a perfect balance between strength and machine ability.

Pros

- Low Cost
- High Durability
- Readily available

Cons

- Increases overall weight

5.3.3 Nose Cone Design

The nose cone design serves the purpose of lower drag due to air resistance. Depending on flight path and objective, different designs have different benefits. The designed path will take place in a subsonic and suborbital flight.

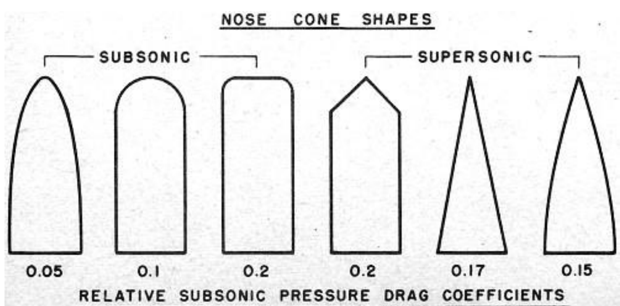

Figure 5.3.3.1 Nose Cone Drag [1]

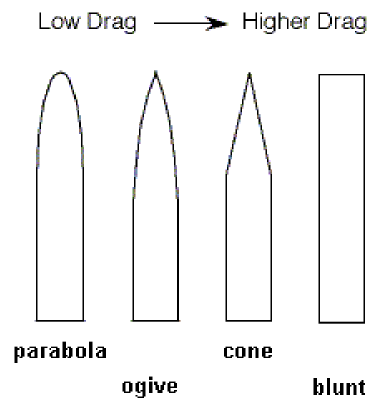

Figure 5.3.3.2 Nose Cone Shapes [9]

Conic

		Conic	
Criteria	Weight	Rating	Weighted
Durability	25%	2	0.5
Cost	20%	4	0.8
Weight	25%	2	0.5
Manufacturing	15%	3	0.45
Accquire Time	15%	3	0.45
Totals	100%		**2.7**

Table 5.3.3.1 Conic

A conic nose cone refers to a more prominent nose point with a straight edge leading to the full diameter of the body. This design is far better than a blunt flat end but still does little to decrease the effects of air resistance.

Ogive

		Ogive	
Criteria	Weight	Rating	Weighted
Durability	25%	4	1
Cost	20%	4	0.8
Weight	25%	3	0.75
Manufacturing	15%	3	0.45
Accquire Time	15%	4	0.6
Totals	100%	3.6	

Table 5.3.3.2 Ogive

Ogive shaped nose cones are similar to a conic but with a less dramatic edge that leads to a point on the nose cone tip. The Ogive does improve upon the traditional conical nose cone design however, with a sharper tip it still is not the optimal design for a subsonic flight.

Parabolic

		Parabolic	
Criteria	Weight	Rating	Weighted
Durability	25%	4	1
Cost	20%	3	0.6
Weight	25%	4	1
Manufacturing	15%	3	0.45
Accquire Time	15%	4	0.6
Totals	100%	3.65	

Table 5.3.3.3 Parabolic

Parabolic is by far the best option for the given design requirements of this competition. A parabolic nose cone has a more rounded tip and softer curves that lead to the full diameter. It has been experimentally tested that the average drag coefficient for a parabolic nose cone is .05.

Material

There are two options for the manufacturing of the nose cone: purchasing an already made nose cone or utilizing a 3D printer to build one. Purchasing a nose cone could be done from Apogee Rocket or another part retailer at a relatively low cost. However, finding a nose cone that fits the diameter of the rocket, is the correct length, a light material, and cheap is going to be hard to find. Utilizing a 3D printer allows the team to pick the exact specifications of the nose cone and gives the design much more freedom. PLA (Polylactic Acid) is the best option for material due to the ease of manufacturing and low cost that it provides to the design.

5.3.4 Fin Materials

Fins are a model rocket are essentially the means to guarantee a stable flight can be achieved. The stability value a rocket has is greatly affected by the size and geometry of each fin. Due to the high importance of the geometry for the fins, manufacturing ease can not be overlooked. The amount of fins a rocket has also greatly affects the stability. Usually the more fins a body has the more stable with the only downside really being the increased weight. Due to this factor the rocket in design will have four fins to maximize the effects on stability.

PLA

		PLA	
Criteria	Weight	Rating	Weighted
Durability	25%	2	0.5
Cost	20%	4	0.8
Weight	25%	3	0.75
Manufacturing	15%	3	0.45
Accquire Time	15%	3	0.45
Totals	100%		2.95

Table 5.3.4.1 PLA

Polylactic Acid also known as PLA is one of the most commonly used materials for 3-D printing. Since PLA can be 3-d print the manufacturing process for fin can be extremely quick given experience in CADing and 3-D printing. Due to the process of 3-D printing, the overall durability of the fins can be susceptible to cracks and chips if struck with blunt force.

Pros

- Low cost
- Easily manufactured
- Light weight

Cons

- Low impact durability
- Requires experience with 3-D printing

Birch Plywood

		Birch Plywood	
Criteria	Weight Importance	Rating	Weighted Rating
Durability	25%	2	0.5
Cost	20%	4	0.8
Weight	25%	3	0.75
Manufacturing	15%	4	0.6
Accquire Time	15%	4	0.6
Totals	100%		3.25

Table 5.3.4.2 BirchPlywood

Birch Plywood is a close runner up for fin material choice. The plywood can be easily manufactured to almost any shape using a laser cutter, it's lightweight, and can easily be purchased at any hardwood store or ordered online. The only drawback is the durability isn't much better than PLA. Instead of completely snapping like PLA might upon impact the plywood will likely chip, which is not a catastrophic failure but greatly lowers the amount of longtime reusability.

Pros

- Light weight
- Easy manufacturing
- Low cost

Cons

- Low impact durability
- Susceptible to damage from moisture

G-10 Fiberglass

		Fibre Glass	
Criteria	Weight	Rating	Weighted
Durability	25%	4	1
Cost	20%	3	0.6
Weight	25%	3	0.75
Manufacturing	15%	4	0.6
Accquire Time	15%	3	0.45
Totals	100%		3.4

Table 5.3.4.3 G-10 Fiberglass

Fiberglass was chosen as the team's fin material due to its high level of resistance to impact and chipping. G-10 fiberglass specifically was designed for use in the aerospace industry and is made for the common types of forces and impacts that a model rocket will encounter during a full launch and recovery. G-10 fiberglass cost still remains relatively low and can also be easily manufactured in a laser cutter such as the Birch plywood. The fiberglass does have a higher density that increases the weight however this can be negated due to its strength by making the fins thinner.

Pros

- Durabile
- Easily manufactured
- More streamline designs available

Cons

- Heavy material
- May take a few weeks to acquire

5.3.5 Payload Handling

The payload may be the most critical component of this project. Carrying chicken eggs to 2000 feet and returning them safely to Earth, requires a cargo hold that can provide maximum protection against aerodynamic forces that will be placed on the rocket throughout the duration of the flight. To achieve this kind of protection, the cargo hold must be constructed in such a way that the security of the eggs is not compromised. To ensure that the frame of the payload area is strong enough to fully protect the payload, but yet light enough to keep the rocket's center of gravity above the aerodynamic center. To achieve this, the cargo hold will be 3-D printed using lightweight and durable PLA filament. Within the cargo holding area, the eggs will be nested within EVA foam. EVA foam is lightweight but firm enough to stave off damaging forces that will be placed on the eggs during flight. The eggs will be stacked vertically inside of the EVA foam as the strength in the eggs shell lies in the top and bottom.

Insulation

The team's goal for the launch includes protecting the payload of eggs from any damage and while a large part of that is protecting the eggs from acceleration or fall damage, another risk is heat from the rocket motor. Eggs are not very resilient to heat, hence why you can cook them, so protecting the eggs in the payload from the heat that is dissipated from the motor is an important aspect of this launch.

“Dog barf” is the nickname for insulation material that is often used in rocketry to protect the payload and parachute from the heat of the motor. The selection of material for insulation is an important factor in the protection of the eggs during launch; however, the heat must be dissipated somewhere and thus the material selected must block enough heat that the eggs do not cook but not so much heat that the motor overheats due to the heat being trapped around it.

Insulation is measured utilizing the R-value which measures how well insulation can prevent the flow of heat. A high R-value will completely block all heat flow while a low R-value will only absorb some heat flow and allow a majority through. Closed cell spray foam and foam boards typically have the highest R-value for insulation materials at an R-value of 5-7 while fiberglass typically has the lowest R-value for insulation starting at an R-value of 2.

Wadding Sheets

		Wading Sheets	
Criteria	**Weight Importance**	**Rating**	**Weighted Rating**
Durability	25%	3	0.75
Cost	20%	3	0.6
Weight	25%	4	1
Manufacturing Time	15%	3	0.45
Accquire Time	15%	4	0.6
Totals	100%		**3.4**

Table 5.3.5.1 Wadding Sheets

Wading sheets are a common option for insulation in a level 1 rocket to protect the parachute from the heat emitted from the engine. Wading sheets are relatively cheap for a single launch, however the price of wading sheets begins to add up after multiple launches. Additionally, wading sheets do a good job of protecting the parachute from damage, however the protection of a payload system that is easily damaged by heat is unknown and thus this option can become risky for a payload of eggs.

Cellulose

		Cellulose	
Criteria	**Weight Importance**	**Rating**	**Weighted Rating**
Durability	25%	4	1
Cost	20%	4	0.8
Weight	25%	3	0.75
Manufacturing Time	15%	3	0.45
Accquire Time	15%	4	0.6
Totals	100%		**3.6**

Table 5.3.5.2 Cellulose

Cellulose has an R-value of 3.5 per inch making it fire resistant while still allowing small amounts of heat through. It has the ability to absorb large amounts of heat while not completely blocking airflow, exactly what is needed for the rocket. Cellulose is also extremely cheap and large amounts can be bought for a few dollars at retailers such as Lowe's and Home Depot.

There are many reviews by individuals who have used cellulose as their form of insulation in their rocket over wadding paper and have claimed the vast improvement that cellulose has not once allowed any impact on their parachutes and have provided great protection to any payload in the rocket.

5.3.6 Rocket Motors

To achieve any of the goals set by the team, the prerequisite requirement of reaching an altitude of 2000ft needed to be met. While other components are important to achieve this requirement; the rocket motor is the only component that can generate the force required to meet that need. The main criteria examined when picking a rocket motor was naturally the impulse provided by the motor. If a motor was not capable of reaching the target altitude given preliminary mass and drag characteristics - that motor received an overall unsatisfactory rating, and more powerful motors were analyzed.

Cost of the motor was the second main criteria examined, to determine in future cost analysis if that motor was too expensive and a less powerful but cheaper alternative was necessary for the project. Initial thrust and weight were also examined for stability purposes of the rocket during launch and flight conditions respectively. Certain rocket motors are reusable and after a flight a new motor can be reloaded easily; because the team is planning test launches this criterion was also examined. Finally, max acceleration is an important factor when protecting the payload: in this case a low maximum acceleration received a higher grade.

Cesaroni I-170

		Cesaroni I170	
Criteria	**Weight Importance**	**Rating**	**Weighted Rating**
Impulse	35%	1	0.35
Cost	25%	3	0.75
Initial Thrust	15%	2	0.3
Weight	10%	3	0.3
Reusability	10%	4	0.4
Max Acceleration	5%	3	0.15
Totals	100%		**2.25**

Table 5.3.6.1 Cesaroni I-170

The Cesaroni I170 is a reusable I level powered motor that has a lower total impulse compared to other alternatives - as such less payload can be brought to the target height. The motor does provide a low maximum acceleration and is cheap and lightweight. Due to its low power, initial thrust is also low and could provide stability issues – however as the rocket would be lighter in the event this motor is used a lower initial thrust is not problematic.

Pros

- Reloadable
- Low cost
- Light weight
- Low Maximum Acceleration

Cons

- Low total impulse
- Low initial thrust

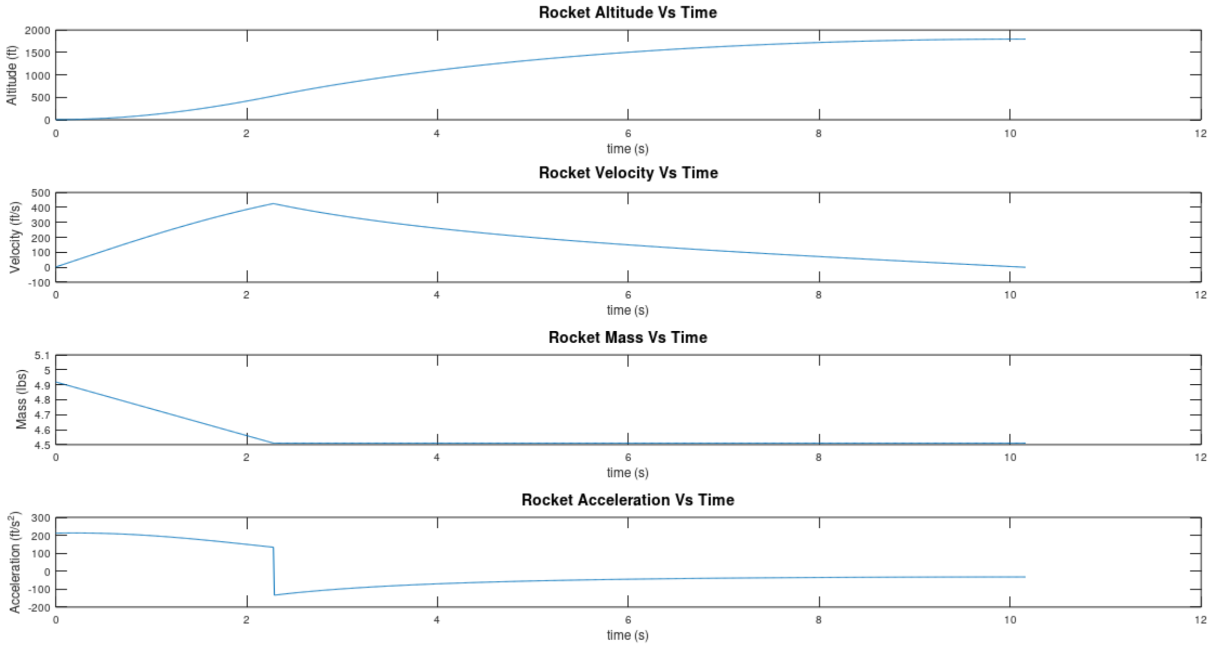

Figure 5.3.6.1 Cesaroni I-170 Simulated Values from Launch to Apogee (Section F)

Aerotech I-280

		AeroTech I280DM-14A	
Criteria	**Weight Importance**	**Rating**	**Weighted Rating**
Impulse	35%	3	1.05
Cost	25%	2	0.5
Initial Thrust	15%	4	0.6
Weight	10%	1	0.1
Reusability	10%	1	0.1
Max Acceleration	5%	1	0.05
Totals	100%		**2.4**

Table 5.3.6.2 Aerotech I-280

The next option for a motor is the Aerotech I-280. This motor provides two large advantages: a high initial thrust and a large total impulse. The large total impulse provides enough force to get the LRS well over the 2000 ft AGL requirement which allows for a greater payload. The motor is moderately priced compared to other alternatives but is not reusable. The high weight of the motor could pose a challenge to stabilize the rocket, but the high initial thrust balances this issue. Finally the motor has the highest maximum acceleration of any of the alternatives which could prove a serious challenge in protecting the payload.

Pros

- Large initial thrust
- High total impulse

Cons

- Nonreloadable
- Heavy
- High max acceleration

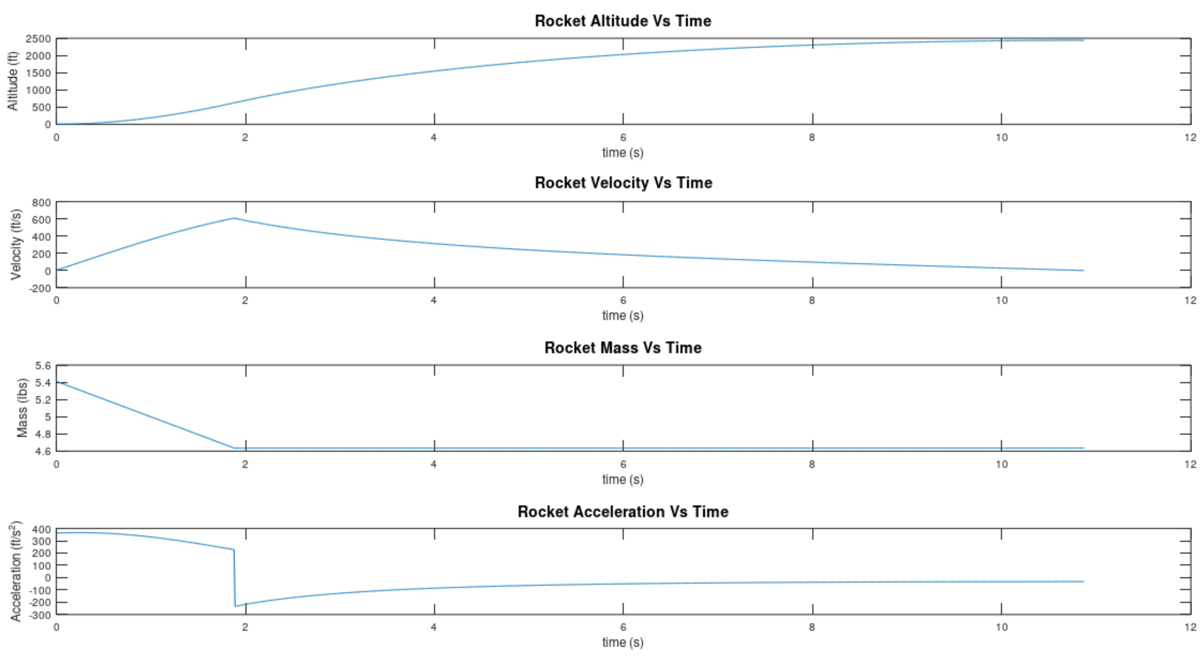

Figure 5.3.6.2 Aerotech I-280 Simulated Values from Launch to Apogee (Section F)

Cesaroni I-216

		Cesaroni 636I216-14A	
Criteria	Weight Importance	Rating	Weighted Rating
Impulse	35%	4	1.4
Cost	25%	1	0.25
Initial Thrust	15%	4	0.6
Weight	10%	1	0.1
Reusability	10%	4	0.4
Max Acceleration	5%	2	0.1
Totals	100%		2.85

Table 5.3.6.3 Cesaroni I-216

The motor with the best overall features needed to fulfill all requirements for competition is the Cesaroni I-216 motor. This motor has the highest total impulse of all the alternatives discussed and is at the cusp of the classification of an I motor. Given the amount of force generated the rocket is simulated to achieve an altitude of over 2100 ft AGL while carrying a payload of 21 eggs. This motor provides a high initial thrust alongside a high weight - which would face similar challenges to the AeroTech I-280 motor. Additionally, the Cesaroni I-216 also has a lower max acceleration and is also reusable. While the Cesaroni I-216 outperforms the rest of the motors discussed it comes at a cost – as the most expensive motor analyzed yet.

Pros

- Exceeds height requirement
- Reloadable
- Large Initial thrust

Cons

- High cost
- Heavy

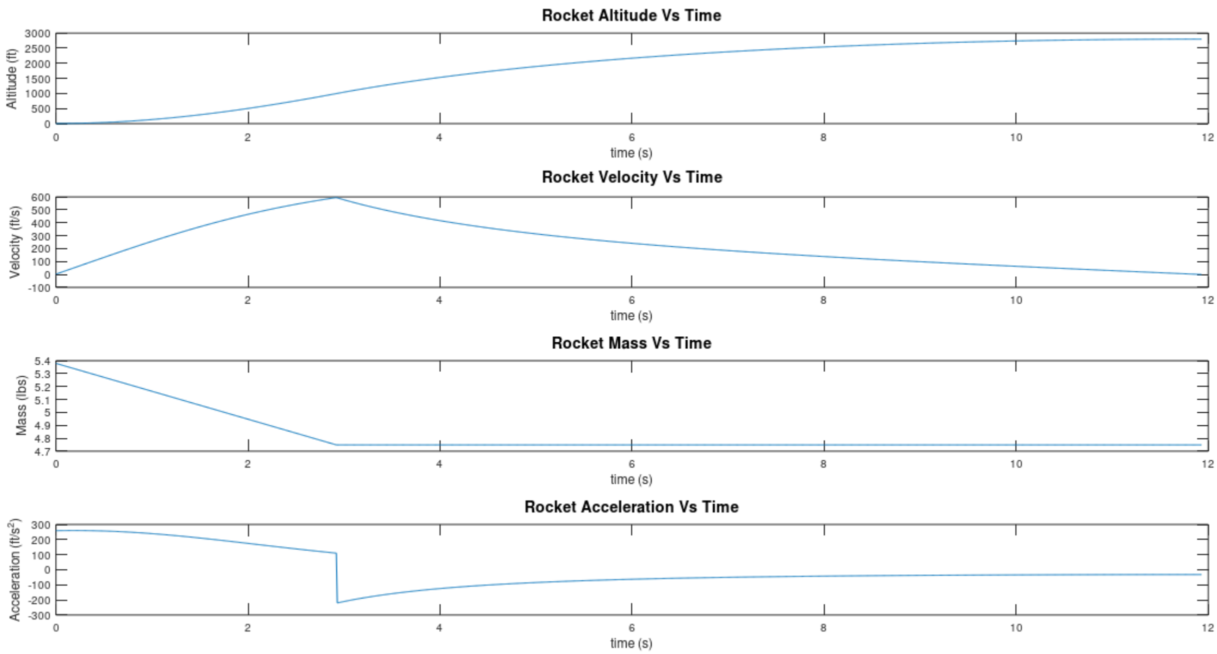

Figure 5.3.6.3 Cesaroni I-216 Simulated Values from Launch to Apogee (Section F)

Cesaroni I-216								
Velocity of rod (ft/s)	Apogee (ft)	Velocity at deployment (ft/s)	Optimum delay (s)	Max Velocity (ft/s)	Max Acc. (ft/s^2)	Time in apogee (s)	Flight time (s)	Impact velocity (ft/s)
35.5	2210	25.7	9.1	372	219	12.1	101s	24.3

Table 5.3.6.4 Cesaroni I-216

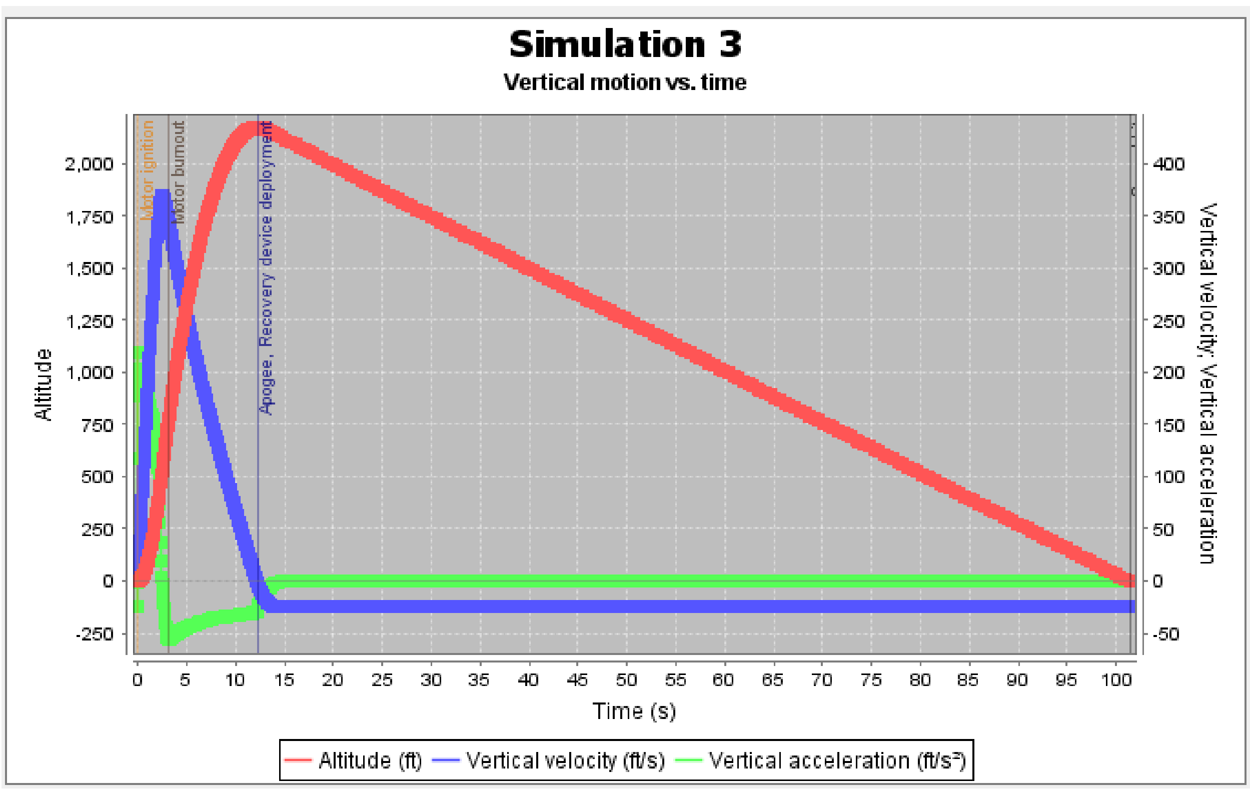

Figure 5.3.6.4 OpenRocket Simulation of Cesaroni I-216

5.3.7 Parachute Recovery System

The requirements for this project state that a rocket carrying a specific amount of eggs, must reach an altitude of 2000 feet and safely be recovered with all eggs on board, fully intact. To be successful in performing this task one must weigh the different options available and use those options to derive a strategy. Section 3.4 of this report illustrated some options that were deemed plausible for this project. One option was to separate the payload from the main rocket and have both bodies return to earth independently, with their own single parachutes. There were pros and cons to this idea:

Pros

- Payload capsule is not burdened with the extra weight of attached rocket
- Being unattached from the rocket, the payload would have a more stable descent
- The payload would not suffer damage from attached rocket parts flailing due to aerodynamic forces.

Cons

- High risk of rocket and payload bay colliding at separation
- High risk of both parachutes involved becoming entangled
- The complexity of separating the two bodies, and then deploying parachutes for the rocket and the payload. 3 ejection charges required
- Two separate avionics components, one for each entity

Another idea discussed in Section 3.4 was a dual deployment parachute system. This recovery system would deploy a 24” drogue parachute at apogee, where the rocket and the connected payload would descend to an altitude of 500 feet. At this altitude, a main 36” parachute would be deployed and the final descent phase would ensue. There were pros and cons to this option as well:

Pros

- The final descent phase would have two parachutes providing extra drag ensuring a slower landing speed
- Having two parachutes would offer more stability during descent
- With the drogue chute having a higher rate of descent, the rocket will come down vertically, eliminating drift.

Cons

- Many moving parts creating a complex environment, increasing risk factor
- Drogue parachute deployment failure would cause potential main chute rupture/failure
- Main parachute deployment failure would cause rocket and payload to land at an unacceptable rate, causing great damage
- Parachute entanglement during deployment or descent

Both options involved have been ruled out due to the cons outweighing the pros. This leaves one viable option on the table. A single, main parachute delivery system that can safely recover the rocket with payload intact:

Pros

- One simple deployment system with one ejection charge
- No risk of parachute entanglement
- Reduced weight onboard the rocket

- More room available for payload or parachute protective wadding
- Lower cost in that only one parachute will be purchased as opposed to two
- Higher drag forces with one larger parachute, ensuring a softer landing

Cons

- If parachute fails, there is no back up
- Deploying a larger main parachute at apogee runs a high risk of drift due to winds
- Larger parachutes have a higher risk of material rupture or inversion

With the pros outweighing the cons, this project will move forward with a single, main parachute deployment at apogee. The parachute size will range between 48” to 60” depending on the final weight of the rocket and its payload. At the time of writing this report a final weight has not been determined, therefore a size has not been chosen.

6 Preliminary Engineering Analysis

6.1 Egg Structure

The structural integrity of the eggs needed to be tested before decisions could be made on the motor size and type and the payload housing structure. A drop test and a centrifugal force test were conducted to determine the g-force and impact velocity that an average egg could withstand without cracking.

Drop Test

The drop test was used to determine the impact velocity an egg could withstand before breaking. This test translates to the recovery process of the rocket. The eggs were dropped from two known heights with five attempts done at each height. PVC pipe was used to guide the egg to ensure it landed in the same orientation on each attempt. Time from release to contact with the ground was recorded and the velocity was calculated using the formula:

Figure 6.1.1 Egg Test Tube

$$Velocity = \frac{Distance}{Time} \qquad \text{(Eq. 6.1.1)}$$

Table 6.1.1 shows the averaged values of the attempts. (*full tables in appendix E*)

Height	Average Time	Calculated Velocity
3 feet	0.556 s	5.396 ft/s
5.83 feet (70 inches)	0.624 s	9.348 ft/s

Table 6.1.1 Egg drop average time and calculated velocity

The maximum impact velocity generated with the equipment used in this study was 9.348 ft/s. However, a vertically landed egg did not break at this velocity. It can be concluded that as long as impact velocities are below this value the eggs should survive in the model rocket. Different methods of padding can be tested additionally to improve the survivable velocity of the egg.

Centrifugal Force Test

The centrifugal force test will be used to determine the maximum g-force an average egg can withstand before breaking. This test translates to the forces the egg will experience during powered and unpowered ascent. A small centrifuge was created using a small gatorade bottle as a capsule and twist ties to secure a cord to the bottle. An egg was placed in the centrifuge and packed tightly with wrapping paper. Fishing line was measured at a

Figure 6.1.2 Egg Gravity Tester

length of 5 ft and was used as the radial arm cord that was attached to the capsule. The capsule was swung. By using video equipment, the footage of the test was slowed and the revolutions per second of the centrifuge was determined. The abbreviated results are as follows: (Full table in appendix section E)

Radius (r)	Average Revolutions (ω)
5 ft	1.43 rev/s

Table 6.1.2 Average revolutions at given radius

The equation for g-force of a centrifuge is as follows:

$$G - Force = \frac{r\,(2\pi * \omega)^2}{32.2\frac{ft}{s^2}} \quad \textit{(Eq. 6.1.2)}$$

By plugging the data from *Table 6.2* into *Eq. 6.2* the g-force is calculated at approximately 13 g’s. While the egg did not break at 13 g’s the data remains useful because there are several motor options that will generate less than 13 g’s.

7 Gantt Chart And Major Deliverables

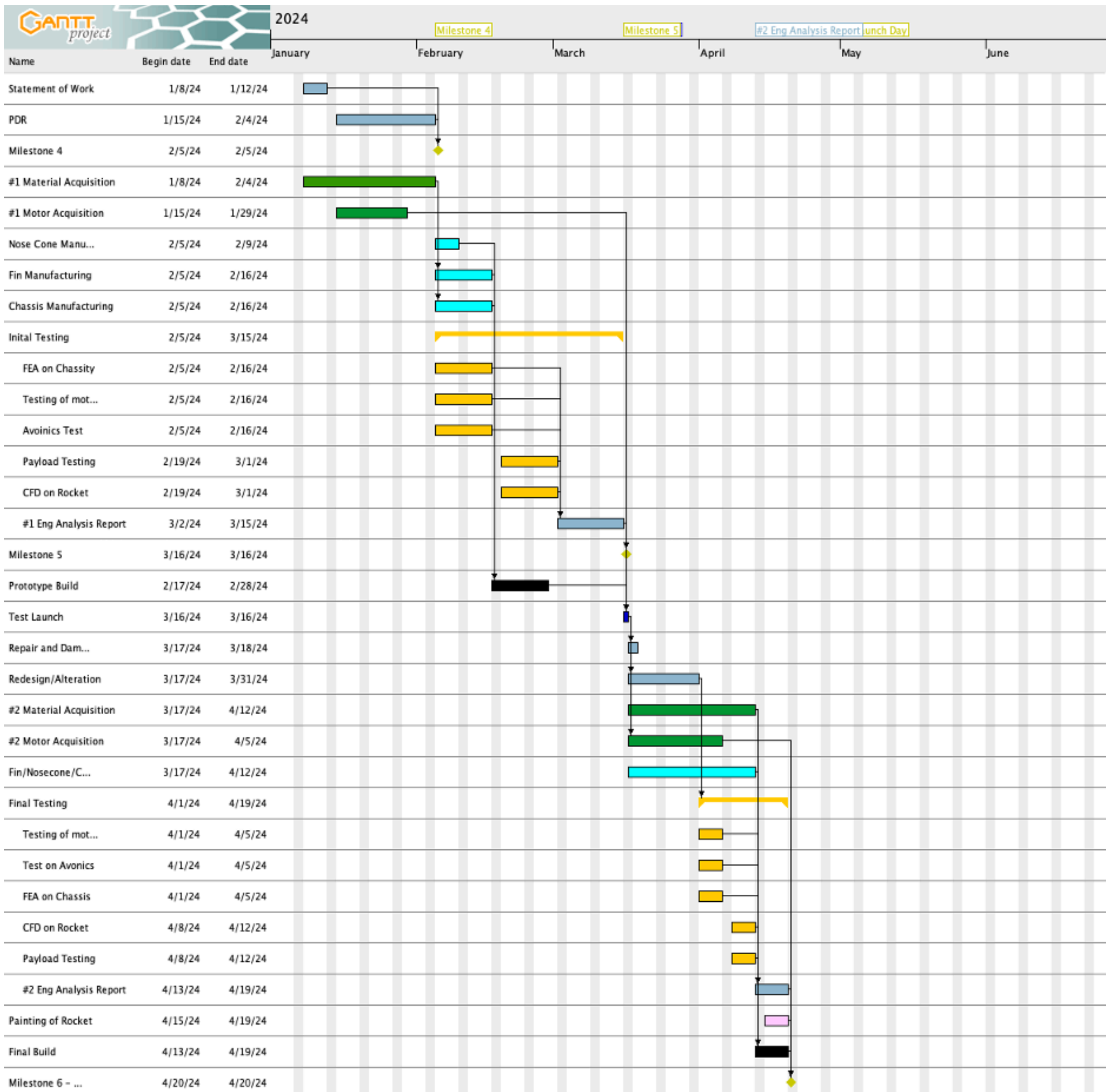

Figure 7.1 Gantt Chart

Figure 7.1 is an export of the planned timeline for completing major tasks and milestones during the project's life span. Beginning at the start of the spring semester Jan 8th and ending on the final launch day of the semester, Apr 20th.

Every action and task listed is placed at a time and date such that it must be done no later than. That being said, most likely tasks such as material acquisition will be completed much sooner. This in return will allow for more time to be spent on more critical tasks as well as give room for error and unforeseen events that may occur. The goal is to have each task done no later than what is seen in figure 7.1. The above gantt chart is to be used as a reference for both customer and provider, to ensure timely action is taken to deliver the product. The following list is a description of color coding and major milestones/tasks to be completed.

Color Coding

Grey - Reports and analysis based events

Green - Time spent acquiring materials and components

Light Blue - Manufacturing of components

Orange - Testing events

Black - Building/assembly of rocket

Pink - Painting

Major Milestones/Task

Milestone 4 (Due 2/5)

Provide faculty advisor with a statement of work and PDR documentation. These documents will demonstrate the team's dedication and continued efforts where milestone 3 left off.

Initial Testing (Due 3/15)

The initial testing for the design choices and materials will be experimented on to serve as evidence for explanation of engineering decisions. This task will be one of the most important due to its significant impact it will have on future builds and design choices. The success or failure of components can heavily affect the ability to stay on schedule.

Milestone 5 (Due 3/16)

Milestone 5 is a report providing evidence found through initial testing as to how well the team's design should operate during competition and explain any alteration necessary due to failed test.

Test launch (Due 3/16)

If possible, a desired launch of a prototype will be launched. A live fire test will be the best way to ensure the product built will perform as intended.

Alteration/Redesign (Due 3/31)

Depending on the results of
the prototype launch, extended time may be needed in order to thoroughly choose redesigns better suited for the competition.

Final Build (Due 4/19)

All redesign considerations
have been finalized and implemented into the final build.

Milestone 6 (Due 4/20)

Final launch day in the
spring semester. On this day the system will be live fired, evaluated, and competed against to compare success to competitors.

8 Concept Evaluation Plans

There are potential risks within the concept of the project that could occur over the next few months of working to deliver this project. Identifying these risks early will help in mitigation to ensure a successful project outcome. These risks could include a vast majority of things however, the ones outlined are of most concern to this project. The major potential risks could include shipping delays from manufacturers, level 1 rocket certification issues, manufacturing delays within the university, inclement weather preventing test launches or the final launch, and insufficient knowledge of basic rocketry.

Shipping delays from manufacturers is an initial concern for the project because without the materials for the rocket, there is no testing or additional manufacturing that can be done. Gathering materials and parts is the first step in the construction for the rocket, a delay here will cause many issues down the line. To mitigate this risk the materials and parts that are required for the rocket are being chosen early giving ample amount of time for the order to process and ship to the university. Additionally, all parts that will be made using a 3D printer will be manufactured during the time period of waiting for shipping to ensure all parts are ready once the parts are shipped.

When launching high powered rocketry, a launch requires somebody present with a level 1 certification. Without someone with that certification present, no test flights can be conducted and the final launch will not happen without that certification within the team. To mitigate this risk the team currently has two members that have a level 1 rocket certification and two other members who are in the process of acquiring theirs as well. By the time test launches are being conducted there will be a minimum of two members that have the certification and two others who will potentially gain their certification making four out of six team members eligible to launch the rocket. With that many members certified, there will be no issues in launching the rocket.

The university has multiple 3D printers on campus that can be utilized to manufacture the parts that the team will build rather than purchase. However, with a large number of senior design teams from mechanical and aerospace engineering along with other engineering students throughout the university, the lab where things get printed can get backed up very quickly. This proposes potential risk if the team is unable to get into the lab to print before the anticipated printing date which throws off the schedule entirely. To mitigate this the team will be scheduling to go to the lab early in the semester while waiting for materials and parts that are shipping. That way there are less people trying to use the lab as most will wait until the middle of the semester to begin printing. Additionally, a member of the team has access to a 3D printer that the team could use if needed due to overbooking of the lab on campus.

Weather will play a factor in the rocket since the rocket must be launched outside where it could potentially be raining or extremely windy. Severe thunderstorms could impact the rocket by resisting the rocket's ability to climb to the intended altitude that was set. This would result in an unsuccessful mission of the rocket, however this is a risk that is going to have to be accepted because there is no way to control it. The rocket will be ready for its first test well in advance of the final launch to ensure that one successful launch is done at some point in time. Additionally, if wind speeds are higher than anticipated, this could cause a very large drift in the rocket after the parachute system is deployed which would result in the rocket landing at a far distance from launch. To mitigate this risk, there will be a GPS tracker put in the rocket to track it down if it does drift far away from the original launch site.

To mitigate risk of weather impacting test launches, the team has other ways to launch and test components of the rocket. While an I level motor must be launched at a launch site at specified times and dates, a D level motor can be launched at any time on any date. If weather impacts the testing launches, the team will gather the rocket and materials and launch the rocket with a D level motor at an alternate site and date to conduct as many tests as possible to ensure success of the rocket.

A final risk that presents the team is the lack of knowledge or experience in advanced rocketry. While two people on the team currently have a level 1 certification, there is still a lack of knowledge among the members of the team on the project that is being delivered. This lack of knowledge could lead to informed decisions and a rocket that does not launch the way that it was intended. This is an assumed risk and one that the team is working on fixing each day with research and collaboration. The team has and will continue to research and understand advanced rocketry to ensure a safe and successful flight on the final launch date.

While there are many other risks other than the ones outlined above that could potentially impact the timeline for the team, these are of the most concern. All risks presented will be dealt with as the team sees fit and handled accordingly. Challenges will be presented and things will go wrong throughout the way, but being able to adapt and overcome any adversities that are presented is what will make the team successful in the following months.

9 Failure Modes And Effects Analysis

9.1 Avionics

The avionics in this system consists of the altimeter, power source, e-matches and black powder charges. The purpose of the avionics is to measure the maximum altitude the rocket reaches and to deploy parachutes after apogee. The success of the flight would be at risk should the altimeter accuracy be poor or the parachutes fail to deploy.

To mitigate the risk of poor altimeter accuracy a test will be performed to verify the accuracy and adjustments to the apogee point will be adjusted as necessary. For example should the altimeter read at an accuracy of +- 1% of the maximum altitude we will adjust the flight to reach an apogee of at least 2020 feet to ensure a successful flight. To test the accuracy of the altimeter the altimeter can be placed at a known height and the measurement can be compared. The altimeter can also be tested utilizing a small pressure chamber, based on the properties of air the simulated height can be calculated by the pressure.

The larger concern is the parachutes failing to deploy. Should the parachutes fail to deploy not only would the flight be a failure but it could also become a hazard. A deployment failure could be caused by:

- A short in the altimeter
- A short in the e-matches
- A poor altimeter to power connection

- Low power source voltage
- Damaged black powder charges

To mitigate the possibility of shortages occurring in the altimeter an avionics bay will be designed to limit vibrations on the altimeter. To ensure no shorts occur in the e-matches, a good connection is made between the power source and altimeter, and that the power source has sufficient voltage proper connection types and insulation will be used. Also a pre-flight check process will be made to verify connections are good and the power source has a sufficient charge for flight. Should the rocket fail the pre-check process the rocket will not be launched. Black powder charges can be damaged during installation or during storage. A proper installation and arming processes will be ensured by a pre-flight check routine. To mitigate any damage during storage black powder charge materials will be stored in an adequate environment and inside a moisture limiting container (eg. ammunition container) black powder charges will also not be prepared more than 1 day prior to use.

Failure Mode	Potential Causes	Effects of Failure	Detection of Failure	Prevention and Mitigation
Altimeter accuracy	Manufacturing	Minimum required apogee not met	Testing	Adjust maximum apogee of the flight path accordingly
Failure to deploy parachutes	Shorts in altimeter or e-matches, poor connection to power, poor power source voltage, damaged black powder charges	Failed flight attempt, hazardous to bystanders	Testing, pre-flight inspection	Proper manufacturing processes, proper storage practices, pre-flight checklist
GPS/Locator failure	Power Failure	Loss of rocket and payload	Pre-flight inspection of wires/battery. Regular testing	Inspect all wire connections. Ground test all systems before flight. Inspect battery

Table 9.1 Avionics FMEA

9.2 Parachute

One of this project's most critical components is the parachute recovery system. In order to safely return the rocket containing the sensitive payload, back to Earth, a successful recovery system must be employed. In order for the recovery to be successful, failure to either of the two parachutes must be avoided at all cost. Parachutes are complex objects that operate in sequence and this presents a high potential for a failed recovery. Ensuring a successful parachute recovery system requires careful planning, testing and adhering to the best practices.

A common problem with a high-powered rocket's parachute is failure to deploy. Reasons for a parachute not deploying, can range from a malfunction in the deployment mechanism, to a tangled parachute or a failure in the ejection charge system. To mitigate these problems, a proven and reliable deployment mechanism must be tested and used, coupled with a pyrotechnic ejection system that will ensure the parachute is forcefully and consistently deployed. Altitude trigger calibration will be performed before launch, to guarantee the parachute deploys at the intended altitude. Proper parachute packing techniques must be practiced, and utilized for a successful deployment. They must be folded, secured and tested according to the manufacturers specifications.

Another complication that occurs with parachutes is late deployment. When a parachute is deployed late the rocket's descent rate becomes critical which increases the risk of impact damage. The cause for late deployment can be from various reasons - many of which were previously explained. The most common reasons are packing errors, software glitches and improper shock cord length. To mitigate late deployment issues with the parachute, again, essential pre-launch testing, including ground tests and simulations, must be thoroughly conducted. A common failure with late deployments are partial deployments of parachutes. A partial deployment is when a parachute fails to fully inflate. A partial deployment can be caused by various factors including line entanglement at discharge. This occurs when a parachute is not properly folded or packed. Practicing proper folding techniques is vital to mitigate this issue. A parachute's inadequate design and size can play a role in partial parachute deployment. This issue was addressed in simulations that have shown the team’s main chute size would need to be 54”. An elliptical design will be used for performance reasons.

Shock cord failures can also contribute to an unsuccessful mission. A shock cord, connecting the parachute to the rocket, has the potential to break, resulting in catastrophic failure. This project will utilize a kevlar shock cord for both of its parachutes. Kevlar is a high-strength synthetic fiber with unique qualities such as high strength, low stretch, durability, resistance to high temperatures and light weight. Utilizing a kevlar shock cord enhances the overall reliability, durability and safety of the rocket's recovery system. Proper knots must be tested and used when connecting the rocket to the parachutes. The shock cord should be securely fastened to an eye bolt that is screwed into the engine mount of the rocket. A tensile test must be performed, pre-launch, to ensure separation does not occur.

A final potential for recovery failure lies in the heat created by the rocket's engines. With modern rocketry designs and materials, these effects can be mitigated. A common insulator, called 'dog barf,' will be used to help shield the parachute from the intense temperatures created at launch. Also, the distance between the engine and the parachute deployment locations, as well as the relatively short duration of engine burn time, will minimize the direct heat impact on the parachutes. This project will be utilizing parachutes made from heat resistant material called Rip-Stop Nylon. This material is made to withstand elevated temperatures and endure thermal abuse. A test flight should be conducted and the parachutes inspected for a reliable performance during the actual launch.

Through a combination of meticulous planning, rigorous testing and adherence to disciplined practices, this project can significantly reduce the risk of parachute related issues. Key factors include the use of a reliable deployment mechanism, proper parachute packing techniques, selective materials, calibration and testing of altitude triggers and thorough pre-flight checks. Continuous improvement through simulation and ground tests is crucial in mitigating failures during deployment procedures. By implementing these measures and fostering a culture of safety, this project can be confident in the reliability of its parachute system, ultimately leading to the successful recovery and the preservation of the sensitive payload.

Failure Mode	Potential Causes	Effects of Failure	Detection of Failure	Prevention and Mitigation
Failure to deploy	Improper packing, failed ejection charge, altimeter glitch, tight nose cone	Increased rate of speed resulting in high impact damage, complete loss of rocket and payload	Pre-launch ground check of parachute packing, nose cone fitting and altimeter testing	Comprehensive pre-flight inspections, proper packing techniques, altimeter calibration, ejection charge testing
Late deployment	Altimeter miscalibration, entanglement, insufficient ejection force, aerodynamic interference	Increased descent rate, parachute rupture potential, higher impact speed, payload damage	Pre-launch ground checks, ejection charge inspection, altimeter testing, packing inspection	Double check packing process, altimeter calibration, ejection charge testing
Partial deployment/ inversion	Packing errors, shroud entanglement, ripped canopy, shroud line separation	Higher landing speed, reduced drag, loss of stability, potential for payload damage	Visual inspection of parachute, shroud lines and shock cord	Conduct pre-launch inspections, adhere to proper packing techniques

Entanglement	Aerodynamic interference, improper packing, poor ejection charge, high winds	Stability loss, canopy inflation failure, reduced drag, higher descent rate, payload damage	Ground inspection of parachute and packing process, pre-launch tests	Proper packing procedures, pre-launch testing, shock cord inspection, anti-tangling devices
Material rupture/failure	Extreme temperatures, high speed during deployment, wear and tear	Canopy inflation failure, loss of stability, higher descent speeds,	Parachute material inspection, wadding inspection	Use high temperature, durable material, inspect parachute regularly
Shock cord failure	Improper attachment, non-durable material, length miscalculation	Complete parachute detachment, entanglement, high impact risk	Shock cord inspection, tensile testing, pre-check cord length	Use of durable material such as Kevlar, inspection of attachment points, ensure proper length of shock cord
Ejection charge failure	Misfire, altimeter glitch, faulty charge, insufficient force	Parachute deployment failure, damage to rocket and payload	Ejection charge ground testing, pre-launch inspection of charge	Pre-launch inspection of altimeter and ejection charge, regular tests, use reliable ejection system manufacturer
Overheating/ burning of parachute	Improper insulation/dog barf placement, parachute location	Damage to parachute and shroud lines causing deployment failure	Inspection of insulation/dog barf, parachute location and packing inspection	Pre-flight testing of parachute location and insulation, durable material selection, use of heat shields

Table 9.2 Parachute FMEA

9.3 Nose Cone

There are two main points of failure that can exist resulting from the nose cone: failure to eject at apogee and a fracture of the material. The nose cone has the sole purpose of being an aerodynamic spike to effectively move air molecules out of the path of the rocket's path of travel. Additionally, upon reaching apogee the nose cone must pop off and split from the rocket allowing the parachute to deploy which will slow down the rate of descent as the rocket travels back towards the ground.

If the nose cone does not pop off allowing the parachute to deploy, this would be a failure within the rocket and would result in both the rocket and payload being severely damaged due to fall damage. In order to ensure this point of failure does not occur, the diameter of the nose cone must be precise in measurement in order for it to pop off as it is supposed to. Additionally, the ejection charge must ignite so the airframe is pressurized enough to pop the nose cone off and release the parachute. This ejection charge is a possible failure point so tests must be done to ensure that it both pressurizes the rocket and pops off the nose cone without impacting the eggs in the process.

The nose cone material must be effective in ensuring it is not damaged during flight which would cause an extreme failure. To ensure there is no failure in the material of the nose cone, PLA will be used which is both strong and light and will not break under the conditions provided to it. Additionally, the nose cone will be sanded down and a layer of epoxy will be applied for a smooth texture to displace air molecules as well to keep the material bound together well.

To ensure there will be no failures within the nose cone testing can be done both through simulations as well as physical testing. Utilizing programs such as open rocket tests can be conducted by inputting the material and geometry that will be used and ensuring the stability remains strong. Additionally, tests can be run while manufacturing the nose cone to ensure the material will hold up during flight and there will be no deficiencies that could cause the rocket to fail.

Failure Mode	Potential Causes	Effects of Failure	Detection of Failure	Prevention and Mitigation
Failure to pop off	Diameter too large, ejection charge failure	Parachute deployment failure, damage to rocket and payload	Testing	Ensure diameter is correct fit for rocket body tube, pre-launch inspection of ejection charge
Material failure	Weak material	Fracture in material causing an unstable flight	Pre-flight inspection	Proper manufacturing processes, detailed research on material used

Table 9.3 Nose Cone FMEA

9.4 Insulation (“Dog Barf”)

The insulation used between the motor and payload system is a key point of failure that can be presented and one that is going to be analyzed and tested extensively. The point of the insulation is to make sure the heat that is released from the motor does not heat up the parachute or the payload which would cause a failure in the project. If the heat affects the parachute it could cause a hole in the parachute which would result in a failed recovery system of the rocket and the rocket would crash back to the ground. Additionally, if the heat from the motor affects the payload system of eggs, it could cook the eggs causing them to break and would once again result in a failure.

The insulation used between the motor and payload system is nicknamed “dog barf” and provides a material that stores and blocks heat from reaching the payload system. The motor of the rocket will ignite at launch and will release large amounts of heat during the duration of launching, and the tube of the rocket is only four feet long. The heat released from the motor must go somewhere and without some sort of insulation, the payload and recovery system become very vulnerable. Hence the need for insulation to protect the payload and recovery system.

The parachute is the only recovery system the rocket has and thus a failure in the parachute will result in a failure in the rocket. Parachutes are generally made out of a nylon material which can be flame resistant but is not flame retardant and can still catch fire or melt if not protected from the heat emitted from the motor. The dog barf must be well insulated and capable of blocking and containing a majority of heat that could affect the parachute which would cause a failure in the system.

The payload bay is another area that is susceptible to heat and must be protected from the motor. A sensitive payload of eggs can especially be impacted by large amounts of heat that could be emitted. The dog barf will insulate enough of the heat to also protect the eggs in the payload bay from cooking. A failure in protecting the eggs would result in cooked eggs which would be considered unsuccessful.

While the insulation must prevent heat from reaching the parachute and payload system, it must also contain the heat rather than blocking it from passing. The motor is kept in a small area within the rocket and the heat emitted from it must be dispersed elsewhere. If the insulation material reflects the heat back to the motor it could cause the motor to overheat which would result in a failure of the motor. The insulation material must store the heat and prevent it from reaching the payload and parachute rather than reject the heat causing issues within the motor.

To mitigate the potential risks that could be caused by the insulation, testing must be done to ensure the correct amount of insulation is used and that it blocks the amount of heat that needs to be blocked. The cellulose insulation that will be used for the project comes in large quantities from many retailers such as Home Depot and Lowe's and thus purchasing a large amount and running tests by emitting heat similar to what the motor will emit will ensure the parachute and payload remain unharmed.

Failure Mode	Potential Causes	Effects of Failure	Detection of Failure	Prevention and Mitigation
Allows too much heat to pass	Not enough insulation used, insulation does not prevent heat from passing	Ineffective parachute leading to failed recovery system and damage to rocket and payload, payload system overheats and payload is damaged	Testing, pre-flight inspection	Proper testing of insulation, proper placement of parachute, payload system, and insulation
Does not store heat, traps heat near motor	Material blocks heat from passing rather	Overheated rocket motor, overheated	Testing	Proper testing of insulation

	than containing heat	rocket tube		

Table 9.4 Insulation FMEA

9.5 Aerodynamic Body Structure

The body tube of the rocket will house most of the most important components of the rocket, which means it is crucial that the structural integrity of the tube is not compromised. The chosen material for the body tube is blue tube, which is made from vulcanized cellulose fiber. This material is abrasion resistant, impact resistant, and lighter than most other materials. Some of the failure concerns with blue tubes is that it absorbs moisture very easily which causes it to warp easily. If the rocket is launched in any kind of rainy conditions or gets wet while being built, it could cause issues with payload placement, stability, and parachute positioning. This is a concern for most body tube materials and affects the requirements for the launch environment.

In flight, the body tube is also subject to compressive and bending loads. In non windy conditions there will be minimal bending loads on the rocket, but taking into account the location of launch we know that strong winds and wind gusts can most definitely be expected. Varying levels of wind or gusts of wind cause the rocket to fly at non-zero angle of attack causing a bending moment on the body tube of the rocket as a result of normal forces at the nose cone and fins of the rocket. The bending moment severity will depend on the wind or wind gust severity and has to be something that is taken into account when choosing the material for the rocket body tube. As mentioned above this shouldn't be a major concern due to the strength of the blue tube.

Failure Mode	Potential Causes	Effects of Failure	Detection of Failure	Prevention and Mitigation
Moisture Absorption	Body tube getting wet	Warping of the body tube resulting in instability and extra costs.	Pre-flight Inspection	Proper storage of the body tube and appropriate launch environment
High Bending/Compressive Loads	Extreme winds/gusts	Could result in bending or breaking of the tube causing instability for the whole rocket and flight failure.	Testing and Pre-flight Inspection	Proper testing and inspection of the body tube. Launch in appropriate environmental conditions.

Table 9.5 Body Structure FMEA

9.6 Payload bay

The payload bay is responsible for the handling and protection of the eggs. The payload bay will be where all the eggs set to be transported will be held and stored. The initial design will involve multiple layers of protection and damping devices to ensure protection throughout launch and recovery. Starting with the most inward layer, foam, this foam will completely encase each egg. Each egg will be placed inside a pre-cut section of the foam to ensure a snug fit is accomplished. The next layer will be an outer casing to keep the foam and eggs securely fastened together. Following the casing will be dampers closed around the outer casing and between the body tube. The purpose of the dampeners will be to minimize the vibration effects during launch and decrease the impact force felt during touchdown. Lastly, there will be a locking mechanism that will serve as the interface for the entire payload bay to the rocket body itself. The goal is to have a payload bay that is easily removable for ease of access.

A possible risk of failure for this payload bay design is the failure of the locking interface. If the material or design is not adequately engineered to withstand the forces it may break off inside the rocket causing catastrophic failure. Methods of mitigation will be to ensure redundancy in design. Such as making thicker than necessary interface parts for strength and stability. Also, adding a secondary fail safe device to both top and bottom of the payload bay to ensure if failure of the locking interface happens the payload bay will not rattle inside the body tube.

A secondary risk is the melting of subcomponents due to the heat generated from the motor. A layer of appropriate heat resistance padding will need to be placed below the payload bay to ensure the integrity of the component is not compromised due to extreme heat deformation.

Another risk is failure to properly seal eggs in foam. Since the foam will be pre-cut and each egg will vary slightly in size and shape, there will be some pre-cut spaces with wiggle room that may cause the egg to damage itself in flight. This risk can be minimized if some material can be used to fill this extra space. Material such as sawdust, packing foam, or even shredded paper may be sufficient enough to mitigate the risk.

Failure Mode	Potential Causes	Effects of Failure	Detection of Failure	Prevention and Mitigation
Failed locking mechanism	Material flaw, poor connection	Payload is damaged, Rocket becomes unstable in flight	Pre-flight check, manufacturing checks	Redundant systems, over engineered for strength
Failed heat protection	Manufacturing defect, heat protection inadequate	Melted mounting components, Rocket becomes unstable	Thermometer	Testing
Egg Fitment	Variation in egg shape	Eggs break	Pre-flight check	Add spacers when loading eggs

Table 9.6 Payload Bay FMEA

9.7 Additive Manufacturing

It is important to note that some components of the rocket will be 3-D printed such as the nose cone will be produced by using a fused deposition modeling printer (FDM) which heats the chosen material to the appropriate specified temperature and builds the nose cone layer by layer. These layers have to successfully fuse together to ensure the structural integrity of any 3-D printed part. Any error by the printing system causing fusion issues, warping of the printed part, or any other defects can compromise the integrity of the component which could jeopardize the flight or integrity of the rocket.

Failure Mode	Potential Causes	Effects of Failure	Detection of Failure	Prevention and Mitigation
Warping/ Cracking	Carelessly removing parts off of the build plate, high specific heat, and incorrect printer axes.	Can cause failure of the printed part resulting in compromising stability, launch, flight, and recovery depending on the printed component.	Component Inspection	Proper removal of the part from the build plate. Correct printing settings and axes set up
Fusion Layer Defects	Extrusion temperature isn't right or the printing axes are off.	Structural integrity of the printed part	Component Inspection	Inspection of layer depositing during print. Correct temperature settings for selected materials.

Table 9.7 Additive Manufacturing FMEA

9.8 Rocket Motor

A single I level solid motor will be the single source of lift for the team's rocket. Meaning it is a critical failure point that is unavoidable. When dealing with explosives the causes for potential failure can occur at a large range of stages during development. Many factors are not preventable and are caused by the manufacturers of rocket motors, however other failures can be prevented or mitigated by the team. Designing a secure motor mount with simplicity and redundancy will be crucial to ensure proper power transfer occurs from motor to chassis and the motor does not fall out during operation. Another area of concern is the ignition system. Precautions must be put in place to ensure not only a successful launch but also a safe launch. Training on proper procedure must be practiced before final or prototype launch.

Failure Mode	Potential Causes	Effects of Failure	Detection of Failure	Prevention and Mitigation
Debonding Failure in Propellant grain	Defects in propellent grain grown due to stresses, thermal conditions and moisture absorption	Rapid buildup of pressure in motor leading to potential motor detonation	None / Component Inspection	Keep motor inside at room temperature, avoid transportation in the rain, reduce stresses endured while transportation
Misfire	Wire shortage, Problem with igniters	Unplanned rocket flight, or takeoff not occurring when planned	Pre-flight checklist	Wait 60 seconds after a misfire occurs and rocket does not launch. Ensure proper setup of ignitor. Safety key to prevent accidental launch.
Motor falls out of rocket	Lack of securing motor casing, or motor retention system failure	Potential lack of parachute deployment leading to rocket missile and loss of rocket.	Component Inspection / Pre-flight checklist	Ensure parts are capable of holding the motor and motor casing securely before launch date. Pre-flight checklist to check system is working
Thrust Transfer Failure	Lack of motor securing	Motor shoots into the body of rocket leading to loss of most if not all of rocket. Rocket Instability causing potential dangerous missile	None	Motor mount capable of withstanding forces of rocket motor.

Table 9.8 Rocket Motor FMEA

9.9 Fins

High powered rocket fins are the closest component to a guidance control system. Fins offer stability and control during all phases of the rocket's mission. The geometry greatly affects the AP of the rocket and the materials of the fin heavily limit the design. When considering Fin materials and design it becomes a dance between those two categories for a successful and effective fin design. Proper consideration must be taken when considering size, thickness and interfaces to avoid critical failure.

Failure Mode	Potential Causes	Effects of Failure	Detection of Failure	Prevention and Mitigation
Fin Failure (Powered Flight)	Glue Fails / Fin Separation	Loss of stability resulting in catastrophic failure	Inspection	Over Design Fins to large FOS.
Fin Failure (Unpowered Ascent)	Glue Fails / Fin Separation	Potential Loss of payload and stability issues resulting in a failure to reach target altitude	Inspection	Over Design Fins to large FOS.
Low Stability of Rocket	Fins not large enough	Instabilities at launch leading to catastrophic failure	Inspection	Large fins that keep rocket within stability requirements

Table 9.9 Rocket Fins FMEA

10 Significant Accomplishments And Future Work

Most significant accomplishments of the first 3 milestones come in the form of gathering information on specific technologies and methods previously used. Collectively, over a hundred hours have been spent researching crucial components and functions that are beneficial to the team's success. For efficiency and clarity the project has been broken down to several key components: propulsion, payload bay, recovery system, body/fin design and avionics.

The next most crucial task to be completed will be the construction of a prototype for the payload bay. While testing still needs to be done on all individual designs, the payload bay will likely consist of several subcomponents that could be constructed with: power tools, 3D printers and/or additive manufacturing. The importance of the construction of the payload bay can not be understated. Most of the assembly time will be spent on the payload bay to ensure the safety of the eggs.

One of the last components to be designed will be the fins. The fins greatly affect the stability of the rocket and therefore need to accommodate the weight distribution of the rocket. First, the design of the inner components of the rocket must be established before finalizing a design for the fins.

Another major point of risk that will need to be mitigated through rigorous testing will be the parachute used for recovery. Deciding to use a single large parachute greatly simplifies the design but also creates a single point of failure. Ensuring proper folding technique is implemented and placement within the body tube will be a crucial component to the success of the launch. Determining impact speeds with varying parachute designs and sizes will directly affect the amount of eggs possible for us to launch and recover.

Future work to be completed is the necessary testing for each subcomponent and integrations needed for quality assurance. Each individual subcomponent has been selected for its reliability, low cost or effectiveness. However, when integrated with other parts of the rocket it may be discovered some component selections are not compatible and therefore secondary options will be needed to progress forward.

11 Conclusions And Recommendations

In this report, the need for a rocket that can deliver sensitive payload has been understood. The major goals set by the team alongside the requirements to achieve those goals have been made clear; and the path to accomplishing these goals has been laid out. Through the effort of research, concept generation and failure effect analysis an initial prototype has been visualized. The next objective of the team is to move forward into manufacturing the prototype and to begin testing of major components such as the payload bay. The timeline for these objectives has been created in section 7 of the report. It is the recommendation of the team to address any future issues external or internal to the project first, to avoid complications during or near the deadline. In the event that major decision points need to be changed near the deadline an additional week has been reserved to resolve those potential issues. As long as the team is able to meet the demands a final model will be constructed early April with the mission of a successful launch shortly after.

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Appendices

A. Requirements

2.1 Geometry

[LRS - 01] The LRS shall have a chassis in the form of a traditional rocket design capable of withstanding launch and recovery conditions necessary to transport payloads safely and effectively.

2.2 Materials

[LRS - 02] The LRS shall use materials that are compliant with L1 certification. Effective October 17, 2023

2.3 Flight

[LRS - 03] The LRS shall be capable of flight and reach a minimum altitude of 2000 ft above ground level (AGL).

2.3.1 Stability Controls

[LRS - 04] The LRS shall engage in stable flight.

2.4 Sensory Systems

[LRS - 05] The LRS shall have a system capable of verifying minimum altitude achieved.

2.4.1 Internal Measurement Unit (IMU)

[LRS - 06] The LRS shall have an IMU for data acquisition.

2.5 Recovery

[LRS - 07] The LRS shall have a subsystem capable of transporting the cargo from launch to recovery phases.

2.5.1 Parachute

[LRS - 08] One or more parachutes shall be utilized in the recovery system.

2.6 Payload

[LRS - 9] The LRS shall contain a specialized cargo bay within the chassis that will house at least 1 chicken egg.

2.6.1 Protection

[LRS - 10] The cargo bay shall be capable of protecting the egg(s) from both external and internal environments in order to ensure cargo is recovered with no damage.

2.7 Propulsion

[LRS - 11] The LRS shall be propelled by a solid rocket motor.

2.7.1 Motor Type

[LRS - 12] The type of the motor shall be within the NAR designated types of either H or I. Effective October 17, 2023

2.8 Logistics

[LRS - 13] The LRS shall be capable of being safely handled without damage to the system or user in all configurations.

2.8.1 Transportation

[LRS - 14] The LRS shall be capable of fitting into the back of a Ford Ranger.

2.9 Safety

[LRS - 15] The LRS system shall comply with all FAA, NAR, TRA and local gov't guidelines to ensure appropriate steps are taken to mitigate risk. Effective October 17, 2023

2.9.1 Arming System

[LRS- 16] The LRS shall be capable of being armed on a launch pad and guide rail provided by the Tripoli Rocketry Association (TRA) Effective October 17, 2023

2.10 Environmental Conditions

[LRS - 17] The LRS shall be capable of launching in clear weather conditions that are standard at the Palm Bay launch site during the month of Apr.

2.11 Launch Interface

[LRS - 18] The LRS shall have an interface capable of remote launch.

2.12 Markings

[LRS - 19] Overall presentation and design shall be the most radical, tenacious, and gnarly rocket to have ever graced the Palm Bay launchpad.

2.12.1 Points of Interest

[LRS - 20] The LRS shall have visible marking along the exterior of the body identifying the center of gravity and aerodynamic center.

Verification Method for Requirement Testing		
Requirement (RIN)	**Target Values/ Range**	**Verification Method**
[LRS - 01] Geometry	N/A	I
[LRS - 02] Materials	NAR L1 Compliant	I
[LRS - 03] Flight	Greater than or equal to 2000 ft AGL	A, T
[LRS - 04] Stability Controls	$1.2 \leq Stability\ (cal) \leq 1.8$	A, T
[LRS - 05] Sensory Systems	Ensure precision of the system has a standard deviation less than 100ft	A
[LRS - 06] Internal Measurement Unit	N/A	I
[LRS - 07] Recovery	Cargo remains unchanged from initial packaging	I
[LRS - 08] Parachute	Reduces velocity to less than 25 ft/s	T
[LRS - 9] Payload	Greater than or equal to 1 chicken Egg	I, T

Verification Method for Requirement Testing		
[LRS - 10] Protection	Keeps payload intact at an impact at 25 ft/s	T
[LRS - 11] Propulsion	N/A	I
[LRS - 12] Motor Type	NAR designated H or I motor	I
[LRS - 13] Logistics	LRS remains functional after configuration changes and usage	T
[LRS - 14] Transportation	No single part shall be longer than 5ft 6in	I
[LRS - 15] Safety	Guideline review	I
[LRS - 16] Arming system	Successful test launch	T
[LRS - 17] Environmental Conditions	Avg Winds: 9.1 knots Avg high/low Temp: 80/65℉ Humidity: 36%	T
[LRS - 18] Launch Interface	Successful test launch	T
[LRS - 19] Markings	N/A	I
[LRS - 20] Points of Interest	N/A	I

B. Relationship Matrix of User Needs to Engineering Requirements

Weight	Customer Requirements (Explicit and Implicit) / Engineering Characteristics	Aerodynamic Performance	Materials	Thrust	Fin Design	Unit Quality	Brand	Protective Devices	Deacceleration	Survival Yes/No	Payload System Design	Motor Count	H or I	Durability	Length	Guideline Reviews	Two stage arming	Durability	Compatibility	Visibility	Accuracy
2	Geometry	●			●			●		●	●	●	●		●						
7	Materials	●	●	●	●		●	●	●	●	●	●		●		●		●	●		
10	Flight	●	●	●	●				●	●		●	●		●	●					●
10	Stability	●	●	●	●			●	●	●	●				●						●
2	Sensory					●	●			●											●
2	IMU					●	●			●											●
7	Recovery		●					●	●		●			●				●		●	
7	Parachute	●	●						●	●								●			
10	Payload			●			●			●		●		●							
10	Protection		●	●					●		●			●				●			
7	Propulsion	●	●	●			●					●	●				●				●
2	Motor Type	●	●	●			●						●	●					●		
1	Logistics													●	●				●		
1	Transportation													●	●				●		
8	Safety		●					●		●				●		●				●	●
3	Arming System		●					●								●	●				
7	Environmental Conditions	●	●	●	●				●					●				●		●	●
2	Launch Interface		●													●			●		●
1	Markings		●											●				●		●	
1	Points of Interest																	●		●	●

C. Relevant Data For Component Selection and Generation

Payload Material Options

	PLA	PETG	ABS	ASA	PC	TPU 95A	PLA-CF	PETG-CF	PET-CF	PLA Aero
Density (g/cm^3)	1.24	1.25	1.05	1.05	1.20	1.16	1.22	1.25	1.29	1.21
Cost ($/kg)	$27.99	$27.99	$27.99	$29.99	$39.99	$41.99	$34.99	$34.99	$44.99	44.99
Impact Strength (kJ/m^2)	26.6	52.7	39.3	41	34.8	78.7	23.2	41.2	36	24.5
Bending Strength (MPa)	76	65	62	65	108	4.3	89	70	131	42
Bending Modulus (MPa)	2750	1670	1880	1920	2310	78.7	3950	2910	5320	1960
Heat Resistance (Celcius)	57	69	87	100	117	74	55	74	205	54
H20 Absorbtion rate (%)	0.43	0.32	0.65	0.45	0.25	1.16	0.42	0.33	0.37	

Foam Materials Options

	EVA Foam	Sorbothane	Polyurethane Foam	Nitrile Foam	Rebonded Foam
Cost	$15.00	$65.00	$27.00	$25.00	$40.00
Density	2 lbs/ft^3	81.22 lbs/in^3	1.2 lbs/ft^3	12.49 lbs/ft^3	5 lbs/ft^3
Tensile Strength	N/A	155 psi	116 - 181 psi	125 psi	10 psi
Compressive Yield Strength	3.63 psi	190 psi	0.25 - 6960 psi	N/A	N/A
Maluable	both	both	rigid	yes	yes

Fin Material Options

Materials									
				3D Printing Materials					
Birch Plywood		G-10 Fibre Glass		PLA		Nylon-12		PETG	
Durability	8170 psi	**Durability**	38000 psi	**Durability**	5511 psi	**Durability**	12038 psi	**Durability**	7251 psi
Cost	$1.00/ft^2	**Cost**	$50/ft^2	**Cost**	$5.45/lb	**Cost**	$59/lb	**Cost**	$7.26/lb
Weight	0.0257 lb/in³	**Weight**	0.0650 lb/in³	**Weight**	.040 lb/in³	**Weight**	0.397 lb/in³	**Weight**	0.036 lb/in³
Manufacturing Time	~30 min	**Manufacturing Time**	~30 min	**Manufacturing Time**	12 Hours	**Manufacturing Time**	12 Hours	**Manufacturing Time**	12 Hours
Accquire Time	Same Day	**Accquire Time**	1 Day	**Accquire Time**	1 Day	**Accquire Time**	1 Day	**Accquire Time**	1 Day

Avionics Options

Name/Brand	AIM Dual Deployment Altimeter/Entacore	Telemetrum Flight Computer/Atlas Metrum	EasyMega Flight Computer/Atlus Metrum	RRC3 "Sport" Dual Deplyoment Altimeter	Blue Raven/Featherweight Altimeters	Chute Release/ Jolly Logic	Adrel Altimeter/North Coast Rocketry
Cost	$121.15	$381.63	$358.31	$101.33	$175.00	$141.52	$85.95
Availability	Yes	Limited	Limited	Yes	Yes	Yes	Minimal
Weight	12.81 g	20.31 g	14.2 g	17.01	24 g (incuding battery)	17.01 g	5.95 g
Dimensions (LxWxH in mm)	65x25x15	27x70x16	57x33x12	100x23	41x21	53x30x10	21x8x6
Built in Battery	NO	No	No	No	No	Yes	No
Battery Type	4v-16v	3.7v+ LiPo	3.7v+ LiPo	9v	9v	Built in	Adrel Battery
Data Downloadable	Yes/USB	Yes/ USB or Software	Yes/USB and Software	Yes/USB interface module	Yes/Phone App	No	Yes
Dual Deployment	Yes	Yes	Yes	Yes	Yes	No	No
Apogee Eject	Yes	Yes	NA	Yes	Yes	No	NA
Descention Eject	Yes	Yes	NA	NA	Yes	Yes	NA
Timer Eject	Yes	Yes	NA	Yes	Yes	No	NA
Barometric Pressure Altitude	Yes	Yes	Yes	Yes	Yes	No	Yes
Accelerometer	No	Yes	Yes	No	Yes	No	No
Gyro tilt sensors	No	No	Yes	No	Yes	No	No
Event Timer	No	Yes	Yes	No	Yes	No	No
Telemetry	No	Yes	No	Optional with add ons	Yes?	No	No
Field Locator	Buzzer?	GPS Telemetry	NA	Optional with add ons	Add on	NA	No
Field Data output	Beeps	Beeps, Software	Beeps, software	Beeps, LCD screen avvailable	Phone App	NA	No
Records Peak Alt	Yes	Yes	Yes	Yes	yes	No	Yes
Records Peak Speed	Yes	Yes	Yes	Yes	yes	No	No
Records Peak and average Ac	No	Yes	Yes	Derivable	yes	No	No
Records time to Apogee	Derivable	Yes	Derivable	Yes	Derivable	No	No
Records Ejection time	Derivable	Yes	Derivable	Derivable	Derivable	No	No
Records Flight Duration	Derivable	Yes	Derivable	Derivable	Derivable	No	No

Rocket Motor Options

Given Info					
Manufacturer:	*AeroTech*	*Cesaroni*	*Cesaroni*	*AeroTech*	*Cesaroni*
Name:	*HP-I140W*	*H125-12A*	*I170*	*I280DM-14A*	*636I216-14A*
Reloadable?	Single-Use	Reloadable	Reloadable	Single-Use	Reloadable
cost (no shipping):	**$69.54**	**$67.83**	**$85.18**	**$103.78**	**$116.74**
Casing:	**N/A**	**$70.98**	**$85.19**	**N/A**	**$110.43**
Initial Weight (g):	356	293	392	616	601
Empty Weight (g):	173	155	205	261	313
Total Impulse (Ns):	339	268	382	561	636
Initial thrust (N):	160	130	175	325	379.5
Burn time (s):	2.4	2.2	2.3	1.9	2.94
Calculations					
Propellant mdot (kg/s):	0.07625	0.06272727273	0.08130434783	0.1868421053	0.09795918367
Total Weight Rocket (kg):	2.196	2.133	2.232	2.456	2.441
Isp(s):	188.8337428	197.9642187	208.234531	161.0888573	225.1104315
h (at burnout) (m):	162.36	117.533	176.599	210.57	250

h (at burnout) (ft):	532.6771662	385.606956	579.3930455	690.8464577	820.209975
V (at burnout) (m/s):	137.6410098	108.3113644	156.1808365	228.0755073	248.4050738
V (at burnout) (ft/s):	451.5781169	355.352246	512.4043199	748.2792247	814.9772774
time till apogee from burnout (s):	14.03068398	11.04091381	15.92057456	23.24928719	25.32161812
h_max (m):	965.5987558	597.9282194	1243.244326	2651.296486	3145.009209
h_max (ft):	3167.974925	1961.70676	4078.885591	8698.479297	10318.2717
Drag From Burnout Included					
vt:	72.53165723	72.20664443	73.1058901	74.10009064	75.0114789
h_from burnout (m):	409.2583243	313.2193678	467.5259844	657.3505662	711.8307017
h_max (m):	571.6183243	430.7523678	644.1249844	867.9205662	961.8307017
h_max (ft):	**1875.388206**	**1413.229555**	**2113.27095**	**2847.508424**	**3155.612543**
Important Parameters					
a_max (ft/s^2):	**179.724**	**155.831**	**212.897**	**366.246**	**263.861**

D. System Concept Selection Matrix

Avionics

		Avionics													
		Chute and Altimeter		Altimeters						Flight Computers					
		Chute Release (Jolly Logic) + Adrel Altimeter		Blue Raven		RRC3 "Sport" Dual Deployment Altimeter		AIM Dual Deployment Altimeter		Telemetrum Flight Computer		EasyMega Flight Computer		Telemetrum Flight Computer	
Criteria	Weight Importance	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Reliability	15%	4	0.6	4	0.6	3	0.45	3	0.45	4	0.6	4	0.6	4	0.4
Accuracy	10%	3	0.3	4	0.4	3	0.3	3	0.3	4	0.4	4	0.4	4	0.4
Cost	20%	2	0.4	3	0.6	4	0.8	4	0.8	1	0.2	1	0.2	1	0.1
Weight	20%	3	0.6	4	0.8	3	0.6	3	0.6	3	0.6	4	0.8	3	0.3
Dimensions	5%	1	0.05	4	0.2	3	0.15	3	0.15	3	0.15	1	0.05	3	0.3
Availability	15%	3	0.45	4	0.6	4	0.6	3	0.45	2	0.3	2	0.3	2	0.2
Features	15%	1	0.15	4	0.6	3	0.45	3	0.45	4	0.6	4	0.6	4	0.4
Totals	100%		2.55		3.8		3.35		3.2		2.85		2.95		2.85

Body Tube

		Body Tube Materials									
		Wound Kraft Paper Tube		Phenolic Tube		Blue Tube		Fiberglass Tube		Carbon Fiber Tube	
Criteria	Weight Importance	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Low Cost	15%	4	0.6	4	0.6	4	0.6	2	0.3	0	0
Strength	30%	3	0.9	2	0.6	4	1.2	4	1.2	4	1.2
Availability	15%	1	0.15	4	0.6	4	0.6	1	0.15	1	0.15
Low Weight	30%	4	1.2	3	0.9	2	0.6	0	0	0	0
Design Flexible	10%	4	0.4	1	0.1	3	0.3	0	0	0	0
Totals	100%		3.25		2.8		3.3		1.65		1.35

Nose Cone

		Nose Cone Shapes					
		Parabolic		Ogive		Conic	
Criteria	Weight Importance	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Durability	25%	4	1	4	1	2	0.5
Cost	20%	3	0.6	4	0.8	4	0.8
Weight	25%	4	1	3	0.75	2	0.5
Manufacturing	15%	3	0.45	3	0.45	3	0.45
Accquire Time	15%	4	0.6	4	0.6	3	0.45
Totals	100%		3.65		3.6		2.7

Fin Materials

		Fin Materials											
						3D Printing Materials					
		Birch Plywood		Fibre Glass		PLA		Nylon-12		PETG	
Criteria	Weight Importance	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Durability	25%	2	0.5	4	1	2	0.5	3	0.75	2	0.5
Cost	20%	4	0.8	3	0.6	4	0.8	1	0.2	4	0.8
Weight	25%	3	0.75	3	0.75	3	0.75	2	0.5	3	0.75
Manufacturing	15%	4	0.6	4	0.6	3	0.45	3	0.45	3	0.45
Accquire Time	15%	4	0.6	3	0.45	3	0.45	3	0.45	3	0.45
Totals	100%		3.25		3.4		2.95		2.35		2.95

Payload Materials

		Payload Handling - Structure											
		PLA		PETG		ABS		PC		ASA		TPU 95A	
Criteria	Weight Importance	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Cost	10%	4	0.4	4	0.4	4	0.4	2	0.2	3	0.3	2	0.2
Weight	20%	2	0.4	2	0.4	4	0.8	2	0.4	4	0.8	3	0.6
Impact Strength	20%	1	0.2	3	0.6	2	0.4	2	0.4	2	0.4	4	0.8
Bending Strength	20%	3	0.6	2	0.4	2	0.4	4	0.8	2	0.4	1	0.2
Heat Resistance	10%	3	0.3	3	0.3	4	0.4	4	0.4	4	0.4	4	0.4
Avalablity	10%	4	0.4	4	0.4	4	0.4	4	0.4	4	0.4	3	0.3
Manufacturing	10%	4	0.4	4	0.4	2	0.2	4	0.4	4	0.4	2	0.2
Totals	100%		2.7		2.9		3		3		3.1		2.7

Foam

		Foam Rubber	Foam Rubber	Gel Pads	Gel Pads	Silicone Rubber	Silicone Rubber	Poly-Foam	Poly-Foam
Criteria	Weight	Rating	Weight Rating	Rating	Weight Rating	Rating	Weight Rating	Rating	Weight Rating
Heat Tolerance	30%	3	0.9	2	0.6	3	0.9	2.75	0.825
Damping Ratio	30%	2.75	0.825	3.5	1.05	3.5	1.05	2.75	0.825
Availability	20%	3.25	0.65	3	0.6	4	0.8	3.5	0.7
Cost	20%	4	0.8	2.5	0.5	2	0.4	3	0.6
Total	100%		3.175		2.75		3.15		2.95

Springs

Sorbothane	Sorbothane	Neoprene	Neoprene	1/4" Springs	1/4" Springs
Rating	Weight Rating	Rating	Weight Ratingh	Rating	Weight Ratin
2	0.6	3	0.9	4	1.2
3.5	1.05	2	0.6	3.75	1.125
3	0.6	3	0.6	3.5	0.7
3.5	0.7	2.5	0.5	3.75	0.75
	2.95		2.6		3.775

Insulation

		Insulation Options			
		Wading Sheets		Cellulose	
Criteria	Weight Importance	Rating	Weighted Rating	Rating	Weighted Rating
Durability	25%	3	0.75	4	1
Cost	20%	3	0.6	4	0.8
Weight	25%	4	1	3	0.75
Manufacturing Time	15%	3	0.45	3	0.45
Accquire Time	15%	4	0.6	4	0.6
Totals	100%		3.4		3.6

Motors

		Rocket Motors Concept Generation									
		Cesaroni H125-12A		AeroTech HP-I140W		Cesaroni I170		AeroTech I280DM-14A		Cesaroni 636I216-14A	
Criteria	Weight Importance	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Impulse	35%	0	0	0	0	1	0.35	3	1.05	4	1.4
Cost	25%	4	1	4	1	3	0.75	2	0.5	1	0.25
Initial Thrust	15%	1	0.15	2	0.3	2	0.3	4	0.6	4	0.6
Weight	10%	4	0.4	3	0.3	3	0.3	1	0.1	1	0.1
Reusability	10%	4	0.4	1	0.1	4	0.4	1	0.1	4	0.4
Max Acceleration	5%	4	0.2	4	0.2	3	0.15	1	0.05	2	0.1
Totals	100%		2.15		1.9		2.25		2.4		2.85

E. Egg Testing Results

Distance (feet):	3
Attempt	**Time (s)**
1	0.550
2	0.530
3	0.530
4	0.570
5	0.600
Average Time (s):	0.556
Calculated Velocity (ft/s):	5.396

Distance (feet):	5.833
Attempt	**Time (s)**
1	0.730
2	0.600
3	0.530
4	0.660
5	0.600
Average Time (s):	0.624
Calculated Velocity (ft/s):	9.348

Radius (mm, ft)	1524	5
Attempt	**Revolutions (rev/s)**	**Revolutions (rpm)**
1	1.43	85.8
2	1.45	87
3	1.41	84.6
4	1.39	83.4
5	1.47	88.2
Average Revolutions:	1.43	85.8
G-Force:	13	

F. Rocket Motor Matlab code

```
clear all; clc
%% Calvin Dahl 11/14/23 %%

%Rocket Geometry
  Cd = 0.75; % (N/A) Coefficient of Drag
  d = 102; % (mm) Diameter of nose
  A = 3.14159*(d/2000)^2; % (m/s) Frontal Rocket Area

%Rocket Specifications
  m = 1.84 + (601/1000); % (kg) Initial Rocket Mass
  Mp = (601-313)/1000; % (kg) Propellant Mass
  Tb = 2.9; % (s) Motor Burn Time
  I = 636.1; % (Ns) Rocket Total Impulse
  Thrust = I/Tb; % (N) Rocket Thrust

%Conditions
  rho = 1.225; % (kg/m^3) Density of Air
  g = 9.81; % (m/s^2) Earth Gravity

%Loop Parameters and Initial Conditions
  h = 1; % (m) Rocket Height
  v = 0; % (m/s) Rocket Velocity
  acc = 0; % (m/s^2) Rocket Acceleration
  dt = 0.01; % (s) Time Step
  tmax = 100; % (s) Max Time till loop ends
  TimeToApogee = 0; % (s) Time once Apogee Achieved
  i = 1; % Counter to store Height & Velocity Values

for t=dt:dt:tmax
      if(v < 0) % Once we reach max height break loop
    TimeToApogee = t;
            break
  endif

  if(t < Tb) %Thrust = 0 once burn time ends
    m = m - (Mp*dt/Tb);
      else
    Thrust = 0;
  endif
      Drag = 0.5*rho*(v^2)*Cd*A; % Drag Calculation

      v = v + (Thrust - Drag - g*m)*dt/m; % Velocity Calculation
  acc = (Thrust - Drag - g*m)/m; % Acceleration Calculation
      h = h +(v*dt); % Height Calculation
```

```
  %CONVERSION FROM METRIC TO IMPERIAL UNITS%
  H(i) = h*3.2808399;
  V(i) = v*3.2808399;
  M(i) = m;
  Acc(i) = acc*3.2808399;
  %CONVERSION FROM METRIC TO IMPERIAL UNITS%
  i++;
endfor

% Print Values
fprintf('\n Rocket Max Altitude = %g', max(H))
fprintf('\n Rocket Max Velocity = %g', max(V))
fprintf('\n Rocket Empty Mass = %g', min(M))
fprintf('\n Rocket Max Acceleration = %g', max(Acc))

%Subplots For Velocity, Height, Mass
t=0:dt:TimeToApogee - (2*dt);
subplot(4,1,1)
plot(t,H)
title('Rocket Altitude Vs Time','fontsize',16)
xlabel('time (s)','fontsize',14)
ylabel('Altitude (ft)','fontsize',14)

subplot(4,1,2)
plot(t,V)
title('Rocket Velocity Vs Time','fontsize',16)
xlabel('time (s)','fontsize',14)
ylabel('Velocity (ft/s)','fontsize',14)

subplot(4,1,3)
plot(t,M)
title('Rocket Mass Vs Time','fontsize',16)
xlabel('time (s)','fontsize',14)
ylabel('Mass (kg)','fontsize',14)

subplot(4,1,4)
plot(t,Acc)
title('Rocket Acceleration Vs Time','fontsize',16)
xlabel('time (s)','fontsize',14)
ylabel('Acceleration (ft/s^2)','fontsize',14)
```

Appendix A

Aerospace Engineering Design Competence Evaluation

Aeronautical	Critical/ Main contributor	Strong Contributor	Necessary but not a primary contributor	Necessary but only a minor contributor	Only a passing reference	Not included in this design project
Aerodynamics	X					
Aerospace Materials			X			
Flight Mechanics		X				
Propulsion	X					
Stability and Controls	X					
Structures		X				

Astronautical	Critical /Main contributor	Strong Contributor	Necessary but not a primary contributor	Necessary but only a minor contributor	Only a passing reference	Not included in this design project
Aerospace Materials			X			
Attitude Determination and Control						X
Orbital Mechanics						X
Rocket Propulsion	X					
Space Environment						X

Space Structures						X
Telecommunications					X	

Mechanical Engineering Design Competence Evaluation

ME Design Areas	Critical /Main contributor	Strong Contributor	Necessary but not a primary contributor	Necessary but only a minor contributor	Only a passing reference	Not included in this design project
Thermal-Fluid Energy Systems	X					
Machines and Mechanical Systems			X			
Controls and Mechatronics	X					
Material Selection	X					
Modeling and Measurement Systems					X	
Manufacturing			X			

Topic Competence Criticality Matrix

Project Title: 2K Rocket Launch **Semester:** Fall 2023

Aeronautical and/or Astronautical topics utilized in this senior design project:

Topic	Criticality to Project	Section and Pages	Comments
Aerodynamics	Critical/Main	3.3, 5.3.3, 9.3, 9.9	
Aerospace Materials	Necessary/Minor	3.2-4, 5.3	
Flight Mechanics	Strong	3.1, 5.3, 9.1	
Stability and Control	Critical/Main	5.3, 9.2, 9.9	
Structures	Strong	5.3.2-4, 9.5, 9.6, 9.7	
Propulsion	Critical/Main	5.3.6, 9.8	

Mechanical topics utilized in this senior design project:

Topic	Criticality to Project	Section and Pages	Comments
Thermal Fluid Energy Systems	Critical/Main	5.3.6	
Machines and Mechanical Systems	Strong	3.1-4, 5.3.1-6	
Controls and Mechatronics	Strong	3.1-4, 5.3.1-6	
Materials Selection	Necessary	3.2-3	
Manufacturing	Necessary	3.2-3, 5.3.4	