Widener University
School of Engineering

Skywalker - Autonomous Self-Charging Hexacopter Drone

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Senior Project Team #17

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i. Disclaimer

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iv. List of Terms

Ardupilot	An open source, unmanned vehicle Autopilot Software Suite
CCW	Counterclockwise
CW	Clockwise
ESC	Electronic Speed Control
FAA	Federal Aviation Administration
FC	Flight Controller
FCC	Federal Communications Commission
GPS	Global Positioning System
IMU	Internal Measurement Unit
INS	Inertial Navigation System
Kv	Constant velocity (rpm/v)
LiDAR	Light Distance And Ranging
LiPo	Lithium Polymer
Li-Ion	Lithium Ion
MAVLink	The Micro-Air Vehicle Communications Protocol
NTRIP	Networked Transport of RTCM via Internet Protocol
OSHA	Occupational Health and Safety Administration
PDB	Power Distribution Board
PWM	Pulse Width Modulation
RPM	Revolutions per Minute
RTCM	Radio Technology Commission for Maritime Services
RTK	Real Time Kinematic
RTH	Return to Home
SoC	State-of-Charge
TWR	Thrust Weight Ratio
UAV	Unmanned Aerial Vehicle
VLOS	Visual Line of Sight

v. List of Units

A	Amp
dBi	Decibel Isotropic
dBm	Decibel Milliwatt
Ghz	Gigahertz
kg	Kilogram
Kv	Constant velocity (RPM/Volt)
MHz	Megahertz
mW	Milliwatt
V	Voltage
W	Watt

vi. Executive Summary

This research project builds upon work completed the previous year, which demonstrated the capability of a UAV's automated flight system to land on charging station platforms, thereby reducing the need for human intervention. Building on that foundation, the focus of this phase was to address the challenge of extending battery life in a multi-rotor drone. The primary objective was to implement a hybrid power system by integrating a combustion engine to supplement the rotors during flight, ultimately enhancing overall drone performance. A critical component of this design was developing an onboard charging system capable of using the engine's idle time after landing to recharge the batteries. The first half of the project centered on testing major components and constructing the multi-rotor drone. In the second half, efforts shifted to integrating electronics, assembling the battery and its charging system, programming the drone for autonomous operation, and conducting multiple flight tests. These activities were completed by mid-April 2025. The entire project, from planning and design to construction and testing, spanned nine months, beginning in late September 2024. The finalized project budget was $2,736.72

1. Introduction

The main objective of this project was to improve upon the design and construction of a multi-rotor drone that incorporates a combustion engine for the purpose of extended flight duration. The intended use for this design is to eliminate human interaction with the drone that would be required for various tasks, such as agricultural, military, or emergency response purposes for example. The drone is designed as a motor-oriented hexa-copter drone, it has two large battery packs and an on-board combustion engine as a source of power. The proposed power system was to use one battery to power the propulsion systems and the on-board electronics. The system would automatically detect when the battery pack in use depletes below a specified percentage of remaining charge, and switch to the secondary battery pack while the engine powers a generator to charge to the first battery pack. This system could repeat until all of the fuel in the engine was consumed. This model would eliminate the drone's obligation to land and charge. The project was divided into four stages: Improving on the drone's design, the continuing construction of the drone, developing a power system and charging circuit that will be monitored by the on-board software, and programming the software to ensure the drone can efficiently navigate an environment while fully autonomous.

1.1. Scope and Objectives

This project focuses on creating an autonomous drone that is battery-powered but also capable of being charged and powered by an internal combustion engine and generator. Objectives are to be broken into three phases: preparing a list of necessary parts and materials for the project, designing infrastructure, and building an autonomous drone, and testing and flying drone capabilities to determine if it is effective and efficient.

The preparation phase of the project will include proposing and deciding upon any new alternatives to the current design and new designs to improve upon the current drone. The manufacturing stage will include our technical analysis/drawings, software programming and architecture, and processes involving the continual construction of drone's and installation of parts. The final stage will involve testing the drone's systems such as software and stability as well as measuring its capabilities like its max weight capacity, total thrust, and other important metrics.

1.1.1. Scope Breakdown

- Assess previous year's work.
- Propose solutions to known issues and overlooked areas.

- Update 3D CAD model to incorporate any new upgrades.
- Assemble the drone when the proposed design changes are finalized.
- Test flights to ensure reliability of drone.
- Implement the generator and create a self-charging system.
- Develop automated software that can efficiently turn on generator to charge batteries.
- Troubleshoot software and hardware errors as needed.
- Create a report and a presentation detailing design, manufacturing, and final testing.
- Senior thesis and presentation.

2. Design Requirements & Considerations

2.1. FAA Regulations

The Federal Aviation Administration (FAA) defines an Unmanned Aircraft System (UAS) as an unmanned aircraft and the necessary equipment required for its safe and efficient operation. An unmanned aircraft, a component of the UAS, is defined by statute as an aircraft operated without direct human intervention from onboard the aircraft itself (Public Law 112-95, Section 331(8)) [1].

Additionally, statutory provisions outlined in P.L. 115-254, Section 350 (as amended by P.L. 116-283, Section 10002), allow drones used for educational and research purposes to operate under recreational flyer regulations. According to FAA guidelines, qualifying educational entities include institutions of higher education, Junior Reserve Officers' Training Corps (JROTC) programs, and educational initiatives chartered by FAA-recognized Community-Based Organizations (CBOs) [3].

The FAA requires compliance with specific regulations when operating drones under the Exception for Limited Recreational Operations. These include:

- Flying solely for recreational (personal enjoyment) purposes.
- Adhering to safety guidelines set forth by FAA-recognized CBOs.
- Keeping drones within visual line-of-sight or employing a co-located visual observer in direct communication with the operator.
- Yielding right-of-way to and avoiding interference with other aircraft.
- Obtaining FAA authorization for drone operations in controlled airspace (Classes B, C, D, and designated surface Class E), using systems such as LAANC or DroneZone.
- Flying at or below 400 feet in Class G (uncontrolled) airspace, avoiding restricted airspaces entirely.
- Completing and carrying proof of The Recreational UAS Safety Test (TRUST).
- Ensuring drones are registered with the FAA, clearly labeled with the registration number, and maintaining proof of registration during flights. Notably, drones registered after September 16, 2023, must broadcast Remote ID information.
- Operating the drone in a manner that does not endanger national airspace safety [4].

Widener University's campus is located within Class B airspace, specifically categorized as

70/SFC, extending from 7,000 feet to the surface. Unlike Class G airspace operations, flights in Class B airspace require authorization for each flight, ensuring air traffic control is adequately informed. The FAA-authorized maximum altitude for UAS operations in this area is 250 feet. Authorization for flights in this controlled airspace is streamlined through the Low Altitude Authorization and Notification Capability (LAANC) system, part of the UAS Data Exchange initiative.

LAANC automates the authorization process by verifying flight requests against comprehensive airspace data, including UAS Facility Maps, Special Use Airspace, Airports and Airspace Classes, Temporary Flight Restrictions (TFRs), and Notices to Airmen (NOTAMs). Approved pilots receive near-real-time authorizations without needing separate notifications to airport towers unless explicitly stated otherwise. Pilots remain responsible for verifying NOTAMs, weather conditions, and other airspace restrictions prior to flight [5].

Philadelphia Airport provides LAANC services covering Widener University airspace, specifically authorizing blocks for 107-AA, 107-FC, and 44809-AA. Our drone operations, classified under recreational flying, utilize the 44809-AA authorization. To ensure compliance and efficiency, a third-party platform named AutoPilot is employed to obtain timely flight authorizations.

Due to anticipated drone weights exceeding the 250-gram threshold, FAA registration is mandated, carrying a fee of $5 and remaining valid for three years. Operators must possess registration documentation while flying, and drones must prominently display their registration numbers. According to FAA regulations, any individual operating the drone must also carry either a paper or digital copy of the registration certificate, which must be presented to authorities upon request [6].

The drone is registered under our advisor, Dr. Daniel Roozbahani's name, clearly marked with its FAA-issued registration number. Team manager, Cole Helmer, has successfully completed the mandatory TRUST examination, and both registration documentation and proof of test completion are consistently available during flight operations. Additionally, compliance with the FAA's Remote Identification regulations, effective from September 16, 2023, is maintained through required drone broadcasting capabilities.

2.2. FCC Codes

The Federal Communications Commission (FCC) oversees the use of radio frequencies in the United States, including those used by drones. Our project complies with Title 47, Part 15.247 of the Code of Federal Regulations (CFR) specifically, which deals with guidelines for unlicensed devices used in the Industrial, Scientific, and Medical (ISM) frequency bands. These frequencies include 902-928 MHz, 2.4-2.4835 GHz, and 5.725-5.875 GHz. We used these frequencies for our communication system as well as for transmitting video because they are less regulated and are popular with drone users as well as hobbyists. Key provisions of CFR Title 47 Part 15.247 that impact our project are:

- **Frequency Ranges:** Our equipment must operate strictly within the specified ISM bands: (902-928 MHz, 2.4-2.4835 GHz, and 5.725-5.875 GHz).
- **Power Output Limits:** There are limits on the maximum power output of unlicensed devices based on the frequency.
- **Emission Standards:** Devices are intended to conform to specific emission standards to avert interruption of other WLAN equipment.
- **Rules on Frequency Hopping:** 2.4 GHz and 5.8 GHz band devices are required to use frequency-hopping spread spectrum (FHSS) technology or direct-sequence spread spectrum (DSSS) technology.
- **Measures to prevent interference:** Devices must include features such as automatic selection of channels or low power modes to limit interference with other devices.
- **FCC Labeling:** All devices are required to bear a visible FCC identifier and adhere to other labeling requirements as appropriate.
- **FCC Certification Requirement:** Devices must be certified by the FCC prior to their marketing or distribution in the United States.
- The requirements of CFR Title 47 Part 15.247 are focused on minimizing the interference from unlicensed equipment, thus promoting safe development and innovation in wireless technology. The system used by our project at 915 MHz for telemetry, as well as the 5.8 GHz for the video link, means compliance with these FCC requirements is required. Keeping compliance is simple as long as pre-certified equipment is utilized.

Key ISM band regulations applicable to our operations are:

- **Power Limits:** The highest permissible power output is one watt (30 dBm) in point-to-point links and 250 milliwatts (24 dBm) in point-to-multipoint communication systems.
- **Power Density Limits:** The maximum power density is limited by regulations to 3,000 microwatts per square centimeter ($\mu W/cm^2$) at three meters from the emitting device.

To ensure compliance, we must check and configure all devices for use in the United States prior to deployment. Because we are employing a point-to-multipoint topology, we are careful not to exceed the 250mW output power.

2.3. Safety Standards

When manufacturing and using an Unmanned Aircraft System (UAS), compliance with several safety standards must be observed to provide safe and legal operations. Furthermore, certain guidelines, like those presented by Underwriters Laboratories (UL), affect how we implement charging systems. FAA regulations are extremely important for safe operations, but those have already been discussed well in advance and therefore are not reiterated here.

Even though we work hard to meet all applicable standards and regulations, the sheer number, technical nature, and level of detail involved in these standards complicate full compliance on behalf of a small-scale, non-business project such as ours. The following standards, however, were used as primary references to inform our decision processes as well as ensure overall safety during the project's development.

2.3.1. ICAO Standards

The International Civil Aviation Organization (ICAO) is responsible for establishing global aviation safety standards, including comprehensive guidelines specifically for the operation of Unmanned Aircraft Systems (UAS). Within this regulatory framework, ICAO has developed several standards and circulars that directly address drone operations. Relevant ICAO publications include:

- Annex 2 to the Convention on International Civil Aviation – Rules of the Air
- Annex 7 to the Convention on International Civil Aviation – Aircraft Nationality and Registration Marks
- Annex 8 to the Convention on International Civil Aviation – Airworthiness of Aircraft
- Circular 328 – Unmanned Aircraft Systems (UAS)
- Circular 330 – Unmanned Aircraft Systems (UAS) Traffic Management (UTM)

These ICAO standards form part of the international regulatory basis guiding the safe integration and operation of drones within global airspace.

2.3.2. ASTM Standards

ASTM International is a widely respected organization known for creating and sharing technical standards across many industries, including aviation. Among its broad efforts, ASTM has developed a comprehensive set of standards tailored specifically for Unmanned Aircraft Systems (UAS). These standards cover essential aspects ranging from design and construction to the safe and efficient operation of drones in commercial settings:

- ASTM F3298-18 – Standard Practice for Design, Construction, and Operation of a LiPo Battery-Powered UAS
- ASTM F2910-14 – Standard Specification for Design and Construction of Micro Air Vehicles
- ASTM F3002-14 – Standard Specification for Electrically Powered Small UAS (sUAS)
- ASTM F3178-16 – Standard Practice for Operational Risk Assessment of Small UAS (sUAS)
- ASTM F38-18 – Standard Specification for UAS Remote Identification

These guidelines have been instrumental in shaping our project's approach, helping ensure our system remains safe, reliable, and aligned with industry best practices throughout its development.

2.3.3. ISO Standards

The International Organization for Standardization (ISO) is a worldwide standards-writing entity that develops and disseminates technical standards for use in many different industries, ranging from aerospace to healthcare. When it comes to Unmanned Aircraft Systems (UAS) technology, ISO has a series of standards in place that are tailored to ensure the design, production, and operating procedures of commercial drones are guided.

- ISO 21384-1:2018 – Aerial Systems – Part 1: General Aerial System Requirements
- ISO 21384-2:2020 – Unmanned Aircraft Systems – Part 2: Product Systems
- ISO/TR 23629:2017 – Unmanned Aircraft Systems – Operational Procedures
- ISO 17889:2015 – Unmanned Aircraft Systems – Safety Management
- ISO 19238:2017 – Unmanned Aircraft Systems – Vocabulary

Together, these ISO standards deliver overall guidance that ensures safe, reliable, and effective integration of drones in aerospace applications. They were used as key references during planning as well as the implementation stages of our project.

2.3.4. NIST Guidelines

The National Institute of Standards and Technology (NIST) has issued several important recommendations aimed at improving cybersecurity for Unmanned Aircraft Systems (UAS) and other Internet of Things (IoT) devices. These guidelines are especially relevant to enhancing the security posture of UAS technologies.

- NISTIR 8228 – Considerations for Managing Internet of Things (IoT) Cybersecurity and Privacy Risks
- NISTIR 8267 – Security Review of Consumer Home IoT Products
- NISTIR 8225 – An Introduction to Cybersecurity for Aviation Cyber-Physical Systems
- NIST SP 800-53 – Security and Privacy Controls for Information Systems and Organizations
- NIST SP 800-190 – Application Container Security Guide

These resources played a vital role in helping us address cybersecurity challenges and ensure strong protection for the UAS components and communication infrastructure used in our project.

2.3.5. UL Rules

Underwriters Laboratories (UL) is a globally respected organization known for its expertise in safety certification. It offers comprehensive testing and certification services across a wide range of product categories, including Unmanned Aircraft Systems (UAS). UL has developed several specific standards that are directly tied to the safety certification of drones and their related systems.

- UL 3030-1 – Standard for Safety of Unmanned Aircraft Systems
- UL 2595 – Outline of Investigation for Battery-Powered Systems for Use in Commercial Drones
- UL 62368-1 – Audio/Video, Information and Communication Technology Equipment –

  Part 1: Safety Requirements
- UL 60950-1 – Information Technology Equipment – Safety – Part 1: General Requirements
- UL 1741 – Standard for Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources

These safety standards from UL were key in guiding the safe design, operation, and ensuring our project met necessary certification requirements for its UAS components.

2.3.6. Industry Best Practices

Alongside formal safety standards, following industry's best practices is equally vital to ensure the safe, legal operation of commercial Unmanned Aircraft Systems (UAS). These practices address key areas that are crucial for maintaining operational safety and compliance.

First and foremost, strict adherence to established regulations and safety standards is non-negotiable. Manufacturers, operators, and regulatory bodies must follow all relevant guidelines covering UAS design, operations, and safety. In the U.S., this includes full compliance with FAA regulations, while also aligning with international standards from organizations such as the ICAO.

Thorough risk assessment and management is another fundamental component. It's essential for UAS developers and users to proactively identify potential hazards and implement strategies to reduce operational risk. This includes evaluating flight conditions, environmental factors like weather, and addressing cybersecurity risks that may affect data and communication systems.

Ongoing maintenance and inspection routines are equally critical. Key components such as airframes, propulsion systems, avionics, and batteries must be inspected and maintained regularly to ensure optimal performance and regulatory compliance.

In addition, pilot training and certification are essential to safe and responsible UAS operation. Operators must receive proper training in areas like flight protocols, airspace regulations, emergency procedures, and other core competencies required to operate safely and in line with regulations.

Finally, a strong focus on data management and privacy is necessary. UAS operators must protect any data collected through encryption, strong cybersecurity protocols, and clear privacy policies to secure sensitive information and respect individual privacy rights.

By staying committed to these industry's best practices, UAS manufacturers and operators can significantly elevate safety standards, meet regulatory expectations, and promote responsible drone use.

2.4. Constraints

The team's main constraints arise from regulations set by the Federal Aviation Administration (FAA) and the Federal Communications Commission (FCC). The FAA enforces strict guidelines for drone operations, especially in terms of flight altitude and proximity to populated areas. While general rules typically allow drones to fly up to 400 feet and require them to stay within the operator's line of sight without special clearance, our project's location near Philadelphia International Airport comes with tighter restrictions. Specifically, our flights are capped at 250 feet and require authorization for every operation.

The FCC, on the other hand, oversees communication aspects like antenna power, directionality, and the radio frequency bands we're allowed to use. To comply, we're restricted to operating within approved Industrial, Scientific, and Medical (ISM) frequency bands for all radio communications.

On the financial side, the project is bound by a set budget of $2,736.72, providing a concrete benchmark for tracking spending. A request was made to increase this amount to accommodate unexpected costs such as replacing or repairing damaged components during construction or testing.

We also face technical limitations tied to the hardware itself, which influence both design decisions and how the system operates. Factors like the physical space available for flight testing and the accessibility of specific parts further impact what's realistically achievable within the scope of the project.

Finally, the project is limited to a two-semester timeline. This fixed schedule helps define clear, measurable goals and supports steady progress toward meeting key milestones on time.

3. 3D Design & System Architecture

3.1. Flight Systems

The Flight Systems encompass several integral subparts essential for the operation and performance of the drone. The frame provides structural support and housing for all components, chosen based on factors like material and durability. The propulsion system, comprising motors, propellers, and ESCs, generates thrust for flight, influencing maneuverability and efficiency. The flight controller acts as the drone's brain, processing sensor data and user inputs to stabilize and control flight, with popular choices like the Pixhawk 2.4.8 offering versatility and compatibility with a wide variety of different components available on the market. The power system, consisting of batteries and distribution components, provides electrical energy for operation. Sensors, including GPS and accelerometers, enable navigation and environmental awareness, while the communication system facilitates remote control and telemetry between the controller and the flight unit. Integration and coordination of these subparts are vital for stable flight and mission success.

3.2. Chassis Structure

Starting this project, the team first deliberated on how to take the adopted drone and improve it. The previous year's iteration had successfully constructed a two-level drone with six arms extending outward from the top level. Given the complexity of building the initial structure from scratch, there remained considerable opportunities for further refinement.

The original design consisted of an upper level, which housed the flight controller and associated electronics, and a lower level dedicated to the LiPo batteries. As part of this year's improvements, the team redesigned many aspects of these already constructed levels to further optimize the drone and fix some issues and expanded the chassis to include a third level to accommodate a gasoline generator and a newly designed landing gear system.

The 3D CAD model was created using Autodesk Inventor, incorporating a combination of custom-designed parts and components sourced from online libraries. Many subassemblies from the previous year's project were reused, simplifying the 3D modeling process. The top acrylic plate was redesigned to match the new electronics layout, providing a cleaner and more refined configuration. The new battery holders and their improved layout on the second level were also implemented. Additionally, the gasoline generator and its chassis were attached to the bottom frame. Furthermore, the implementation of a landing gear system, designed to improve landing stability and structural resilience, was also added onto the model.

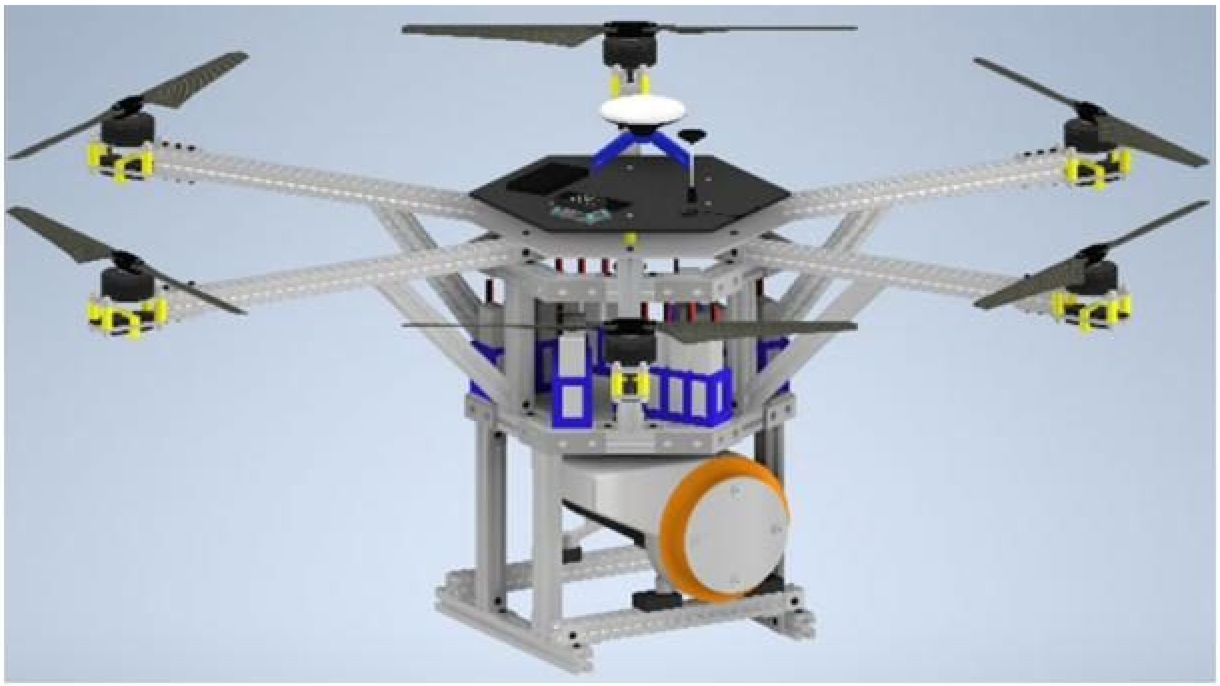


Figure 1: Previous Year's 3D CAD Model

The middle level of the drone, which houses all the batteries, was one of the first areas targeted for redesign. The new battery holders were designed to optimize the space being used and for better weight distribution. Two different battery holders were designed, one which holds three batteries and one which holds six. This was done to optimize the amount of space that was being taken up due to the more than two times increase in the amount of LiPos that are planned to be attached. The layout of the battery holders underwent multiple design iterations before a final configuration was selected.

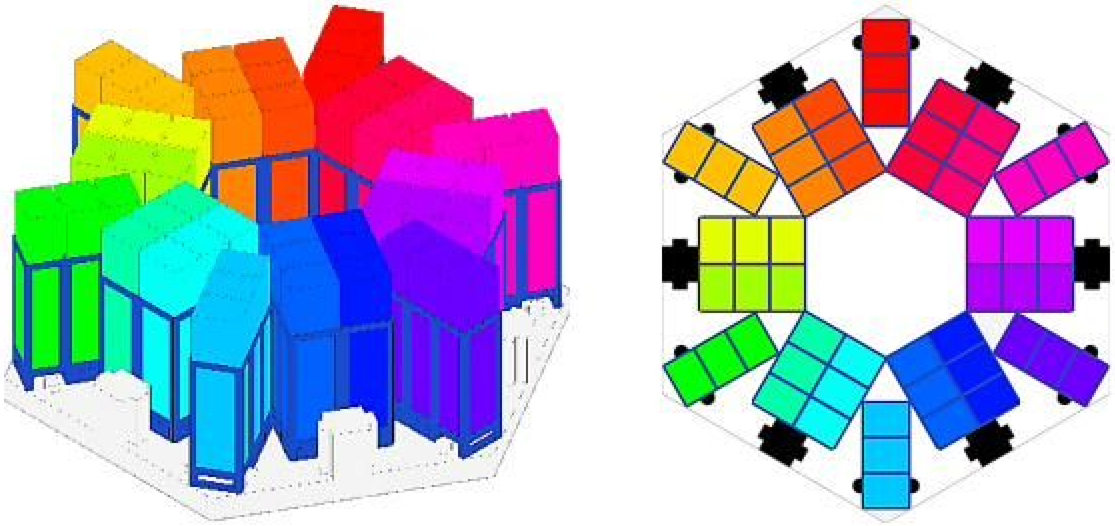


Figure 2: New Battery Floor Layout

The top acrylic plate was also redesigned as the one currently attached to the drone was seen as insufficient as it had some incorrect angles causing it to be lopsided. The new model shares the same hexagonal shape the rest of the drone consists of, but it has a smaller hexagon cut out of the center to allow for better cable management and to allow for more heat to escape. The layout of the electronics was then reorganized on the plate, which ended up with a more streamlined layout and more space to implement new additions such as the live camera system.

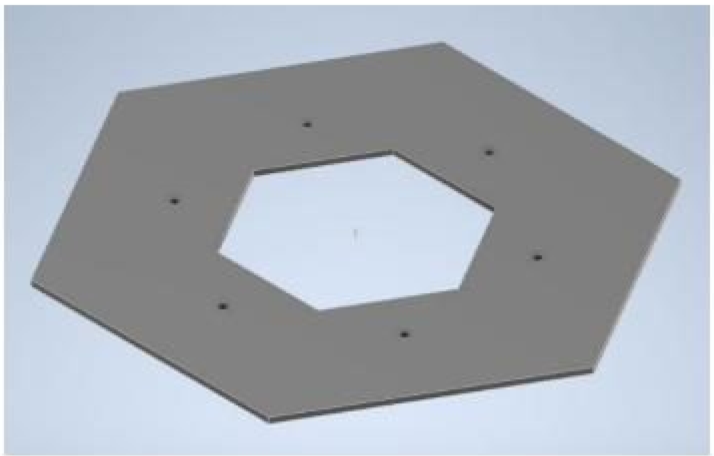


Figure 3: Acrylic Plate Design

The landing gear system was inspired by the lunar lander designs from NASA's Apollo missions. The same aluminum T-slot bars that made up the rest of the chassis were used to form the legs. Hinges were modeled and attached to the ends of the legs to securely fasten them to the chassis. Large shock springs, sourced from online component libraries, were integrated between the legs to absorb the forces felt when landing. Given the size and weight of the drone, this was a critical consideration in designing the landing gear as a proper landing was never executed so there were many unknowns to the reaction the chassis would have when one was performed. The shocks are fastened on both ends with shock pin eliminators which act as a pivot point and work together with the legs hinge to promote movement when a large force occurs. This strengthens the system as the bolts will not receive a large force which could cause them to fail. Instead, the leg moves and the shock compresses which dampens the vibrations the chassis feels and protects the areas more prone to damage. The length and angle of the legs were designed to extend past the motors to combat any tipping motion while taking off, this is due to the top-heavy nature of the drone and knowledge of previous year's testing. Initial concepts modeled after helicopter "skis" were abandoned, as they would have required unreasonably long extension to achieve the desired stability and had no dampening aspects.

Figure 4: Landing Gear Subassembly

These modifications to the chassis structure not only enhanced the drone's functionality and endurance but also improved its serviceability, and readiness for testing. Much of the first semester was spent on the design phase of these planned improvements with the second semester consisting of procurement and implementation.

The final CAD model can be seen below in Figure 5. This model contains all the final design considerations and formed the basis for procurement of parts and installation/execution of all improvements.

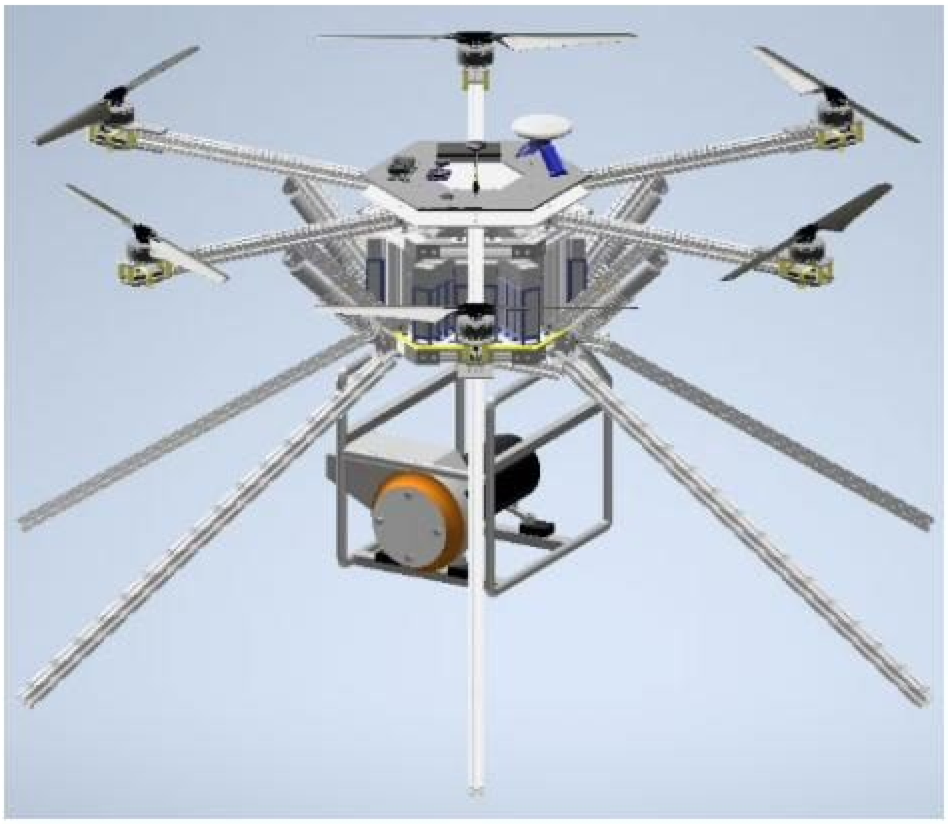


Figure 5: Finalized 3D CAD Model

3.2.1. Construction

The construction of the new upgrades was done throughout the second semester to get the project ready for testing. The first portion consisted of utilizing a spare, clear, acrylic sheet and measuring out the dimensions of the 3D model to ensure accuracy. The outside shape of the plate was cut with help from Widener machine shop located on the first floor of Kirkbride hall. The inner hexagon was cut in the lab using a Dremel tool to keep the plate solid. Then, all the holes for mounting the electronics were marked and then all the actual devices were laid out and taped to ensure that the CAD design was proper. From there the holes were all drilled, and the electronics were fastened to the plate. The auxiliary batteries proved to be an issue when trying to fit both on the plate so a mount which can hold both on their sides was 3D printed using PLA plastic.

On the second level of the drone all the wiring was redone to be more manageable and easier to connect and disconnect for ease of testing. Three separate bus ducts were mounted just outside the level on the braces of the motor arms where the batteries and motors were all routed with a safety power switch between the motors and the batteries. Unfortunately, the new battery holder designs were not on hand until late into the project due to printing constraints, so the new layout was never fully implemented.

The gasoline generator was stripped off its chassis to be installed onto the bottom of the chassis, connecting to two T-slot aluminum bars which ran parallel on the underside of the battery level. The chassis was first spray painted to match the color of the aluminum seen all over the drone as a more uniform design. Holes were measured and drilled for the fastening bolts so the generator's chassis could be securely fastened but also quick to remove if needed. Custom L-brackets were cut using a bandsaw due to where the connections were on the aluminum. The brackets on hand would stick out and interfere with the landing gear hinges so angled cuts were made to allow for both to fit without interfering.

Once all of the parts arrived work began on the landing gear. The hinges purchased were weldable trailer hinges which were heavy duty and didn't have pre-drilled holes so they could be manipulated into what exactly was needed. The hinges were 4" x 4" and fit perfectly between the angle brackets on the bottom hexagonal plate directly under the arm bracings. Two holes were drilled on both faces of the hinge to allow for two connection points for a sturdier attachment between the landing gear leg and the chassis. The pins in these hinges allowed for some rotation on the X-axis, which was not desirable, so the hinges were retro fitted with a wider diameter pin which was hammered in to eliminate this movement. The shocks have two pin connections on either side so shock pin eliminators were ordered to fasten the shocks to the chassis. These are essentially U brackets with a pin hole, where two holes were drilled on the bottom face of these brackets for connections. The legs were ordered to be 4' long each, this allowed for the legs to extend out past the motors on the x-axis. The pin eliminators were mounted at the top of the arm bracings and approximately 10" down on each leg. The shocks were then attached between the two to complete the designed landing gear system.

Below is a sequence of figures 6-14, which outline the complete construction process:

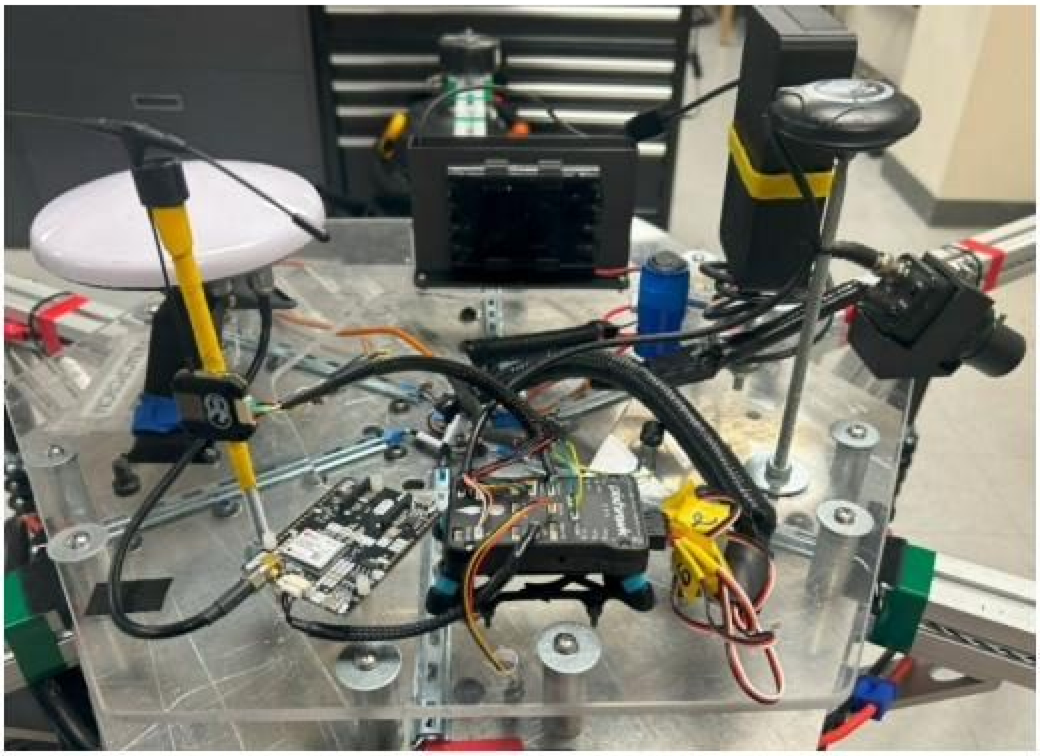


Figure 6: New Implementation of Flight System

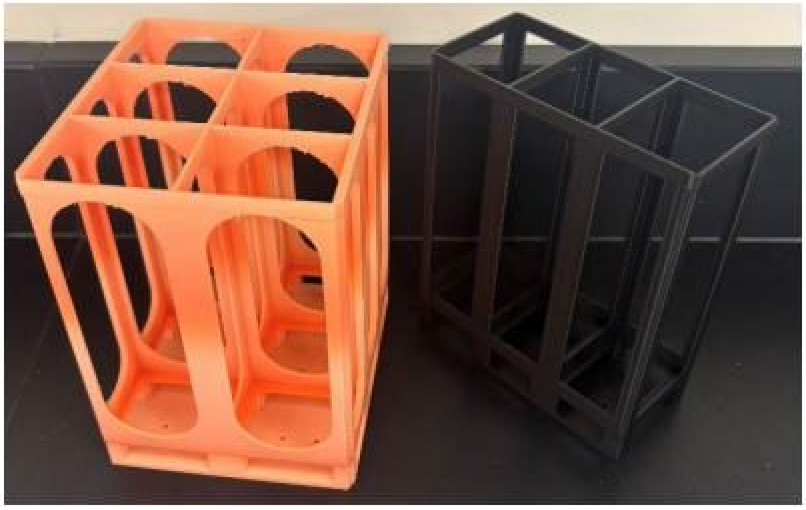


Figure 7: Printed 6 and 3 Cell Battery Holders

Figure 8: Generator Chassis with Aluminum T-Slot Bars

Figure 9: Painted Generator Chassis

Figure 10: Angle Cut L-Brackets

Figure 11: Hinge with Bolt Holes

Figure 12: Shock Pin Eliminators with Bolt Holes

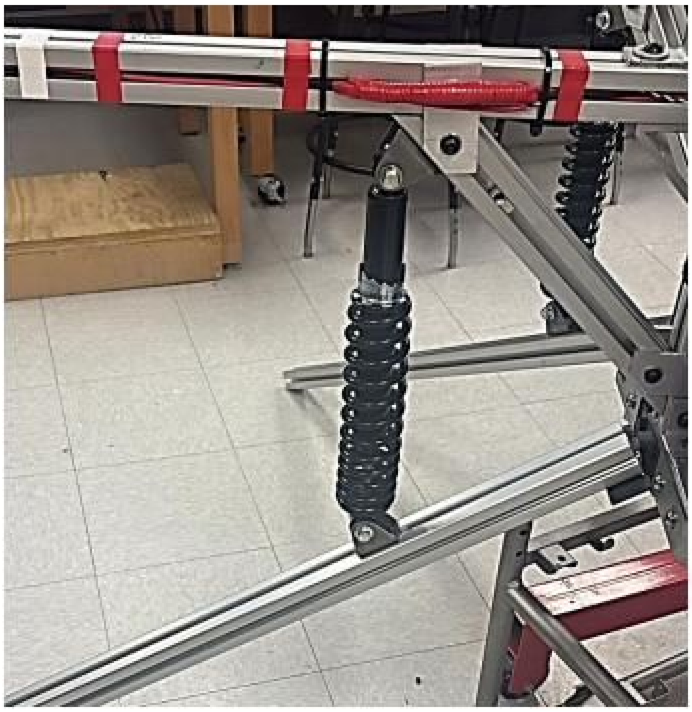


Figure 13: Finalized Landing Gear Assembly

Figure 14: Fully Assembled Drone

3.2.2. Propulsion

The drone's propulsion system is composed of three primary components: the motor, the propeller, and the Electronic Speed Controller (ESC). Each of these elements must be powerful enough to support the drone's size as well as compatible with one another to function effectively as a system. The propulsion system must be capable of producing thrust that exceeds the drone's total weight to achieve lift. To initiate the selection process for the propulsion system, a Microsoft Excel spreadsheet was developed listing all components intended for the drone, along with their respective weights or close estimations. This tool helped approximate the final weight of the drone during the early design phase, although some discrepancies from the final build are expected.

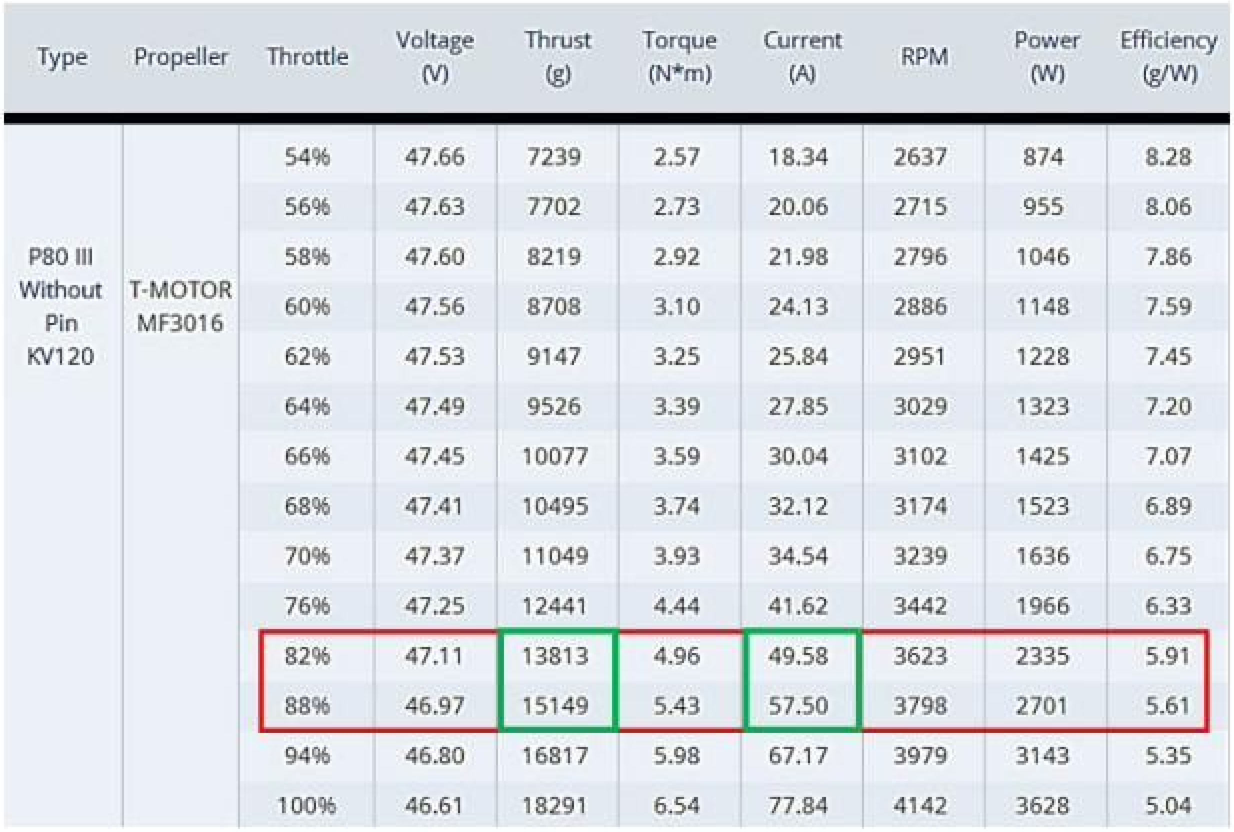
The primary objective of the propulsion system is to achieve a target thrust-to-weight ratio (TWR) at a manageable throttle level. The TWR compares the total thrust output to the drone's weight. A TWR of 1 means the drone can hover in place, as the thrust equals the drone's weight. Smaller, more agile drones often aim for a TWR of 3 or higher to enable rapid and precise maneuvers, while large heavier drones typically operate at lower TWRs due to their mass. For this drone, a TWR of 1.3 was chosen to ensure an adequate lift with additional throttle capacity for maneuverability.

The estimated weight of the drone is approximately 65 kg, with the capacity to carry an additional 20 kg payload. This estimate is based on component datasheets. The six motors are projected to weigh around 4 kg, while the six propellers are expected to add approximately 0.5 kg. The six ESCs will also weigh roughly 0.5 kg. The battery system contributes about 9 kg, and the wires and general hardware are expected to add another 4 kg. The chassis is estimated at 10 kg, and the generator, after optimization, is reduced to 40 kg. Combined, these elements yield an estimated drone weight of 65 kg.

To calculate the required total thrust, the drone's weight is multiplied by the desired TWR. This total thrust requirement is then evenly distributed across the drone's six propulsion units, as it is a hexacopter. Weighing 65 kg, with a TWR of 1.3, the drone must generate a total thrust of approximately 84.5 kg, which translates to roughly 14.1 kg of thrust per arm.

Motor and propeller compatibility is a key consideration, and selecting both from the same manufacturer is generally preferred to ensure optimal performance. After market research, the most powerful and budget-appropriate pairing identified was the T-Motor P80III Kv120 Motor and the T-Motor MF3016 30-inch Propeller. T-Motor provides detailed datasheets that include essential metrics such as throttle percentage, voltage consumption, thrust output, torque, current draw, RPM, power consumption, and overall efficiency. Key parameters for our selection included thrust, voltage, and current. This motor-propeller combination operates on a 48V power input, draws up to 77A at full throttle, and can produce 18.3 kg of thrust at maximum throttle.

At 83% throttle, it generates the target 14.1 kg of thrust. When carrying the full 20 kg payload, the system reaches the necessary TWR at 100% throttle. This configuration was deemed the most effective and cost-efficient choice to meet performance requirements.



Type	Propeller	Throttle	Voltage (V)	Thrust (g)	Torque (N*m)	Current (A)	RPM	Power (W)	Efficiency (g/W)
P80 III Without Pin KV120	T-MOTOR MF3016	54%	47.66	7239	2.57	18.34	2637	874	8.28
		56%	47.63	7702	2.73	20.06	2715	955	8.06
		58%	47.60	8219	2.92	21.98	2796	1046	7.86
		60%	47.56	8708	3.10	24.13	2886	1148	7.59
		62%	47.53	9147	3.25	25.84	2951	1228	7.45
		64%	47.49	9526	3.39	27.85	3029	1323	7.20
		66%	47.45	10077	3.59	30.04	3102	1425	7.07
		68%	47.41	10495	3.74	32.12	3174	1523	6.89
		70%	47.37	11049	3.93	34.54	3239	1636	6.75
		76%	47.25	12441	4.44	41.62	3442	1966	6.33
		82%	47.11	13813	4.96	49.58	3623	2335	5.91
		88%	46.97	15149	5.43	57.50	3798	2701	5.61
		94%	46.80	16817	5.98	67.17	3979	3143	5.35
		100%	46.61	18291	6.54	77.84	4142	3628	5.04

Figure 15: Motor + Propeller Combination Data Sheet

Figure 15 illustrates the T-Motor MF3016's specifications. Due to the combination of motors and propellers demanding 77A of current at maximum throttle, we browsed the market for an ESC capable of delivering 80A. The best ESC on the market within budget, capable of delivering the 80A of current, and compatible with the previously selected motor and propeller combination is the FlyDragon Flycolor V4 80A ESC. The following graph was created using the data sheet to estimate the throttle needed to propel off the ground with different weights:

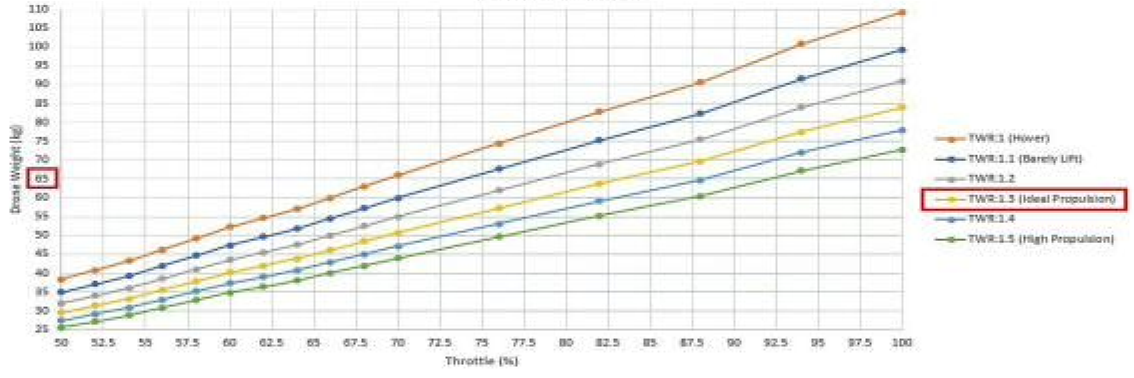


Figure 16: Drone Weight vs. Throttle

The motor, along with the propellors and the chosen ESC are shown below in Figure 17.

Figure 17: Propulsion System Materials

Once these items were decided, ordered, and delivered, a workbench with a power supply was created to ensure all the components worked as intended and were compatible with each other. The test was a success, and the focus was shifted to creating a mount for this propulsion system.

With the aluminum T-slot configuration, custom motor mounts had to be designed and machined. The first step of this process was to model the design and ensure it would fit on our motor. When the model was completed, we printed a top mount and a bottom mount shown in Figure 18 as a prototype to ensure the connections were secure and the motor and ESC would fit on the mount.

Figure 18: 3D Printed Motor Mount Prototype

The motor and ESC produce heat, so they cannot be enclosed in the mount, so because of this, there was a top mount that the motor would attach to and then a bottom mount that the ESC would sit in, while still being out in the open to allow for airflow.

After the prototypes were confirmed to be the correct size, the mounts were then customized CNC machined out of excess metal we had from cutting the aluminum plate on the top of the drone. The mounts had to be metal due to the force that the propulsion system produces, we needed a strong material that will not warp or bend with the force or heat.

These mounts were then added to the end of the t-slot arms to add the propulsion system onto the drone. To allow airflow into the propulsion mount, it consists of a top plate and a bottom plate, while the middle is open. There then needed to be a way to hold both plates together. We had an aluminum tube that was cut into 1.5" spacers and this could be added as a standoff between the plates. When cutting the tube, not all spacers came out as exactly 1.5", so these spacers could not be used due to the variable sizes, so the alternative created was to 3D print spacers as seen in

Figure 19 with a strong material at 100% infill which would ensure the pieces were strong.

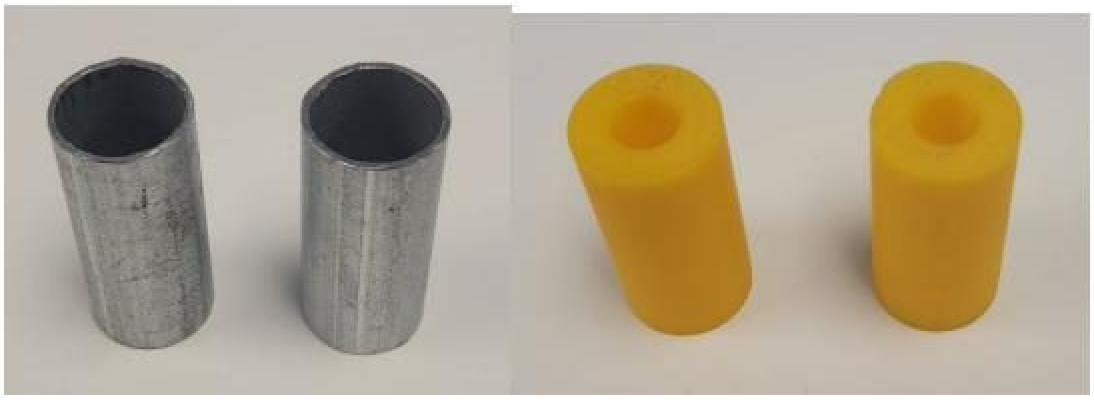


Figure 19: 3D Printed Spacers

Our full propulsion system is made of machined aluminum and 3D printed parts.

3.2.3. Flight Controller & Firmware

The flight controller of the hexacopter is the Pixhawk 2.4.8. It provides power and reads information from multiple sensor inputs, can operate up to eight motors through PWM, and can be controlled remotely through external communication devices such as a remote controller or flight software. The Pixhawk 2.4.8, as shown in Figure 20, can be controlled from a laptop base station or from the transmitter through radio communication and Wi-Fi. For this project, the base software used was ArduPilot's Mission Planner. It allows for real-time observation of the GPS and positioning sensors, as well as full control over each individual motor via remote input.

Figure 20: Pixhawk Diagram

The base station uses the Ardupilot software to calibrate sensors, change settings, and adjust parameters on the flight controller to optimize the drone. The Team BlackSheep receiver and transmitter shown in Figure 21 are responsible for connecting the base station and Pixhawk to the transmitter. The receiver-to-transmitter connection is established through Team BlackSheep's proprietary Crossfire communication software. The transmitter is a 2-in-1 remote controller with both Crossfire and Wi-Fi built in, allowing for the Crossfire connection between the receiver and controller to be managed in ArduPilot remotely over Wi-Fi through a software protocol called MAVLink.

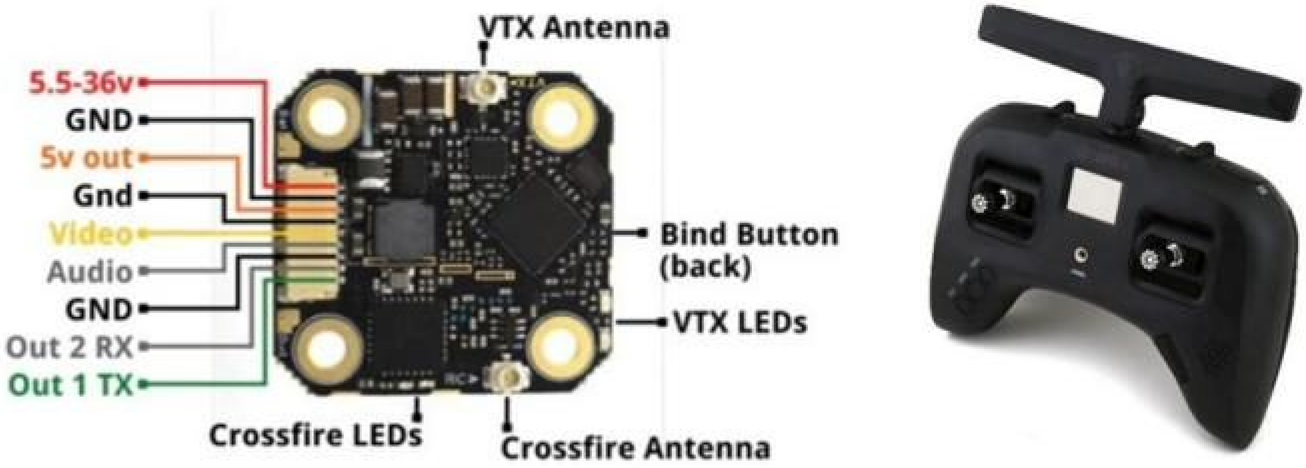


Figure 21: Controller and Antenna Board

3.2.4. Power Systems

Based on the decision to use the T-Motor P80III motors for our propulsion system, we needed to choose a power system using batteries that met the 47V and 80A requirements of the drive system. We investigated many options for fully functional batteries with "plug and play" capabilities but were discouraged from many of the options due to the high price and low reliability of vendors. We began to research how batteries were made and realized we could create our own 48-volt batteries with enough current capabilities by placing multiple batteries in series for voltage increases and parallel for current increases. With our general battery design in mind, we found suitable 4S batteries (Youme Power 4s 6500mAh 80C LiPo Battery) that were able to be connected in series and parallelled to create large capacity 12S batteries.

- **Series –** The 4S batteries were connected using the series connectors shown in Figure 22 with TRX High-Current battery connector plugs. By plugging one connector into the other and three batteries into the other free plugs, it results in a 12S (48-volt) 6500mAh battery as shown in Figure 23.

- **Parallel –** The combined 12s battery packs were then placed in parallel by snipping off the female TRX connector from the end of each series connection and replacing them with a ring terminal for both a positive and negative lead from the battery pack. These ring terminals would be grouped together on their respective bus ducts to combine all serried battery packs in a parallel formation.

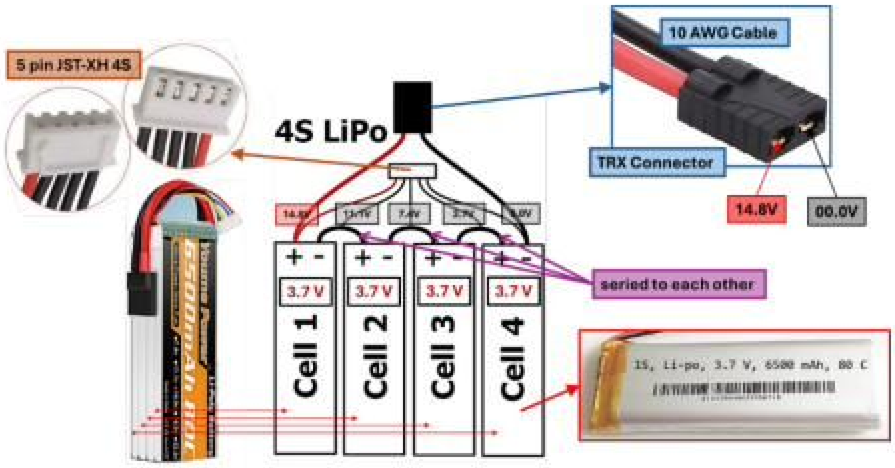


Figure 22: Individual Battery Architecture

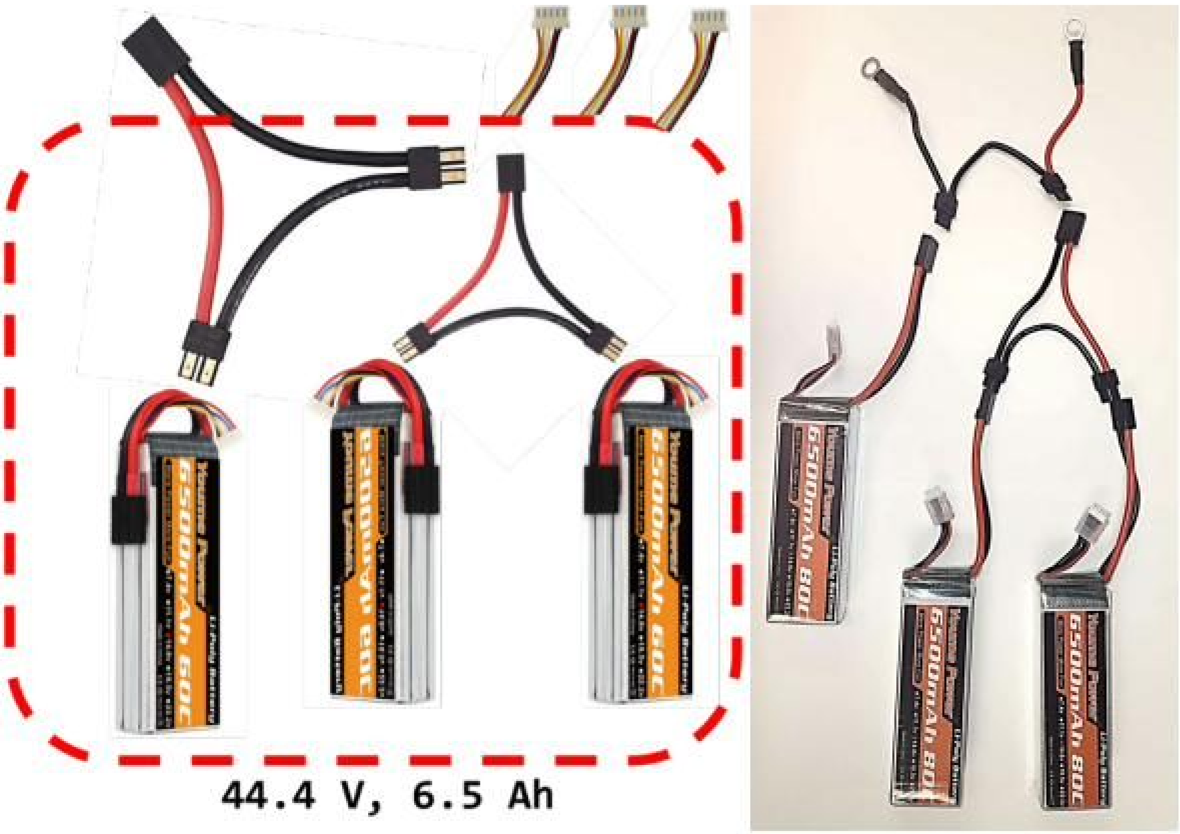


Figure 23: 3x Series Battery Pack Representation

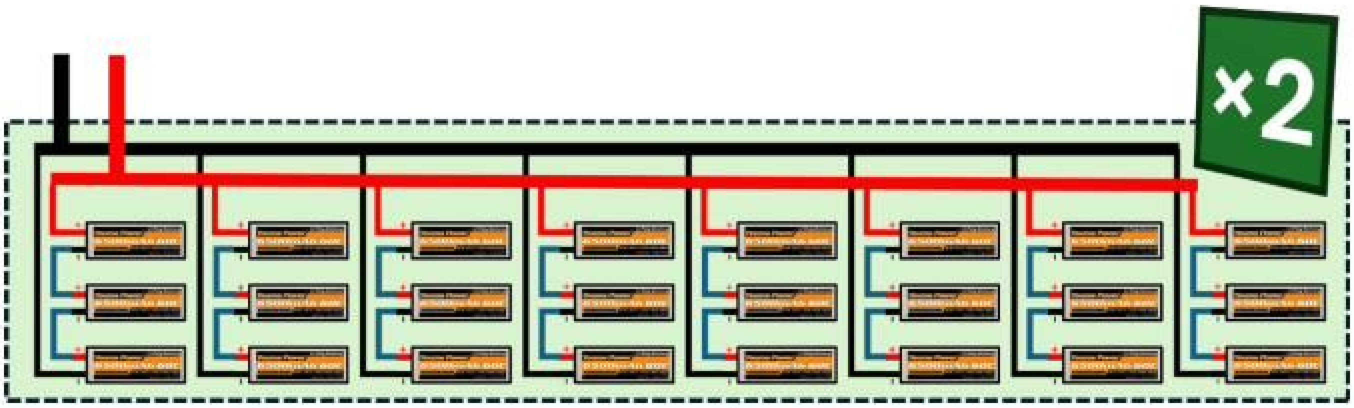


Figure 24: Packs of Three Wired in Parallel to Form the Two Sets

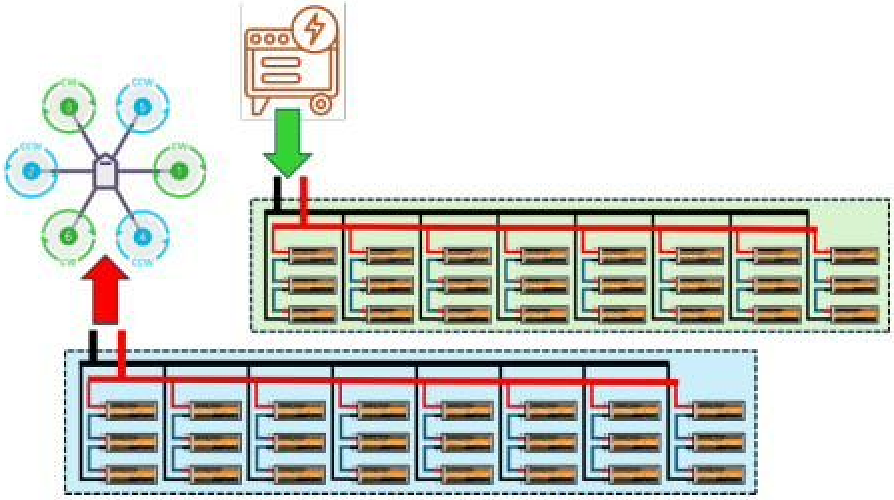


Figure 25: Battery System Theory | One set charges, One set fly

To provide power from the batteries to the motor drives, three bus ducts were used. A green bus duct was used to combine the positive leads from each of the battery packs, and a red bus duct was used for the positive motor cables. A black bus duct was used for the negative leads of both the battery packs and the motors, acting as a unified ground for both components. A power switch was installed to allow for manual activation and deactivation of the power system to the drone; the positive switch terminal was connected to the green bus duct and the negative switch terminal was connected to the red bus duct, each using a 2AWG wire to allow for maximum current flow.

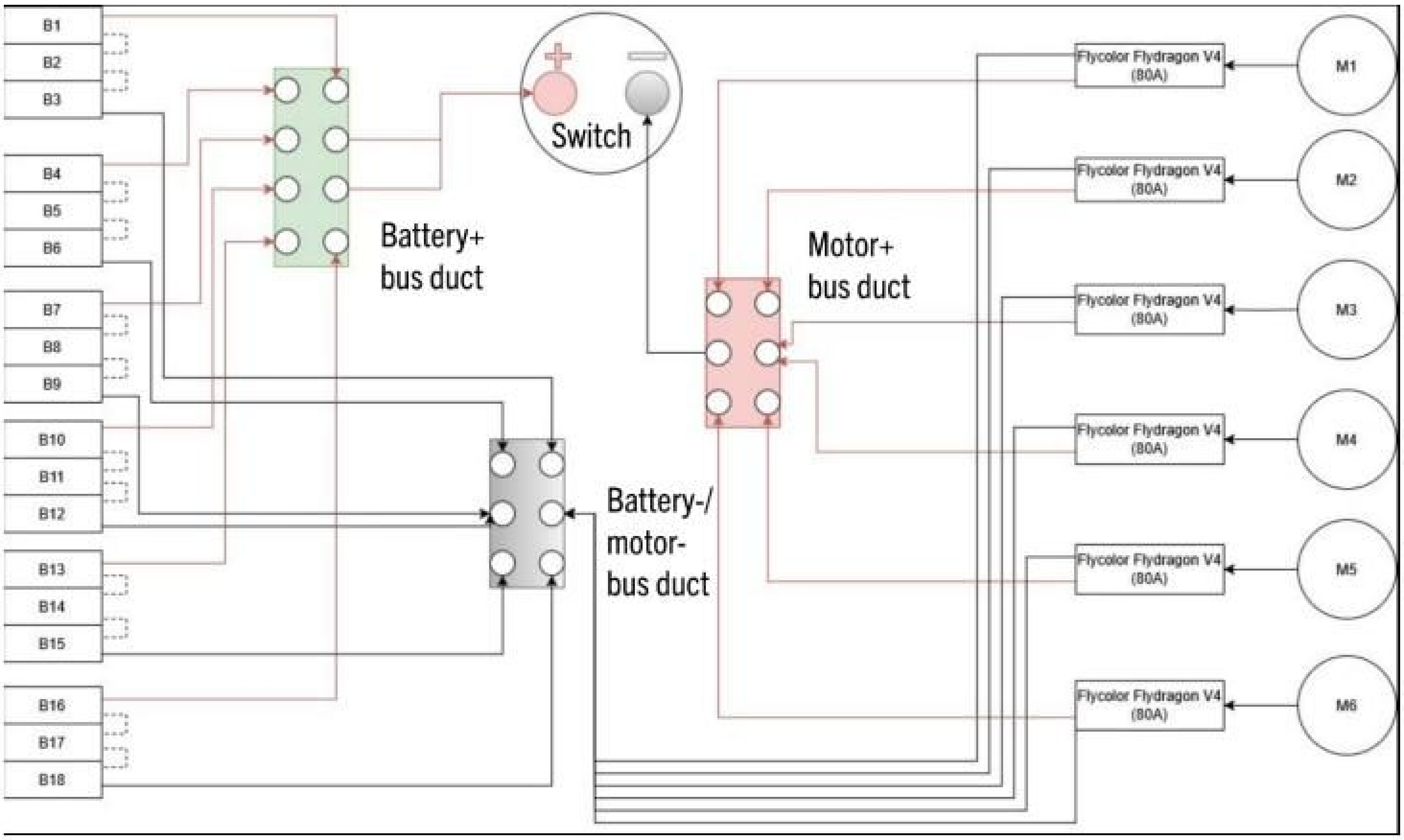


Figure 26: Final Battery Circuit Diagram

3.2.5. Sensors

In the scope of a long-term sensor project, integrating a range of sensors into a fully autonomous drone is critical for achieving accurate navigation, stable flight, and effective obstacle avoidance. This section outlines the selected sensors, explaining their individual roles within the system and the reasoning behind their inclusion. It also explores how these sensors are implemented on the UAV platform.

While the drone is capable of long-distance travel and high-speed operation, the sensor suite has been selected with a focus on delivering stability and precision for targeted applications, rather than pushing the limits of performance. The core aim is to ensure dependable flight performance with high accuracy, with sensors primarily dedicated to achieving robust localization and absolute positioning.

For missions such as aerial surveying and mapping, absolute positioning, a method for determining the drone's exact location relative to fixed reference points like GPS coordinates is necessary. To fulfill this requirement, the ArduSimple SimpleRTK2B Multiband GNSS module has been chosen as the primary positioning system. This decision is based on its strong performance record, including successful deployment in the Skywalker I, and Skywalker II platforms. Its compatibility with the Pixhawk flight controller—through standardized connectors, wiring conventions, communication protocols, and the widely adopted U-Blox chipset—makes it a wellsuited component for this project.

Figures 27 and 28 depict the device, with antenna specifications detailed in Figures 29 and 30. The GNSS module plays a key role in enabling stable and accurate flight, supporting the broader objectives of the project.

Figure 27: SimpleRTK2B Multiband GNSS

Figure 28: GPS

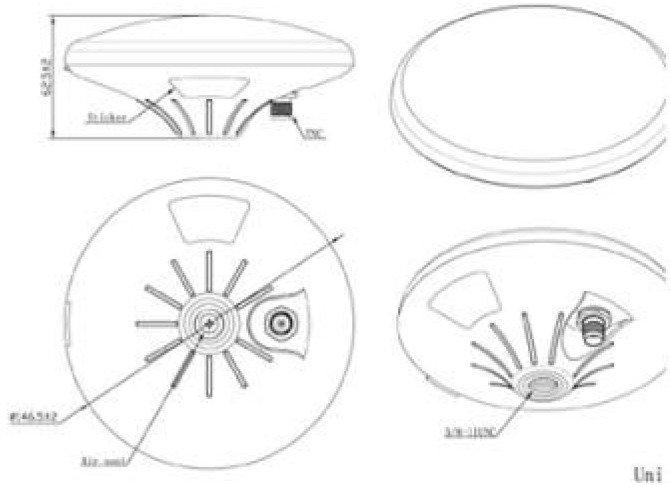


Figure 29: GPS Diagram

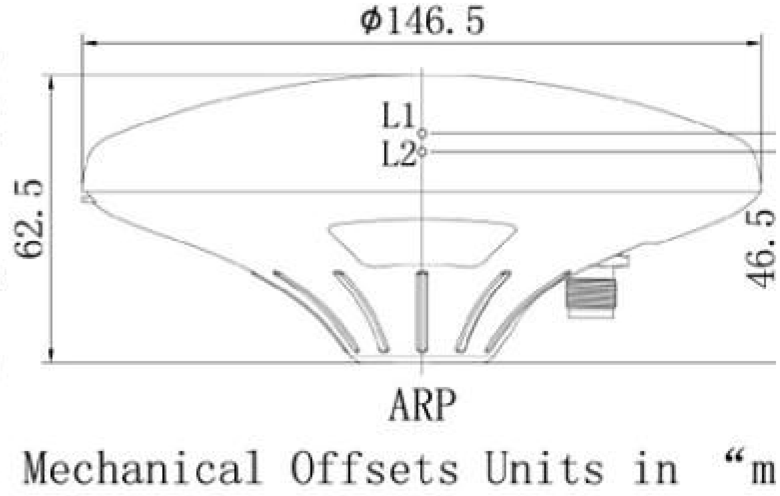


Figure 30: GPS Diagram (Side)

The decision to use the same survey-grade antenna as employed in both Skywalker I and Skywalker II was largely influenced by its proven performance and manageable weight of 390 grams, making it a practical choice for the current drone platform. The design and building of survey-grade antennas inherently support higher positioning accuracy, further justifying its selection. In addition to the primary compass and magnetometer, an external module was integrated to function both as the main compass and as a backup GPS system. The ReadytoSky Ublox M8N, illustrated in Figure 31 and widely regarded within the Pixhawk community for its dependable performance, was chosen for its reliability. An added benefit was the included mounting bracket, which simplifies the installation process. While the main objective was to address issues associated with the flight controller's internal compass and GPS, the external module also serves as a redundant system. If the primary GPS fails, the Ublox M8N chipset within the ReadytoSky unit automatically takes over, maintaining the UAV's autonomous navigation capabilities without interruption.

Figure 31: Readytosky Ublox M8N

3.3. Final Design

By combining all the subsystems together, we created a diagram for the entire flight system as shown in Figure 32, with the Pixhawk 2.4.8 allowing each piece to be integrated to the overall system through the various inputs.

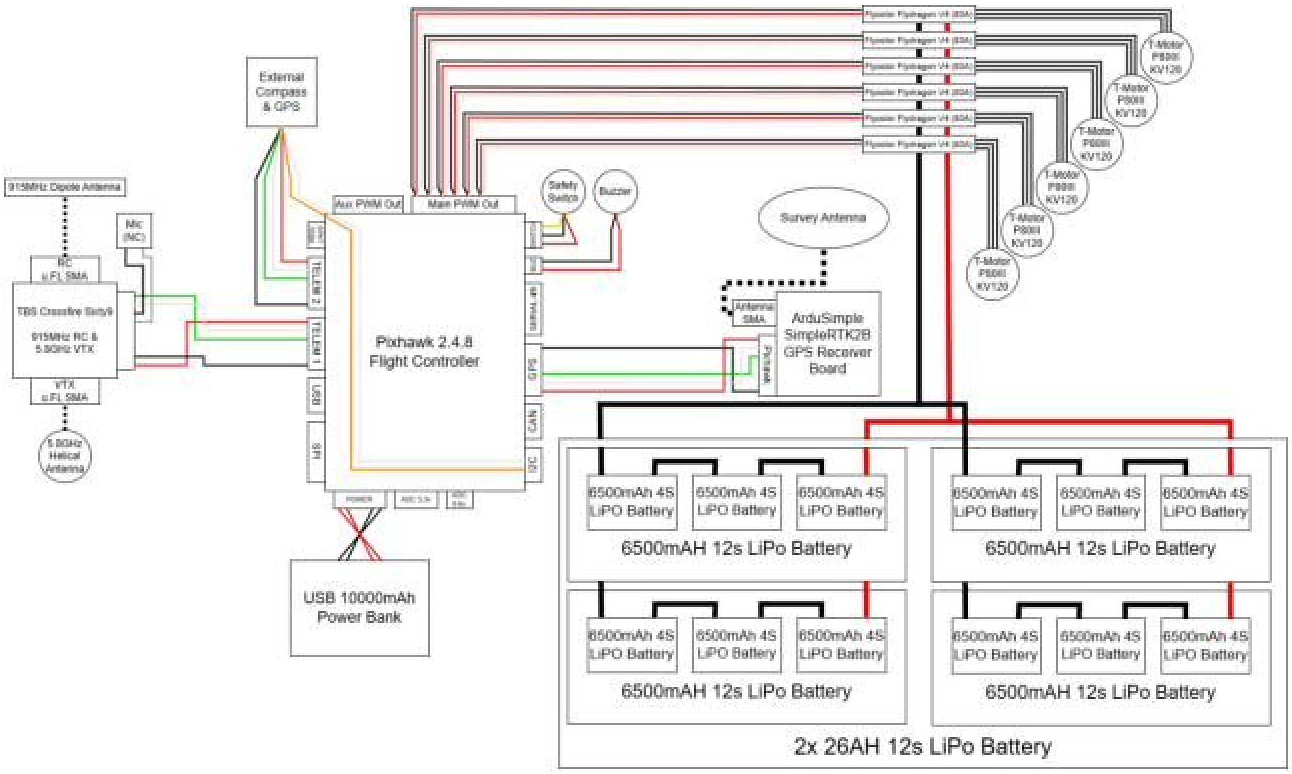


Figure 3227: Complete Circuit Diagram

This system has been designed to ensure that each component can accurately and reliably complete its task in the project. By implementing each piece of hardware into the Pixhawk, these subsystems can be calibrated, updated, and monitored via the Pixhawk and ArduPilot system. Through radio transmitter, the Pixhawk and base station can accurately communicate and control the drone remotely and autonomously.

3.4. Power Consumption

Calculating a drone's power consumption is crucial for optimizing flight time, ensuring system reliability, and preventing unexpected failures mid-flight. In our case, the primary electrical consumers in this drone are the six T-Motors, which are responsible for generating the lifting power of the drone. The technical specifications of the motors are as follows:

Item	Details	Item	Details
Brand	T-Motor	Model	P80 Ⅲ
Propeller	MF 3016	Type	KV 120
Weight	649 g	Dimensions	Φ91.6 × 43 mm
Internal Resistance	41 mΩ	Lead	14 AWG Silicone Wire
Configuration	36 N 42 P	Shaft Diameter	15 mm
Rated Voltage	12S	Idle Current (10V)	≤2.0A
Peak Current (180s)	70A	Max. Power (180s)	3600W
Throttle	100%	Voltage	46.61 V
Thrust	18,291 g	Torque	6.54 N·m
Current	77.84 A	RPM	4142
Power	3628 W	Efficiency	5.04 g/W

Figure 3328: Motor Technical Specifications

The drone is equipped with six motors, each requiring 77.84 Amps of 12S power:

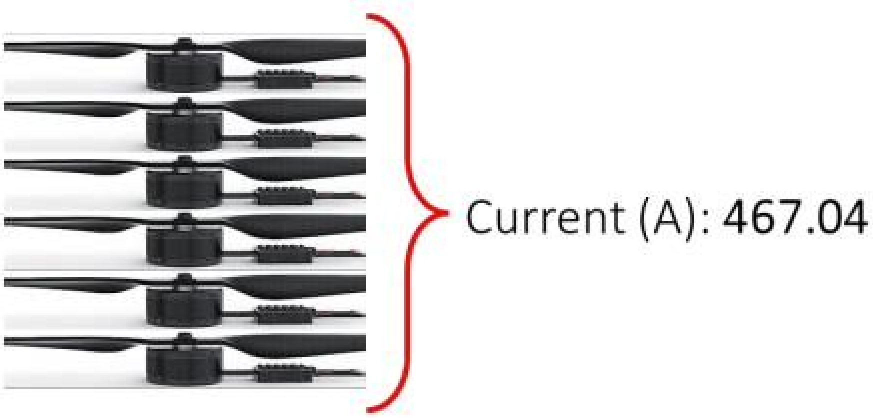


Figure 3429: Total Motor Amperage

When considering additional consumers, such as controllers and cameras, whose power demands are significantly lower than those of the six motors, a total maximum current demand of 480 Amps is a reasonable estimate.

3.5. Power Distribution Cabling

To supply 480 amps of 12S current to the drone at peak demand, each battery unit should contribute 20 amps, with a total of 234 batteries. This implies that each set of three batteries connected in series must provide 60 amps at peak power:

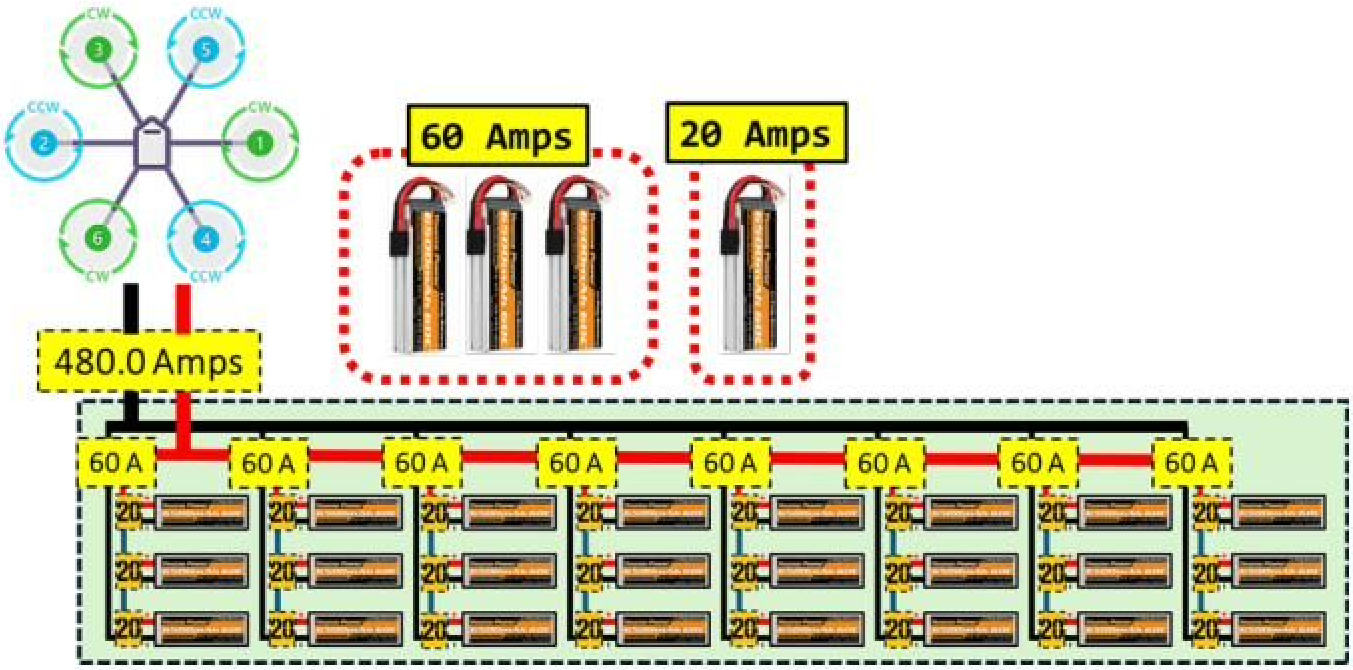


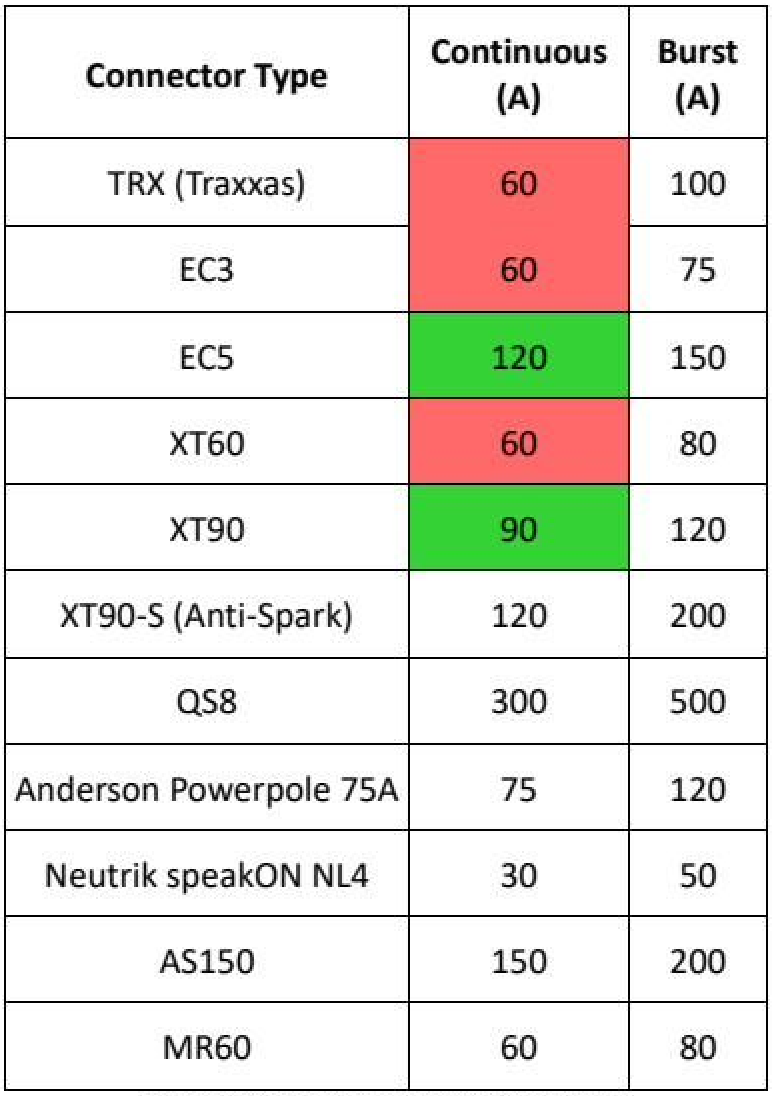
Figure 3530: Battery to Drone Configuration

Based on these calculations and referencing the cable sizing chart for 12S battery units, an 8-gauge cable is appropriate for use as the main connector for each set of three batteries to the bus ducts:

AWG Size	Max Continuous Current (A) 4S (14.8 V)	Max Continuous Current (A) 12S (44.4 V)	Max Burst Current (A)
22	5	3	8
20	8	5	12
18	16	10	24
16	22	15	33
14	32	25	45
12	41	35	55
10	55	50	75
8	73	68	100
6	101	90	135
4	135	125	170
2	181	160	225
1	211	190	260
J-00	245	225	300
F-00	283	265	340
M-00	329	310	390
A-00	380	360	450

Figure 3631: Cable Gauge Size Chart

Furthermore, an EC5 or XT90 connector can be safely employed to connect these battery packs:



Connector Type	Continuous (A)	Burst (A)
TRX (Traxxas)	60	100
EC3	60	75
EC5	120	150
XT60	60	80
XT90	90	120
XT90-S (Anti-Spark)	120	200
QS8	300	500
Anderson Powerpole 75A	75	120
Neutrik speakON NL4	30	50
AS150	150	200
MR60	60	80

Figure 3732: Battery Connections Chart

As indicated in the table, even an A-00 cable is unsuitable for transferring 480 amps of 12S power. Consequently, the team has opted to utilize three 500-amp industrial bus ducts as the terminal connectors.

4. Heat Generation Analysis

4.1. Introduction

Managing thermal output in unmanned aerial vehicles (UAVs), particularly in hexacopter designs, is a crucial issue because it directly affects the safety, maintenance, reliability, and longevity of key components.

During operation, components like batteries, power generators, electronics, chargers, the power management system, and motors all produce heat, with the amount varying depending on the drone's activity state. Environmental factors, such as sunlight exposure for larger drones like the one currently being developed, or the ambient temperature on any given day, can also significantly influence the drone's heat distribution and overall temperature.

Excessive heat buildup can pose serious safety risks, including the possibility of thermal runaway in battery cells, and can accelerate the wear of moving parts, ultimately undermining the drone's reliability and safety.

Therefore, implementing effective temperature monitoring and control systems is vital. These systems not only help maintain safe thermal conditions but also enhance performance and prolong the lifespan of critical components.

4.2. Heat Sources

In general, there are two primary sources of heat generation or heated environments: internal and external. Internal sources are associated with the drone itself and its components, while external sources come from the environment and are independent of the drone's systems.

Internal factors, which are part of the drone, produce heat mainly through conduction. Their heat outputs are typically derived from manufacturer specifications. In most cases, the heat generated by a component corresponds to the portion of its total power output that is not converted into mechanical work.

External factors, on the other hand, involve environmental influences, contributing heat through solar radiation and air convection.

For the Skywalker III drone considered in this study, six internal factors and two external factors are the primary contributors to the overall thermal output.

The internal factors examined are:

- Motors
- Motor Controllers

- Power Generator
- Batteries
- Battery Charger
- Electronics and Power Management Units
- The external factors considered are:
- Solar radiation (sunshine)
- Elevated ambient air temperature

It is important to note that the calculations in this evaluation do not account for aerodynamic effects that could impact the actual amount of heat needing management for thermal control. For the purposes of this study, it is assumed that the drone remains stationary when assessing heat emissions. The influence of drone movement on heat dissipation will be addressed and calculated in the following chapter.

4.3. Internal Factors

4.3.1. P80Ⅲ P Type Agricultural UAV Motors (KV120)

Each of Skywalker III's six propellers is powered by a T-Motor P80III Brushless DC (BLDC) motor. The P-series motor is specifically engineered for agricultural applications and plant protection tasks. Its design incorporates features to enhance heat dissipation, including airflow through the chassis and steel shafts. These motors draw electrical energy from the battery to rotate the propellers, generating the lift needed for the aircraft's flight. Technical Specifications of the motor:

- Manufacturer: T-Motor
- Model: P60 Without Pin P Type Agricultural UAV Motor KV120
- Type: Brushless DC (BLDC)
- Weight: 647g
- Size: Diameter: 92 mm, Height: 43 mm
- Internal resistance: 36-41 milli ohm
- Lead: 14AWG Silicone wire
- Configuration: 36N42P
- Shaft diameter: **15mm**

- Rated voltage: 12S (S=3.7V)
- Idle Current at 10 V: **2.0A**
- Peak Current: 70A
- Maximum power: 3600 W
- Efficiency of each motor (ηm): **80%**
- Electrical power input (Pin): 3628 W at max throttle
- Mechanical power output (Pout): See calculation below
- Number of units: **6**

The airflow inside the motor is illustrated in Figure 38.

Figure 3833: Motor Expanded View and Airflow

Heat Calculation:

To find P_{out}, the mechanical power output:

$$P_{out} = P_{in} \times \eta_m = 3628 \times 0.80 = 2902.4 \text{ W}$$

Power loss, which is converted into heat, is therefore:

$$P_{in} - P_{out} = 3628 \text{ W} - 2902.4 \text{ W} = 725.6 \text{ W per motor}$$

Therefore, for six motors:

$$\text{Total Heat generated} = 725.6 \times 6 = \mathbf{4353.6\ W}$$

4.3.2. Portable Power Generator (5600 W)

The power generator, shown in Figure 39, utilizes a gasoline-powered combustion engine to produce electricity. This generator is connected to the battery charger, which replenishes the aircraft's battery, enabling extended flight time.

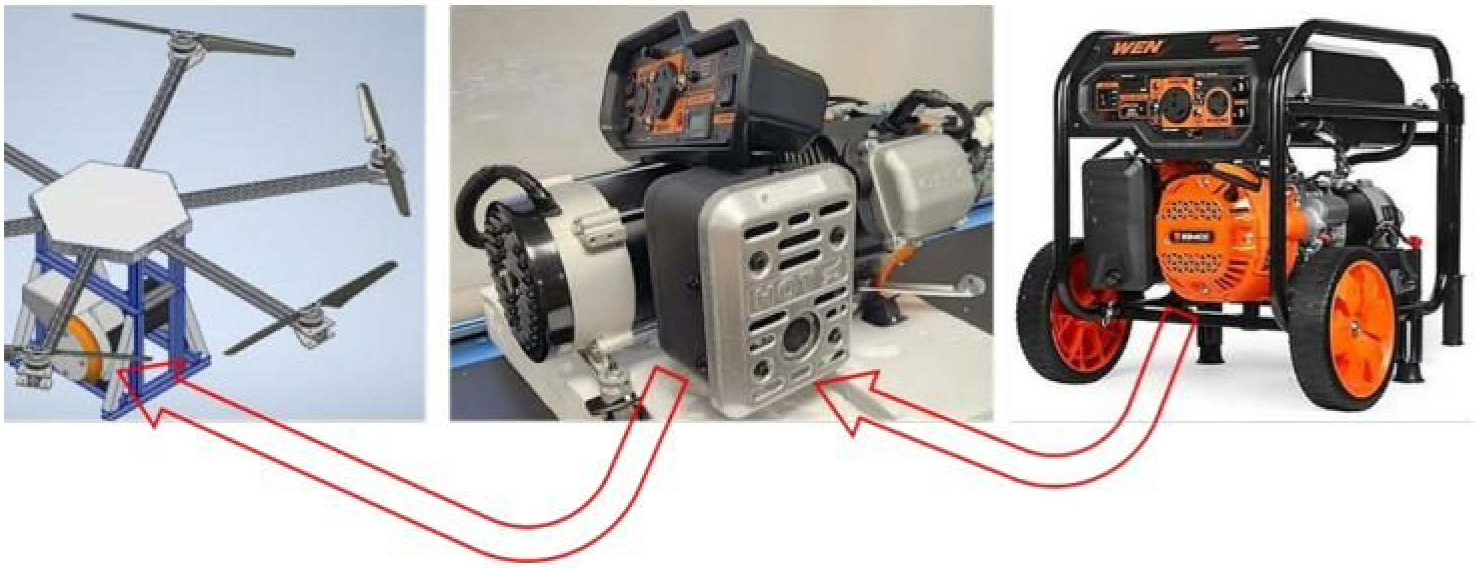


Figure 3934: Power Generator

Technical Specifications:

- Model: WEN GN5602X 5600-Watt Portable Generator
- Dimensions: 579 mm × 599 mm × 584 mm
- Max Rated Power (Epwr): **4500 W**
- Engine Type: 4-Stroke, OHV, Single Cylinder with Forced Air-Cooling System
- Engine Efficiency (ηm): 20% - 30% (Using 25% for a reasonable estimate)
- Engine size: 224 cc
- Fuel Delivery Method: Carburetor
- Spark Plug Type: Torch F7TC (NGK BP7ES)
- Fuel Tank Size: 16.5 Liters
- Fuel Used: Gasoline - 93% quality
- Energy Content of the Fuel: 34,200 kJ/liter
- Max Output power in 1 hour: 16000 Watts

Heat Calculation

Total Produced Energy by the Motor [E_{tot}] = Electrical Generator Power Output [E_{pwr}] + Generated Heat Waste[E_{heat}]

$$Etot = Epwr + Eheat$$

Electrical Generator Power Output[E_{pwr}] =

Total Produced Energy by the Motor [E_{tot}] × Efficiency Ratio of the Motor (η_m) Epwr = Etot × ηm

By combining and rearranging these two equations, we can conclude that:

$Eheat = (Epwr / \eta m) - Epwr$

$E_{heat} = (4500 / 0.25) - 4500$

$\mathbf{E_{heat} = 13500}$

4.3.3. Flycolor Flydragon V3 ESCs (80 A)

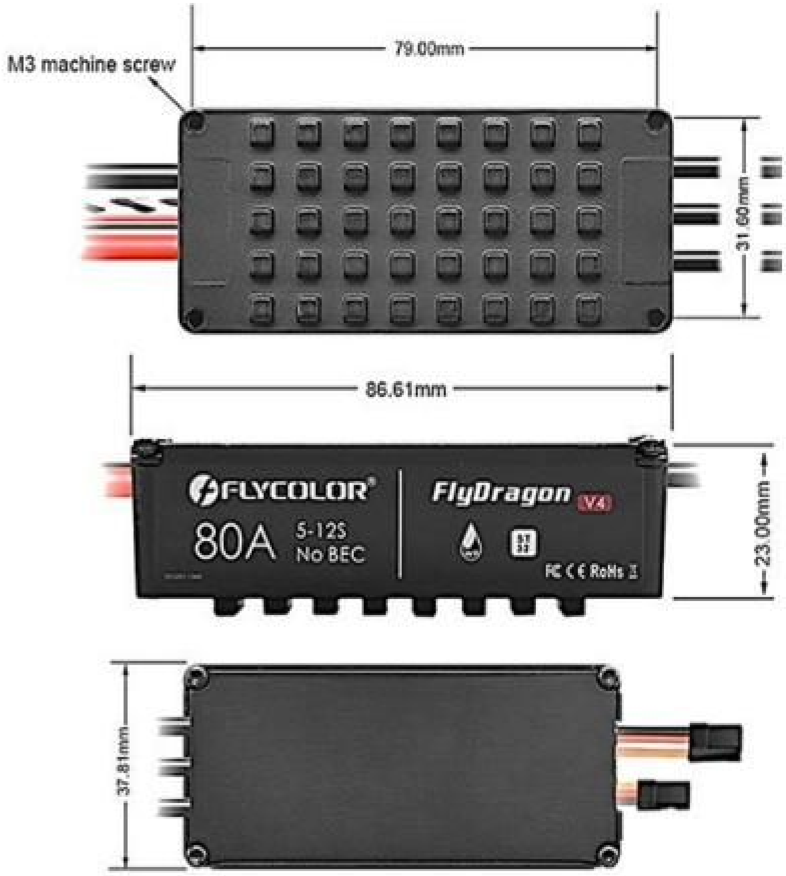


Figure 4035: Flycolor Flydragon V3 ESC

Six Flydragon V3 Electronic Speed Controllers (ESCs) are equipped on Skywalker III - one for each motor. ESCs are devices that allow the speed of the drone's electric motors to be controlled and adjusted.

This ESC is equipped with a highly efficient microcontroller unit (MCU), featuring the ARM 32-bit Cortex core, specifically the STM32F051. This design enables fast calculations and smooth operation while optimizing power usage to minimize heat generation.

The firmware is tailored for multi-rotor systems and utilizes Active Switch Continued Flow (ASCF) technology to enhance energy efficiency and reduce heat production.

The aluminum housing significantly improves heat dissipation.

It supports a throttle signal frequency of up to 500 Hz and is compatible with a maximum 12S LiPo battery. Additionally, it supports a single LiPo battery with a maximum voltage of 4.35 V per cell (Vcell).

Technical Specifications:

- **Model:** FlyDragon V3 (80 A)
- **Battery:** 12s
- **Continuous Current (Iunit):** 80 A
- **Burst Current (10S):** 120 A
- **Weight:** 103 g
- **Dimensions:** 81.5 mm × 36.5 mm × 21.1 mm
- **Assumed Efficiency (ηm):** 80% - 95% (Using 90% for a reasonable estimate)

Heat Calculation

Assuming the highest demanding circumstance, a 12S battery with each cell at S = 3.7 V supplying an ESC:

$$V_{total} = V_{cell} \times 12 \text{ cells} = 3.7 \text{ V/cell} \times 12 \text{ cells} = 52.2 \text{ V}$$

Since 6 ESCs are used on Skywalker III:

$$I_{total} = 6 \times I_{unit} = 6 \times 80 \text{ A} = 480 \text{ A}$$

Therefore the total power intake is:

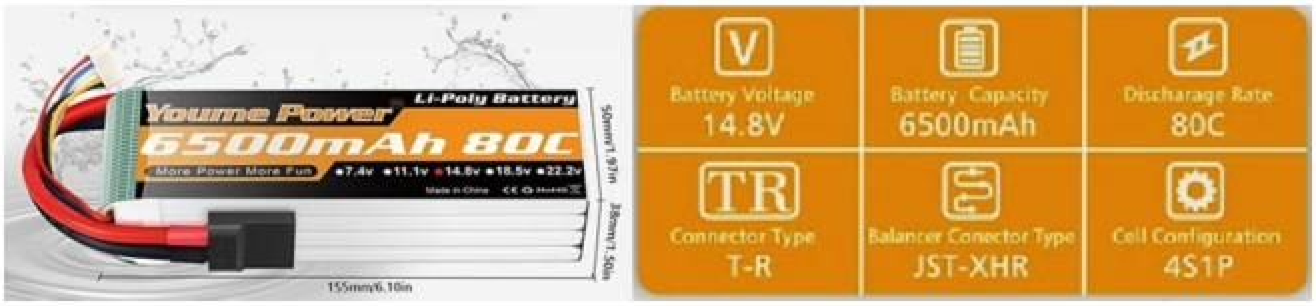
$$P_{total} = V_{total} \times I_{total} = 52.2 \text{ V} \times 480 \text{ A} = 25{,}056 \text{ W}$$

However, the heat produced from this amount of power being consumed is:

$$\textbf{Total Heat} = P_{total} \times (1.00 - \eta_m) = 25{,}056 \text{ W} \times (1.00 - 0.90) = \mathbf{2505.6\ W}$$

4.3.4. Batteries

Skywalker III is equipped with 48 rechargeable batteries, arranged into sixteen sets of three batteries connected in series. The series connection is used to increase the voltage while keeping the current constant. These series-connected sets are then arranged in parallel to increase the total current while maintaining a constant voltage. This combination allows for scalability in both total voltage and current. Calculations indicate that with this configuration, the drone is capable of a flight time of 10 to 15 minutes.



41: One of the sixteen series of 3 Youme 4S LiPo Batteries

Technical Specifications:

- **Brand:** Youme
- **Material:** Li-Polymer
- **Number of units: 4**
- **Cells:** 4S
- **Voltage:** 14.8 V (3.7 V/cell)
- **Max Voltage/cell:** 4.2 V
- **Capacity:** 6.5 Ah
- **Discharge Rate:** 80 C
- **Suggested Charge Rate:** 0.5 C-1.0 C (3.25 A-6.50 A)
- **Efficiency (ηm):** 90%
- **Dimensions:** 155 mm × 50 mm × 38 mm
- **Mass:** 574 g

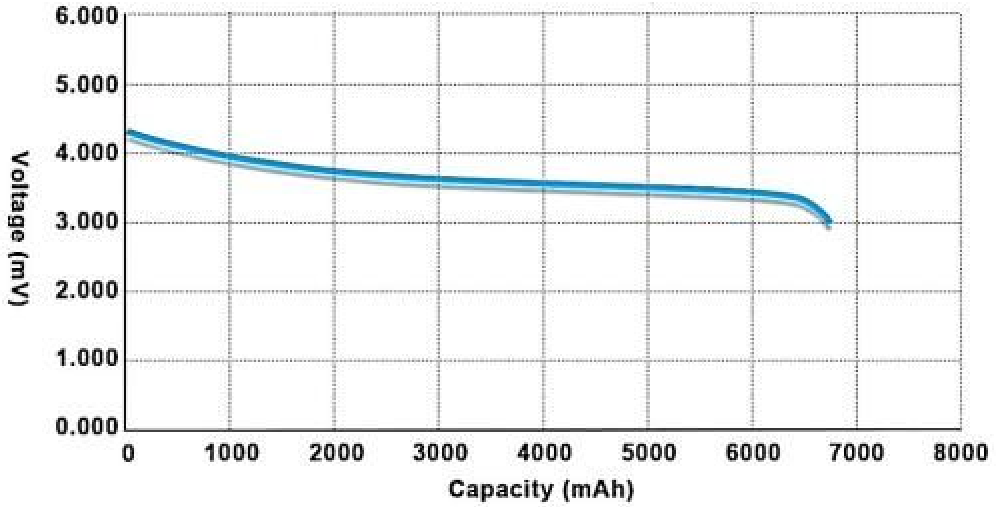


Figure 4236: Youme 6500 mAh Lipo Battery Discharge Curve (discharge rate of 1C)

The voltage and amperage of a single battery is shown above. However, the new voltage and amperage of the 48 batteries connected in series must be calculated to provide the power output (per hour), and thus the heat generated (per hour).

Heat Calculation

Since one battery is 14.8 V and 6.5 Ah, and the batteries are connected in 16 sets of 3 batteries in series:

3 Batteries in Series:

$$3 \times 14.8\ \text{V} = 44.4\ \text{V},\ 6.5\ \text{Ah}$$

16 sets of 3 serried batteries in parallel:

$$16 \times 6.5\ \text{Ah} = 104.0\ \text{Ah}$$

Therefore, the total capacity of the 48-battery pack is 104.0 Ah (I_{out}).

Battery Power per hour:

$$P_{out} = V_{out} \times I_{out} = 44.4\ \text{V} \times 104.0\ \text{Ah} = 4617.6\ \text{Wh}$$

Therefore, the amount of heat generated in 1 hour:

Total Heat per hour = $P_{out} \times (1.00 - \eta_m) = 4617.6\ \text{Wh} \times (1.00 - 0.90) = 461.76\ \text{Wh}$

4.3.5. Battery charger

As previously mentioned, the batteries being charged operate at 44.4 V and have a total energy capacity of 1154.4 Wh. Several additional key parameters regarding the charger are:

- **Input power to the charger from the Power generator:** 110V, 4500 Wh
- **Output power from the charger (Pout):** 1400 Wh
- **Transformer efficiency (ηm):** 85%

Heat Calculation

The heat generated by the charger over the course of one hour can be estimated using the following equation:

Total Heat per hour = $P_{out} \times (1.00 - \eta_m) = 1400 * (1.00 - 0.85) = \mathbf{210\ Wh}$

It is important to note that the actual heat generated will likely be somewhat lower, as the total energy supplied by the charger to the batteries in one hour is only 1154.4 Wh. This calculation represents a conservative estimate to ensure sufficient thermal management margins.

4.3.6. Voltage converters (From 48V DC to 24V, 12V, 5V)

There was initial consideration of incorporating two to three voltage converters into the system; however, for now, their impact on heat generation has been deemed negligible and is excluded from this analysis. This decision may be revisited in future evaluations.

4.4. External Factors

4.4.1. Sunshine

Basic formula for absorbed energy:

$$Q = A \times I \times \alpha \times t$$

A: Drone surface area: 2.00 (m^2)

I: Solar radiation intensity: 5,750 (W/m^2) (per day)

α: Absorptivity coefficient of the drone material: 0.615

t: Length of time of exposure: 7200 (s)

Solar radiation intensity:

According to https://www.solarenergylocal.com/, July is the month with the highest historical solar radiation values in Philadelphia, with an average of 5,750 Wh/m^2 per day.

Absorptivity coefficient of the drone material:

Material	Absorptivity coefficient (α)	Total surface area %
Aluminum, rough polished	0.5	30
Aluminum, smooth polished	0.2	10
Black matte	0.95	25
Black polished	0.95	5
Chromium plate	0.20	2
Steel sheet	0.7	8
Grey paint	0.95	5
Orange paint	0.35	15
Overall	0.615	100

Figure 4337: Raw Sheet Metal and Hex

Time of Exposure:

At present, the drone can fly for approximately 10 to 15 minutes. However, the goal is to optimize its performance so that it can remain airborne until the gasoline fuel supply for the battery charger is depleted.

At maximum performance — assuming a mechanical efficiency of 25% (η_{m}) as previously noted — the generator can continuously charge the batteries throughout the time it takes to consume the entire 16.5-liter fuel tank.

The relevant parameters are:

- **Maximum Output Power (over 1 hour)**: 16,000 W
- **Energy Content of Fuel**: 34.2 MJ/liter

Thus, the total energy available from a full fuel tank is:

$$34.2\ \text{MJ/liter} \times 16.5\ \text{liters} \times 3{,}600\ \text{MJ/Wh} = 156{,}750\ \text{Wh}$$

Given the maximum efficiency of 25%, only 25% of this energy is converted into mechanical energy, while 75% is lost as heat. Therefore:

$$\text{Mechanical Energy Output} = 156{,}750 \times 25\% = 39.2\ \text{kWh} = 39{,}200\ \text{Wh}$$

The operational time can then be calculated as:

$$T = 39200 / 16000 = 2.45 \text{ which is equal to } 147 \text{ minutes}$$

Additionally, the drone begins each flight with fully charged batteries. According to calculations made by James, the batteries alone support flight for approximately 10 to 15 minutes. Altogether, the drone's total estimated flight time is around 120 minutes, equivalent to:

$$T = 7200 \text{ seconds}$$

Regarding solar heating, the energy absorbed from sunlight is given by:

$$Q_{sun} = A \times I \times \alpha \times t = \mathbf{294.69\ W}$$

4.4.2. Hot ambient air temperature

Let us set the drone's ambient design temperature at 25 °C. Below are the average maximum and minimum monthly temperatures (in °C) for Philadelphia throughout the year. The highest average temperatures occur during June, July, and August.

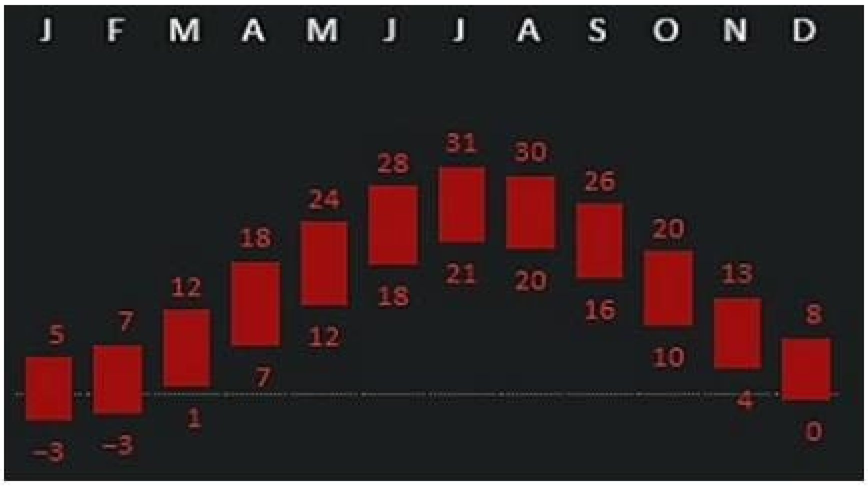


Figure 4438: Temperature Recordings

Initially, the drone is not intended to be tested during these three months, allowing us to disregard high ambient temperatures during that period. However, to ensure a robust year-round design, we will still consider these months.

The average maximum and minimum temperatures for June, July, and August are as follows:

- **June**: 18 °C (min) – 28 °C (max)
- **July**: 21 °C (min) – 31 °C (max)
- **August**: 20 °C (min) – 30 °C (max)

To find the maximum and minimum temperature differences ($\Delta T = T_{outside} - T_{drone}$), we subtract the drone's ambient design temperature (25 °C) from these values:

June:
ΔT_{min} = 18 °C – 25 °C = **–7 °C**
ΔT_{max} = 28 °C – 25 °C = **+3 °C**

July:
ΔT_{min} = 21 °C – 25 °C = **–4 °C**
ΔT_{max} = 31 °C – 25 °C = **+6 °C**

August:
ΔT_{min} = 20 °C – 25 °C = **–5 °C**
ΔT_{max} = 30 °C – 25 °C = **+5 °C**

On average, ambient temperatures are not excessively high for extended periods, and the temperature differentials are generally moderate. However, for design safety, we must plan for worst-case scenarios. The highest recorded temperature in Philadelphia was 106 °F (41 °C) on August 7, 1918. Thus, we will consider $\mathbf{T_{max} = 41\ °C}$ for extreme case analysis. The basic formula for convective heat transfer is:

$$Q = h \times A \times \Delta T$$

Where:

- **Q** is the heat transfer rate (W)
- **h** is the convective heat transfer coefficient (W/m²·°C)
- **A** is the surface area of the drone (m²)
- **ΔT** is the temperature difference between the drone and ambient air (°C)

The drone's surface area is relatively small, approximately **2 m²**. We will proceed with **A = 2 m²**.

Assuming:

- Ambient air temperature of 25 °C,
- Drone speed around 10 km/h (2.78 m/s),
- Turbulent airflow conditions,
- A fully polished and smooth drone surface, then, based on thermodynamics air tables, we can use **h = 100 W/m²·°C** for the convective heat transfer coefficient.

So, the Q_{max} for $T_{max} = 41$ °C will be as follows:

$$Q_{max} = h\ .\ A\ .\ \Delta T \quad h = 100\ W/m^{2}{}^{\circ}C \quad A = 2\ m^{2}$$

$$T_{max} = 41\ ^{\circ}C \quad T_{drone} = 25\ ^{\circ}C \quad \Delta T_{Max} = +16\ ^{\circ}C$$

$$Q_{max} = h\ .\ A\ .\ \Delta T = 100 \times 2 \times 16 = 3200 \text{ Watts}$$

$$Q_{max} = 3200 \text{ Watts} = 11{,}000 \text{ BTUs/Hr} = 4.3 \text{ hr}$$

4.5. Total Heat Output

Part	Total heat output (W)
P80Ⅲ P Type Agricultural UAV Motor KV120	4353.6
WEN 5600 W Generator	13500
Flydragon v3	2505.6
Youme 4S LiPo Battery (per hour)	461.76
Battery chargers (per hour)	210
Voltage converters - from 48V DC to 24 V, 12 V, 5 V	0
Sunshine	294.69
Hot air temperature	3200
	24,525.65

4.6. Discussion

After calculating the total heat output of Skywalker III while stationary, it can be reasonably concluded that the amount of heat generated is significant. As a result, it would be prudent to consider implementing a cooling system on the aircraft. However, as previously noted, this study does not take into account aerodynamic factors that could affect the actual thermal load requiring mitigation.

Aerodynamic influences primarily involve convection — the transfer of heat through the movement of a fluid, such as air or liquid. Several additional external convection-related factors that are important to consider include:

- The surrounding air temperature being cooler than the drone components
- Airflow generated by the propellers
- The drone’s flight speed, which may enhance ventilation by delivering cooler air across the components and removing heated air

These factors could assist in cooling the drone without relying solely on an active cooling system. Moving forward, it will be important to calculate the effects of these three factors to fully assess both sides of the thermal management equation:

A) The amount of heat that must be dissipated

B) The amount of heat that can naturally be removed through aerodynamic convection.

If the gap between these two values does not achieve a thermal equilibrium where all components remain within safe operating temperatures, then additional cooling measures will be necessary. For instance, installing a fan to direct airflow between the batteries or incorporating a water-cooling system for the power generator could be viable solutions.

5. Implementation & Testing (Procedure)

5.1. Hardware Assembly

Once the 3D model of the drone's assembly was finalized, the construction process began. To maintain being within budget, parts were custom made in the machine shop by the team members when seen fit, and most of the parts were created using scrap metal already in our possession. Some parts were also custom 3D printed to cut down on costs as there was filament available at no cost to the team. Parts such as the shock springs, pin eliminators, and aluminum T-slot bars were purchased online. Whenever possible parts were ordered on amazon with a premium subscription to reduce shipping costs and get a small percentage of the total cost back that could be put towards more purchases. This membership was also at no cost to the team as the ARTEMIS Lab has its own amazon account used to source materials.

Following all the new additions and alterations to the 3D model, the new acrylic plate was fabricated and prepared for the addition of all the flight control system electronics and auxiliary devices. The plate was first cut on a bandsaw, and the center cavity was done with a Dremel tool. The plate was fastened to the top hexagonal structure with metal spacers and M8 nuts, bolts, and washers. All electronic components were fastened with their hardware provided. The bus ducts added onto the battery level were fastened with M8 bolts and the lab provided tension nuts specific to the aluminum T-slot bars. All the wiring was fastened to these ducts with their provided hardware. For the landing gear system all components were fastened with M8 bolts and the same tension nuts, except for the shock springs which were secured to the pin eliminators with the pin and hex bolts provided with them after purchase. The generator chassis and added aluminum bars utilized the same M8 bolts and tension nuts. The generator itself is secured with its manufacturers providing hardware and while disassembled all components are clearly organized and labeled to avoid confusion. The drone now consists of three total levels with the top designated for the propulsion system and all flight control and auxiliary electronic devices. The second level houses all the LiPo batteries and the connections of the power system, and the third level is the generator and the landing gear system.

5.2. Flight Systems

The flight systems of this drone are powered by the Pixhawk flight controller and connected to the transmitter through a radio receiver on the drone. To begin sending a signal to the drone, the PixHawk controller is powered on with an external 5V power source and delivers power to the receiver. Once communication between joystick and Pixhawk is established, the batteries are powered on and the motor ECSs are connected to the PixHawk. Ardupilot is then launched on the laptop, which is connected to the transmitter(joystick) via MAVlink, and connected to the controller by UDP Port 5670. The signal is then established, and the drone is ready to be monitored and armed through Mission Planner.

The Sky-Walker III team ran into several issues with the flight systems throughout the semester. The TBS Tango II transmitter and TBS Sixty9 RF crossfire receiver proved to be problematic as they were constantly experiencing firmware corruption and refusing to bind. The development and construction of the drone was focused on budget and extending flight duration, which were both hindered in the search for a new receiver. In the upcoming Sky-Walker IV, it would be recommended to upgrade the communications system between PixHawk and Joystick, for ease of use and for general time-saving purposes.

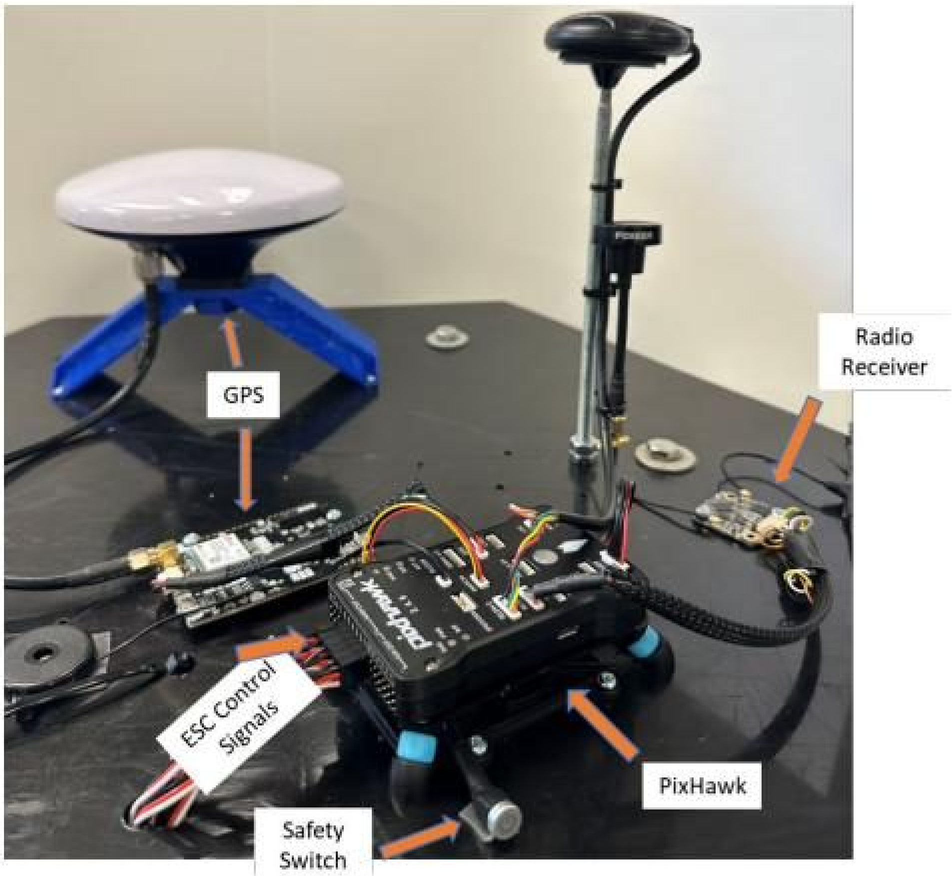


Figure 4539: Flight System Electronics

5.3. Flight Testing

The flight systems are still in their testing phase. The propulsion system has been tested both in our lab, as well as outside where the propellers could be attached. For this, the team followed two separate procedures. The first was indoor tests, that if ran successfully, the drone could be brought outside and tested further into the outdoor testing phase. Below in this section, you will find the full procedure for both our indoor tests and our outdoor testing.

	Instruction
Visual Inspection	- Verify all components are securely mounted and connections are tight.
	- Ensure wiring is organized to prevent interference with moving parts.
Power System Verification	- Confirm battery configuration provides the correct voltage and current (12S-14S).
	- Check each T-Motor P-80III motor for smooth operation without unusual noises.
	- Ensure FlyDragon 80A ESCs are properly calibrated and responsive.
Flight Controller Calibration	- Calibrate the PixHawk 2.4.8 accelerometer and gyroscope using ArduPilot.
	- Verify the correct orientation and secure mounting of the flight controller.
Radio System Check	- Bind the TBS Tango 2 Pro controller with the TBS Sixty9 receiver.
	- Test all control inputs for proper response and range.
GPS and Compass Calibration	- Calibrate the ReadytoSky M8N GPS and magnetometer for accurate positioning.
	- Verify functionality of the ArduSimple SimpleRTK2B GPS board.
Motor Tests	- Direction of Rotation: Verify each motor's direction matches the flight controller's configuration (CW/CCW).
	- Low-Speed Test: Run motors without propellers to check for smooth and synchronized operation.
	- 20% Load Test: Attach propellers, arm the drone, and slowly throttle up to 20% power while securely restraining it.
	- Check motor performance under load for uniform thrust and stability.
Failsafe Configuration	- Set up failsafe protocols in ArduPilot for signal loss or low battery scenarios.
	- Test failsafe activation to confirm expected behavior.
Sensor Validation	- Use ArduPilot to monitor real-time sensor data for accuracy.
	- Verify GPS module acquires satellites and provides correct location data.
Software Parameter Review	- Review and adjust flight parameters to match the hexacopter's specifications.

	- Confirm firmware is up-to-date for all components.
Ground Control Station (GCS) Connectivity	- Establish connection between the drone and the GCS via MAVLink over Wi-Fi.
	- Test telemetry data transmission and responsiveness to commands.
Balance Testing	- Use the crane to suspend the drone by its center of gravity.
	- Check for balance in all axes (roll, pitch, and yaw).
	- Adjust weight distribution if necessary to achieve equilibrium.
Propeller and Final Motor Test	- After ensuring balance, attach propellers and perform a controlled test with the drone hanging from the crane.
	- Slowly throttle up to simulate hover conditions (e.g., 20% power) and observe stability.
	- Verify thrust symmetry and motor alignment during operation.

Before testing the flight system outside the motors were tested to make sure that they were all spinning at the same rate. This was done with a Tachometer, and a strip of reflective paper on the side of the motor, the Tachometer gave us the RPM if each of the motors which we could compare to the others to make sure they are within a certain range. This testing resulted in us finding one motor that would consistently spin around 400 RPM faster than the rest at low throttle, at high throttle the motor would spin slower than the rest. The discrepancy between motors is shown in figure 46.

Figure 4640: Tachometer Display of two motor's RPM

Believing this to be a calibration issue, a calibration was run multiple times for all of the ESCs and motors, This however did not fix any of the issues we had encountered.

The flight testing of the drone started on 4/20/25 in the courtyard next to the Kirkbride Hall main entrance as shown in Figure 47. The outdoor flight testing procedure, found below, is what the team used to test Sky Walker's vertical take-off ability.

Item	**Instruction**
Weather and Environmental Check	- Check weather conditions (wind speed, temperature, visibility) to ensure safe flying conditions.
Pre-Flight Safety Check	- Confirm a clear and open flying area with no obstacles or hazards (e.g., trees, power lines, buildings).
Battery Check	- Verify battery charge level and inspect for any signs of damage or wear. Ensure the battery is securely mounted on the hexacopter.
Flight Mode Configuration	- Ensure the correct flight modes (e.g., Stabilize, Loiter, AltHold, RTL) are configured and easily switchable on the transmitter.
Arming Check	- Arm the motors in a safe environment (with propellers off or in a safe location) and verify the throttle response and ESC calibration.
GPS and Compass Signal Check	- Ensure that the GPS signal is strong and the compass is calibrated and pointing in the correct direction (verify satellite lock).
Compass Interference Check	- Check for magnetic interference in the area (e.g., power lines, metal objects) and ensure the compass is not giving erroneous readings.
Motors and ESC Performance	- Verify that all motors are running smoothly with the correct direction of rotation (CW/CCW) and check ESC performance under load with propellers attached.
Failsafe Functionality	- Test failsafe settings, including signal loss and low battery failsafes, to ensure proper activation.
Control Range Test	- Perform a short-range test to verify the response and range of the radio control system, checking for any loss of signal or unexpected behavior.

Flight Controller Orientation	- Confirm the flight controller's orientation in relation to the vehicle (ensure roll, pitch, yaw axes are correct) and check for proper flight controller response.
Motor and Propeller Test	- Perform a brief hover test in a safe, open area to verify thrust symmetry, motor alignment, and overall vehicle stability with propellers attached.
Flight Mode Transition Test	- Test mode transitions (e.g., from Stabilize to Loiter, or Loiter to AltHold) and verify the behavior of the aircraft in each mode during flight.
Return to Home (RTH) Test	- Test the Return to Home feature (RTH) in a controlled environment to ensure the hexacopter correctly returns to its launch location or designated RTH point.
GCS Communication Check	- Verify telemetry data transmission and responsiveness of the Ground Control Station (GCS), ensuring the link is stable and data is updating properly.
Propeller Check	- - Ensure all propellers are securely attached and free of damage before flight.
Altitude and GPS Hold Test	- Test GPS hold by flying the hexacopter to a stable altitude (e.g., 10-20 feet) and ensuring the drone holds position and altitude steadily in GPS mode.
Takeoff and Flight Stability	- Perform a slow takeoff to ensure stability during ascent and observe for any vibrations, yaw drift, or other signs of instability.
Hover and Maneuver Test	- Conduct a hover test and basic maneuvering (e.g., roll, pitch, yaw) to verify control stability, responsiveness, and smooth transitions in the air.
Emergency Landing Test	- Simulate an emergency landing (e.g., cut throttle and initiate descent) to verify safe and controlled descent behavior.
Post-Flight Inspection	- Inspect the drone after the flight for any signs of wear, damage, or component failure (motors, ESCs, battery, etc.).

Figure 4741: Satellite Image of Test Area

In the first flight test attempts, the motors were set to low throttle to make sure everything was connected after having to partially take it apart to bring it outside. With everything working, the throttle each motor was set began to increase, testing all motors at 65% where it had been previously determined was the point in which all motors spun the same. The motors were all set to throttle percentages through the test motor page in Mission Planner, as seen in figure 48.

Throttle % 5

Duration (s) 2

Set the min % that will be output when armed, but still on the ground

Set the min % that will be output when flying

NOTE: PLEASE HOLD DOWN YOUR UAV
This will test your motors are working
Motors are tested in a clockwise rotation starting at the front right.

Please click here to see your motor numbers, scroll to the bottom of the page.

Figure 4842: Motor Test

During the high throttle tests, a strange chattering sound started coming from the motors. Upon inspection of the system it was found that since the blades could rotate freely in their housing, the sudden acceleration caused the blade housing to crash into the blade, which caused the chattering sound as well as damage to the sides of the blades. In further tests the blades were fastened in order to avoid this damage. This damage is marked in figure 49.

Figure 4943: Blade Damage Caused by Acceleration

With the motors tightened, the flight testing was continued at higher speeds, however at 100% throttle, the drone would still not take off, to reduce the weight of the drone, the generator chassis was removed, as well as 6 of the batteries, this final configuration can be seen in Figure 50.

Figure 5044: Drone After Removing Weight

With Less weight, the flight tests began to look more promising, until testing at 100% throttle. At this point the drone was able to overcome the ground forces and achieve liftoff for a short time, however with one motor under spinning, the rest of the drone started to rotate in that direction, using the leg of the landing gear as a fulcrum and rotation over itself. The drone can be seen mid crash in Figure 52.

Figure 5245: Mid Crash

With too many components damaged, this was the end of testing, all of the propellers had been damaged, and some parts of the frame had been bent due to the force. The aftermath can be seen in Figure 53.

Figure 5346: Aftermath of Crash

6. Results

This project called for a truly deep, system-wide push, from the ground-up fabrication of the airframe and the installation of intricate power electronics to the full configuration of an autonomous flight stack. Every stage came with its own unique hurdles, and piecing together the tangled web of dependencies between the mechanical, electrical, and software subsystems took days of intense research, iteration, and hands-on integration.

The team inherited the Sky-Walker II drone model from the previous team. With most of the drone airframes being constructed already, the Sky Walker III team took more of a refining approach to the design. Staying consistent with the materials previously used, as well as optimizing free space on the drone itself. With the main electronics in mind, the chassis of the drone was completely modeled using Inventor CAD software as shown in Figure 54 which helped decide the best material type to use to construct the drone which was determined to be aluminum t-slot.

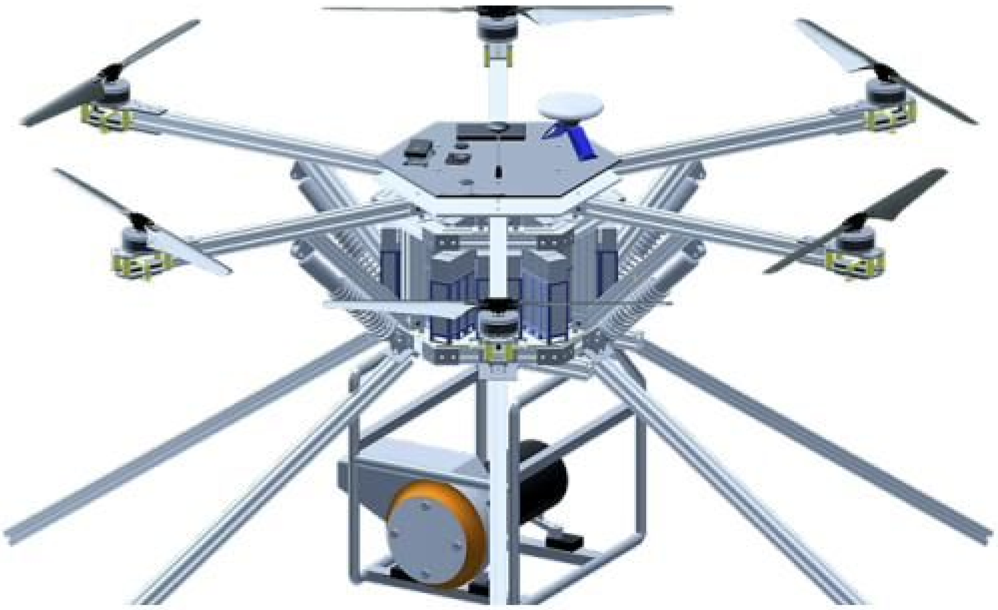


Figure 5447: Final Drone CAD Model

Above, is the final CAD model for Sky-Walker III hexa-copter drone prototype. As you can see, the team was able to add a full landing gear to the drone's body, which in theory should make having a vertical take-off and landing much smoother. The landing gear was also equipped with shock absorbers designed for dirt bikes. These shocks help distribute the forces the drone will experience during a drone landing. The modification and installation of the landing gear, proved to quite helpful for protecting the chassis, which in future will house the combustion engine used for in flight battery charging.

Once most the components were created and durability tested, the construction of the drone was started by creating the multiple hexagonal structures, attaching them together to create floors for electronics, batteries, and generator, connecting the motor arms to the top by sandwiching the hex plate and base plate together, and installing all the electrical components, including the flight system. This process was meticulously thought out and drafted into a procedure depicted in Figure 55 to ensure that construction was sturdy and durable enough to sustain flight without risk of damage to persons or property in close proximity to the drone.

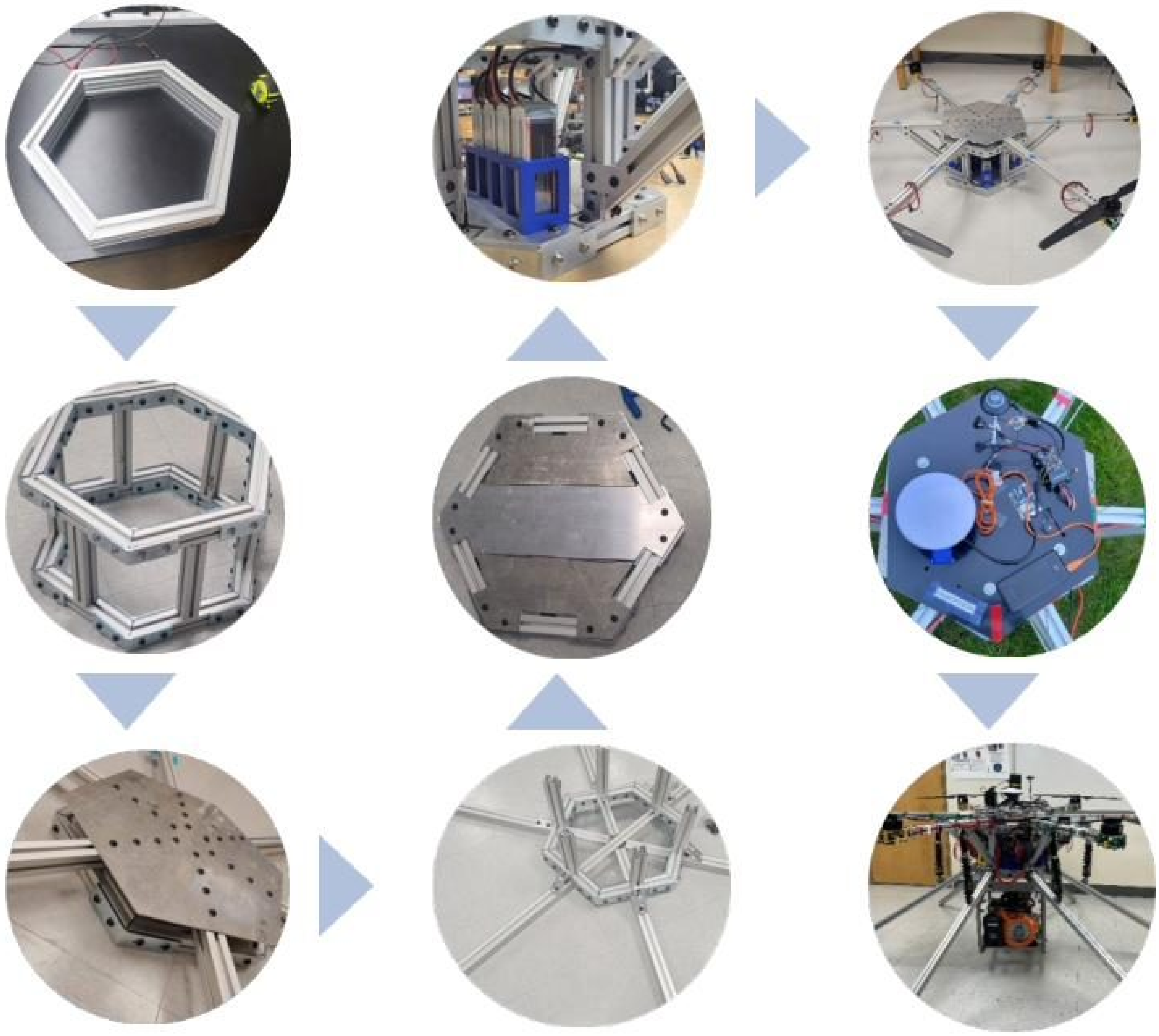


Figure 5548: Construction Process

Following the proposed design, the drone was completely constructed by April, after confirming the Power systems were correctly built and everything on the drone was working, flight testing began.

Following the FAA guidelines, the drone was tested on campus and was able to lift itself entirely off the ground. The initial testing showed stability issues when controlling the drone manually and due to transmitter issues, the drone had to maintain a USB connection to a laptop to test the motors. This issue regarding the stabilization of the drone is the root cause of this drone being unable to fly at the time, but once the motors can be checked that they all function properly again, and the ESC's are calibrated, it will have full capabilities and the functionality of a modern off-the-market multirotor drone.

Figure 5649: Final Drone in Field

7. Conclusion

7.1. Conclusion

During the time spent working on the project, the team were able to learn many different skills, techniques, and useful information about multi rotor UAV's, flight control, and other more basic engineering topics. By taking on the previous year's work and improving it with new additions and changes to old designs, the team was able to make substantial progress on this large-scale project. Along with all the technical information learned, this project also allowed us to learn many life skills to take with us as we continue to the workplace or higher education. Project and time management, collaboration, leadership, communication, comprehension and execution of material are all valuable skills that were either learned or improved upon during the duration of this project.

With the completion of this year's iteration of the project, it signifies the culmination of all the time and effort that was poured in over the past school year. The timeline and milestones hit during the project duration give a visual representation of the growth the team experienced which can be taken into the next steps of life. This idea for a multi rotor drone with onboard charging could make waves in the drone industry and every other industry in which drones are utilized. The low-cost requirements and expanded flight duration alone are two massive feats the entire industry has been continually improving and this project, if done correctly, would be a major step in the right direction.

In conclusion, the team worked together tirelessly to try and achieve all of the goals set during the inception of this year's project. These goals were to improve upon the current drone, implementation of the smart recharging system, and autonomous, smooth flight. The techniques and skills learned will allow the team members to have a strong foundation in autonomous systems, manufacturing, design, project management, and implementation of an idea to a physical product. Continuing to work on this project has great potential and can lead to large steps in the right direction for the drone industry and also humanitarian causes by providing long-range flight capabilities and minimal to zero human interaction.

7.2. Recommendations

If another iteration of the Skywalker project were to happen there are many recommendations that can be made to further improve upon the hexacopter to ensure success. First and foremost is weight reduction, a large reason why a proper takeoff did not occur was due to the weight. While testing items non-essential to motor control and flight control were removed to get the drone to lift off the ground with no success. Many of the brackets are made of steel adding a lot of weight, a good alternative material for the brackets would be carbon fiber which has high tensile strength and very low weight when compared to steel. Another recommendation would be to fully disassemble the motor and related ESC for motor 5 which had RPM issues that was believed to have caused the drone to flip over in testing. This is a large issue and should not be overlooked. Furthermore, the proper implementation of the generator and smart power system should be further developed and possibly installed.

8. Project Budget

Team: 17

Project name: Skywalker III

Advisor: Dr. Daniel Roozbahani

Total budget: 2736.72$

Submission date: 10/23/2024

Approved date:

Final Totals:

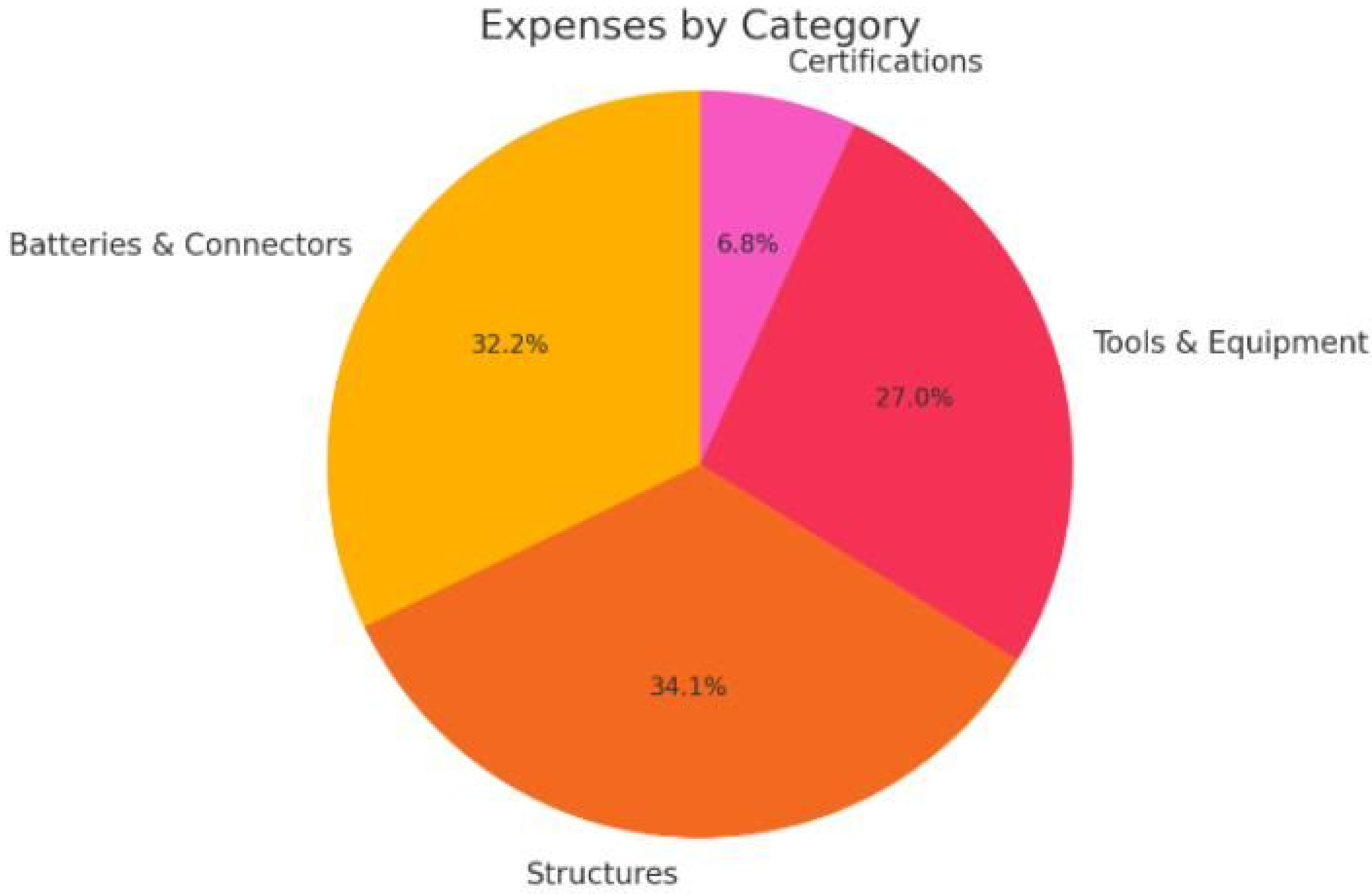
Description	Amount
Total Budget	$2,736.72
Total Spent	$3,063.93
Remaining Balance	- **$327.21** (Over Budget)

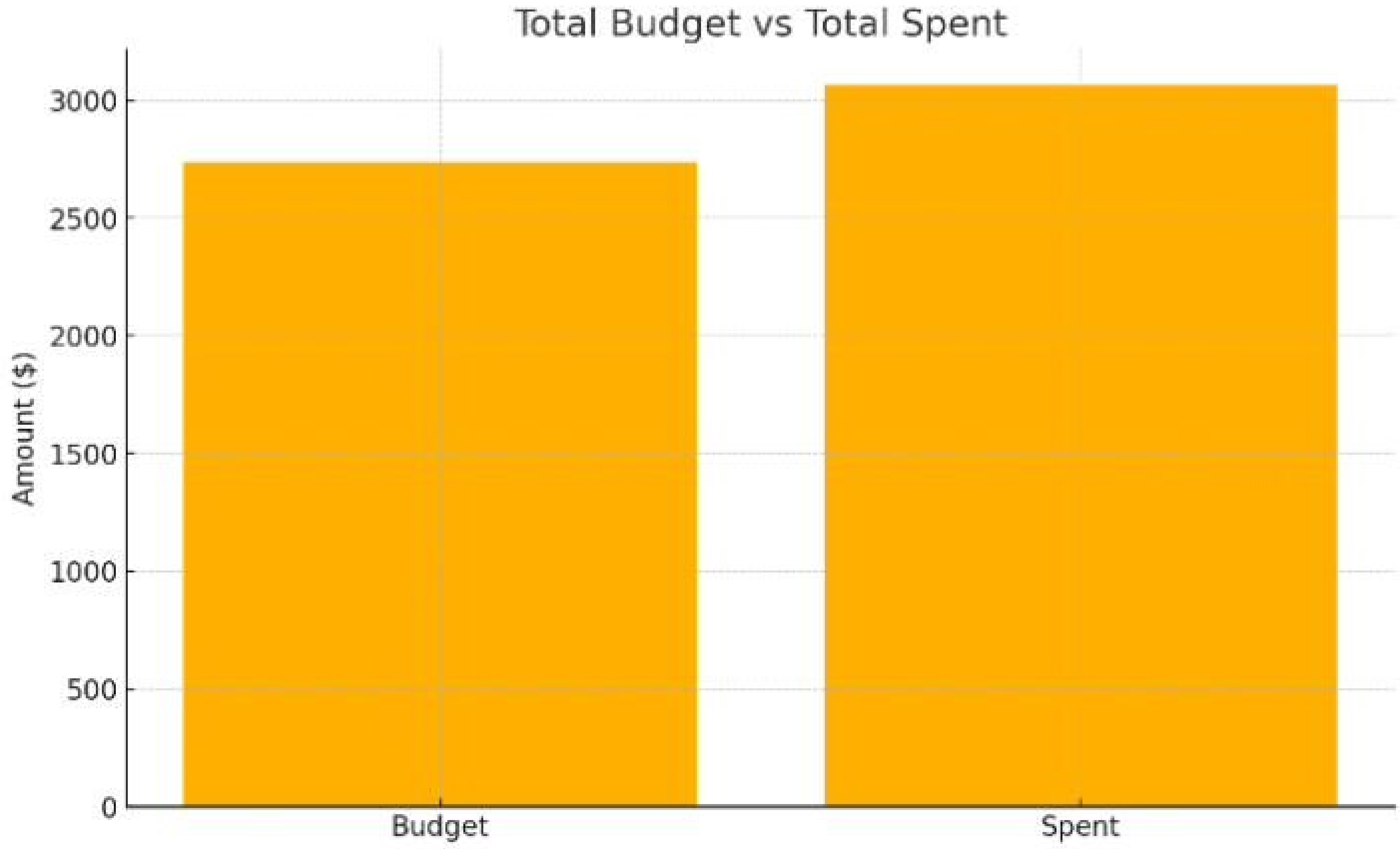
8.1. Major Spending Areas

- Batteries and Connectors: $826.66
- Structural and Mechanical Parts: $875.50
- Tools and Measurement Equipment: $693.01
- Certifications and Administrative: $175.00

8.2. Budget Details:

In#	Date	Vendor	Description	Qt	Subtotal	Tax	Total
1	10/14	Amazon	Youme 4S Lipo Batteries (10 units, 2 packs each)	10 units	$738.60	$43.92	$776.36
2	10/15	Amazon	BIG RED T32100 Engine Hoist Leveler	1	$30.35	$1.82	$32.17
3	11/21	Amazon	RC Connectors, Cables, Wires (FLYRC, kinoble, BNTECHGO, lytona, BDHI)	Multiple	$394.68	Included	$394.68
4	11/21	Amazon	XT90S Connectors + 500A Bus Bar Distribution Block	Multiple	$99.96	$6.00	$105.96
5	10/19	Amazon	Lipo Fireproof Battery Safe Bags (2 units)	2 units	$32.38	$1.94	$34.32
6	10/15	Amazon	YITAMOTOR Folding Engine Hoist	1 unit	$249.99	$15.00	$264.99
7	10/15	Micro Center	E3D V6 Hotend Kit	1 unit	$27.55	Included	$27.55
8	10/5	PSI Services	Unmanned Aircraft General (UAG) Certification Exam Fee	1 exam	$175.00	Included	$175.00
9	12/31	Amazon	18650 Rechargeable Batteries (4-pack, 2 sets)	2 sets	$43.98	$2.64	$46.62
10	3/15	Amazon	Ethernet Cables, Stencil Sheets, Organizer, Rotary Locks	Multiple	$154.96	$9.30	$164.26
11	2/15	Amazon	Battery Spot Welder + Nickel Strips	2 items	$47.98	$2.88	$50.86
12	2/6	Amazon	Clevis Pins (10 pcs)	1 pack	$14.49	$0.87	$15.36
13	2/6	Amazon	Leg Caps, Cotter Pins, Hinges, Shock Absorbers	Multiple	$269.88	Included	$269.88
14	2/6	Amazon	Door Saver III Hinge Pin Door Stops (6 units)	6 units	$24.24	$1.44	$25.68
15	2/7	Amazon	48" Aluminum Extrusion Profiles (2 sets)	2 sets	$193.98	$11.64	$205.62
16	2/18	Amazon	Shock Mount Rod Pin Eliminators (4 pcs)	1 set	$19.69	$1.18	$20.87
17	3/27	McMaster-Carr	Carbon Steel Clevis Pin (10-pack)	1 pack	$13.20	$9.09 (Shipping)	$22.29
18	4/3	Harbor Freight	Digital Photo Sensor Tachometer	1 unit	$37.99	$2.28	$40.27
19	4/4	Home Depot	Cable Ties + 3-Term Ground Bar	2 items	$18.51	$1.11	$19.62
20	4/4	Harbor Freight	Tools and Consumables	Multiple	$350.50	$21.03	$371.57


Expenses by Category
Certifications
6.8%
Batteries & Connectors
32.2%
Tools & Equipment
27.0%
34.1%
Structures


Total Budget vs Total Spent
Amount ($)
3000
2500
2000
1500
1000
500
0
Budget
Spent

9. Acknowledgments

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10. References

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