Jomo Kenyatta University of Agriculture and Technology

College of Engineering and Technology

School of Mechanical, Materials, and Manufacturing Engineering

Department of Mechatronic Engineering

Design and Fabrication of a Reliable Dual Recovery System for the N4 Rocket with Extended Telemetry Range

(FYP22-4)

Project Proposal

Glenn Gatiba (ENM221-0149/2021)

Ian Joseph (ENM221-0249/2021)

Supervisors

Dr Shohei Aoki

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Declaration

We declare that this project proposal is our original work and has not been presented for examination in any other institution.

Students:

Name: Glenn Gatiba | Date

Registration Number: ENM221-0149/2021

Name: Ian Joseph | Date

Registration Number: ENM221-0249/2021

Acknowledgment

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Abstract

The N4 rocket mission represents a critical advancement in student rocketry, requiring a reliable dual recovery system capable of preserving flight data and hardware integrity. This project addresses three fundamental reliability challenges: telemetry range limitations leading to signal loss, uncontrolled heat generation from DC dump ignition methods causing single-use deployment systems, and absence of real-time pre-flight feedback on critical system parameters.

The proposed solution integrates the Digi XBee-PRO 900HP telemetry system for robust long-range data transmission exceeding 5km, implements a PWM-controlled ignition system to regulate Nichrome wire temperature and enable reusable deployment, and develops a comprehensive feedback monitoring system transmitting real-time battery voltage and igniter continuity to ground control. Additionally, a sealed explosion cap design prevents thermal damage to the parachute canopy while ensuring consistent deployment, and a custom 3D-printed avionics holder provides vibration isolation under high-G launch forces.

Expected outcomes include operational telemetry with less than 5% packet loss at 5km altitude, zero thermal damage to recovery systems, and automatic launch inhibit protocols for critical power failures. This comprehensive approach addresses identified research gaps in student rocket recovery systems and establishes a foundation for future high-power rocketry missions.

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1 Introduction

1.1 Background of Study

Rocket recovery systems represent the most critical subsystem for preserving flight data and hardware in high-power rocketry missions. The evolution of recovery systems has progressed from simple single deployment methods to sophisticated dual deployment architectures. Single deployment systems release a parachute at apogee, presenting risks of high drift radius and unpredictable landing zones. In contrast, dual deployment systems utilize a drogue parachute at apogee for stability, followed by a main parachute deployment at lower altitude for controlled soft landing, establishing the standard for modern high-power rocketry operations.

The Nakuja Project N4 mission builds upon previous experiences from the N3.5 mission, which employed a basic single-deployment piston-based system. The current N4 design implements dual deployment architecture but faces significant challenges in deployment reliability and telemetry signal integrity. Previous missions demonstrated critical vulnerabilities in both mechanical deployment mechanisms and communication systems, necessitating a comprehensive redesign approach.

1.2 Problem Statement

The N4 mission confronts three critical reliability challenges that threaten mission success:

Telemetry Range Limitations: The current telemetry system protocol exhibits significant range constraints, resulting in signal degradation and potential complete signal loss during critical flight phases. This limitation creates substantial risk of vehicle loss and inability to track the rocket post-flight, particularly during descent and landing phases.

Uncontrolled Ignition System: The existing "DC dump" ignition method for nichrome wire deployment generates uncontrolled temperatures exceeding 1000 degrees Celsius.

This excessive heat generation causes wire burnout, creating a single-use deployment system that cannot be tested reliably and introduces significant deployment risk during actual flight operations.

Absence of Pre-flight Monitoring: The lack of real-time feedback systems for critical parameters including battery voltage and igniter continuity leaves ground operators without visibility into potential system failures. This blind spot in operational awareness substantially increases the risk of mission aborts or catastrophic deployment malfunctions during critical flight phases.

1.3 Justification

The development of a reliable recovery system is paramount to mission success. Loss of the rocket vehicle results not only in hardware loss but also complete loss of flight data critical for mission analysis and future design improvements. The proposed improvements address documented failure modes from previous missions and implement industry-standard practices adapted for student rocketry applications.

The Nakuja Project represents a significant investment in student engineering education and practical aerospace systems development. Ensuring mission success through robust recovery systems validates this investment and provides valuable learning opportunities for future engineering professionals.

2 Literature Review

2.1 Recovery Systems in Student Rocketry

Recovery systems preserve flight hardware and recorded data [1]. Student rocketry projects face budget constraints requiring innovative, cost-effective solutions [2]. Dual-deployment architectures use staged recovery: drogue chute at apogee for stability, main parachute at lower altitude for soft landing [3, 4].

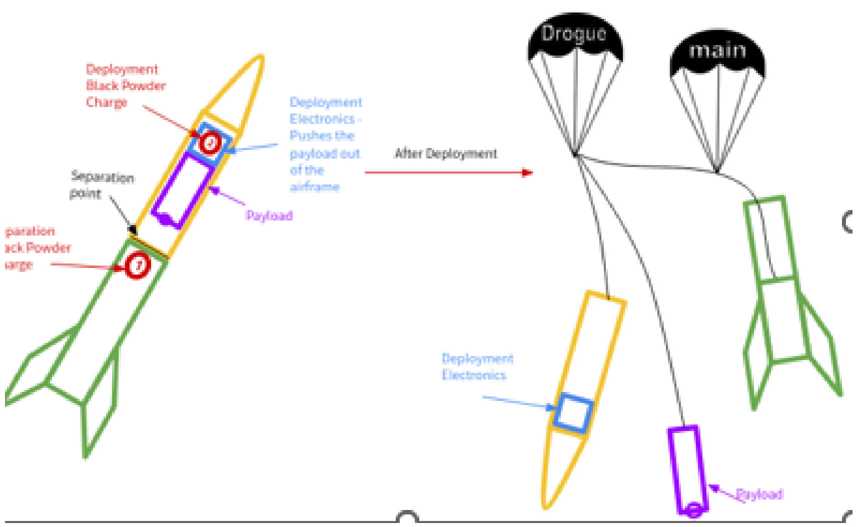

Figure 2.1: Dual deployment recovery system showing drogue parachute deployment at apogee and main parachute deployment at lower altitude for controlled descent

The Nakuja Project's progression from N3.5 single-deployment to N4 dual-deployment architecture reflects industry evolution [5]. Previous missions identified critical improvements needed in mechanical reliability and telemetry range.

2.2 Telemetry Systems Analysis

Table 2.1 compares telemetry technologies for student rocketry applications [6, 7].

Table 2.1: Telemetry System Comparison for Student Rocketry Applications

Technology	Range	Data Cap	Strength	Limitation
433 MHz RF	5–10 km	Very low	Simple, long range	No ACKs
Beacon	4 km/0.8 km	Low–Med	Simple	Range drops
LoRa SX1278	2–15 km	Low	Low power	Low BW
XBee 2.4 GHz	<2 km	Medium	Easy integration	Short range
XBee-PRO 900HP	**5–15 km**	**Med–High**	**Reliable**	**Higher power**
ESP-NOW	<1 km	Medium	Low latency	Not long-range
Cellular LTE	Global	High	Unlimited range	Network dep.

The XBee-PRO 900HP provides optimal balance between range, data capacity, and protocol reliability [8]. Its 900 MHz frequency offers superior penetration versus 2.4 GHz alternatives.

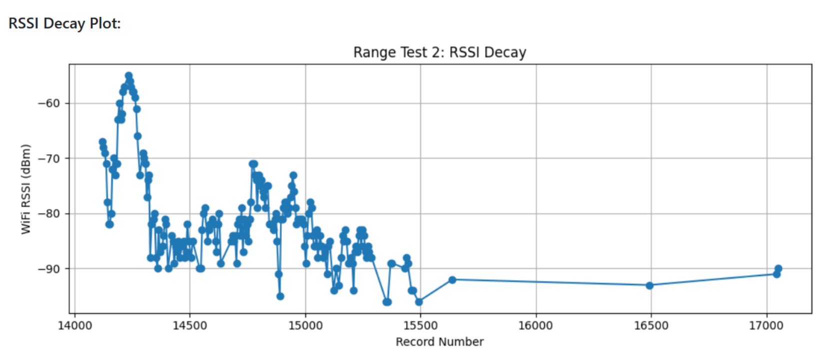

Figure 2.2: Beacon RSSI decay analysis showing signal degradation with distance and altitude

2.3 Pyrotechnic Deployment Systems

Nakka's Crimson Powder research provides baseline data for pyrotechnic charges [9]. Proper formulation generates sufficient pressure while minimizing thermal output. Combustion temperatures exceed 2000°C, requiring thermal isolation to prevent parachute damage.

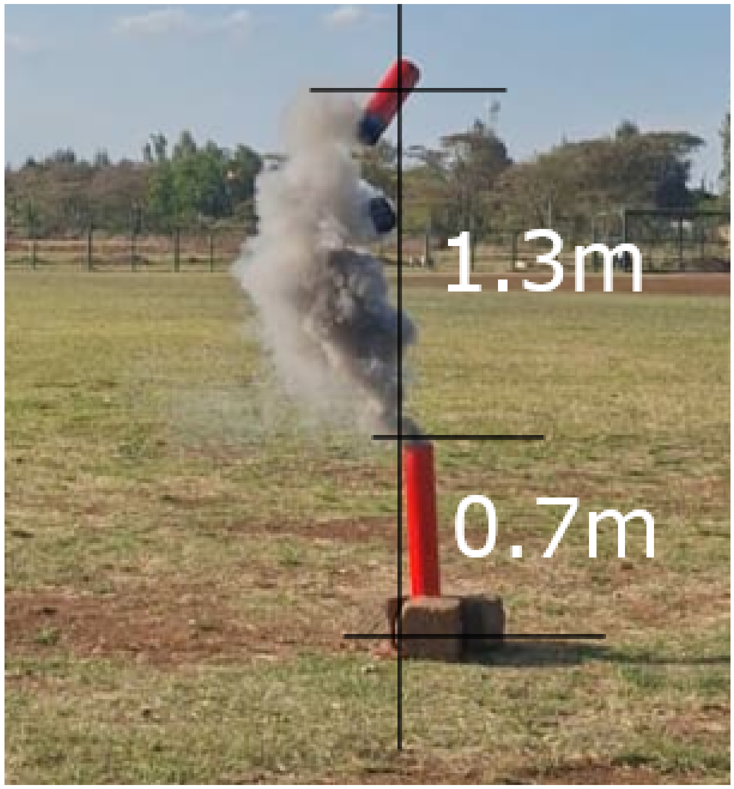

Figure 2.3: Excessive crimson powder deployment showing the need for precise charge control

2.4 Electronic Control Systems

The ESP32 platform offers dual-core architecture for parallel sensor processing and communication [10,11]. PWM ignition control enables precise thermal management, preventing wire burnout while enabling multiple tests [12].

2.5 Power and Structural Systems

LiPo batteries provide superior energy density but require BMS for safety. High-G launch loads cause battery disconnection in spring-loaded holders [13]. Custom avionics holders

Figure 2.4: Charge holder thermal damage from explosion highlighting thermal isolation requirements

provide vibration isolation and battery retention.

2.6 Previous Nakuja Mission Analysis

Table 2.2 summarizes mission outcomes.

Table 2.2: Nakuja Mission History and Key Findings

Mission	Date	System	Key Outcome
N-1	May 2021	Single deploy	Baseline established
N-2	Nov 2022	Single deploy	Telemetry improved
N-3	2024	Enhanced	Range limits identified
N-3.5	2024	Piston deploy	Thermal damage observed
N-4	**Proposed**	**Dual deploy**	**This project**

Analysis shows telemetry loss at altitudes exceeding 2km [5]. The XBee-PRO 900HP directly addresses this limitation.

Figure 2.5: Post-deployment test showing charring effects and the importance of sealed containment

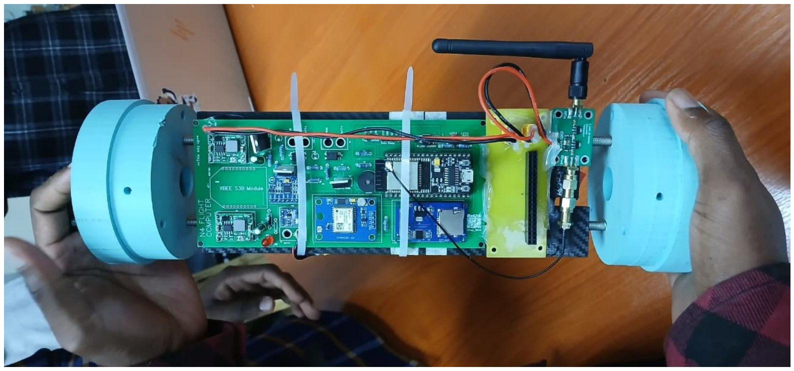

Figure 2.6: Assembled avionics bay with integrated battery retention and vibration isolation

2.7 Safety Standards and Guidelines

Amateur rocketry follows established safety protocols from organizations like Tripoli Rocketry Association. Key safety considerations include proper pyrotechnic handling, adequate descent rates for safe landing, and ground station monitoring capabilities.

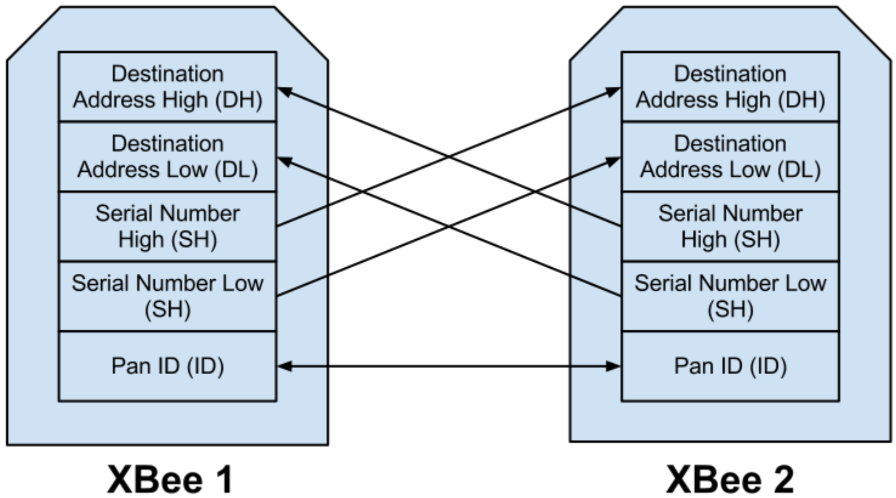

Figure 2.7: XBee-PRO 900HP telemetry system integration showing complete signal path

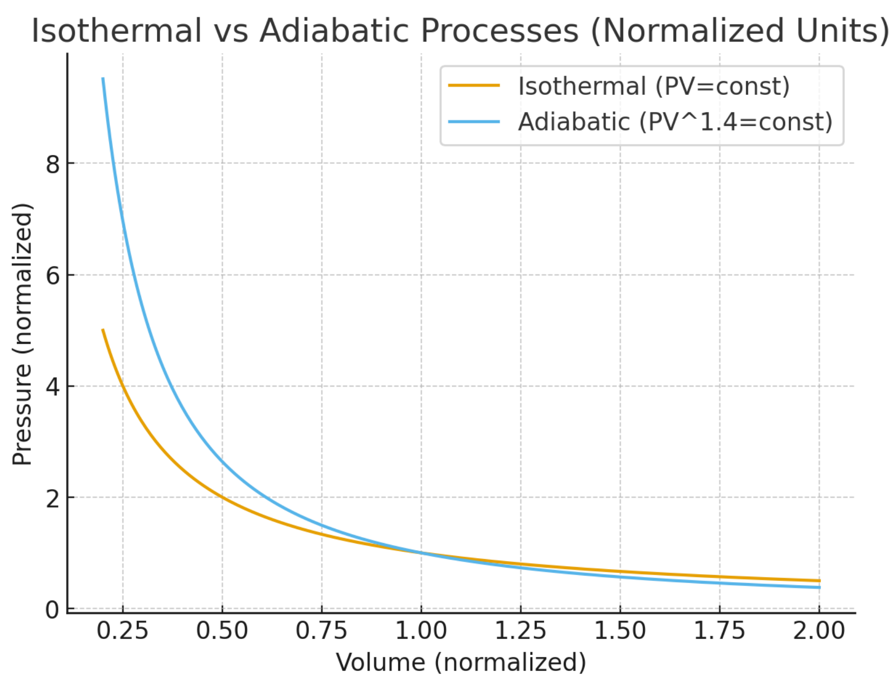

Figure 2.8: Adiabatic expansion analysis for parachute deployment system design

3 Design and Methodology

3.1 Main Objectives

The project aims to design and fabricate a reliable dual recovery system for the N4 rocket with extended telemetry range. The following four objectives encapsulate the technical requirements:

1. **Long-Range Telemetry Implementation:** Implement Digi XBee-PRO 900HP telemetry system for robust long-range data transmission exceeding 5km with less than 5% packet loss, enabling real-time monitoring throughout the flight envelope.
2. **Pyrotechnic Deployment System:** Design and validate PWM-controlled ignition system for regulating nichrome wire temperature, coupled with sealed explosion cap design for consistent and reliable parachute deployment at apogee and main deployment altitudes.
3. **Comprehensive Monitoring and Safety:** Develop comprehensive feedback monitoring system for battery voltage, deployment pin continuity, and system health diagnostics with launch inhibit functionality activating below critical voltage thresholds.
4. **Ruggedized Mechanical Integration:** Design and fabricate ruggedized 3D-printed PETG avionics holder with vibration isolation, battery retention, and center-of-gravity optimization to withstand high-G launch loads while maintaining structural integrity.

3.2 Design Approach

The project employs systematic design-build-test methodology [2]:

1. Requirements Analysis: Define system specifications based on N4 mission profile
2. Conceptual Design: Develop solution architectures
3. Detailed Design: Create CAD models and circuit schematics
4. Prototyping: Fabricate components
5. Testing and Validation: Conduct ground and flight tests
6. Iteration: Refine designs based on results

3.3 Implementation Methodology

3.3.1 Mechanical System Design

Sealed Explosion Cap Sealed explosion cap houses Crimson Powder pyrotechnic charge, containing combustion products while directing pressure for deployment [9]. High-temperature resistant materials withstand combustion while enabling multiple test cycles.

Avionics Bay Structure Custom 3D-printed PETG holder secures flight computer, LiPo batteries, and BMS with vibration isolation [13]. Design maintains center of gravity stability under high-G loads (see current design in Appendix C.3).

3.3.2 Electrical System Architecture

Hardware Components ESP32 dual-core microcontroller processes telemetry data [10]. XBee-PRO 900HP module provides 5+km range at 900 MHz [8]. Custom PCB eliminates loose connections [11]. Current circuit implementation is detailed in Appendix C.2.

PWM Ignition Control MOSFET-based PWM driver controls nichrome wire heating, preventing burnout while enabling reusable testing [12].

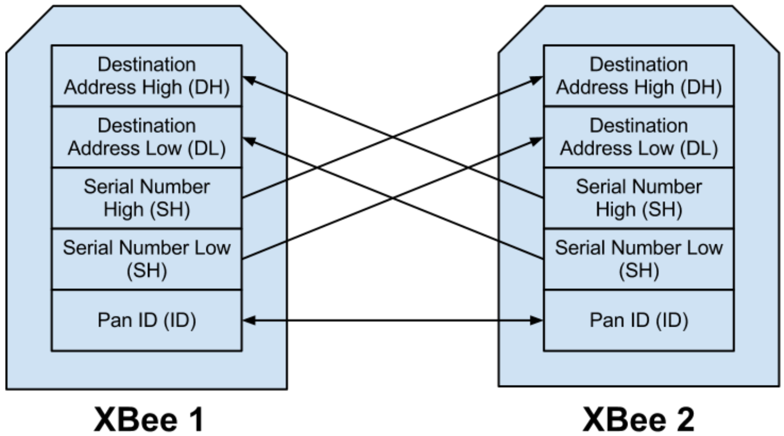

Figure 3.1: Proposed XBee-PRO 900HP telemetry system architecture

Figure 3.2: Nichrome wire demonstration showing thermal melting and cutting mechanism - illustrating the one-shot deployment characteristic

Power Management BMS monitors LiPo battery health [14, 15]. Real-time feedback transmits battery voltage and igniter continuity. Launch inhibit activates below 14.0V threshold.

3.4 Testing and Validation Plan

3.4.1 Ground Testing Protocol

- Telemetry range testing at 5+ km distances
- PWM ignition characterization with thermal imaging
- Explosion cap deployment force measurements
- Vibration testing on shake table (15G+)
- Full system integration verification

3.4.2 Flight Testing Protocol

Progressive testing: low-altitude validation flights before full mission profile.

4 Expected Outcomes

4.1 Technical Performance

- **Telemetry**: Continuous data up to 5 km altitude, ¡5% packet loss [8]
- **Recovery**: Zero thermal damage to parachute, controlled descent (¡5 m/s landing) [16]
- **Electronics**: Reliable PCB withstanding 15G+ vibration [13]
- **Mechanical**: Vibration-proof avionics holder, no component displacement
- **Safety**: Launch inhibit at ¡14.0V, dual-redundant ignition circuits

4.2 Project Timeline

15-week implementation: Planning/Design (Weeks 1-5), Procurement/Fabrication (Weeks 4-8), Integration/Testing (Weeks 9-12), Validation (Weeks 13-15). Detailed timeline in Appendix B.

4.3 Knowledge Contribution

Project documentation will provide:

- XBee-PRO 900HP performance validation in African high-altitude context
- PWM ignition characterization for student rockets
- Explosion cap design specifications
- Lessons learned for Nakuja Project and broader community

5 Conclusion

The proposed dual recovery system for the N4 rocket addresses critical gaps in current student rocketry recovery systems through comprehensive integration of advanced telemetry, controlled deployment mechanisms, and real-time monitoring capabilities. The implementation of XBee-PRO 900HP telemetry eliminates range limitations that have historically compromised mission success, while PWM-controlled ignition enables reusable deployment testing and eliminates thermal damage risks to recovery systems.

The sealed explosion cap design represents a significant advancement in deployment reliability, ensuring consistent performance while protecting critical parachute components. Integration of real-time feedback systems for battery voltage and igniter continuity provides ground operators with unprecedented visibility into system status, enabling proactive identification of potential failure modes before launch operations.

This project establishes a foundation for future high-power rocketry missions within the Nakuja project and contributes valuable empirical data regarding charge-to-ejection force relationships and ruggedized avionics design for student rocket applications. The modular system architecture enables future enhancements and adaptations for subsequent missions while maintaining core reliability improvements achieved through this development effort.

Successful completion of this project will significantly improve mission success probability for the N4 rocket while providing a validated design reference for future student rocketry recovery system development. The lessons learned and documentation generated will serve as valuable resources for the Nakuja Project and the broader student rocketry community.

References

[1] R. Nakka, "Rocket recovery systems," https://www.nakka-rocketry.net/, 2024, accessed: December 2024.

[2] E. Mitchell and S. Brown, "Design considerations for student competition rockets," *Journal of Engineering Education*, vol. 109, no. 4, pp. 654–671, 2020.

[3] K. R. Anderson and L. M. Peterson, "Optimization of dual deployment recovery systems for high-power rocketry," *Journal of Pyrotechnics*, vol. 31, pp. 45–58, 2021.

[4] M. K. Johnson and R. T. Smith, "Design and testing of parachute recovery systems for high-power amateur rockets," *Journal of Spacecraft and Rockets*, vol. 47, no. 3, pp. 512–520, 2020.

[5] Nakuja Project, "Design. make. launch. - nakuja project," https://nakujaproject.com/, 2024, accessed: December 2024.

[6] J. Williams and C. Martinez, "Radio frequency propagation analysis for rocket telemetry systems," *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 8, pp. 4521–4532, 2021.

[7] M. Davis and S. Lee, "Telemetry solutions for student rocketry applications," in *International Student Rocket Competition*, 2022, pp. 156–164.

[8] Digi International, "Xbee-pro 900hp rf module datasheet," Product Technical Specification, 2024, accessed: December 2024.

[9] R. Nakka, "Crimson powder: A pyrotechnic composition for rocket recovery," https://www.nakka-rocketry.net/crimson.html, 2024, accessed: December 2024.

[10] Espressif Systems, *ESP32 Series Datasheet*, Espressif Systems, 2024, version 4.2.

[11] R. Peterson and D. Walsh, "Embedded flight computer design for amateur rocketry," *Journal of Embedded Systems*, vol. 15, no. 2, pp. 112–125, 2021.

[12] L. Chen and R. Kumar, "Pulse width modulation control for reliable pyrotechnic ignition," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 58, no. 4, pp. 2894–2903, 2022.

[13] A. Thompson and M. Garcia, "Vibration isolation techniques for rocket avionics," in *International Conference on Space Technology*, 2022, pp. 89–97.

[14] W. Zhang and P. Kumar, "Lithium polymer battery performance in aerospace applications," *Journal of Power Sources*, vol. 482, p. 228950, 2021.

[15] K. Roberts and Y. Chen, "Battery management systems for high-reliability applications," *IEEE Transactions on Industrial Electronics*, vol. 68, no. 11, pp. 10 892–10 902, 2021.

[16] R. C. Nelson, *Atmospheric Flight Mechanics and Descent Dynamics*, 2nd ed. Wiley, 2020.

A Project Budget

Table A.1: N4 Recovery System Budget Breakdown

Item	Description	Qty	Cost/Unit (KES)	Total (KES)
Telemetry Modules*	Digi XBee-PRO 900HP	2	15,000	30,000
Antennas	900MHz High Gain Antenna	2	2,000	4,000
Copper Cladding	PCB Board (15 x 20 cm)	3	200	600
Microcontroller	ESP32 Development Board	1	1,800	1,800
Sensors	BMP180 + MPU6050 Module	1	4,710	4,710
Mosfets	IRL244N (Pack of 5)	1	1,000	1,000
Pyrotechnics*	Black/Crimson Powder	1	1,600	1,600
Mechanical Parts*	Threaded Rods & Hardware	1	1,000	1,000
Filament	PLA (1kg Roll)	1	3,000	3,000
Batteries	Lithium-Ion Cells (18650)	4	500	2,000
Total (With Purchased)				**49,710**
Total (Without Purchased)				**13,110**

*Components already available from Nakuja Project inventory. Out-of-pocket expenses: KES 13,110. Funding sources: Personal contribution (KES 7,000), Nakuja Project allocation (KES 6,110), university facilities for fabrication (in-kind).

B Project Timeline

Implementation follows a 15-week schedule with critical milestones:

- **Weeks 1-4:** Proposal presentation, continuous presentation, literature review and design phase
- **Weeks 5-8:** Mechanical, electrical, and control design with interim report submission

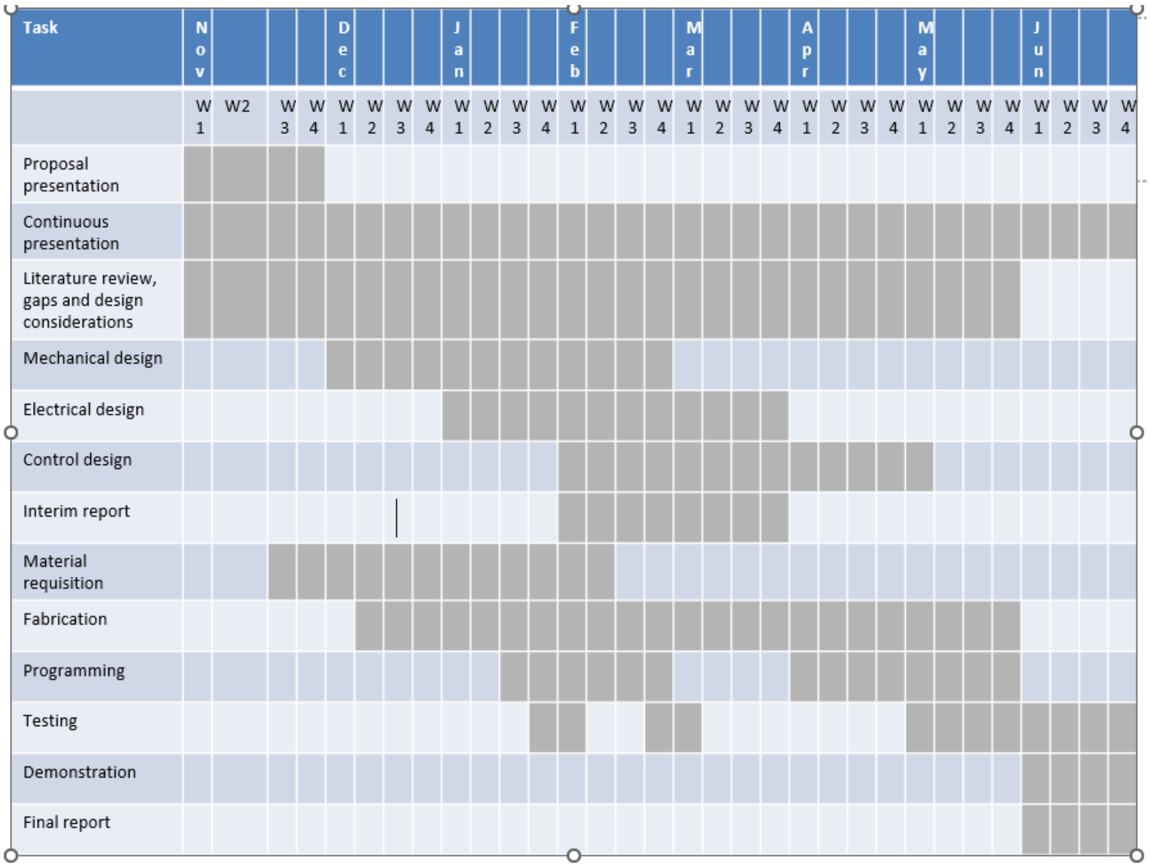

Figure B.1: 15-week project timeline showing task dependencies and critical path through design, fabrication, and testing phases

- **Weeks 9-11:** Material requisition, fabrication, and programming
- **Weeks 12-14:** Testing, demonstration, and final report preparation
- **Week 15:** Final report submission and project closeout

Critical path: PCB fabrication (2-week lead time), component procurement (3-week buffer). Risk mitigation: backup components ordered Week 4, 2-week weather contingency for launch operations.

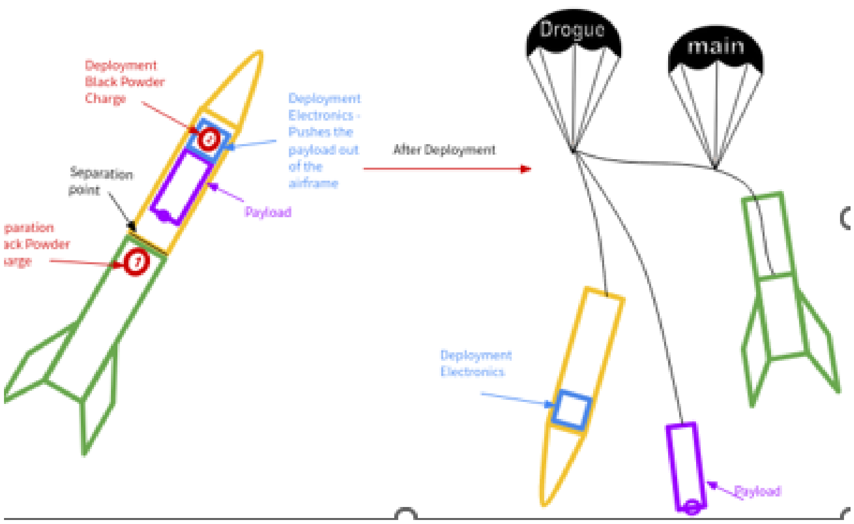

Figure C.1: Nakuja N3 rocket showing avionics bay configuration (reference design for N4 dual deployment architecture)

C Previous N4 Design References

Previous Nakuja missions (N1, N2, N3, N3.5) provide critical design heritage and lessons learned. The N3 single-deployment system identified key improvements needed for the N4 dual-deployment architecture, particularly in telemetry range extension (from 2km to 5+km) and pyrotechnic deployment reliability (see Figures C.2 and C.3).

The current design iterations (Figures C.2 and C.3) represent the latest improvements incorporating lessons from previous test campaigns, with enhanced vibration isolation and optimized circuit layout for reliability.

D Nakuja Project Resources

Project Website: `https://nakujaproject.com/`

GitHub Repository: `https://github.com/nakujaproject`

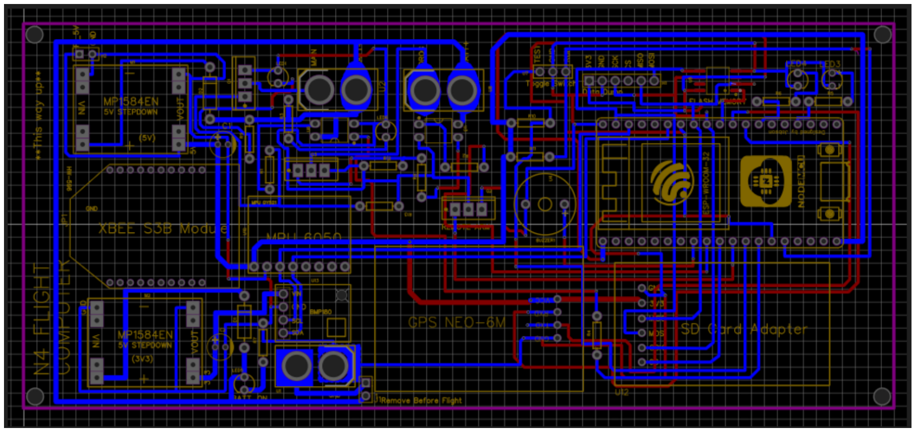

Figure C.2: Current N4 flight computer circuit design showing ESP32 microcontroller integration, XBee telemetry module, sensor interfaces (BMP180/MPU6050), MOSFET-based PWM ignition drivers, and power management circuitry

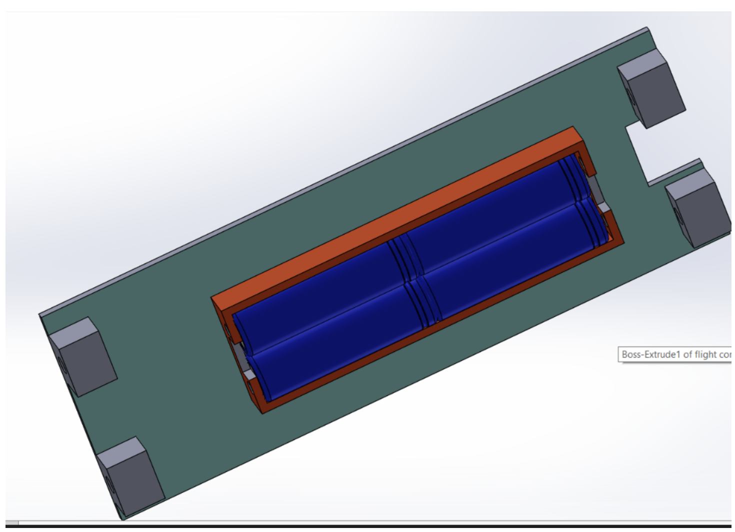

Figure C.3: Current flight computer holder design featuring 3D-printed PETG construction with integrated battery retention mechanism, vibration isolation mounts, and modular component placement for easy assembly and maintenance

The Nakuja Project maintains open-source repositories for:

- Flight computer firmware (ESP32-based)
- Ground station telemetry software
- PCB design files (KiCAD format)
- Simulation and trajectory analysis tools
- Recovery system control algorithms

All documentation is available under open-source licenses to support the student rocketry community.