Introduction

Experimental rocketry represents a captivating intersection of science, engineering, and sheer innovation. At its core, it embodies the spirit of exploration and discovery, where enthusiasts explore into the realms of aerospace engineering and flight dynamics to push the boundaries of what is possible. In this domain, rockets aren't just objects of fascination but tangible manifestations of human resourcefulness, crafted from scratch to ascend into the unknown.

Amateur Experimental Rocketry (AER) exemplifies this spirit of hands-on exploration and DIY mentality. Unlike conventional rocketry that rely on commercially available components, AER embrace the challenge of designing, fabricating, and testing rockets entirely from the ground up. From crafting custom motors to formulating specialized propellants, every aspect of the rocket's construction is a testament to the maker's skill, creativity, and dedication.

Central to the essence of AER is the pursuit of knowledge through hands-on experimentation. Every rocket built is not merely a vehicle for reaching new heights but a platform for scientific inquiry and technological advancement. From studying aerodynamic stability to optimizing thrust-to-weight ratios, each launch serves as a valuable learning experience, offering insights that can inform future designs and techniques.

In the context of our recent project, the fabrication of a solid motor rocket with the goal of achieving an apogee of 1600 meters exemplifies the spirit of AER. From the initial design phase to the detailed construction of the airframe and propulsion system, every step of the process embodies the principles of collaboration and hands-on experimentation that define AER.

Simulation using open rocket

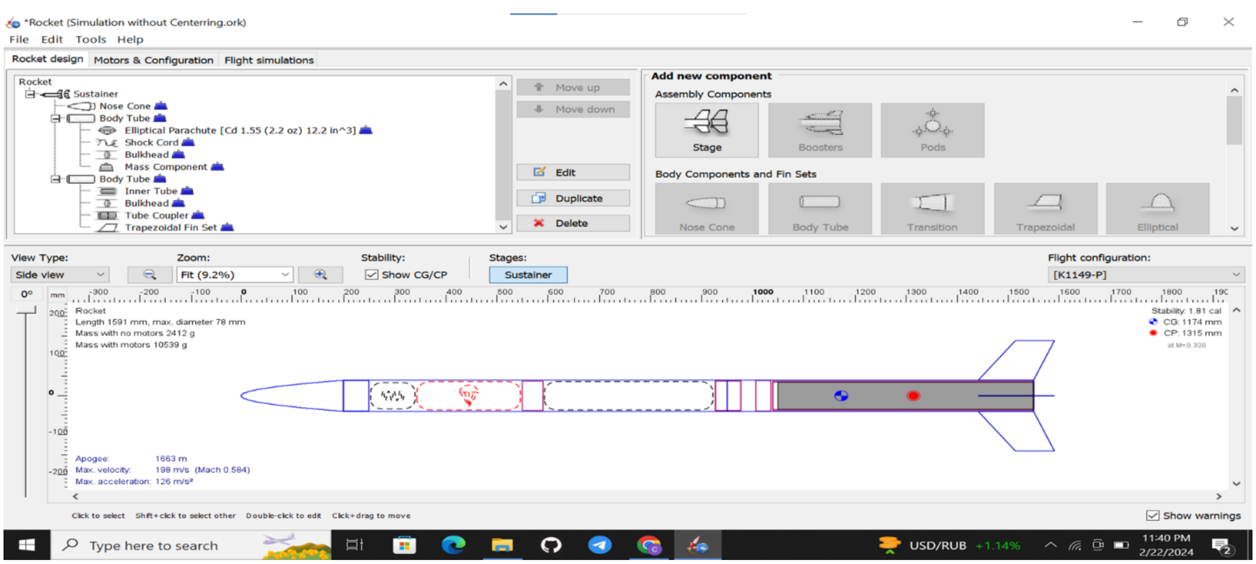
Open Rocket Software

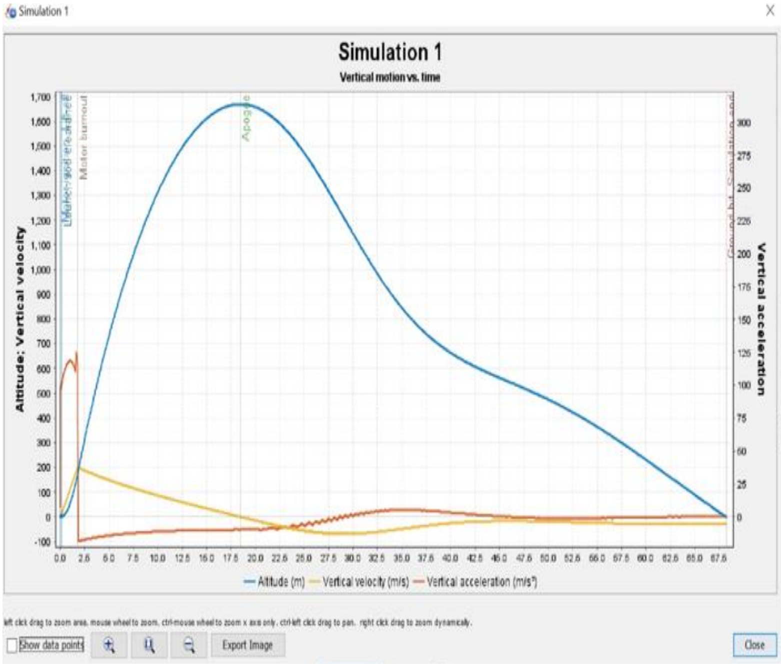
Open Rocket is an open-source software tool specifically designed for the design, simulation, and analysis of model rockets. It provides users with a platform to create virtual representations of rockets, simulate their flight dynamics, and analyze various performance metrics. Here are some key features and functionalities of Open Rocket:

Rocket Design: Open Rocket allows users to create and customize the design of model rockets, including specifying dimensions, materials, components, and configurations. Users can design different types of rockets, such as single-stage, multi-stage, and clustered configurations, and incorporate various components such as body tubes, nose cones, fins, and payload sections.

Stability Analysis: One of the core features of Open Rocket is its stability analysis capabilities. The software calculates stability margins, such as the center of pressure (CP) and center of gravity (CG), to assess the aerodynamic stability of the rocket throughout its flight trajectory. Users can visualize and analyze stability characteristics to ensure safe and stable flight.

Flight Simulation: Open Rocket simulates the flight dynamics of model rockets based on user-defined parameters such as rocket design, engine specifications, launch conditions, and environmental factors. Users can run simulations to predict the altitude, velocity, acceleration, and other flight characteristics of the rocket under different scenarios.





Stability of a Rocket

The stability of a rocket, including a model rocket, refers to its ability to maintain a steady and predictable flight path. In the context of model rockets, stability is crucial for achieving a successful launch and ensuring that the rocket flies straight and true without veering off course or tumbling uncontrollably.

There are a few key factors that contribute to the stability of a rocket:

Center of Gravity (CG): The center of gravity is the point within the rocket where the mass is concentrated. Ideally, the CG should be located ahead of the center of pressure to ensure stability. This means that the weight of the rocket should be distributed so that it is heavier towards the front.

Center of Pressure (CP): The center of pressure is the point where the aerodynamic forces acting on the rocket can be considered to be concentrated. The CP is affected by the shape and size of the rocket, as well as the placement of fins and other aerodynamic surfaces. For stability, the CP should be located behind the CG.

Fins: Fins are aerodynamic surfaces attached to the rear of the rocket. They help stabilize the rocket by creating aerodynamic forces that counteract any tendency for the rocket to deviate from its intended flight path. The size, shape, and placement of fins play a crucial role in determining the stability of the rocket.

Nose Cone: The nose cone of the rocket also affects stability. A streamlined nose cone helps reduce air resistance and contributes to smoother flight.

Ways of increasing the stability of a rocket

Lowering the Center of Pressure (CP)

- **Increasing Fin Area**: Fins play a crucial role in stabilizing a rocket by generating aerodynamic forces that help keep the rocket pointed in the right direction. By increasing the area of the fins, you effectively move the center of pressure rearward, creating a more stable configuration. Larger fins increase the surface area exposed to airflow, which enhances their stabilizing effect.

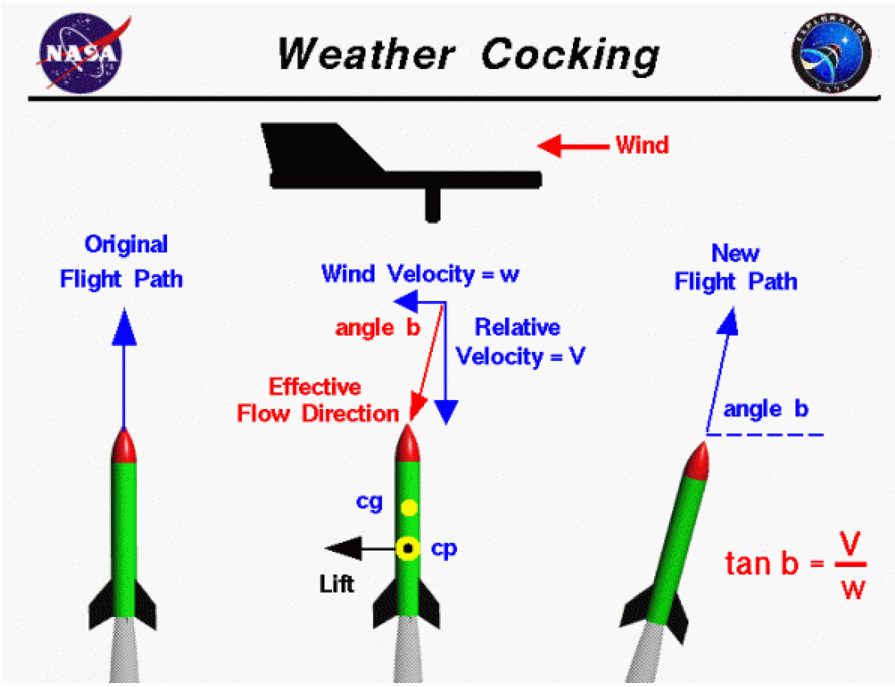
- **Adjusting Fin Geometry**: Besides increasing the area of the fins, altering their shape and geometry can also impact stability. For example, swept-back or angled fins can provide more stability than straight fins by increasing aerodynamic stability and reducing the risk of drag-induced instability.

Raising the Center of Gravity (CG)

- **Increasing Nose Cone Mass:** As you mentioned, adding mass to the top part of the rocket, typically in the form of a heavier nose cone, raises the center of gravity. A heavier nose cone shifts the balance of the rocket towards the front, making it inherently more stable. Additionally, a streamlined nose cone design not only adds weight but also reduces air resistance, contributing to smoother flight.
- **Payload Placement:** Placing the payload, such as electronics or other equipment, closer to the nose cone can also raise the center of gravity. This configuration helps maintain stability throughout the flight, especially as the rocket loses mass from consumed propellant.

By implementing these strategies, you can effectively increase the stability of a rocket, ensuring smoother and more predictable flights.

Effect of too much stability



Weathercocking is a term used in rocketry to describe the phenomenon where a rocket turns into the wind during flight, much like a weathervane or weathercock. This maneuver is caused by aerodynamic forces on the rocket.

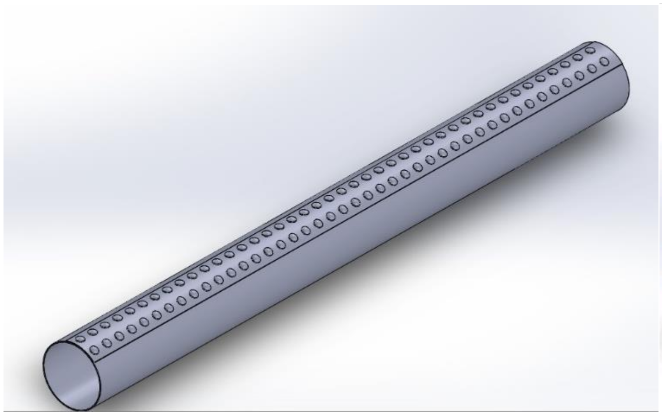
As the rocket accelerates away from the launch pad, the velocity increases and so do the aerodynamic forces on the rocket. These forces depend on the square of the velocity of the air passing the vehicle. If there's no wind, the flight path would be vertical.
However, the presence of wind introduces an additional velocity component perpendicular to theflight path. This changes the effective flow direction, which is inclined to the rocket axis. This inclination generates an aerodynamic lift force on the rocket body and fins.
The lift force acts through the center of pressure of the rocket, which for stability reasons, is located below the center of gravity. This force generates a torque about the center of gravity, causing the rocket to rotate.

The rotation of the rocket produces a new flight path into the wind. When the new flight path aligns with the effective flow direction, no lift force is generated and the rocket continues to flyin the new direction. This phenomenon reduces the maximum altitude a model rocket can achieve, as the flight path deviates from the vertical.

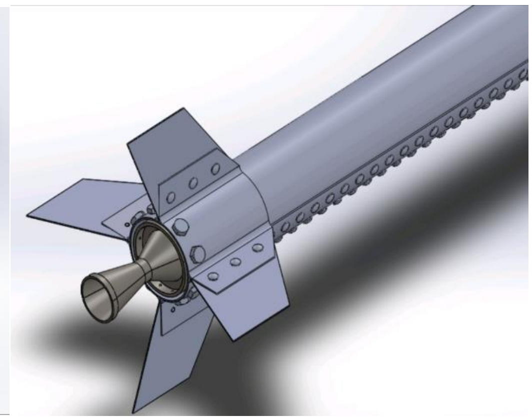
While increasing stability is important, too much stability can lead to Weathercocking, where the rocket turns into the wind during flight. Therefore, it's important to find a balance. A stability between 1.5 and 2 calibers is generally considered acceptable for most rockets.

Engineering Drawings using SolidWorks

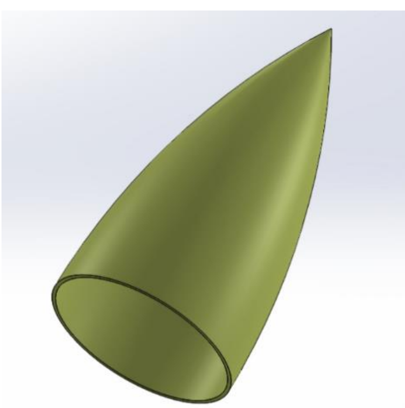
Engineering drawing using SolidWorks for a model rocket involves creating detailed visual representations of the rocket's components, including the body tube, nose cone, fins, launch lug, launch pad and any other parts. Some of the parts include the following:



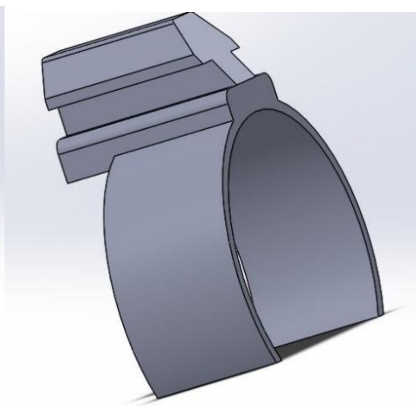
Upper body part



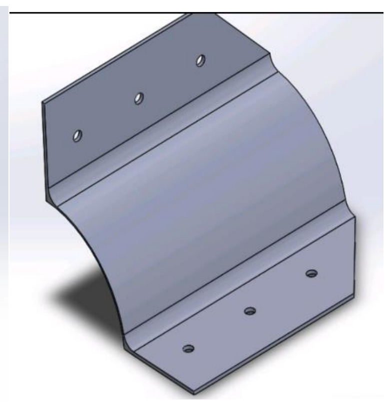
Lower body part



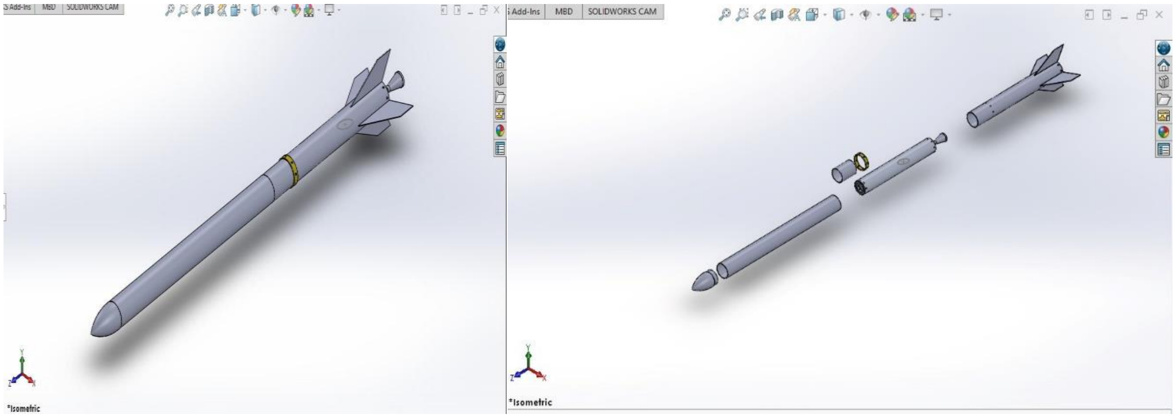
nosecone



Launch lug



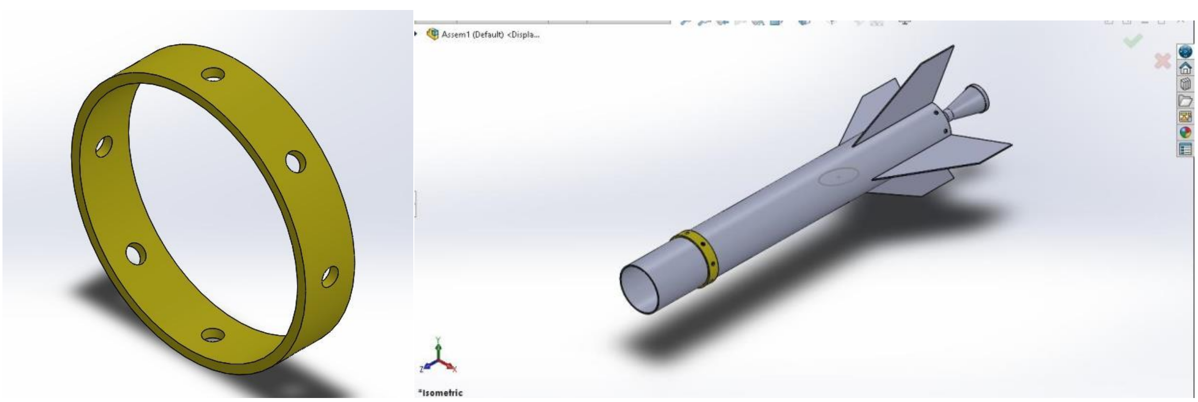
Fin supporter



The assembly

Challenge faced in N3: misalignment of the holes of the airframe, and the other rocket parts.

Proposed solution:



A 3D template with evenly spaced holes that align with the desired location on the cylindrical surface

SIMULATION

Simulation of objects in simulation software refers to the process of creating virtual representations of physical objects or systems within a computer program and using mathematical models to predict their behaviour under various conditions. This process involves several key steps:

Modelling: The first step in simulating objects is to create a digital representation, or model, of the object within the simulation software

Physics-based Representation: Once the object is modelled, the next step is to define its physical properties and behaviour using mathematical equations and algorithms. This involves specifying parameters such as mass, density, material properties, dimensions, and constraints that govern how the object interacts with its environment and other objects in the simulation.

Simulation Setup: With the object model and physical properties defined, the simulation setup involves configuring the simulation environment and specifying the conditions under which the simulation will be run. This may include setting initial conditions, boundary conditions, external forces, constraints, and other parameters that influence the behaviour of the object during the simulation.

Analysis and Visualization: Once the simulation is complete, the results are analysed and visualized to interpret the behaviour of the simulated object.

Performing simulations on a rocket design using software like ANSYS and SolidWorks serves several critical purposes in the design and development process:

1. **Structural Analysis**: This involves assessing how the various components of the rocket, such as the body, fins, and engine mounts, will respond to the loads and forces experienced during launch, flight, and landing/recovery. By simulating these conditions, engineers can identify areas of high stress, potential failure points, and areas where reinforcements may be necessary to ensure the structural integrity of the rocket throughout its mission.

2. **Thermal Analysis:** Rocket engines generate intense heat during operation, which can affect the structural integrity of the rocket as well as the performance of sensitive components such as electronics and payloads. Thermal analysis simulations help engineers understand how heat is distributed throughout the rocket and identify areas that may require additional insulation or cooling systems to prevent overheating and ensure the safe operation of the rocket.

3. **Fluid Dynamics Analysis**: Simulating the airflow around the rocket helps engineers understand aerodynamic forces such as drag and lift, which are critical for optimizing the rocket's performance and stability during flight. By analysing the flow of air around the rocket's body, fins, and other components, engineers can make adjustments to improve aerodynamic

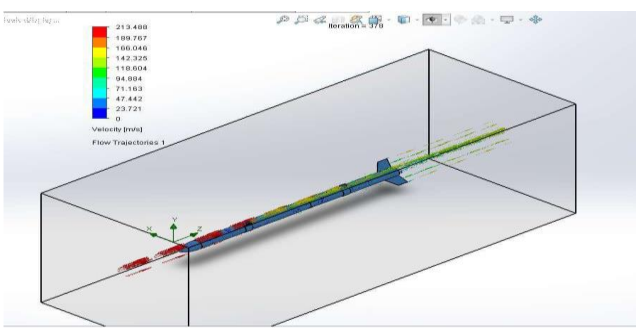
efficiency and minimize drag, allowing the rocket to achieve higher speeds and travel further distances with greater accuracy.

4. **Optimization and Iteration:** By conducting simulations iteratively, engineers can optimize the design of the rocket to improve performance, reliability, and safety. Simulations allow engineers to quickly evaluate the effects of design changes and make adjustments accordingly, reducing the time and cost associated with physical prototyping and testing.

The results of these simulations provide valuable insights into the behaviour of the rocket under various conditions and help inform design decisions to ensure the successful development and operation of the rocket. These realizations may include stress distribution maps, temperature profiles, aerodynamic coefficients, vibration modes, and other key performance metrics that guide the refinement of the rocket design. Ultimately, simulations help in the development of rockets that are safer, more efficient, and more reliable, leading to successful missions.

The airframe team conducted the following simulation.

Simulation using SolidWorks

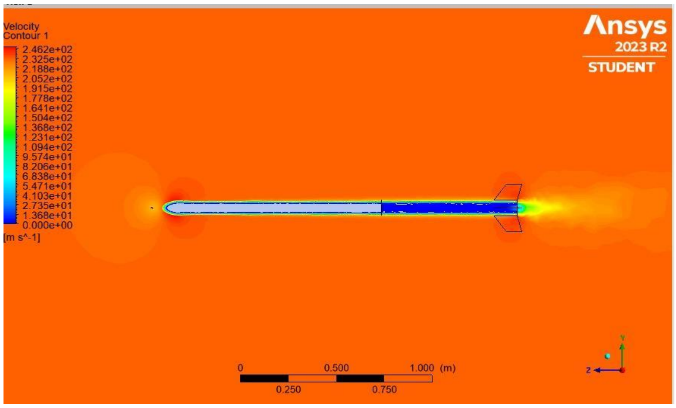


Initial Conditions:

Initial velocity: 230.48m/s

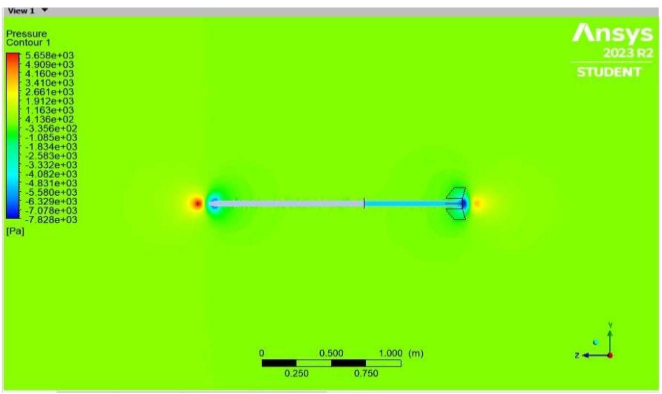
Initial pressure (atmospheric): 1.03bar

<u>Simulation using ANSYS</u>



Velocity Contour

- **Nosecone**: High air velocity is experienced as this component directly encounters the full force of incoming air.
- **Body tube**: Experiences a slightly lower velocity as it is shielded from direct impact by some air molecules.
- **Body tube**: Experiences a slightly lower velocity as it is shielded from direct impact by some air molecules.
- **Tail fin**: As rockets move forward, they push a significant amount of air backward, resulting in high velocity experienced by the fin.



Pressure contour

- ✓ **Nosecone:** Elevated pressure resulting from the presence of densely packed air molecules.

- ✓ **Body**: Pressure is slightly reduced as the surrounding air molecules around the rocket remain relatively undisturbed.

Rivet Joining Method

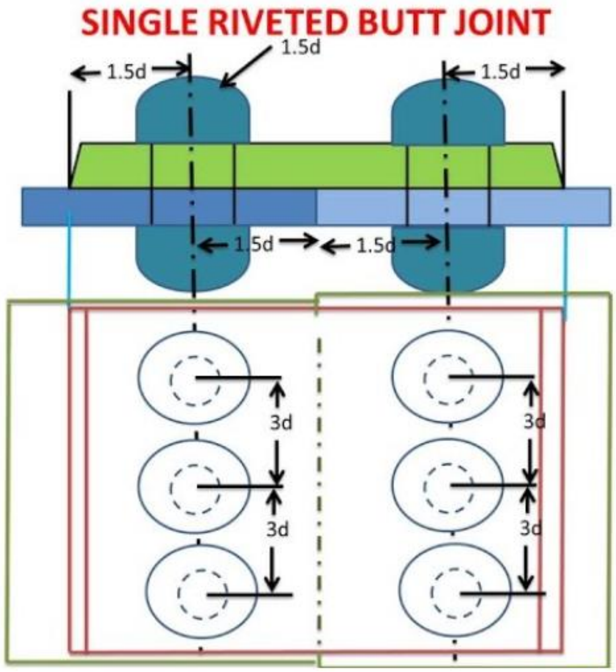
Rivets are mechanical fasteners consisting of a cylindrical shaft with a head on one end. The rivet is inserted into holes drilled through the materials to be joined, and then the protruding end is deformed to create a second head, securing the materials in place. There are several types of rivet joining methods, including:

Solid Riveting: This is the traditional method where a solid rivet is inserted into pre-drilled holes in the materials to be joined. The protruding end (the "tail") is then hammered or mechanically compressed ("bucked") to deform it and create a second head, forming a tight joint.

Blind Riveting: In blind riveting, a rivet with a mandrel is inserted into the pre-drilled hole. As the mandrel is pulled, it deforms the rivet body, expanding it against the materials being joined. Blind rivets are commonly used when access to the rear side of the materials is limited.

Rivet joint strength calculation

A single-rivet butt joint is a simple type of joint where two pieces of material are joined end-to-end with a single rivet. This type of joint is commonly used in various applications where a simple and relatively strong connection is needed.



The single-riveted butt joint (chain arrangement) is opted for in our design due to its simplicity in design and fabrication.

Definition of terms

1. Pitch-It is the distance from the center of one rivet to the center of the next rivet measured parallel to the seam. It is denoted by p
2. Thickness- It refers to the depth of the sheet riveted. Denoted by t
3. Diameter- It refers to the diameter of the rivet hole, denoted by d
4. Margin- It is the distance between the center of rivet hole to the nearest edge of the plate. Denoted by m

A 4mm diameter rivet will be utilized in our design.

Pitch p=minimum pitch is given by 3d

Therefore $minimum\ pitch = 3x\ 4 = 12mm$

Margin m = minimum margin is given by 1.5d

Therefore $minimum\ margin = 1.5x\ 4 = 6mm$

A factor of safety of 2 will be used in the calculations

Types of forces in a riveted joint

1. Tearing force
2. Crushing force
3. Shearing force

Tearing force (Pt)

$$Pt = area\ subjected\ to\ tearing\ \ x\ \ \sigma t$$

$$Pt = (P - d)t\ x\ \ \sigma t$$

$$Pt = (0.017 - 0.004)0.0012\ x\ 190\ x\ 10^6 = \mathbf{2964N}$$

Crushing force (Pc)

$$Pc = Area\ subjected\ to\ crushing\ x\ \sigma c$$

$$A = d\ x\ t$$

$$Pc = d\ x\ t\ x\ \sigma c$$

$$Pc = 0.004\ x\ 0.0012\ x\ 241\ x\ 10^6\ x\ 2\ = \mathbf{2313N}$$

Shearing force

$$Ps = \ Area\ subjected\ to\ shearing\ x\ \tau$$

$$Ps = \frac{\pi}{4}\ x\ d^2\ x\ \tau\ x\ n$$

$$Ps = \frac{\pi}{4}\ x\ 0.004^2\ x\ 240\ x10^6 x\ 1 = \mathbf{3015.93N}$$

Minimum force

Since the safety of factor used is 2 and the minimum force of the three is the crushing force;

Then

Minimum force = $\frac{2313.6}{2}$ $= \mathbf{1156.8}\boldsymbol{N}$

Change in circumference due to heat

$$\Delta C = \alpha \; x \; C_o \; x \; \Delta T$$

$$\alpha = 12 \; x \; 10^{-6} {}^{\circ}C^{-1}$$

$$C_o = \pi D = \pi \;\; x \; 73 \; x \; 1000 = \mathbf{0.2293}\boldsymbol{m}$$

Taking temperature in the chamber as 1100℃ and 25℃ as room temperature, therefore change in temperature is 1075℃

$$\Delta C = 12 \; x \; 10^{-6} \; x \; 0.2293 \; x \; (1075 + 273) = 3.7092 \; x \; 10^{-3} m$$

As this constitutes the change in circumference of the motor casing, and considering our design as a fitting airframe without a centering ring, then a force will be exerted on our airframe, compelling it to undergo a change in circumference of equal magnitude.

Stiffness of aluminum is 0.10N/mm which is equivalent to 100N/m

The force required to change the circumference of our aluminum by $\mathbf{3.7092} \; \boldsymbol{x} \; \mathbf{10^{-3}}\boldsymbol{m}$ is calculated by;

$$F = k.e$$

$F = 100 \; x \; 3.7092 \; x \; 10^{-3} = \mathbf{0.37092}\boldsymbol{N}$ This force is too small compared to 1157N

Efficiency of the rivet

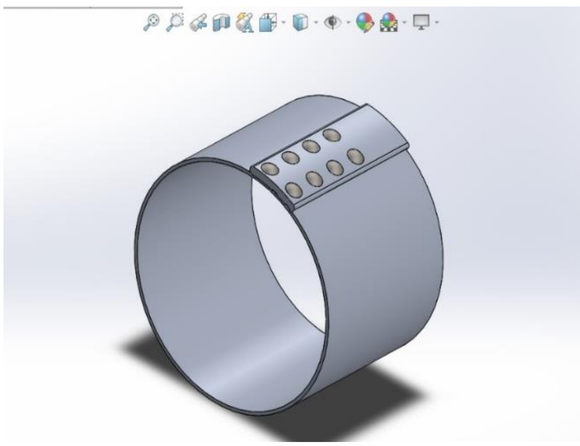
$$e = \frac{Least \; force \; between \; the \; three}{Force \; for \; unreveted \; plates}$$

$$e = \frac{d \; x \; t \; x \; \sigma c}{P \; x \; t \; x \; \sigma t}$$

$$e = \frac{0.004 \; x \; 0.0012 \; x \; 241 \; x \; 10^6 \;\; x \; 2 = \mathbf{2313.6}\boldsymbol{N}}{0.015 \; x \; 0.0012 \; x \; 190 \; x \; 10^6 \;\; = \mathbf{3420}\boldsymbol{N}} = \mathbf{0.6765}$$

$$\boldsymbol{e} = \mathbf{67.65}\%$$

A template with rivet joining method



BOLTS CULCULATIONS

In securing the motor casing, the decision to utilize the same bolts that fasten the bulkhead and nozzle to the casing streamlines the attachment process while ensuring structural integrity. This approach not only simplifies the assembly but also optimizes efficiency by reducing the number of components required. By employing eight M8 bolts to connect the motor casing to the lower part of the airframe, a robust and reliable attachment is achieved, crucial for withstanding the forces experienced during launch and flight

The maximum pressure (P_{Max})as simulated in open motor was **8.02Mpa**.

$$P_{Max} = 8.02Mpa$$

The pressure force (F_P):

$$F_P = P_{Max} \times Cross\ sectional\ area$$

Inside diameter(d)=68mm

$$F_P = 8.02 \times \frac{\pi}{4} \times 68^2 = 29126.08N$$

The shear stress (τ) acting on each bolt

$$\tau = \frac{F_B}{bolt\ x{-}area}$$

M8 Bolt x-area= 50.265mm^2

Force acting on each bolt:

$$F_B = \frac{F_P}{n},\ \textit{Where n= number of bolts}$$

Using **8** M8 Bolts:

$$F_B = \frac{29126.08}{8} = 3640.76N$$

$$\therefore\ \tau = \frac{3640.76N}{50.265mm^2} = 72.431\frac{N}{mm^2}$$

The **yield strength** of mild steel bolt is 250N/mm^2.

Using **von misses yield criterion** to calculate the maximum shear stress:

$$\tau_{Max} = 0.58\sigma_{yield}$$

$$\tau_{Max=0.58\times250=145N/mm^2}$$

Using a safety factor of 1.5:

$$Maximum\ allowable\ shear\ stress = \frac{145}{1.5} = 96.67N/mm^2$$

72.431 < 96.67

$$\therefore \tau_{bolt} < \tau_{yield}$$

Hence the design using 8 M8 bolts is safe.

Below is an excel sheet showing variations of the bolts and comparing with the maximum allowable stress to obtain an optimum design:

BOLTS SHEAR STRESS CALCULATIONS

	Bolt diameter	No. of bolts	CSA (per bolt)	Force per bolt	Shear stress(per bolt)
M6	6	6	28.27433388	4854.34708	171.6874074
		8		3640.76031	128.7655556
M8	8	6	50.272	4854.34708	96.56164625
		8		3640.76031	72.42123469
M10	10	6	78.55	4854.34708	61.7994536
		8		3640.76031	46.3495902

Pipe diameter	68
Tube Pressure(Max)	8.02
Yield stress(Mild steel)	250
Safety factor	1.5
CSA(tube)	3631.681108
Force on tube(max)	29126.08248
shear stress(Max)	145
Bolt Shear stress(allowable)	96.66666667

NB: CSA means cross section area
RESULTS: 72.4212Pa < 96.67Pa
INFERENCE: MINIMUM BOLT DIAMETER = M8
NO. OF BOLTS = 8

ACQUISITION OF MATERIALS

The acquisition of materials for the fabrication of the airframe body and parachute involves several steps and considerations.

Material Selection

It begins with selecting the appropriate materials based on factors such as strength, weight, durability, and cost. For the airframe body, aluminum was considered due to its lightweight yet robust properties. Similarly, for the parachute, materials like ripstop nylon or polyester are commonly used for their strength and flexibility.

Sourcing

Once the materials are chosen, the next step is sourcing them from suppliers. This may involve reaching out to multiple vendors to compare prices, quality, and availability. For specialized materials or components, it may be necessary to work with specific manufacturers or distributors.

Negotiation and Procurement

Negotiating favorable terms such as pricing, delivery schedules, and payment terms is essential to ensure cost-effectiveness and timely procurement. This may involve bulk purchasing to take advantage of discounts or negotiating contracts for long-term supply agreements.

Quality Assurance

Ensuring the quality of the materials is crucial to the overall safety and performance of the airframe and parachute. This may involve inspecting samples, requesting material certifications, or conducting quality audits of suppliers' facilities.

Logistics and Inventory Management

Once the materials are procured, logistics come into play to transport them to the fabrication facility.

Storage and Handling

Proper storage and handling of materials are essential to prevent damage or degradation before they are used in fabrication

Documentation and Compliance

Keeping accurate records of material transactions, including invoices, receipts, and certifications, is essential for traceability and compliance with regulatory requirements.

Some of the Materials purchased:

FABRICATION

FABRICATION OF THE AIRFRAME BODY

The fabrication process of the airframe body involved several precise steps to ensure structural integrity and functionality:

1. Marking the Desired Length

The first step is to mark the desired length on the aluminum sheet, which should be equal to the circumference of the outer diameter of the airframe body. This marking ensures that the sheet will wrap around the airframe properly, covering its entire circumference.

2. Cutting the Aluminum Sheet

Once the desired length is marked, the aluminum sheet is cut using a shearing machine. This machine provides precise cuts, ensuring that the sheet is trimmed to the correct size without any jagged edges or uneven edges.

3. Marking Rivet Points

After cutting the sheet, the next step is to mark the points where rivets will be placed. These points are determined based on calculations, considering factors such as the structural requirements of the airframe and the distribution of loads during flight.

4. Reinforcing Rivet Points

Before drilling, the marked points are reinforced using a center punch and a mullet. The center punch creates an indentation at each rivet point, providing a precise starting point for drilling. The mullet, also known as a hand-held striking tool, is used to ensure that the center punch is firmly set, which eases the drilling process and helps prevent the drill bit from slipping.

5. Drilling Holes

Once the rivet points are reinforced, the next step is to drill holes using a drilling machine. The size and depth of the holes are critical to ensure proper fit and strength of the rivets. Careful attention is paid to drilling each hole accurately, following the markings made earlier.

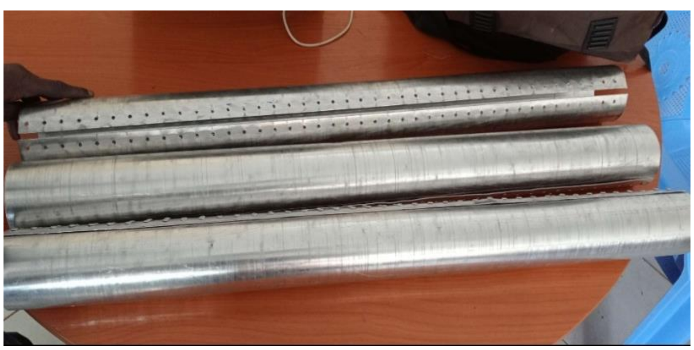
6. Rolling the Sheet

With the holes drilled, the aluminum sheet is rolled using a plate rolling machine. This machine allows the sheet to be formed into a cylindrical shape, gradually bending it until the two ends meet. This process is crucial for creating a seamless airframe body, especially when using a butt riveting joint.

7.Riveting:

Once the sheet is rolled into shape, the final step is riveting. Rivets are inserted into the pre-drilled holes, and a riveting gun is used to secure them in place. The riveting process ensures that the two ends of the aluminum sheet are securely joined together using a strip, creating a strong and durable airframe body.


Overall, the fabrication process outlined above demonstrates the precise attention to detail required to construct the airframe body of a model rocket. Each step, from marking and cutting the sheet to riveting the joints, plays a crucial role in ensuring the structural integrity and reliability of the final product.



The image below displays a drilled sheet and strip prepared for rolling.

The image below depicts a rolled sheet that is prepared for riveting.

Butt riveting was chosen as the preferred method due to its tendency to produce more circular tubes in contrast to lap riveting.

Fabrication of the plastic coupler

The purpose of the plastic shaft is to serve as a coupler to connect the upper and lower tubes of the airframe. By cutting and machining the plastic shaft to the required dimensions, it can effectively bridge the gap between the upper and lower tubes, ensuring they are securely connected while allowing for any necessary adjustments or movement.

The steps curried out are as follows:

1. Cutting the Shaft to Size: The first step was to cut the plastic shaft to the desired length of 150mm using a hacksaw. This initial length was determined through previous calculations, presumably based on the specifications or requirements of the airframe.

2. Facing on the Lathe Machine: After cutting the shaft to length, the next step involved using a lathe machine to face the ends of the shaft. Facing is a machining operation where the ends of the workpiece are made flat and perpendicular to the axis of rotation. This ensures that the ends of the shaft are smooth, flat, and at right angles to the axis, which is important for proper alignment and fit within the airframe.

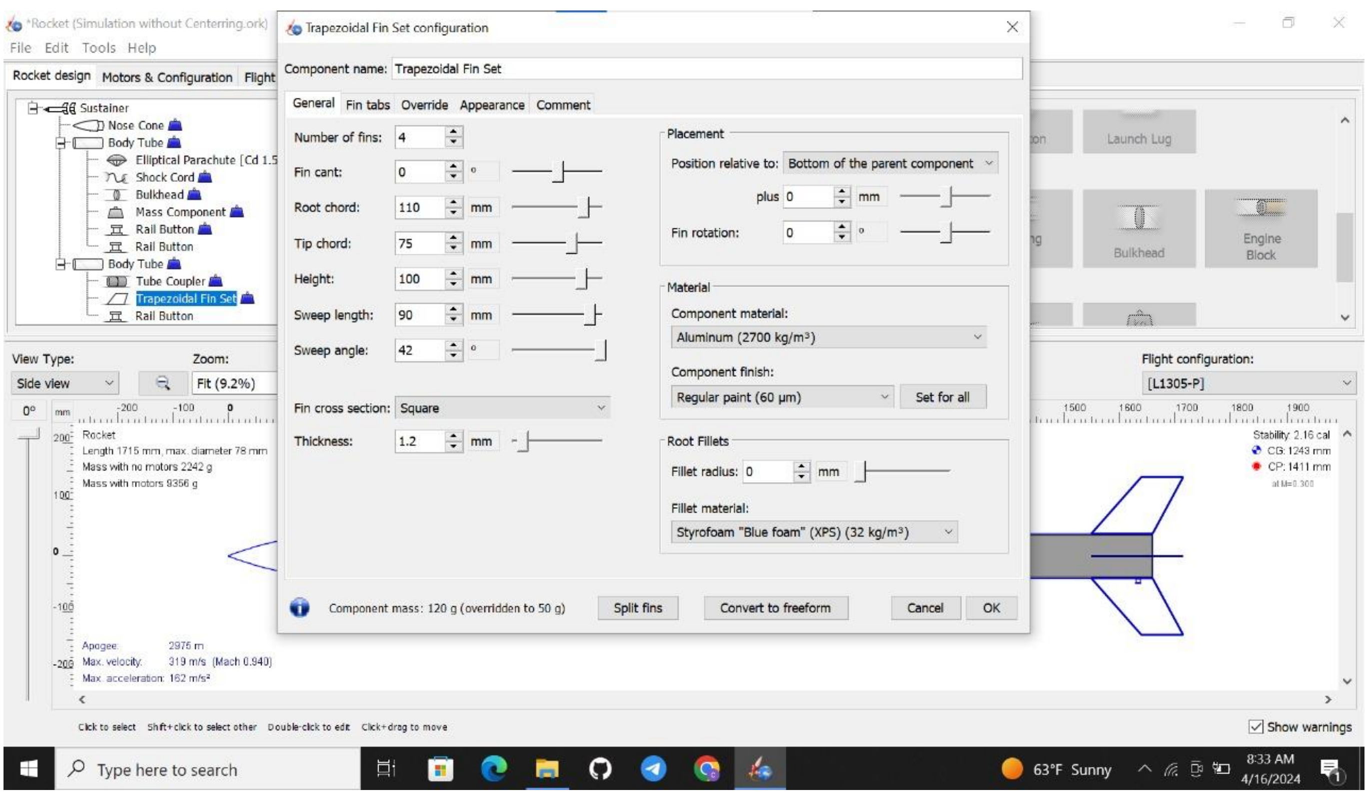

3. **Turning to Desired Diameter:** The final step was to use the lathe machine to turn down the diameter of the shaft from 90mm to 75mm. This means reducing the outer diameter of the shaft to match the internal diameter of the airframe. Turning is a machining process where material is removed from the workpiece to achieve the desired shape and dimensions. In this case, material was removed from the outer diameter of the shaft until it reached the required diameter of 75mm, ensuring a proper fit within the airframe.

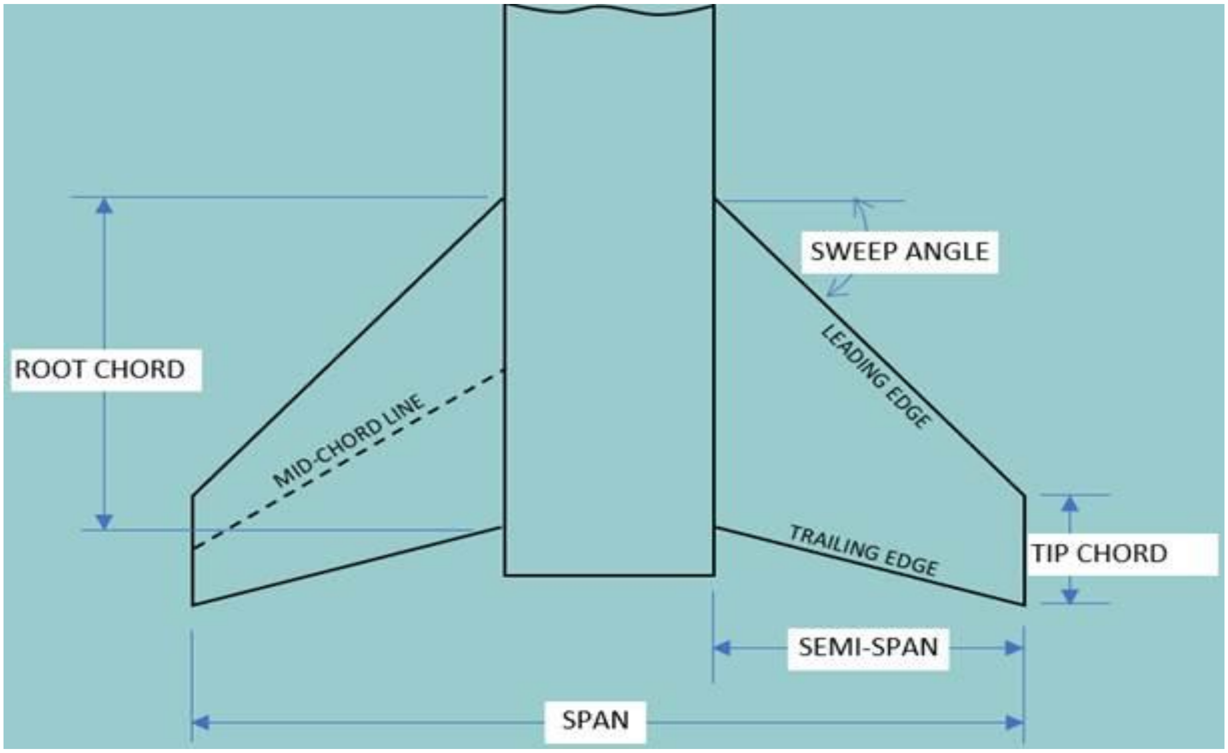

By following these steps, the plastic shaft was prepared and modified to serve as a coupler, connecting the upper and lower tubes of the airframe with the desired dimensions and specifications.

Fabrication of the fins and fins supporter

Fins

- Obtaining of the fins measurement from open rocket simulations





- Cutting of rectangular aluminum pieces

  Length of the rectangle is equal to (Tip Chord + Sweep length) =165 mm

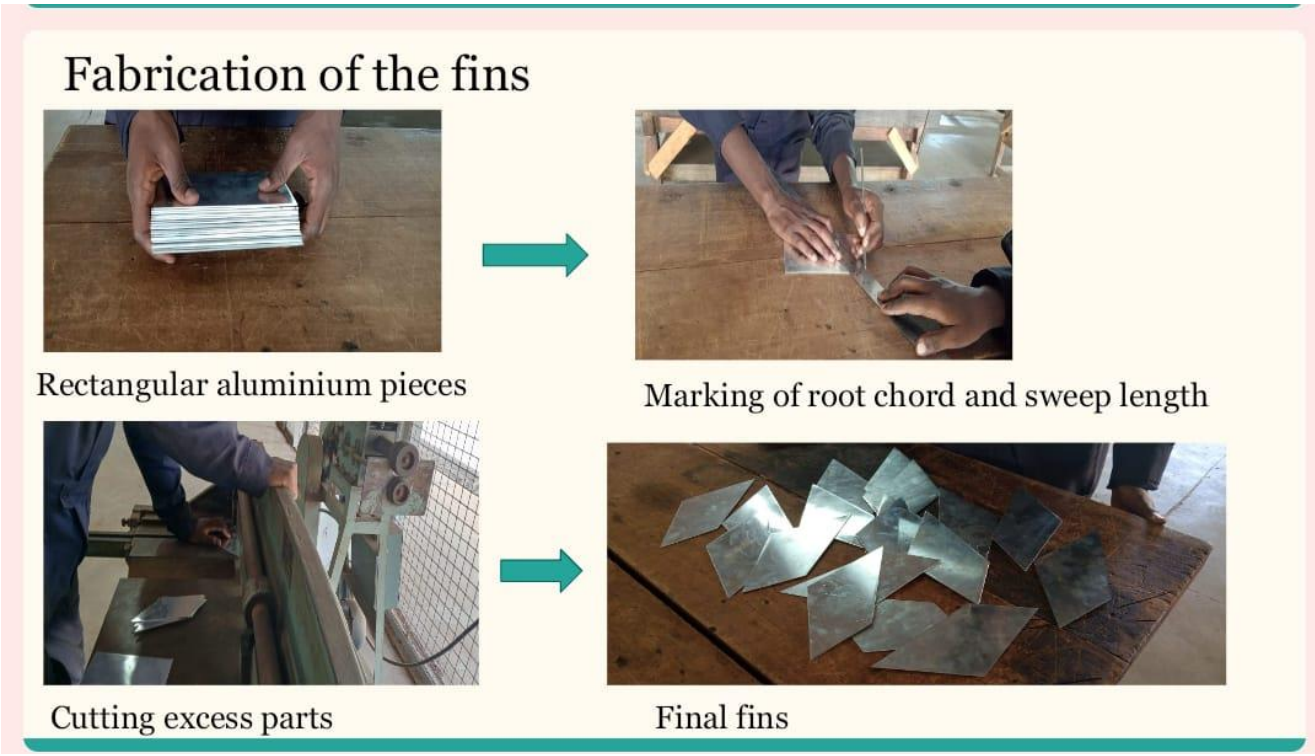
  Width of the rectangle is equal to height =100mm

- Marking of root chord and sweep length in the rectangular pieces

  Root chord-110mm

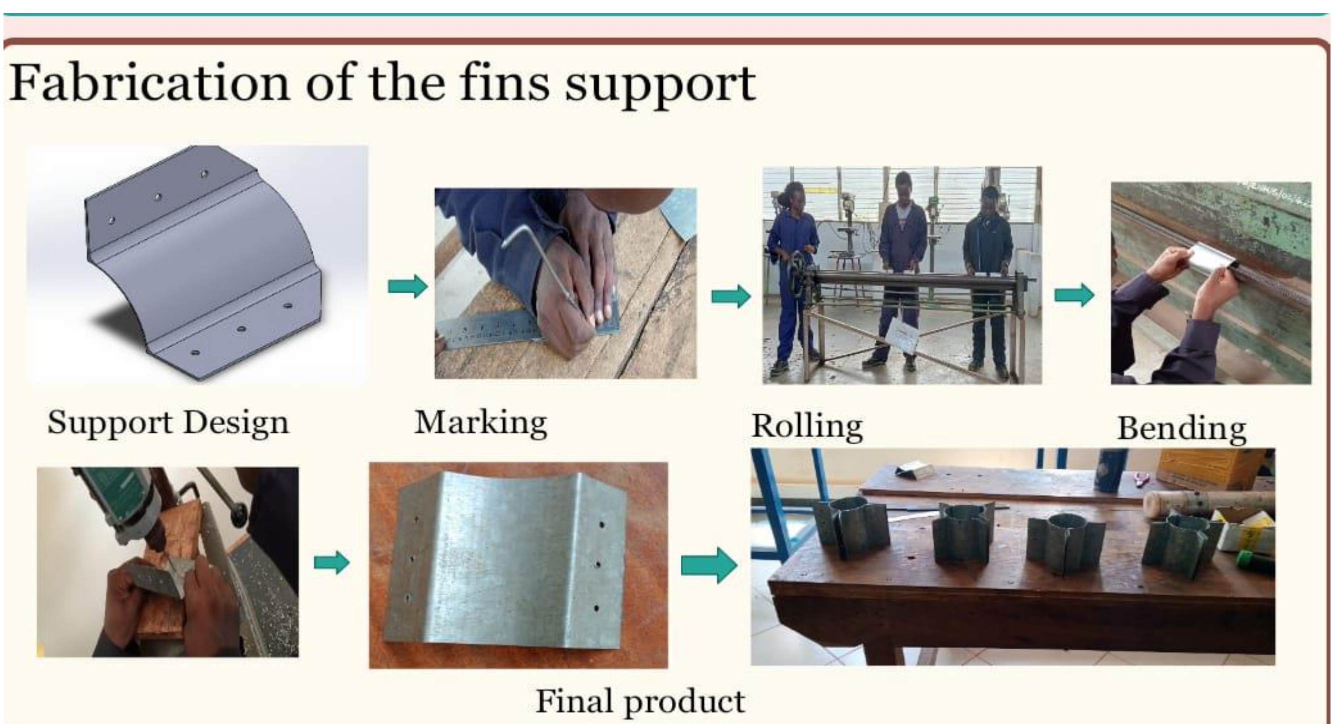
  Sweep length -90mm

- Removal of excess materials
- Final products

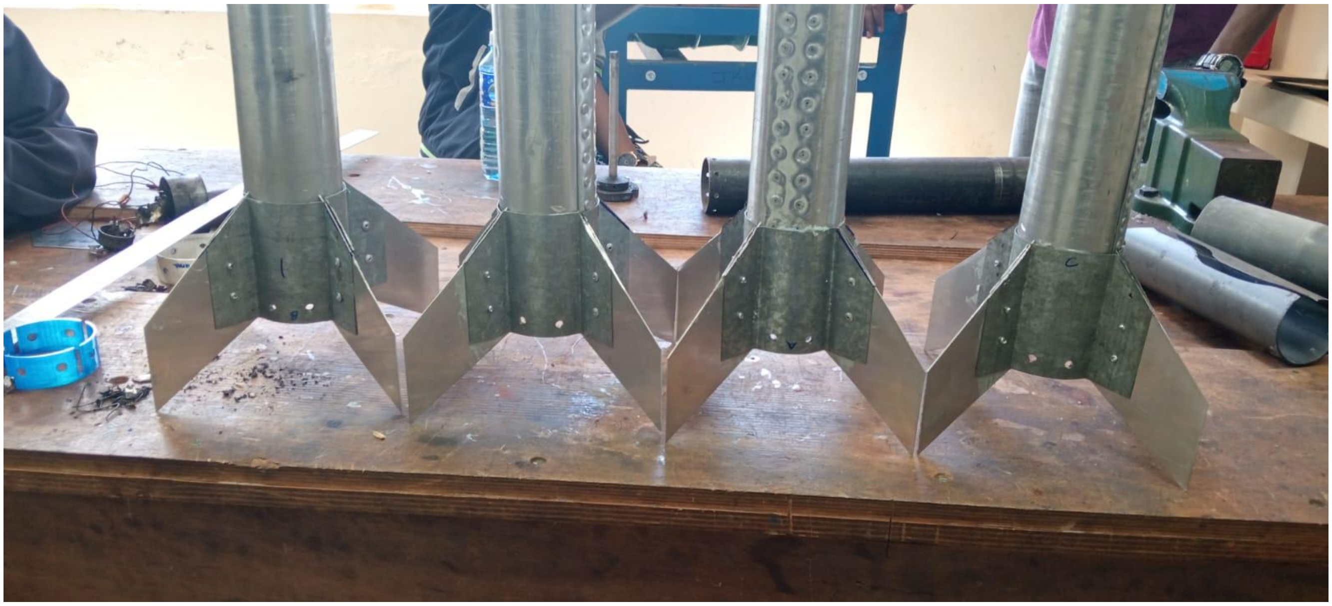


Fins supporter

- Designing of the fin supporter
- Marking and cutting of the rectangular pieces based on required measurements
- Rolling of the pieces to attain curve structure
- Bending the pieces at both ends (90 degrees)
- Drilling rivet points at each end



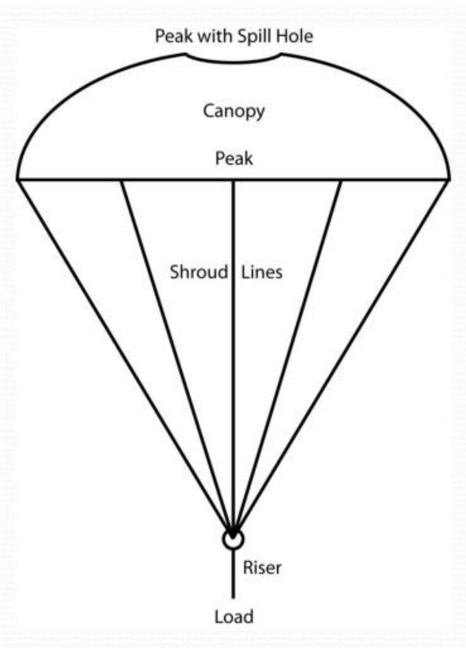
- Final product and assembly



The parachute

Design of parachute

Model rockets are designed for reusability, making them a cost-effective hobby. While theengine may need replacement after each launch, the rocket itself can be used repeatedly.
However, for this to be feasible, the rocket must return in good condition, which hinges on asafe and secure landing facilitated by a reliable parachute.
When considering the size of the parachute for a model rocket, it's essential to factor in itsshape. In this case, we're assuming a flat circular parachute.



Problem Statement

- ✓ Determining the ideal diameter of the parachute
- ✓ As the rocket descends with its parachute deployed, it accelerates towards the ground until the drag force acting on the parachute matches the weight of the rocket. To address this scenario, we must establish equations for both the drag force and therocket's weight and then equate them.

During recovery

Drag force = Rocket’s weight

Calculation of the drag force

$$F_d = \frac{1}{2} \rho c_d A v^2 \quad --------(i)$$

Where

F_d - Drag force

ρ - Air density (About 1.225 m^3)

A - Area of the chute

V -Velocity through air (Terminal Velocity)

c_d - Drag coefficient of the chuteCalculation of the rocket weight

$$F_g = mg \quad ---------(ii)$$

Where

m - Mass of the rocket

g - Gravitational acceleration 9.81 \s

Equating equation (i) and (ii)

$$F_g = F_d$$

$$mg = \frac{1}{2} r c_d A v^2$$

Making A (Area of the parachute) the subject of the formula

$$A = \frac{2mg}{\rho c_d v^2}$$

$$A = \frac{\pi D^2}{4}$$

$$\frac{\pi D^2}{4} = \frac{2mg}{\rho c_d v^2}$$

Making the parachute diameter the subject of the formula,

$$D^2 = \frac{8mg}{\rho \pi c_d v^2}$$

Therefore

$$D = \sqrt{\frac{8mg}{\rho \ \pi \ c_d \ v^2}}$$

Key points

- ✓ The drag coefficient (c_d) is 0.75 for a para sheet (Flat sheet used e.g. Ester rockets) or 1.5 for a parachute (i.e. true dome shaped chute)
- ✓ Speed we want to imparts with the ground (about 5m/s or less)

Given a mass of the parachute =8kg

Terminal velocity =5 m/s

$$D = \sqrt{\frac{8 \ x \ 8 \ x 9.81}{1.225 \ x\pi \ x \ \ 0.8 \ x \ 5^2}} = 2.856m$$

Therefore, the nominal diameter is 2.86m

Design of the spill hole

Spill surface area is typically equal to 1% of nominal surface area

To calculate the nominal surface area;

$$s_o = \frac{\pi d^2}{4}$$

$$s_o = \frac{\pi \; x \; 2.856^2}{4} = 6.4063m^2$$

Vent surface area is 1% of nominal surface area

1% x 6.4063 = $0.0641m^2$

Material for the parachute

The following fabrics are used in parachute fabrication

Natural Fibers

- silk
- cotton

Man-made fibers

- Kevlar
- Dacron
- Nylon

The choice of materials for the parachute of a model rocket typically revolves around factors such as light weight, elasticity and availability. In this context, nylon and cotton arecommonly considered options due to their respective elastic properties and widespread availability.

silk

advantages:

1. **Lightweight:** this is advantageous for reducing the overall weight of the parachute system
2. **Good Strength** This ensures that the parachute can withstand the stresses and forces experienced during deployment and descent.
3. **Fire Resistance**: This characteristic adds an extra layer of safety to the parachute system, reducing the risk of damage or failure due to heat sources.
4. **Ease of Folding**: This can simplify the packing and deployment process of the parachute. This ease of folding contributes to quicker preparation time for launching the model rocket.

Disadvantages

1. **Easy to Tear**: It can be relatively delicate and prone to tearing under certain conditions.

2. **Susceptible to Sunlight and Chemicals**: Prolonged exposure to UV radiation can weaken the fabric over time.

Nylon

Nylon offers several advantages as a material for parachutes:

1. **Lightweight**: it makes it an ideal choice for minimizing the overall weight of the parachute system

2. **Excellent Wind Resistance**: This allow them to maintain stability and control during descent, even in windy conditions.

3. **Good Elasticity**: this enables the parachute to stretch and absorb shock forces during deployment and descent.

4. **Exceptional Strength**: Nylon is renowned for its exceptional strength-to-weight ratio, providing the parachute with robust durability and resistance to tearing or damage.

5. **Cost-Effective:** Nylon is generally more affordable compared to silk, making it a cost-effective option for model rocket.

disadvantages:

1. **Sensitivity to UV Light**: Nylon is susceptible to damage from ultraviolet (UV) light exposure

2. **Melting at High Temperatures:** Nylon has a relatively low melting point.

Parachutes, more specifically, are constructed from ripstop nylon, a fabric woven withdouble or extra-thick thread at regular intervals, forming a pattern of small squares. Advantages of Ripston nylon

- light weight,
- available in different color and sizes,
- water and fire resistant

- Tear resistant with zero porosity
- favorable strength to wait ratio

The parachute fabricated: