ECE 445

SENIOR DESIGN LABORATORY

Design Document

ABCD

Antweight Battlebot Champion Destroyer

Team No. 30

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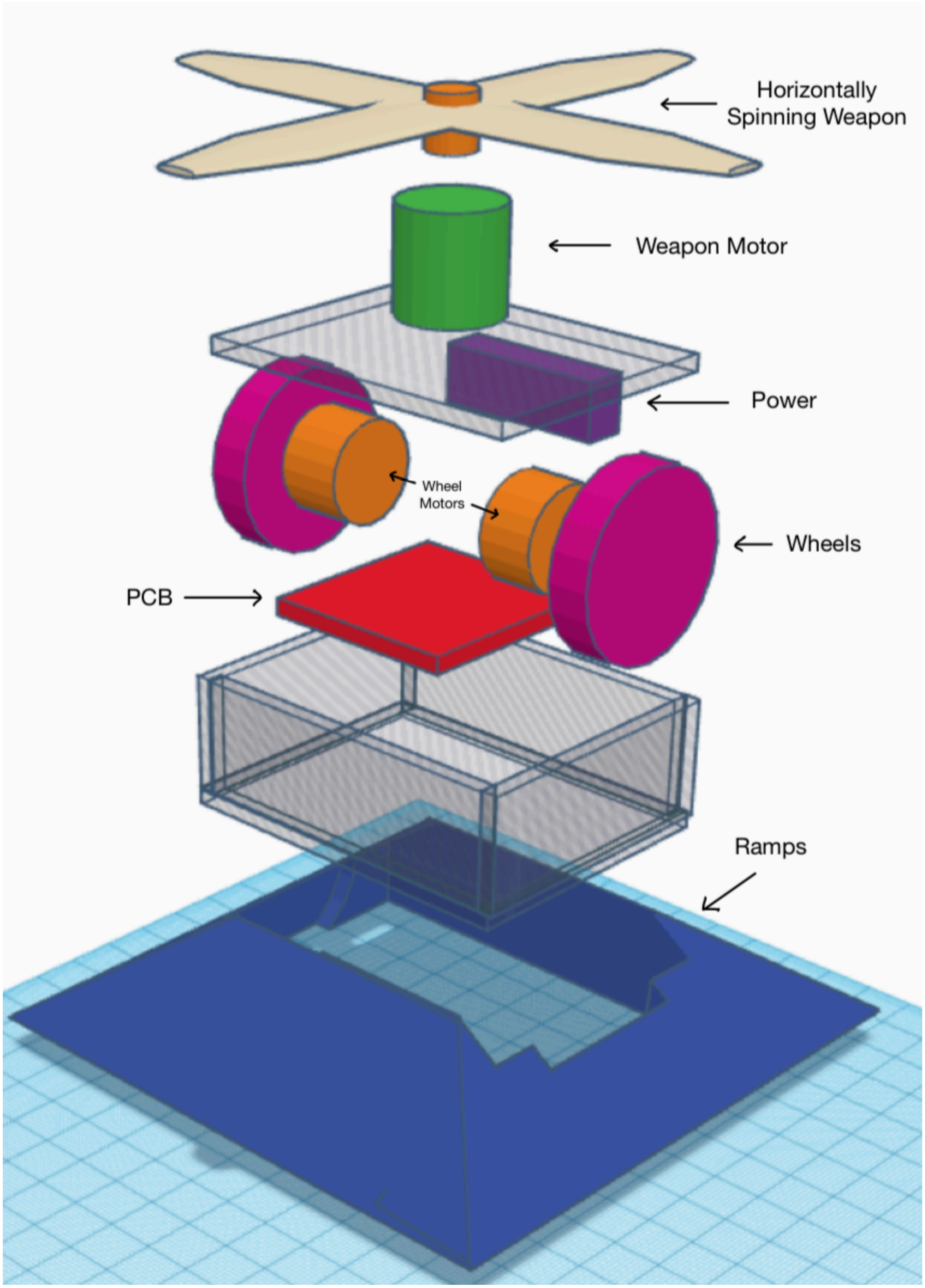
Introduction

We are tasked with designing and building a PC-controlled battlebot for an elimination-style competition, as per Prof. Gruev's instructions. Battlebots engage in 2-minute combat rounds, showcasing unique designs within specific constraints. These restrictions present significant challenges to the design process, including a maximum weight of 2 lbs, the use of only 3D-printed parts for the chassis and weapon (limited to PET, PETG, ABS, or PLA/PLA+), wireless control via Bluetooth or WiFi-enabled microcontroller, visible mobility, indicator lights for power and optional wireless connection, a battery voltage limit of 16V, and a manual disconnect for safety. Additional rules govern pneumatic weapons (under 250 psi with a bleed valve) and spinning weapons (60-second stop time after power disconnection). A custom PCB must also be implemented.

To address these challenges, our proposed solution involves developing a battlebot using an STM32 microcontroller with a WiFi module for laptop-based wireless control. The design incorporates three gear motors: two for the drivetrain and one high-RPM motor for the weapon, a horizontal spinning blade. The chassis will be 3D-printed using PETG filament, optimized for weight and durability, featuring ramps on all sides to lift opponents. We'll use lightweight 3D-printed wheels coated with Plasti-dip for traction and defense. The weapon will be 3D printed using a durable material capable of withstanding ≥1000 rpm without fragmenting on impact. This solution aims to maximize performance within the given constraints, offering a unique combination of mobility, weapon effectiveness, and structural integrity while adhering to all competition rules.

Visual Aid



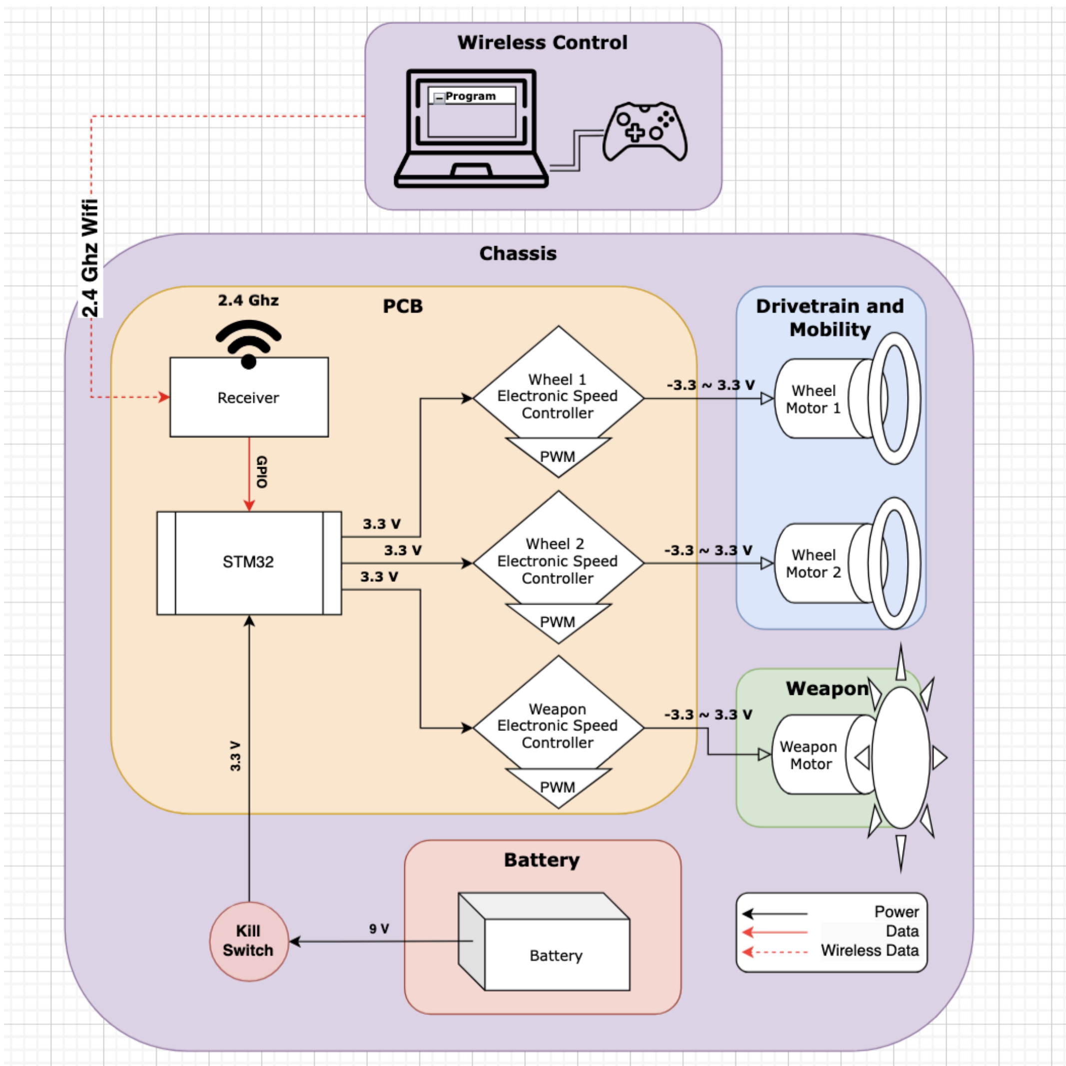
Horizontally
Spinning Weapon
Weapon Motor
Power
Wheel
Motors
Wheels
PCB
Ramps

High Level Requirements List

To be considered successful, we aim to hit the following goals.

- Proper wireless communication must be established and the bot should respond precisely (acceleration increases smoothly with joystick controls) and swiftly (500-1000 ms).
- The entire battle bot should meet the 2lb weight requirement, be made of strictly permitted materials, and be powered the entire battle duration.
- The battlebot's weapon should operate according to rules and be able to maintain structural integrity at rpm > 500 including on impact.

Design

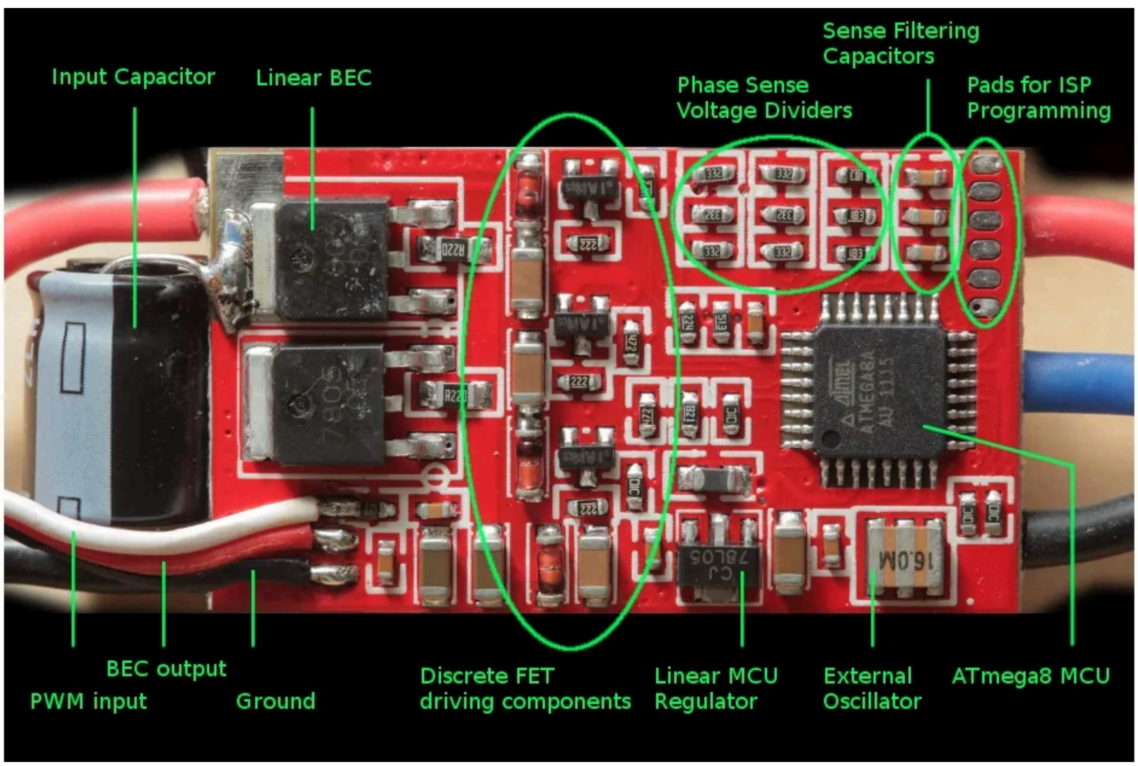


Subsystems

Wireless Control: The main purpose of this subsystem is to communicate driving directions with the STM32WB microcontroller using BLE (Bluetooth Low Energy) from a Windows Laptop, with an attached console controller.
This subsystem is the topmost subsystem in terms of interfacing and creates the signals that drive the entire bot. We will program a lightweight (C#/Python) interface that will send a constant feed of Left and Right Joystick forward and backward intensity that corresponds to each wheel, the Right Trigger will be routed to the Weapon Speed and the Home Button will be the remote kill switch to terminate. This interface will send text data to the MCU which will return a confirmation, and we will use this handshake to find our latency which is targeted to be < 1000 ms. This controller setup is an intuitive design that follows many video games and will enhance the user experience and mobility when controlling the bot.

Drive Train and Mobility: This subsystem contains and manages all locomotion of the battlebot, with the use of two electronic speed controllers (ESCs), whose control of the drive motors dictates the bot's velocity. This subsystem will take input from the microcontroller in the form of a 50 Hz PWM signal with extremely precise width, which modulates the motor speed and direction based on the pulse width. We will also have to shift up the 3.3 V signal from the MCU to the 5 V rating of the motor. The exact timing of the pulse widths will be determined based on the requirements of the ESC and may vary depending on its design. The ESC interprets this signal and adjusts the power supplied to the gear motors accordingly, converting the PWM into a modulated output that controls motor speed and torque. The ESC then passes this modulated power signal to the gear motors, ensuring precise velocity control and responsiveness within our goal of 1000 ms.

This subsystem will have low-torque gear motors with enclosed gearboxes to drive the wheels. These kinds of motors will have enough precision to provide controlled movement while maintaining sufficient torque to overcome minor obstacles during combat.
The wheels will be approximately 3 inches in diameter and 3D-printed to be as hollow as possible while still maintaining structural integrity and durability, furthermore, they will be protected by the armor as shown in the visual aid. For improved traction and mobility, we are considering coating the wheel treads with Plastidip or a similar high-friction grippy material based on testing.
A key point of discussion is the gear ratio. We are targeting a maximum motor speed of around 600-750 RPM to achieve a balance between speed and maneuverability.



Chassis: The chassis serves as the structural foundation of our project. It is designed using a combination of PLA+ and PETG to balance strength and weight constraints. PLA+ is used for the main structure due to its lightweight properties, while PETG is reserved for key stress points, such as weaponry. The outer design, as seen in the visual aid, contains ramps that serve a dual purpose: protect electronic components and wheels and redirect opponent bots into our horizontally spinning blade. These features ensure structural integrity and minimize damage taken while maintaining the 2lb limit. The chassis width is going to be 0.18m ± 0.01m.

The chassis interfaces with other subsystems through strategically placed mounting points that secure the motors, control electronics, and battery, ensuring effective stability and minimal vibrations. To verify that our design meets the high-level requirements, we will conduct tests to confirm that the chassis can withstand collision forces up to 30 N and maintain its structure under impact while keeping the overall weight within limits.

Weaponry: The weaponry subsystem of our battle-bot features a horizontally spinning blade designed to damage, flip, and destabilize opponent bots when used in conjunction with the ramps placed around the bot. This subsystem contributes to the high-level requirements by ensuring offensive capabilities while adhering to weight and competition rules. The blade, constructed from 3D-printed PETG, has pronged ends to maximize damage during impact, with PETG chosen for its strength and impact resistance. The blade is driven by a high-torque motor centrally mounted for optimal balance and responsiveness, allowing for controlled attacks at a speed of 493 RPM (within a tolerance range of 425-575 RPM).

The motor and blade assembly are mounted on the chassis in a way that minimizes vibrations, ensuring overall stability. The blade's mass of 0.15 kg ± 0.01 kg and radius of 0.09 m ± 0.005 m were specifically chosen to optimize rotational inertia for effective strikes. The blade is designed to withstand impact forces of up to 30 N ± 2 N without structural compromise, and these parameters will be verified through thorough physical testing. The Requirements and Verification (R&V) process will include tests such as verifying the rotation speed, impact resilience, and material durability.

Power: The power subsystem of our battlebot is designed around a 9V D-cell battery that powers all key components, including the drivetrain, PCB, and weaponry. This battery was chosen to balance size, weight, and power output, allowing us to meet the strict 2lb weight limit while ensuring adequate power for competitive performance. If necessary for enhanced capabilities, we may upgrade to a 14.8V LiPo battery to support higher current requirements for the motors and increase endurance. We chose 9V as an initial voltage as it provides sufficient power to handle all operational demands while minimizing excess weight.

The power subsystem interfaces with other components by supplying regulated voltage. Specifically, the blade motor requires 2.5 A to achieve the target speed of

493 RPM, while each drivetrain motor draws 1.5 A under normal operation, with peak draw potentially reaching 2 A during maneuvers or under heavy load. The STM32 microcontroller requires 500 mA for reliable operation. This means that the power system must sustain a total draw of up to 7 A under peak conditions. Additionally, the power system includes a remote kill switch for safety, which is required to shut down all systems—including the weapon—within 60 seconds of activation, as per competition regulations.

The Requirements and Verification (R&V) process will ensure all design aspects meet the set goals. This includes verifying battery capacity to sustain the 7 A peak current draw for the entire two-minute match, monitoring voltage output across subsystems to ensure stability, and testing the remote kill switch for responsiveness.

Requirements and Verifications Table

Subsystem	Requirements	Verifications
Wireless Control	1.1 The system must establish a BLE connection between the Windows laptop and the STM32WB microcontroller with a latency of < 1000 ms. 1.2 The control interface must accurately translate joystick movements to wheel control signals with a precision of ±5% of the full range. 1.3 The weapon control (Right Trigger) must provide at least 10 distinct speed levels between 0% and 100% power. 1.4 The remote kill switch (Home Button) must completely cut power to all motors within 500 ms of activation.	**Equipment**: Laptop with BLE capability and control software, STM32WB microcontroller, oscilloscope, digital multimeter, and fully assembled battlebot. **Procedure**: Set up the laptop and microcontroller with the control software. Latency Test (Req 1.1): a. Use the oscilloscope to measure the time between sending a command from the laptop and receiving the confirmation from the microcontroller. b. Repeat the measurement and calculate the average latency. Joystick Precision Test (Req 1.2): a. Move each joystick to 25%, 50%, 75%, and 100% of its range in both forward and backward directions. b. For each position, measure the corresponding output signal from the microcontroller using the multimeter. c. Compare the measured values to the expected values.

		Weapon Control Test (Req 1.3): a. Gradually increase the Right Trigger from 0% to 100%. b. Use the oscilloscope to measure the PWM signal output at 10 evenly spaced intervals. c. Verify that each measurement corresponds to a unique duty cycle. Kill Switch Test (Req 1.4): a. Operate the battle bot at full speed with the weapon active. b. Activate the kill switch while monitoring the power lines to the motors with the oscilloscope. c. Measure the time between kill switch activation and power cut-off. d. Repeat the test. **Results Presentation:** Req 1.1: Present the average latency in a table. Req 1.2: Present the data in a table showing expected vs. actual values for joystick positions. Req 1.3: Present the data in a graph showing trigger position vs. PWM duty cycle. Req 1.4: Present the data in a table showing the cut-off time for each test. **Pass/Fail Criteria:** Req 1.1: Pass if the average latency is < 1000 ms. Req 1.2: Pass if all measurements are within ±5% of the expected values. Req 1.3: Pass if at least 10 distinct levels are identifiable. Req 1.4: Pass if all trials show a cut-off time < 500 ms.
Drive Train and Mobility	2.1 The drive motors must achieve a maximum speed of 600-750 RPM when supplied with full power. 2.2 The ESCs must accurately interpret PWM signals from the	**Equipment**: Tachometer, power supply, signal generator, oscilloscope, ESCs, drive motors, stopwatch, measuring tape, smooth test surface, fully assembled battlebot.

	microcontroller, with a linear response within ±3% across the entire 0-100% range. 2.3 The wheels must provide sufficient traction to accelerate the bot from 0 to its maximum speed within 2 seconds on a smooth surface.	**Procedure**: Motor Speed Test (Req 2.1): a. Supply full power to each drive motor individually. b. Use the tachometer to measure the RPM of each wheel. c. Repeat the measurement 5 times for each wheel. ESC Response Test (Req 2.2): a. Generate PWM signals corresponding to 0%, 25%, 50%, 75%, and 100% throttle. b. Apply each signal to the ESCs and measure the voltage output to the motors using the oscilloscope. c. Compare the measured output to the expected linear response. Acceleration Test (Req 2.3): a. Mark a starting line and a distance of 3 meters on the test surface. b. Place the bot at the starting line and apply full throttle. c. Measure the time it takes to reach the 3-meter mark. d. Repeat the test 5 times. **Results Presentation:** Req 2.1: Present the data in a table showing the RPM for each trial and wheel. Req 2.2: Present the data in a graph showing input PWM vs. output voltage. Req 2.3: Present the data in a table showing the time for each acceleration trial. **Pass/Fail Criteria:** Req 2.1: Pass if the average RPM for each wheel falls within the 600-750 RPM range. Req 2.2: Pass if all points fall within ±3% of the ideal linear response. Req 2.3: Pass if the average time is ≤ 2 seconds.
Chassis	3.1 The chassis must be able to	**Equipment**:

	withstand collision forces of up to 30 N without structural deformation. 3.2 The overall battlebot mass must not exceed 0.9 kg ± 0.05 kg to stay within the weight requirement for the competition. 3.3 The chassis must provide stable mounting points for motors, battery, and control system	Force gauge, digital scale, high-speed camera, fully assembled battlebot. **Procedure**: Collision Test (Req 3.1): a. Apply a 30 N force at multiple critical points on the chassis using the force gauge. b. Record if any deformation occurs. Weight Test (Req 3.2): a. Weigh the fully assembled chassis on the digital scale. b. Ensure the weight falls within the target range of 0.9 kg ± 0.05 kg. Vibration Test (Req 3.3): a. Operate the bot at full speed and use a high-speed camera to visually assess the movement of mounted components. **Results Presentation:** Req 3.1: Present video or images showing the results after applying the force. Req 3.2: Present the weight measurements in a table. Req 3.3: Present video footage with observations on the lack of part displacement. **Pass/Fail Criteria:** Req 3.1: Pass if no deformation is detected after the application of 30 N force. Req 3.2: Pass if the measured weight falls within 0.9 kg ± 0.05 kg. Req 3.3: Pass if no excessive movement or vibrations are detected.
Weaponry	4.1 The spinning blade must achieve and maintain a rotational speed of 493 RPM ± 82 RPM at full power. 4.2 The blade must have a mass of 0.15 kg ± 0.01 kg and a radius of 0.09 m ± 0.005 m.	**Equipment:** Tachometer, power supply, precision scale with 0.1 g resolution, digital caliper, force gauge, rigid test fixture, fully assembled weapon system.

	4.3 The blade and its mounting must withstand impact forces of up to 30 N ± 2 N without structural failure.	**Procedure:** Blade Speed Test (Req 4.1): a. Apply full power to the weapon motor. b. Use the tachometer to measure the RPM of the blade once it reaches steady state. c. Maintain full power for 2 minutes, taking RPM measurements every 30 seconds. Blade Dimensions Test (Req 4.2): a. Weigh the blade using the precision scale. b. Measure the radius of the blade from the center of rotation to the tip using the digital caliper. c. Repeat each measurement 3 times. Impact Resistance Test (Req 4.3): a. Secure the weapon system to the test fixture. b. Apply a 30 N force to the tip of the blade using the force gauge. c. Inspect the blade and mounting for any signs of damage or deformation. d. Repeat the test at 4 different points around the blade. **Results Presentation:** Req 4.1: Present the data in a graph showing RPM over time. Req 4.2: Present the data in a table showing each measurement for mass and radius. Req 4.3: Document the results in a table, noting any observed damage. Include photos before and after testing. **Pass/Fail Criteria:** Req 4.1: Pass if all measurements fall within the range of 411-575 RPM. Req 4.2: Pass if the average mass is between 0.14-0.16 kg and the average radius is between 0.085-0.095 m. Req 4.3: Pass if no structural failure or permanent deformation is observed in any test.

Power	5.1 The battery must provide sufficient power to maintain the operation of all subsystems, sustaining a peak current draw of 7 A for the entire two-minute match. 5.2 The voltage supplied to the blade motor, drive motors, and control electronics must remain within ±5% of their nominal values during operation. 5.3 The remote kill switch must completely cut power to all subsystems within 60 seconds of activation.	**Equipment**: Ammeter, digital multimeter, oscilloscope, stopwatch, fully assembled battlebot. **Procedure**: Battery Capacity Test (Req 5.1): a. Run the battlebot for two minutes at peak operational settings. b. Monitor the current draw with the ammeter and ensure it remains 7 A or below. Voltage Regulation Test (Req 5.2): a. During operation, measure the voltage output to each motor and control subsystem using a digital multimeter. b. Verify that the voltage remains within ±5% of nominal values throughout operation. Kill Switch Test (Req 5.3): a. Run the bot at full speed, then activate the remote kill switch. b. Use a stopwatch to measure the time taken for power to be cut off. c. Repeat the test five times for consistency. **Results Presentation:** Req 5.1: Present a current vs. time graph showing the two-minute match. Req 5.2: Present a table showing measured voltages with acceptable ranges. Req 5.3: Present the cut-off times recorded for each test in a table. **Pass/Fail Criteria:** Req 5.1: Pass if the current remains 7 A or below for the duration of the match. Req 5.2: Pass if all voltages stay within ±5% of their nominal values. Req 5.3: Pass if power is cut off within 60 seconds for all trials.

2.4 Tolerance Analysis

Parameters:

- Maximum bot mass (M) = 0.9 kg
- Blade mass (m) = 0.15 kg
- Blade radius (r) = 0.09 m
- Desired impact force (F) = 30 N
- Bot width = 0.18 m

Analysis:

1. Moment of inertia (I) of the blade: $I = (1/2) * m * r^2 = 0.5 * 0.15 * 0.09^2 = 0.000608\ kg \cdot m^2$
2. Angular velocity (ω) required for the desired impact force: $F = m * r * \omega^2$ $\omega = sqrt(F / (m * r)) = sqrt(30 / (0.15 * 0.09)) \approx 51.64$ rad/s Converting to RPM: $51.64 * (60 / (2\pi)) \approx 493$ RPM
3. Angular momentum (L) of the blade: $L = I * \omega = 0.000608 * 51.64 \approx 0.0314\ kg \cdot m^2/s$
4. Gyroscopic precession torque (τ) when the bot turns: Assume a turning rate (Ω) of 2.5 rad/s $\tau = L * \Omega = 0.0314 * 2.5 \approx 0.0785\ N \cdot m$
5. Compare the gyroscopic torque to the bot's weight: Bot's weight moment = $M * g * (width/2)$ Weight moment = $0.9 * 9.81 * 0.09 \approx 0.795$ N·

Tolerance range:

- Lower bound: 425 RPM (to maintain sufficient impact force)
- Upper bound: 575 RPM (to limit gyroscopic effects)

Feasibility: The calculated optimal speed of 493 RPM falls within our new tolerance range. The gyroscopic torque (0.0785 N·m) is still significantly less than the bot's weight moment (0.795 N·m), suggesting that the bot should remain stable during turns, even at this smaller scale.

Considerations:

1. Motor selection: We need a small, light motor capable of reaching higher RPMs (425-575 RPM range) to maintain effectiveness at this scale.
2. Control system: The control system must be more precise to manage the higher rotational speeds within the tolerance range.
3. Structural integrity: With the mass available for structural components, we need to ensure the chassis can withstand the forces generated by the faster-spinning weapon.

4. Heat management: Higher RPMs may generate more heat, so we need to consider cooling solutions for the motor and control systems.
5. Power supply: We must select a battery that can provide sufficient power for the higher RPM motor while staying within the weight constraints.

Conclusion: The battle bot having a maximum mass of 2 lbs presents challenges, particularly in terms of maintaining weapon effectiveness while ensuring stability. Our analysis shows that a blade speed of 425-575 RPM should provide a good balance between impact force and controllability.

The higher rotational speeds required at this scale introduce additional considerations for motor selection, control precision, structural design, heat management, and power supply. However, with careful component selection and design optimization, creating an effective battlebot at this scale is feasible.

To mitigate risks to project success, we should:

1. Prioritize lightweight yet durable materials for construction
2. Invest in high-quality, precise control components
3. Conduct thorough testing of the weapon system at various speeds
4. Optimize the chassis design to maximize stability and protection with minimal weight.

Cost and Schedule

Cost Analysis: Labor: 50$/hour x 3 x 60 hours to complete = $9000 TOTAL
Machine Shop: We are currently not planning on using any machine shop parts help. We went for one consultation on motors to be used. Furthermore, we will be using a personally owned 3d printer at no additional cost
Senior Design Lab Resources: We are planning to utilize the soldering and testing resources in the Senior Design Lab including a soldering iron, an oscilloscope, a Digital Multimeter, and DC Power Supplies.

Description	Part Number	Unit Price	Quantity Needed
PCB			
STM32WB Microcontroller	STM32WB	$10.00	1
Electronic Speed Controllers (ESCs)			
Linear MCU Regulator	TBD	$0.50	1
Linear BEC	TBD	$1.00	2
Discrete FET Driving Components	TBD	$0.75	6
Phase Sense Voltage Dividers	TBD	$0.30	6

Sense Filtering Capacitors	TBD	$0.20	6
Pads for ISP Programming	ATmega8	$5.00	1
ATmega8 Microcontroller (MCU)	TBD	$1.00	1
External Oscillator	TBD	$1.11	2
MOSFETs	N/A	$0.5	5
Low-Torque Gear Motors	20mm Low Noise Micro Planetary Gear Motor	$5.00	3
Chassis			
PETG Filament 1kg		$16	1
3D-Printed Wheels	N/A	$0	2
Plastidip/High-Friction Coating		$9	1
Battery Charge IC (MCP73844-840I/MS)	MCP73844-840I/MS	$1.78	1
Battery Holder	1123	$5.69	1
Boost Converter IC	LM2585S-12/NOPB	$10.41	1
Schottky Diode	SS24FL	$0.45	1
GPS IC	NEO-M9N-00B	$27.00	1
ADC	ADS1113IDGST	$6.49	1
0.1uF Capacitor	T491A104K035AT	$0.62	3
10uF Capacitor	EEE-FN1E100R	$0.50	2
100uF Capacitor	16SVPC100M	$1.19	2
220uF Capacitor	UUD1C221MCL1GS	$0.40	2
50kΩ Resistor	RT0603BRD0750KL	$0.33	2
10Ω Resistor	RT1206FRE1310RL	$0.14	2
1kΩ Resistor	RT0603FRE131KL	$0.10	2
Miscellaneous Wires		$0.1	10
Manual Kill Switch	L101011MS02Q	$2.26	1
Battery	9V	$2	2
Sum		$136.98	

Schedule

Week 6 (9/30 - 10/6): Complete Design Document
Week 8 (10/14 - 10/20): Order PCB and Parts
Week 9 (10/21 - 10/27): Complete Prototype 1
Week 12 (11/11 - 11/17): Complete Prototype 2
Week 13 (11/18 - 11/24): Mock Demo
Week 15 (12/2 - 12/8): Final Demo
Week 16 (12/9 - 12/15): Final Presentation and Paper Submission

Ethics and Safety

Expand upon the ethical and safety issues raised in your proposal to ensure they are comprehensive. Add any ethical and safety concerns that arose since your proposal.

A. User safety: The spinning weapon and the potential for high-speed collisions pose risks to operators and spectators.
B. Battery safety: Lithium polymer (LiPo) batteries, commonly used in such projects, can be dangerous if damaged or improperly handled.
C. Electrical safety: The custom PCB and wiring could present shock hazards if not properly insulated.
D. Mechanical safety: Rapidly moving parts like wheels and weapons can cause injuries if touched during operation.
E. Environmental impact: The use of 3D-printed plastics raises concerns about waste and recyclability.
F. Ethical use: While designed for competition, the skills and technologies involved could potentially be misused for harmful purposes.

Document procedures to mitigate the safety concerns of your project. For example, include a lab safety document for batteries, human/animal interfaces, aerial devices, high-power, chemicals, etc. Justify that your design decisions sufficiently protect both users and developers from unsafe conditions caused by your project.

A. Projects dealing with flying vehicles, high voltage, or other high risk factors, will be required to produce a Safety Manual and demonstrate compliance with the safety manual at the time of demo.

1. User safety:
    a. Implement a robust, shatterproof enclosure around the spinning weapon.
    b. Establish a marked safety perimeter around the competition area.
    c. All operators are required to wear safety glasses.
    d. Install an emergency stop button that immediately cuts power to all systems.
2. Battery safety:
    a. Use LiPo-safe bags for storage and charging.
    b. Implement over-discharge protection in the circuit design.
    c. Create a detailed battery handling and disposal protocol.
    d. Train all team members in proper LiPo battery safety procedures.
3. Electrical safety:
    a. Ensure all wiring is properly insulated and secured.
    b. Use strain relief on all connections to prevent accidental disconnections.
    c. Implement fuses or circuit breakers to avoid overcurrent situations.
    d. Conduct regular inspections of all electrical components.

4. Mechanical safety:
    a. Design protective covers or guards for all moving parts.
    b. Implement a software-based motor lock-out when the bot is not in combat mode.
    c. Create a pre-operation checklist to ensure all mechanical systems are secure.
5. Environmental impact:
    a. Choose recyclable or biodegradable filaments when possible.
    b. Implement a recycling plan for damaged or obsolete parts.
    c. Minimize waste by optimizing 3D printing processes and reusing materials where possible.
6. Ethical use:
    a. Develop and adhere to a code of conduct for the team.
    b. Limit the dissemination of detailed design information to prevent misuse.
    c. Focus on the educational and competitive aspects of the project in all communications.

Citations: Any material obtained from websites, books, journal articles, or other sources not originally generated by the project team must be appropriately attributed with properly cited sources in a standardized style such as IEEE, ACM, APA, or MLA.

https://www.st.com/en/microcontrollers-microprocessors/stm32wba-series.html