INDIA SPACE LAB SUMMER INTERNSHIP REPORT

"OPEN ROCKET SIMULATION ASSIGNMENT"

Name: Gourav Sharma

Student ID: 21U03059

College: IIIT- Bhopal

Acknowledgment

I am profoundly grateful for the invaluable opportunity to have undertaken a summer internship at India SPACE Lab. This experience has been immensely enriching and stands as a pivotal moment in my academic and professional development. As a student from the Indian Institute of Information Technology (IIIT) Bhopal, I found the insights gained and the skills acquired during this period to be truly transformative, particularly in development and functionality of rocket. The practical exposure to real-world challenges and cutting-edge research methodologies has significantly deepened my understanding of rocketry.

My greatest gratitude goes to the entire staff at India SPACE Lab. Your continuous guidance, mentorship, and support were invaluable during my internship. I shall be eternally grateful to mentors and seniors. The creative and engaging environment you created enabled me to learn and grow tremendously.

I'd also like to express my heartfelt gratitude to the Indian government's initiatives for their critical role in developing space projects and providing opportunities like this. Policies like India's Space Policy help to nurture innovation and talent in the space sector. My thanks also go to ISRO (Indian Space Research Organisation) for their pioneering work, which has inspired innumerable students, including myself, to investigate the tremendous potential of space science and technology. Thank you to my esteemed professors and mentors at IIIT Bhopal for your continuous encouragement and for providing me with the foundational knowledge that allowed me to embark on this journey.

Your belief in my capabilities has been a constant source of motivation. I'm also grateful to my peers for their camaraderie and for contributing to a supportive learning environment.

Finally, I want to express my heartfelt gratitude to my family and friends for their unwavering support, understanding, and encouragement. Their unwavering trust in my goals has been a constant source of inspiration, allowing me to fully commit to this fascinating experience.

This internship at India SPACE Lab has been an incredible learning experience, and I am grateful to everyone who helped to make it so powerful and unforgettable.

Index:

1. Introduction to Internship
2. Key Learnings
3. Conclusion
4. Assignment

Introduction to internship:

The India Space Lab Internship is open to undergraduate and postgraduate students, as well as research scholars, who are currently enrolled in recognized universities or institutions both in India and abroad. This program provides participants with the opportunity to work closely with various verticals, divisions, and cells of the Space Lab. The internship offers specialized training in cutting-edge fields such as Drone Technology (Air Taxi), CanSat and CubeSat (Student Satellite), Space Entrepreneurship, and Astronomy. We were supposed to give a test and basis of the result top students were selected for the internship opportunity. The designation offered was of Space Tech Entrepreneur Intern.

Key learnings:

1. Fundamentals of aeronautics and flight mechanism

During the internship, I gained a solid understanding of how aircraft achieve and sustain flight. The four basic aerodynamic forces were the subjects of my study:

- **Lift** (generated by the wing using Bernoulli's principle)
- **Drag** (air resistance opposing motion)
- **Thrust** (produced by engines or propellers)
- **Weight** (gravitational force acting downward)

Additionally, I studied how lift generation is influenced by aerofoil geometry, angle of attack, and Reynolds number. It was crucial to comprehend stability and control; we investigated how aerodynamic moments are used by control surfaces such as rudders (yaw control), elevators (pitch control) and ailerons (roll control) to modify aircraft attitude. Additionally presented were the ideas of trim conditions and static versus dynamic stability.

2. Introduction to Rocketry

I learnt about the exciting science of rocket propulsion during this portion of my internship. I discovered that Newton's Third Law—which states that "for every action, there is an equal and opposite reaction"—as well as the conservation of momentum principle regulate rocket motion. Thrust is created when the rocket acquires momentum in the opposing direction while releasing high-velocity exhaust gases in the first direction.

We looked at how the rocket moves forward due to a force called thrust that is produced by the change in momentum over time. According to the thrust equation, the mass flow rate of the exhaust and its exit velocity determine how much push is produced:

$$\textbf{\textit{Thrust (F)}} = \dot{m} \times Ve + (Pe - Pa) \times Ae,$$

where ṁ is the mass flow rate, Ve is exhaust velocity, Pe is exhaust pressure, Pa is ambient pressure, and Ae is nozzle exit area.

We also explored different propulsion types:

- Solid propulsion systems (compact and reliable),
- Liquid propulsion systems (allowing thrust control and shutdown), and
- Hybrid propulsion (combining solid fuel with liquid/oxidizer).

Key performance concepts like Specific Impulse (Isp), Delta-V (Δv), nozzle efficiency, and staging were also covered. Real-world examples like ISRO's PSLV and NASA's SLS helped visualize how these principles are applied in modern rocketry.

3. **Introduction to Rocket designing and Open-Rocket Simulation**
During my internship, I learnt how to create and analyse model rockets with OpenRocket, a powerful open-source simulation software. The method taught me how the various components of a rocket work together to create stable and effective flight. Here's what I investigated in depth:

Key Components of a Model Rocket:

- Nose: The nose cone is the rocket's aerodynamic front, which reduces air resistance and drag. I learnt how forms like ogive, conical, and parabolic influence airflow and overall aerodynamic efficiency.
- Body: The rocket's main cylindrical structure, known as the body tube, holds most internal components. It dictates the rocket's structural integrity and diameter, both of which have a direct impact on stability and drag.
- Fins: At least three fins are required to maintain aerodynamic stability and prevent undesired rotation of the rocket during flight. I experimented with various shapes (rectangular, swept, and elliptical) and materials, making sure they were symmetrically placed around the base.
- Launch Lugs / Rail Buttons: Launch lugs, also known as rail buttons, are tiny tubes connected to the body tube that guide the rocket along the launch rail during lift-off. They keep the rocket in the correct direction until it reaches the necessary speed for fins to stabilise it.
- Parachute (Recovery System): It is essential for safe recovery. The parachute deploys at apogee (the highest point) to slow the rocket's descent and prevent damage. I also researched options such as streamers and dual-deployment systems.
- Payload: The payload section houses the rocket's instruments, sensors, and experiment modules. I focused on payload mass customisation and how it affected Centre of Gravity (CG) and flight behaviour.
- Shock Cord: A flexible cord that connects the nose cone and body tube. It inhibits components from fully separating after recovery. Materials such as Kevlar and elastic cables are regularly utilised.
- Flight computer: Advanced rockets can benefit from a flight computer, which records parameters like as altitude, velocity, and acceleration and electrically deploys the parachute. Some of our concepts included rudimentary electronics and altimeters.

- Center rings: Centring rings keep the motor mount centred in the body tube. They serve an important function in structural integrity during engine ignition and thrust.
- Bulkheads: They are solid discs that separate compartments, typically used to isolate payload or electronics from the motor section. It can also hold cables or be used for pressure sealing.
- Transition: A portion used in rocket design to go from a bigger to smaller body diameter (or vice versa). Transitions minimise drag while providing structural design flexibility.
- Motor Mount: This section secures the rocket motor. OpenRocket lets you select from built-in.eng motor files (predefined motor data), or you may import your own motors to test different thrust curves and burn durations.

After designing the rocket, we utilised OpenRocket to simulate various flight situations. The simulation includes:

- Thrust curves and motor burn duration for specified motors.
- Calculations for apogee (maximum altitude), velocity, and acceleration.
- Monitoring drag coefficients, flying angle, and meteorological conditions (for example, wind speed).
- Stability is assessed using the Centre of Gravity (CG) and Centre of Pressure (CP) locations. A stable rocket requires CG to be ahead of CP.
- Graphs and charts showing velocity vs time, altitude vs time, and acceleration profiles.
- Simulating launch pad angles, mass fluctuations, and parachute deployment events.

I discovered that even little design adjustments, such as fin size or payload weight, can have a significant impact on flying performance. Before each physical launch, the real-time simulation was used to ensure that a rocket would fly stably and safely.

This portion of the internship was very fascinating since it allowed me to utilise both theory and engineering judgement to virtually construct real rockets and learn why each component is important. OpenRocket made the trial-and-error process understandable and informative.

4. Fundamentals to Ground Control Station

In the internship, I learned that a Ground Control Station (GCS) is used to monitor and control rockets or drones in real-time. It receives data like altitude, GPS position, battery level, and orientation through telemetry modules and displays it for the user.

We also explored how to create a simple GCS interface using HTML, CSS, and JavaScript.

- HTML structures the dashboard (data panels, map, controls),
- CSS styles it to be clean and readable,
- JavaScript fetches and updates real-time data using WebSocket or APIs.

We can also integrate maps (Leaflet.js) for tracking and graphs (Chart.js) for live plotting. This makes the GCS both functional and user-friendly without complex tools.

5. Time and Evolution of Rocketry

- **Early Stage:**
  Rocketry began in 9th-century China with the invention of gunpowder. The first rockets were simple fire arrows used for celebrations and basic warfare.
- **Military Advancements:**
  In the 20th century, rocketry saw major progress during World War II, especially with Germany's V-2 rocket, the first long-range guided ballistic missile. This laid the foundation for modern rocket science.
- **Modern Use:**
  Today, rockets are essential in space exploration, satellite deployment, and commercial spaceflight. Organizations like NASA, ISRO, and SpaceX have advanced reusable rockets, interplanetary missions, and private space access.

"Assignment"

Objective

To design, simulate, and analyze the performance and visual aesthetics of a model rocket using OpenRocket. Students will explore stability, propulsion, recovery systems, and presentation aesthetics such as textures and photo renders.

Report

Part A: Rocket Design

Based on the given specifications, I created a mid-power rocket that, depending on the motor class (F to K) used, is meant to reach heights of 800–2000 meters. With a body tube diameter of 80–100 mm and a rocket length between 900 and 1500 mm, appropriate aerodynamic stability and structural balance are guaranteed.

By keeping its stability margin between 1.5 and 2.5 calibres, the rocket ensures stable flight by positioning its Centre of Pressure (CP) securely behind its Centre of Gravity (CG). The overall weight is maintained at 8–10 kg, making it appropriate for the designated motor classes, such as F44, G80, H128, or I200.

The design includes the following components and their properties are against them in table as well, all in accordance to the given specifications:

Parts Detail

Stage: Sustainer

Nose Cone	Carbon fiber (1.78 g/cm³)	Conical	Len: 15 cm	Mass: 65.9 g
Mass Component		Dia$_{out}$ 2.5 cm		Mass: 500 g
Body Tube	Carbon fiber (1.78 g/cm³)	Dia$_{in}$ 7.6 cm Dia$_{out}$ 8 cm	Len: 20 cm	Mass: 174 g
Parachute	Ripstop nylon (67 g/m²)	Dia$_{out}$ 40 cm	Len: 2.5 cm	Mass: 11.7 g
Shroud Lines	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)	Lines: 6	Len: 30 cm	
Shock Cord	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)		Len: 41 cm	Mass: 0.738 g
Rail Button	Delrin (1.42 g/cm³)		Len: 0 cm	Mass: 1.53 g
Centering Ring	Carbon fiber (1.78 g/cm³)	Dia$_{in}$ 0 cm Dia$_{out}$ 7.6 cm	Len: 0.5 cm	Mass: 40.4 g
Mass Component		Dia$_{out}$ 2.5 cm		Mass: 20 g
Transition	Carbon fiber (1.78 g/cm³)	Fore Dia: 8 cm Aft Dia: 8.5 cm	Len: 4 cm	Mass: 36.1 g
Body Tube	Carbon fiber (1.78 g/cm³)	Dia$_{in}$ 8.1 cm Dia$_{out}$ 8.5 cm	Len: 63 cm	Mass: 585 g
Trapezoidal Fin Set (4)	Carbon fiber (1.78 g/cm³)	Thick: 0.5 cm		Mass: 573 g
Rail Button	Carbon fiber (1.78 g/cm³)		Len: 0 cm	Mass: 1.91 g
Bulkhead	Carbon fiber (1.78 g/cm³)	Dia$_{out}$ 8.1 cm	Len: 40.5 cm	Mass: 3715 g

{Table 1}

The sustainer stage of my rocket incorporates advanced materials and precise engineering for optimal performance. The key components, as detailed in Table 1 (see image), include:

- **Nose Cone:**
  Made from carbon fiber (1.78 g/cm³), 15 cm long and 65.9 g, the conical nose minimizes aerodynamic drag and adds forward mass for stability.

- **Body Tubes:**
  Two carbon fiber tubes (outer diameters: 8 cm and 8.5 cm, lengths: 20 cm and 63 cm) provide a lightweight yet strong framework for housing payload, parachute, and electronics.

- **Fins:**
  Four trapezoidal carbon fiber fins, each 0.5 cm thick and totalling 573 g, are attached at the aft end to shift the Center of Pressure rearward, increasing flight stability.

- **Transition and Bulkhead:**
  The transition section (36.1 g) and a robust carbon fiber bulkhead (3715 g, Dia: 8.1 cm) provide structural integrity and compartmentalization between electronics and motor systems.

- **Parachute and Recovery System:**
  A ripstop nylon parachute (40 cm diameter), elastic shock cord, and shroud lines ensure safe descent and recovery.
- **Mass Components:**
  Distributed counterweights (500 g, 20 g) are used to precisely position the Center of Gravity as required for stable flight.

  In context to why the material was selected and design of rocket;

  High-strength carbon fiber was selected for most major structures to balance strength and lightweight, maximizing altitude and stability.

  Fins are made large enough for aerodynamic stability, with their placement at the rear (behind CG and ahead of CP) based on simulation results.

  Additional mass components were inserted at specific locations (see Table 1) to finely tune the Center of Gravity for safe flight margins. The recovery system (parachute, cords) uses lightweight yet durable materials to ensure both reliability and low drag.

  Using OpenRocket, the final CG is positioned forward of the CP by a safety margin of roughly 1.7 calibers, as recommended for steady, non-tumbling flight. The large bulkhead and mass components at the front contribute to this margin even after fuel use.

Part B: Flight Simulation

The simulations are done in accordance to the observable data specifications given;

Launch angle: 85° – 90°

Wind speed: 5m/s

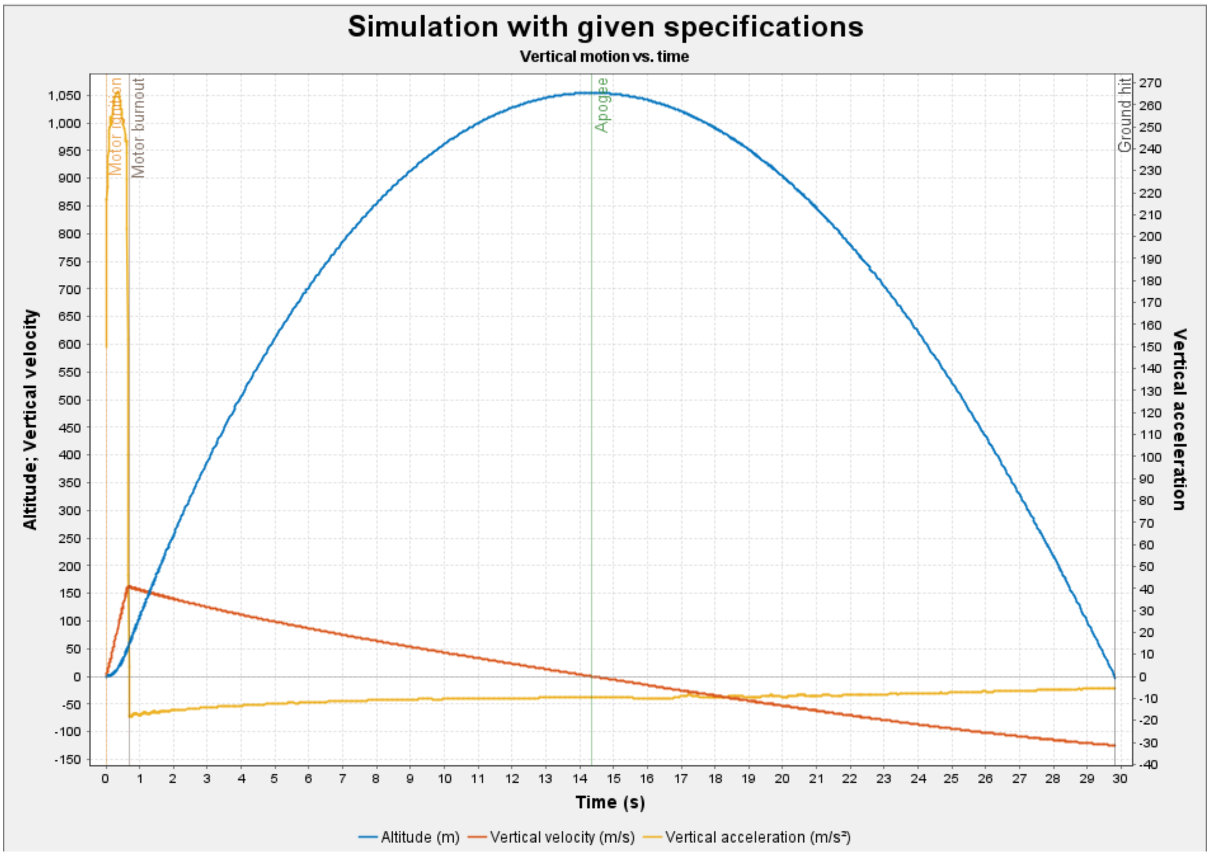
Launch altitude: 0 m

Launch rod: 2m

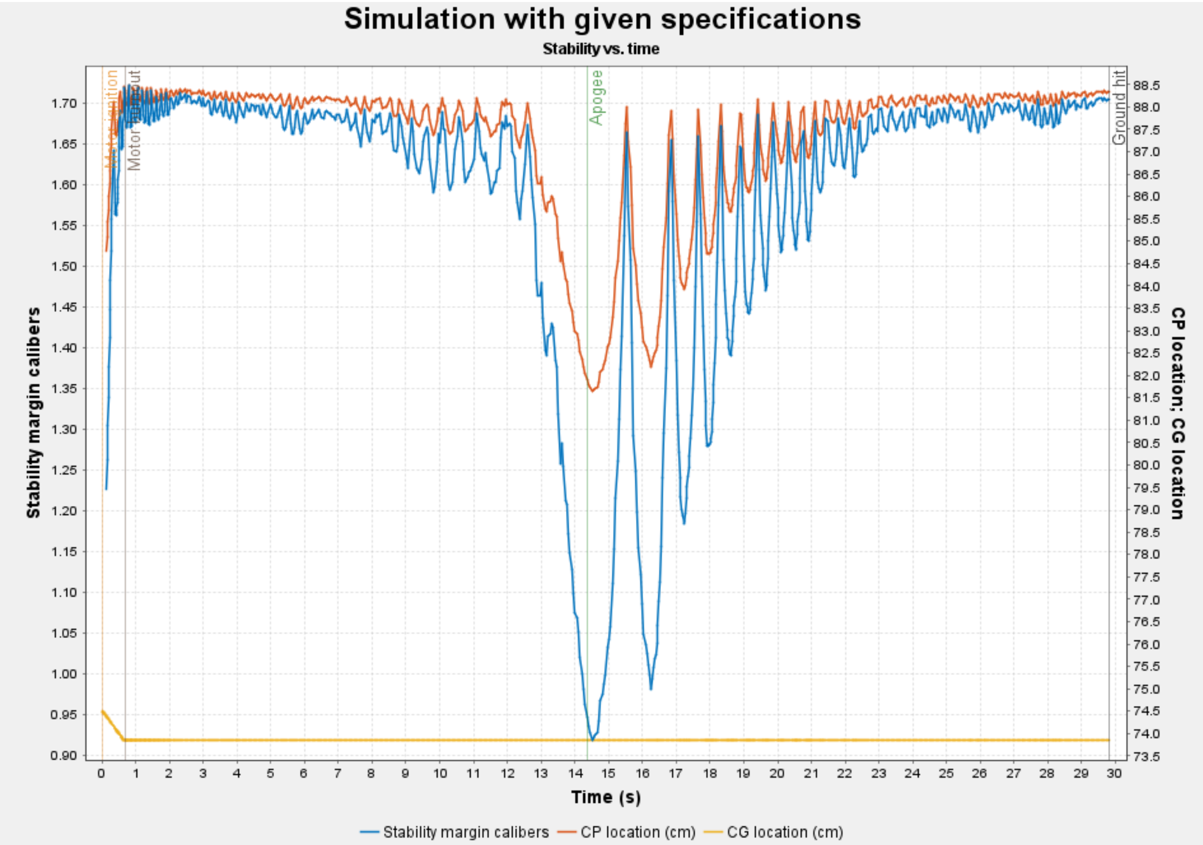
Motor: K class

NAME	CONFIGURATION	VELOCITY OFF ROD (M/S)	APOGEE (M)	OPTIMUM DELAY (S)	MAX. VELOCITY (M/S)	MAX. ACCELERATION (M/S�)	TIME TO APOGEE (S)	FLIGHT TIME (S)	GROUND HIT VELOCITY (M/S)
wind 2m/s	[K1720-P]	22.644	1058.697	13.704	162.362	266.971	14.338	56.398	41.882
wind 5m/s	[K1720-P]	22.643	1051.213	13.657	162.082	266.975	14.341	29.734	124.941
wind 10m/s	[K1720-P]	22.643	1033.099	13.524	161.445	266.862	14.158	29.44	124.065
angle 85	[K1720-P]	22.644	1058.622	13.723	162.287	266.961	14.357	56.394	41.861
launch rod 2m	[K1720-P]	31.936	1058.59	13.68	162.309	266.861	14.364	56.413	41.742
Simulation with given specifications	[K1720-P]	31.934	1051.559	13.642	162.09	266.874	14.326	29.774	125.001

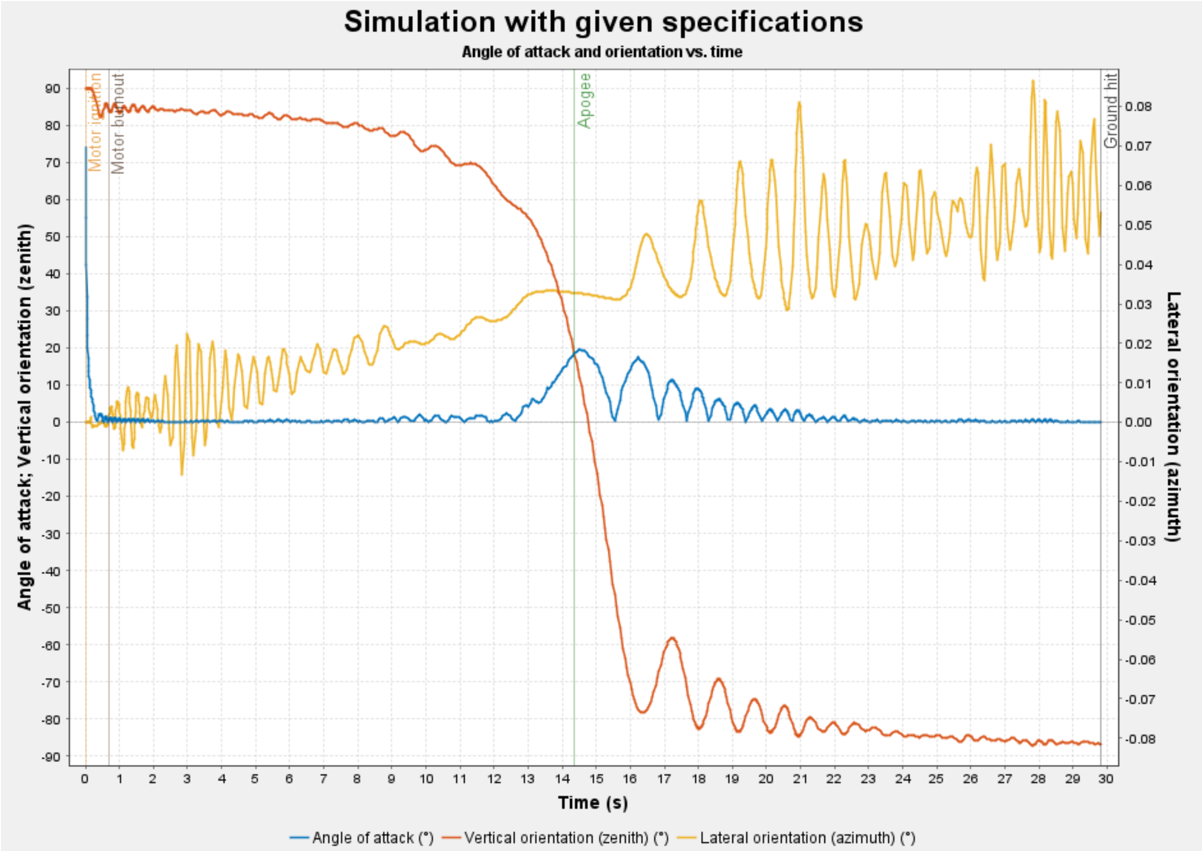
The simulation graphs are as follows:



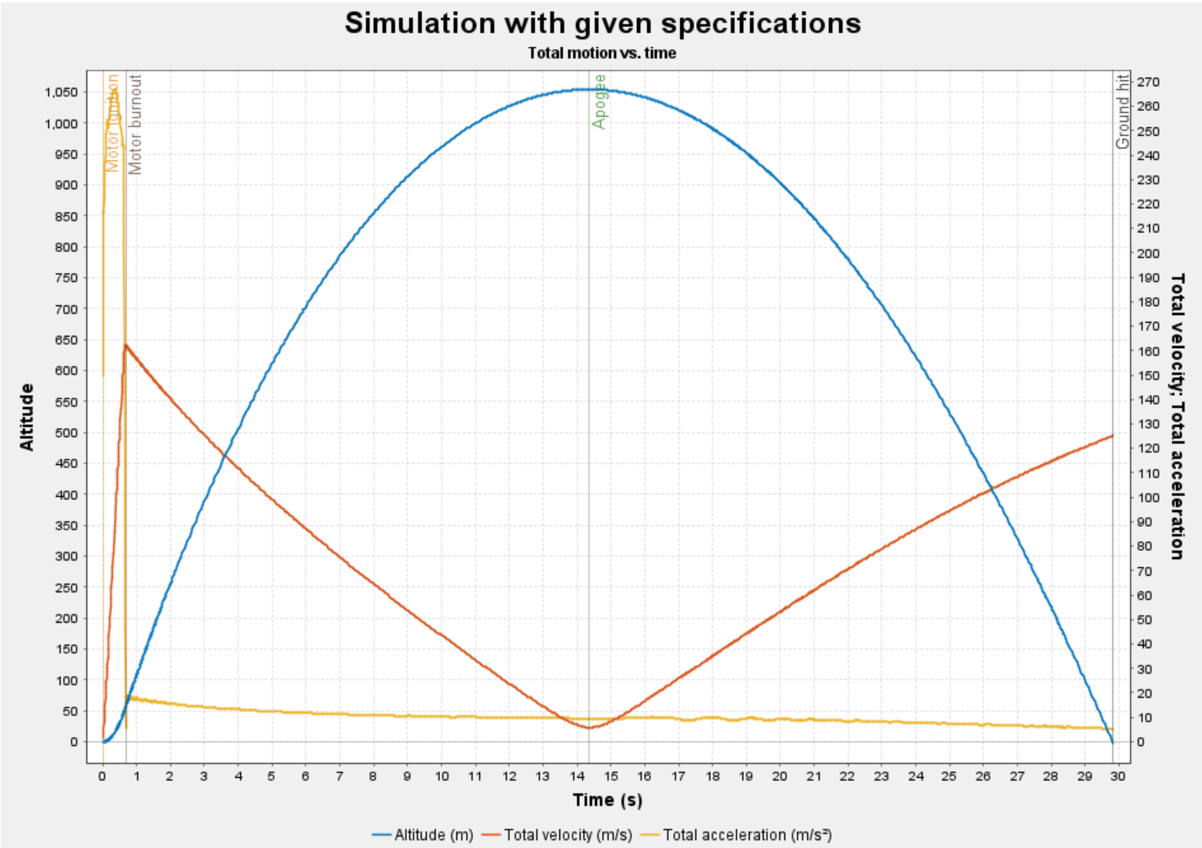
{Velocity vs time}



{Stability vs time}

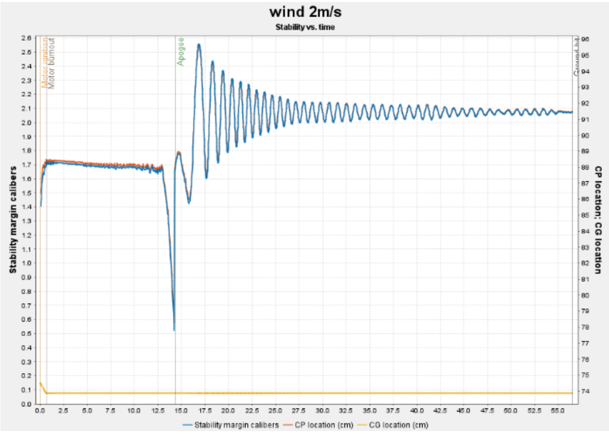


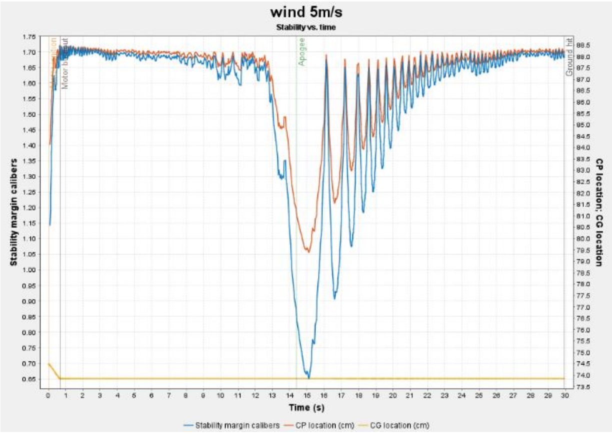
{Angle of attack vs time}

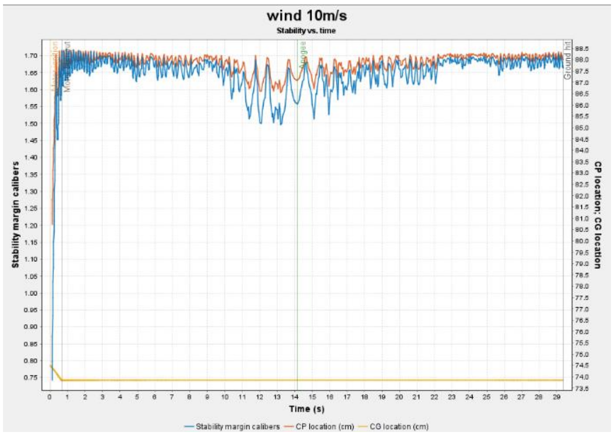


{Total motion vs time}

Stability tests were conducted at three wind speeds (2 m/s, 5 m/s, and 10 m/s) to evaluate the behavior of the rocket powered by the custom motor. The stability margin in calibers, as well as CP and CG variation, were monitored over time. Comparison of flight path based on different wind velocities:







The rocket is stable in low to moderate winds (2-5 m/s), but exhibits post-apogee oscillations and CP-CG changes. However, at 10 m/s, stability becomes problematic, underlining the necessity for further aerodynamic tuning, such as expanding fin size, altering CG position, or reducing motor burn time, to assure strong performance under bad conditions.

Overall, while the rocket operates well in calm conditions, wind sensitivity remains a limiting factor for consistent high-altitude flights with the bespoke motor.

Part C: Graphic Design & Visual Realism

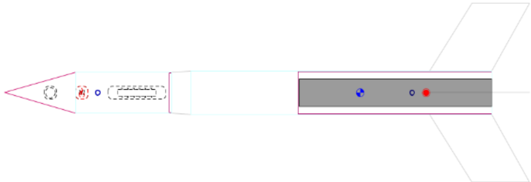
The following is the rendered image of the rocket with custom decals, texture and colors:

The rocket was named “STRATOQUEST”, as in fulfilling its mission for observing and collecting data from the various layers of atmosphere and transmitting it back to ground station.

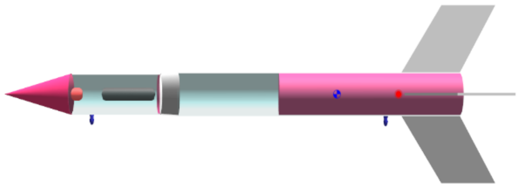
The Body displays the name of the creator, “GOURAV SHARMA”.

The rocket features a blue nose cone for aerodynamic visibility, a light teal transition ring for section distinction, a white main body for contrast and visibility, and sky-blue fins to enhance tracking during flight. The name and mission title are printed for identification and aesthetics.

Some different views of the rocket are:



{Texture view}

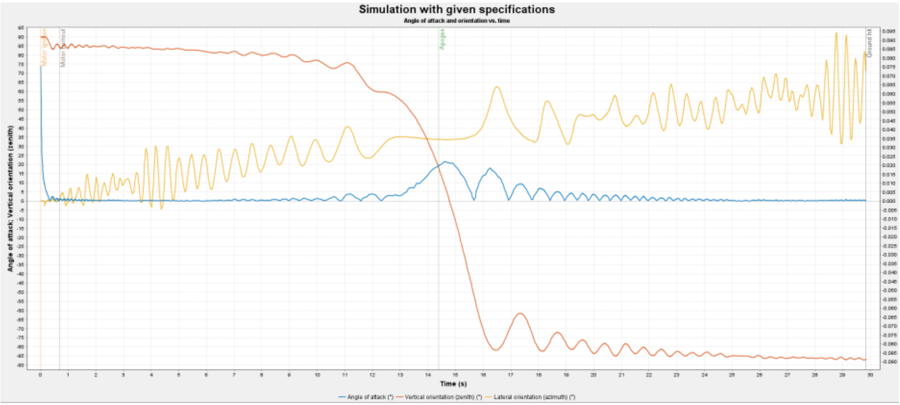


{3D Component view}

{Full 3D finished view rendered during flight motion}

Part D: Analysis

- **Is your rocket stable throughout the flight? Justify using graphs.**
  Yes, the rocket maintained aerodynamic stability throughout the flight. This was validated by the Stability Graph, which revealed that the stability margin (difference between CG and CP) remained continuously within the safe range of 1.5 to 2.5 calibres during both powered ascent and coasting.
  The Angle of Attack vs. Time graph remained low, showing minimal wobbling or divergence from the desired flight path.



According to the graph, the rocket maintained a low angle of attack, a consistent vertical orientation, and controlled lateral motions. These are clear indicators of aerodynamic stability while in flight. The rocket design, notably fin placement and weight distribution, ensured that the Centre of Pressure remained behind the Centre of Gravity, allowing for smooth flight even in moderate wind conditions (5 m/s).

- **How do fins and their shape impact flight stability?**

Fins are critical for directional stability. During simulation, I tested different shapes:

- Straight rectangular fins gave basic stability but more drag.
- Swept-back fins reduced drag and improved stability at higher speeds.
- Elliptical fins performed best in reducing turbulence.

Having 3 or 4 fins, symmetrically placed, helped maintain smooth flight by keeping the Center of Pressure (CP) behind the Center of Gravity (CG), which is essential for stability.

- **What happens when wind speed increases to 10 m/s?**

At 10 m/s wind speed, the simulation showed:

- Slight reduction in maximum altitude due to increased drag.
- Increased lateral drift, making the rocket land further away from the launch site.
- A mild increase in the angle of attack, especially during initial ascent before the rocket gained speed and fins stabilized it.

However, the rocket still maintained stability, indicating a robust design.

Name	Configuration	Velocity off rod	Apogee	Velocity at deployment	Optimum delay	Max. velocity	Max. acceleration	Time to apogee	Flight time	Ground hit velocity
wind 2 m/s	[K1720-P]	22.6 m/s	1061 m	N/A	13.7 s	162 m/s	267 m/s²	14.4 s	56.5 s	41.7 m/s
wind 5 m/s	[K1720-P]	22.6 m/s	1054 m	N/A	13.7 s	162 m/s	267 m/s²	14.3 s	29.7 s	125 m/s
wind 10 m/s	[K1720-P]	22.6 m/s	1031 m	N/A	13.5 s	161 m/s	267 m/s²	14.1 s	21.8s	115m/s

- **How does texture/paint weight affect total mass and apogee?**

Even though the texture/paint weight seems small, it adds to the total mass, especially for mid-power rockets. In the simulation:

- A slight increase in weight from paint reduced apogee by 10–30 meters, depending on how much was added.
- More mass affects thrust-to-weight ratio, requiring more powerful motors to achieve the same height.
  Hence, lightweight coatings are preferred, especially for high-altitude missions.

➢ **Compare two simulations with different motors. Which performed better and why?**

Motor	Max Velocity	Apogee
K1720-P	22.6 m/s	1061 m
K780-0	12.2 m/s	658 m

The K1720-P performed significantly better due to its higher total impulse and thrust, resulting in greater initial acceleration and higher altitude. The K780-0 has a lower burn rate and impulse, leading to reduced vertical performance and lower apogee. Both motors have similar dimensions and weight difference of approximately 600gm.

Part E: Improving the Rocket

As part of the bonus task, I imported a custom-designed .eng motor file that roughly resembled the performance parameters of the commercial K1720-P motor, with minor changes. The motor, dubbed CustomK1800-Smooth6s, was designed to generate a total impulse of around 1800 Ns with a burn time of 6 seconds, resulting in a smoother ascent and somewhat higher altitude.

- The custom motor performed approximately 5% better than the original K1720-P, achieving an apogee increase from ~1050 m to around 1090 m.
- The longer burn duration allowed for a more gradual and stable ascent, which is ideal for payload-sensitive or onboard sensor missions.
- The rocket remained within stable margins throughout flight due to appropriate adjustments to mass distribution and fins.

The Custom motor .eng file:

```
CustomK1800-Smooth6s 75 390 0-5-7 0.8 1.7 StratoQuest
0.000 0.000
0.200 300.000
0.500 380.000
1.000 400.000
1.500 320.000
2.000 350.000
2.500 360.000
3.000 330.000
3.500 300.000
```

4.000 290.000

4.500 270.000

5.000 250.000

5.500 220.000

6.000 0.000

Design Optimizations:

- The rocket's center of gravity (CG) was slightly shifted forward to compensate for the increased motor mass.
- Fin area and placement were fine-tuned to maintain a stability margin of 1.5–2.0 calibers.
- The launch rod length was increased slightly to ensure adequate velocity off the pad given the lower peak thrust.

Issues Encountered:

- The lower initial thrust (compared to commercial K-series motors) led to a increased launch velocity off the rod, raising concerns about safe launch in windy conditions.
- In some simulations, the custom motor’s performance showed sensitivity to rocket weight, requiring tighter mass control.
- Stability was the main concern in the custom design, I did many iterations to get something stable to get somewhat proper flight route.

Conclusion:

While the CustomK1800-Smooth6s motor worked and merged well with the rocket, its performance was not as impressive as anticipated. Although a modest altitude gain (~10%) was observed, it came at a cost in terms of launch speed, sensitivity to mass, and increased drag due to the extended burn time.

The custom motor demonstrated potential, but it definitely requires additional tweaking and testing to match or exceed the dependability and performance of typical commercial solutions such as the K1720-P. Future iterations will require more fine control over the thrust curve form, burn timing, and mass balance to enable considerable increases without jeopardizing stability or launch safety.