NAKUJA PROJECT
DESIGN.MAKE.LAUNCH

KENYA SPACE AGENCY
Possibilities beyond our skies

N-3.5 Launch report

15th July 2024

Summary

The Nakuja project team, consisting of 5 JKUAT faculty members, 24 students from Jomo Kenyatta University of Agriculture and Technology (JKUAT), and two students from Kenyatta University (KU), jointly launched the new high-power model rocket called the N-3.5 rocket on 8th May 2024, facilitated by the Kenya Space Agency (KSA). The launch site was arranged at Isiolo by the Kenya Space Agency (KSA) courtesy of KDF.
The team launched three rockets and collected the data. The significant achievement was to reach the apogee beyond 1,000 meters.

Background

The Nakuja project is a research and development group at Jomo Kenyatta University of Agriculture and Technology (JKUAT) that aims to develop a rocket to bring nanosatellites into the Earth's orbit. The team has developed and launched several high-power model rockets so far. The N-3 rocket that was launched last had several issues, such as the solid rocket motor and the airframe structure. The N-3.5 rocket was an improved version of the N-3 rocket that aimed to reach the same apogee as the N-3 rocket, 1,600 meters.

Rocket specification

The specifications of the N-3.5 rocket are shown in Table 1.

Table 1. List of specifications

Rocket	**N-3.5 (Alpha, Beta, Charlie, Delta)**
Airframe material	Aluminum
Length	1.72 m

Rocket	**N-3.5 (Alpha, Beta, Charlie, Delta)**
Internal diameter	76 mm
External diameter	78.6 mm
Dry mass	6.7 kg
Total mass	8.7 kg
Simulated apogee	1,650 m
Propellant	KNSB
Simulated total impulse	2,976 [N•s] (L1305 motor)
Total impulse from the static test	2,773 [N•s]

Figure 1. N-3.5 rocket installed at the launch pad

Rocket sub-components

Flight computer and avionics bay

Flight computers use the ESP32 microcontroller as the processor. Various sensors, such as the accelerometer, gyroscope, barometer, and GPS, are used. A LiPo battery is used for the power supply.

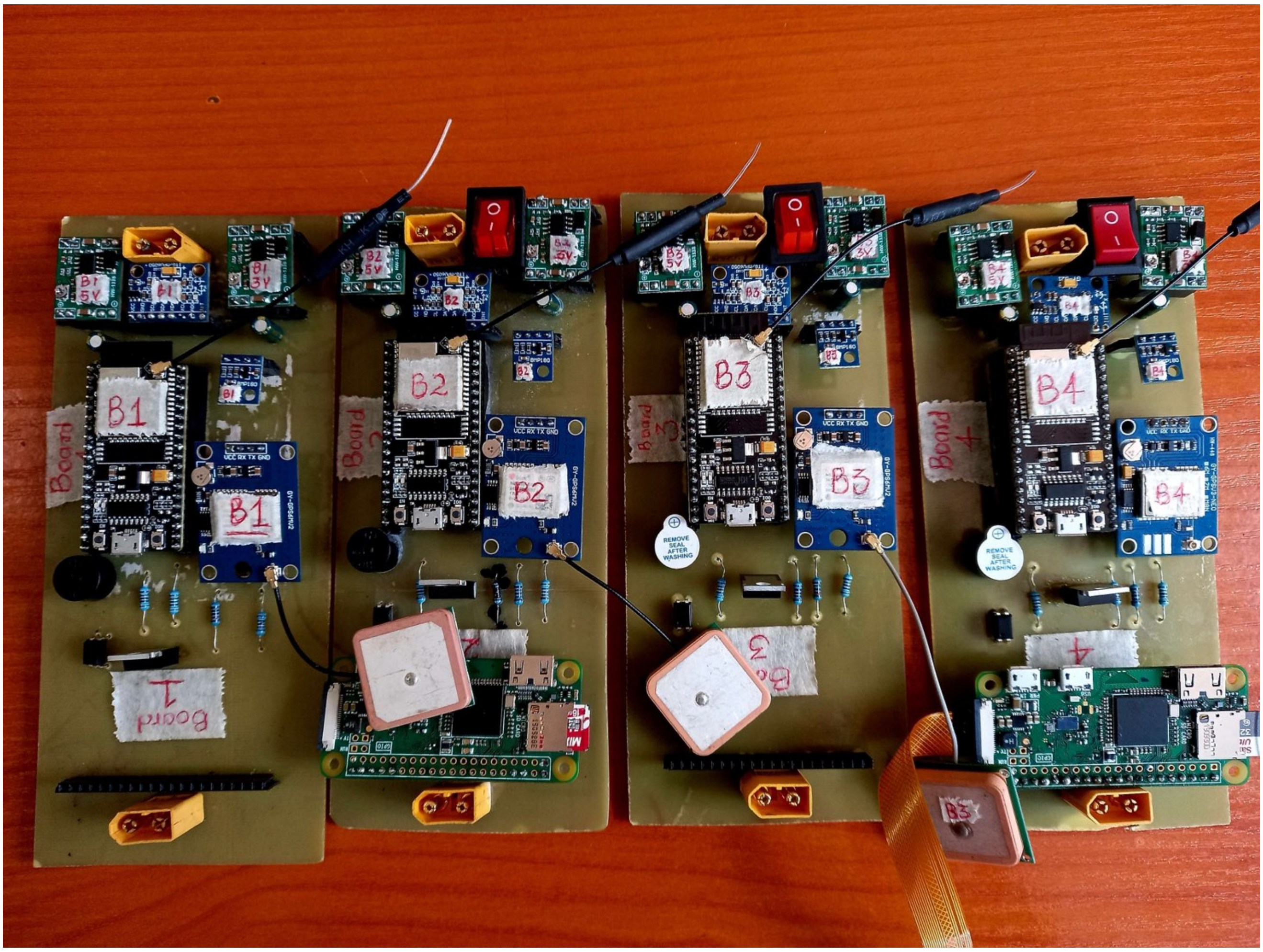

Figure 2. Flight computer PCB

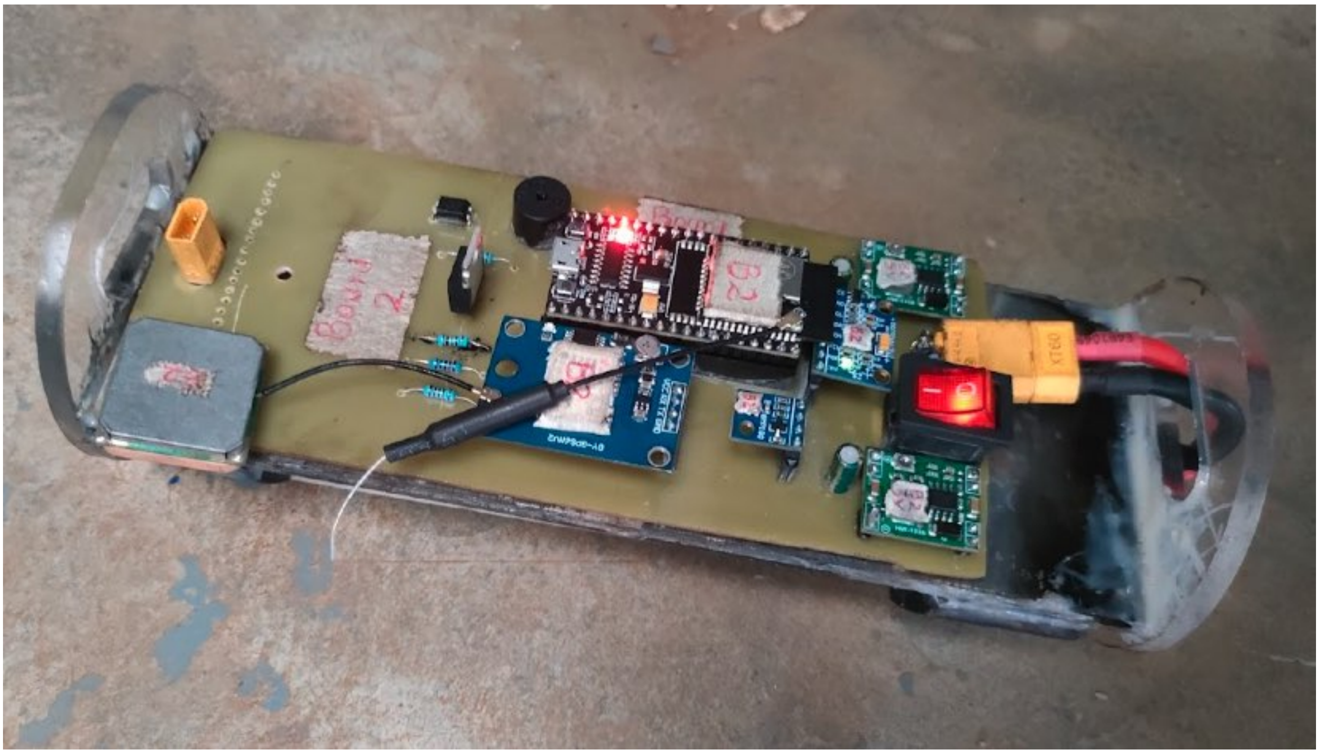

Figure 3. Flight computer PCB installed on avionics bay

A state machine is implemented on the flight computer software to detect the apogee and trigger the parachute ejection. The transition of the state machine was confirmed through flight testing using a DJI Matrice M300/M350 drone.

Figure 4. Flight computer testing using Drone

A web-based dashboard application was developed to monitor the rocket's state in flight. The application displays the rocket's information, such as a 3D visualization of its orientation, location from GPS, altitude, velocity, acceleration, and state machine's state.

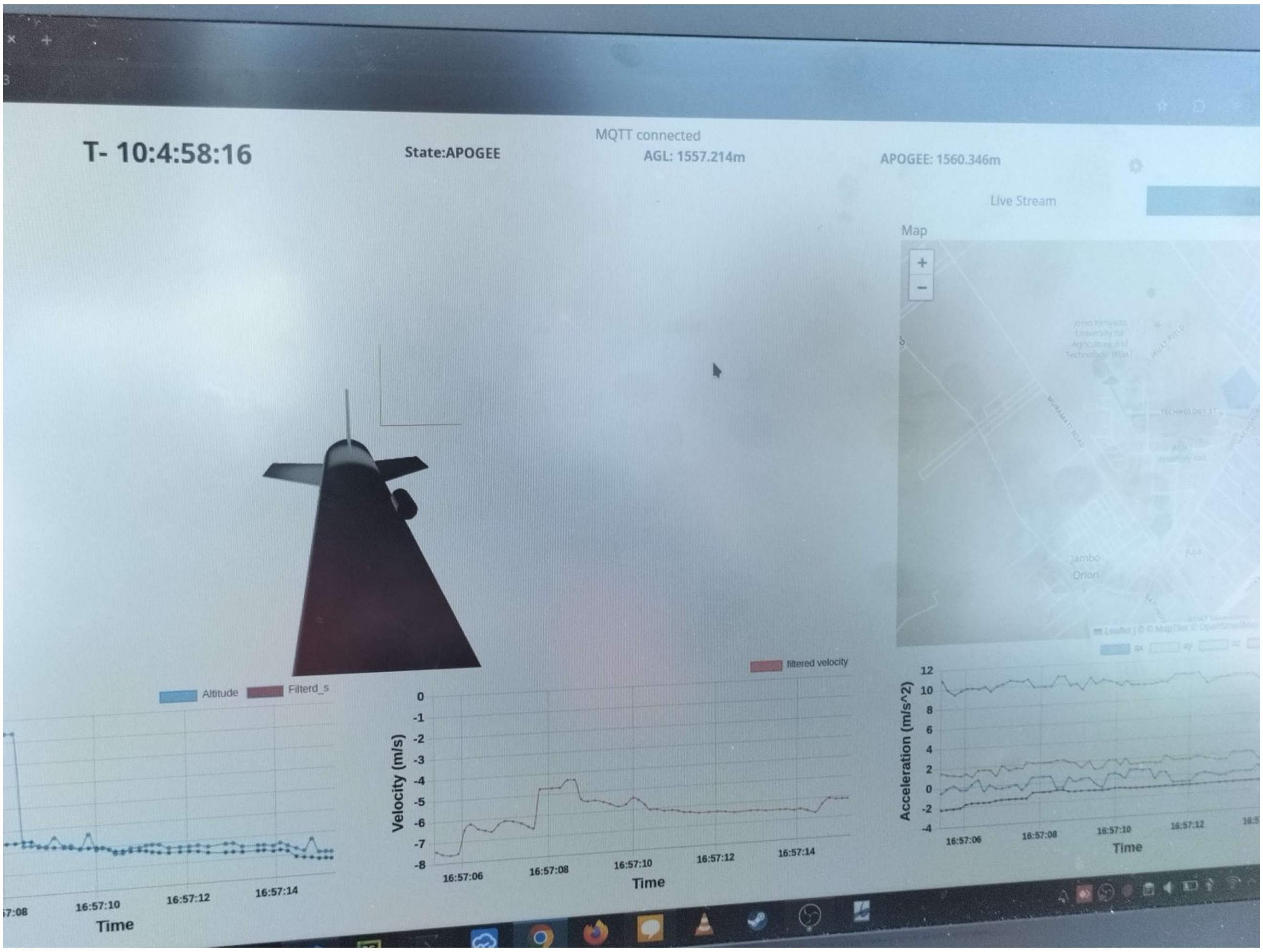

Figure 5. Web-based application for the base station

Parachute ejection mechanism

The N-3.5 rocket uses the pyrotechnic parachute ejection mechanism as the N-3 rocket. The PVC cylinder has a crimson powder ignited to generate high-pressure gas that pushes the piston forward.

Figure 6. Parachute ejection mechanism

The parachute ejection mechanism was tested through the pop test. The amount of the crimson powder necessary to push the piston was identified as 17 grams.

Figure 7. Pop test

Solid rocket motor

The solid rocket motor is a KNSB propellant, which uses sorbitol and potassium nitrate as fuel and oxidizer, respectively. The casted grains are shown in Figure 8. Four grains are installed in a single rocket motor casing.

Figure 8. KNSB grains

The designed parameters from the OpenMotor software are shown in Figure 9.

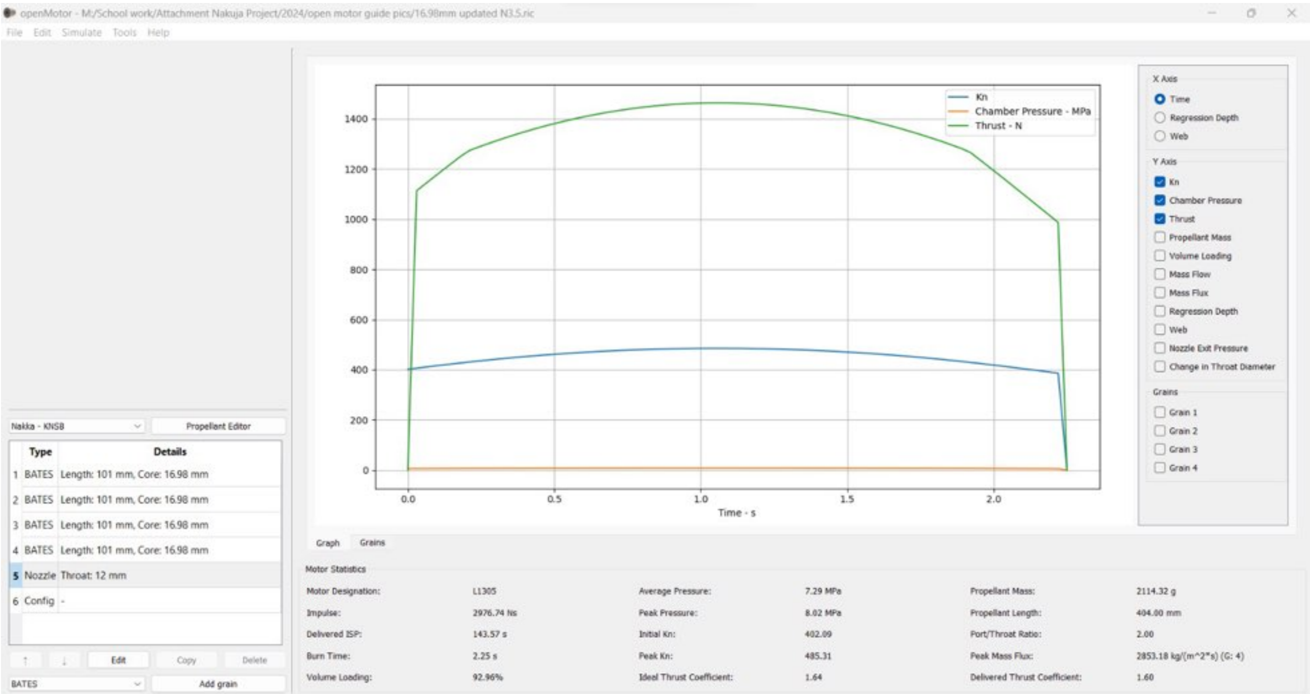

Figure 9. Designed parameters of grains using OpenMotor

The summary of the static tests is shown in Table 2.

Table 2. Summary of static test

No.	Date	Remark	Video
1	9/02/2024	Motor was intact as the steel bolt worked. However, the test stand was damaged (plastic support and cantilever)	https://youtu.be/DbxF1Cq-gdQ
2	23/02/2024	Success	https://youtu.be/Flo1cixbKFA
3	21/03/2024	CATO	https://youtu.be/8IasJ8upjbU
4	21/03/2024	Casing burst (thin wall thickness)	https://youtu.be/kngmGEmYRNg

No.	Date	Remark	Video
5	12/04/2024	83% of theoretical total impulse. Airframe also withstood.	https://youtu.be/5G2vEjkUCaA
6	25/04/2024	Outsourced casing had to have 2.5mm thickness, but the thinnest thickness turned to be 1.7mm. It worked without burst.	https://youtu.be/if4z0yCCtAo

Figure 10. Static test on 25th April 2024

Figure 11 plots the two successful static tests carried out on April 12th and 25th, 2024. The static test on April 25th confirmed a total impulse of 2,773 N•s, which is 93% of the designed performance.

Figure 11. Thrust curve obtained from the static test

The total impulses of the solid rocket motor are summarized in Table 3.

Table 3. Solid rocket motor performance from static test

Motor type	**Total impulse [N•s]**	**Peak thrust [N]**
Designed value from simulation	2,977	1,450
Static test on 12th April 2024	2,482	4,000
Static test on 25th April 2024	2,773	3,092

Figures 12 and 13 show images of the solid rocket motor's casing, nozzle, and bulkhead.

Figure 12. Nozzle and bulkhead

Figure 13. Solid rocket motor assembly

Airframe

The body tubes were made from rolled and riveted aluminum sheets, as shown in Figure 14.

Figure 14. Body tubes

The solid rocket motor is fastened to the airframe using the bolts, as shown in Figure 15.

Figure 15. Assembly of airframe and solid rocket motor

The fins have tapered swept shapes and are made from aluminum sheets, as shown in Figure 16. The four fins are attached to each rocket.

Figure 16. Lower part of the airframe with fins attached

The final values for the total rocket mass are shown in Table 4.

Table 4. List of total mass

Rocket	**Mass (kg)**
Alpha	9.935
Beta	10.382
Charlie	9.914
Delta	8.747

Improvement from N-3 rocket

The N-3.5 rocket sorted out the issues raised after the launch of the N-3 rocket.

1. **Replacement of the inappropriate bolts**
   During the launch of the N-3 rocket, the shear force cut all eight bolts, fastening the solid rocket motor with the airframe. This was due to the abrupt replacement of the steel bolt with the silicon bronze bolt, which has way lower strength, especially in a high-temperature environment. The bolts were replaced with the proper steel bolts, and the function was confirmed through the static tests.

Figure 17. Silicon bronze bolts that were cut by shear force (from previous N-3 launch)

Figure 18. Catastrophic failure caused by the bolts (from previous N-3 launch)

2. **Enhanced fastening of solid rocket motor to airframe**
   The airframe of the N-3 rocket did not have sufficient strength as it was torn by the thrust generated by the solid rocket motor. The team conducted material testing and ensured the strength where the solid rocket motor was joined with the airframe.

Figure 19. N-3 rocket airframe torn by the thrust (from previous N-3 launch)

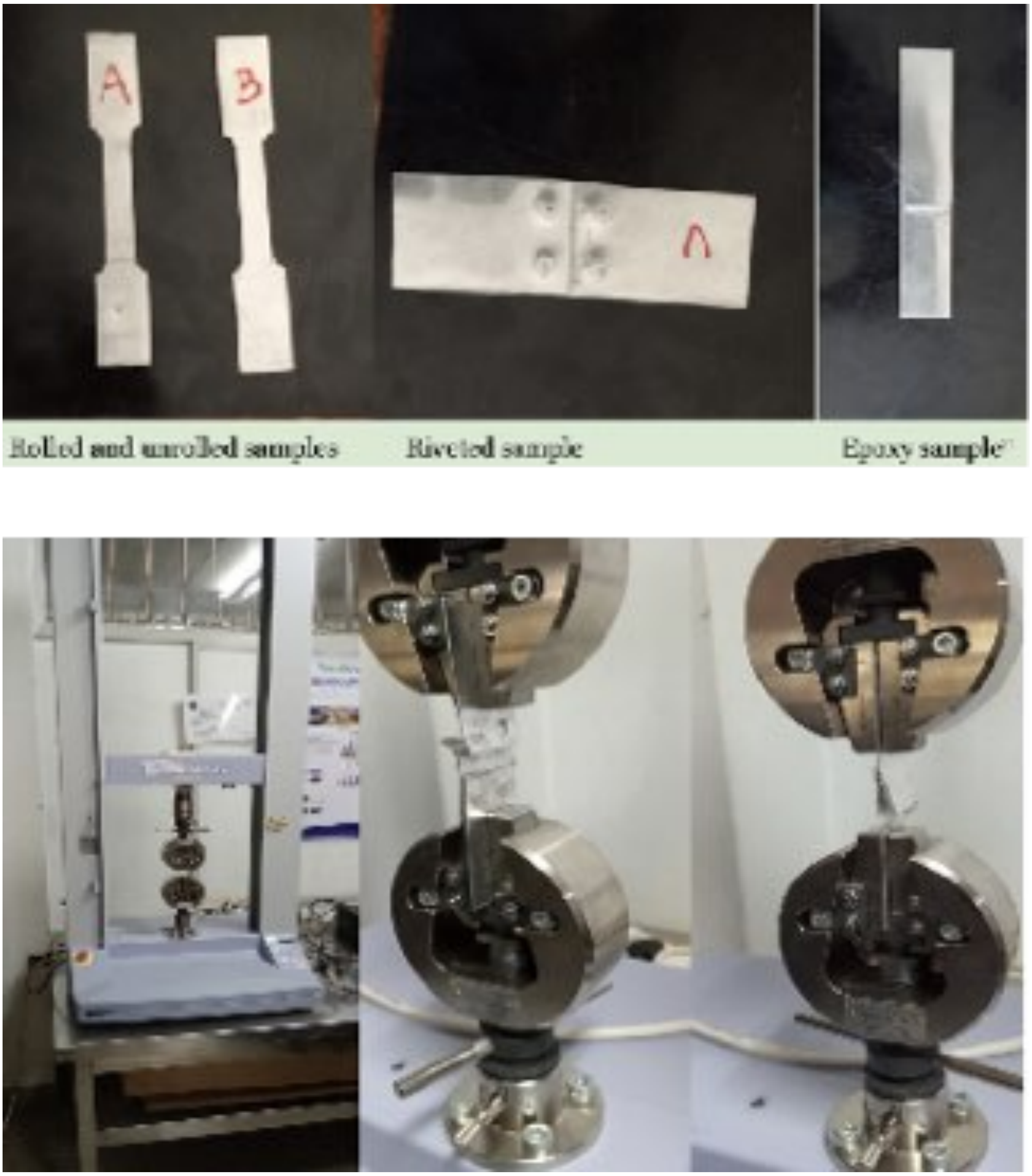

Figure 20. Tensile test conducted to evaluate the material strength

Launch procedure

Safety distance and launchpad location

The high-power rocketry safety code prepared by the National Association of Rocketry (NAR) in the USA defines the minimum personnel distance for the L-class solid rocket motor as 300 feet (91 meters). The launch area diameter was determined as 800 meters, considering one-half of the target apogee.

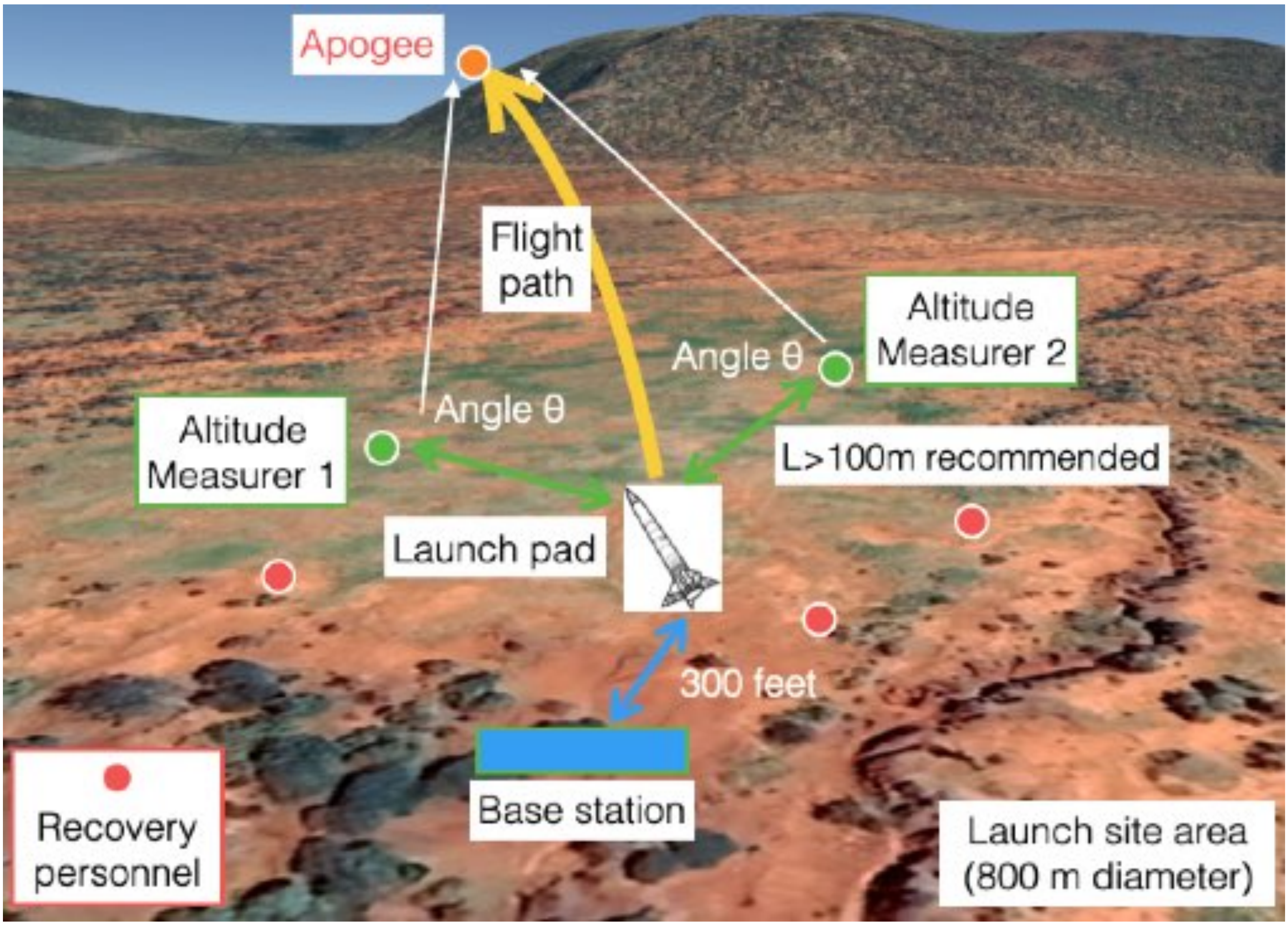

Figure 21. Launch pad setup

Timeline

The timeline for the launch is shown in Table 5.

Table 5. Launch events timeline

Time	Event
10:50	Arrival at the launch site
11:00	Above airspace closed
11:54	Launch of the 1st rocket
12:53	Launch of the 2nd rocket
13:37	Launch of the 3rd rocket
13:50	Airspace surrendered and reopened

Post analysis

Flight path analysis

Among the three rockets (Beta, Delta, and Charlie), the Delta rocket was the only one that could fly vertically straight. The Beta and Charlie rockets were diverted horizontally due to weathercocking.

Figure 22. Flight path of Beta rocket

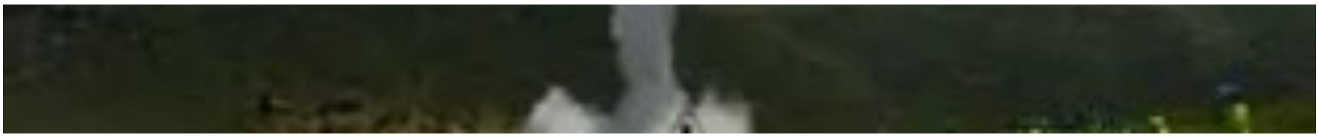

Figure 23. Flight path of Delta rocket

Figure 24. Flight path of Charlie rocket

Below are close-ups of the initial orientations. The images show that the weathercocking starts immediately after the launch.

The reasons for the weathercocking may be multilateral. In general, too much stability and strong wind would have caused weathercocking. From the mass measurement, the successful Delta rocket was found to be the lightest, whereas the rest had much higher mass. This means the three rockets had different positions in the Center of Gravity. Some team members also reported that the failed Beta and Charlie rockets had **misalignment between the upper and lower parts of the rocket airframe**.

To avoid weathercocking, the **measurement of the Center of Gravity and Center of Pressure** must be conducted to check the final value of the static stability. In addition, the weather must be carefully observed, and the rocket must be launched while the wind is calm.

Figure 25. Orientation of Beta rocket after launch

Figure 26. Orientation of Delta rocket after the launch

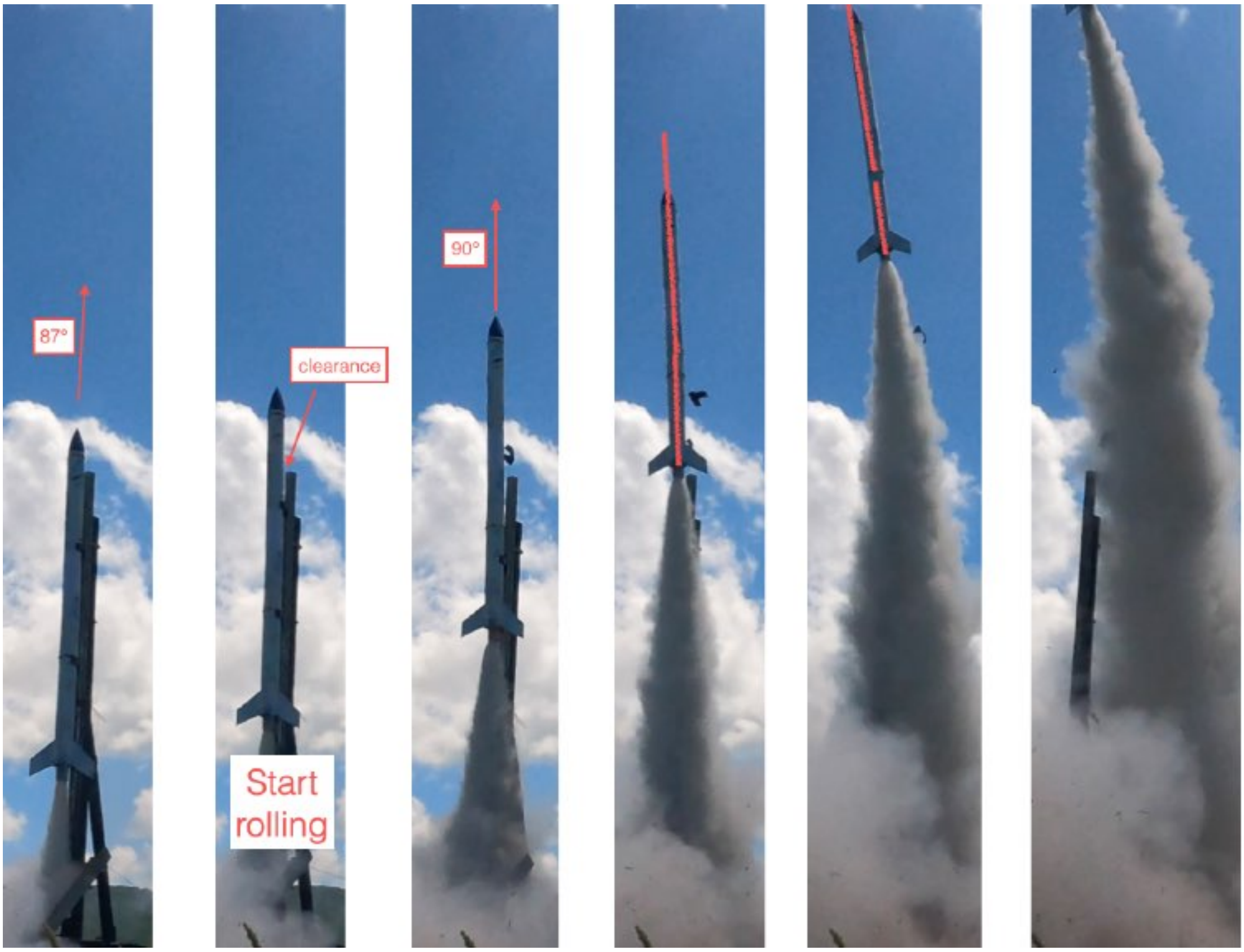

Figure 27. Orientation of Charlie Rocket after launch

Apogee measurement (manual)

Two altitude measurers (measurer one and measurer two) were placed at points 100 meters from the launch pad, respectively. The altitude was measured using the altitude measurement device.

The following formula can calculate the apogee.

$$\text{apogee} = (\text{distance from launchpad}) \times \tan(\text{altitude})$$

The obtained altitude (angle in degrees) and calculated apogees are listed in Table 6.

Table 6. Apogees from manual measurement

	Measurer	Angle (deg)	Apogee (meters)
Beta	Measurer 1	35	70
	Measurer 2	42	90
Delta	Measurer 2	84 – 86	951 – 1,430
Charlie	Measurer 2	44	97

Apogee measurement (altimeter)

The data recovered from the Beta rocket's flight computer PCB showed a 167-meter apogee. The data for the other two rockets were not recovered because the microcontrollers were damaged, probably due to the ballistic hard landing.

Interference of telemetry signal

Accidental firing occurred three times while preparing the pyrotechnic used for the parachute ejection. In the beginning, the short circuit of the flight computer PCB was suspected. However, the main culprit was concluded to be the interference between the first flight computer, which had already launched and landed, and the second flight computer, which was being prepared on the ground. The first flight computer was continuously sending its own state to the base station, which mistakenly updated the state of the second flight computer.

To address the issue, each flight computer PCB must have a unique identifier, and the base station must recognize each board as a different board.

Figure 28. Accidental firing of ejection pyrotechnic

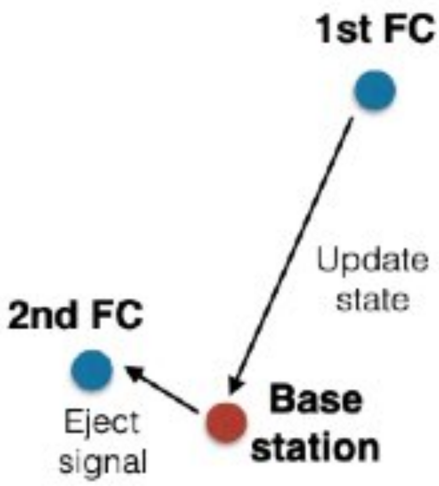

Figure 29. Interference between two flight computers

Way forward

Based on the success, the team will start developing the new rocket that could reach an apogee of 10,000 feet (3 km). During the development, the issues observed in the N-3.5 rocket launch will be addressed. Software testing is particularly crucial for achieving the rocket's successful recovery, which is a critical milestone for the project.

Conclusions

The conclusions from the launch are as follows.

- Three N-3.5 rockets (Beta, Delta, and Charlie) were launched. Another rocket (Alpha) was carried as a backup.
- The rocket was designed to reach a maximum altitude of 1,600 m, whereas one rocket was supposed to achieve more than 1,000 m. From the manual measurement using the protractor, it could have reached up to 1,400 m.
- Solid rocket motor maintained its structural integrity. That was a significant improvement from the last launch test in January 2024.
- The section where the solid rocket motor was installed to the airframe didn’t fracture. The results confirmed the validation of the strength in the static test.
- Out of the three rocket launches, two rockets didn’t fly upward; the flight paths were diverted. During the post-review, it was reported that there was a misalignment between the top body and bottom body, which may have caused the erroneous flight.
- The recovery system was activated, and the parachute was ejected. However, the successful recovery of the rocket is still unconfirmed and will require future work.
- The quality assurance of the software must be conducted based on more testing.

Acknowledgements

Nakuja project appreciates the support from JKUAT, JICA, Kenya Space Agency, and KDF.

Team photo at the launch