DESIGNING AND SIMULATING A MODEL ROCKET IN OPENROCKET

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1. INTRODUCTION

A model rocket is a small solid fuel-powered rocket that is designed to reach low altitudes (under 500 meters) and can be effectively recovered by a variety of means (parachutes predominantly). It is a relatively safe and inexpensive way for students to learn the basics of forces and the response of a vehicle to external forces. Model rockets can be used to launch and deploy CanSats/Sensors, for low atmosphere scientific observations and aerial photography.

1.1 OPENROCKET

OpenRocket is an open-source program that simulates a rocket launch. Using this software, the rocket design was made into a detailed 2D model with all components. In simulations, weather conditions could also be altered to see how the rocket would perform under various wind speeds. OpenRocket was a major tool used in determining the design of the rocket, as it tracked the stability of the rocket as well as the apogee when components are added and altered for their best performance. OpenRocket was also used to track the center of pressure and center of gravity of the rocket actively throughout the design process.

1.2 ANSYS FLUENT

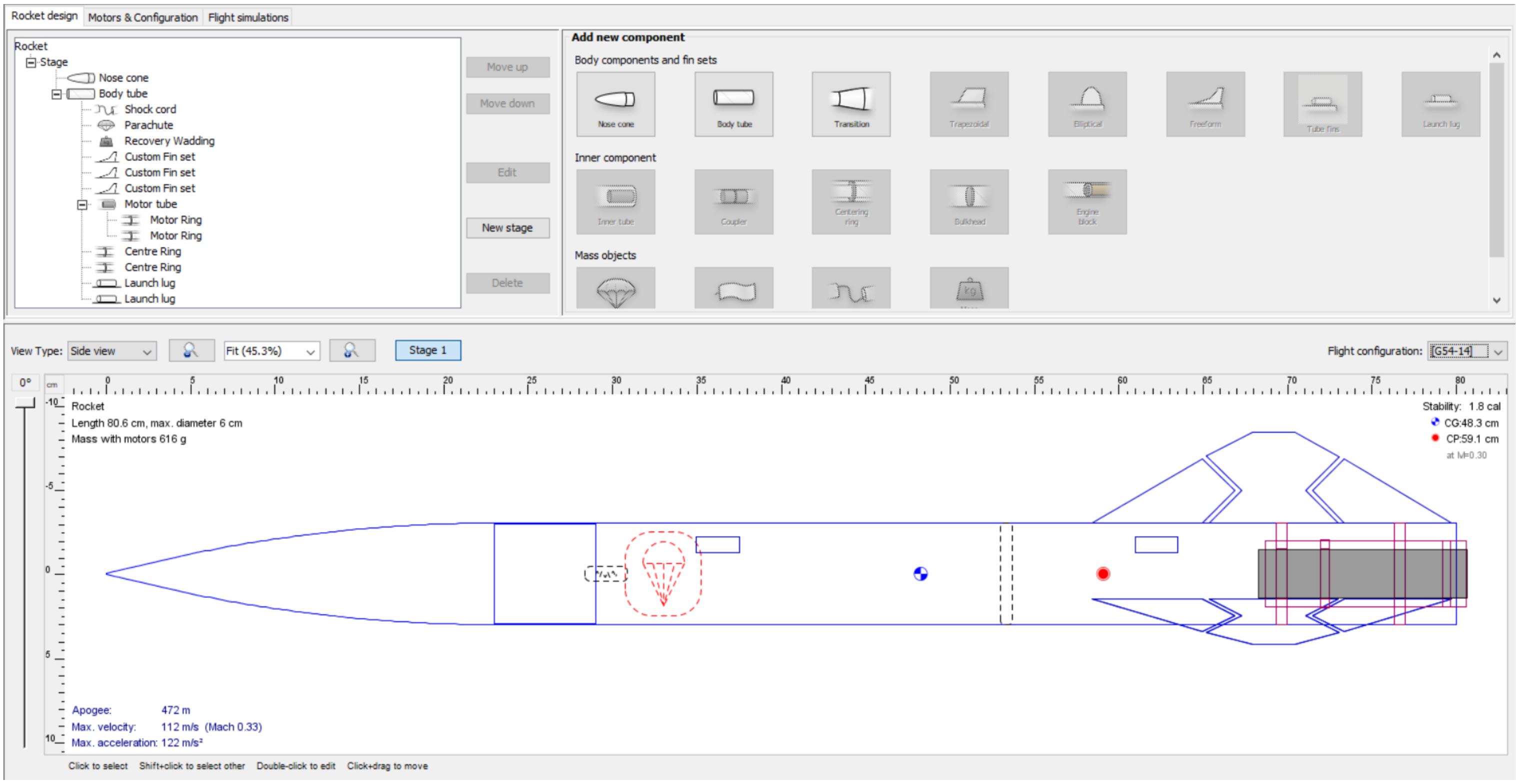
Ansys Fluent is used for the CFD simulation. Ansys CFD solvers are based on the finite volume method. The CAD model is built and meshed into multiple elements. Boundary conditions are set at both inlet and outlet to simulate free field conditions. Once the simulation is done, we will be able to visually evaluate the result in the form of contours and animations as well as graphs.

2. DESIGN REQUIREMENTS

We are required to design a Model Rocket that is capable of reaching an altitude of 450 meters for experimental purposes. The maximum allowed rocket length is 1 meter, with a maximum admissible wet mass of 0.65 kilograms.

3. THE ROCKET MODEL

Taking the above-mentioned requirements into account, a rocket has been designed such that its wet mass is 0.616 kilograms and a dry mass of 0.480 kilograms with a length of 0.806 meters, a diameter of 0.06 meters, and an apogee of 472 meters. We make use of a “Launch Lug” to provide stability for the rocket before and during liftoff. The launch lug works by forcing the rocket to remain parallel to the launch rod, ensuring a smooth, vertical lift-off.



(Fig 1: Sectional Rocket Model)

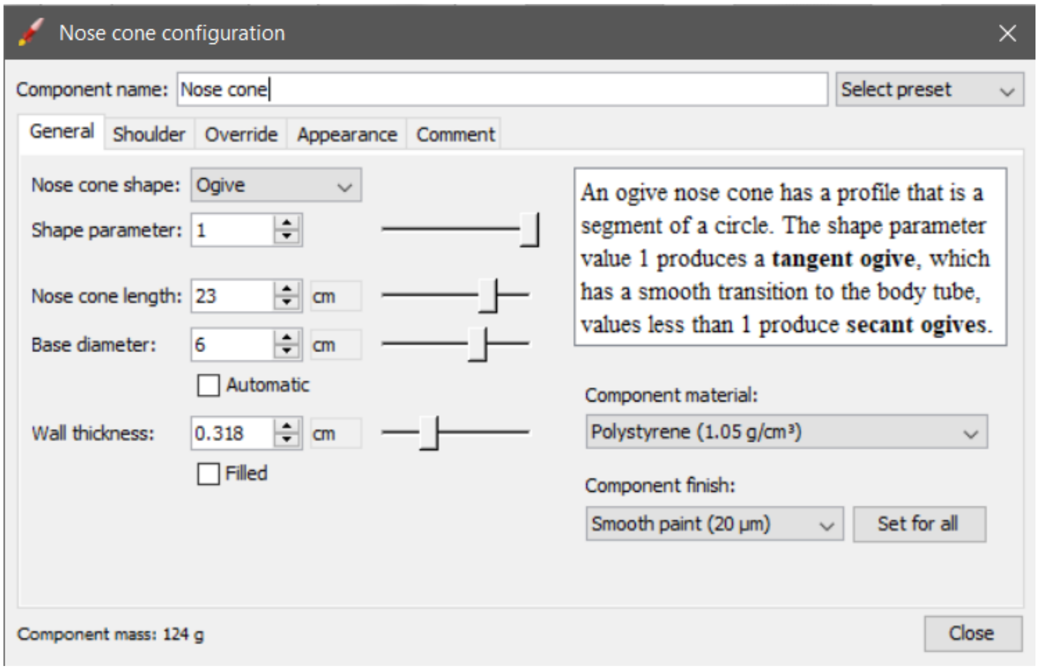
(Fig 2: 3D rendered Rocket Model)

3.1 NOSE CONE

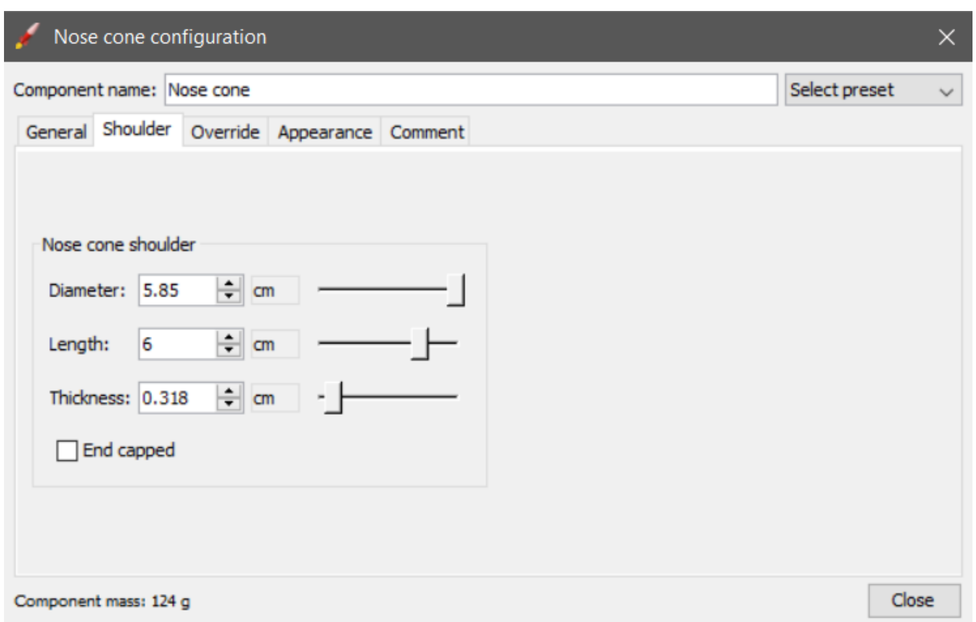
The nose cone is the part of a rocket that's forward-most. Its purpose is to reduce aerodynamic drag on the model. The ogive nose cone has a smooth arc that meets the body's contour perfectly. This characteristic prevents the ogive from breaking in line with the cylindrical body. As a general thumb rule, the length of the nose cone is taken to be 4 times that of its diameter. Following this rule, the nose cone is designed to have a 6 cm diameter and a 23 cm length. A shoulder of length 6 cm and 5.85 cm diameter was built into the nose cone to secure the body tube with the nose cone.

As the rocket will be experiencing accelerations of up to 122 ms^{-2} (approximately 12.5 g's) and velocities of up to 112 ms^{-1} (Mach 0.33), polystyrene (1.05 gcm^{-3}) has been selected as a suitable material for designing the nose cone has it is both durable and lightweight. The total mass of the nose cone is estimated to be around 124 grams.

The nose cone is connected to the parachute bay through an elastic shock cord, to ensure its successful retrieval.



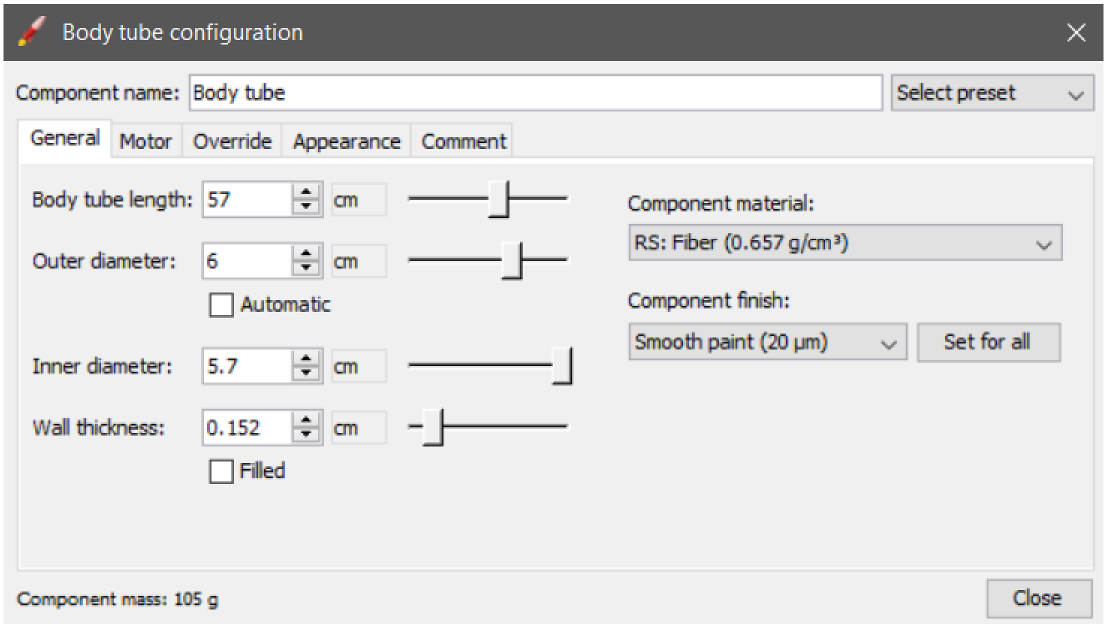
(Fig 3: Nose Cone Specifications)



(Fig 4: Shoulder Specifications)

3.2 BODY TUBE

The main facet of the model rocket is, of course, the body tube. This part is responsible for bringing all pieces of the model rocket together such as the nose, fin, engine, and recovery system. The body tube measures 57 cm in length with an inner diameter of 5.7 cm and is 0.152 mm thick. We use fiber (0.657 gcm^{-3}) as the material.



(Fig 5: Body tube Specifications)

These are the parts in the body tube:

3.2.1 Shock cord

The shock cord connects the model rocket's body tube and nose cone once the parachute has been deployed. It is typically an elastic material. Though it is not visible while the rocket is assembled, it plays a key role in the recovery of the flight.

As a general rule of thumb, the shock cord measures approximately three times the length of the rocket's body tube. It gently withstands the force of ejection and parachute opening. Following this rule, the shock cord measures 200 cm in length.

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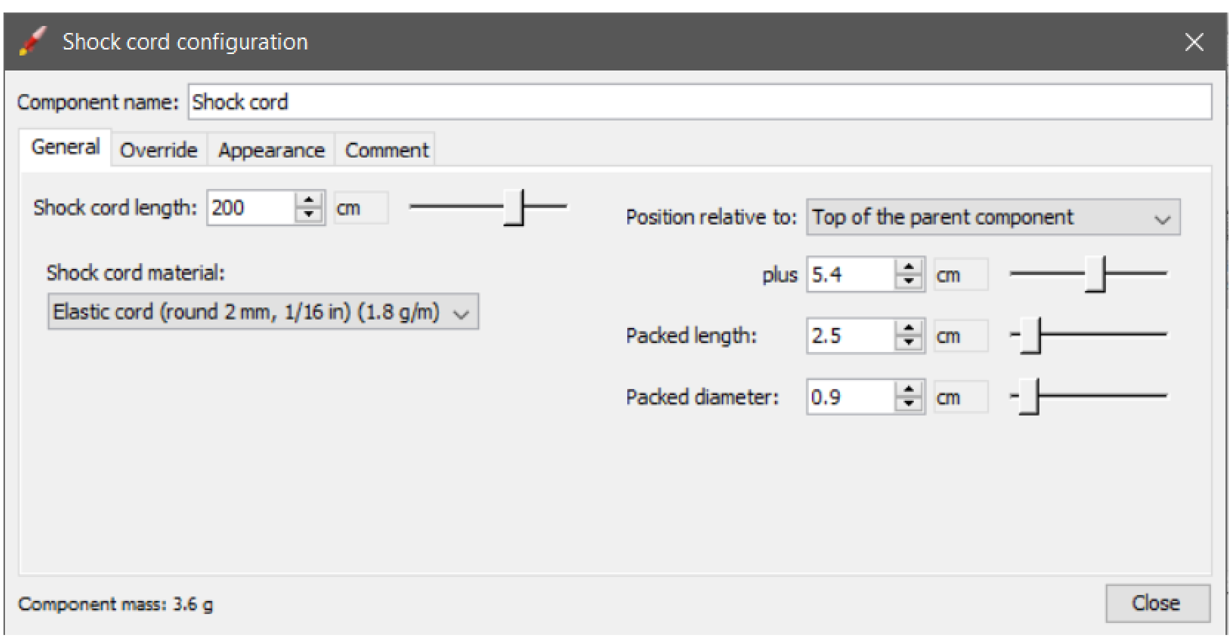


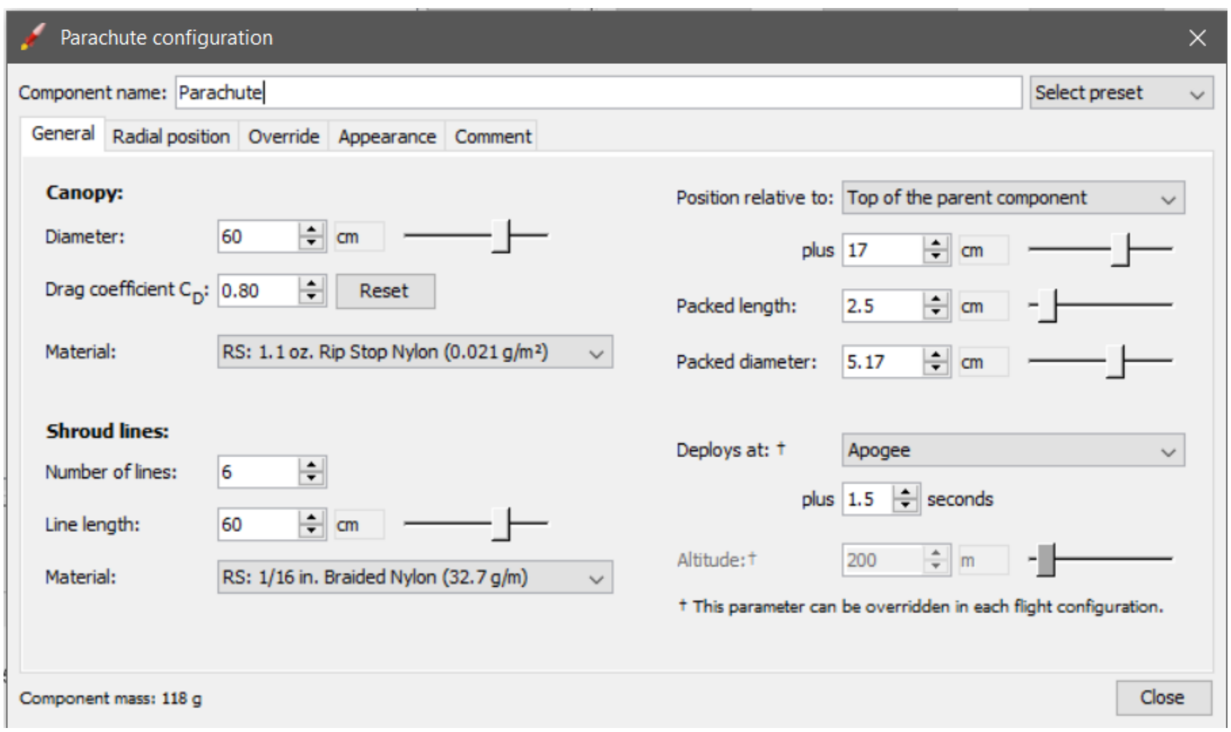
(Fig 6: Shock cord Specifications)

3.2.2 Parachute

The parachute is the most crucial component of a rocket. A successful parachute deployment is a key to ensuring the rocket's retrievability. It is typically an elastic material.

For a safe touchdown, keeping the rocket's touchdown velocity in mind, a 60 cm diameter wide parachute with six 60 cm long lines has been selected for this purpose. The parachute is made of standard off-the-shelf 1.1 oz. Rip-Stop Nylon(0.021 gm^{-2}) to prevent it from tearing under stress. The parachute weighs about 118 grams.

The parachute is expected to deploy as the rocket reaches apogee. This is done to ensure the parachute deploys when the rocket is at low velocities, in an attempt to further minimize tearing. The payload charges are expected to fire at least 1.5 seconds before apogee, to ensure that the payload has enough time to separate from the main rocket body. This can be accounted for by the flight computer onboard the payload.



(Fig 7: Parachute Specifications)

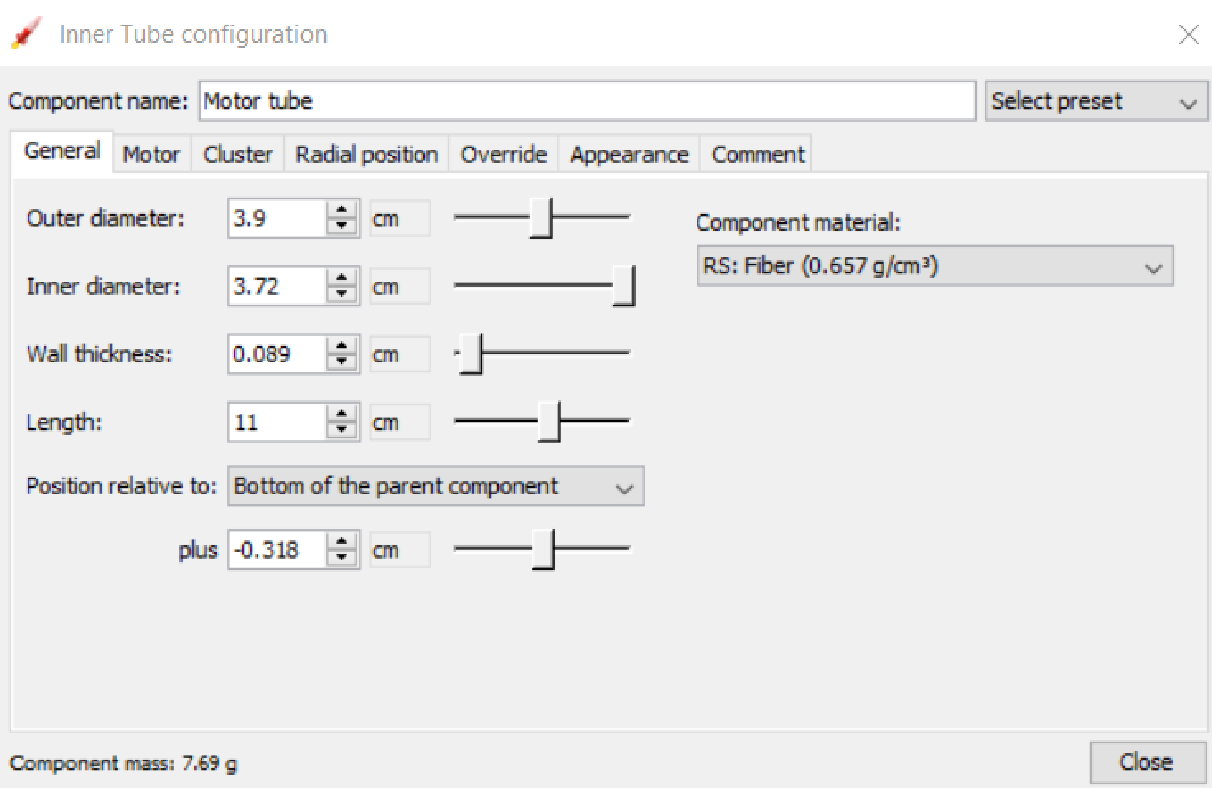
3.2.3 Recovery Wadding

The Recovery wadding is a material that is fire resistant and aids in protecting the parachute from the recovery charge of the model rocket engine. The hot gases released from the engine could damage the parachute, so the wadding acts as an interceptor for the parachute. Additionally, the wadding can aid in the successful ejection of the parachute. It weighs about 70 g and is of dimensions 1 cm x 6 cm.

3.2.4 Motor Tube

The motor tube contains the motor and is attached to the airframe in some manner, usually with centering rings. The motor tube is often made of the same material as the airframe. A model-rocket motor tube often has a thrust ring inside, and the motor pushes against the ring during thrust. High power rockets have no thrust ring inside — the thrust ring is at the aft end of the motor. This lets you insert motors of different lengths without spacers. The motor tube transfers the thrust of the motor to the centering rings, which transfer it to the airframe. Therefore, the motor tube and centering rings must be able to withstand the highest impulse produced by the motor. In addition, the motor tube must be able to handle the heat produced by the motor.

In this model, we use a motor tube of length 11 cm of material fiber (0.657 gcm^{-3}) considering the above. The motor tube is stabilized by 2 centering rings to the airframe and 2 centering rings to fix the motor with the motor tube at the fore-end.



(Fig 8: Motor tube Specifications)

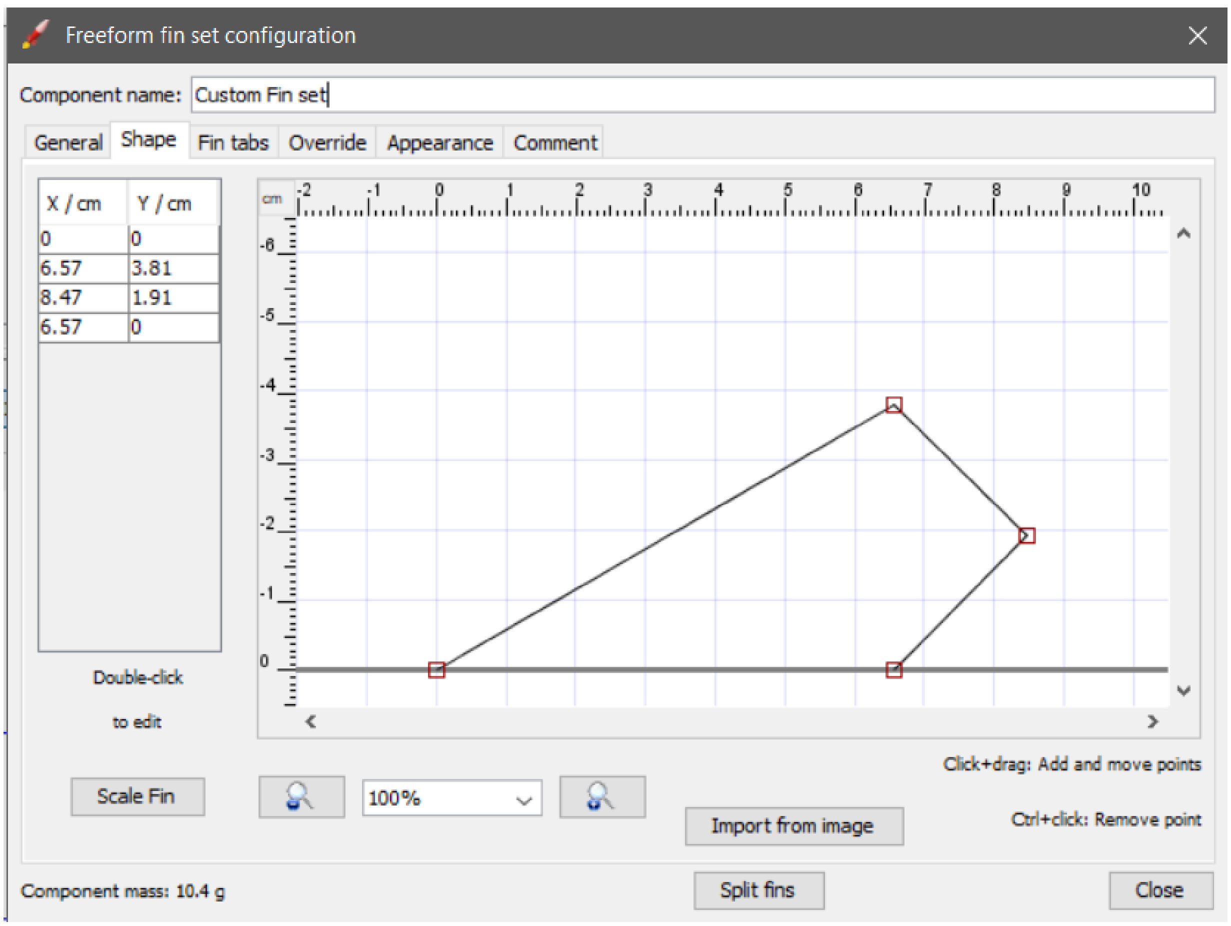
3.3 FINS

Model rocket fins are one of the most important parts of a rocket's anatomy and can determine whether the rocket flies correctly at all.

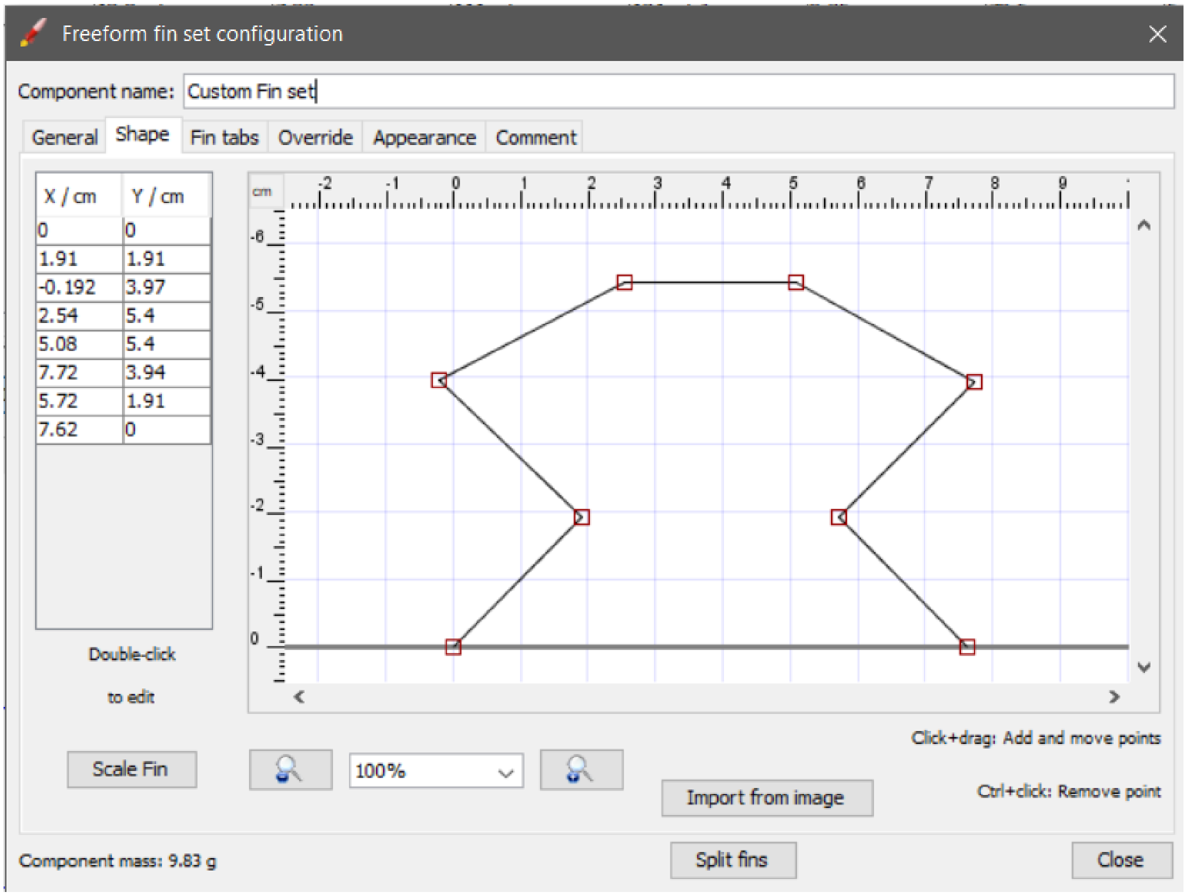
Fins at the base of the rocket stabilize and guide a rocket's flight trajectory by creating a center of pressure that is rearward of its center of gravity. Without a stabilizing force, a rocket would begin to tumble in mid-air soon after launch, just due to the influence of wind and other aerodynamic factors. Fins are built in various designs that optimize stability and drag to create the desired flight characteristics of the rocket.

As a general rule of thumb, a model rockets' stability is expected to be between 1 and 2 cal. Lower than 1 cal and the rocket becomes unstable. Greater than 2 cal, the rocket becomes overstable.

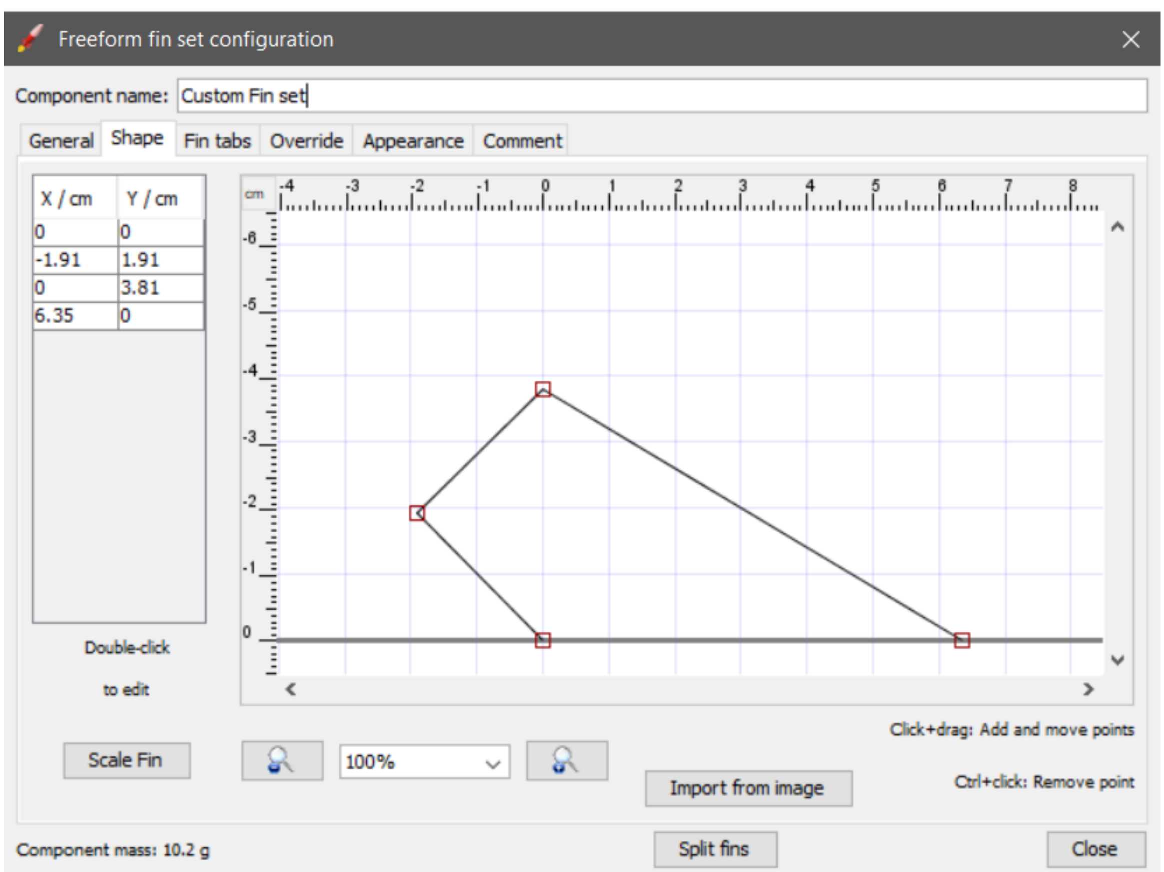
Here, three custom-made fins are made of Aircraft plywood (Birch) (0.725 gcm^{-3}) of thickness 0.3 cm each. The overall stability of the rocket is 1.75 cal, which is moderately stable.



(Fig 9: Fin 1 Geometry)



(Fig 10: Fin 2 Geometry)



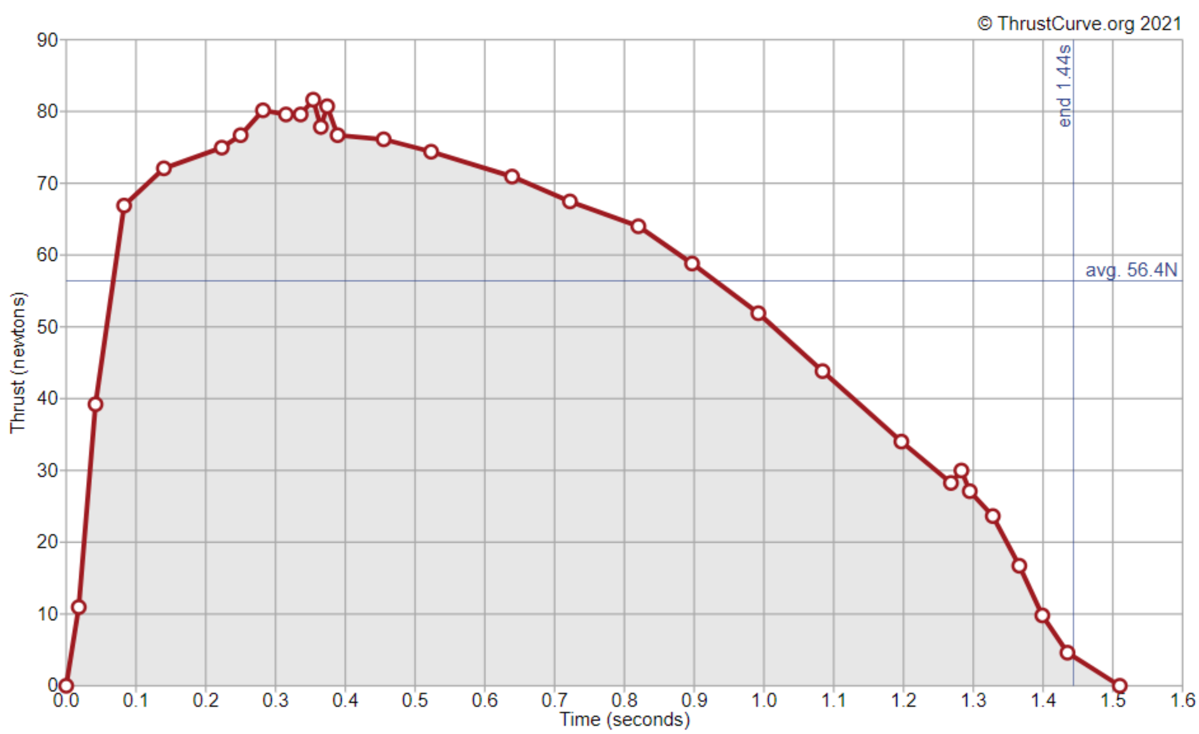
(Fig 11: Fin 3 Geometry)

3.4 ROCKET MOTOR

An AeroTech G54 motor with 14 seconds ejection charge delay is selected to power the rocket. This motor was selected for being a relatively budget-friendly 'G' series motor, while also being powerful enough to meet the altitude requirements. Its properties are as follows:

Total impulse:	81.1 Ns (1% G)
Avg. thrust:	56.3 N
Max. thrust:	81.6 N
Burn time:	1.44 s
Launch mass:	136 g
Empty mass:	90.5 g
Data points:	30

(Fig 12:Rocket Motor Specifications)



(Fig 13: Thrust curve of G54)

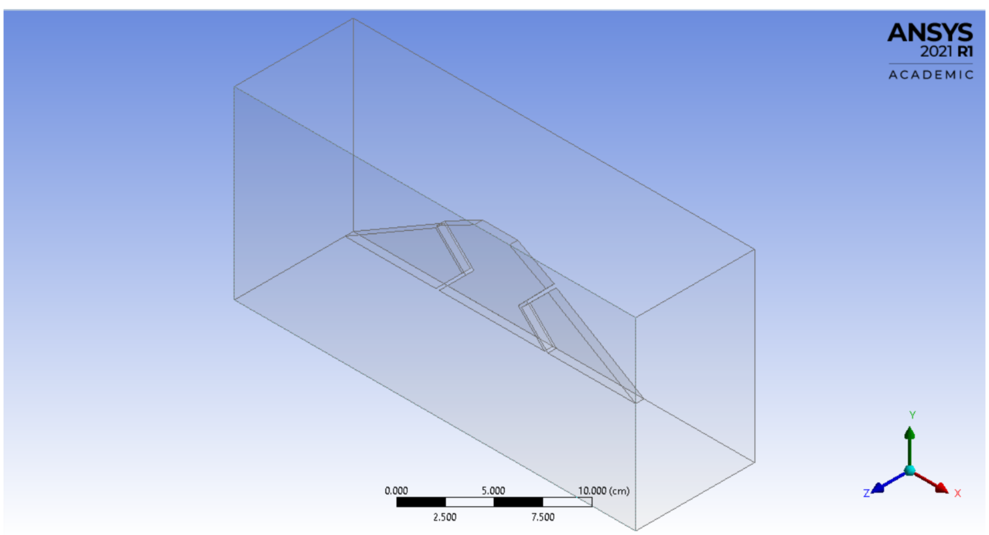
4. CFD ANALYSIS OF THE MODEL FIN

Computational Fluid Dynamics (CFD) is the analysis of fluid flows using numerical solution methods. Using CFD, you are able to analyze complex problems involving fluid-fluid, fluid-solid or fluid-gas interaction. Engineering fields where CFD analyses are frequently used are for example aerodynamics and hydrodynamics.

Fluid dynamics is involved with physical laws in the form of partial differential equations. Sophisticated CFD solvers transform these laws into algebraical equations and are able to efficiently solve these equations numerically.

4.1 3D MODEL GEOMETRY

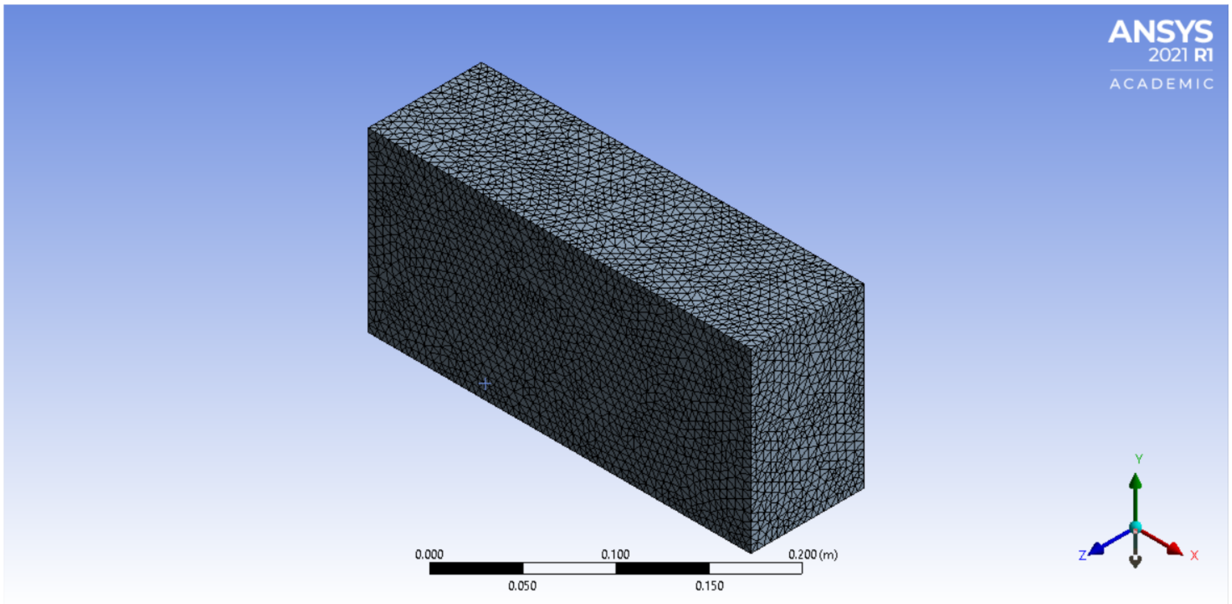
The 3D model of the rocket fin is built using CAD. The base length of the fin is 21.04 cm and the thickness is 0.3 cm. The fin is confined inside an enclosure, in such a way that the lateral edges of the fin are 4 cm away from the boundary of the enclosure.



(Fig 14: CAD Model)

4.2 MESH GENERATION

In order to analyze fluid flow, flow domains are split into smaller sub domains. The governing equations are then discretized and solved inside each of these sub domains. Here the fin as well as the enclosure is meshed, which is shown in the below figure. The software meshed the model into 114900 elements.



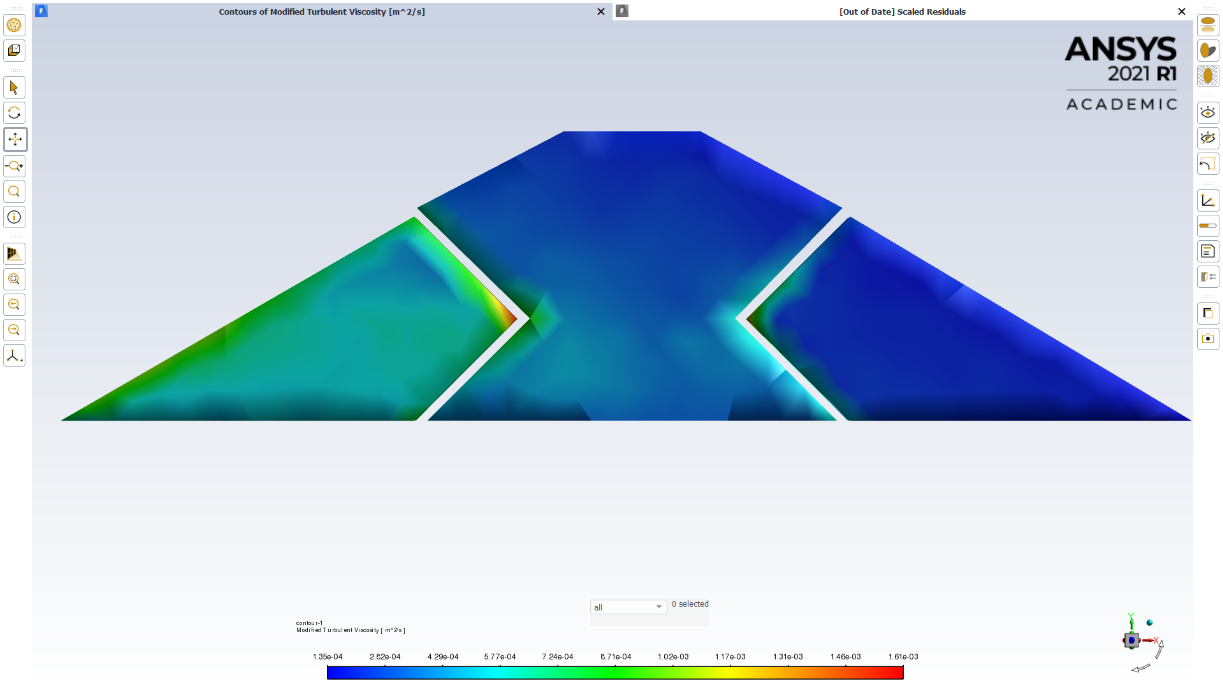
(Fig 15: Meshed Model)

4.3 INPUTS AND BOUNDARY CONDITIONS

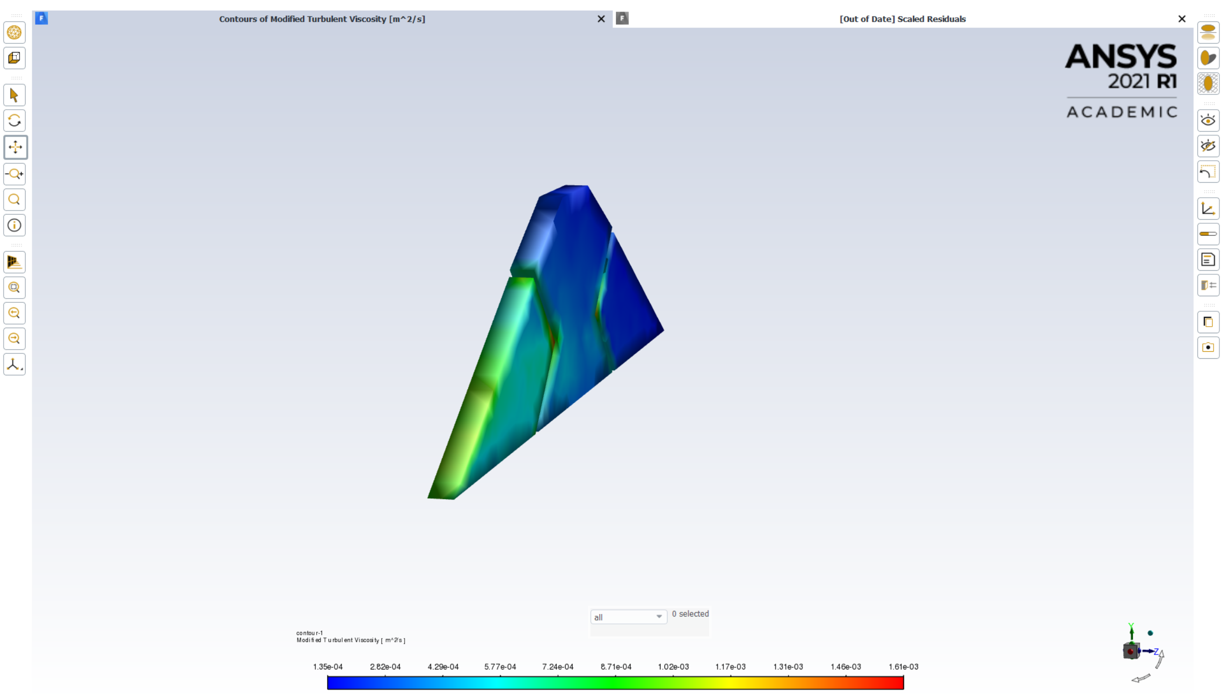
No	Input	Value
1	Velocity of flow	0.33 Mach or 112 ms^{-1}
2	Operating temperature	300 K
3	Operating pressure	101325 Pa
4	Density of fluid	1.225 Kgm^{-3}
5	Length	21.04 cm
6	Fluid	Air as an ideal

4.4 CONTOURS OF TURBULENCE OVER THE ROCKET FIN

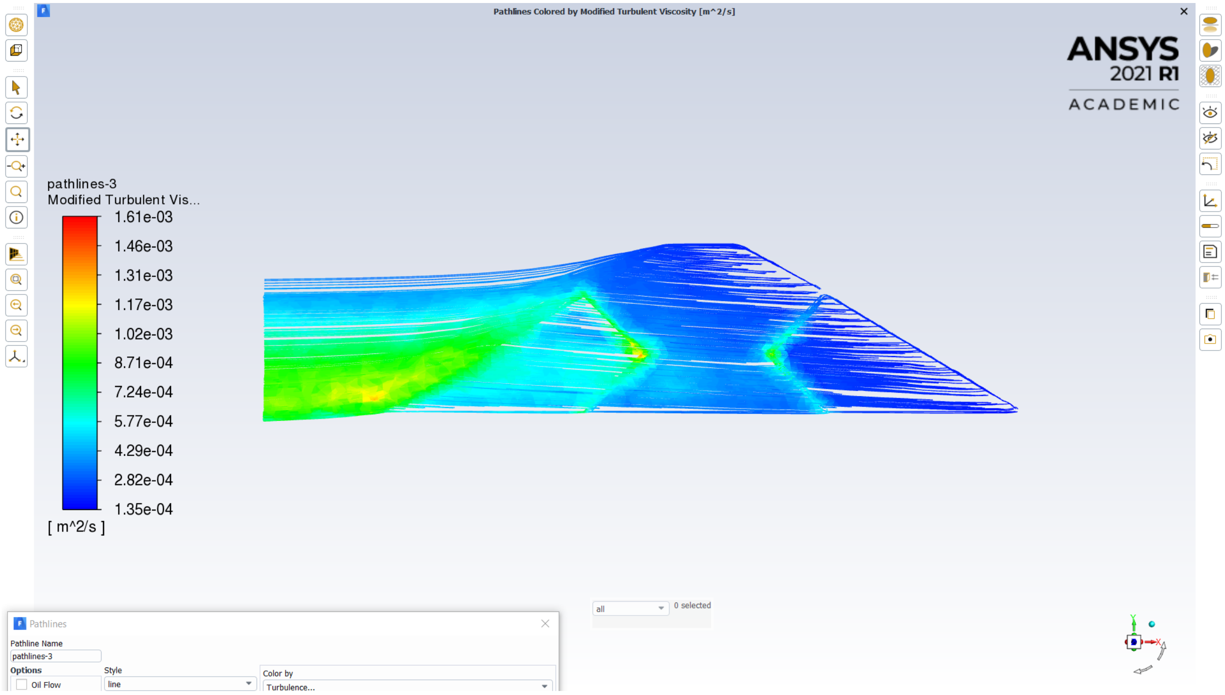
The turbulence or turbulent flow is fluid motion characterized by chaotic changes in pressure and flow velocity.



(Fig 16: Contour 1)



(Fig 17: Contour 2)



(Fig 18: Pathline Contour)

4.5 INFERENCE

Concerning the gaps between the rocket fins will produce drag, CFD analysis was made on the rocket fins.

Based on the CFD analysis of the flow over rocket fins we can infer that the turbulence caused between the gaps is not significantly high to cause instability of the rocket.

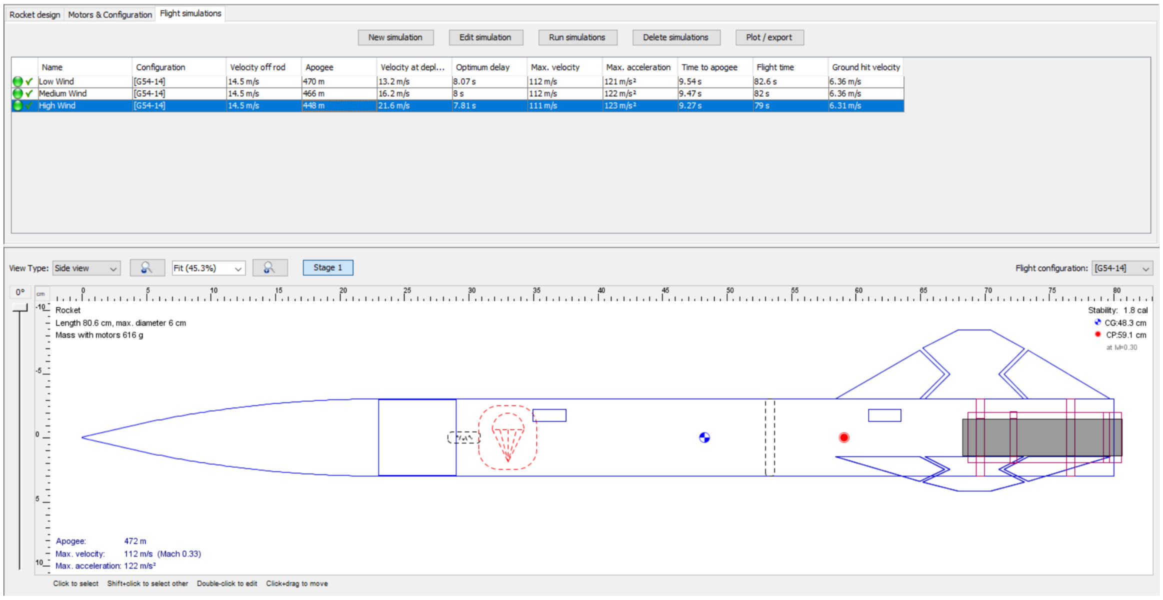
FLIGHT SIMULATION

OpenRocket simulator is a java-based rocket simulator software. You can simulate a designed rocket by specifying simulation parameters like launch conditions (wind, atmospheric conditions, launch site, etc.) and simulation options (time step, geodetic calculations, etc.). As a result, it plots various graphs which you can study and analyze. The graphs include Velocity Motion vs Time, Total Motion vs Time, Roll Characteristics, Stability vs Time, Flight Side Profile, etc. You can export analysis data to CSV files. The good thing is that it lets you add multiple simulations with different configurations for a rocket and execute and simulate them one by one.

The rocket is simulated under three different weather conditions. They are as follows:

1. Low Wind (wind velocity of about 2 ms^{-1})
2. Medium Wind (wind velocity of about 4 ms^{-1})
3. High Wind (wind velocity of about 8 ms^{-1})

It is observed that the rocket reaches apogee at above 448 meters for all three wind conditions. For further interpretations, the Medium wind velocity simulation is used.

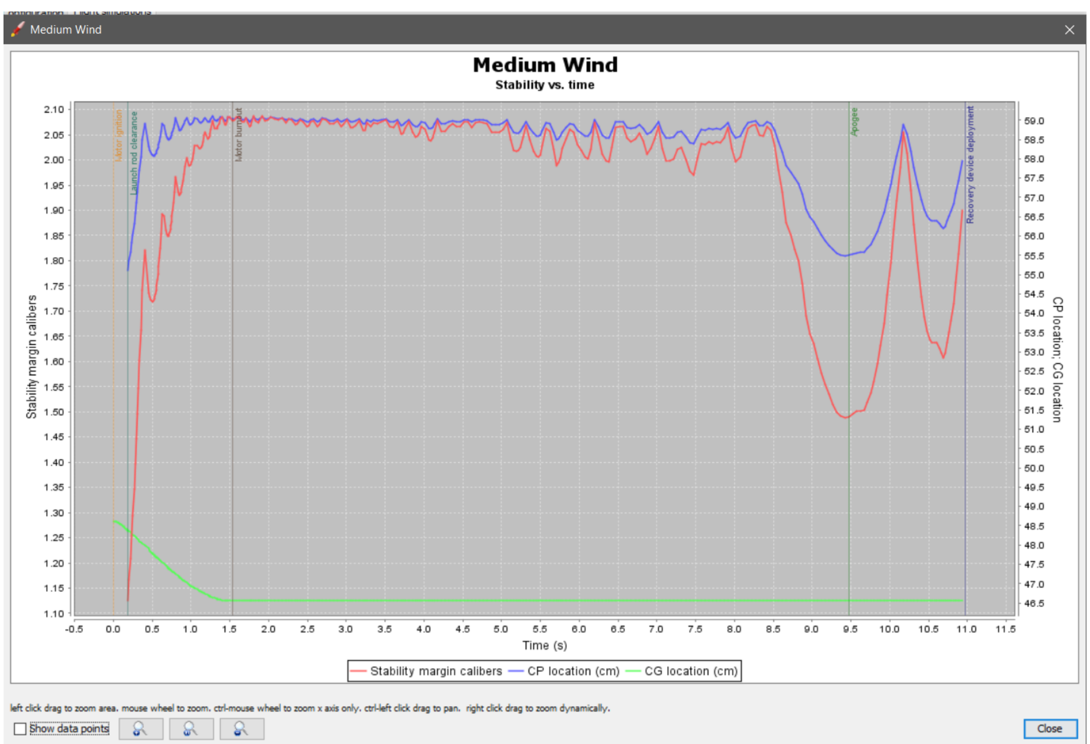


(Fig 19: Rocket Simulations)

5.1 STABILITY VS TIME

Here, the fig. plots the stability of the rocket as it flies. From this graph, the following inferences can be made:

- The stability margin starts at about after the motor burn out, here the rocket is stable until 9, implying that the rocket is stable most of the time.
- The center of gravity moves up with time, which is expected because the motor's weight decreases as it burns.



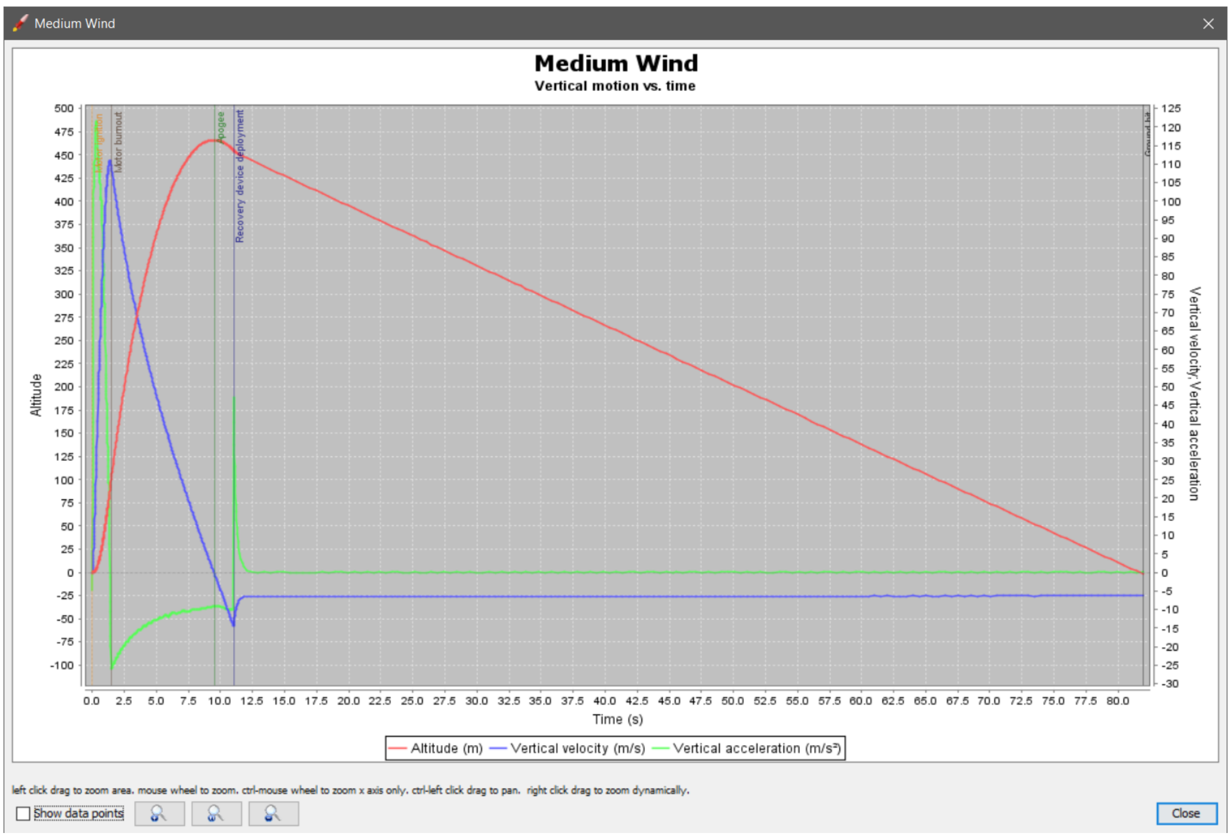
(Fig 20: Stability vs Time Plot)

5.2 VERTICAL MOTION VS TIME

Here, fig. plots the altitude, velocity, and acceleration of the rocket throughout its flight. From this graph, the following inferences can be made:

- The maximum altitude reached by the rocket is 466 meters.
- It takes the rocket 9.47 seconds to reach apogee.
- The Velocity of the rocket as it leaves the launch rod is 14.5 ms^{-1}.
- The Velocity of the rocket at the time of parachute deployment is 16.2 ms^{-1}.
- The rocket hits the ground with a velocity of 6.36 ms^{-1}.
- The maximum acceleration experienced by the rocket is 122 ms^{-2}.
- The total flight time comes out to 82 seconds.

The negative acceleration is due to reduced net acceleration as the motor burns.

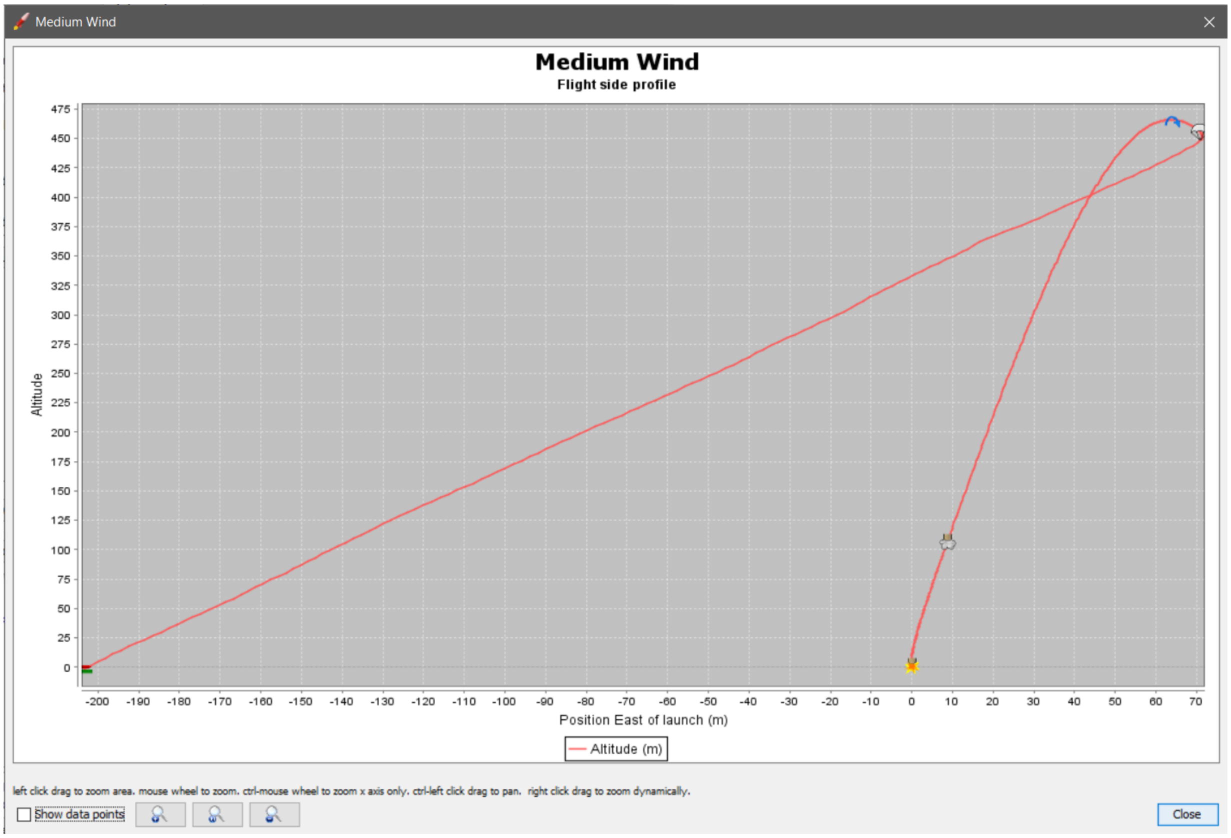


(Fig 21: Vertical Motion vs Time Plot)

5.3 FLIGHT SIDE PROFILE

Here, the fig. depicts the downrange position of the rocket with time. The following inferences can be made from this graph:

- The rocket can be retrieved about 200 meters downrange from the launch location.
- The rocket initially drifts to the west, but finally ends up falling in the east.



(Fig 22: Flight Side Profile)

5. CONCLUSION

Through this project, we can conclude that the model rocket design is nearly stable and can be used for an experimental purpose to reach an approximate altitude of 472 metres.

6. FUTURE ENHANCEMENT

The next logical step after designing and simulating a rocket would be to fabricate one in real life and try launching it. But these are a few of the features which can be taken into consideration:

- Simulating a 3D model with more accurate details
- Could modify the rocket to carry a payload.
- Alternative simulators: These could take into account for example the curvature of the Earth and include the Coriolis effect and various others.
- Further UI enhancement: These could include for example a 3D view of the rocket, an animation of the rocket flight.
- Could include various other components to achieve a better result/ data
- Rocket with multiple stages could be built.
- Modifying the present could help us to have a heavier payload

7. LINKS

- OpenRocket : Openrocket
- ANSYS Fluent : ANSYS
- Rocket Model: github.com/A-Shankar-mahadevan/Model-Rocket
- Rocket Motor: AeroTech G54 motor
- Rocket Fins: 3D Comet

8. REFERENCE

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- Model Rockets - NASA
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