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

Project Proposal

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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: [Your Name] Date

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Name: [Team Member 2] Date

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Acknowledgment

We would like to express our sincere gratitude to the Nakuja Project team for providing the opportunity to work on this critical recovery system for the N4 rocket mission.

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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].

[Placeholder: Dual Deployment Recovery System Diagram]

Figure 2.1: Dual deployment recovery system architecture showing drogue and main parachute deployment sequence

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].

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

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.

alternatives.

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 [10]. Combustion temperatures exceed 2000°C, requiring thermal isolation to prevent parachute damage [11].

[Placeholder: Explosion Cap Cross-Section]

Figure 2.2: Sealed explosion cap design showing thermal isolation and pressure channeling

2.4 Electronic Control Systems

The ESP32 platform offers dual-core architecture for parallel sensor processing and communication [12,13]. PWM ignition control enables precise thermal management, preventing wire burnout while enabling multiple tests [14].

2.5 Power and Structural Systems

LiPo batteries provide superior energy density but require BMS for safety [15,16]. High-G launch loads cause battery disconnection in spring-loaded holders [17]. Custom avionics holders provide vibration isolation and battery retention.

[Placeholder: Avionics Bay Assembly]

Figure 2.3: 3D-printed avionics holder with integrated battery retention and vibration isolation

2.6 Previous Nakuja Mission Analysis

Table 2.2 summarizes mission outcomes.

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

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**

2.7 Safety Standards and Guidelines

Amateur rocketry follows established safety protocols from organizations like Tripoli Rocketry Association [18]. Key safety considerations include proper pyrotechnic handling [10], adequate descent rates for safe landing [19], and ground station monitoring capabilities [11].

[Placeholder: System Integration Diagram]

Figure 2.4: Complete N4 recovery system showing integration of all subsystems

3 Design and Methodology

3.1 Project Objectives

3.1.1 Main Objective

To design and fabricate a reliable dual recovery system for the N4 rocket with extended telemetry range, ensuring mission success through enhanced communication capabilities, controlled deployment mechanisms, and comprehensive real-time monitoring systems.

3.1.2 Specific Objectives

1. Implement Digi XBee-PRO 900HP telemetry system for robust long-range data transmission exceeding 5km with ¡5% packet loss
2. Design and validate PWM-controlled ignition system for regulating nichrome wire temperature
3. Develop comprehensive feedback monitoring system for battery percentage and deployment pin continuity
4. Implement sealed explosion cap design for consistent parachute deployment
5. Design ruggedized 3D-printed avionics holder with vibration isolation

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 [17]. Design maintains center of gravity stability under high-G loads.

[Placeholder: PCB Schematic Diagram]

Figure 3.1: Custom PCB schematic showing ESP32, XBee-PRO 900HP, and PWM driver circuits

3.3.2 Electrical System Architecture

Hardware Components ESP32 dual-core microcontroller processes telemetry data [12]. XBee-PRO 900HP module provides 5+km range at 900 MHz [8]. Custom PCB eliminates loose connections [13].

PWM Ignition Control MOSFET-based PWM driver controls nichrome wire heating, preventing burnout while enabling reusable testing [14].

Power Management BMS monitors LiPo battery health [15, 16]. Real-time feedback transmits battery voltage and igniter continuity. Launch inhibit activates below 14.0V threshold.

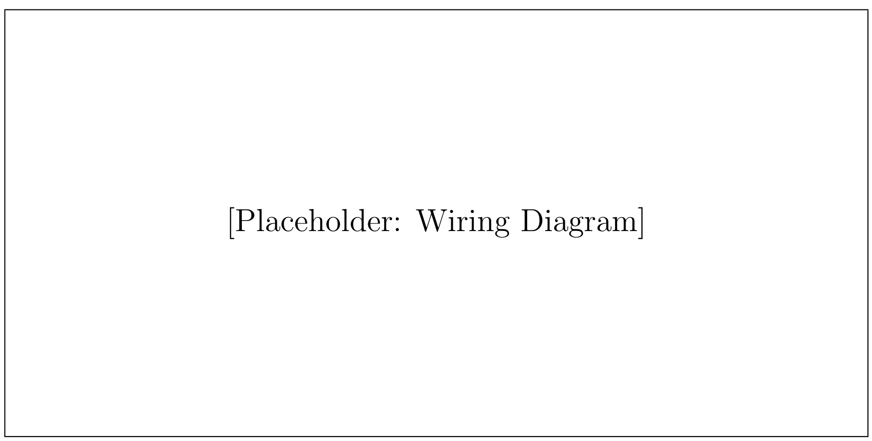

Figure 3.2: System wiring diagram showing power distribution and signal connections

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) [19]
- **Electronics**: Reliable PCB withstanding 15G+ vibration [17]
- **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.

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A Project Budget

Table A.1: Budget Breakdown

Component	Specification	Cost (KES)
XBee-PRO 900HP (2 units)	900 MHz, 15+ km range	15,000
ESP32 Development Boards	Dual-core, WiFi/BT	2,000
Custom PCB Fabrication	2-layer, FR4 substrate	5,000
LiPo Battery (3S, 2200mAh)*	11.1V, 25C discharge	4,000
BMS*	3S, 30A continuous	4,000
3D Printing Filament	PETG/PLA	3,000
Pyrotechnic Components	Nichrome wire, igniters, Crimson powder	4,000
Electronics Components	MOSFETs, regulators, passives, connectors	4,000
Miscellaneous	Wire, solder, hardware	1,000
Total		**42,000**

*Components already available from Nakuja Project inventory, reducing out-of-pocket to KES 30,000. Funding: Personal (KES 15,000), Nakuja Project (KES 15,000), university facilities (in-kind).

B Project Timeline

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

C Component Specifications

XBee-PRO 900HP: 902-928 MHz ISM band, up to 200 kbps data rate, 15 km outdoor LOS range, 24 dBm transmit power, -110 dBm sensitivity, 2.1-3.6V operation, -40°C to

Table B.1: Implementation Schedule

Week	Activity	Status
1-2	Literature review, requirements	Completed
3	System architecture design	In Progress
4	PCB schematic design	Planned
5	3D CAD modeling	Planned
4-6	Component procurement	Planned
6-7	PCB manufacturing, soldering	Planned
7-8	3D printing, assembly	Planned
9	Firmware development	Planned
10	Telemetry range testing	Planned
11	PWM ignition tests	Planned
11-12	Explosion cap deployment tests	Planned
12	Vibration/environmental testing	Planned
13	System integration testing	Planned
13-14	Documentation	Planned
14	Flight readiness review	Planned
15	Launch operations	Planned

+85°C, UART interface.

ESP32: Dual-core Xtensa LX6 (240 MHz), 520 KB SRAM, 4 MB flash, WiFi 802.11 b/g/n, BLE 4.2, 34 GPIO, 18-channel 12-bit ADC, 16-channel PWM, 2.2-3.6V operation, -40°C to +85°C.

LiPo Battery: 3S configuration, 11.1V nominal (12.6V max, 9.0V min), 2200 mAh capacity, 25C continuous discharge, 180g weight, XT60 connector.

D Testing Protocols

Telemetry Range Test: Transmit packets at 1 Hz, measure RSSI at 500m increments to 6 km. Success: RSSI ¿ -100 dBm at 5 km, ¡5% packet loss.

PWM Ignition Test: Apply PWM at 20-100% duty cycles, record thermal profile, verify ignition. Success: controlled temperature ramp, no burnout, repeatable 10+ cycles.

Explosion Cap Deployment: Test charge masses (0.5-1.5g), measure deployment force with load cell, inspect parachute. Success: clean separation, zero thermal damage, 200-400 N force, consistent across 5 tests.

Vibration/Shock Test: Shake table 5-500 Hz sweep, 15G shock impulse, verify continuity. Success: zero component displacement, no structural failure, maintained continuity.