Capstone Design: NRC Combat Robot

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Abstract—This capstone project involves Sweet Briar College students designing a beetleweight combat robot to compete in the National Robotics Challenge. The robot employs a Systems engineering approach to ensure that mechanical, electrical, and control subsystems operate as a single integrated unit. The methodology involved researching weapon types and drive systems, with concepts assessed through sketching, TinkerCAD, Fusion modeling, and physical prototyping. Electrical components were tested and simulated using an oscilloscope and multimeter to evaluate battery discharge characteristics and verify component performance under load conditions. Materials were assessed using standardized mechanical tests to evaluate structural suitability and were subsequently machined accordingly. Mechanical components were integrated with the control system throughout the prototyping process, including continuous validation, functionality tests, safety checks, and compliance with National Robotics Challenge verification criteria. The resulting robot design named Munchkin features a dual-weapon system consisting of a high-speed beater bar for heavy impact and an optimized ramming chassis. This design allows for a strategy that adapts to various opponents while adhering to competition regulations. Beyond technical milestones, the effort focuses on establishing repeatable design processes and team structures to allow the program to continue beyond the current members' graduation. The entire project cycle, from initial decision-making to post-competition analysis, is documented in an engineering file book to support future teams in tackling real-world engineering challenges.

Keywords—Combat Robotics, Beetleweight, Robotics, Coding

I. INTRODUCTION

The engineering program at Sweet Briar College emphasizes hands-on learning and multidisciplinary problem-solving. It is one of only two ABET-accredited women's college engineering programs in the United States [1]. As part of the senior capstone sequence, students are establishing the college's first competitive robotics team. The team participates in the National Robotics Competition (NRC), where collegiate teams design and operate combat robots under defined weight classes and safety regulations [2].

This project focuses on developing a beetleweight (under 3 lb) combat robot for the NRC competition. The robot is designed using a Systems engineering approach that integrates mechanical, electrical, and control subsystems. Its dual-weapon configuration combines a high-speed kinetic beater bar with a ramming chassis to enable flexible combat strategies. In addition to competition performance, the project establishes a scalable framework to support future robotics teams and ensure team continuity at Sweet Briar College.

II. OBJECTIVES AND REQUIREMENTS

A. Engineering Department & Robotics Team Building

The NRC robotics team at Sweet Briar College is collaborating with the Society of Women Engineers (SWE) Student Chapter to support team outreach and recruitment initiatives, helping expand awareness and continuity of the robotics program. The team seeks to bring together students from the Engineering, Arts, Business, and Science disciplines to create a more diverse and innovative design environment.

As part of long-term sustainability and NRC requirements, the team has documented and developed detailed engineering records, design decisions, and testing results to ensure future students can effectively understand, maintain, and continue advancing the robotics team at Sweet Briar.

B. National Robotics Competition

The competition's safety and operational evaluation criteria drive the primary constraints for the robotic system. The design must strictly adhere to 6 pages of safety requirements [2] to ensure the robot's clearance for competition. For example, a few NRC requirements are …

"Mechanical & Weapon Systems

- Weight limit compliance (REQ-1.1)
- No weapon contact with arena walls above 5 in (REQ-1.2)
- Visible weapon locks required (REQ-1.3)
- Locks must fully stop motion (REQ-1.4)
- Must allow lock/pin insertion during power-on (REQ-1.5)

"Electrical Power & Deactivation

- Voltage < 48V (REQ-2.1)
- Full power shutdown within 60s (REQ-2.2)
- Critical systems disconnectable within 15 s (REQ-2.3)

"Failsafes & Braking

- Safe/zero-energy fail state on power or signal loss (REQ-3.1)"

III. RESEARCH

A. Mechanical

Research for our combat robot's mechanical weapon and chassis highlights the critical collaboration between mobility, durability, and energy output. The design centers on a modular chassis that balances structural integrity with rapid maintainability, allowing for quick armor swaps and strategic reconfigurations. By utilizing DC motors for their superior power-to-weight ratio and low time constants, the drivetrain achieves the near-instantaneous acceleration required to maximize linear momentum and traction during engagement. Ultimately, the system is engineered to optimize energy transfer, leveraging high rotational speeds and mass distribution to convert battery power into devastating kinetic impact during collisions.

B. Materials

The material selection was conducted based on three major criteria. These include weight optimization, structural integrity, and fabrication efficiency. The chassis was 3D printed using Carbon Fiber PLA. It is a composite filament made of PLA (Polylactic Acid) infused with carbon fiber strands. These fibers will give the filament extra strength, stiffness, and a matte finish, giving the robot chassis higher rigidity and lightweight structural support [16].

C. Electrical, Computer, and Controls

The electrical research phase focused on evaluating microcontrollers, radio communication protocols, battery limitations, and the theoretical power requirements necessary to sustain a 3-minute combat match. Ensuring the robot maintains full mobility and weapon functionality requires a balance of current draw and battery capacity while actively preventing interference between subsystems.

1) Component Evaluation

Initial research into the control architecture required a rigorous comparison of teleoperation methods and motor systems to maximize responsiveness. Early concepts explored using a radio frequency gamepad paired with an Arduino IDE programmable logic controller (PLC). However, research into combat robotics arena environments revealed that programming protocols for game pads are highly susceptible to latency and signal dropping due to the original interference. Consequently, the team pivoted to evaluating dedicated 2.4GHz RC systems. The Radiolink remote system was selected due to its robust Frequency-Hopping Spread Spectrum (FHSS) protocol, which ensures zero-latency communication and complies with NRC radio safety standards. [5]

For the motive force, various DC gearmotors were evaluated. "Just Cuz Robotics" drive motors and their paired Electronic Speed Controllers (ESCs) were ultimately selected for the beetleweight class due to their optimal balance of high stall torque, compactness, and reliability in high-kinetic impact scenarios. Furthermore, during the evaluation of the Arduino Uno microcontroller and receiver integration, a tremendous oversight of centralized power systems was identified. When a heavy kinetic weapon initiates spin-up or impacts an opponent, it draws a massive current spike. In a single-battery system, this spike causes an instantaneous voltage drop (a "brownout"). If the Arduino (drawing roughly 50mA) and the Radiolink receiver (drawing roughly 30mA) experience this voltage sag, the logic systems will reset, resulting in a temporary loss of teleoperation. Consequently, the research concluded that a decentralized, multi-battery architecture was required to mechanically and electrically isolate the logic components from the high-current weapon and drive systems. [6]

2) Power and Runtime Calculations

To ensure the mechatronic system could survive the duration of an NRC match, theoretical power consumption and runtime calculations were conducted using standard Watts' Law and battery capacity formulas.

By analyzing the subsystems independently, the total estimated current load (I_{Load}) was segmented. For example, calculating the localized load for a centralized 9V baseline yielded the following:

$$W_{Load} = I_{Load} \times V \tag{1}$$

Assuming a combined draw of 6.08A, this configuration would yield a total continuous load of roughly 54.72W. Using the energy capacity equation (2) the battery life was estimates at 5.4minutes.

$$T_{minutes} = E_{Cap} / W_{Load} \tag{2}$$

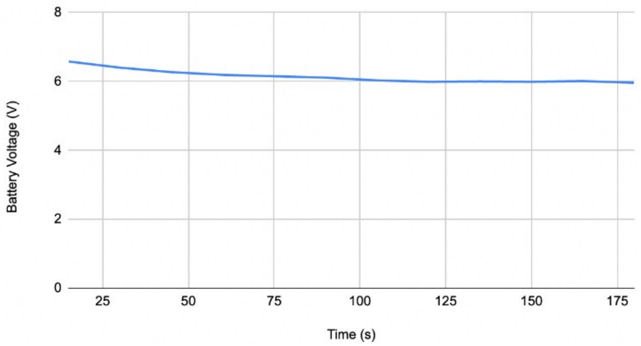

Fig. 1: Battery Voltage Loss vs Time, for 3min test, showing power supply validation.

While 5.4 minutes theoretically exceeds the 3-minute match duration, this mathematical model does not account for the instantaneous current spikes of the beater bar motor. This calculation was validated with a Voltage loss test running the beater bar for three minutes. The results of this test are in figure 1.

This validation further reinforced the necessity to abandon a single LiPo system in favor of dedicated batteries properly sized for the individual loads of the weapon, the 4S drivetrain, and the logic board.

IV. SYSTEMATIC DESIGN

A. Mechanical

Our project features a high-kinetic-energy offensive robot built into a compact frame. We've developed a hybrid "exo-skeleton" architecture using a 3D-printed PLA chassis reinforced by external aluminum plating, as seen in figure 2. A key innovation is our use of an internal honeycomb infill within the PLA; this geometric lattice acts as a high-frequency shock absorber, providing "bounce back" elasticity that dampens impact forces before they reach the sensitive internal electronics.

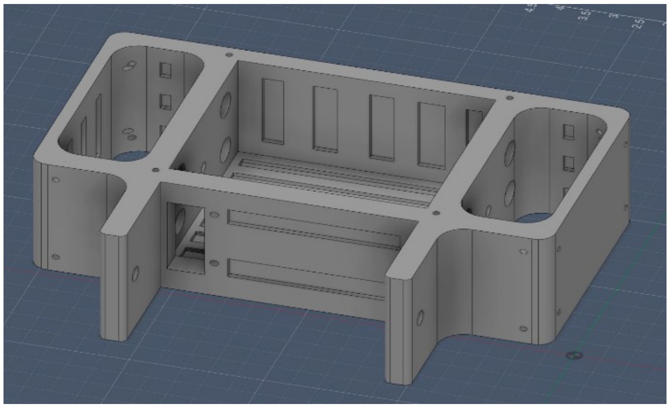

Fig. 2: Chassis Fusion 360 Design

The primary weapon is a 4-inch beater bar featuring an elongated 4.8-inch asymmetrical tooth. This can be seen at the bottom left of figure 3. By exceeding the width of the bar itself, this tooth profile ensures a wider engagement zone and deeper "bite" into opponents. The bar rotates on a dead-shaft assembly, which uses a stationary hardened axle to bridge the 4.7-inch chassis width, significantly increasing structural stiffness. To accommodate the drive system, we've integrated wheel wells into the chassis walls.

To manage the physics of such a powerful weapon, we positioned the batteries and motors in the rear third of the 9.6-inch chassis. This rearward Center of Gravity (CoG) is essential for counteracting gyroscopic precession, which is the tendency of the bot to tilt when turning with a spinning mass, and ensures the honeycomb core can dissipate hitting forces without the robot losing traction or "hopping" during an exchange.

B. Materials

Carbon Fiber PLA exhibits good tensile strength: 38 ± 4 MPa in the X-Y directions and 26 ± 2 MPa in the Z direction [3], along with measurable elongation before fracture. The higher tensile strength in the X-Y plane indicates that it can sustain relatively high loads along this orientation, while the lower strength in the Z direction suggests some anisotropy in load-bearing capability. Its impact strength (23.2 ± 3.7 kJ/m² unnotched, 7.6 ± 2.6 kJ/m² notched in X-Y; 7.8 ± 0.7 kJ/m² in Z) [3] indicates reasonable toughness, meaning the material can absorb moderate energy before fracturing. Combined with a density of 1.22 g/cm³ [3], the material balances load-bearing capacity and energy absorption with moderate ductility, making it suitable for applications where moderate mechanical resilience and impact tolerance are required.

C. Electrical, Computer, and Controls

Based on the foundational power research, the finalized electrical and control architecture of Munchkin is designed around a decentralized, three-position power requirement.

This physical topology decouples the high-draw mechanical actuators from the low-voltage Arduino Uno. The decentralized power distribution is primarily used to eliminate the risk of voltage sag and logic resets during high-kinetic impacts. The robot's power distribution is separated into three isolated power circuits: Logic Circuit (9V), Drive Circuit (4s LiPo), and Weapon Circuit (Dedicated 9V).

For the Logic Circuit, a single 9V battery is dedicated exclusively to powering the Arduino Uno microcontroller and the integrated Radiolink 2.4 GHz receiver. By isolating the logic board from the mechanical actuators, the system guarantees uninterrupted teleoperation and signal fidelity, even when the weapon or drive motors draw massive instantaneous current spikes.

For the Drive Circuit, mobility is powered by a single 4S Lithium Polymer (LiPo) battery. To distribute this power equally, the battery is connected to a parallel Y-harness. This harness splits the voltage perfectly between the two drive Electronic Speed Controllers (ESCs), which in turn power the independent Just Cuz Robotics drive motors.

For the Weapon Circuit, the beater bar is powered by its own independent battery, routed directly into a 20A ESC. The high-power distribution networks (the weapon and drive circuits) are wired to an easily accessible manual disconnect setup to satisfy NRC safety guidelines (REQ-2.2 and REQ-2.3) [2]. allowing the dangerous kinetic systems to be rapidly deactivated within the mandated 15-second window.

While the power supplies are decentralized, the signal architecture is completely centralized. Teleoperation is achieved via the handheld Radiolink transmitter. The onboard Radiolink receiver captures the driver's inputs and feeds them directly into the Arduino Uno. Arduino serves as the "brain." It processes the raw receiver inputs and translates them into Pulse Width Modulation (PWM) signals. The signal wires from all three ESCs (the two drive ESCs and the one weapon ESC) are routed back to the Arduino's General Purpose Input/Output (GPIO) pins. This ensures that while the motors draw their heavy currents from separate batteries, they take their precise operational commands strictly from the isolated Arduino.

In combat scenarios, the ESCs are subjected to severe thermal and electrical stress. Component degradation directly impacts motor efficiency, primarily through the heat-induced increase in the MOSFET on-resistance.

To mitigate these issues, the internal chassis layout was systematically designed to separate the three batteries, the three ESCs, and the logic components. The logic circuitry is securely housed within internal enclosures to isolate the sensitive microelectronics from high-frequency weapon vibrations, while the 20A weapon ESC and drive ESCs are positioned to allow for passive thermal dissipation during the 3-minute match duration.

V. MANUFACTURING AND ASSEMBLY

The above-described subsystems were assembled as shown in figure 3. For clarity, some of the parts are shown outside of the chassis.

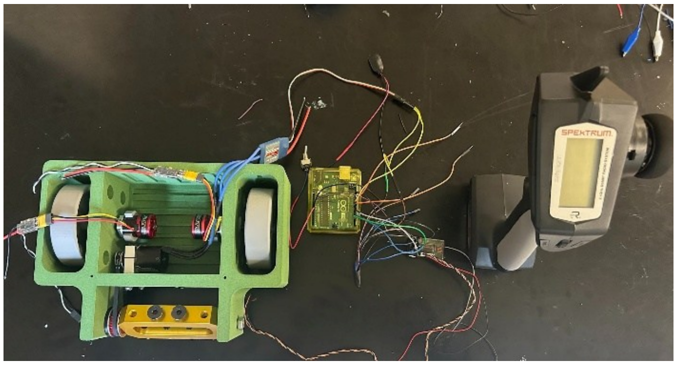

Fig. 3: Chassis and subsystem connections, and remote controller.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to the Sweet Briar Department of Engineering for their technical and administrative support and for their invaluable guidance and resources throughout the duration of this project. Furthermore, we are deeply grateful to our mentors, Lem Curran and Gunther, for their dedicated mentorship, constant encouragement, and insightful feedback over the past year.

REFERENCES

[1] Sweet Briar College, “Accreditation,” Engineering Science—About the Program, 2026. [Online]. Available: https://www.sbc.edu
[2] National Robotics Challenge, “About the NRC,” 2026. [Online]. Available: https://www.thenrc.org
[3] Bambu Lab, “Carbon Fiber PLA Filament Technical Datasheet,” 2023.
[4] S. Becker, N. Lechner, R. Almazrouei, and B. Romero, “Design of a BattleBot system to maximize the probability of winning the competition,” in Proc. Annu. Gen. Donald R. Keith Memorial Conf., West Point, NY, USA, Apr. 2022.
[5] J. Zhao, B. Yin, Z. Zeng, P. Yuan, and Y. Li, “Application and exploration of competitive combat robot technology in engineering education,” in Proc. IEEE 12th Int. Conf. Engineering Education (ICEED), Shah Alam, Malaysia, 2023, pp. 148–152.
[6] G. E. Gorospe, “A study of the degradation of electronic speed controllers for brushless DC motors,” Oct. 2025.
[7] P. Sattayasoonthorn and J. Suthakorn, “Battery management for rescue robot operation,” in Proc. IEEE Int. Conf. Robotics and Biomimetics (ROBIO), Qingdao, China, Dec. 2016.
[8] R. Hajare and M. Gowda, “Design and development of combat robot for military applications,” Int. J. Robot. Autom. Syst., vol. 9, no. 2, pp. 125–132, Jul. 2020.
[9] T. Mikołajczyk et al., “Energy sources of mobile robot power systems: A systematic review and comparison of efficiency,” Appl. Sci., vol. 13, no. 13, 2023.