FEYNMAN AEROSPACE

Rocket Design

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CONTENTS

Abstract

Model rockets are small-scale replicas of real rockets that are primarily used for educational and recreational purposes. They are designed to provide a hands-on learning experience for students and enthusiasts interested in aerospace and rocketry. Model rockets typically consist of a lightweight body, fins for stabilization, a recovery system (such as a parachute or streamer) to ensure a safe descent, and a propulsion system powered by commercially available solid rocket motors. This report presents a comparative analysis between single-stage and multi-stage model rockets, utilizing OpenRocket software for designing and simulating the rocket dimensions and trajectory. Through iterative adjustments and simulations, the dimensions of both single-stage and multi-stage model rockets are tailored to meet predefined mission objectives, such as achieving specific altitudes, velocities, payload capacities, and ensuring overall stability. Additionally, SolidWorks is employed to create detailed CAD models of the designed rockets, offering valuable insights into structural integrity and aerodynamics and providing visual representations. The outcomes of this research contribute valuable insights to the hobbyist rocketry and aerospace engineering community, shedding light on the distinct advantages and trade-offs associated with single-stage and multi-stage model rockets. Furthermore, the integration of advanced software tools, such as OpenRocket and SolidWorks, showcases their pivotal role in the iterative design process, empowering enthusiasts to refine and optimize their model rockets for enhanced performance and an enriched understanding of aerospace principles.

I. Single Stage Rocket

Single-stage model rockets are compact and simplified versions of real rockets that consist of a single propulsion stage. These rockets typically feature a lightweight body, fins for stabilization, a recovery system, and a single solid rocket motor. These rockets are launched vertically from a launch pad using an electrical ignition system. Once ignited, the motor propels the rocket into the air, reaching a predetermined altitude. After reaching its peak, the recovery system is deployed to safely return the rocket to the ground, typically through the use of a parachute or streamer.

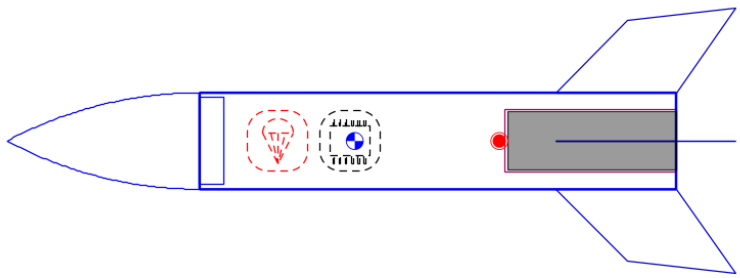

Fig. 1. Single Stage Rocket

A. Mission Objective

The mission objectives for the single-stage rocket are as follows:

- **Maximum Mass:** 700 g
- **Minimum Apogee:** 400 m
- **Stability:** 1.5 cal

B. Rocket Components

In order to achieve the required mission objective, OpenRocket software was used to generate rocket components. The description of each rocket component is given below.

*1) **Nose Cone**:* The nose cone is a filled ogive structure with a length of 80 mm and a base diameter of 40 mm. Additionally, base shoulders of length 10 mm and base diameter 36 mm are used to fit the nose cone with the body tube.

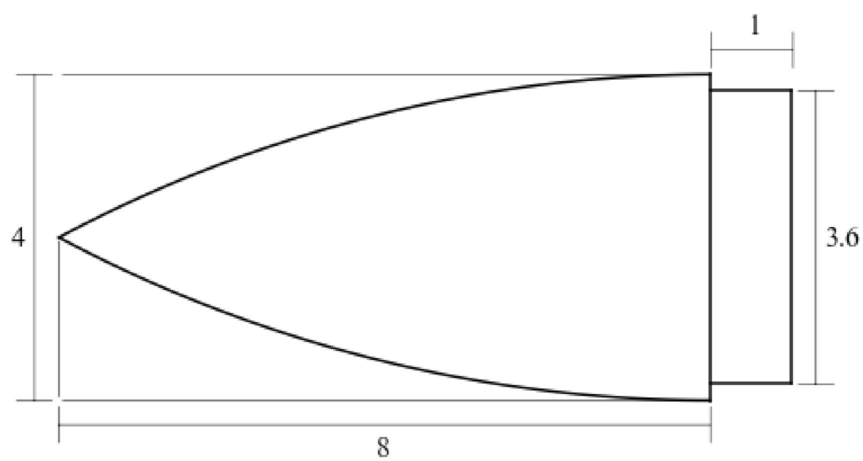

Fig. 2. Nose Cone (Markings are in cm scale)

The material used for the nose cone is **Fiberglass** ($1.85\ g/cm^3$) with a total mass of 101 g

*2) **Body Tube**:* The body tube is a hollow cylinder of thickness $2\ mm$ with a length of $200\ mm$ and an outer diameter of $40\ mm$. The body tube is used to store the motor mount, the flight computer ($150\ g$), and the recovery system.

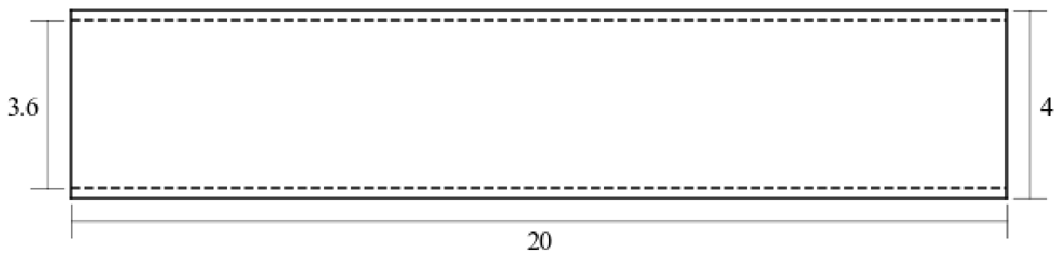

Fig. 3. Body Tube (Markings are in cm scale)

The material used for the body tube is **Cardboard** ($0.68\ g/cm^3$) with a total mass of $32.5\ g$

*3) **Recovery System**:* The recovery system used in the rocket is a **Ripstop Nylon** ($67\ g/m^2$) parachute having a drag coefficient of 0.8. The specifications of the recovery system are given in the table below.

Specification	**Value**
Diameter	$300\ mm$
No. of lines	6
Line Length	$300\ mm$
Packed length	$25\ mm$
Packed Diameter	$25\ mm$
Mass	$7.98\ g$

TABLE I
SPECIFICATIONS OF THE RECOVERY SYSTEM

The recovery system is scheduled to be deployed at the Apogee of the rocket.

*4) **Fins**:* Fins are situated at the bottom of the body tube. The fin cross-section is a NACA 0006 airfoil with a hub chord length of $50\ mm$. The shape of the fin is shown below.

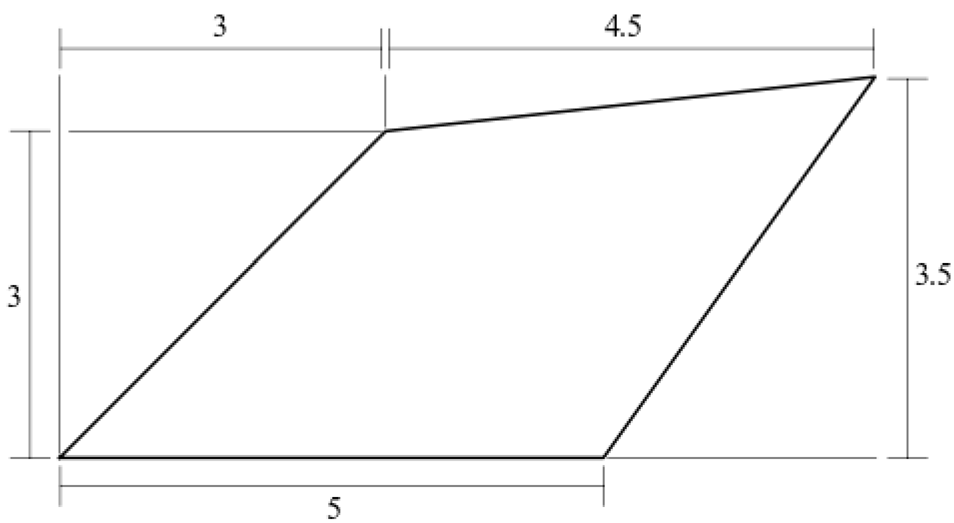

Fig. 4. Fins (Markings are in cm scale)

The fin is a **Nylon** ($1.15\ g/cm^3$) material with a total mass of $17.3\ g$.

*5) **Motor Mount**:* The motor mount is a 1 mm thick cylindrical container of length 71 mm and outer diameter 26 mm. It prevents the propellant from colliding with the electrical components of the rocket.

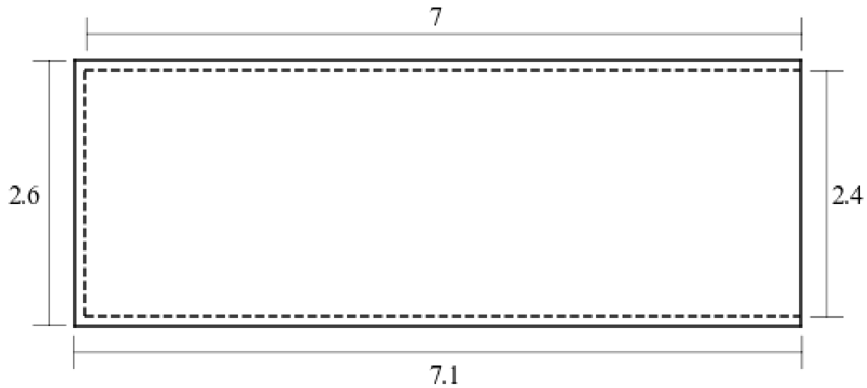

Fig. 5. Motor Mount (Markings are in cm scale)

It is made up of **Fiberglass** (1.85 g/cm^3) with a total mass of 10.3 g.

*6) **Propellant**:* The solid rocket propellant is an **E28-8T** manufactured by **Aerotech**. The characteristics of the propellant are given below.

Parameter	**Value**
Length	70 mm
Diameter	24 mm
Burn Time	1.16 s
Total Impulse	39.7 Ns
Mass	18.4 g

TABLE II
PROPELLANT CHARACTERISTICS

The Thrust-Time curve of the propellant is shown below.

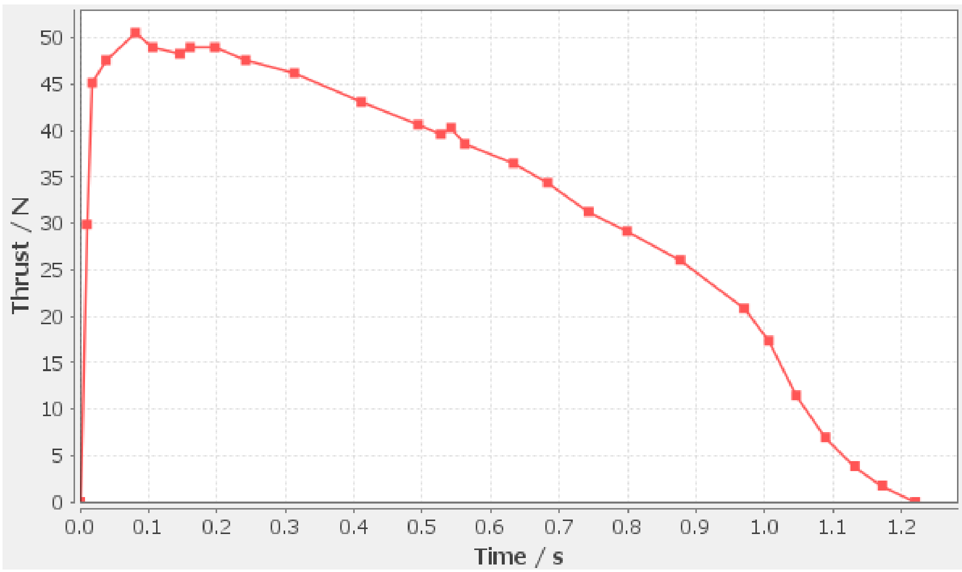

Fig. 6. AeroTech E28-8T Thrust Curve

C. Simulation

The flight path trajectory of the rocket and the time stamps of the key events during the flight are shown in the diagram below.

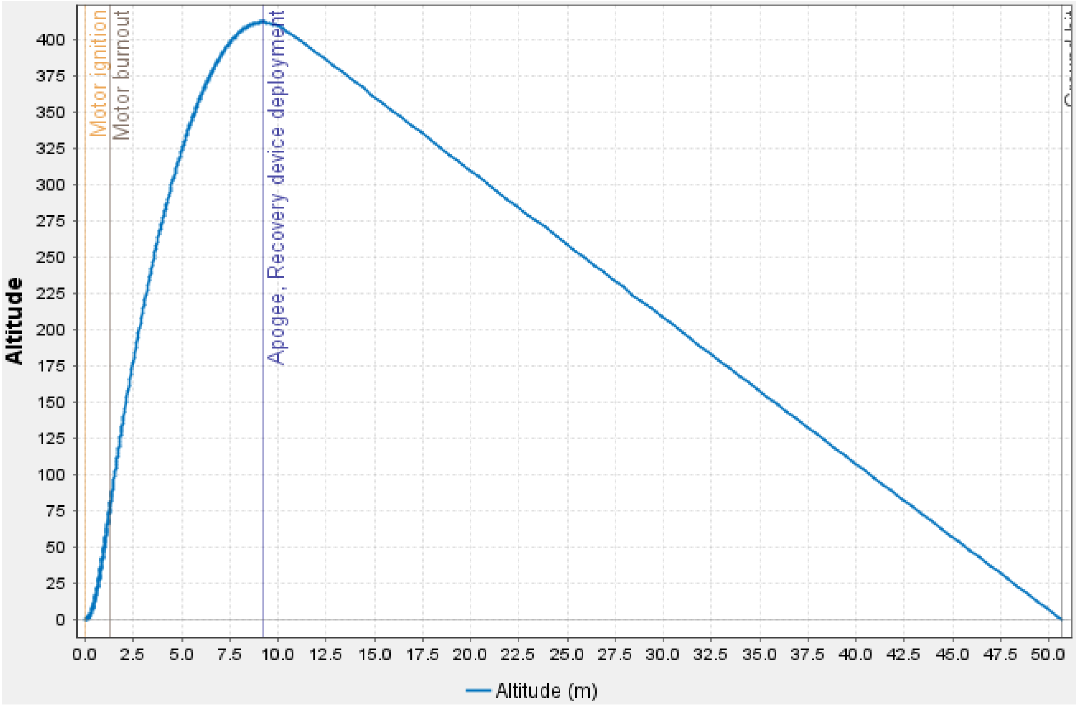

Fig. 7. Flight Path Trajectory

The velocity and acceleration plot (burnout phase) is shown below

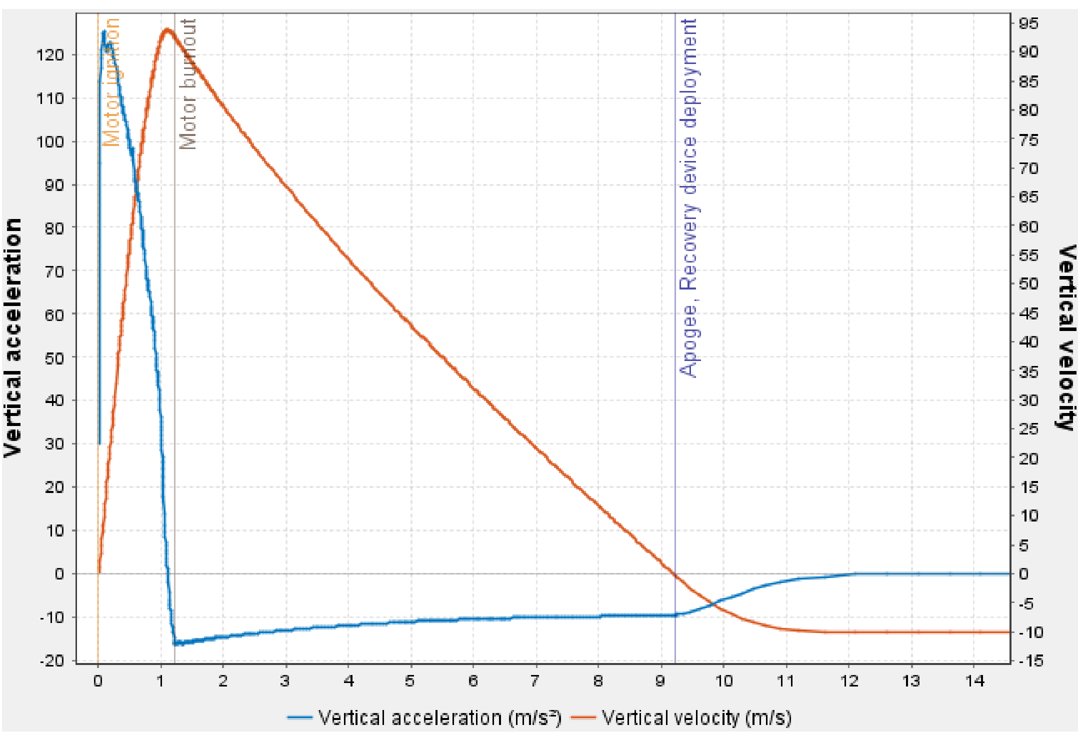

Fig. 8. Velocity and Acceleration Curve

D. CAD Model

1) Nose Cone

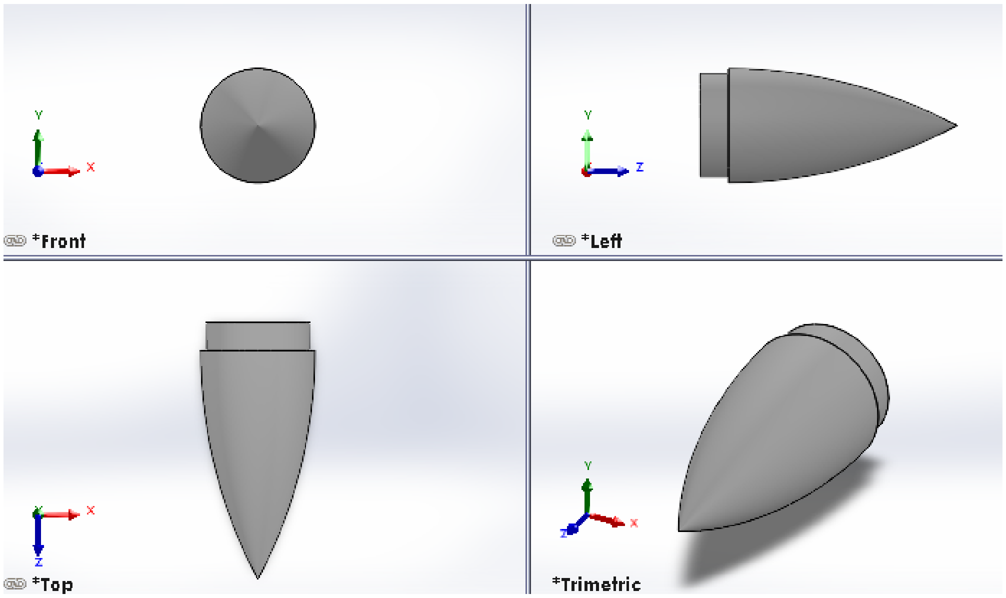

Fig. 9. Nose Cone

2) Body Tube

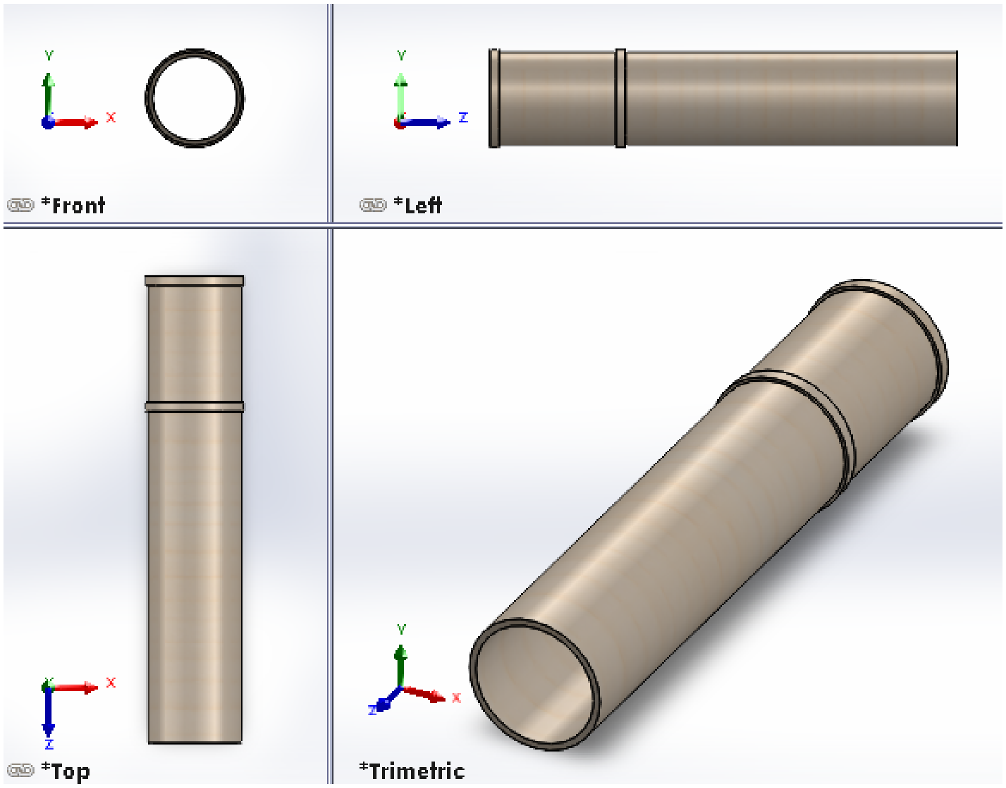

Fig. 10. Body Tube

3) **Fin Ring**

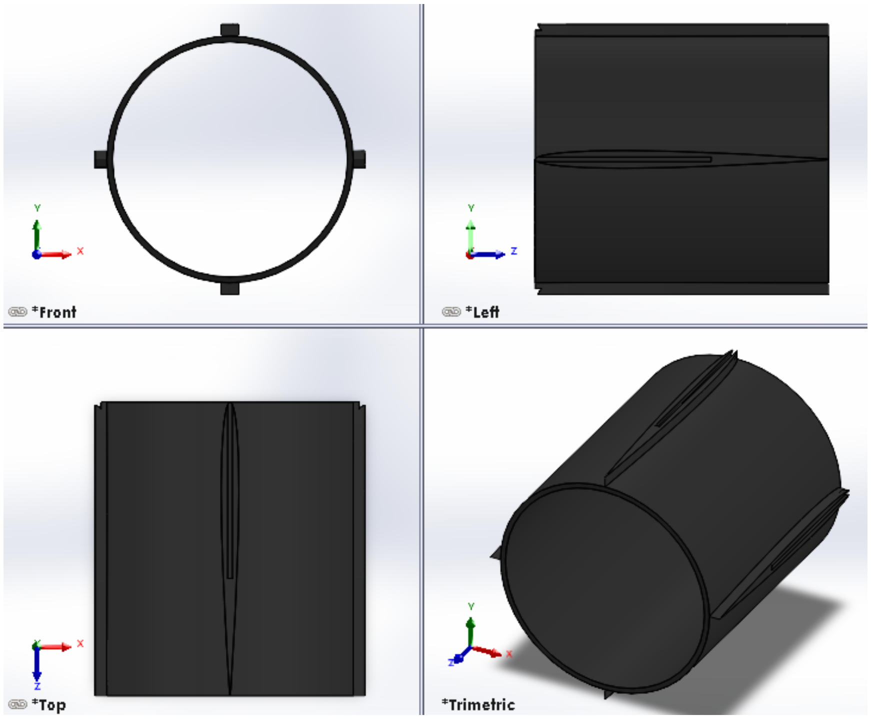

Fig. 11. Fin Ring

4) **Fin**

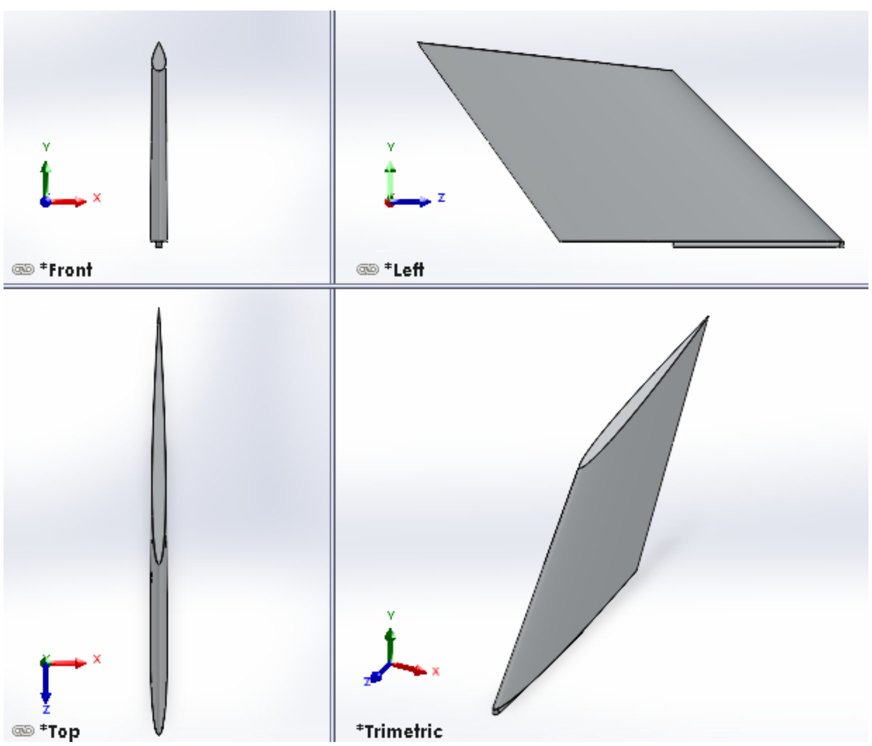

Fig. 12. Fin

5) **Motor Mount**

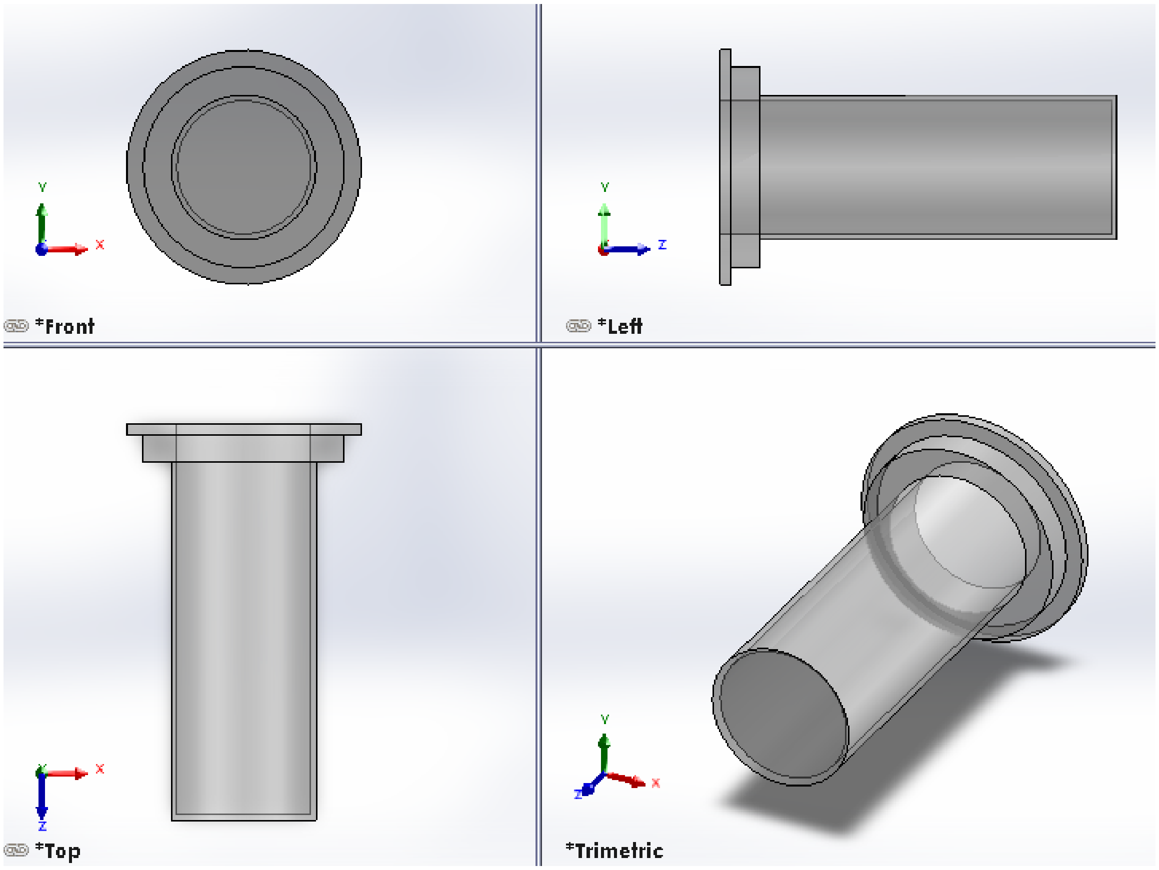

Fig. 13. Motor Mount

6) **Exploded View**

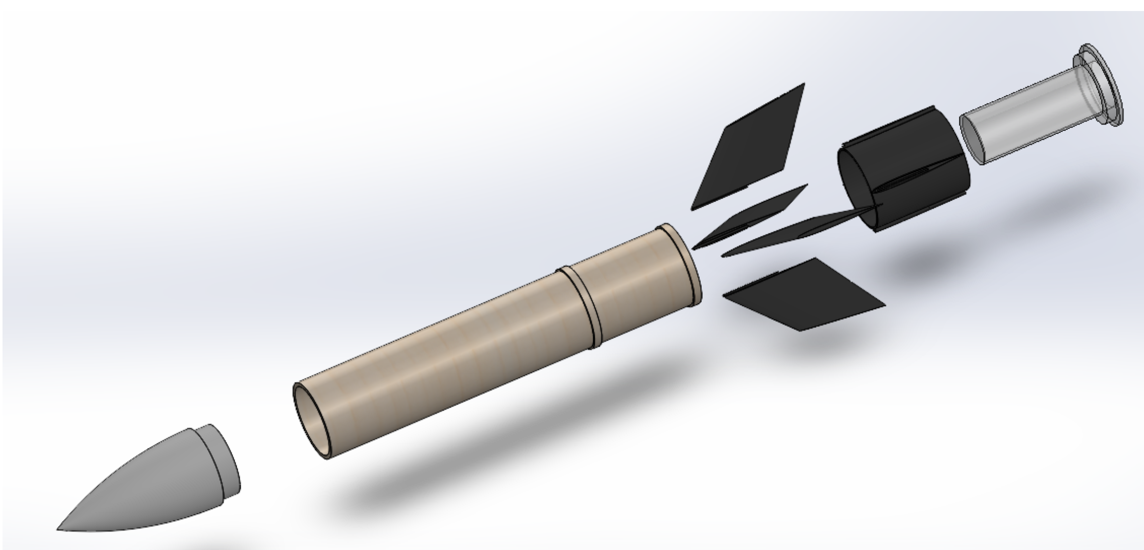

Fig. 14. Single Stage (Exploded View)

7) **Complete Rocket**

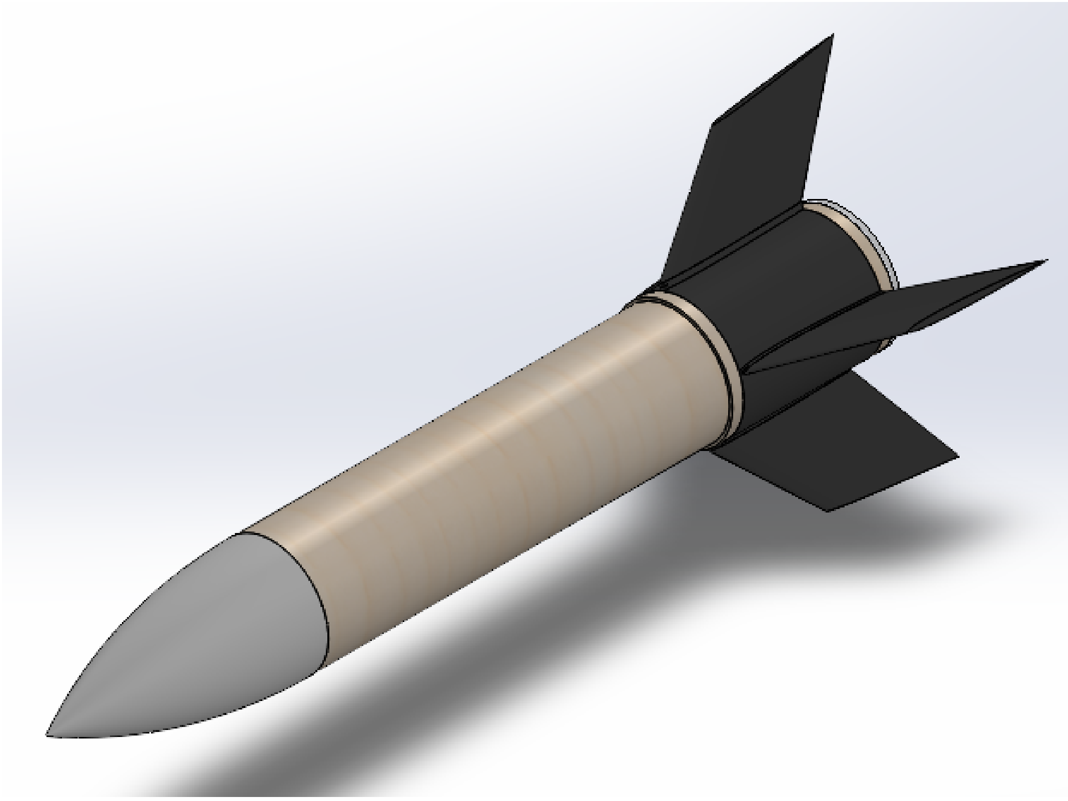

Fig. 15. Single Stage Rocket

II. Multi Stage Rocket

A multi-stage model rocket is an advanced type of hobbyist rocketry that achieves impressive altitudes and velocities. It operates by using distinct stages, each with its own propulsion system, that ignite and separate in sequence during flight. The initial stage propels the rocket upwards until its fuel is depleted, at which point it is discarded, reducing weight and drag. Subsequent stages continue the ascent, each igniting as the previous one is expended. This staged approach optimizes efficiency and allows the rocket to reach higher altitudes than single-stage rockets. Multi-stage model rockets often employ sophisticated recovery systems like parachutes for safe retrieval after reaching peak altitude. They offer rocket enthusiasts exciting challenges and a chance to explore engineering and physics principles while simulating the awe of space exploration on a smaller scale.

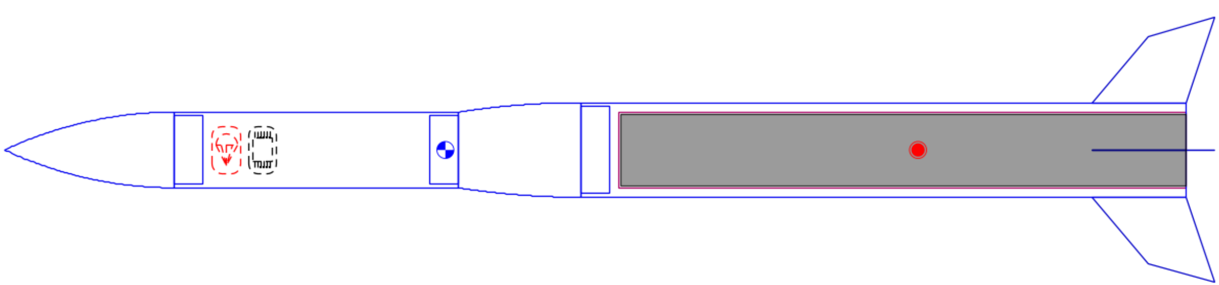

Fig. 16. Multi Stage Rocket

A. Mission Objective

The mission objectives for the multi-stage rocket are as follows:

- **Maximum Mass:** $3000\ g$
- **Minimum Apogee:** $2\ km$
- **Stability:** $5\ cal$

B. Rocket Components

In order to achieve the required mission objective, OpenRocket software was used to generate rocket components. The description of each rocket component is given below.

1) ***Nose Cone****:* The nose cone is a filled ogive structure with a length of $90\ mm$ and a base diameter of $40\ mm$. Additionally, base shoulders of length $15\ mm$ and base diameter $36\ mm$ are used to fit the nose cone with the body tube.

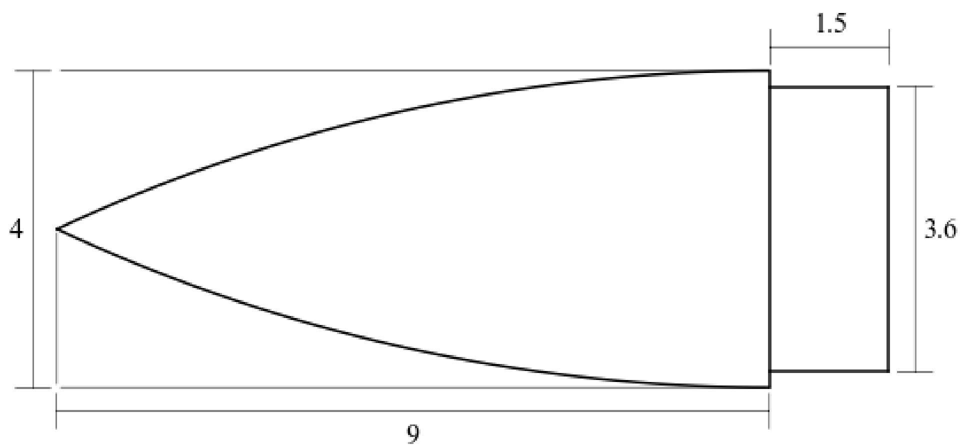

Fig. 17. Nose Cone (Markings are in cm scale)

The material used for the nose cone is **Fiberglass** ($1.85\ g/cm^3$) with a total mass of $113\ g$.

2) ***Upper Body Tube****:* The upper body tube is a hollow cylinder of thickness $2\ mm$ with a length of $150\ mm$ and an outer diameter of $40\ mm$. The body tube is used to store the flight computer ($1526\ g$) and the recovery system.

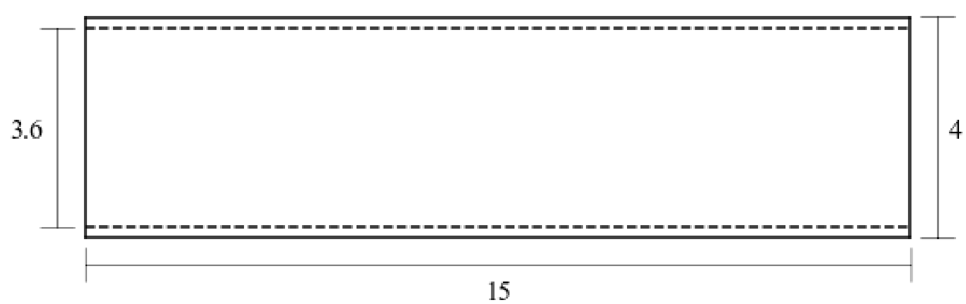

Fig. 18. Upper Body Tube (Markings are in cm scale)

The material used for the upper body tube is **Cardboard** ($0.68\ g/cm^3$) with a total mass of $24.4\ g$

*3) **Recovery System**:* The recovery system used in the rocket is a **Ripstop Nylon** ($67\ g/m^2$) parachute having a drag coefficient of 0.85. The specifications of the recovery system are given in the table below.

Specification	Value
Diameter	$450\ mm$
No. of lines	10
Line length	$350\ mm$
Packed length	$15\ mm$
Packed Diameter	$25\ mm$
Mass	$17\ g$

TABLE III
SPECIFICATIONS OF THE RECOVERY SYSTEM

The recovery system is scheduled to be deployed at the Apogee of the rocket.

*4) **Transition**:* The transition is a $2\ mm$ thick hollow ogive structure with a length of $65\ mm$, a fore diameter of $40\ mm$, and an aft diameter of $50\ mm$. The shoulders of length $15\ mm$ each are constructed on the ends to ensure a perfect fit with the body tubes.

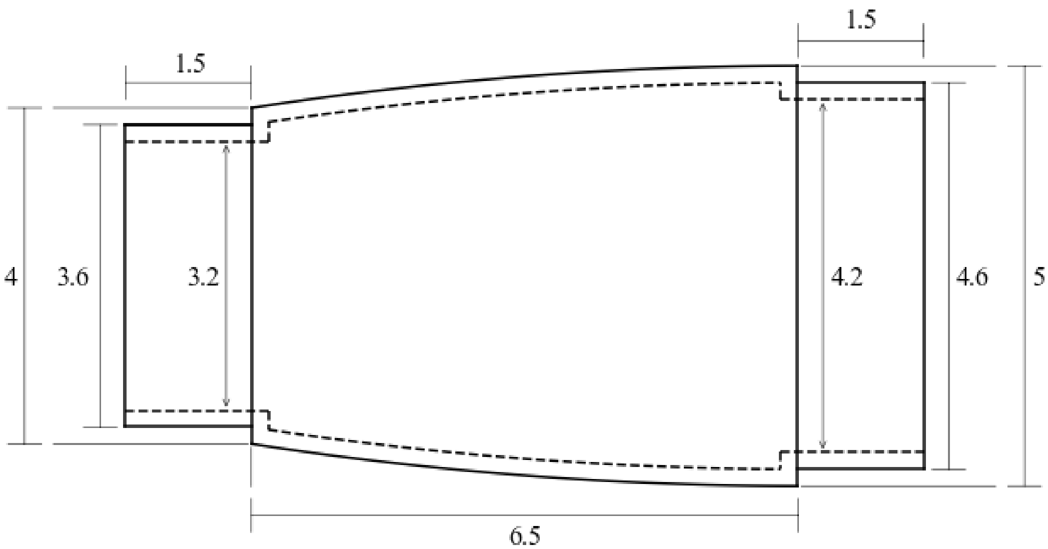

Fig. 19. Transition (Markings are in cm scale)

The material used for the transition is **Fiberglass** ($1.85\ g/cm^3$) with a total mass of $33.9\ g$.

*5) **Lower Body Tube**:* The lower body tube is a hollow cylinder of thickness $2\ mm$ with a length of $320\ mm$ and an outer diameter of $50\ mm$. The lower body tube is used to store the motor mount and to host the fins.

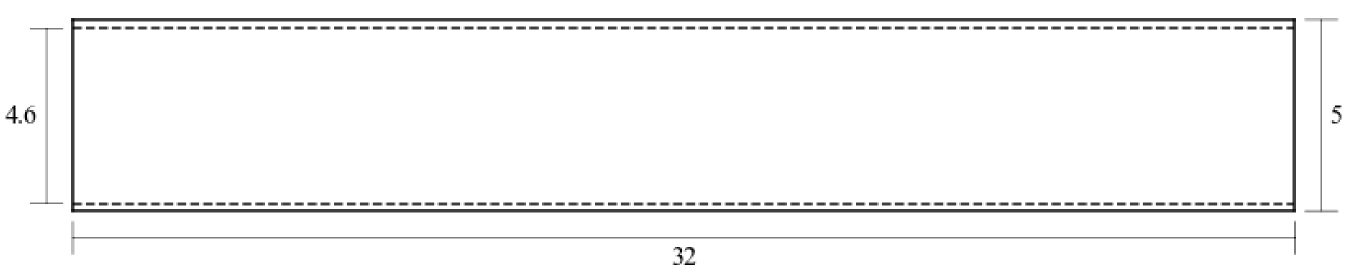

Fig. 20. Lower Body Tube (Markings are in cm scale)

The material used for the lower body tube is **Cardboard** ($0.68\ g/cm^3$) with a total mass of $65.6\ g$

*6) **Fins**:* Fins are situated at the bottom of the body tube. The fin cross-section is a NACA 0006 airfoil with a hub chord length of $50\ mm$. The shape of the airfoil is shown below.

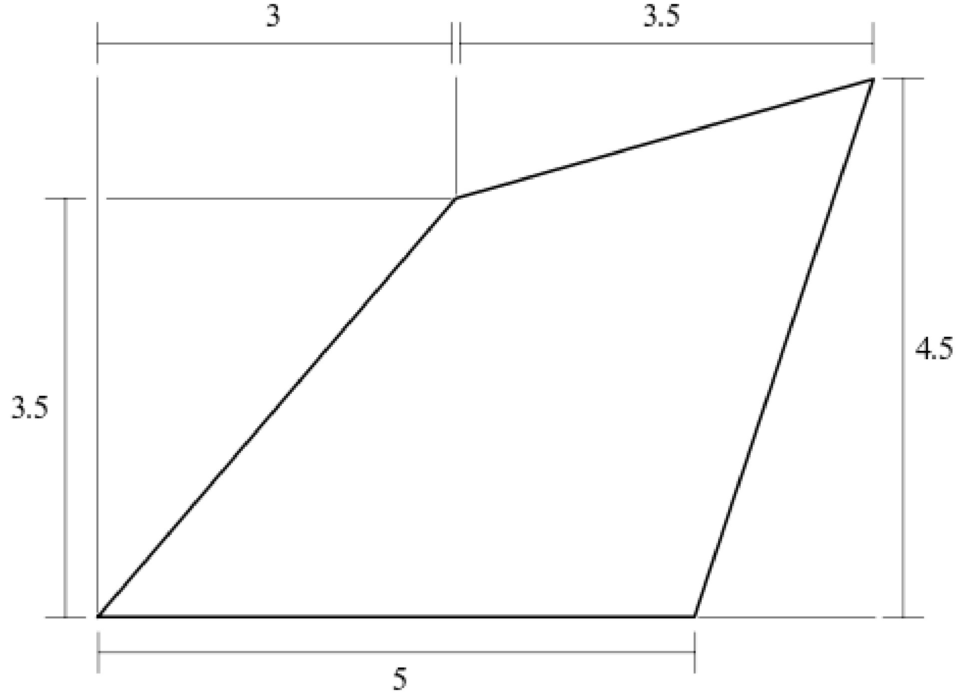

Fig. 21. Fin (Markings are in cm scale)

The fin is a **Nylon** ($1.15\ g/cm^3$) material with a total mass of $18.6\ g$.

*7) **Motor Mount**:* The motor mount is a $1\ mm$ thick cylindrical container of length $300\ mm$ and an outer diameter $40\ mm$. It prevents the propellant from colliding with the electrical components of the rocket.

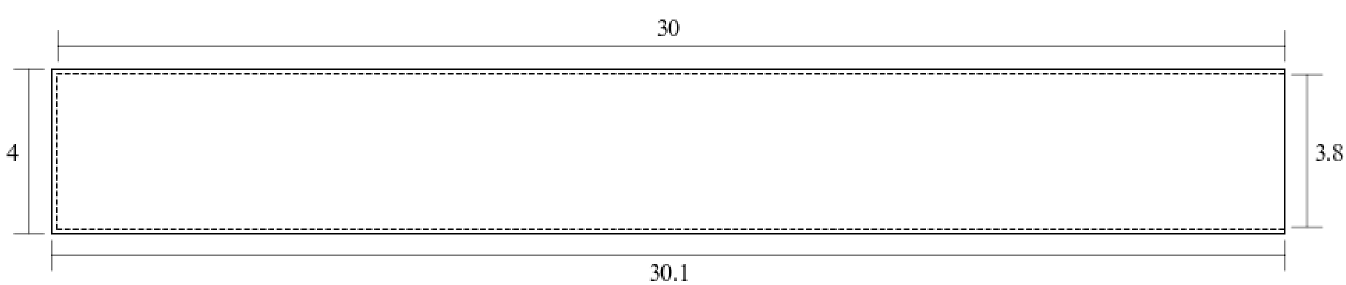

Fig. 22. Motor Mount (Markings are in cm scale)

It is made up of **Fiberglass** ($1.85\ g/cm^3$) with a total mass of $68\ g$

*8) **Propellant**:* The solid rocket propellant is a **I435-14T** manufactured by **Aerotech**. The characteristics of the propellant are given below.

Parameter	**Value**
Length	299 mm
Diameter	38 mm
Burn Time	1.16 s
Total Impulse	561 Ns
Mass	266 g

TABLE IV
PROPELLANT CHARACTERISTICS

The Thrust-Time curve of the propellant is shown below.

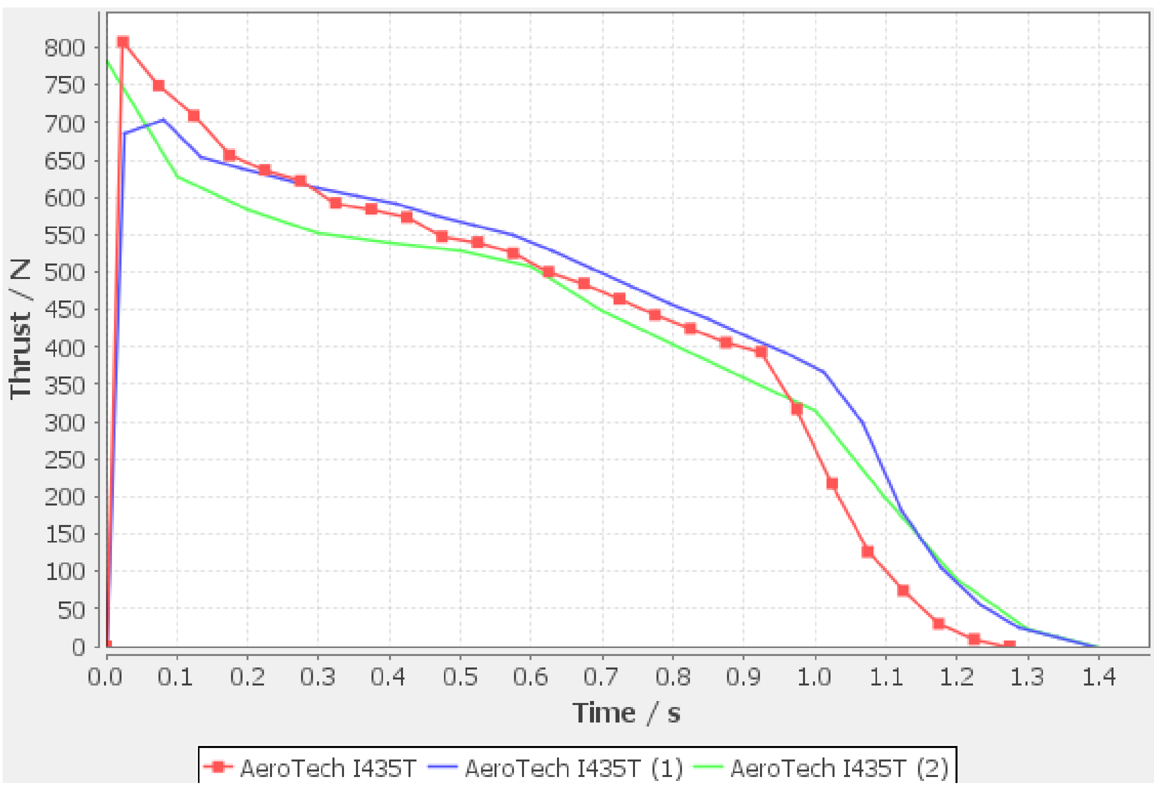

Fig. 23. AeroTech I435-14T Thrust Curve

C. Simulation

The flight path trajectory of the rocket and the time stamps of the key events during the flight are shown in the diagram below.

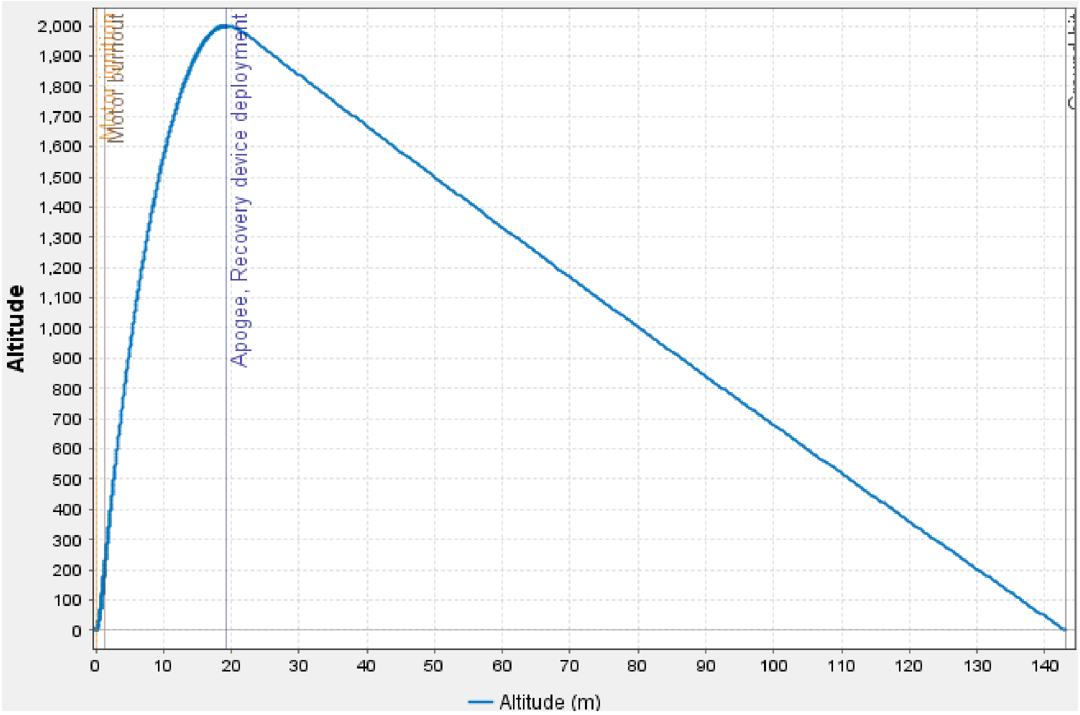

Fig. 24. Flight Path Trajectory

The velocity and acceleration plot (burnout phase) is shown below

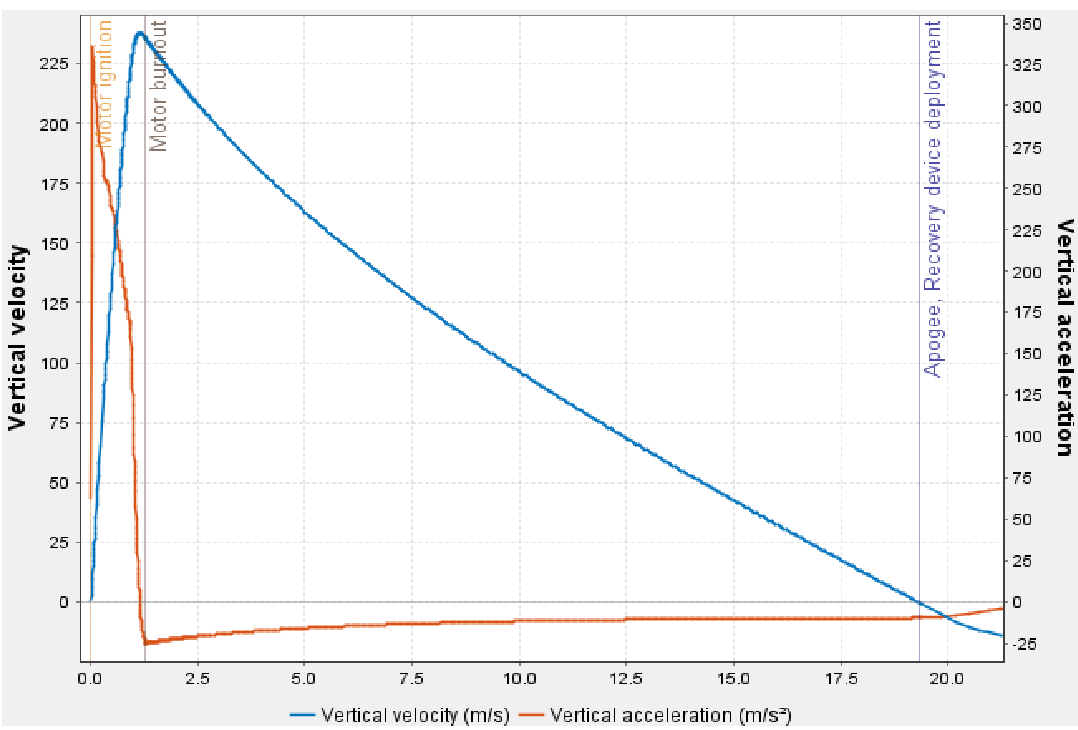

Fig. 25. Velocity and Acceleration Curve

D. CAD Model

1) **Nose Cone**

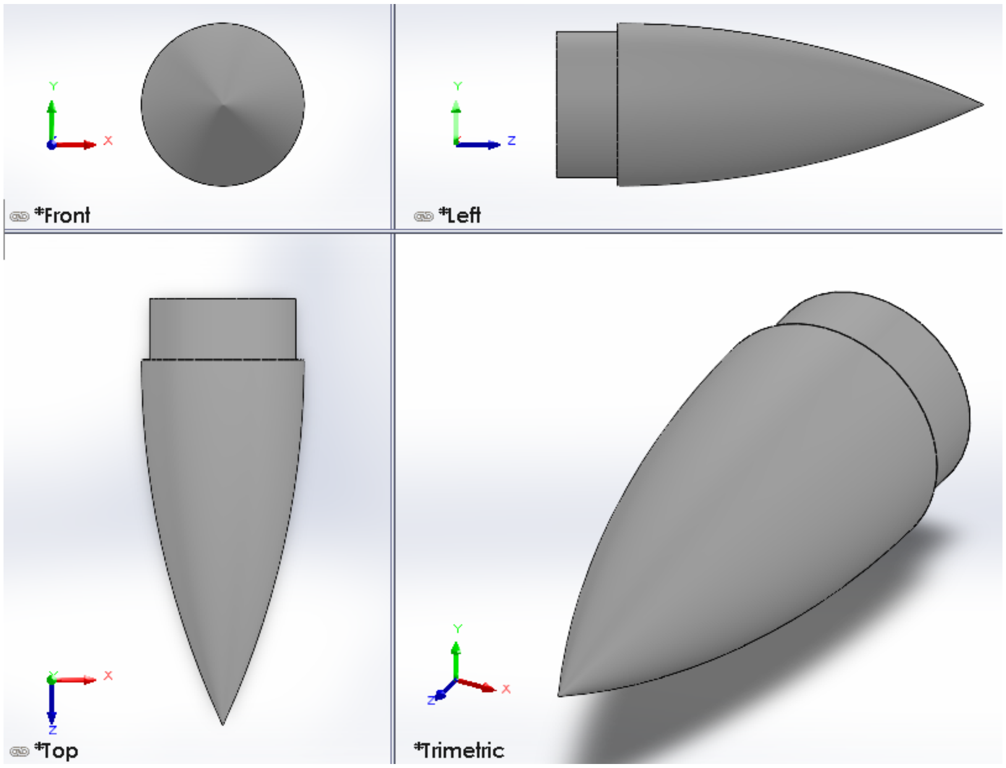

Fig. 26. Nose Cone

2) **Upper Body Tube**

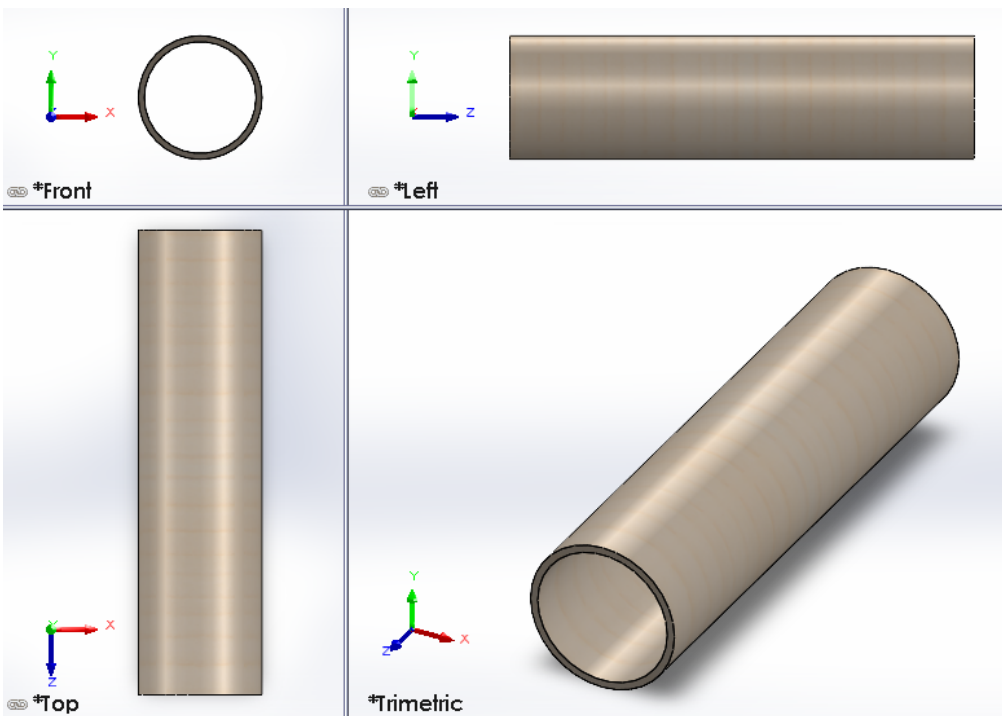

Fig. 27. Upper Body Tube

3) **Transition**

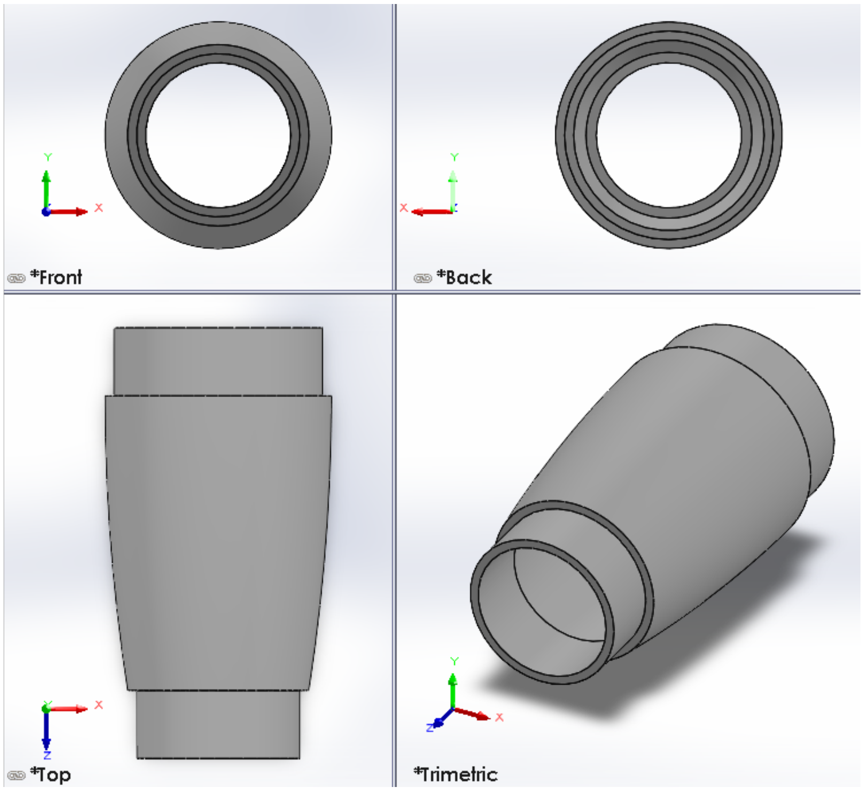

Fig. 28. Transition

4) **Lower Body Tube**

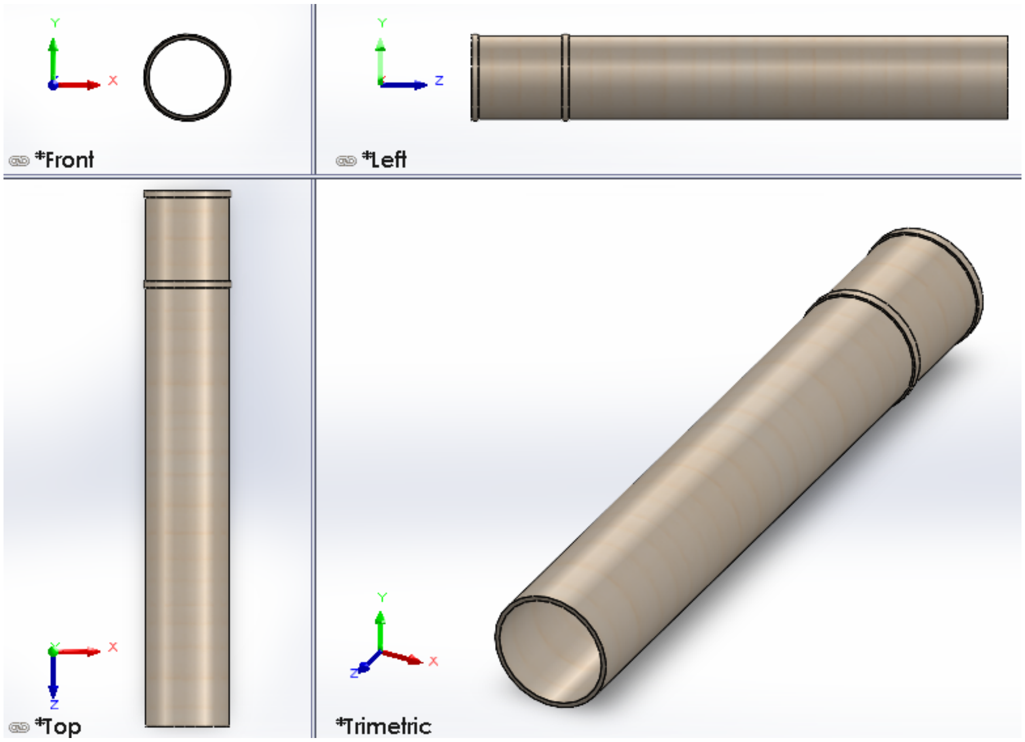

Fig. 29. Lower Body Tube

5) Fin Ring

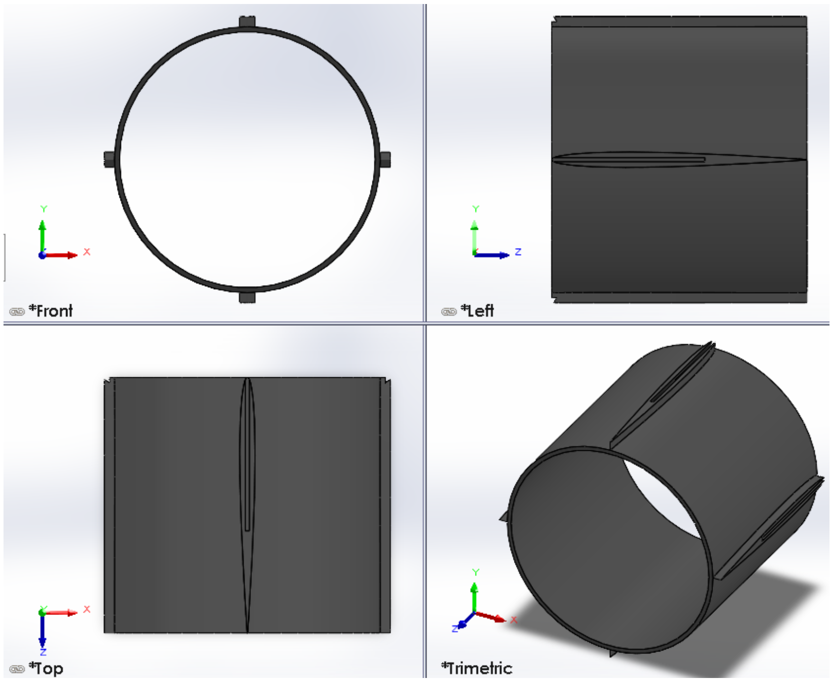

Fig. 30. Fin Ring

6) Fin

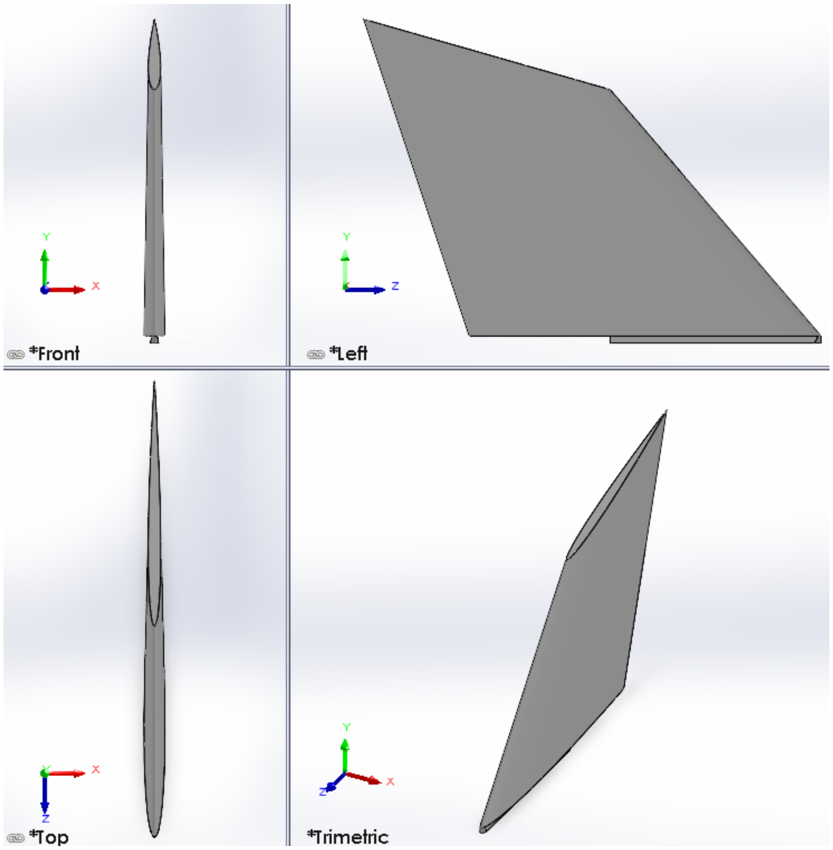

Fig. 31. Fin

7) **Motor Mount**

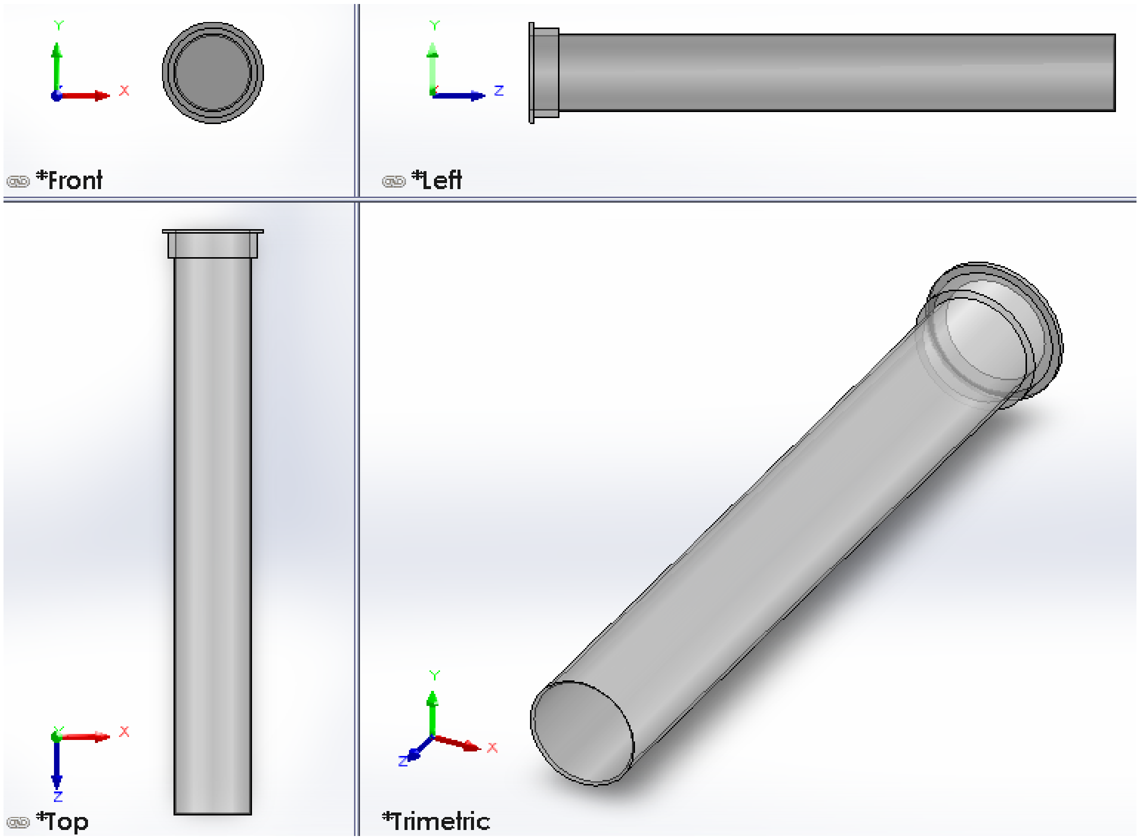

Fig. 32. Motor Mount

8) **Exploded View**

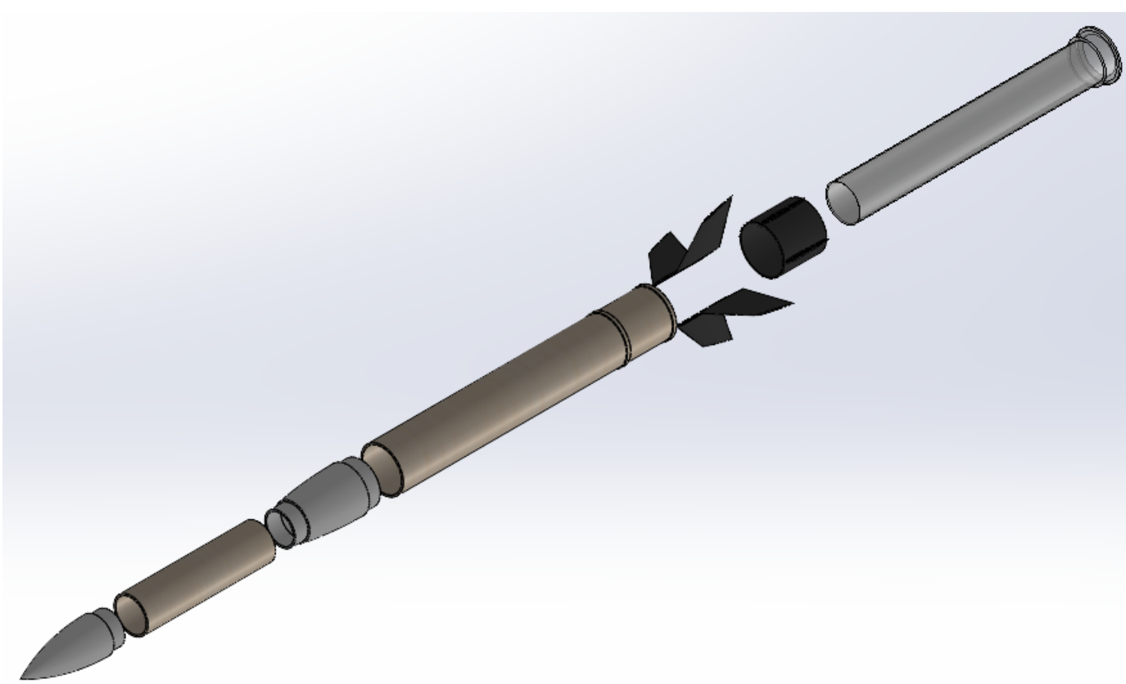

Fig. 33. Multi Stage (Exploded View)

9) **Complete Rocket**

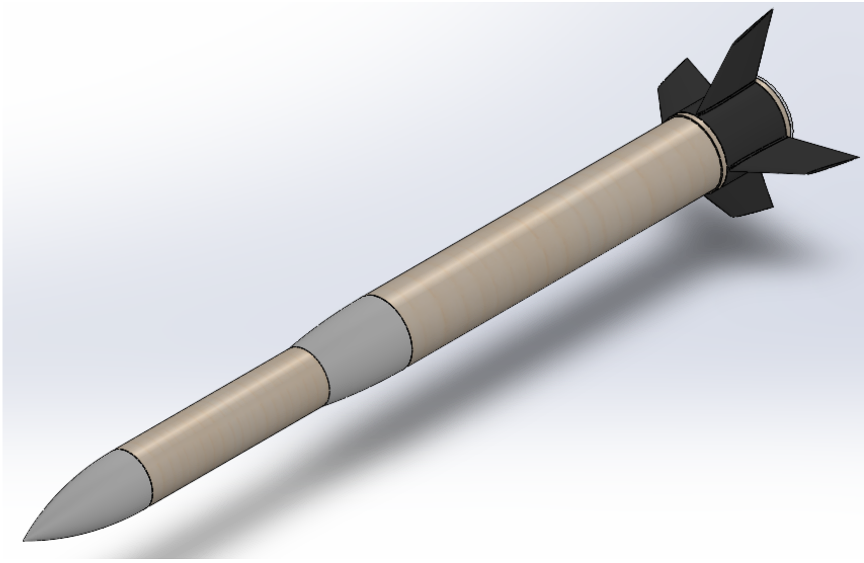

Fig. 34. Multi Stage Rocket

III. RESULTS

The following final configurations are obtained for the single and multi-stage rockets.

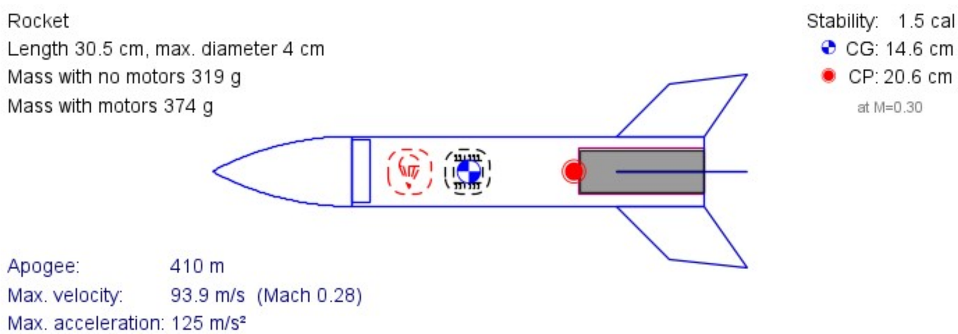

Fig. 35. Single Stage Configuration

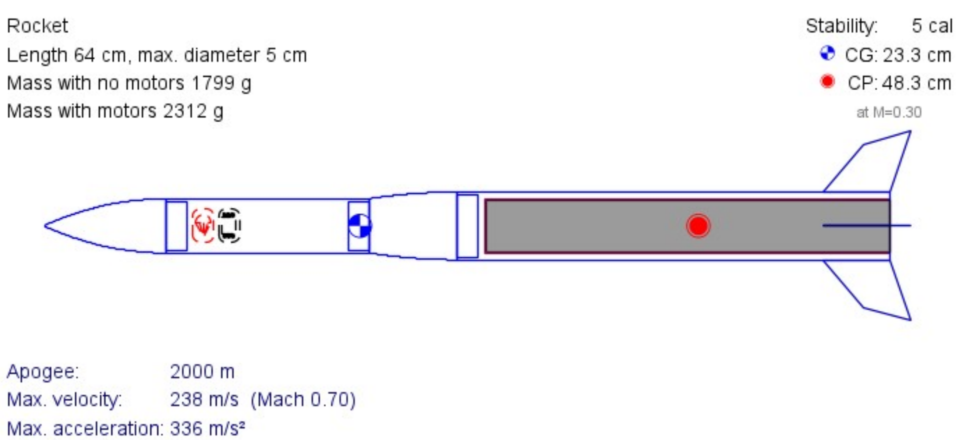

Fig. 36. Multi Stage Configuration

IV. Appendix A

A. The Ogive Curve

Most of the typical nose cones used in rocket design are of ogive shape. To construct an ogive shape in SolidWorks, the ogive equation is used.
For a given ogive length L and a base radius R, the ogive equation is given by

$$y = \sqrt{\rho^2 - (L - x)^2} + R - \rho; \quad x \in [0, L]$$

$$where,$$

$$\rho = \frac{R^2 + L^2}{2R}$$

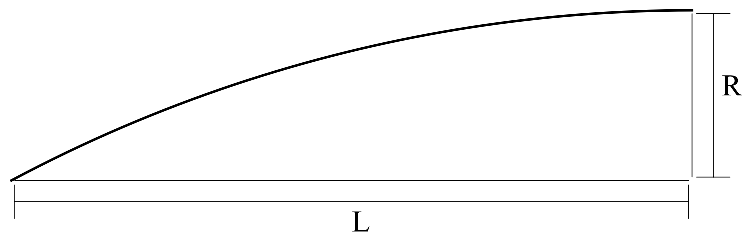

Fig. 37. Ogive Curve

B. The Semi-ogive Curve

Similar to the nose cones, a transition between the body tubes is a semi-ogive structure. The equation of the same can be achieved by the domain transformation of the original ogive equation.
For a semi-ogive with a fore diameter r, an aft diameter R and a length l is given by

$$y = \sqrt{\rho^2 - (L - x)^2} + R - \rho; \quad x \in [L - l, L]$$

$$where,$$

$$\rho = \frac{(R - r)^2 + l^2}{2(R - r)}$$

$$L = \sqrt{R\left(\frac{l^2}{R - r} - r\right)}$$

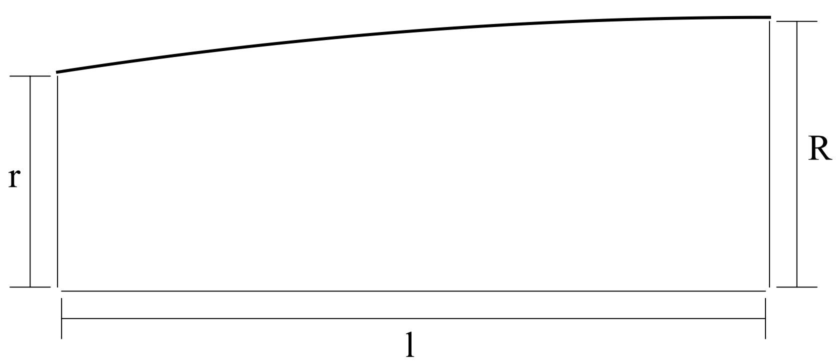

Fig. 38. Semi-Ogive Curve