Most Optimal Design for a Cost-Effective, High-Power Rocket Capable of Delivering a Drone to an Altitude of 10,000 Feet

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The demand for cost-effective rocketry has been established through an analysis of existing literature and methodologies, leading to the development of a high-power rocket capable of delivering a drone to an altitude of 10,000 feet. A comprehensive evaluation of materials and designs was conducted, resulting in a total project cost of $2,212. The construction of the rocket was carried out utilizing innovative approaches to materials modification and aerodynamic optimization, ensuring both performance and safety. Performance data were meticulously recorded during simulations, confirming the rocket's ascent and descent profiles, with a maximum velocity of Mach 0.94 and an effective recovery system. Recommendations for individuals with budget constraints were formulated, emphasizing the potential for making rocketry accessible to a broader audience. The importance of cost-effective strategies in advancing rocketry, driving innovation, and promoting sustainability in future aerospace endeavors was underscored by the findings.

Introduction

The history of model rocketry began with the first modern model rocket motor being designed by the Carlisle brothers in 1954. This innovation was prompted by safety concerns that arose from young people attempting to create their own rocket engines following the launch of Sputnik. The motor design by the Carlisles was intended for educational purposes but later led to the foundation of the first American model rocket company, Model Missiles Incorporated (MMI)[1].

The establishment of Estes Industries in 1958 was made possible by the success of MMI's rocket engines, which played a significant role in the development of a highly efficient automated manufacturing machine for solid model rocket motors[1]. The market was quickly dominated by Estes, with kits and motors being offered, and influence was expanded through discounts provided to schools and organizations like the Boy Scouts of America[2].

During the 1960s-1980s, competitors like Centuri and Cox emerged, but Estes remained the primary source for rockets and equipment. In recent years, the market has seen the entry of companies like Quest Aerospace, yet a central role in the low- to medium-power rocketry hobby continues to be played by Estes[1].

The introduction of high-power rocketry in the mid-1980s brought a variety of companies into the market, including Aerotech Consumer Aerospace, LOC/Precision, and Public Missiles Limited. Larger and more powerful rockets were offered, with motors reaching significant energy levels. Contributions to the market were also made by custom motor builders who created specialized propellants and large motors[2].

Concerns about reliability and cost in high-power rocketry led to the introduction of reloadable motor designs by Aerotech and others, which offered more cost-effective and reliable options. The metal containers with propellant could be cleaned and refilled after each launch, significantly improving reliability. The performance of high-power rocketry was further enhanced by the ability to customize thrust profiles through the selection of different propellant designs. Flexibility to rocket enthusiasts was provided by standardized reload sizes, while continuous innovation was pursued by custom engine builders[1].

Cost-effective rocketry is recognized as a critical area of research in the aerospace industry, with the goal of making space more accessible and sustainable. Various strategies are being explored to reduce the cost of launching payloads into space[2].

One of the primary focuses is placed on reusability. Significant cost reductions can be achieved through reusable launch vehicles, which allow multiple uses of the same hardware. Extensive research into the design, engineering, and maintenance aspects of reusable rockets has been sparked. Advanced manufacturing techniques, such as 3D printing, are being studied to reduce material waste, accelerate production, and optimize component design[1]. The development of lightweight yet robust materials, including composites and alloys, is considered crucial for lowering rocket weight and launch expenses. Another research area focuses on propulsion efficiency, aiming to develop engines with higher specific impulse to reduce fuel requirements. Dedicated small satellite launch services, ride-share programs, and spaceplane concepts are being explored to cater to varying mission needs and cost-effectiveness [2]. Collaboration between government space agencies and private companies, as well as public-private partnerships, helps share research and development costs. Innovations in launch services, lean manufacturing, and optimized supply chains further contribute to cost-effective rocketry. The collective efforts of these research initiatives strive to unlock the potential for more affordable space exploration, satellite deployment, and commercial ventures in space, ultimately expanding humanity's reach into the cosmos [1].

The goal is to optimize a design for a cost-effective, recoverable, high-power rocket that will safely deliver a payload with a mass of 5 pounds and a payload length greater than 8 inches, which can fit in a rocket body tube with a diameter of 6 inches, to an altitude of 10,000 feet. To achieve this objective, a mixed method of qualitative and quantitative research methods will be employed. An explanation of the principles of rocketry-related physics and aerodynamics will be provided, using various sources online that will be referenced [2]. This paper will cover the medium of model rocketry, followed by extensive research on important variables and justification for each decision made. Experiments will be conducted using a rocket simulator. Through this, rockets will be designed and simulated before building and flying them, with all aspects of the simulation being analyzed using advanced plotting and exporting tools. Performance data such as center of pressure, center of gravity, maximum altitude, maximum velocity, and stability will be examined. Through these efforts, the basics of rocketry will be educated to the masses while demonstrating the necessity for cost-effective rocketry [1].

Literature Review

A model rocket operates on the fundamental principles of rocketry, following a straightforward but effective process. It all begins with the rocket engine, or motor, which contains solid propellant chemicals. Before launch, an electric igniter is placed in the rocket engine's nozzle. When triggered, this igniter ignites the propellant in the rocket engine, leading to a controlled explosion within the engine. The resulting rapid combustion generates hot gases that are expelled through the rocket's nozzle, thus creating the thrust that propels the rocket upwards into the sky. The aerodynamic design of the rocket, including its shape, size, and fin placement, is considered crucial for ensuring stable flight. At its highest point, called apogee, the engine burns out, and the maximum altitude is reached by the rocket. Most model rockets are equipped with a recovery system, such as a parachute, streamer, or other mechanism, which is deployed at apogee to slow the descent, ensuring a safe landing. Various aspects of model rocketry are encompassed, from design and construction to launch and safety considerations. A complete understanding of the subject requires knowledge of these different aspects of model rocketry. [2].

Design and Construction

Creating a model rocket involves the designing of the rocket's structure, the selection of materials, and the construction of the rocket. This includes the choosing of the rocket's shape, size, and components like the airframe, nose cone, fins, and motor mount. [2].

The first step in designing a model rocket is to choose a design or to create one. Rocket kits are available with pre-designed components, or a rocket may be designed from scratch. The design should be based on the intended purpose of the rocket, whether for basic experimentation, education, competition, or achieving specific performance goals.

Materials used vary from rocket to rocket, depending on the primary objective. Model rockets are typically constructed from lightweight materials. The airframe is often made of lightweight cardboard or plastic, while the fins can be made from balsa wood or plastic. Common plastics used in rocket construction include polystyrene, polyethylene, and fiberglass-reinforced plastic, which are chosen for their lightweight and durable properties. In this model rocket, fiberglass was used to build the rocket The choice of materials affects the rocket's weight, durability, and performance. [2]

A model rocket is composed of several components:

- Nose Cone: The pointed front part of the rocket that reduces air resistance. [2,3].
- Airframe: The main body of the rocket, typically a cylindrical tube. [2,3].
- Fins: Stabilizing surfaces attached to the rocket's lower section to keep it flying straight. [2,3]
- Motor: It is used to propel the rocket. Rocket engines come in various sizes and power levels, so one should be selected that matches the rocket's weight and aerodynamic characteristics and caters to the needs of the final goal. Understanding how different engines work, their classifications, and how they are installed is crucial. [2,3]
- Motor Tube: The primary function of the motor tube is to house and secure the rocket motor. It covers the exposed end of the rocket motor, ensuring a smoother transition between the motor and the rest of the rocket, maintaining the rockets aerodynamic shape. It also shields the rest of the rocket from heat released by the motor. [2,3]
- Motor Mount: The compartment that holds the rocket engine securely. [2,3]
- Recovery System: The mechanism used to slow down the rocket's descent and ensure a safe landing. Various types of model rocketry recovery methods include

parachute/streamer, featherweight recovery, tumble recovery, nose-blow recovery, glide recovery, helicopter recovery, and propulsive recovery.[2,3]

- Payload Bay: If the rocket carries payloads, a separate compartment may be provided for them.[2,3]
- Bulkhead: Bulkheads are used to create payload bays for model rockets. They block off the air flowing through the tube, protecting the delicate payload from the heat of the ejection charge.[2,3]
- Coupler: Tube couplers allow for the joining of two tubes having the same diameter, thereby making a longer rocket. It is crucial to remember that a coupler should always extend into both sections it joins, spanning a length equal to the rocket's diameter.[2,3]
- Thrust Rings and Model Rockets: Thrust rings or engine blocks are glued inside the motor mount and prevent motors from going forward.[2,3]
- Ejection Charge: The ejection charge releases gases and pressure upon ignition. Ejection charges are explosives that help in the separation of certain sections of the rocket to ensure the deployment of the recovery system. The precise timing and control of these charges are facilitated by electronic altimeters, which are commonly used in more advanced model rocketry and high-power rocketry. Proper operation of the ejection charge is essential for the safety and success of rocket flights.[2,3]
- Shear Pins: Shear pins are used to hold the airframe sections in place during the effects of inertia encountered at apogee. These pins can be easily sheared by calculating the proper amount of the ejection charges.[2,3]
- Launch Lug: The launch lug is what allows the model rocket to slide along the rod. On a model rocket, the launch lug is typically a small diameter tube.[2,3]
- Shock Cords: The parts of the rocket are held together by the shock cord after they separate at an ejection. The forces generated by the ejection and deployment events are absorbed by the shock cord, preventing damage to the rocket. The length and elasticity of the shock cord are important to ensure that adequate shock absorption occurs, especially in high-altitude rockets where ejection velocities are high.[2,3]

Physics in context with model rocketry

Physics and aerodynamics are regarded as a fundamental aspect of model rocketry, as they directly influence a rocket's flight stability, performance, and safety. Understanding the principles is considered vital for designing rockets that fly efficiently.

- Center of Gravity (CG): The center of gravity is recognized as a critical concept in model rocketry. It represents the point within the rocket where gravitational forces act. For stable flight, the CG should be positioned forward of the center of pressure (CP). This positioning ensures that the rocket naturally wants to orient itself with the nose facing forward during flight. If the CG is located too far back, the rocket may become unstable and tumble or veer off course. Each part is associated with a weight that can be estimated or calculated using Newtons weight equation, where w is the weight, m is the mass, and g is the gravitational constant:

  $$w = mg \tag{1}$$

  To determine the center of gravity (CG), a reference location or reference line is chosen. The CG is determined relative to this reference location. The total weight of the model rocket is calculated as the sum of all the individual weights of the components. Since the center of gravity represents an average location of the weight, it can be stated that the weight of the rocket (W) multiplied by the location (CG) of the center of gravity is equal to the sum of the weight (w) of each component multiplied by the distance (d) of that component from the reference location.

  $$Wcg = [wd](nose) + [wd](recovery) + [wd](engine) + \cdots \tag{2}$$

  Mechanical methods can be utilized as well. The first method, known as the balancing method, involves placing the component or entire rocket on a string or edge. The point at which balance is achieved indicates the center of gravity (CG), similar to how a pencil is balanced on a finger; this method is effective for simpler geometries but is not suitable for larger rockets like the Space Shuttle. The second method, referred to as the weighted string method, is ideal for irregular shapes. In this procedure, the model is hung from a point (such as the corner of a fin), and a weighted string is dropped to draw a vertical line along the rocket. When this process is repeated from another point (like the nose), a second line is created, and the intersection of these lines marks the CG. While this method works well for complex geometries, it should be noted that the CG can sometimes fall outside the body of the rocket.[4,5]

- Center of Pressure (CP): The center of pressure is defined as the point along the rocket's body where the aerodynamic forces are exerted. The center of pressure is influenced by the rocket's shape and the positioning of its fins. To achieve stability, the CP should be positioned behind the CG. When the CP is located behind the CG, a stabilizing torque is created by the aerodynamic forces acting on the rocket, which keeps the rocket's nose pointed forward. If the rocket deviates from its intended path, self-correction is caused by the stabilizing forces, preventing tumbling and maintaining a smooth trajectory. This is why a proper balance between the CG and CP is considered critical for maintaining stability in flight. The greater the distance between the CG and CP, the more stability will be exhibited by the rocket.[4,5]

- Fins: Fins are considered crucial for rocket stability. The necessary aerodynamic surfaces to keep the rocket flying straight are provided by them. The shape, size, and placement of the fins are significantly affected by a rocket's stability. The fins should be evenly spaced and symmetrically attached to the airframe. The effectiveness of the fins in moving the CP rearward and stabilizing the flight increases as the fins are larger or positioned farther back. The design should ensure that the CP is positioned behind the CG, and the fin area is recognized as a key factor in determining the position of the CP. Restoring forces are also generated by the fins to counteract any unwanted rotation or changes in flight path.[4,5]
- Nose Cone Shape: The shape of the nose cone is affected by a rocket's aerodynamics. Varying levels of aerodynamic drag are created by different nose cone shapes, such as ogive, conical, or elliptical. The intended purpose of the rocket and the desired flight characteristics should be considered when selecting the nose cone shape. For example, an ogive nose cone is often chosen for high-performance rockets because low drag and high efficiency at supersonic speeds are offered by it. Conversely, a conical nose cone may be used for simpler designs because it is easier to fabricate, though more drag is produced by it. A smoother airflow over the rocket is contributed to by the right nose cone shape, thereby reducing turbulence and drag.[4,5]
- Streamlining: A streamlined shape should be given to rockets to minimize aerodynamic drag. Smooth transitions between components, such as between the nose cone and body tube, should be created, and protrusions like launch lugs should be minimized to help reduce drag. A lower drag coefficient will be achieved by a streamlined rocket, allowing higher altitudes to be reached and more stable flight to be maintained. In practice, this means that all parts of the rocket should be carefully designed to reduce any air resistance or disruption of airflow. A highly streamlined design will be performed better, particularly at higher velocities.[4,5]
- Material Selection and Air Friction: The type of material used in the rocket's construction is also affected by the level of air friction (drag) experienced during flight. Materials with smoother surfaces, like fiberglass or polished aluminum, are created to generate less friction with the air, resulting in lower drag and higher velocities. Rougher materials, such as unfinished wood or certain plastics, are associated with increased air friction and drag, which can slow the rocket down. The material's surface texture and finish are played a crucial role in determining the overall drag coefficient (Cd) of the rocket. Therefore, low-friction, aerodynamic materials should be chosen to enhance the rockets speed and altitude performance.[4,5]
- Recovery System Deployment: The deployment of a recovery system, such as a parachute or streamer, can impact the rocket's aerodynamics during descent. A well-designed deployment mechanism ensures that the recovery system is opened properly, slowing the descent and avoiding instability due to sudden changes in drag. The recovery system needs to be deployed in a way that does not cause the rocket to spin or descend uncontrollably. Parachutes, for example, should be fully inflated to provide enough drag to slow the rocket to a safe landing speed without creating an excessive shock load on the rockets structure.[4,5]
- Velocity and Altitude Considerations: As a model rocket ascends, its velocity is increased, and aerodynamic forces acting on it are also increased. At apogee, the highest point in its flight, ascent is stopped, and descent begins. Aerodynamic forces are acted upon differently during ascent and descent, so the design should account for these varying conditions. A rockets maximum velocity is reached before apogee, and the airframe must be designed to handle the increased aerodynamic pressure at higher speeds. During descent, the deployment of recovery systems must occur in a timely manner to slow the descent.[4,5]
- Drag Coefficient: The drag coefficient (Cd) is a measure of how aerodynamic or streamlined the rocket is. Lowering the Cd is considered critical for improving performance and reaching higher altitudes. The drag coefficient is determined by the rockets shape, surface roughness, and material selection. A smoother, sleeker rocket with minimal surface protrusions and well-designed fins is typically associated with a lower Cd, allowing air resistance to be overcome more effectively. Materials with low friction against the air, such as fiberglass, are used to help reduce drag and improve the rocket's efficiency.[4,5]
- Newton's Third Law of Motion: This law is often summarized as ”For every action, there is an equal and opposite reaction.” In rocketry, it is implied that the expulsion of mass (the propellant) out of the rocket engine nozzle generates thrust, which causes the rocket to be propelled upward. This law forms the foundation of rocket propulsion.

  F_{thrust} is the force by which rocket is propelled forward (action force). F_{exhaust} is the force exerted in the opposite direction by the expelled gases (reaction force).

$$F_{\text{thrust}} = -F_{\text{exhaust}} \tag{3}$$

The thrust equation can be written as follows: V_{exhaust} is considered the exhaust velocity relative to the rocket. m is defined as the rate of mass flow (mass of exhaust gases per second and therefore is taken as dm/dt).)[4,5]

$$F_{\text{thrust}} = v_{\text{exhaust}} \times \frac{dm}{dt} \tag{4}$$

- Conservation of Momentum: According to this principle, the total momentum of a system is maintained as constant if no external forces are acting on it. In rocketry, the initial momentum of the rocket (when at rest) is considered zero. As mass is expelled at high velocity by the rocket, momentum is gained by the remaining rocket in the opposite direction. This principle illustrates how acceleration by the rocket is achieved.[4,5]
- Impulse: Impulse is defined as the product of force and time and is related to the change in momentum. In rocketry, the impulse generated by the rocket engine is what propels the rocket. It is measured in newton-seconds (Ns) or pound-seconds (lbfs) for various rocket engines. The rocket's altitude and speed are directly affected by the total impulse.[4,5]
- Thrust: Thrust is produced by the rocket engine and is essential for rocket acceleration and reaching altitude. The rocket's flight is affected by the duration, magnitude, and direction of thrust. Proper engine selection and thrust management must be ensured so that the rocket reaches its intended apogee without exceeding structural limits.[4,5]
- Apogee and Descent: Apogee is reached at the highest point during a rocket's flight, after which the descent begins. The physics of these phases must be understood for the proper deployment of recovery systems such as parachutes or streamers. At apogee, gravitational forces are dominated, causing the rocket to come to a halt before the descent begins. During descent, drag forces are encountered as the rockets recovery system slows its fall.[4,5]

Safety

Safety Safety is regarded as a paramount aspect of model rocketry. Small, controlled explosives that may become hot, rupture, or ignite, potentially causing serious injury and/or damage, are involved in rocketry. Personnel injury or death may result from mishandling the rockets.

A launch system, consisting of a launch pad, launch rod or rail, and an ignition system, is required for launching a model rocket. Proper setup and adherence to safety protocols are essential to ensuring a safe launch. Some model rockets are equipped with payloads, such as altimeters, cameras, or scientific instruments, and learning how to integrate and deploy these payloads is a key aspect of model rocketry.

All manufacturers safety instructions should be followed. In cases where discrepancies exist between these instructions and the manufacturers instructions, the more restrictive or safer option should be chosen.

- General Handling:
  Use only certified, commercially made model rocket motors. Do not tamper with them for any reason. Do not use them for any purposes except those recommended by the manufacturer.
  Only use those rockets with an electrical launch system and electrical motor igniter that includes an interlock in series with the launch switch. The launch switch must return to the off position when released.

- Prior to the activity:
  Review and be familiar with the National Association of Rocketry (NAR) safety code. www.nar.org
  Determine if there are any local rules and regulations regarding the type, size, and launching of rockets within your community.
  Appoint a Safety Observer to ensure that safety is maintained throughout the activity. The Safety Observer shall have no other duties. If the activity is to take place over an extended period, appoint two or more Safety Observers that can take turns and prevent fatigue.
  Safety Observers do not eliminate the need for all participating members to be vigilant. Encourage all participants to speak up if they see something that may be unsafe. Stop the activity until the issue is resolved.
  Use only prepackaged solid model rocket engines. Check the engines before installing them in the rocket to make sure that the casing and nozzle are sound and have no defects or cracks.
  Before the flight, check for loose fins, launch lugs, and shock cords as well as the condition of the recovery system.
  Ensure that only flame-resistant or fireproof recovery system wadding is used in the rocket.
  Ensure that a fire extinguisher or similar fire suppression system is at hand during the launch.
  Ensure that the unit commander is aware of the rocketry activity.

- At the beginning of the activity, provide a safety briefing:
  Brief all the manufacturers safety precautions. Note any items where an additional layer of safety has been added by the activity director.

Do not launch any rocket at a target, into a cloud, or near airplanes. Do not put any flammable or explosive payload into any rocket.
Always launch outdoors, in an open area. Do not launch near trees, houses, or highways.
Always launch in safe weather conditions. Check the weather prior to the launch. If lightning has been seen within 10 miles of the launch site, postpone the activity. Continue to monitor the weather throughout the launch period.
Ensure that no dry grass is close to the launch pad.
Never try to recover a rocket from power lines, tall trees or other dangerous places.
Never try to reuse or repack a spent solid rocket engine.
Do not attempt to modify the nozzle or the casing of a solid rocket engine.

- During the activity:
  If there is a misfire. Wait at least 60 seconds after the last launch attempt before approaching the rocket.
  At no time is any member to place any portion of the body over the rocket, in the direction of travel. This includes but is not limited to, the face and arms.
  Use a countdown before launch. Ensure everyone in the area is paying attention.
  At no time should any member be within 15 feet of the rocket(s) being launched. If the manufacturer recommends a greater distance, especially for the larger rockets, then the manufacturers distance shall be used.
  Ensure that the launch pad is securely anchored so that it doesnt tile or fall over. Between launches, check that the security of the launch pad has remained intact.

- After the activity:
  Always follow local ordinances for proper disposal of the rockets and any associated batteries. Many places consider rocketry supplies and batteries to be hazardous materials.
  If your system uses lithium or lithium-ion batteries: Many places consider lithium and lithium-ion batteries to be hazardous materials. To properly dispose of li-ion batteries, it is recommended that you take them to a battery recycling location or contact your local waste management service provider for disposal instructions. Put batteries in a sealed metal container before recycling them.
  Cap the end of the launch rod when it is not in use to prevent eye injury[6–8]

- Safety Measurements:
  Through the given required dimensions, the parts that are bought can be modified so that the rocket can be made. When fiberglass is modified, a systematic approach should be followed. Safety should be prioritized, and protective gear such as goggles, gloves, and a dust mask should be donned. The fiberglass component should be assessed carefully, with specific modifications being identified. The surface should be ensured to be clean and free of contaminants, and sanding should be considered if paint is planned to be applied. Suitable cutting tools should be used to achieve precise and clean cuts, and sandpaper or a sanding block should be employed for smoothing or reshaping if necessary. To add material or repair damage, epoxy resin and compatible adhesives should be used, and additional layers of fiberglass or carbon fiber should be bonded for reinforcement. Once the modifications are complete, the fiberglass should be inspected for structural integrity, and any final adjustments should be made.[6–8]

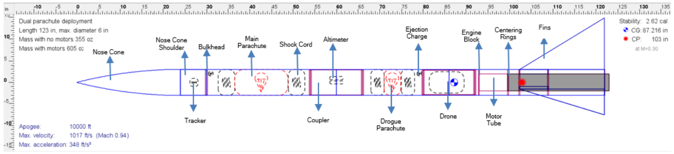


Fig. 1 Full Scale OpenRocket design schematic

Methods

Flight Design

A target altitude of 10,000 ft has been established for the rocket. This target will be utilized using a framework(Figure 1) that caters to all the needs of the given rocket. The payload design comprises a 9 oz drone, an altimeter, and a tracker. The drone has been placed in the drogue section, which is located in the lower half to ensure that the altimeters and the charges remain connected, resulting in the release of the parachute and payload at apogee. The data collected by the altimeter and tracker will then be used to determine the rocket's location. Upon landing, the payload inside the rocket will send the position of the system, assisting in recovery.

The AeroTech M1305M motor has been chosen for the rocket, as it provides the right amount of power to reach the apogee of 10,000 ft. The structure of the body and its various parts are strong enough to withstand the high speeds and high altitudes that the rocket will experience. The selection of the types and materials used to construct the rocket, along with the electronics and other aspects implemented within the rocket, will be further emphasized in the rest of the paper.

Recovery

The recovery method to be utilized will involve parachutes, specifically a double deployment system. Other components of the recovery system will include the shock cords, harnesses, shear pins, and the components within the avionics bay. An in-depth analysis has been conducted regarding the selection of each material used and the design decisions made.

Material Selection

The selection of fiberglass as the primary material for the rocket's construction was driven by its superior attributes compared to alternatives such as aluminum and carbon fiber. Fiberglass is renowned for its high strength-to-weight ratio, providing the structural integrity necessary to withstand the extreme stresses encountered during high-speed flight. This is particularly important when operating at velocities approaching Mach 0.94, where catastrophic failures could be caused by the inadequate materials used in the rocket. Unlike aluminum, which may be initially considered due to its lower cost, fiberglass offers better resistance to the high temperatures generated during motor ignition and ascent. While strong, aluminum tends to deform and fail under the immense pressure and aerodynamic forces experienced at such speeds, which would compromise the rocket's structural integrity and jeopardize the mission.[9]

Carbon fiber, another potential candidate, was ruled out primarily due to cost considerations. Although lightweight and incredibly strong, the financial implications of incorporating carbon fiber into the rocket's design exceeded the project's budget constraints. Moreover, the property of carbon fiber to absorb and attenuate radio frequency radiation poses a significant risk of interference with the electronic systems housed in the avionics bay, potentially leading to malfunctions during flight. In contrast, fiberglass maintains its structural integrity and is more effective in protecting internal components from heat and mechanical stress, thereby enhancing overall flight safety and performance.[9] This combination of factorsstrength, lightweight characteristics, cost-effectiveness, and compatibility with the rocket's electronic systemssolidified fiberglass as the ideal choice for constructing the nose cone, body tubes, bulkheads, couplers, motor tube, and fins.

The materials generally used to make parachutes include ripstop nylon, polyester fabric, nylon fabric, heat-resistant silicone fabric, and mylar. However, only two of the given materials can satisfy the high altitude and high-speed requirementsnylon and heat-resistant silicone fabric.[10]

The parachutes have been made from ripstop nylon. The typical composition of ripstop nylon is Nylon 6,6 (Polyamide), with the chemical formula ($C_{12}H_{22}N_2O_2$), though variations in the exact formula can occur based on the specific blend and manufacturing process. Ripstop nylon is regarded as a popular choice for high-speed, high-altitude model rocket parachutes. It is characterized as lightweight, strong, and durable. The "ripstop" design is incorporated with reinforcing threads in a grid pattern, which helps prevent tears or damage. The stresses of rapid deployment and high-velocity descents can be handled by ripstop nylon, making it considered a reliable choice.[10]

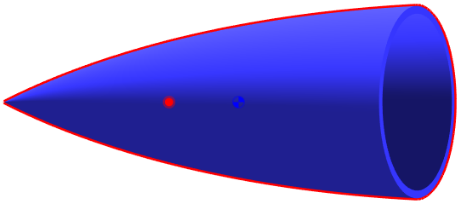


Fig. 2 O-give Nose cone

Ripstop nylon, like other nylon fabrics, is primarily regarded as an insulator and is not inherently able to absorb electromagnetic waves. However, its effectiveness can be affected by factors such as thickness, weaves, and any treatments applied to the fabric.[10]

Nylon is not significantly capable of absorbing electromagnetic radiation in the radio frequency (RF) range. Instead, certain wavelengths may be reflected or transmitted, depending on the thickness and weave of the fabric. Electromagnetic waves can be interacted with by nylon fabrics across a wide range of frequencies, but they are most effective at reflecting or attenuating waves in the microwave and RF ranges. Typically, microwave frequencies are considered to range from 300 MHz to 300 GHz, where some absorption properties may be exhibited by thicker or specially treated nylon. In the radio frequency range, which is commonly understood to span from 3 kHz to 300 GHz, energy is not effectively absorbed by nylon, but some interaction can occur.[10]

Heat-resistant silicone fabric, though better suited for high-power rocketry, is considered more expensive compared to ripstop nylon, thus making it regarded as less budget-friendly. Silicone itself is regarded as having poor conductive behavior; it is primarily considered an insulator and is not effectively able to transmit electromagnetic waves. In applications where EMI shielding is critical, silicone materials are often combined with conductive materials or coatings to enhance their protective capabilities. In the event of lightning striking it, silicone would not be absorbed. Instead, any lightning would likely affect the rocket's conductive components.[11]

The shock cords have been made using the braided nylon cord. The braided nylon cord is considered a cost-effective option that offers good strength and durability, making it suitable for high-speed and high-altitude rockets. It is regarded as more affordable than Kevlar but provides better heat resistance and strength than basic materials like rubber bands or twine.

Vehicle Design

1. **Nose Cone Selection:**

   The type of nose cone that has been used is an O-give nose cone(Figure 2). O-give cones are recognized for excelling in aerodynamic efficiency, mitigating drag due to

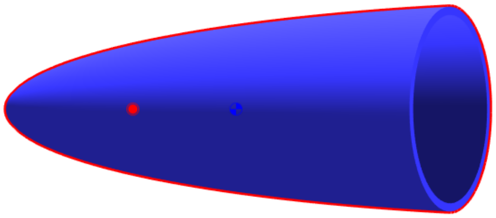


Fig. 3 Elliptical Nose cone

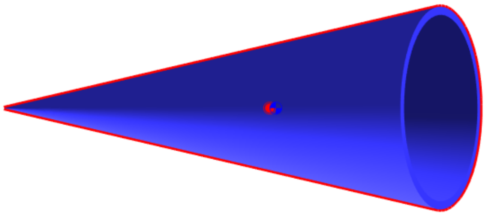


Fig. 4 Conical Nose cone

their sleek, elongated design, which ensures smooth airflow and reduced air resistance. This quality is considered particularly critical in applications where drag reduction is a top priority, such as high-speed aircraft and rockets. O-give cones are found in supersonic and hypersonic vehicles, where they are proven to be highly effective in maintaining stability during high-velocity flight and enhancing overall operational efficiency. Their elongated configuration is believed to contribute to flight stability by minimizing oscillations and instability tendencies compared to alternative nose cone shapes. O-give cones provide more internal space compared to other nose cone shapes, which allows for a larger payload capacity; the cone has been used to accommodate the tracker.[12]

The other types of nose cones, such as elliptical nose cones(Figure 3), conical nose cones(Figure 4), and hemispherical nose cones, were ruled out as they were found to fail to meet the high-altitude requirement of the rocket. Other shapes like the biconic nose cone, multi-cone nose cone, and secant ogive nose cone were found to meet the high-altitude requirement; however, their fabrication was considered much more complex compared to an O-give nose cone. The shoulder of the nose cone is used to help attach it to the body tube. It is understood to follow the same principle as a coupler. Additionally, the drag force associated with O-give nose cones is regarded as significantly lower than that of other shapes due to their ability to maintain attached flow over the surface and reduce pressure drag. The streamlined design of O-give cones is believed to enable them to gradually redirect airflow around their surface, minimizing turbulence and separation, which are common causes of increased drag. As a result, it is understood that both form drag and skin friction drag are effectively reduced by the O-give configuration, enhancing overall aerodynamic performance. This characteristic is considered to allow the O-give design to achieve optimal aerodynamic performance, making it regarded as the preferred choice for high-speed applications. Furthermore, O-give nose cones are considered particularly advantageous at supersonic speeds, where shock waves can significantly affect drag; it is believed that their shape helps manage these shock waves more effectively, thus maintaining lower drag coefficients compared to more conventional nose shapes.[12,13]

The drag force experienced by the rocket can be calculated using the formula below, where F_d is the drag force, ρ represents the fluid's density (in kg/m), u is the velocity of the object relative to the fluid (in m/s), Cd is the drag coefficient, and A is the reference area, often taken as the frontal area of the object (in m^2). This equation is regarded as crucial for determining how much resistance or drag is experienced by the rocket as it moves through the air. Higher velocities, larger surface areas, or higher fluid densities will all increase the drag force acting on the rocket, impacting its performance and altitude.

$$F_d = \frac{1}{2}\rho u^2 C_d A \tag{5}$$

For various nose cone shapes, typical drag coefficients are approximately: O-give nose cone ≈ 0.10.15
Conical nose cone ≈ 0.50.8
Hemispherical nose cone ≈ 0.40.5
For O-give Nose cone assuming drag co-efficient to be 0.12

$$F_d(\text{O-give}) = \frac{1}{2} \times 0.12 \times 1.225 \times (100)^2 \times 0.1$$

$$F_d(\text{O-give}) = \frac{1}{2} \times 0.12 \times 1.225 \times 10000 \times 0.1$$

$$F_d(\text{O-give}) = 0.5 \times 0.12 \times 1.225 \approx 7.35\ \text{N}$$

For Conical Nose cone assuming drag co-efficient to be 0.6

$$F_d(\text{Conical}) = \frac{1}{2} \times 0.6 \times 1.225 \times (100)^2 \times 0.1$$

$$F_d(\text{Conical}) = \frac{1}{2} \times 0.6 \times 1.225 \times 10000 \times 0.1$$

$$F_d(\text{Conical}) = 0.5 \times 0.6 \times 1.225 \approx 36.75\ \text{N}$$

From this analysis, we can conclude that the drag force experienced by an O-give nose cone is significantly lower than that experienced by a conical nose cone under the same conditions.

The shoulder of the nose cone helps attach it to the body tube. It follows the same principle as a coupler.[14]

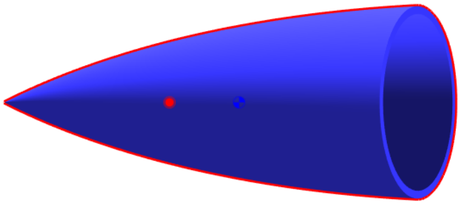


Fig. 5 Different types of fins (Parallelogrammatic, triangular, rectangular, and trapezoidal from left to right)

2. **Fin Selection:**

   The most common types of fins used are parallelogrammatic fins, trapezoidal fins, rectangular fins, and triangular fins. Conventionally, triangular fins are used in high-speed and high-altitude rockets. Excellent aerodynamic efficiency and reduced drag are offered by triangular fins, making them suitable for high-speed flight. They are considered a common choice for rockets approaching or exceeding the speed of sound (Mach). Stability is provided by triangular fins while minimizing aerodynamic drag, which is crucial for reaching high altitudes. It is understood that the other types of fins would fail to reach such high altitudes as effectively as triangular fins would.[13]

   Parabolic fins are also used for high-altitude and high-speed flights. However, a major drawback is recognized as the complex manufacturing process. Achieving the correct curvature is required by its shape, which makes it labor-intensive and requires advanced construction techniques that may not be known by someone new to rocketry.[13]

   Triangular fins have been used in this rocket. The material used for the fins is fiberglass, with a thickness of 0.1 inches. The number of fins that have been used is 3, as the right amount of stability required while reaching the apogee is provided by them. The fins have been attached using through-the-wall fin tabs. These fin tabs are extended through precisely cut slots or holes in the rocket's body tube and are firmly attached to the rocket's fins. This secure mounting method, which anchors the tabs both inside and outside the body tube, ensures a stable attachment. Beyond their structural advantages, noteworthy aerodynamic benefits are also offered by through-the-wall fin tabs. By extending through the body tube, a smoother, drag-reducing surface on the rocket's exterior is created by them. Due to this setup, the fins are kept firmly in place, even during the forces and stresses of rapid ascent and descent.

3. **Motor Selection:**
   The three motors up for selection were the Aerotech M1075, Aerotech M1305, and Aerotech M1600.

Table 1 Selection Grid for Motor

	Length	Diameter	Impulse	Cost	Apogee	Maximum Velocity
M1075	23.5 inches	3.86 inches	5628	$641.99	8200 feet	Mach 0.80 (869 ft/s^2)
M1600	23.5 inches	3.86 inches	6889	$641.99	10,000 feet	Mach 1.03 (1118 ft/s^2)
M1305	22.8 inches	3.86 inches	7002	$640.99	10,000 feet	Mach 0.94 (1017 ft/s^2)

   The motors were shortlisted based on length and diameter criteria, limiting the options to those under 25 inches in length and 3.86 inches in diameter. The three motors consideredM1075, M1305, and M1600had similar costs and impulses. While a maximum velocity of Mach 0.80 was achieved by the M1075 motor, the required apogee of 10,000 feet was not reached. On the other hand, the desired altitude was reached by the M1600 motor, but the sound barrier was exceeded, increasing the risk of structural failure. Ultimately, the M1305 motor was selected as it effectively meets the altitude requirement while staying below the sound barrier.[15]

   Rocket motors primarily derive their energy from chemical propulsion, a process where thrust is generated by the combustion of chemical propellants. High-pressure gases are produced by the burning of either solid or liquid fuels, which are expelled through a nozzle, adhering to Newton's third law of motion. There are two main types of rocket motors in chemical propulsion: solid and liquid. Solid rocket motors utilize a uniform mixture of solid propellant that burns to create thrust. A rapid energy release occurs over a short duration, providing the necessary impulse for launch and ascent. Conversely, propellants are stored in separate tanks by liquid rocket motors, which mix them in a combustion chamber. Precise control over the propellant flow is offered by this design, allowing for throttling, shutdown, and restarts during flight, making it advantageous for more complex missions.[15]

   The Aerotech M1305 motor, specifically used for the rocket project, employs Ammonium Perchlorate Composite Propellant (APCP), a solid propellant known for its efficiency and performance in high-power rocketry. APCP consists of a mixture of oxidizers, such as ammonium perchlorate, combined with a fuel binder, providing high thrust and reliable combustion. The choice of propellant enhances the motor's ability to deliver the required impulse while maintaining stability and safety during flight, making it suitable for reaching the designated apogee of 10,000 feet.[15]

Although it is theoretically possible for solar panels to be used to provide electric current for propulsion in rockets, several practical challenges limit this application. Sunlight is converted into electricity by solar panels, but their power output is generally insufficient for the high thrust required during launch and ascent. The weight and volume of solar panels, along with the associated components needed for energy storage and management, could add significant mass to the rocket, counteracting any benefits of using solar energy.[16]

Additionally, challenges for effective solar energy collection are presented by the operational environment during launch, as the rocket will rapidly ascend through the atmosphere and into space, where sunlight can be sporadic. Furthermore, the necessary power density to meet the propulsion demands of high-speed rockets may not be provided by current battery technology. Therefore, while solar panels could theoretically contribute to some onboard systems, relying on them for primary propulsion is not currently feasible.[16]

Impulse

Impulse is defined as the change in momentum of an object when a force is applied over time. Mathematically, impulse (I) can be expressed as:

$$I = F \cdot t \tag{6}$$

Where I is the impulse, F is the average force applied, and t is the duration of time the force is applied. In rocketry, the primary force applied is the thrust produced by the rocket motor. However, during ascent, frictional forces opposing its motion, such as aerodynamic drag and internal friction within the motor, are experienced by the rocket. Therefore, the net force Fnet acting on the rocket can be described as:

$$F_{net} = F_{thrust} - F_{friction} \tag{7}$$

Where F_{thrust} is the thrust produced by the rocket motor and $F_{friction}$ is the total frictional force acting on the rocket. The total frictional force can be expressed in terms of drag as:

$$F_{\text{friction}} = \frac{1}{2} \cdot C_d \cdot \rho \cdot A \cdot v^2 \tag{8}$$

Where C_d is the drag coefficient, ρ is the density of the fluid (air) through which the rocket is moving, A is the reference area (frontal area of the rocket), and v is the velocity of the rocket. Substituting the expression for friction into the impulse equation yields:

$$I = \left(F_{\text{thrust}} - \frac{1}{2} \cdot C_d \cdot \rho \cdot A \cdot v^2 \right) \cdot t \tag{9}$$

In rocketry, the impulse delivered by the thrust must overcome the combined effects of gravity and friction for successful ascent of the rocket. If friction is significant, the net impulse will be reduced, affecting the rocket's velocity and altitude. Therefore, understanding and minimizing friction is considered crucial for maximizing impulse, which directly relates to the rocket's performance, altitude, and overall mission success. Choices in materials, aerodynamics, and propulsion can be informed by this understanding to achieve desired flight profiles. In the methods section, it can be elaborated how the calculations for impulse will account for frictional forces, ensuring that the rocket design is optimized for efficient flight performance.[17]

Recovery System Analysis

A pre-built avionics bay has been utilized. The avionics bay is connected to the ejection charge. Upon reaching the designated altitude, the black powder charges are set off, resulting in the deployment of the recovery system. The dual-deployment parachute method(Figure 6) is employed as the recovery method. Safety and precision during a rocket's descent are enhanced by this system through the incorporation of two distinct parachute deployments during flight. The initial deployment is represented by a smaller parachute known as the ”drogue chute,” which is released at an altitude significantly above the rocket's apogee, or highest point. The stabilization of the rocket during descent is the primary role of the drogue chute, which prevents erratic tumbling or spinning, especially crucial for high-powered rockets reaching extreme altitudes.[18] Following the deployment of the drogue chute, the primary event is the release of the larger ”main parachute,” which occurs at a lower altitude, nearer to the landing area, ensuring a gentle and safe descent for a secure landing. Precise ejection charges and electronic altimeters are relied upon by dual deployment systems to control the timing of each parachute deployment, ensuring a safe and controlled descent. In this case, the drogue parachute, which is located in the lower part of the rocket, is released at 10,000 feet, while the main parachute, located in the upper part of the rocket, is released at 500 feet. The reason for the specific altitude of parachute deployment will be justified in the parachute selection. This design configuration has been justified in the flight design. The ejection charge is determined to be black powder. Black powder is considered the most common choice used as ejection charges for model rockets. It is regarded as very cheap and is noted to take up minimal space within the bulkhead. However, it must be handled with care and safely due to its explosive nature. A carbon dioxide system, though considered the safest and least likely to explode, was not chosen as it would consume significantly more space within the rocket.[19] In the rocket, the motors ejection charge is ignited, generating hot gases that pressurize the rockets airframe and exert a net force on the bulk plate of the nose cone. This net force is responsible for ejecting the nose

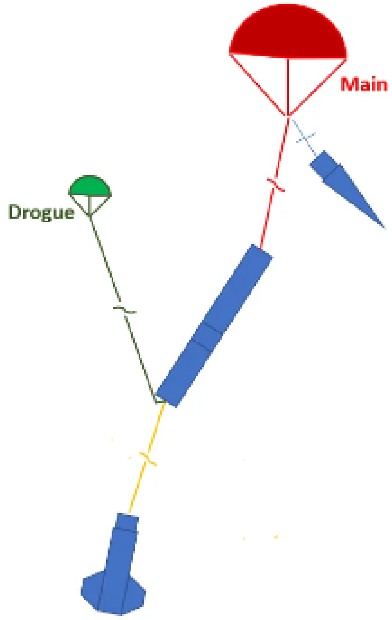


Fig. 6 Dual Deployment System

cone, shock cord, and parachute out of the rocket airframe. This occurs because the Ideal Gas Law is obeyed by the rocket. Upon reaching the specified altitude, the shear pins are broken, and the ejection charges are exploded, resulting in the deployment of the parachutes.[20] The shear pins used are identified as 2-56 nylon screws, also known as #2 shear pins. Redundant charges have been added to the rocket in case the initial charges fail to execute their task. The calculations have been made using the formulas below. Equation 10 is used to represent the relationship between force and the area over which the force is applied. In this context, pressure (measured in pounds per square inch, or psi) is defined as the amount of force exerted per unit area. The greater the force applied over a smaller area, the higher the pressure is observed to be. Conversely, when the same force is applied over a larger area, the pressure is reduced.

$$\text{Pressure (psi)} = \frac{\text{Force (lbs)}}{\text{Area (in}^2)} \tag{10}$$

In Equation 11, the volume is calculated in cubic inches. The inside diameter of the airframe is referred to by the diameter, and the unfilled length of the tube is represented by the length. The formula is essentially used to compute the volume of a cylindrical section of the airframe by multiplying the area of its circular cross-section by its length. The circular cross-section area is calculated by squaring the diameter, multiplying it by , and then dividing it by 4.[21]

$$\text{Volume (in}^3) = \frac{\pi \times (\text{Diameter (in)})^2 \times \text{Length (in)}}{4} \tag{11}$$

Equation 12 is utilized to calculate the amount of black powder (in grams) that is needed to create enough pressure for the ejection of the recovery system. The numerator, Pressure Volume, is represented by the force needed to eject the components, while constants for energy conversion (266) and gas properties at standard conditions (3307 R) are included in the denominator. The result is converted to grams by multiplication with 454 grams/lbf.[21]

$$\text{Grams}_{(\text{BP})} = \frac{454\,\text{grams}}{1\,\text{lbf}} \times \left(\frac{\text{Pressure (psi)} \times \text{Volume (in}^3)}{266\,(\text{in}\cdot\text{lbf})/\text{lbm} \times 3307 \cdot R} \right) \tag{12}$$

The formula used to calculate the force generated by the black powder during the ejection process is $F = p \times A$, where F is represented by the force in pounds (lbf), p is represented by the pressure generated by the black powder charge in psi, and A is represented by the cross-sectional area of the ejection chamber in square inches. This equation is considered essential for determining the amount of force exerted on the components during the ejection phase. To find the number of shear pins required to hold the components in place until ejection, the calculated force F is divided by 25 pounds, which is recognized as the force threshold at which the shear pins are designed to fail. This process ensures that safe and effective ejection is achieved under the right conditions.[21]

$$F = p \cdot A \tag{13}$$

The calculations for the main and drogue charges used in the rocket's deployment system are presented in Table 2. For the main charge, 7.48 grams of black powder are used, with an inner body tube diameter of 6 inches and a tube length of 36 inches. Thirteen shear pins (#2) are necessitated by this combination to withstand the forces exerted before the main parachute is deployed. For the drogue charge, 3.82 grams of black powder are needed, with the same inner diameter of 6 inches but a shorter body tube length of 26 inches, requiring 9 shear pins to handle the force of deployment.[21]

Table 2 Main Charge Calculation

	Main Charge	Drogue Charge
Black powder(grams)	7.48	3.82
Inner diameter(inches)	6	6
Body tube length(inches)	36	26
Number of #2 shear pins	13	9

Table 3 is presented with the calculations for the redundant charges, which provide a backup to ensure successful deployment if the main charges fail. Slightly more black powder, at 8.6 grams, is required for the redundant main charge, which has the same 6-inch diameter and 36-inch body tube length. Like the main charge, 13 #2 shear pins are used. For the redundant drogue charge, 4.49 grams of black powder is utilized, with the same 6-inch diameter and 26-inch body tube length, requiring 9 shear pins to manage the deployment of the drogue parachute.[21] To calculate this the following equation and method were used. Redundancy factor has been taken 0.15 as it is standard practice:

$$\begin{aligned}\text{Redundant Main Charge} &= \text{Original Main Charge}\times \\ (1+\text{Redundancy Factor}) &= 7.48\,\text{grams}\times(1+0.15) \\ &= 7.48\,\text{grams}\times 1.15 \approx 8.60\,\text{grams}\end{aligned} \tag{14}$$

$$\begin{aligned}\text{Redundant Drogue Charge} &= \text{Original Drogue Charge}\times \\ (1+\text{Redundancy Factor}) &= 3.82\,\text{grams}\times(1+0.15) \\ &= 3.82\,\text{grams}\times 1.15 \approx 4.39\,\text{grams}\end{aligned} \tag{15}$$

Table 3 Redundant Charge Calculation

	Redundant Main Charge	Redundant Drogue Charge
Black powder(grams)	8.6	4.39
Inner diameter(inches)	6	6
Body tube length (inches)	36	26
Number of #2 shear pins	13	9

These calculations ensure that the correct amount of black powder is used to generate the necessary force for deployment while preventing premature failure of the shear pins, allowing the recovery system to operate reliably at high altitudes and speeds.[21]

Parachute Selection

The parachute selection was accomplished using the simulations, done in OpenRocket, by calculating different kinetic energies at main deployment and on impact with the ground, using the simulations run. The Drogue parachute has a diameter of 36 inches while the main parachute has a diameter of 120 inches. Both parachutes have drift distances within the desired criteria as well as safe kinetic energy calculations on impact. This is justified by the drift simulations shown in simulations.

The figure shows the ideal ascent and descent data for the full-scale model while using parachutes of given dimensions, by showing the predicted behavior of the vertical velocity, vertical acceleration and altitude of the vehicles ascent and descent As shown(Figure 7), the apogee of the rocket is 10,000 feet which is where the drogue parachute gets deployed. The second parachute is deployed at 500 feet. Given below are the values of velocity and acceleration at specific times of the rockets flight and the total flight time taken

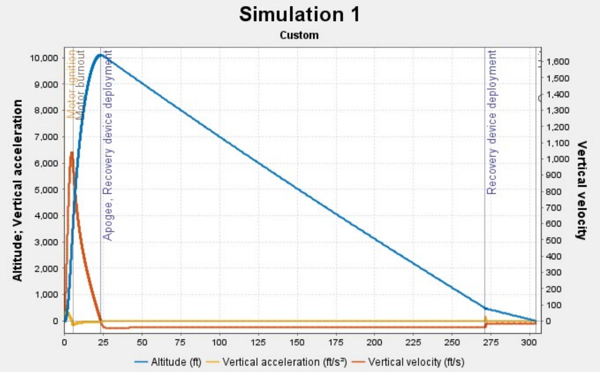


Fig. 7 Open Rocket vertical motion simulation of flight

Table 4 Data related to velocity at various times of flight

Velocity off rod	Velocity at deployment	Maximum velocity	Maximum acceleration	Time to apogee	Flight time	Ground hit velocity
95.5 ft/s	36.2	1034 ft/s	356 ft/s2	23.1s	301s	14.8 ft/s

The Drogue parachute is released at apogee (10,000 feet) while the main parachute is released at an altitude of 500 feet. The drogue chute's primary function is to stabilize the rocket's descent. It reduces the rocket's descent speed and prevents it from tumbling or spinning uncontrollably. This is particularly important for rockets that reach high altitudes and experience turbulent airflows. By stabilizing the rocket with the drogue chute, the main parachute deployment is delayed until a lower, safer altitude. The main parachute is deployed at such a low altitude so as to reduce drift. This will cause difficulty in the recovery of the rocket, and it could land outside the designated landing area.

The length of the shock cord attached to the nose cone and the shock cord in the drogue section attached to the AV bay coupler measure 60 inches each, while the shock cord in the main section attached to the AV bay coupler is 250 inches long and shock cord in the drogue section attached to the payload coupler is 200 inches long. The lengths have been set such that upon descending the different sections dont crash into each other and get tangled.

Couplers

In the context of rocketry, couplers are integral components that play a crucial role in maintaining the structural integrity and functionality of a rocket. These short tubes are designed to connect different sections of the rocket's body, ensuring that they are securely joined while allowing for smooth airflow and minimizing drag during flight. In model rocketry, couplers are commonly used to join sections of the airframe, connect different stages, or facilitate access to payload bays.[22]

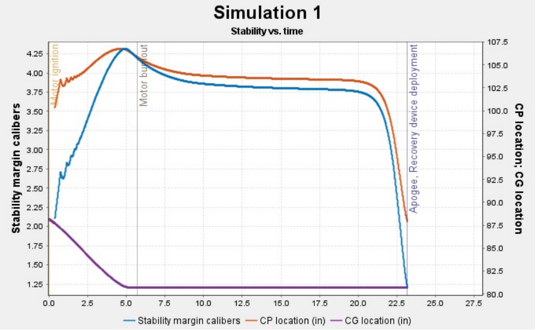


Fig. 8 Open Rocket stability time simulation

In model rocketry, couplers are structural components used to join two sections of the rocket's body tube, ensuring a strong and secure connection. Typically, they are short tubes made of the same material as the body tube but with a slightly smaller diameter so that they can fit snugly inside both body tube sections being joined. Couplers are commonly used to connect different stages of the rocket, sections of the airframe, or payload bays.[22]

Couplers serve several important purposes in model rocketry. First, they provide structural integrity to the rocket by maintaining alignment between sections, ensuring that the rocket flies straight and minimizes wobble or instability during flight. They also allow for modular design, making it easier to transport and assemble the rocket by breaking it into smaller sections. Additionally, couplers are often used in rockets with removable payloads or recovery systems, providing a method for easy access to these components.[22]

In more advanced designs, couplers can house electronics such as altimeters or trackers, especially in the avionics bay. They often feature internal bulkheads or seals to protect the electronics from exposure to gases or pressure changes during launch and recovery.[22] In the model rocket the couplers were made of fiberglass.

Payload Configuration

The altimeters, trackers and the drone were placed in their respective couplers. The couplers have been secured using bulkheads.

Performance Simulations

1.Stability Simulations As shown above (Figure 8) predicted stability value is higher than the predicted stability given in Figure 1.

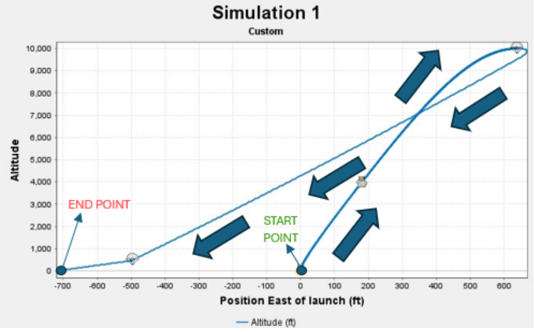


Fig. 9

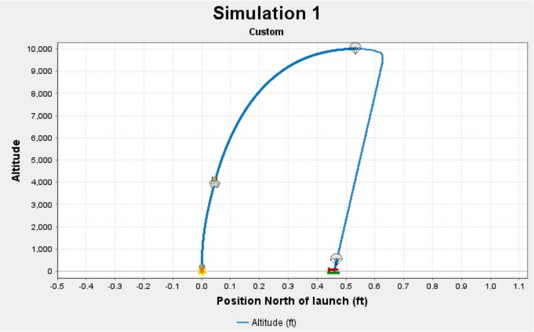


Fig. 10

2. Drift Simulation

Below (Figure 9 and Figure 10) are simulations on open rocket showing altitude vs position east of launch and altitude vs position north of launch. The thicker line shows an upward flight and the thinner line shows downward flight. As shown in the above figure (Figure 9) upon hitting the ground after flight, the rocket lands -0.46 feet north. As shown in the above figure (Figure 10) upon hitting the ground after flight, the rocket lands -720.42 feet east from its original point.

To find the distance and direction from the original point to the rocket's final landing point, you can use the Pythagorean theorem for distance and trigonometry for direction.

The distance (D) can be found using the Pythagorean theorem:

$$D = \sqrt{((-0.46\,\mathrm{ft})^2 + (-720.42\,\mathrm{ft})^2)}$$

$$D = \sqrt{(0.2116\,\mathrm{ft}^2) + (518755.5364\,\mathrm{ft}^2)}$$

$$D = \sqrt{518755.748\,\mathrm{ft}^2}$$

$$D \approx 720.44\,\mathrm{feet}$$

So, the rocket is approximately 720.44 feet from its original point.

To find the direction (θ) in which the rocket landed, you can use the inverse tangent (arctan) function:

$$\theta = \arctan(\Delta E / \Delta N)$$

Where ΔE is the change in the east direction (-720.42 feet) and ΔN is the change in the north direction (-0.46 feet). Plugging in these values:

$$\theta = \arctan(-720.42\,\text{ft} / -0.46\,\text{ft})$$

$$\theta = \arctan(1561.9565)$$

Using a calculator:

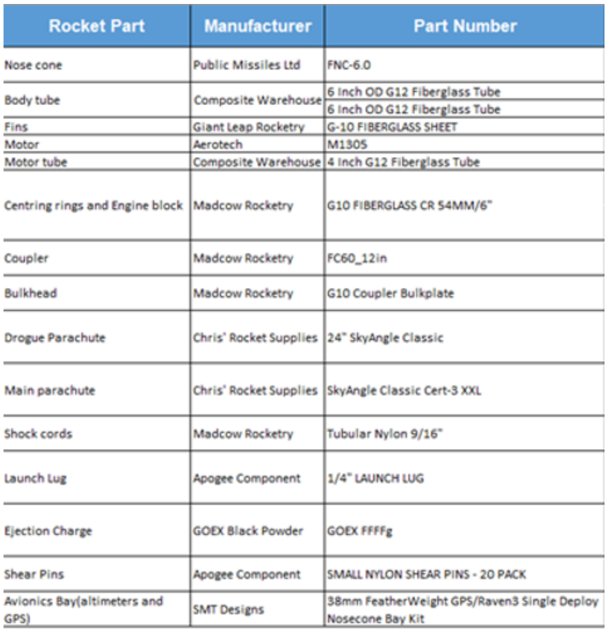
$$\theta \approx 57.92^\circ$$

So, the rocket is approximately 720.44 feet from its original point, and it landed at an angle of approximately 57.92 degrees east of north. From this we get an estimate of what the recovery radius will be.

The landing position of the rocket, approximately 0.46 feet north and 720.42 feet east from its original launch point, can be attributed to several key factors. Wind can exert lateral forces during both ascent and descent, causing the rocket to drift, especially during parachute descent. Asymmetrical drag can occur if the rocket's fins or recovery system are not symmetrical or misaligned, leading to uneven drag that affects the descent path. Additionally, if the recovery system deploys too late or at an angle, it can cause the rocket to land off-target. The launch angle may also influence the final landing position; a launch angle with an eastward component affects the trajectory. Lastly, ground effects, particularly near obstructions or uneven terrain, may interact with the rocket during descent, further influencing its landing position. Collectively, these factors explain the observed displacement of the rocket from its intended landing point.

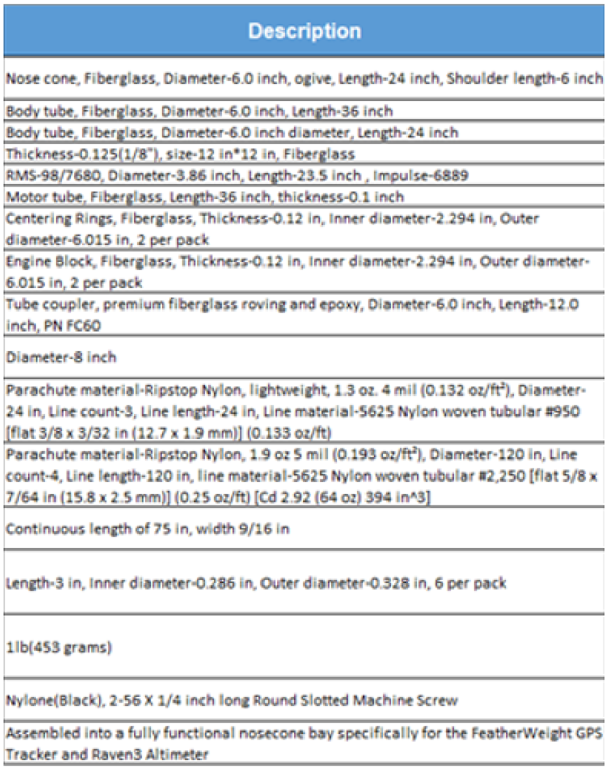
Results

Using all the methods above, Ive arrived at the most cost-effective way to build a rocket. Below is the table of all the materials utilized in making the rocket along with its costs and dimensions if required. Its a total cost of $2,212.



Rocket Part	Manufacturer	Part Number
Nose cone	Public Missiles Ltd	FNC-6.0
Body tube	Composite Warehouse	6 Inch OD G12 Fiberglass Tube 6 Inch OD G12 Fiberglass Tube
Fins	Giant Leap Rocketry	G-10 FIBERGLASS SHEET
Motor	Aerotech	M1305
Motor tube	Composite Warehouse	4 Inch G12 Fiberglass Tube
Centring rings and Engine block	Madcow Rocketry	G10 FIBERGLASS CR 54MM/6"
Coupler	Madcow Rocketry	FC60_12in
Bulkhead	Madcow Rocketry	G10 Coupler Bulkplate
Drogue Parachute	Chris' Rocket Supplies	24" SkyAngle Classic
Main parachute	Chris' Rocket Supplies	SkyAngle Classic Cert-3 XXL
Shock cords	Madcow Rocketry	Tubular Nylon 9/16"
Launch Lug	Apogee Component	1/4" LAUNCH LUG
Ejection Charge	GOEX Black Powder	GOEX FFFFg
Shear Pins	Apogee Component	SMALL NYLON SHEAR PINS - 20 PACK
Avionics Bay(altimeters and GPS)	SMT Designs	38mm FeatherWeight GPS/Raven3 Single Deploy Nosecone Bay Kit

Fig. 11 Rocket Parts, Manufacturers and Part Number

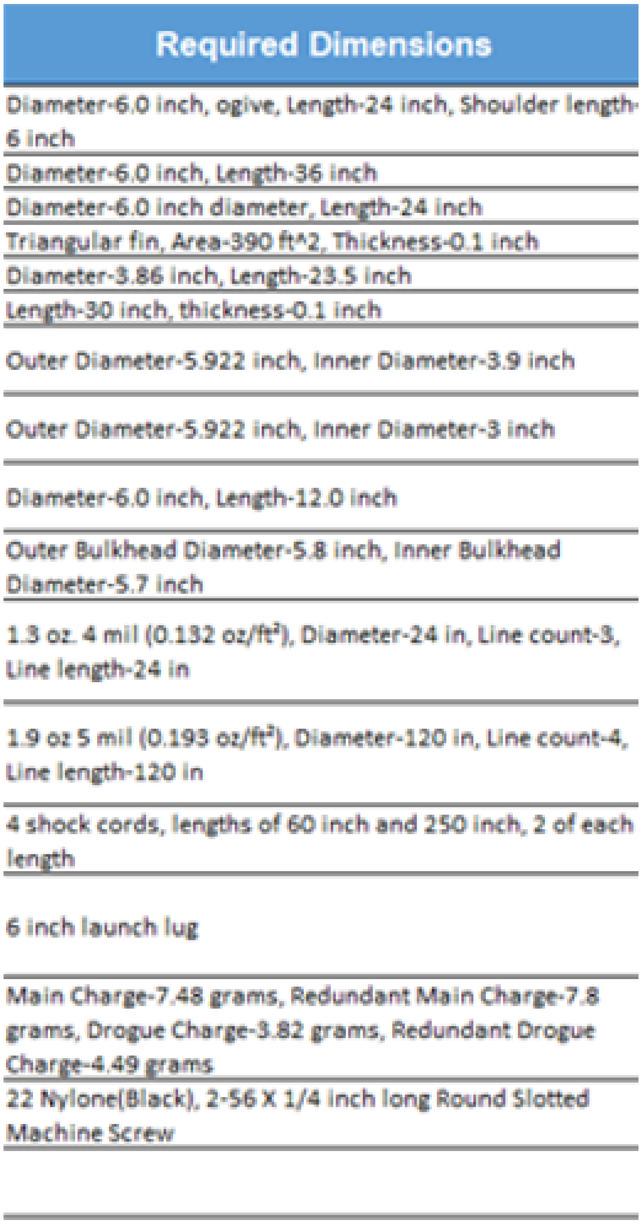


Description
Nose cone, Fiberglass, Diameter-6.0 inch, ogive, Length-24 inch, Shoulder length-6 inch
Body tube, Fiberglass, Diameter-6.0 inch, Length-36 inch
Body tube, Fiberglass, Diameter-6.0 inch diameter, Length-24 inch
Thickness-0.125(1/8"), size-12 in*12 in, Fiberglass
RMS-98/7680, Diameter-3.86 inch, Length-23.5 inch , Impulse-6889
Motor tube, Fiberglass, Length-36 inch, thickness-0.1 inch
Centering Rings, Fiberglass, Thickness-0.12 in, Inner diameter-2.294 in, Outer diameter-6.015 in, 2 per pack
Engine Block, Fiberglass, Thickness-0.12 in, Inner diameter-2.294 in, Outer diameter-6.015 in, 2 per pack
Tube coupler, premium fiberglass roving and epoxy, Diameter-6.0 inch, Length-12.0 inch, PN FC60
Diameter-8 inch
Parachute material-Ripstop Nylon, lightweight, 1.3 oz. 4 mil (0.132 oz/ft^2), Diameter-24 in, Line count-3, Line length-24 in, Line material-5625 Nylon woven tubular #950 [flat 3/8 x 3/32 in (12.7 x 1.9 mm)] (0.133 oz/ft)
Parachute material-Ripstop Nylon, 1.9 oz 5 mil (0.193 oz/ft^2), Diameter-120 in, Line count-4, Line length-120 in, line material-5625 Nylon woven tubular #2,250 [flat 5/8 x 7/64 in (15.8 x 2.5 mm)] (0.25 oz/ft) [Cd 2.92 (64 oz) 394 in^3]
Continuous length of 75 in, width 9/16 in
Length-3 in, Inner diameter-0.286 in, Outer diameter-0.328 in, 6 per pack
1lb(453 grams)
Nylone(Black), 2-56 X 1/4 inch long Round Slotted Machine Screw
Assembled into a fully functional nosecone bay specifically for the FeatherWeight GPS Tracker and Raven3 Altimeter

Fig. 12 Description

Conclusion

This research highlights several innovative avenues for enhancing cost-effectiveness in rocketry. Key areas of focus include



Required Dimensions
Diameter-6.0 inch, ogive, Length-24 inch, Shoulder length-6 inch
Diameter-6.0 inch, Length-36 inch
Diameter-6.0 inch diameter, Length-24 inch
Triangular fin, Area-390 ft^2, Thickness-0.1 inch
Diameter-3.86 inch, Length-23.5 inch
Length-30 inch, thickness-0.1 inch
Outer Diameter-5.922 inch, Inner Diameter-3.9 inch
Outer Diameter-5.922 inch, Inner Diameter-3 inch
Diameter-6.0 inch, Length-12.0 inch
Outer Bulkhead Diameter-5.8 inch, Inner Bulkhead Diameter-5.7 inch
1.3 oz. 4 mil (0.132 oz/ft^2), Diameter-24 in, Line count-3, Line length-24 in
1.9 oz 5 mil (0.193 oz/ft^2), Diameter-120 in, Line count-4, Line length-120 in
4 shock cords, lengths of 60 inch and 250 inch, 2 of each length
6 inch launch lug
Main Charge-7.48 grams, Redundant Main Charge-7.8 grams, Drogue Charge-3.82 grams, Redundant Drogue Charge-4.49 grams
22 Nylone(Black), 2-56 X 1/4 inch long Round Slotted Machine Screw

Fig. 13 Respective costs of each material and final cost

materials innovation, emphasizing lightweight, high-strength materials and alternative manufacturing techniques to reduce costs without compromising safety and performance. The exploration of propulsion efficiency through superior thrust-to-weight ratios and alternative fuels is also crucial. Aerodynamic optimization aims to minimize drag, enhancing overall efficiency with unique design configurations. The integration of reusable rocket technology further contributes to cost reduction by enabling multiple launches with the same components. Detailed cost analyses will identify areas for savings while maintaining quality and safety. Additionally, this paper serves as a comprehensive guide for newcomers to rocketry, detailing assembly procedures, construction techniques, and the fundamental physics of rocket operation. By fostering a profound understanding of these concepts, this research aims to inspire a new generation of rocketry enthusiasts, igniting their passion for the field.

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