N-3 Launch report

27th February 2024

Nakuja Project

Summary

The Nakuja project team consisting of 3 JKUAT faculty members, 27 students, and alumni from Jomo Kenyatta University of Agriculture and Technology (JKUAT) and Kenyatta University (KU) jointly launched the 3rd model rocket (N-3 rocket) with the assistance from the Kenya Space Agency (KSA) on 30th January 2024. The launch site was arranged by the Kenya Space Agency (KSA).
The team successfully launched the three rockets and collected the data, which will be utilized to improve the rocket.

Objectives

The experiment aimed to confirm the following issues.

- Apogee of the rocket: compare the obtained with the simulated apogee.
- Structural integrity of the solid rocket motor: whether the motor casing, nozzle, and bulkheads are intact.
- Structural integrity of the rocket airframe: whether the sub-components of the rockets are intact.
- Recovery of the rocket using the parachute
- Activation of the ejection mechanism by using the apogee detection algorithm
- Data acquisition and transmission of the sensor data, as well as the onboard camera

Rocket

The specifications of the rockets are summarized in Table 1.
We have two rockets that use different materials for the body tube. N3-F (Code name: Simba, Kifaru) uses fiberglass, whereas N3-A (Code name: Tembo, Kabura) has a body tube made of aluminum. Both of the rockets use the same solid rocket motor classified as a K-class motor. The simulated apogee was about 1,600 meters.

Table 1: Specification of rocket

Rocket	**N3-F (Simba, Kifaru)**	**N3-A (Tembo, Kabura)**
Airframe material	Fibreglass	Aluminum
Length	192 cm	200 cm
Diameter	86 mm	82 mm
Dry mass	5.1 kg	5.1 kg
Total mass	10.5 kg	10.5 kg
Simulated apogee	1,636 m	1,637 m
Propellant	KNSB (K1149 motor)	KNSB (K1149 motor)
Simulated total impulse	2,104 [N•s]	2,104 [N•s]

The rocket and the launchpad are shown in Figure 1. The rocket airframe comprises nose cone, rocket body, and fins. The launch pad is fixed on the ground using the pegs. The rocket has two launch lugs that are sliding on the launch rail, which can guide the rocket into the vertical flight path.

Figure 1. Rocket and launchpad

The rockets are equipped with an onboard flight computer with multiple sensors, as shown in Figure 2. The MCU is ESP32, and the sensors are GPS, Gyroscope, and accelerometer. It also has a circuit for the parachute ejection.

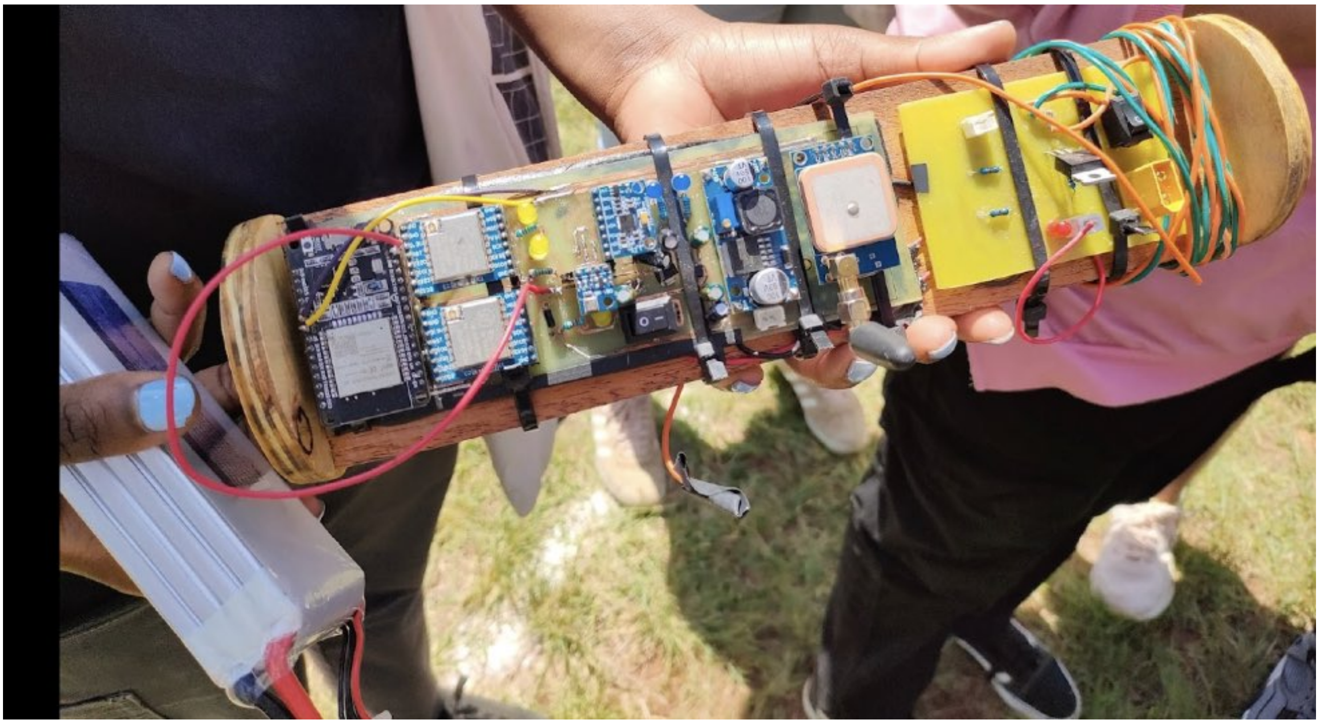

Figure 2. Avionics (flight computer and ejection circuit)

Figure 3 shows the mechanism of the parachute ejection using pyrotechnics. It contains gunpowder called crimson powder stored in a small cylinder, which the ejection circuit will ignite. The explosive gas will push the piston, and the parachute installed in the large cylinder will be ejected. The amount of the crimson powder required to eject the parachute was identified as 10 grams through experiments.

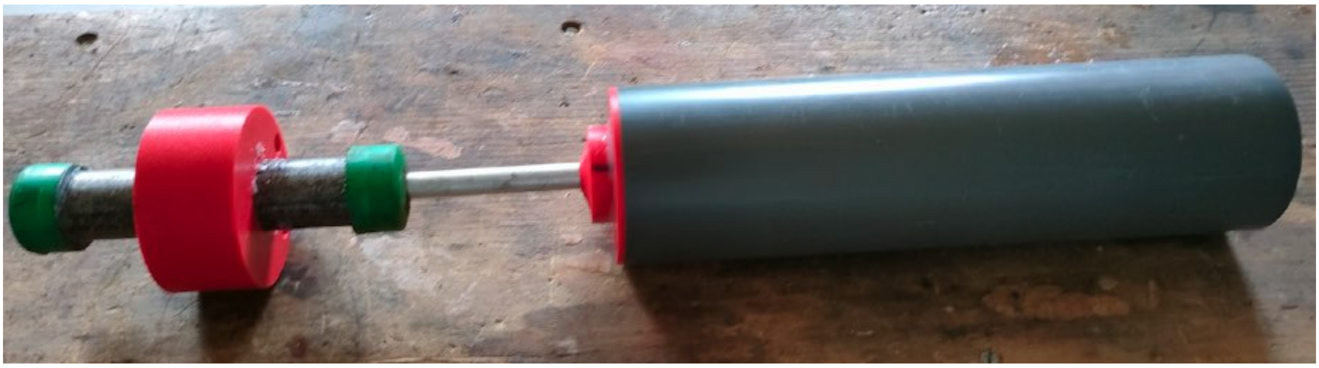

Figure 3. Ejection mechanism

The solid rocket motor is made of casing, nozzle, and bulkhead. The casing is a mild steel cylinder with an internal diameter of 69mm and an external diameter of 73mm. The nozzle is also made of mild steel, whereas the bulkhead uses aluminum for its material. The setup of the solid rocket motor is shown in Figure 4.

Figure 4. Solid rocket motor components (bulkhead, casing, nozzle)

From a number of static tests, it was confirmed that the motor case can withstand high pressure as well as high temperature during the combustion.

Algorithm to detect apogee for parachute ejection

The flight computer firmware implemented an algorithm to eject the parachute at the highest altitude, an apogee. The team compared three algorithms to detect the apogee.

1. Consecutive decrease in specific times
2. The difference between the current altitude and the last altitude exceeds the threshold
3. The difference between the current altitude and temporal maximum altitude exceeds the threshold

The simulation results of each method for the experimental data of the N-2 rocket are shown in Figure 5. The red dot shows the detected apogee, and the blue dot shows the timing when the crimson powder is ignited to deploy the parachute.

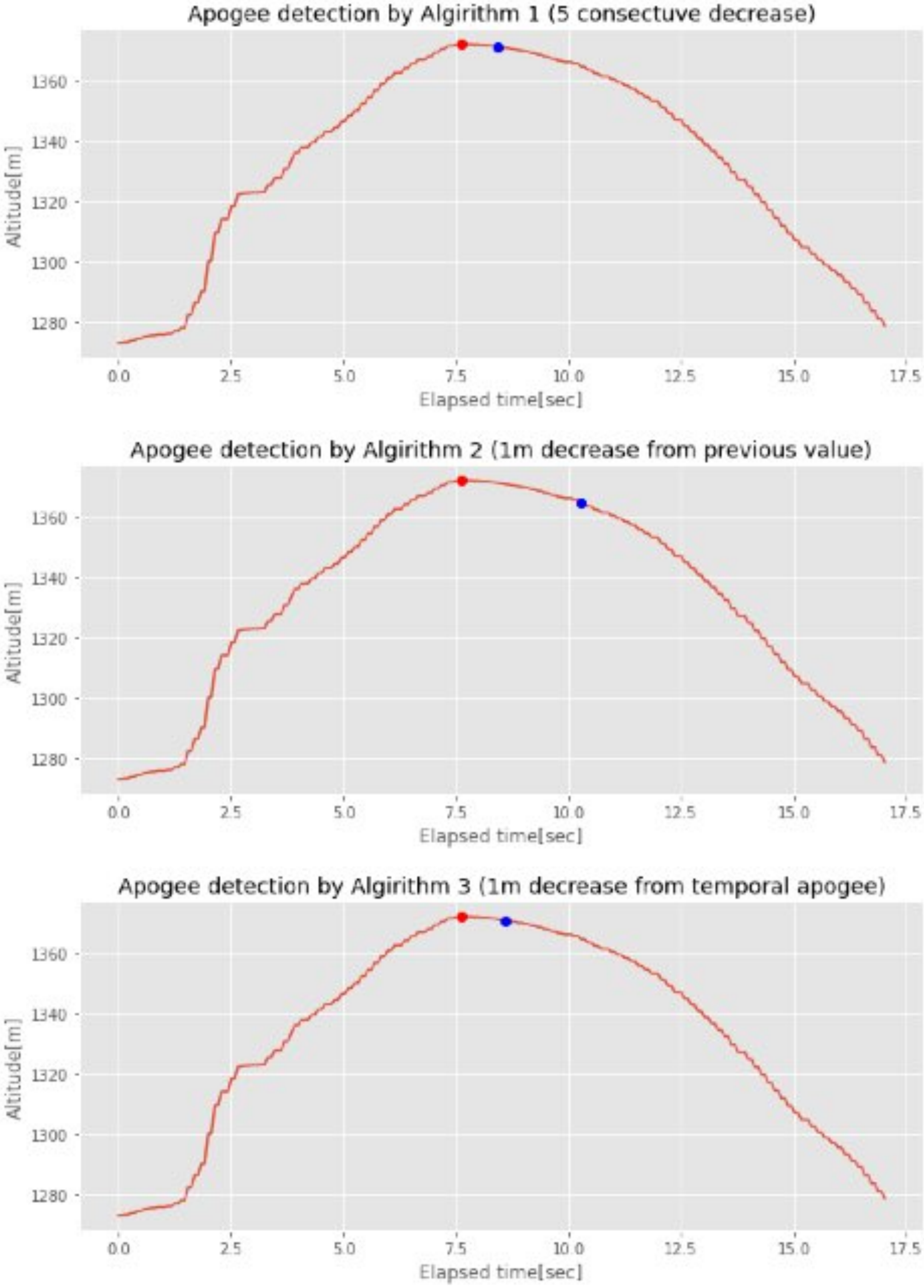

Figure 5. Comparison of apogee detection algorithms

The team decided to use algorithm 3, which the team concluded to have the most efficient performance. The threshold of the difference between the current and temporal maximum altitudes was set as 5 m, considering extra margin.

Result

Launch sequence

The three rockets, Tembo, Kabura, and Kifaru, were launched in this order. The preparation and launch were generally conducted smoothly, as the team rehearsed in JKUAT before the launch. Some of the issues that caused the delays are:

1. On-site assembly of the avionics bay into the rocket body.
2. Misfiring of the ignitor.
3. Malfunction of the ejection mechanism.

The details of the issues and the solutions will be discussed in the following sections.

The team also expected to launch another rocket with a fiberglass body tube, Nyati. Since the ignition circuit stopped working due to the low battery, the team could not complete the launch of the Nyati rocket.

Launch footage

The video footage of the launches is available from the following playlist.
https://www.youtube.com/watch?v=rPNIgGKvPc8&list=PLU4mNMcaNBwan6Zludw_mrr6JHKA9nVRA
The lesson to be learned to improve the quality of the shot is to point the camera at the launch pad to avoid the afternoon sun..

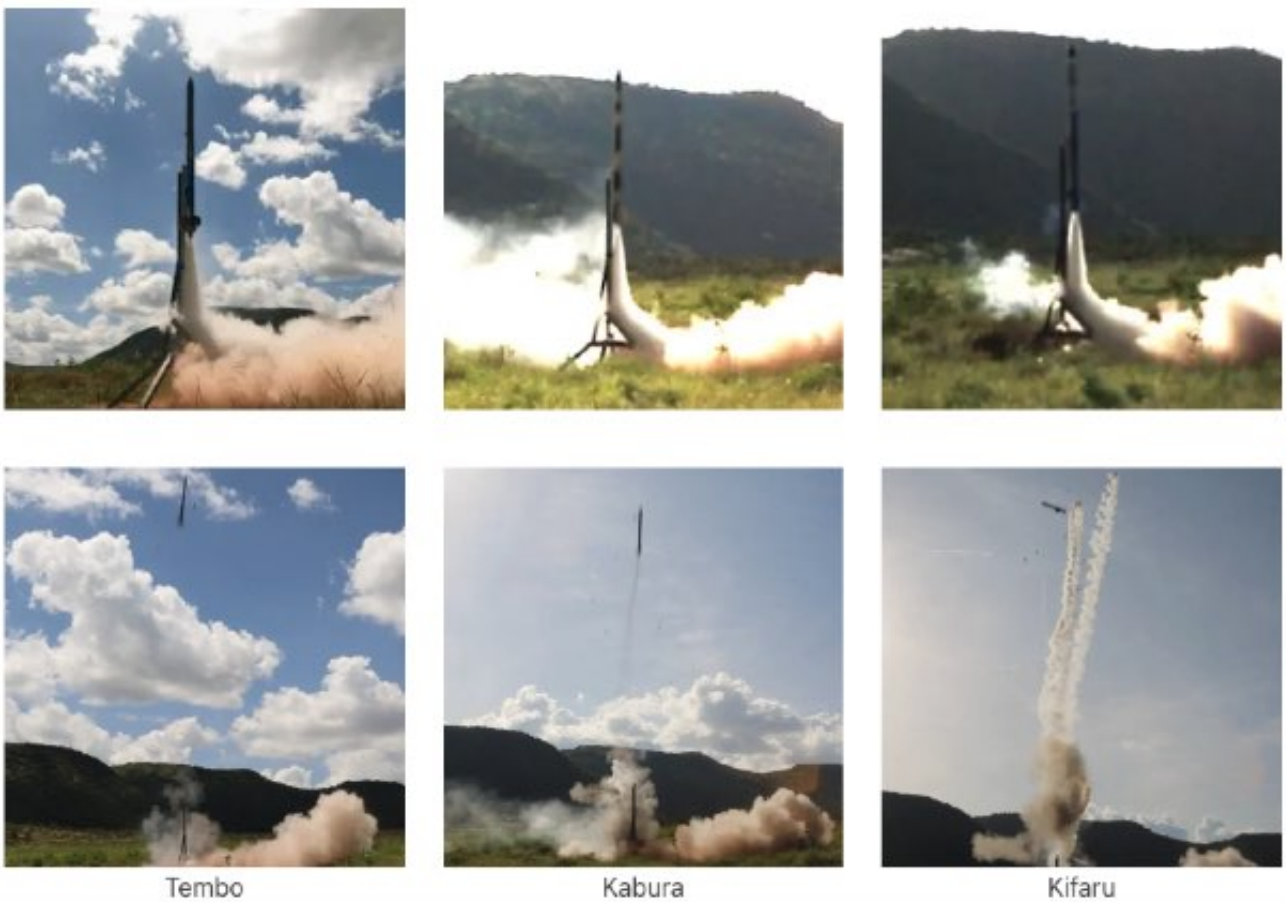

Figure 6. Rocket launch videos

Apogee

The two altitude measurers (Paul and Harun) used the altitude tracker by NASA's website to record the apogee. From the measured angle, the apogees were calculated as follows.

Tembo: 93 m
Kabura: 90 m
Kifaru: 46 m

The observed apogees were way lower than the simulated apogees, at around 1,600 m. The reason for the discrepancy is the significant low performance of the solid rocket motor, which was caused by the pressure release due to the ejection of the nozzle and bulkhead from the solid rocket motor casing during the initial stage of combustion. The details will be discussed in the section on solid rocket motors.

The onboard flight computer also measures the apogee, which stores altitude value in the onboard flash memory and transmits the data to the ground station. The altitude values recovered from the flash memory and the ground station were incorrect. The reasons for the errors are still being identified.

Rocket motor

The failure of the launch was mainly due to the issue of the solid rocket motor. From the recovered rocket motor, it was found out all eight bolts used to fasten the nozzle to the casing were cut by the shear force, as shown in Figure 7. It was an unexpected failure as the design was confirmed to have sufficient strength against the shear. Moreover, it was even strange because the casing was intact against the tensile force, which was supposed to have less strength compared to the shear force. After the investigation, the team found out that the bolts were changed to the new bolts just before the launch, as shown in Figure 8. Initially, the bolts were made of steel, whereas the new bolts were made of silicon bronze. After the launch, the team did a calculation again and confirmed the new bolts could not withhold the generated force.
Based on the findings, the team replaced the bolts with steel bolts and conducted a static test, where they successfully confirmed that the revised motor worked.

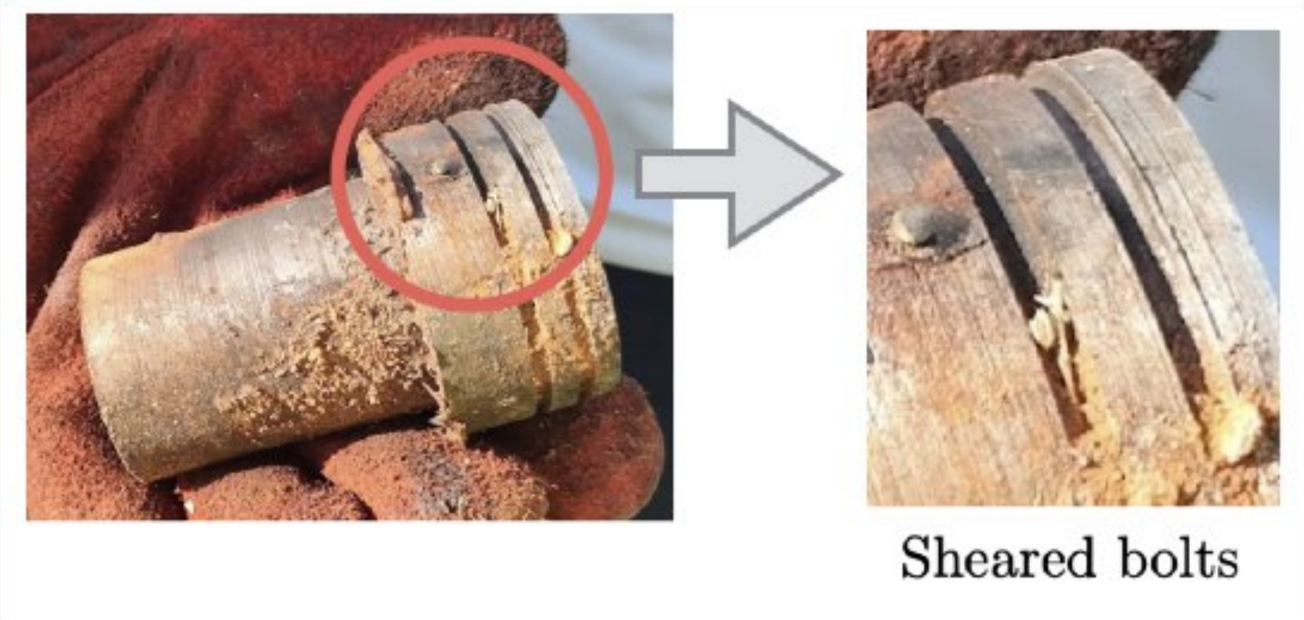

Figure 7. Sheared bolts

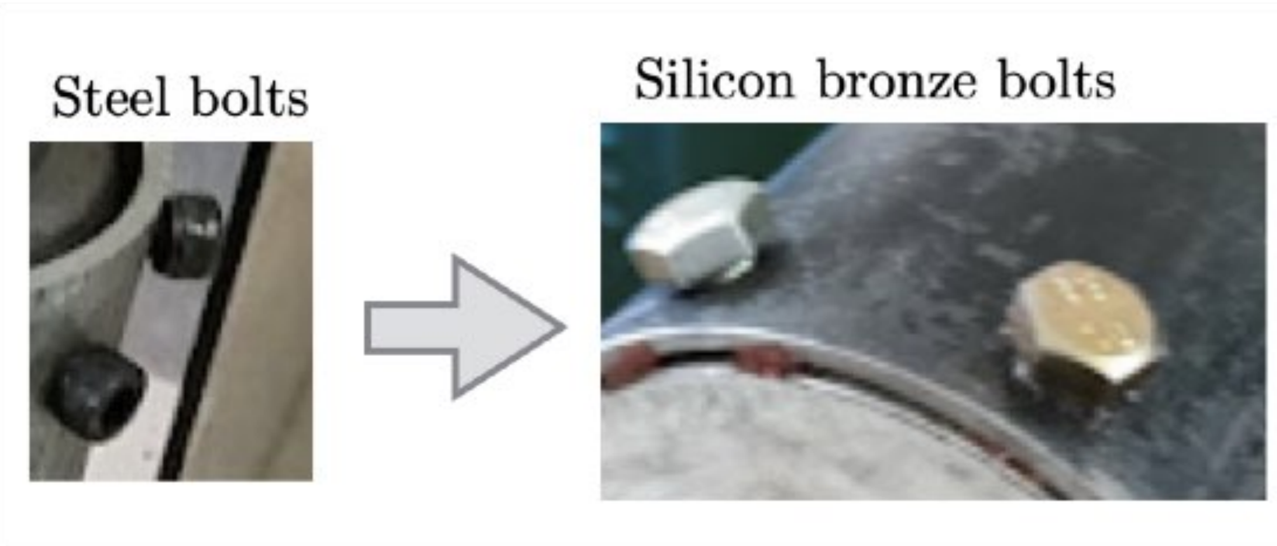

Figure 8. Change of the bolt materials

Ignition system

In the second launch test (Kaburu rocket), the team had an issue igniting the solid rocket motor. Through the measurement of the resistance using a digital multimeter, the team identified the problem was caused by the poor crimping at the end of the nichrome wire, which caused the loose connection, as shown in Figure 9. The lesson learned is to always check the continuity of the ignitor during the fabrication.

Figure 9. Terminal crimp that malfunctioned

To replace the terminal crimp, the team extracted the ignitor pre-inserted into the rocket motor. After removing the ignitor from the rocket motor, the team faced difficulty installing the spare ignitor into the rocket motor because the ignitor was not designed to be installed smoothly on-site, forcing the team to smash it to be smaller, as shown in Figure 10. Considering the potential misfiring of the rocket motor in a future launch, the ignitor must be redesigned to be reloadable on-site. Concretely, the ignitor needs to be made much thinner to go inside the grain holes.

Figure 10. Modified ignitor

The ignition circuit worked as expected, but there were also some improvements observed:

1. The circuit needs a more appropriate protective cover to keep it from dust and thrust and a longer cable to install it far from the launch pad, as shown in Figure 11.
2. The team must carry the backup power pack to source the circuit longer.
3. The team will need to make a backup ignition circuit so that the spare system can take over while the other malfunctions.

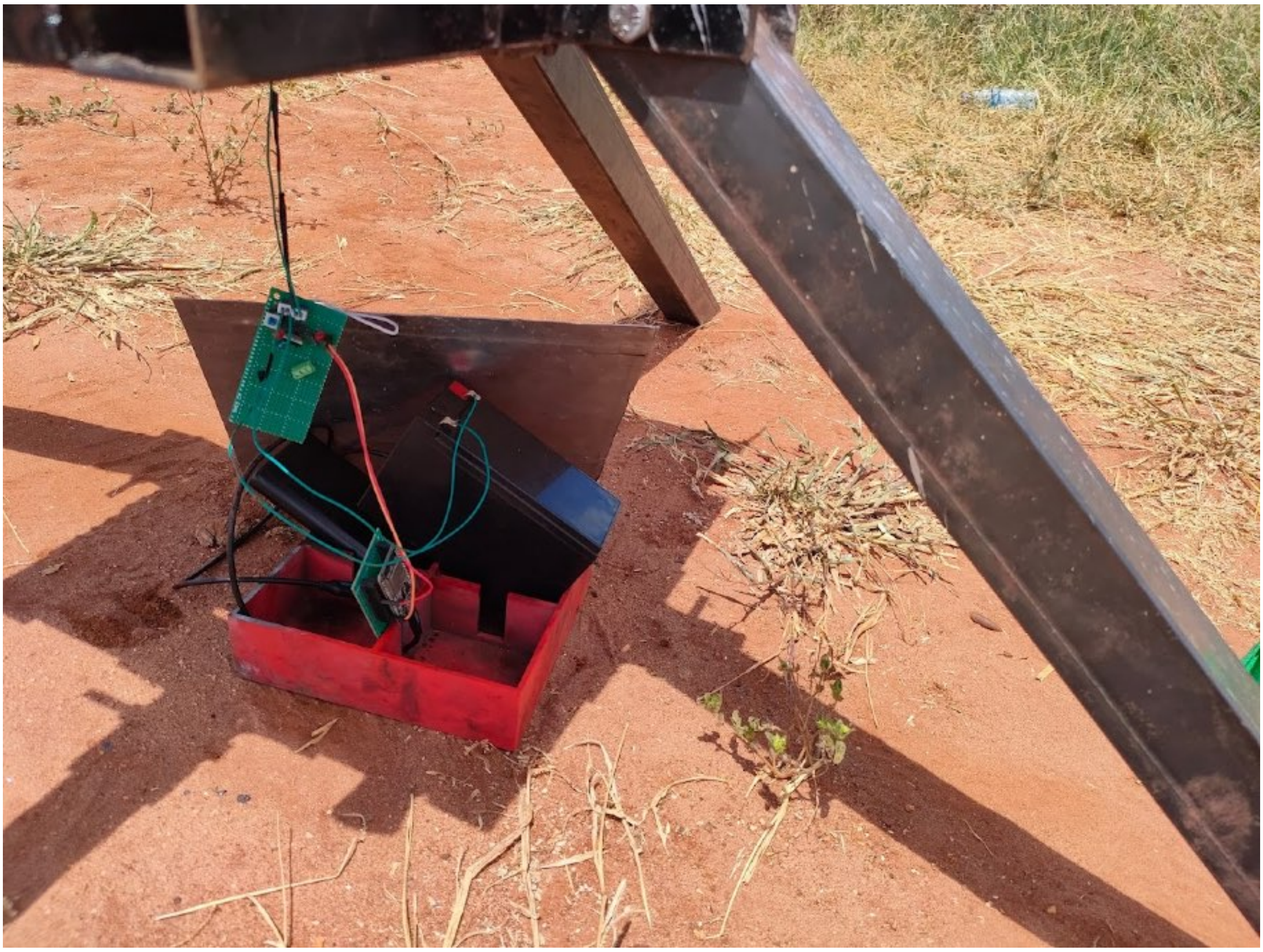

Figure 11. Ignition circuit suspended

Avionics

Preparing the flight computer and ejection board was another time-consuming task on the site, which delayed the scheduled launch. For instance, the team had a wrong soldering on the ejection board, which led to the accidental firing of the ejection mechanism for the Tembo rocket. Based on the accident, the team needed to disassemble the rocket again and start the installation again. The reinstallation process revealed that the team didn't carry enough amount for the backup; the team needs to bring more in the next launch.
Several short circuits were seen here and there, which caused the team to lose two Raspberry Pi Zeros for video capture. It made the team learn the importance of quality control, where they secured enough time to check the successful function of each fabricated PCB.

Figure 12. Preparation of avionics before the launch

Sensor data from Tembo rocket

The sensor data received at the base station is shown in Figure 13. The flash memory was damaged because of the hard landing, which made it impossible to recover the data from the onboard flight computer. The graph seems reasonable, but there are two issues. First, the data acquisition is stopped at a certain point, where the data transmission is terminated. The team will conduct the test to confirm if the rise in temperature would affect it in that manner.

Secondly, there is an offset between the actual altitude of the launch site (around 1,200 m) and the measured altitude (around 900 m). The team suspects the issue was caused by the operating heat during the launch, which is being investigated.

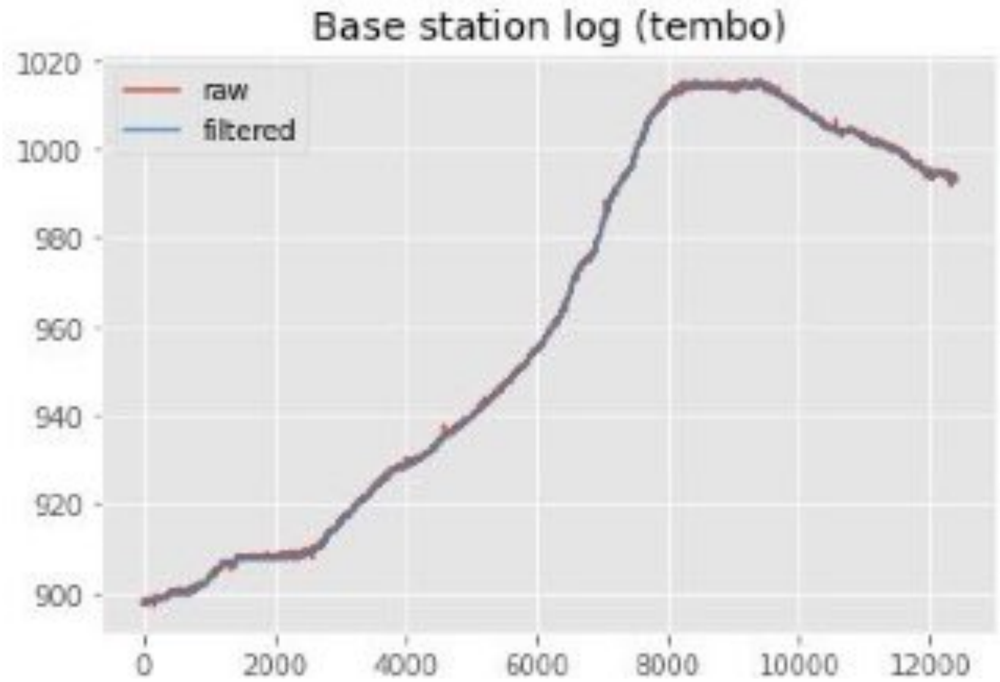

Figure 13. Data stored in the base station (Kabura rocket)

Sensor data from Kabura rocket and Kifaru rocket

Because of the hard landing, the team could recover only the sensor data stored on the flash memory from the Kabura rocket. The data recovered from the Kabura rocket indicated strange and complex behavior, as shown in Figure 14. The reason is being identified by the flight computer team.

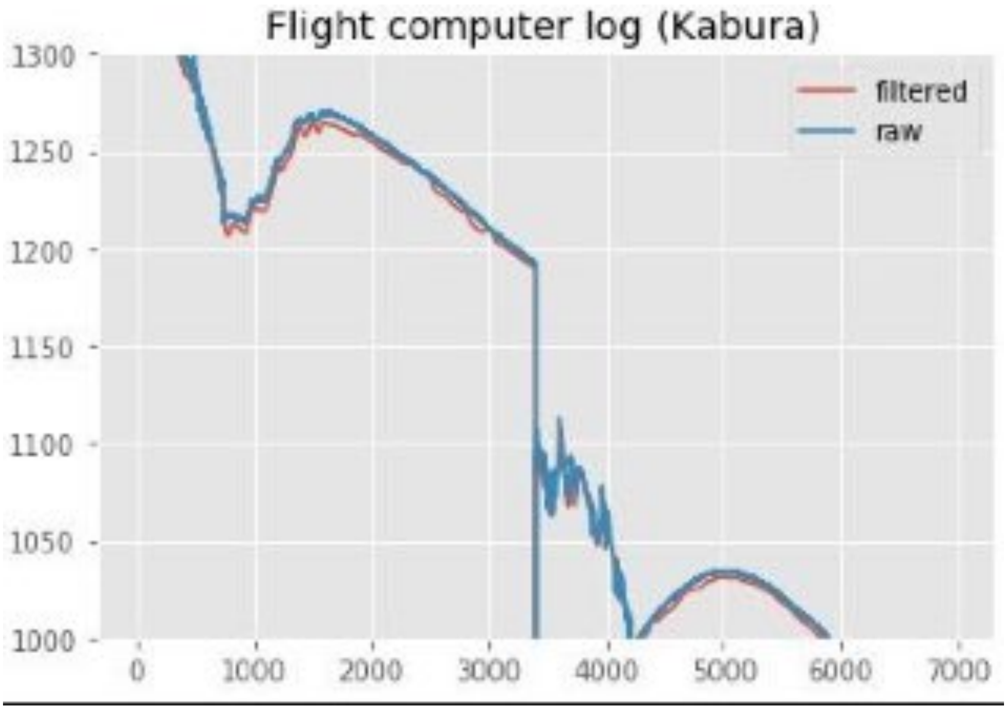

Figure 14. Data acquired from flight computer (Tembo rocket)

Regarding the base station log, neither Kabura nor Kifaru had meaningful data. As shown in Figure 15, the sensor data Kabura received at the base station was almost stable with a random noise. Figure 16 shows the base station data acquired from Kifaru, which recorded a monotonous decrease trend, which is not an expected behavior. To identify the cause of the malfunction, the team needs to conduct several tests at the laboratory by emulating the condition of the launch site.

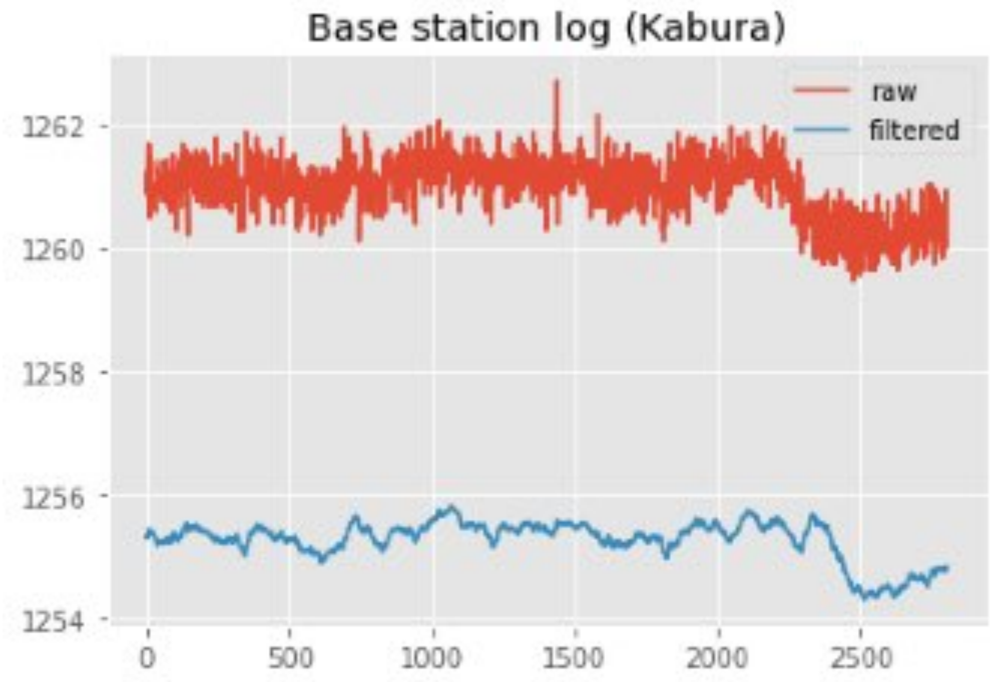

Figure 15. Data acquired from base station (Kabura rocket)

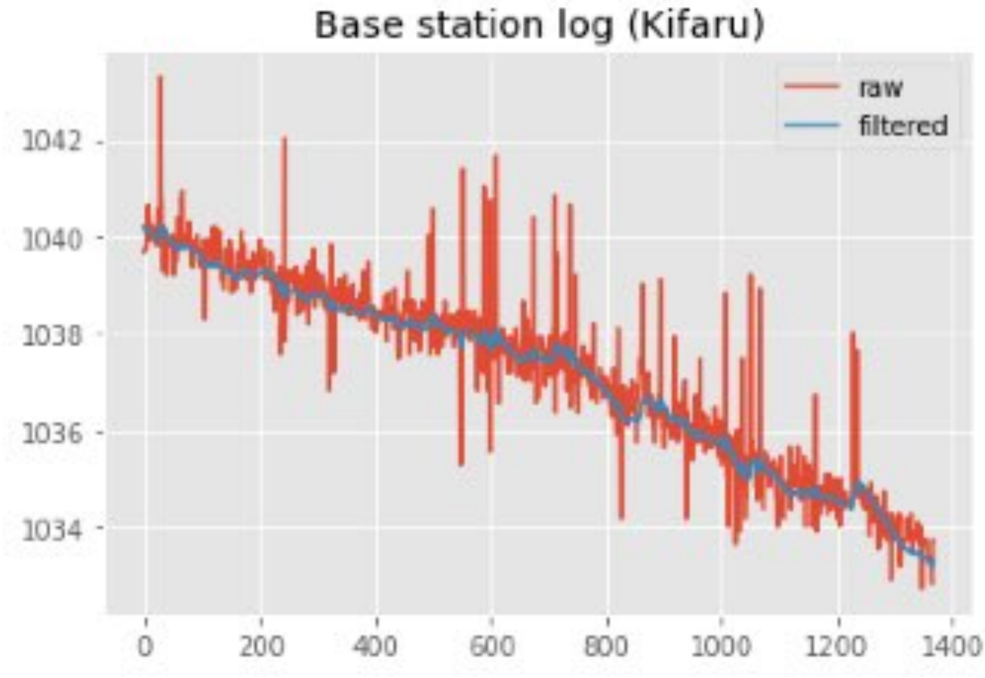

Figure 16. Data acquired from base station (Kifaru rocket)

Airframe

From the recovered airframe, as shown in Figure 17, the team found tears on the rocket body, where the solid rocket motor was joined with a few bolts. It signifies that the rocket body could not maintain its structural consistency against the generated thrust. It let the team realize the necessity of integration testing during the static test to confirm the strength of the joint mechanism of the solid rocket motor and body tube. The team conducted a post-calculation and found that the 8 bolts were required to resist the crushing force, as opposed to the four bolts used in the launch.

Figure 17. Teared rocket body

Regarding the assembly of the rocket airframe, the airframe needs to be redesigned so that the markers will indicate the location of the alignment more clearly.

Figure 18. On site assembly of the rocket airframe

Launchpad

The launchpad was intact after the launch, except for the damaged launch rail during the first flight. The team initially adhered launch rugs to the rocket airframe, increasing the friction between the rocket and the launch pad. Based on the advice from Major Were, the team decided not to adhere the launch rugs on the airframe using epoxy. In the 2nd and 3rd launches, the rails were not damaged, so the effectiveness of the new method was proven.

Figure 19. The team fixes launch rail after the 1st launch

Recovery

The recovery system was not activated in the three launches, mainly due to the failure of the solid rocket motor. Concretely, the state machine was not transiting to the next state. The reason for the state machine was still being investigated, but the violent oscillation during the catastrophic launch is suspected to be the culprit.

Moreover, even if the state could work properly, there was a fail-safe mechanism to prevent the parachute from accidentally being deployed. During the initial phase of the launch, just after the launch, there was a high chance of the flight computer overestimating the current altitude. The Kalman filter needs some initial warm-up time to stabilize its filtering performance. Since the delay likely triggered the ejection mechanism accidentally, the team set the safety threshold as 100 m. In other words, the rocket was programmed to ignore the apogee detection and parachute deployment signal if the apogee was under that altitude. The team lowered the threshold to 50m after the 1st launch, but based on the state machine's malfunction, it was impossible to eject the parachute in the three launches..

Way forward

The team conducted a static test to confirm the upgraded solid rocket motor, as shown in Figure 20. The thrust curve obtained in the test is shown in Figure 21.

Figure 20. Static test of the improve solid rocket motor

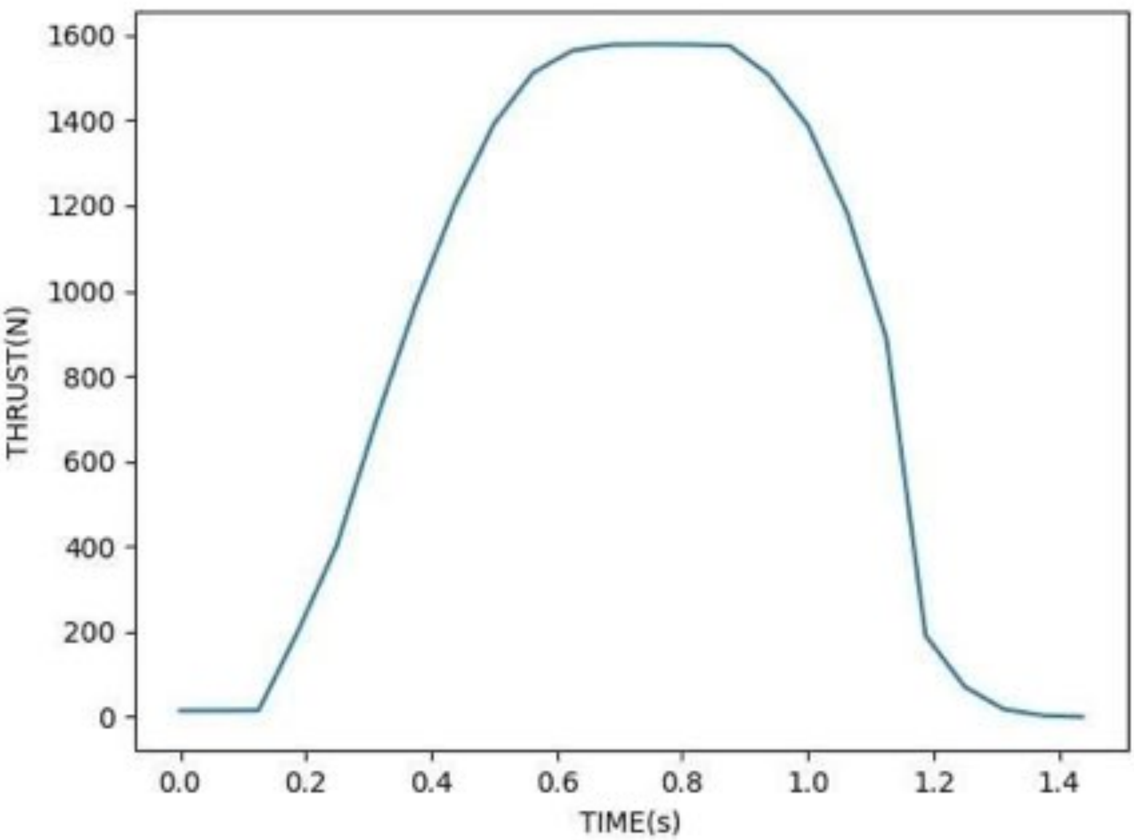

Figure 21. Thrust curve of the new solid rocket motor

The total impulse of the motor is calculated as 1220.74 [N•s], which is categorized as a J-class motor. This means there is still room for improving the solid rocket motor's performance since the designed motor's theoretical performance is 2,104 [N•s], categorized as a K-class motor.
The next rocket, which upgraded the N-3 rocket, was named the N-3.5 rocket. The team is currently sorting out the issues described in the report. The team proposes to conduct the next launch in April 2024 to prove the successful operation of the N-3.5 rocket.

Recommendation

Based on the completion of the experiment to launch the N-3 rocket, the team expresses an interest in participating in the annual world competition of model rocketry called the Spaceport America Cup (SA Cup). The event is held in Spaceport America, New Mexico, the United States. Participation in the event will enable the team to gain more knowledge in rocketry and advertise the achievements of the Kenyan institution to the worldwide space community.

The SA Cup 2024 will be held from 17th to 22nd June 2024. The registration for the SA Cup 2024 competition is already closed, and the registration for the next competition is expected to begin in October 2024. To be accepted in the world-class competition, the team will start the preparation immediately, study the guidelines carefully, and redesign the N-3 rocket to observe the regulations.

The timeline for the Spaceport America Cup 2024 is described in Table 2. The SA Cup 2025 would have a similar timeline, but it needs to be confirmed.

Table 2. Timeline for Spaceport America Cup 2024

Sep. 21	Date launched
Oct. 1	Application
Oct. 21	Team entry form due
Oct. 25	Team application evaluations
Nov. 7	Team acceptance announcement
Dec. 16	1st interim progress report due, entry fee due
Feb. 17	2nd interim progress report due
Apr. 20	Deadline for refunds, rocket fee due, rocketeer fees can be paid
May. 1	3rd interim progress report and video review session deadline
May. 11	Project technical report due, school participation letter, poster and podium materials

Jun. 17	2024 Spaceport America Cup onsite registration
Jun. 18	2024 Spaceport America Cup conference day
Jun. 19	2024 Spaceport America Cup launch day 1
Jun. 20	2024 Spaceport America Cup launch day 2
Jun. 21	2024 Spaceport America Cup launch day 3
Jun. 22	2024 Spaceport America Cup FINAL launch day
Jun. 23	2024 Spaceport America Cup - Closing awards ceremony

Acknowledgements

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