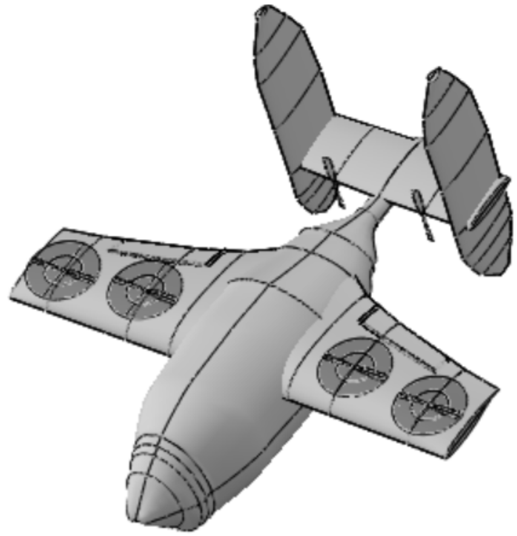
C21 Fantail

Submitted in Response to the Real World Design Challenge



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Executive Summary

Unmanned Aerial Vehicles (UAVs) show considerable potential in the package delivery sector. Current means of package delivery face unpredictable variables, including traffic congestion and personnel productivity issues, making them inefficient. The commercial use of UAVs has the potential to render road traffic issues and unreliable delivery personnel null. Continual technological improvements make UAVs more efficient, safe, and profitable for companies than conventional delivery methods.

The following report details the design process used in developing Pacific Projects' proposed solution for an Unmanned Aerial Service (UAS) in the package delivery sector. Additionally, information on the UAV's reliability and the company's profit analysis is provided.

Companies such as Amazon are one of the first in the industry to test the possibility of a UAV delivery system. Pacific Projects aims to provide an improved service by delivering up to 5.00 kg within 30 minutes or less. Using well-tested engineering design methods, Pacific Projects created the C21 Fantail.

Pacific Projects' C21 Fantail is capable of flying 10.00 km within seven minutes. The UAV can attain a maximum horizontal flight speed of 72.80 kt maintaining a noise level of 32 decibels. Its weight is 11.65 kg with a package and 6.65kg without a package.

The C21 Fantail is a hybrid UAV with a fixed-wing design possessing built-in rotors making it capable of Vertical Take-offs and Landings (VTOL). Its battery life is capable of completing three full deliveries before swapping out with a new one. The sensor system monitors both the UAV's surroundings and provides accurate telemetry. The noise produced by the UAV on average has minimal effect on noise pollution. The delivery mechanism secures the package inside the UAV keeping it safe from external forces. The mechanism itself is simple in design, yet effective as it can release the package automatically. Emergency procedures allow the C21 to fall at a speed making it incapable of breaking bones or damaging car windshields. Emergency equipment provides both visual and audible cues to alert nearby pedestrians to a falling UAV. Company protocols allow the C21 to complete deliveries in the event of total communication loss or engine failure. The C21 Fantail is able to complete 156 deliveries in a day due to the efforts of company personnel.

Pacific Projects maintains its values of being safe and reliable even in operational procedures. Highly-trained personnel efficiently follow company procedures allowing for faster deliveries and reduced slack time while providing enough time for breaks. The process to prepare flights maximizes work performance while reducing the stress put on personnel by giving an ample amount of time to finish tasks. Pacific Projects has enough personnel so that workers can go on break while others take over.

The nine UAVs are capable of delivering multiple packages throughout the 12-hour flight window and are mathematically proven to be safe and efficient during deliveries. With a daily net income exceeding $11,000, the C21 Fantail is a viable solution that can rival current delivery services in terms of performance and profitability.

Specification Sheet

Criteria	Value	Met (yes/no)	Section #, page #
General			
Takeoff weight including single package	11.65 kg		2.3.1, p.16
Wingspan (fixed-wing) or max width (other)	1.09 m		2.5, p.34
Aircraft only carries single package (weight of 5 kg and dimensions of 0.5 m by 0.5 m by 0.25 m)		Yes	1.3, p.10
UAS Airfield			
All takeoff/landing, loading of packages, refueling/recharging, and any additional aircraft checks takes place in one of three 10 m X 10 m staging areas		Yes	3.1.1, p.41
The 3 staging areas are side-by-side with a 3-m space between them and are 15 m away from warehouse/hanger		Yes	3.1.1, p.41
Flight Corridors			
Flight speed within 35 kt and 55 kt		Yes	3.2, pp.48-49
Flight altitude within 150 m and 250 m		Yes	3.2, pp.48-49
Aircraft can climb from airfield to flight corridor within 150-m radius		Yes	3.2, p.48
Aircraft can descend from flight corridor to airfield within 150-m radius		Yes	3.2, p.49
Aircraft can stay in holding zone at 150-m altitude above airfield and delivery location until given clearance		Yes	3.2, p.49
UAS Command, Control, and Communication			
Up to a maximum of 20 aircraft in air at a single time		Yes	1.3, p.10
Redundant systems		Yes	3.3.7, p.55
Aircraft has transponder to identify itself and provide current speed, heading, and altitude to CUTC		Yes	2.3.4, p.52
Aircraft continuous monitor by personnel at airfield		Yes	3.1.4, p.44
Aircraft capable of receiving new commands while in flight and modify flight pattern accordingly		Yes	3.3.3, p.52
Human pilot available to take manual control if necessary		Yes	2.3.1, p. 16
Package Delivery			
Aircraft can climb/descend between delivery location to flight corridor within 100-m radius		Yes	3.2, pp.48-49
Aircraft capable of landing at single 3 m by 3 m delivery zone		Yes	3.1.3, pp.43-44
Aircraft lands to delivery package (no dropping or lowering while in flight)		Yes	3.1.3, p.43
Package is left automatically		Yes	3.1.3, pp.43-44

1. Team Engagement

1.1 Team Formation and Project Operation

Pacific Projects (referred to as “Company” or “team”) is a team consisting of six Pre-Engineering Honors students attending John F. Kennedy High School (JFKHS). Class members created teams with each member choosing their role based on individual abilities and interests. The project manager created objectives consisting of tasks with deadlines that needed to be met to ensure timely completion of the engineering design notebook. Tasks were assigned based on a member’s ability along with their current workload from classes. Tasks that required skills outside of an individual’s ability were performed with multiple team members. Communication between the team and coach was ensured in case of any questions or misconceptions. Before moving forward, all members would complete their tasks and a group meeting would be held to discuss the team’s progress and project status. A brief description of team members and their roles are provided below.

Samuel Ha (Project Manager)

Samuel Ha became Project Manager because of his past experience in Science, Technology, Engineering, and Mathematics (STEM) participating in Lego Robotics and Marine Advanced Technology Education (MATE) competitions. Samuel continues to pursue his interests and participate in competitions for robotics and engineering.

Jimi-K Daniel (Lead Mathematician)

Jimi-K Daniel was designated as Lead Mathematician because of his enthusiasm for STEM, specifically mathematics. His experience in First Lego League (FLL) competitions gives him insight as to what would have to be accomplished mathematically. Jimi-K continues to pursue information in the fields of engineering and mathematics.

Jerlann Latag (Lead Writer)

Jerlann Latag chose the role of Lead Writer due to his skills and experience in writing. His background in English Honors and AP Language Composition as well as writing technical papers provided the necessary foundation for being the project’s lead writer. His well-rounded nature and skill set also allowed him to assist in additional tasks. Jerlann’s fascination with science fiction stories led to an interest in advanced designs and technology.

Daniel Min (Business Analyst)

Daniel Min was selected as the Business Analyst for his interest in business in addition to his experience in stocks and knowledge of company practices. Daniel’s background in

JFKHS's Finance club gave him the foundation required for the role. Daniel pursues entrepreneurship and builds his knowledge in STEM and marketing.

Robbi Natividad (Project Researcher)

Robbi Natividad was asked to become the Project Researcher due to his previous involvement in robotics, having participated in FLL and MATE. Robbi has a keen interest in STEM and plans to pursue a career in software development. His knowledge in programming and electronics makes him a good candidate for research, as he can visualize how each component functions.

Shaoying Zheng (CAD Specialist)

Shaoying Zheng was selected as the CAD Specialist because of her knowledge of STEM and passion for learning the design of 3D models. Additionally, she has experience in design due to her participation in MATE competitions, serving in her team's mechanical engineering department. Her completion of the JFKHS Robotics Honors class last year allows her to add additional insight to the design process.

1.2 Acquiring and Engaging Mentors

A close reading of the Detailed Challenge Statement helped the team to identify requirements in the Real World Design Challenge (RWDC) that exceeded their knowledge. The team identified potential mentors based on the specializations provided in the 2020-2021 Mentor list. The team needed mentors to guide them in areas such as aerospace engineering, mechanical and electrical engineering, Federal Aviation Administration (FAA) regulations, and hybrid UAV designs. The team secured three mentors and maintained contact via email and Discord.

Mr. Wesley Mittlesteadt was selected for his knowledge in civil engineering and FAA regulations. His guidance in FAA regulations helped the team ensure all regulations were met while his knowledge of transportation projects assisted in maximizing the efficiency of the UAV.

Mr. Robert Sprayberry was chosen by the team for his expertise in aviation engineering and his knowledge of FAA rules and regulations.

Kaifeng Chen was picked by the team due to his role as Project manager for Hafa Hive, the FY20 RWDC National winning team and is currently studying mechanical engineering at Syracuse University. He provided input on time management and guided the team on how to proceed. He assisted the team Mathematicians by providing explanations in complex mathematical formulas.

1.3 State the Project Goal

The FY21 RWDC involves developing an Unmanned Aircraft System (UAS) for delivering packages within a five km radius of the warehouse and UAS airfield. The UAS cannot exceed 20 UAVs active in the air.

Additionally, the UAS is to complete a given flight profile to prove that the aircraft has sufficient energy to perform deliveries. The flight profile requires the aircraft to perform a VTOL (Vertical Take Off and Landing) maneuver at both the staging area when departing the UAS airfield and at the delivery zone after the package has been delivered. The aircraft is to fly five km at a speed of 35 to 55 knots at an altitude of 250 m. The aircraft must reach this altitude within a 150 m (meter) radius of the airfield. Similarly, following package delivery, the aircraft must reach the 250 m altitude within a 100 m radius of the delivery zone. At both the delivery zone and airfield, a 10 minute loitering period is required and the UAV must perform VTOL at the delivery location.

During the 12-hour period of UAS operations, the UAV must maintain safe flight while delivering one package with dimensions of 0.5 m x 0.5 m 0.25 m to a delivery zone situated on a rooftop 60 m above the ground. The package cannot be dropped or lowered but is to be released from the UAV through an automated mechanism after landing. The UAS will follow the FAA Part 107 and 135 Regulations ensuring private and public safety.

1.4 Tool Setup/Learning/Validation

Due to the state-mandated lockdowns, face-to-face classes have been canceled since March 13, 2020. As a result, the team and coach faced difficulties meeting each other. The team required easily accessible tools to be used at home to work on the challenge.

Google Suites:

Google meet allowed the team to communicate at home, Google Docs provided documentation and file sharing, and Google Sheets assisted in organization and calculations. Research papers and important documents were kept in a shared Google Drive that could be accessed by all members and the team's coach.

Discord:

Discord allowed the team to coordinate additional meetings and provide daily reminders for tasks and notifications for new material. The team was able to interact and send material to one another to inform other members of any documentation or files the team needs to focus on.

Trello:

The team decided on creating a Trello to act as both a task organizer and a reminder of objectives with upcoming due dates. Trello acted as a task manager for the team to go to whenever they needed to check what tasks, objectives, and goals the team needed to accomplish. With the collaboration with the team and with Trello's organization, many tasks were recorded to broadcast for the rest of the team to see.

Open VSP:

The CAD specialist chose Open VSP for drafting the team's designs. These designs are to create the finalization of the aircraft along with detailing of propeller placement, shape, and geometry, alongside mathematical analysis of testings.

FPV Range Calculator:

This calculator is used to estimate the FPV Range using the dB values of the FPV equipment the team will use. This will be used to help the team understand the capability, performance, and limitations of the FPV components that were chosen.

Static Thrust Calculator:

The static thrust calculator was used to find out the static thrust lift of a propeller and estimated flying speed with an x amount of diameter and an x amount of pitch will do with a motor that has an x amount of RPM (rounds per minute) with an air density of 1.23 kg/m^3.

Fruity Chutes Parachute Descent Rate Calculator:

Fruity Chutes Parachute Calculator was used by the team to find the estimated flying speed of their parachute products with the UAV mass of 11.65 kg with the package and 6.65 kg without the package.

Battery Life Calculator:

The battery life calculator provided the total battery milliamps per hour (mAh) with consumption of milliamps (mA). With the calculator, the team found the maximum life span of the battery in both minutes and hours.

Voltage Divider Calculator:

To measure the number of Ohms (Ω) needed in a resistor to decrease voltage distribution from the battery to components, this calculator was used by the team to determine the number of ohms needed to decrease the voltage to a number suitable for the components requirements.

XFLR5

XFLR5 Program is an analysis tool for testing wings, airfoils, and aircraft. The website analyzed the testings to program graphs and keep them in a Portable Document Format (PDF). Although the CAD Specialist had troubles with testing the capabilities of the aircraft and understanding terminologies, online forums and videos helped alleviate the confusion.

LibreCAD:

The CAD Specialist used LibreCAD to draft 2D figures. The program was used to accurately scale figures. The program was also open-source, which allowed the CAD Specialist to learn much faster. With learning at an accelerated rate through assisted tools and tips, creating 2D figures.

1.5 Impact on STEM

Having learned from previous JFKHS teams' experiences in completing the RWDC, all members understood the rigorous effort required to complete the challenge by the given deadline. The current members had to research and learn complex concepts to validate team choices when designing the system. The challenge required members to learn new skills or improve upon pre-existing skills to finish the challenge.

Most members had an interest in STEM before entering the challenge. Understanding that STEM careers are rigorous and require various skills to succeed, members saw RWDC as an opportunity to improve their skills and gain insight into STEM fields. With this, members adapted to meet challenge requirements and improved skills such as writing and organization.

JFKHS has a long-running robotics club, but its Pre-Engineering class has only existed for three years, including this year. RWDC has provided opportunities to students interested in STEM within JFKHS. The Pre-Engineering class continues to grow every year with this year's class containing three teams at the start of the challenge whereas last year only had two. Faculty and staff continue to advocate for further STEM involvement through competitions and club activities.

2. System Design

2.1 Engineering Design Process

Conceptual Design Phase

Before beginning the challenge, Pacific Projects' coach taught the engineering design process ("1.3: What is the Engineering Design Process?", n.d.) which would be a key aspect of the team's methodology when facing a new problem during the challenge. Using the previously discussed process, the Company made their own variation of the 11 steps (Figure 1). The Company first identified the problem they were facing. Members then generated potential solutions in order to solve the problem. Solutions were researched further to determine their viability in the UAS. From the research, the solutions were narrowed down based on comparisons between them. The final options were further reduced with the chosen solution being put into the final design.

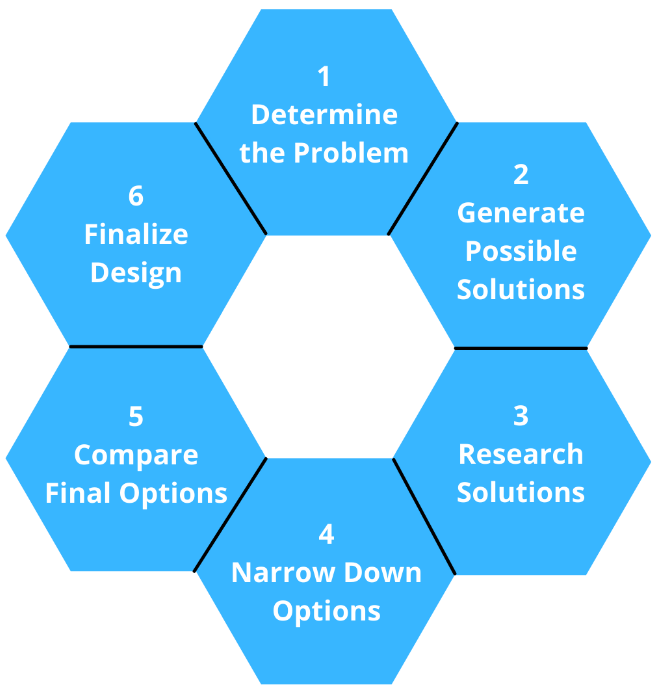


Figure 1. Company Design Process.

Preliminary Design Phase

To narrow down design candidates, the Project Manager created decision matrices to reflect the Company's desired primary and secondary qualities for specific aspects in the design candidates (Figure 2). Each member provided input on desirable qualities and the Project Manager compiled the data and recorded the desired traits. Primary traits included VTOL capability and the ability to fly with the loss of one engine. Secondary traits included cost-friendly components, good obstacle avoidance, and high speed. With these traits, the Company ruled out components, airframes, and systems that failed to match the criteria made by the matrices.

Detailed Design Phase

Once the Company determined qualities they wanted in the UAV, components were selected based on how well they fit into the Company's preferences. All members analyzed component traits, such as cost, dimensions, weight, and unique features that the component offered. After a vote was made, components with the majority vote were chosen as the finalized choice. Airframe design was picked through a decision matrix, with the final three choices being rated for how well they were able to fit into three traits: VTOL performance, dimensions within 3 m x 3 m, and ability to perform with a malfunctioning engine (Figure 2).

Objective	Weighting Factor	Agusta Westland	Digi Robotics Droxi	Ascendance Tech Atea
VTOL	20	940	800	800
One Engine Out	5	75	140	120
Dimensions	15	210	585	195
Packaging	10	410	440	430
Total		1635	1965	1545
	Primary	Secondary		

Figure 2. Airframe Decision Matrix.

2.2 Project Plan

The Project Manager created a Gantt chart specifying tasks assigned to each member of the Company (Figure 3(a); Figure 3(b)). Color-coded areas differentiated the levels of importance for each task and indicated the department responsible. The Gantt charts addressed important objectives and milestones the Company had to accomplish along with a start and end date with the number of weeks worked into the phase(s) between the starting and ending end dates.

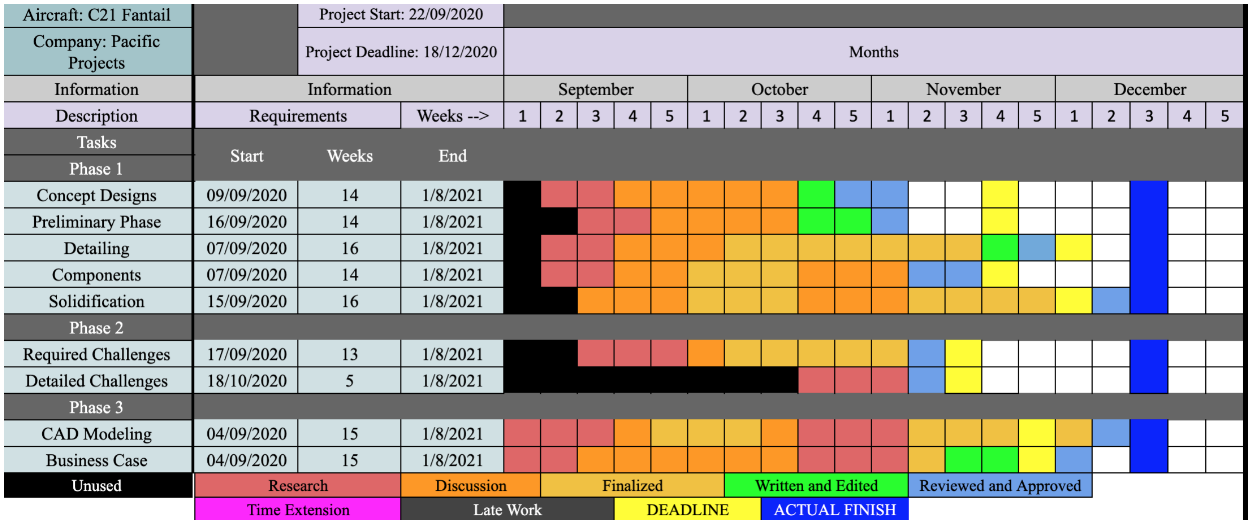


Figure 3(a). State Gantt Chart.

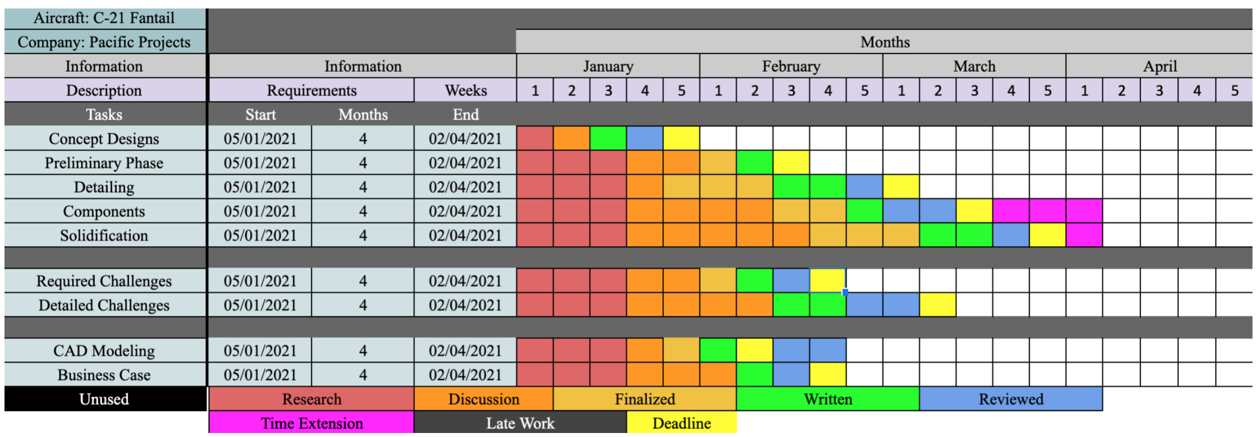


Figure 3(b). National Gantt Chart.

A Trello map was created by the Project Manager to assign tasks to the Company (Figure 4). Tasks were sent as a reminder to the Company to complete before the deadline. These reminders helped the Company complete tasks before their due date. Tasks were assigned to members best suited to their roles. The tasks were given a deadline, different levels of priority, and description explaining to the members what they need to do. Trello was used as a reminder to the Company for completing tasks before their deadline.

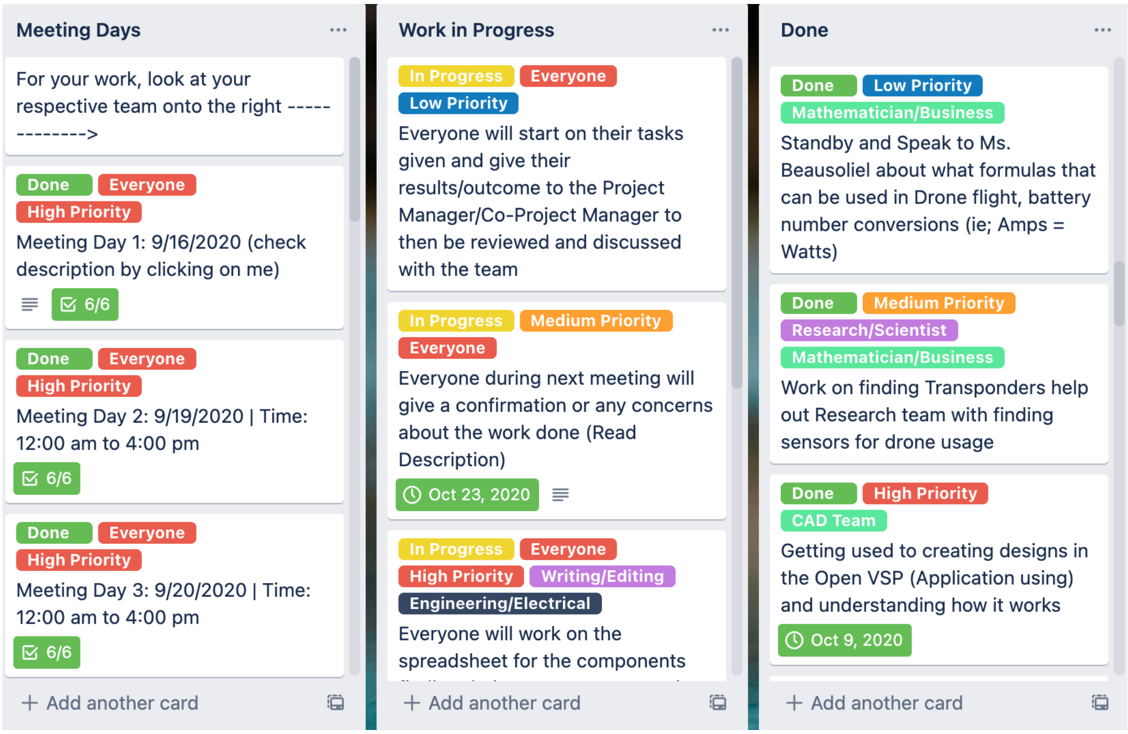


Figure 4. Trello Task Management.

2.3 Subsystems

2.3.1 Air Vehicle

Airframe

The Company's ideal airframe must be safe, reliable, and capable of VTOL. Each member conducted their research on aircraft designs based on its airframe and flight performance. The Electric VTOL News Aircraft Directory (eVTOL Aircraft Directory, 2020) was key in assisting research. The Company would use the directory's database of aircraft to choose potential UAV designs. After researching, members explained their choices and the advantages each held. After a vote, the team narrowed the choices down to eight aircraft: 1) *AgustaWestland Project Zero* ("AgustaWestland Project Zero (defunct)", 2019), 2) *Digi Robotics Droxi* ("Digi Robotics Droxi (UAD-M20)", 2017), 3) *Ascendance Flight Technologies Atea* ("Ascendance Flight Technologies Atea", 2019) 4) *Gestalt Aeronautics VTOL* ("Gestalt Aeronautics VTOL", n.d.) 5) *Boeing Phantom Swift* (Rogoway, T., 2017) 6) *Birdlike Foldable Drone* (Mok, K., 2018) 7) *Elroy Air Chapparral* ("Elroy Air Chapparral", n.d) 8) *Droneball* (Tickle, G., 2017). The Researcher sketched out the selected designs which held qualities the Company wished to have in their UAV (Figure 5).

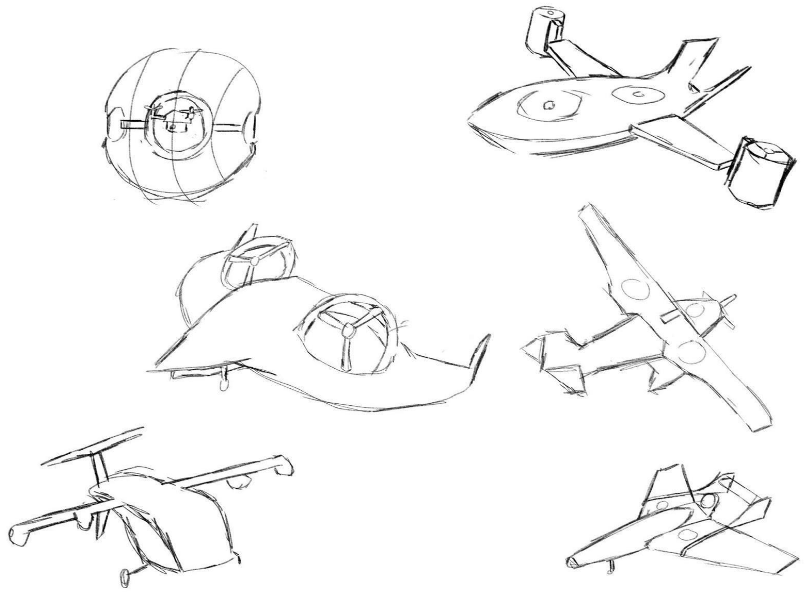


Figure 5. Sketches of selected airframes.

Material

The Company decided the aircraft material must remain stable in flight and withstand heavy use. UAV material is identified through density, strength, electrical conductivity, thermal expansion, and dissipation. Aluminum alloy and carbon fiber were selected and analyzed based on their qualifications in the above property categories.

Power and Propulsion

With only a 12-hour flight window, the Company decided the power supply must be capable of enduring the whole flight and be able to refuel in a short time frame. With these requirements, the Company unanimously opted to use batteries as the power supply due to the ability to swap used batteries with fully charged ones. As a result, the Company will not have inactive UAVs due to refueling, thereby making launches faster. Researchers looked into batteries and battery chargers that met company standards.

Preliminary Design Phase

Airframe

After narrowing down the conceptual design candidates to eight UAVs, the Company decided to pick three designs based on their preferred qualities. The final three designs chosen were 1) *AgustaWestland Project Zero* (“AgustaWestland Project Zero (defunct)”, 2019), 2) *Digi Robotics Droxi* (“Digi Robotics Droxi (UAD-M20)”, 2017), 3) *Ascendance Flight Technologies Atea* (“Ascendance Flight Technologies Atea”, 2019)

AgustaWestland Project Zero: Project Zero, created by AgustaWestland, is an all-electric, tilt-rotor/fan-in-wing UAV ("AgustaWestland Project Zero (defunct)", 2019). The UAV can fly in high altitudes and hazardous conditions ("AgustaWestland Project Zero (defunct)", 2019). Additionally, the UAV produces low noise and has a low thermal signature ("AgustaWestland Project Zero (defunct)", 2019). Although defunct, the project was able to perform several successful test flights ("AgustaWestland Project Zero (defunct)", 2019).

Digi Robotics Droxi: Droxi is a fixed-wing VTOL UAV that fits within the 3 m x 3 m dimension limit of the challenge ("Digi Robotics Droxi (UAD-M20)", 2017). Unique to its design is the advanced autopilot which ensures stable flight requiring minimal input from the pilot ("Digi Robotics Droxi (UAD-M20)", 2017). The lockable cargo pod also provides added package protection ("Digi Robotics Droxi (UAD-M20)", 2017).

Ascendance Flight Technologies Atea: The Atea is an airbus that, at the time of writing this, has not been made ("Ascendance Flight Technologies Atea", 2019). The design team of the Atea created it with the idea of an air vehicle capable of safe, quiet, long-distance flights ("Ascendance Flight Technologies Atea", 2019). Additionally, the Atea was designed to have low operational costs ("Ascendance Flight Technologies Atea", 2019).

With the selected airframes, Researchers sketched potential hybrid-fixed wing designs (Figure 6). Placement of rotors was discussed as their location could pose problems to human safety or damage the UAV's surroundings. Built-in rotors were preferable as their sides would be protected by the wings during flight.

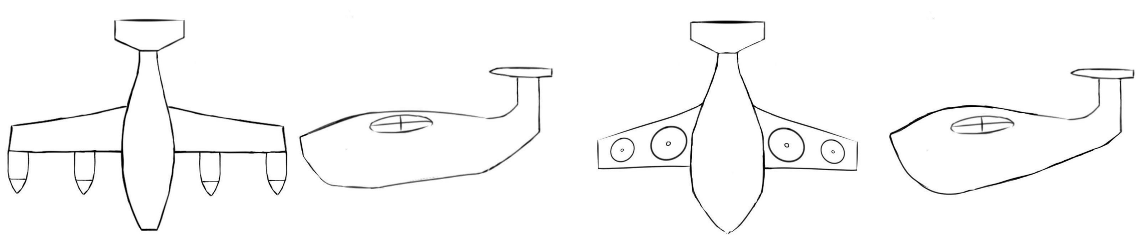


Figure 6. Sketches of preliminary airframes.

Material

Aluminum alloy and carbon fiber were discussed as the most preferable material by the Company as both have pros and cons in their resistances, usage, weight, and durability.

Aluminum Alloy: Commonly used in the manufacturing of aircraft because of its low density, high strength, resistance to corrosion, and long term use (Festus, 2017). Aluminum alloy is lightweight and features high ductility and electrical conductivity (Festus, 2017). Furthermore, it has been widely applied in various industries, especially battery technology (Trinh, 2020).

Carbon fiber: Carbon fiber offers its high strength outranking that of steel while retaining 20% of the weight (Goto, 2011). higher corrosion resistance and improved fatigue performance (Deokar, 2016). Composites are used widely in aircraft, pressure vessels, sports equipment, and many automotive parts (Erber et al., 2018; Padmaraj et al., 2020).

Power and Propulsion

After a discussion, the Company decided to use one battery for propellers and components. After researching, the options for batteries were the DJI Mavic, SNAPTAIN S5C, Sea Jump, Continoxo, LiPo 4850 3S, MaxAmps 6000 XL, and the 6S1P Lipo Battery Pack with AS150 +XT150 Plug (Table 1). These batteries fit the requirements as they had a battery lifespan of 30 minutes to 6 hours.

Table 1. Battery comparison.

Battery	Weight (g)	Capacity (mAh)	Voltage (V)	Watts (W)
DJI Mavic	317.51 g	2400.00 mAh	7.20 V	17.28 W
SNAPTAIN S5C	11.00 g	550.00 mAh	3.70 V	2.04 W
Sea Jump Battery	156.00 g	2800.00 mAh	7.40 V	20.72 W
Continoxo	204.12 g	2500.00 mAh	11.10 V	27.75 W
6S1P Lipo Battery Pack with AS150 +XT150 Plug	2100.00 g	32000.00 mAh	44.40 V	1420.80 W
MaxAmps LiPo 6000XL	284.00 g	6000.00 mAh	7.40 V	44.40 W

The Hitec RDX2, LiPo Charger Discharger, and DUO Dual Multi-Charger were deemed the best candidates for battery chargers as they were able to charge any of the aforementioned batteries in under 30 minutes (Table 2) (Hitec, n.d.) (LiPo Charger Discharger, n.d.) (DUO Dual-Multi-Charger, n.d.)

Table 2. Battery charger comparison.

Battery Charger	Weight	Max Charge power (W)	Charging Range (A)	Battery cell upkeep
Hitec RDX2	500.00 g	100.00 W	0.10 – 50.00 A	2 – 4
LiPo Charger Discharger	997.90 g	120.00 W	0.10 – 10.00 A	1 – 6
DUO Dual Multi-Charger	980.00 g	300.00 W	0.10 – 10.00 A	1 - 6

The Xoar PJH-ET, Carbon Prop 2-blade, Xoar PJP-T-L 14x5 1450, Mejzlik Propeller 16.0" x 5.5", and GM 16x10 folding prop blades were selected by the Researchers (Table 3). These propellers were selected due to their material and high diameters reaching from 14 to 32 inches and a pitch of 5 to 13.

The Company decided to use covers to prevent propellers from damaging their surroundings or falling out during a malfunction. Preferred designs were ones that did not significantly increase noise or restrict airflow. After researching cover designs, members opted for a wire or swirl pattern as these were some of the best in terms of the previously mentioned qualities (Bach, M., 2011; SilverStonetek, n.d.)

Table 3. Propeller comparison.

Propeller	Diameter (mm)	Pitch (mm)	Material	Weight
XOAR PJH-ET	533.40 mm	330.20 mm	Carbon fiber	20.00 g
Carbon Prop 2-blade	812.80 mm	304.80 mm	Carbon fiber	342.00 g
Xoar PJP-T-L 14x5 1450	355.60 mm	127.00 mm	Carbon fiber	17.00 g
Mejzlik Propeller 16.0" x 5.5"	406.40 mm	139.70 mm	Carbon fiber and Epoxy	20.00 g
GM 16x10 Folding prop blades	406.40 mm	254.00 mm	Carbon fiber	15.10 g

Detailed Design Phase

Airframe

After narrowing down to the final three airframe designs, the Company deemed the Digi Robotics Droxi as the superior choice. The Droxi's original design fits within the dimensions of the challenge requiring little modification. Its hybrid fixed-wing design makes it capable of VTOL and gliding during horizontal flight. The Company decided to alter the wings of the Droxi to a similar design to the Atea's built in wing rotors. A sketch of the finalized design was drawn by the Researcher (Figure 7).

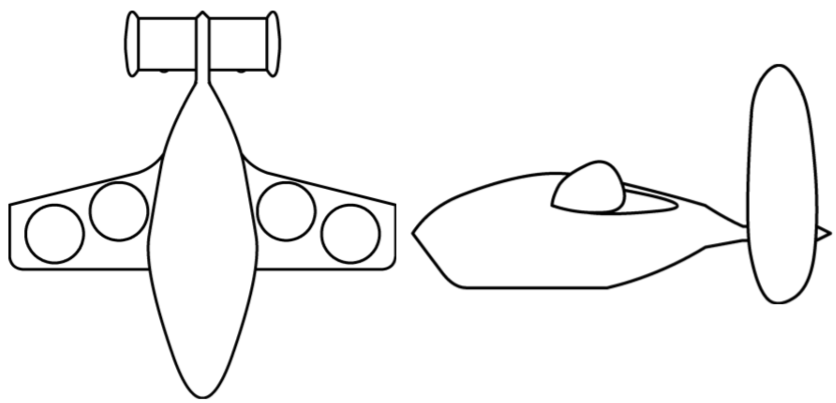


Figure 7. Final Airframe Design.

Material

After the Company viewed the advantages and disadvantages of aluminum alloy and carbon fiber, aluminum alloy with a grade of 6061-0 and a thickness of 0.02 inches was chosen as the airframe's material. This was due to the Company having trouble finding the cost for carbon fiber along with how the material affects its surroundings during an emergency landing. Carbon fiber's rigid and high strength composition when struck can also increase costs in maintenance and repairs. Additionally, it can warp either through blunt force or long term use in heavy winds while the 6061 aluminum alloy has a 6061 aluminum alloy has a yield tensile strength of 276 MPa (40,000 psi), and an ultimate tensile strength of 310 MPa (45,000 psi) (Cavallo, 2021).

The total surface area of the UAV is 1.70 m^2. The surface area of both the front and tail wings is 0.60 m^2 with the fuselage being 1.10 m^2. The aluminum alloy will encase the UAV in the aforementioned areas to protect the framing and internal components from external forces.

Power and Propulsion

With the weight of the UAV being 11.65 kg (with package), the propellers have to generate above 11.65 kg of lift with the revolutions per minute (RPM) being 6,200 emitting a decibel of four per propeller to a max of 28 decibels requiring 10.28 watts. The speed for horizontal flight is 28.29 m/s at 6,200 RPM.

The battery chosen by the Company was the 6S1P Lipo Battery Pack with AS150 +XT150 Plug. Due to the performance of the battery, one is enough to power the UAV throughout the flight with its capacity of 32,000 mAh. The motor only requires 7.4V running 20.72W, which at its full power prevents an excessive amount of energy intake (Alibaba, 2021). The UAV needs six motors, four for the wings and two on the tail end of the UAV as it will provide both a frontal boost and sharp turn.

The four side propellers are the Mejzlik 16.0 x 5.5-inch propeller blades that have a diameter of 16 inches (0.40 m) and a pitch of 5.5 inches (0.13 m) (Mejzlik, n.d). The two rear propellers are the GM 16x10 Folding Prop Blades that have a diameter of 16 inches (0.40 m) and a pitch of 10 inches (0.25 m) along with the ability to fold into the motors to reduce blade exposure (Hyperflight, n.d).The motor chosen was the Emax MT2213-935KV with 935 kilovolts (kV).

The servo chosen was the DSSERVO DS3225 servo with a torque of 25 kg/cm running on 6.8 V. It will operate the clamping mechanism inside of the UAV to secure and release the package during delivery. With an RPM of 95 per minute, it can efficiently retract and extend the clamping mechanism for a quick lock and release of the package (DSServo, 2021).

To regulate the voltage-current in the UAV, the D24V6F3 Step-Down Voltage Regulator was chosen. Component voltages ranged from 3.8 Volts (V) to 33 V. The D24V6F3's can regulate voltage flow from the battery to the components (Pololu, 2021).

The final cover design was chosen to be a wire cover due to it only reducing airflow by 29% and its minimal noise increase (Bach, M., 2011; SilverStonetek, n.d.). Designs for the cover were drafted by both the CAD Specialist and Researcher. The final approved design was drafted by the Lead Researcher (Figure 8).

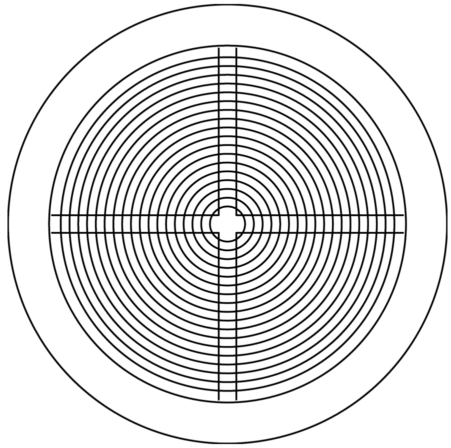


Figure 8. Finalized Propeller Design.

Flight Controls

The controller selected is the ThrustMaster Hotas. UAV flight control is possible by the controller sending signals to the multiplexer instructing the UAV for movement along with the Pixhawk 4 for autopilot. The controller is only used for manual control via the Operational Pilot to adjust flight path or in the event of autopilot failure. The LPC1758FBD80K is a microcontroller that functions to operate the UAV. Microcontrollers can handle hundreds of thousands of integrated circuits and can perform routine and long operations quickly (Coşgun., Güven., Kocaoğlu., Gezici., 2017). With the microcontroller having 51 in and out (I/O) pins with a voltage of 2.4, it gives the UAV faster response times to given instructions (Arrow, 2021).

Emergency Landing Systems

Due to the importance of an emergency landing system, the Company unanimously opted for three key components: sirens, lights, and parachutes. These systems provide visual and audible warnings to pedestrians below. The parachute acts as a way to slow the fall of a UAV reducing damage taken from a crash. The parachute to be used was decided last to ensure it could compensate for the finalized UAVs weight. The components chosen were compiled in the table below (Table 4).

Sound and Alarms: With use of the VIFLY Finder V2 FPV Racing Drone, the UAV can emit 110 dBa with a Light Emitting Diode (LED) capable of flashing for 30 hours straight before shutting down (VIFLY Finder V2, 2021.). The DJI Mavic Air/Pro Spark Phantom will emit a strobe light effect at a viewable distance of 100 m for a total of 20 hours (Drone Flash Strobe Lamp, 2021.).

Iris Ultra 96: With the UAV weighing in at 6.65 kg (without the package), the Iris Ultra 96 was chosen by the Company due to it supporting a weight of 50 lb (IRIS ULTRA, n.d.). A fall speed of 6.09 m/s makes a falling UAV incapable of damaging a car's windshield. The parachute will be attached to a servo to be extended and retracted for rapid deployment and packing.

Nova and Mayday Combo: Mayday and Nova are parachute deployment systems that are activated under emergencies with the Nova being manually initiated while Mayday is automatic (Nova & Mayday, n.d.). The Nova is activated by the Safety Pilot when the UAV is 60 ft (18 m) above the ground. The Mayday can detect the 60 ft distance and deploy its parachute with a 0.12-second delay for the parachute to deploy.(Mayday & Nova, n.d.) The Safety Pilot will have 56 ft of altitude to react and attempt to land the UAV safely.

Mallofusa Landing Gear: Mallofusa Landing Gear is to create a stable landing withstanding an impact force of 900 N (newtons) (Design and Manufacture of Composite Landing Gear for a Light Unmanned Aerial Vehicle) (2021, January).

Table 4. Total cost and weight of air vehicle components.

Components	Quantity	Weight (g)	Unit Value	Total Cost
6061 Aluminum Alloy	**1**	2332.88 g	$311.00	$311.00
Emax MT2213-935KV	**6**	55.00 g	$49.79	$298.74
6S1P Lipo Battery Pack with AS150 +XT150 Plug	**1**	2100.00 g	$51.99	$51.99
Mallofusa Landing Gear	**1**	90.32g	$6.99	$6.99
DJI Mavic Air/Pro Spark Phantom	**1**	10.00 g	$25.06	$25.06
LPC1758FBD80K	**1**	0.53g	$10.58	$10.58
Iris Ultra 96	**1**	708.00 g	$348.15	$348.15
D24V6F3	**1**	0.50 g	$6.89	$6.89
Nova and Mayday Combo	**1**	71.53 g	$290.99	$290.99
DSSERVO DS3225 with Rack and Pinion	**1**	67.00 g	$11.99	$11.99
GM 16x10 Foldable Propeller Blades	**2**	15.10 g	$34.45	$68.90
Mejzlik 16x5.5 Propeller Blades	**4**	20.00 g	$59.99	$239.96
	Total:	**5820.97 g**		**$1671.24**
	Total for 12 UAVs:			**$20054.88**

2.3.2 Package Delivery System

Conceptual Design Phase

The Company decided that the delivery system needs to follow two requirements: secure the package in flight and be autonomous. With the previously mentioned restrictions (Refer to 1.3 “State the Project Goal”), the delivery system would only need to fit one package and deliver it automatically to the delivery zone after the UAV lands at the delivery location. Further consideration was placed on where to put the package, the method to secure it, and how to automate the system. Methods such as a spring, claws, hooks, clamps, and a combination of the devices listed previously were considered as potential choices (Figure 9).

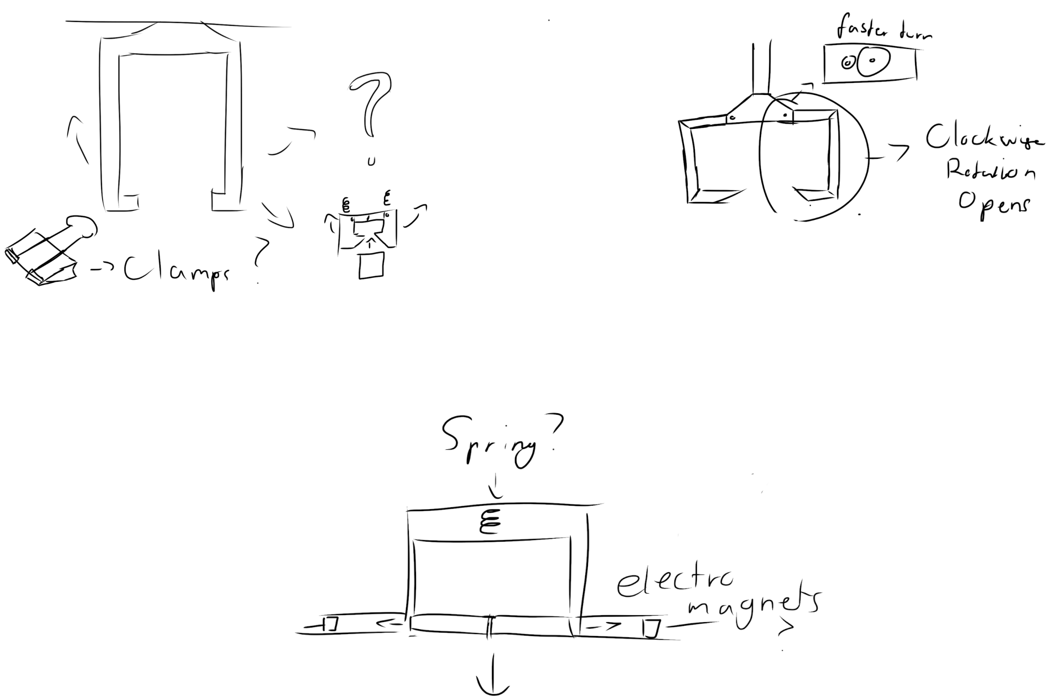


Figure 9. Conceptual package design sketches.

Preliminary Design Process

Four mechanisms were considered following the conceptual design phase. After creating sketches based on the suggested methods, two were ruled out due to a visually obvious higher risk of losing the package. The hook was ruled out as pressurized wind could easily knock the hook and release the package alongside the claw as it would not be able to protect the underside of the package. The spring was ruled out as ejecting the package could result in damages (Figure 10). Clampers were chosen as these are able to grasp the package while protecting the underside of the package.

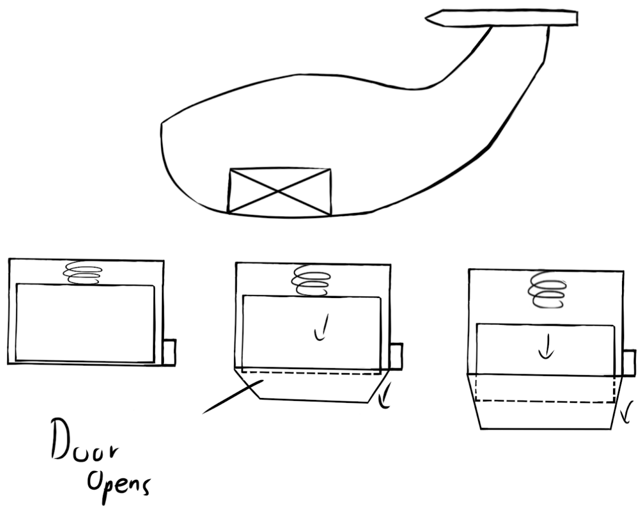


Figure 10. Preliminary package placement and spring mechanism.

Detailed Design Phase

Having chosen a preliminary mechanism, the company designed an interior delivery mechanism in which a clamp will be in use during the entire UAV flight and operation (Figure 11). The package will be secured via a clamp connected to a rack and pinion controlled by a DSServo DS3225. The clamps' dimensions are 0.55 x 0.55 m x 0.30 m (length, width, height) with the clamps being able to retract horizontally up to one meter. The material selected was 6061 aluminum alloy as it can flex under impact or blunt force, allowing the alloy to withstand damage and protect the package. Fracture toughness of aluminum alloy varies from 14 to 28 MPa m^2 and the resistance was found to be less than 28 MPa m^2 for various toughness test methods (Doddamani Saleem Saab., Kaleemulla Mohamed., 2016).

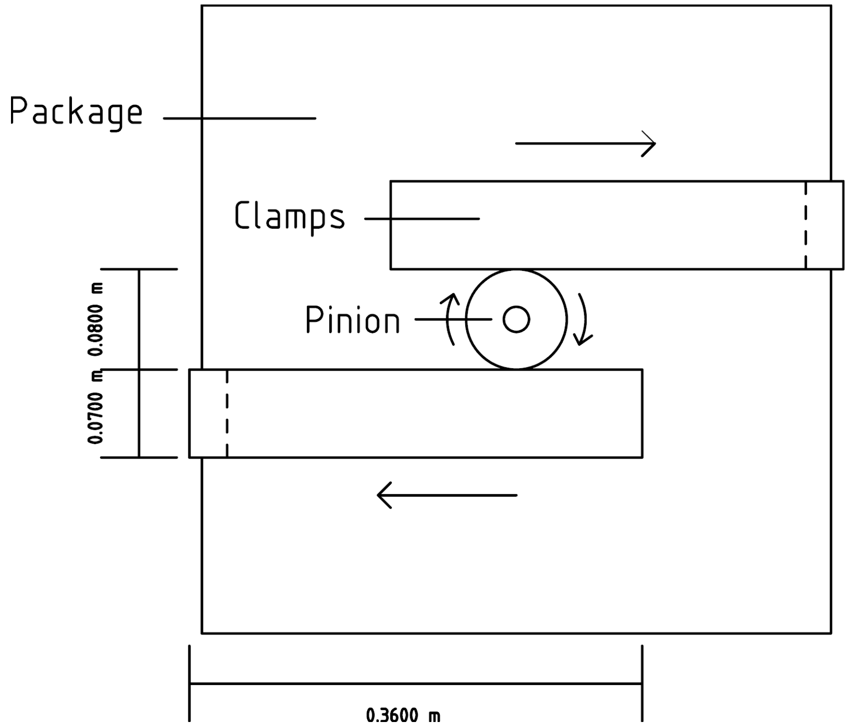


Figure 11. Finalized Delivery Mechanism (Top Down).

The components required to make the delivery mechanism cost $11.99: including the servos, racks, and pinions (Table 5).

Table 5. Total cost of Servo, Rack, and Pinion.

Components	Quantity	Weight (g)	Unit Value	Total Cost
DSSERVO DS3225 with Rack and Pinion	**12**	67.00 g	$11.99	$143.88

2.3.3 Sensors

Conceptual Design Phase

Company Researchers began looking into different types of sensors typically used in aircraft. The Company wanted a sensor that can detect and avoid obstacles that are around the UAV and to measure the distance of the object to the UAV in a quick manner. The ideal sensor for the company would possess a 360-degree view to monitor the UAV's surroundings and a long-range sensor to give the UAV more time to avoid obstacles.

During flight, the UAV must handle at least a one-meter distance between itself and both mobile and stationary objects in its path. A LiDAR sensor that can see beyond the five-meter distance was desired for the Company. With such a distance, it gives both the pilot and UAV to adjust course to alter its flight path to minimize damages. The Company considered having more sensors to monitor more of the UAV. This was believed to assist the pilot in getting accurate information on the UAV's surroundings and reduce the chance of losing telemetry.

Preliminary Design Phase

After viewing the sensor's requirements, the Company narrowed the sensors down to three categories: an Inertial Measurement Unit (IMU), a rangefinder, and a camera. These categories qualified as they gave vital information to the pilot along with providing an adequate detection distance for the UAV or the pilot to evade obstacles.

IMU

A 9-axis IMU enables the UAV to locate where it is without the assistance of a GPS transmitter. Additionally, it allows the UAV to record its location and adjust its orientation accordingly within three-dimensional space.

Rangefinder

The Company decided a rangefinder would be necessary for the UAV as a precise tool for measuring altitude and giving data of incoming obstacles. This information assists the UAV in adjusting flight paths to avoid obstacles.

Camera

In the event all other navigation systems fail, a camera would be needed for the pilot to effectively operate a UAV. For this, the company decided that the camera would need to excel in two categories: resolution and framerate.

Detailed Design Phase

IMU

The ICM-20948 enables the UAV to locate where it is without the assistance of a GPS transmitter (ICM-20948, n.d.). In addition, it allows the UAV to record its location and adjust its orientation accordingly within three-dimensional space. With this, the pilot can know the precise location of the UAV. For this purpose, the IMU was incorporated into the design.

Camera

The Caddx Turtle V2 enables pilots to view a UAV's surroundings with 155 degrees of view and a distance of 213.36 m (RaceDayQuads, n.d). The UAV's environment is shown with detailed video as the camera records in 60fps at 1080p resolution (RaceDayQuads, n.d). Furthermore, a weight of 12 g has little effect on UAV performance.

Rangefinder

For a forward-facing LiDAR sensor, the Company chose the TF03-100. With a range of 0.1 to 100 meters and an update rate of 1,000 times per second with a 0.5-degree field of view, the sensor allows the UAV to take note of any sudden obstacles and allow it to move accordingly (SmartFly INFO, n.d). Being only 77.1g, it is a lightweight component with little effect on flight performance (SmartFly INFO, n.d).

To avoid collisions, the company decided to install a second LiDAR sensor onto the UAV. The Slamtec RPLIDAR A1M8 has a 360-degree of view with a range of 0.15 to six meters and an update rate of 2-10 times per second (SmartFly INFO, n.d.). The sensor system was categorized based on a component's features (Table 6) and cost (Table 7).

Table 6. Camera and sensor details.

Component	Angular Range	Distance Range (m)	Scanning Frequency
ICM-20948	Interior of UAV	Interior of UAV	230.00Hz
Caddx Turtle V2	155.00 degrees	213.36 m	67800.00Hz
Smart Fly TF03-100	0.50 degrees	0.10 – 100.00 m	1000.00Hz
Slamtec RPLIDAR A1M8	0.00 – 360.00 degrees	0.15 – 6.00 m	5.50Hz

Table 7. Total cost and weight of sensor and camera system.

Component	Quantity	Weight (g)	Unit Cost	Total Cost
ICM-20948	**1**	0.14g	$5.10	$5.10
Caddx Turtle V2	**1**	12.00g	$64.99	$64.99
Smart Fly TF03-100	**1**	77.00g	$219.99	$219.99
Slamtec RPLIDAR A1M8	**1**	317.00g	$99.99	$99.99
	Total:	**406.14g**		**$390.07**
	Total 12 UAV:			**$4680.84**

2.3.4 Command, Control, and Communications (C3) Selection

Design Process

The Company needed the UAS to maintain communication throughout the whole five kilometer flight. To better ensure this, the Researchers looked into ways warehouse control can receive telemetry from the UAS. The Researchers determined that the UAS would require antennas to receive instructions from their pilot. Additionally, the UAS could rely on Wi-Fi signals to communicate in the event of GPS failure. A transponder was also required in order for the City UAS Traffic Control (CUTC) to monitor the UAS as well.

Components

AKK X2 FPV VTX: The AKK X2 (AKK X2 FPV VTX, n.d) is a video transmitter that has a range of four km in an open area which helps the Operational Pilot see a clear visual on UAV sightline activity adjusting any controls or flight path being made.

Holybro 100mW Transceiver Telemetry Radio Set V3 (915MHz): The Holybro 100mW gives the Operational Pilot a range up to six kilometers with the help of a patch antenna on the ground or mounted on the UAV(GetFPV, n.d). The radio's frequency is 915 MHz: able to penetrate through crowded buildings, skylines, and dense trees the radio uses open source firmware which has been specially designed to work with MAVLink packets and to be integrated with the Mission Planner, Copter, Rover, and Plane (GetFPV, n.d).

IFlight 2pc Sigma 5.8GHz: The IFlight Sigma is a video antenna with a gain of three dBi in a frequency range of 5,500-6,000 MHz that is connected to the transmitters (IFlightFPV, n.d). The

the transmitter will connect to the multiplexer which will provide the Operational Pilot video feed on their monitors for UAV activity.

FPV Triple Feed Patch Antenna 5.8GHz: The Triple Feed is a patch antenna with a gain of 9.4 dBi with a beamwidth of 55 degrees in both horizontal and vertical directions (RCmall, n.d).

Pixhawk 4: With its autopilot and UAV antenna tracking features along with a precoded Dronecode stack, the Pixhawk 4 was chosen to track the UAVs position and adjust any antennas that have been installed.

ThrustMaster T.Flight Hotas: The ThrustMaster will give the Operational Pilot direct control of the UAV manually. It also adapts to aerial movement along with being able to control acceleration to give the pilot more maneuverability throughout the airspace.

Multiplexer: The TS5MP645NYFPR will provide the Operational Pilot the ability to switch between manual and autopilot modes (TS5MP645NYFPR, n.d.). These set modes are necessary to give flexibility for the Operational Pilot as they oversee a UAVs flight path and intervene when necessary. With the onboard transceivers it will be connected to, it will receive and transmit data to the UAV.

Trig TT21 Class 2 Mode S Transponder: A transponder will give the UAV the capability to provide collision avoidance and situational awareness, along with being able to maintain distance between other UAVs. With a price of $2,408, it was cost-efficient compared to transponders costing $3,000 and higher as well as having better security measures in both collision avoidance and distance between other UAVs.

Monitor: A Samsung CF390 will be used as both Operational Pilot and Safety Pilot monitors with an aspect ratio of 16:9 being 27 inches. There will be a total of four monitors, one for each pilot, with each monitor costing $169.99. The monitors link up to five different UAVs, two interchangeable screens with both screens able to monitor two UAVs at a time. This gives the Operational Pilot and Safety Pilot the ability to survey five UAVs at a time whenever necessary.

Keyboard and Controller: A BronaGrand 2 will be used as the keyboard and ThrustMaster T. Flight Hotas will be used as a controller. These two devices will be used to pilot the UAV.

Central Processing Unit: To operate the monitors, the processing unit chosen is the AMD Ryzen 5 5600X 3.7 GHz 6-Core Processor and NVIDIA GeForce RTX 3070 8GB GDDR6 PCI along with a Crucial Ballistix 16 GB (2 x 8 GB) DDR4-3600 CL16. The AMD Ryzen will be used to operate all software in the UAV.

Network Connection: For the Operational Pilot to communicate with the UAV, the computers the pilots are provided with will have an NET-DYN USB adapter that is able to create a communication signal from HQ to the towers that will send and receive signals from the UAV.

With a download and upload speed of 865 megabits per second (Mbps) with a GHz range of 5.0 along with a sim card with a capacity of 256 megabytes (MBs), the Pilot will be given both camera and sensor feed at all times from the UAV. With the components, a fixed cost was calculated along with the mass and quantity needed for one UAV (Table 8).

Table 8. Total cost of C3 components.

Product	Quantity	Weight	Unit Cost	Total Cost
AKK X2 FPV VTX	**1**	6.80g	$16.99	$16.99
Holybro 100mW Transceiver Telemetry Radio Set V3	**1**	27.00g	$39.99	$39.99
IFlight 2pc Sigma	**1**	1.00g	$17.99	$17.99
FPV Triple Feed Patch Antenna 5.8GHz	**1**	23.00g	$12.99	$12.99
Pixhawk 4	**1**	15.80g	$180.99	$180.99
TS5MP645NYFPR	**1**	0.01g	$1.48	$1.48
Trig TT21 Class 2 Mode S Transponder	**1**	440.00g	$2128.81	$2128.81
Total Cost and Weight of UAV Components		**513.61g**		**$2399.24**
Total Cost of 12 UAV				**$28790.88**
Monitor	**4**	----	$169.99	$679.96
Keyboard	**4**	----	$7.99	$31.96
Controller	**4**	----	$139.42	$557.68
CPU	**4**	----	$1241.78	$4967.12
NET-DYN USB Adapter	**1**	----	$44.87	$44.87
Total Cost				$6281.59
Total Cost (Includes UAV components cost above)				**$35072.47**

Effect on Human Resources

Due to the limited amount of UAVs in the air, the Company believed that two Operational Pilots and two Safety Pilots were enough to monitor the UAS (Table 9). Each pilot costs $35 per hour and can monitor up to five UAVs (Cummings et al., 2007). Operational Pilots are tasked to monitor the assigned UAVs and adjust flight paths according to CUTC. Safety Pilots are tasked with taking over the Operational Pilot and manually controlling a UAV entering emergency procedures.

Table 9. Costs of Operational and Safety Pilots.

Personnel	Number of Personnel	Work Hours	Pay Rate	Total Hourly Cost
Operational Pilots	3	12	35	$105
Safety Pilots	3	12	35	$105
Total	**6**			**$210**

Warehouse personnel are individuals whose tasks are mainly found within the warehouse itself with all personnel costing $35 per hour. The company businessman calculated the hourly wages of all warehouse personnel (Table 10). Range Safety Personnel are tasked with monitoring city airspace to ensure company operations do not interfere with other ongoing flights. The Company decided that three Range Safety Personnel were to monitor the UAVs leaving the warehouse. Each staging area would be monitored by a Range Safety Personnel. Air Traffic Managers determine when and where a UAV will land once it returns to the warehouse. Two Air Traffic Managers were deemed sufficient for performing the given tasks. Recovery Personnel are tasked with the retrieval of any UAV that experienced an emergency landing or had lost communication with the pilot. Two pairs of Recovery Personnel will be responsible for retrieving any malfunctioning UAV.

Table 10. Warehouse Personnel Costs.

Personnel	Number of Personnel	Work Hours	Pay Rate	Total Hourly Cost
Air Traffic Manager	2	12	35	$70
Recovery Personnel	4	12	35	$140
Range Safety Personnel	3	12	35	$105
Total	**9**			**$315**

2.3.5 Ground/Support Equipment

Design Process

The design process for the ground equipment occurred after the Company had finalized the flight operations. This was done so that equipment selected was necessary for the tasks, but did not exceed the budget. The computer setup was given special attention as it needed the capacity to monitor five UAVs and their telemetry for a pilot. To balance out the cost of the computers, the Company cut costs on mobile carts: only requiring a cart to lift a single UAV or multiple packages.

Components

Trolley Cart: At the cost of $15.99, the trolley is both inexpensive and able to carry UAVs and packages.

DUO Dual Multi-Charger: The Dual Multi-Charger can charge two batteries at once along with being flexible to charge different battery types, Li-poly being the main battery type preferred. After a UAV returns from a flight, the batteries will be transferred to the battery charger. The charge calculation will take one minute and 55 seconds to fully charge the 6S1P Lipo Battery Pack with AS150 +XT150 Plug. Ground control and support equipment were calculated for their total cost and quantity needed for operation (Table 11).

Table 11. Total cost of support equipment.

Components	Quantity	Unit Cost	Total Cost
Trolley Cart	3	$15.99	$47.97
Duo Dual Multi Charger	9	$93.69	$843.21
Total Cost			**$891.18**

Effect on Human Resources

Ground crew are the personnel found mostly working on the staging areas. Quantity and cost of ground crew were calculated based on what was needed for company operations (Table 12). Package Handlers cost $15 an hour with nine handlers in total. Each handler is tasked with replacing the UAV's battery with a fully charged one and loading a package into the UAV. Handlers can also bring out packages from the warehouse onto the staging areas and place used batteries into the charging stations. Each Launch and Recovery Assistant cost $15 an hour with nine Launch and Recovery Assistants in total. Launch and Recovery Assistants are charged with bringing UAVs out of the warehouse before the flight hours begin and preparing UAVs for take off. In between landings and take offs, Launch and Recovery Assistants can help Package Handlers with their tasks. Maintenance Technicians perform maintenance checks on UAVs on the staging area or make repairs within the warehouse. Each technician costs $35 an hour with five technicians in total.

Table 12. Ground Crew Costs.

Personnel	Number of Personnel	Work Hours	Pay Rate	Total Hourly Cost
Launch and Recovery Assistants	9	14	15	$135
Package Handler	9	14	15	$135
Maintenance Technicians	5	12 (+2 hours for 2 Technicians)	35	$175 ($70 for pre and post flight hours)
Total	**23**			**$445**

2.4 Lessons Learned

During the Conceptual Phase, the Company had many ideas on how the UAV could be designed. Members provided potential solutions that could be implemented into the UAS. All options were respected by the Company, though, some members struggled with justifying design choices due to lack of knowledge in aircraft designs and aerodynamics.

During the Preliminary Phase, Researchers looked into UAV technology to understand the purpose and function of each component. After further discussions, feedback was obtained from the coach and mentors to assist the team in refining design ideas. Members also provided justifications and ideas by adding comments and suggestions whenever deemed necessary. Sources and calculations used were all cited and recorded for later use.

In the Detailed Phase, concepts related to engineering, power, aerodynamics, and mathematical formulas that the Company had to learn were all challenges the Company had to overcome. 2D and 3D drafting was also an obstacle the CAD team had to learn as they were new skills to the Company at the time. The team remained on schedule and communicated with one another whenever help was needed. Members knew the importance of time management and communication in order to accomplish tasks according to the schedule.

2.5 Component and Complete Flight Vehicle Weight and Balance

The C21 Fantail will have two separate weights during the mission: one without a package (Figure 12) and one with (Figure 13). Without the package, the UAV weighs 6.65 kg and 11.65 kg with the package. The Center of Gravity (CG) for no package is 101.79 cm (1.01 m) (Figure 12) while one package will be 103.37 cm (1.03 m) (Figure 13.). The Neutral Point of the UAV is 109.33 cm (1.09 m) and the wingspan of the UAV is 1.09 m. The UAV's side CG without the package is 39.82 cm from the bottom of the UAV (Figure 14(a)) and with the package is 41.32 cm from the bottom (Figure 14(b)).

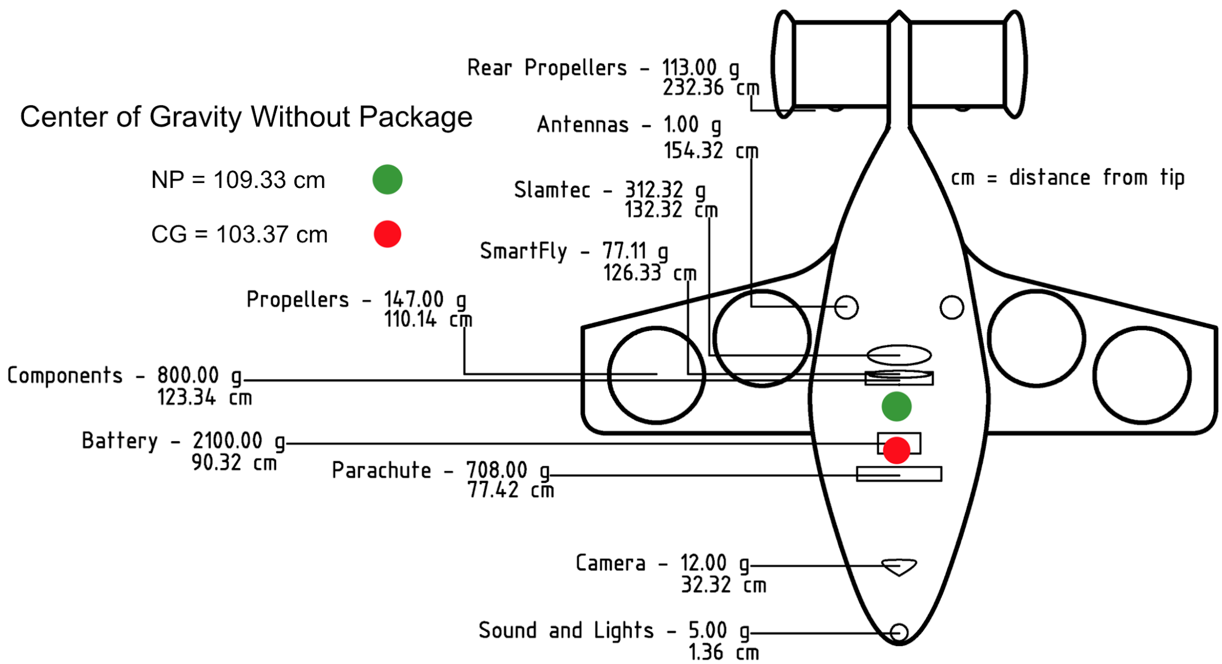


Figure 12. Center of Gravity - Without Package.

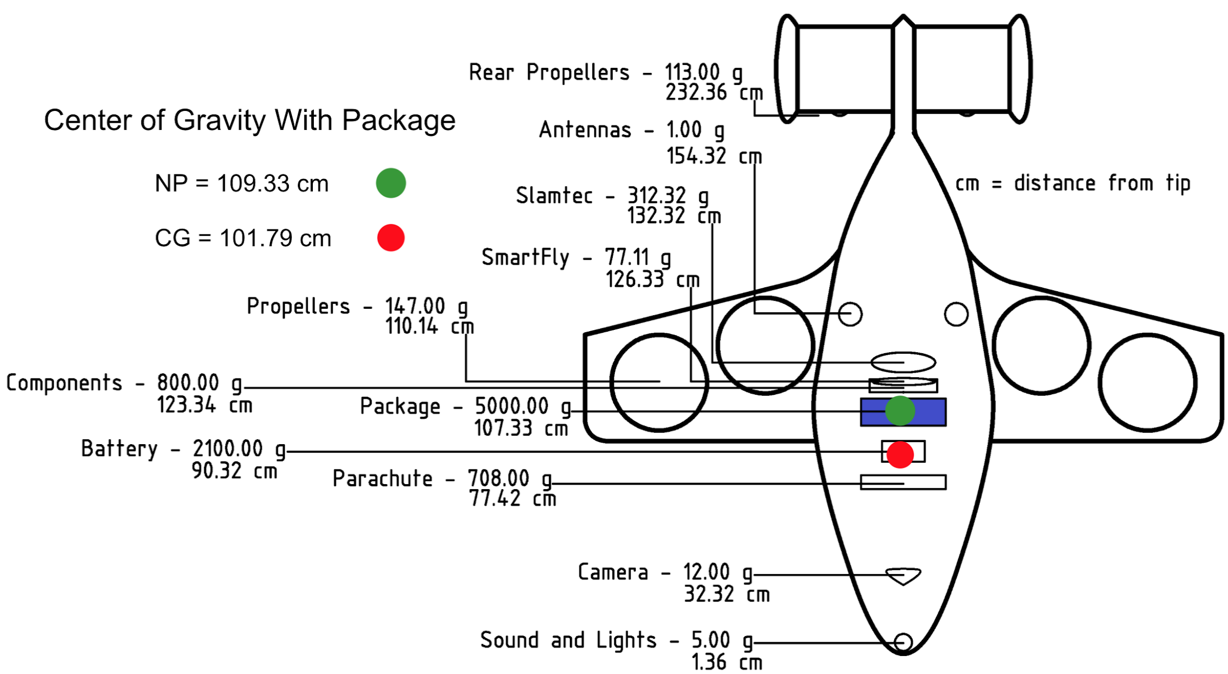


Figure 13. Center of Gravity - With Package.

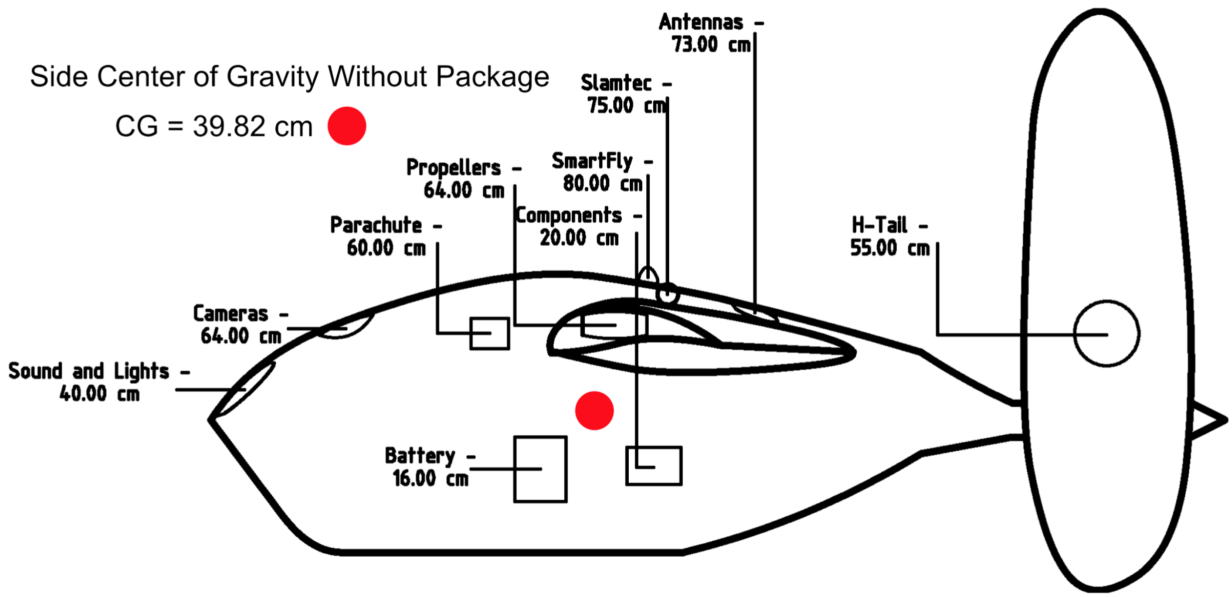


Figure 14(a). Side View Center of Gravity - Without Package.

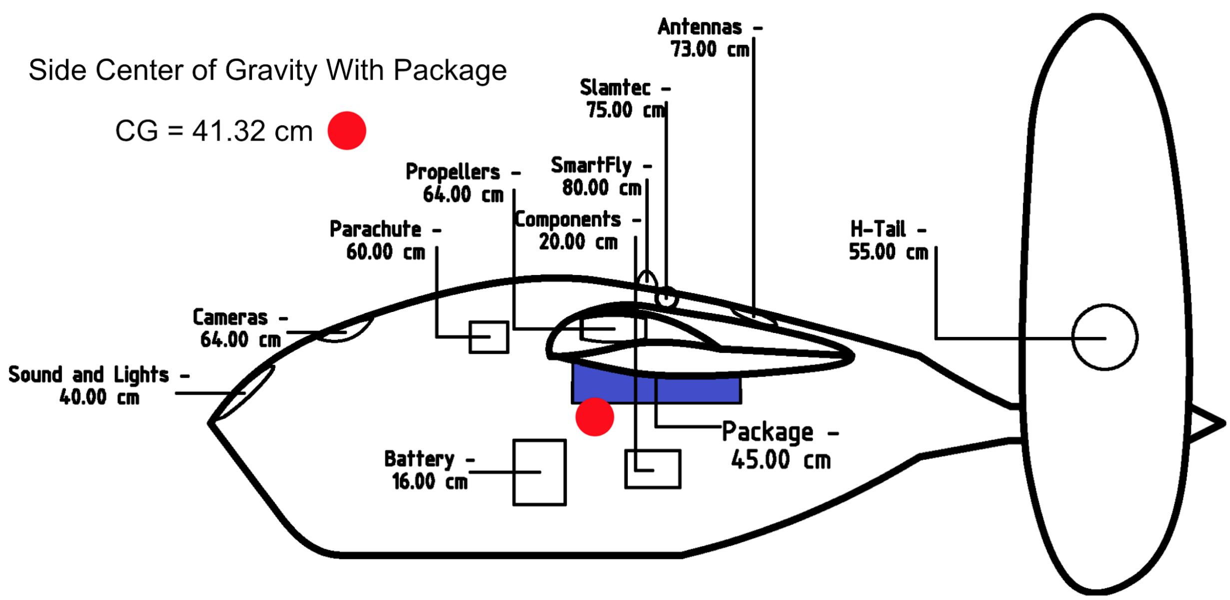


Figure 14(b). Side View Center of Gravity - With Package.

2.6 Final Design Drawings

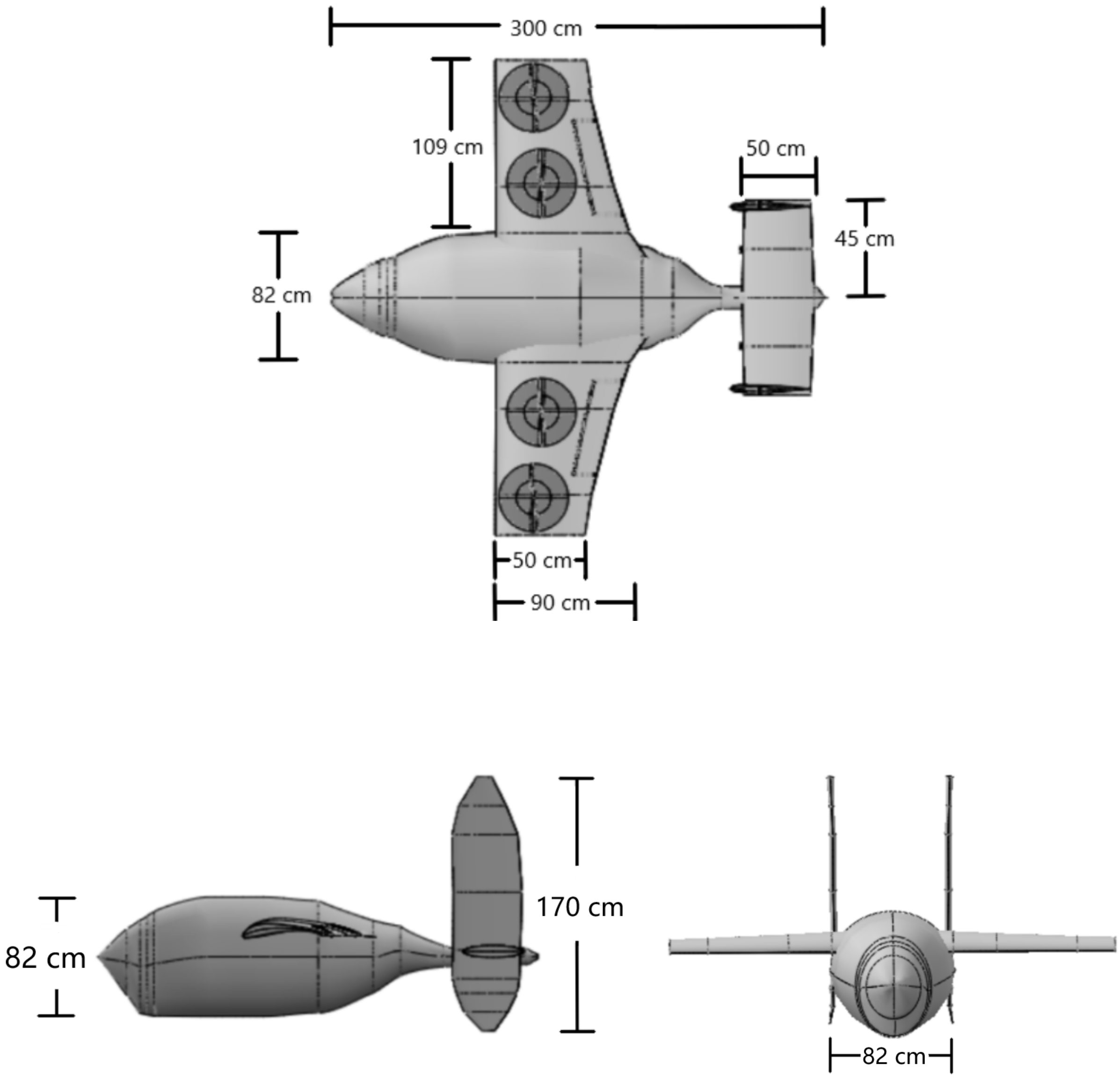


Figure 15. Three-view of final unmanned system design.

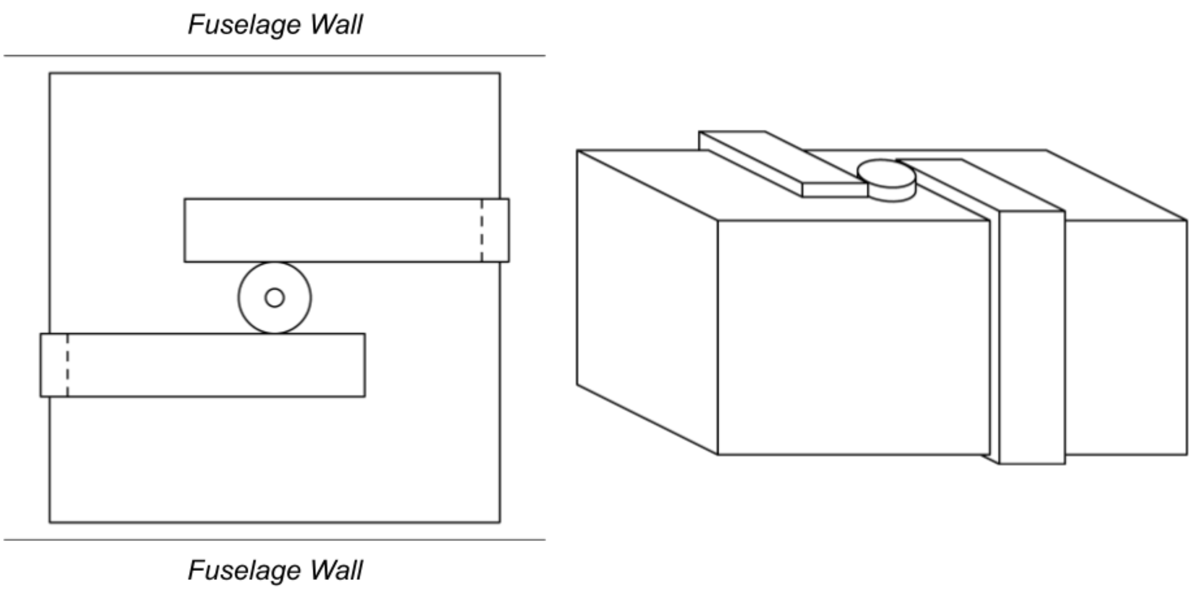


Figure 16. Automated Delivery System (Exposed Form).

3. Missions

3.1 Concept of Operations

3.1.1 Pre-Mission

Pacific Projects aims to deliver 156 packages in a single workday by using nine UAVs launched in sets of three. In case of a UAV breaking down during the day, three additional UAVs will be kept in storage as backups to minimize potential delivery disruption.

Before Flight Hours

An hour before the twelve-hour flight window, employees will begin to set up their work stations. Two Maintenance Technicians will perform maintenance checks on UAVs and resume general service and repairs of damaged UAVs (if needed) from the previous day while Package Handlers and Launch and Recovery Assistants will prepare all fully functional UAVs for the day's first flights. Packages will be brought outside to their respective staging areas via a QR code attached to them as a security measure. Each QR code is assigned to a specific delivery location and each staging area has its locations that it will deliver to.

Preparation for Launch

Each of the three staging areas will prepare one UAV at a time with each staging area capable of performing battery hot swaps, package reloading, maintenance checks, landings, and takeoffs (Figure 17). The dimensions of the staging areas is 10 m x 10 m with a three-meter distance separating each staging area. All staging areas are 15 m away from the warehouse.

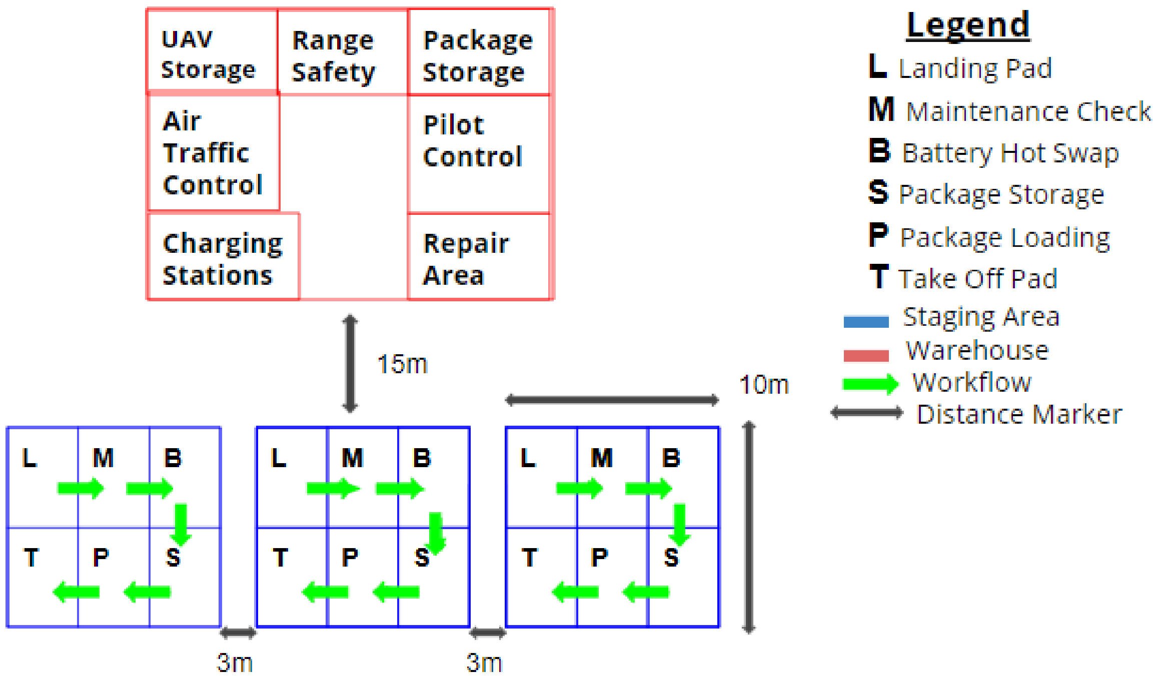


Figure 17. Warehouse and staging areas layout.

Maintenance Technicians will perform a maintenance check to ensure the UAV is fully operational before passing it to a Package Handler. The Package Handler will remove the battery of the UAV and replace it with a new fully charged battery. The used battery will be taken to a charging station inside the warehouse by another Package Handler. The handler will scan the QR code with the UAV's forward-facing camera thus giving the UAV a predetermined flight path towards the package's delivery zone. Once scanned, the package will then be loaded into the UAV. Launch and Recovery Assistants will take the UAV and place it onto a pad from which the UAV will perform vertical take off to the required 250 m altitude.

3.1.2 Flight to Delivery Location

Before Launch

Before the UAV is launched, Range Safety Personnel will check with CUTC if the predetermined flight path is safe to operate in. If the latter sees an issue with the flight path, they will communicate with the assigned Operational Pilot to determine a new path to the delivery zone. Once the path is approved by both the warehouse crew and CUTC, Launch and Recovery Assistants will launch the UAV when the all-clear is given by an Air Traffic Manager. Flights will be in sets of three UAVs each with each set having a ten-minute difference between them. In total, a maximum of nine UAVs will be flown in the air at any given time. One Operational Pilot will monitor three UAVs (Cummings et al., 2007) during flight through camera and sensor feeds: totaling to three Operational Pilots.

During Flight

Each UAV will ascend to an altitude of 250 m with the four built-in rotors in its wings at an acceleration of 2.0 meters per second squared. This allows the UAV to reach the flight corridor within 15.81 seconds. Once altitude is reached, the rear rotors initiate horizontal flight until reaching a maximum speed of 55 knots, its most inefficient speed, in order to meet challenge requirements. The UAV will fly at an altitude of 250 m throughout the entire five-kilometer distance.

During the flight, an Operational Pilot will constantly monitor UAV telemetry to find any issues or to check if the UAV is operating optimally. If a discrepancy is found, the Operational Pilot will alter the UAV's routing through manual control following approval from CUTC. In case of major malfunction, the Operational Pilot passes control to a Safety Pilot who takes control of the UAV to perform an emergency landing in a safe, low populated area. Once the UAV lands, a recovery team of two Aircraft Recovery Personnel will retrieve the UAV.

UAVs will rely on the Pixhawk 4 Autopilot throughout the whole mission unless sensor systems fail, then the assigned Operational Pilot will manually control the UAV. Transponders will notify UAVs of other aircraft within the airspace. The remaining sensor system acts as additional obstacle avoidance and redundancies.

3.1.3 Package Delivery

Once the UAV arrives at the delivery location, it emits signals (based on the scanned QR code on the package) towards the delivery zone. As it descends, the UAV glides to 150 m altitude at an angle of 26.56 degrees. The UAV will circle around the zone for ten minutes. After the zone emits the approval signal to land, the UAV slowly descends to the location. The UAV will glide down to an altitude of 65 m at an angle of 23.03 degrees. For the last five meters, the UAV will complete a vertical landing onto the delivery zone.

When the UAV is five meters above the delivery zone, it will begin stabilizing itself. After landing at the location, the UAV will release the package via a clamping mechanism. Clamps will release the package using a rack and pinion system. The servo is programmed to stop rotating the pinion after a 165 degree turning point as to not over-release the racks. As the servo rotates the pinion, the clamps will move away from the package creating a one-centimeter space between the package and mechanism. The package will then fall through the space and land onto the delivery zone. The mechanism will be built into the UAV with the clamps acting as its sides.

Once the package is safely delivered, the Operational Pilot and Range Safety Personnel will wait for CUTC to approve a return flight. After approval is given, the Operational Pilot will give a command letting the UAV ascend to an altitude of 250m and make a return flight to the warehouse. The UAVs acceleration will be 2.0 meters per second squared allowing the UAV to reach the 250 m mark within 13.78 seconds. After reaching the required altitude, the rear rotors will initiate horizontal flight until reaching the max speed of 55 knots.

3.1.4 Return Flight

After delivering the package and ascending to an altitude of 250 m, the UAV travels at 55 knots for the entire five-kilometer return flight. Returning UAVs will use either a predetermined return flight path given by the package's QR code or a returning path decided on by the Operational Pilot and Range Safety Personnel. Operational Pilots will continue to monitor UAV telemetry to see if UAVs are performing optimally. Air Traffic Managers will monitor telemetry if UAVs require adjustments in the flight path. Range Safety Personnel will communicate with CUTC to ensure the flight path is safe to operate in. All flight path changes will be made by the monitoring Operational Pilot with guidance from Range Safety Personnel and Air Traffic Managers. Safety Pilots and recovery teams will remain on standby in case of UAV failure during this phase of the mission.

When nearing the warehouse, the UAV will glide from 250 m in altitude to 150 m at an angle of 18.43 degrees with a speed of 28.294m/s. Air Traffic Managers will notify the UAV when and where to land. The UAV will circle over the warehouse for ten minutes until given the signal to land. When Air Traffic Managers find a clear staging area, the UAV will glide down to five meters above the area and perform a vertical landing above the staging area. The gliding angle for the descent will be 25.79 degrees. The UAV will land on the available spot and be retrieved by Launch and Recovery Assistants.

3.1.5 Post-Mission

Preparation for New Flights

After being retrieved by Launch and Recovery Assistants, the UAV will go through a preparation process for its next flight (Figure 18). The process to prepare new flights will take a maximum of eight minutes from the UAV landing to the moment it takes off. Each staging area during this phase will prepare a single UAV.

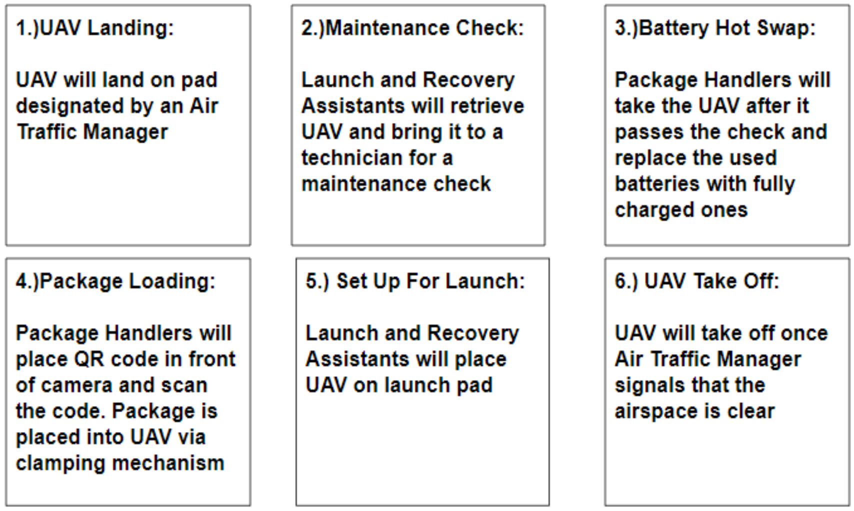


Figure 18. Conceptual operations for new flights.

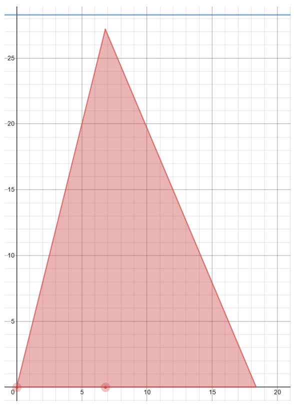
End of Flight Hours

Nearing the end of the 12-hour flight window, the ground crew at the staging areas will stop preparing UAVs for additional deliveries, so that all nine UAVs are accounted for once the 12 hours are complete. Once the final UAV is accounted for, the ground crew at the staging areas will begin to break down their workstations. Packages at the staging areas, which were not delivered, will be brought back into the warehouse. UAVs will be stripped of their batteries and go through a final maintenance check for the day. UAVs passing the check will be stored inside the warehouse for safety. UAVs that fail the check will go through any necessary repairs. Two Maintenance technicians will remain for an additional hour to continue repairs on damaged UAVs. Any repairs not completed during this time will be continued the next day.

3.2 Flight Profile Analysis

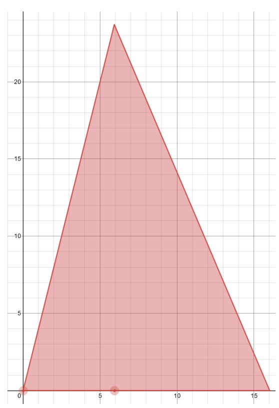
To find the amount of power consumed for an ascent, Company Mathematicians used the equations shown below (Figure 19; Figure 20). Using known variables (weight of UAV with package = 11.65 kg, altitude = 250 m, gravity = 9.8m/s^2, and acceleration = 2.0 m/s^2), the Mathematicians, with the help of the mentors and coach, found the time in hours and power in watts (10.28 watts). After finding the number of watts, the Mathematician used a watts to amps conversion calculator (rapidtables, n.d.) to find the amount of mA. The Mathematician then multiplied the mAs with 1000 to find total mAh for ascent.

To find the optimal method for ascension, the Mathematicians employed integral calculus. This method would be used for an easy model of the aircraft's altitude (area), velocity (y-axis), and time taken (x-axis) during an ascent. However, the Company was unable to create an algorithm to speed up the process of optimization. As such, the Mathematicians worked with trial and error methods using a Desmos Calculator (Desmos, n.d).



$$\int_{0}^{6.8} 4x\,dx + \int_{6.8}^{18.3745} \left(-2.35x + 43.18\right) dx$$

Figure 19. Example of ascent calculation from airfield.

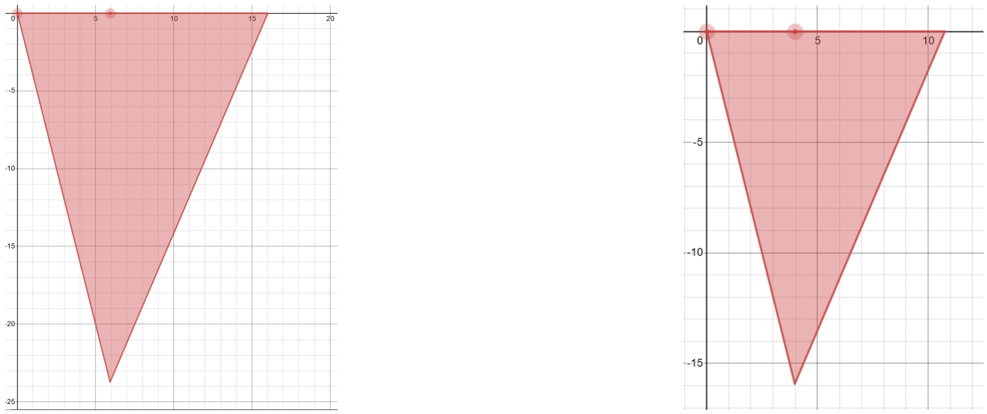


$$\int_{0}^{5.928} 4x\,dx + \int_{5.928}^{16.02} \left(-2.35x + 37.643\right) dx$$

Figure 20. Example of ascent calculation from delivery zone.

Calculations for Descension

Company Mathematicians used a variation of the same formula modified to find the descent of the UAV (Figure 21; Figure 22). When descending, the C21 Fantail will glide down to a certain altitude (depending on where it is descending to). Afterwards, it will use its four wing rotors to perform a VTOL maneuver.

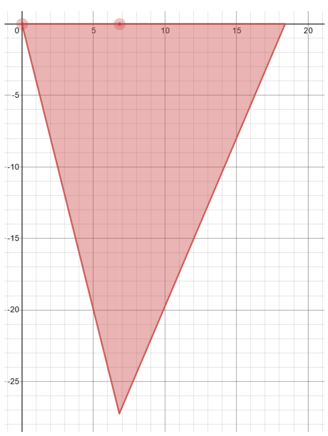


$$\int_0^{4.3} -4x\,dx + \int_{4.3}^{11.6} (2.35x - 27.305)\,dx + \int_0^{3.98} -4x\,dx + \int_{3.98}^{10.75} (2.35x - 25.273)\,dx$$

Descent from 250m to 150m

Descent from 150m to 65m

Figure 21. Example of descent calculation to delivery zone.



$$\int_0^{6.81} -4x\,dx + \int_{6.81}^{18.4} (2.35x - 43.2)\,dx$$

Figure 22. Example of descent calculation to staging area.

Calculations for Horizontal Flight

The C21 Fantail needs the rear propellers to spin at 6,200 RPM to sustain a horizontal speed of 55 kt (Static Thrust Calculation, n.d.). The result doubled as the UAV used two rear propellers in the operation. Different amp power was extracted from the RPM of the motor. The miles per hour (mph) was a result of the static thrust calculator (Figure 23). To account for mAh being consumed from the battery, the Company used a conversion from mph to meters per second (m/s), then divided the total distance of travel with meters per seconds. Using seconds, it was converted into hours to follow a formula of multiplying the time by an hour, amperage current, and 1,000 to get the total mAh usage for the travel distance needed (Figure 24).

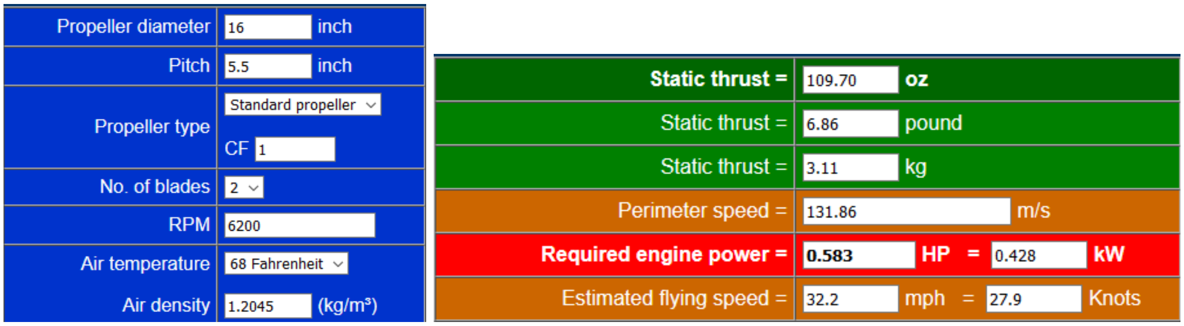


Figure 23. Example of horizontal flight calculation results.

With Package									
Description	Time in hours	Time in minutes	Time in seconds	Motor RPM	kw for 2 motors	Kw to W	Amperage Current (A)	Voltage Intake (V)	mAh usage
4km or 4000m	0.038	1.157	69.47	6200	88	0.088	4	44.4	154.377
1km or 1000m	0.009	0.578	34.345	6200	88	0.088	4	44.4	38.594
								Total	192.971
Loitering time	minutes	hours	Amp current	mAh usage					
20 min with package	20	0.333	4	1333.332					
Without the Package									
Description	Time in hours	Time in minutes	Time in seconds	Motor RPM	kw for 2 motors	Kw to W	Amperage Current (A)	Voltage Intake (V)	mAh usage
4km or 4000m	0.038	1.157	57	6200	88	0.088	4	44.4	63.333
1km or 2000m	0.009	0.578	13.025	6200	88	0.088	4	44.4	14.472
								Total	77.805

Figure 24. Horizontal flight calculation spreadsheet.

Phase I

The goal for C21 in Phase I is to reach an altitude of 250 m using a VTOL maneuver. Due to the added weight from a loaded package, C21's propellers will have to spin at 6,200 RPM to accelerate at 4.0 m/s^2 for 7 seconds. Next, C21's propellers will spin at 3,650 RPM in order to decelerate at 1.57 m/s^2 to a stop for 11.915 seconds. In a total of 18.915 seconds, the drone will ascend to 250 m, consuming 99.45 mAh.

Phase II

Starting 13.915 seconds into the ascent of Phase I, C21 will fly for five kilometers at a speed of 55 knots. This is done to increase movement efficiency. The total power consumed equates to 192.97 mAh and total flight time is 2.89 minutes.

Phase III

Upon reaching the delivery zone, the UAV will glide down to an altitude of 150 m and circle over the zone. The C21 will descend at a speed of 4.0 m/s^2 for 4.3 seconds, then decelerate to a hovering position in 7.3 seconds. The descent will take 11.6 seconds and consume 36.44 mAh. The UAV will then circle over the zone for ten minutes, using 666.66 mAh.

Phase IV

After completing the loiter, the UAV will glide down to an altitude of 65 m while keeping the same RPM speed to reach the delivery zone. Gliding angle will be 23.03 degrees and deceleration rate will be 0.5 m/s^2 until it reaches a speed of 9.49 m/s. Once the UAV is five meters above the landing zone, the UAV will perform a vertical landing. The UAV will accelerate downwards at 2.0 m/s^2 for 1.58 seconds, later decelerating at 2.0m/s^2.for 1.58 seconds. The total time of descent is 12.15 seconds and will consume 115.86 mAh.

Phase V

After the package has been delivered, the UAV must ascend to an altitude of 250 m from 60 m by increasing the RPM speed from 4,740 to 6,200 from its starting point. C21 will ascend at 4.0 m/s^2 for 5.93 seconds and decelerate at 2.35 m/s^2 for 10.09 seconds. The total time for ascent equates to 16.02 seconds with total power consumed being 35.6 mAh.

Phase VI

Starting 12.02 seconds into the ascent of Phase I, C21 will fly for five kilometers at a speed of 55 knots. The horizontal flight will take 2.89 minutes, consuming 77.81 mAh.

Phase VII

Once the UAV returns to the warehouse, it will descend at a speed of 4.0 m/s^2 for 4.3 seconds, then decelerate to a hovering position in 7.3 seconds. The descent will take 11.6 seconds and consume 38.34 mAh. This puts it at an altitude of 150 m, where it will then loiter for ten minutes. The power consumed during the circling period equates to 432.35 mAh.

Phase VIII

After the 10-minute loitering period, the UAV will make a final descent to the staging area. First, the UAV will glide down to an altitude of five meters above the staging areas. Gliding angle for the UAV is 25.79 degrees. For the final five meters, the UAV will perform a vertical landing. The UAV will accelerate downwards at 2.0 m/s^2 for 1.58 seconds, later decelerating at 2.0m/s^2 for 1.58 seconds. The power consumed during this phase equates to 93.67 mAh and the time spent is 10.58 seconds.

Overall Performance

A single UAV flight consumes roughly 7,781.62 mAh, which is 25.37% of the UAVs battery life. A full flight is approximately 27 minutes (1638.6 seconds) (Figure 25(a) and 25(b)).

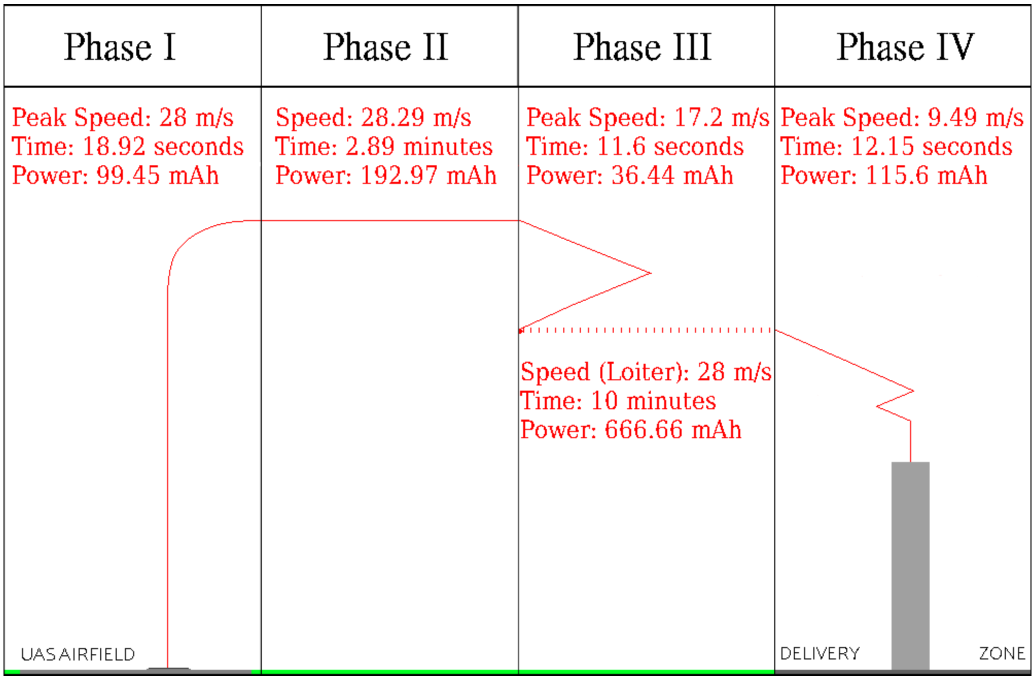


Figure 25(a). Flight Profile Analysis - UAV Delivery Flight.

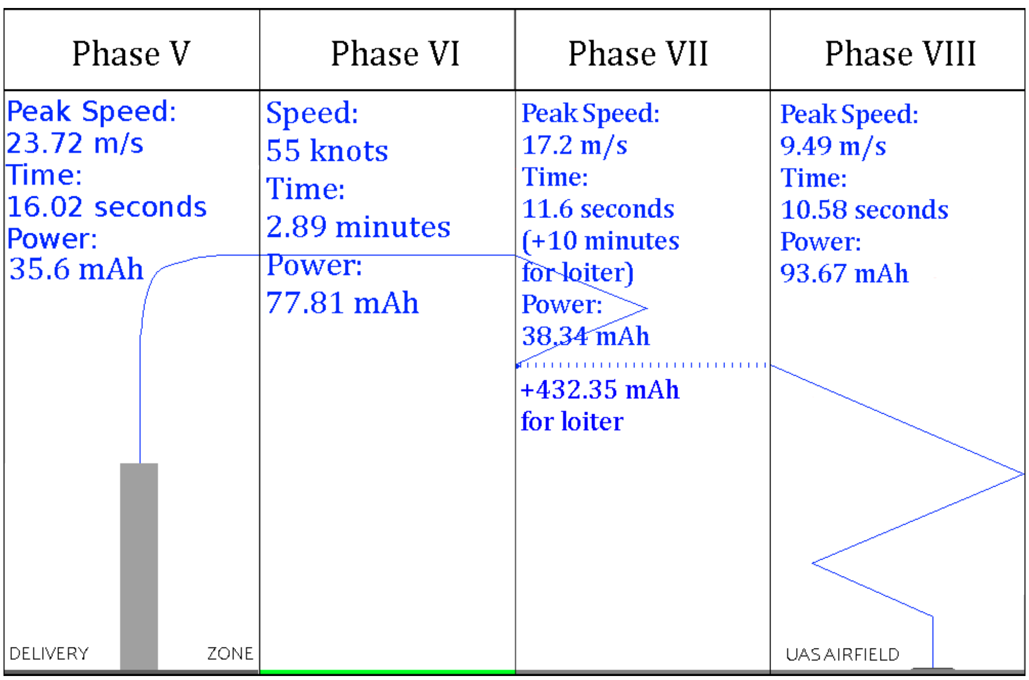


Figure 25(b). Flight Profile Analysis - UAV Return Flight.

3.3. Safety Requirements

3.3.1 Guidance without GPS

UAVs that have lost GPS signal will rely on remaining sensor systems to complete the mission. The Holybro Pixhawk 4 Autopilot (Holybro Pixhawk 4 Autopilot, n.d.) will continue acting as the autopilot with the use of NET-DYN USB, a network adapter within the Operational Pilot computers, and will connect to Wi-Fi via the towers scattered throughout the city. Before takeoff, the UAV will have a flight map preplanned that will guide it to the delivery location. The SmartFly info TF03-100 will act as the main sensor due to its obstacle avoidance capabilities and ability to measure the distance (SmartFly INFO, n.d.). With the distance measuring system, the UAV can track the remaining distance in order to deliver the package. Furthermore, the corridor mapping feature allows the UAV to create and reuse previously traveled flight paths to return to locations. With this feature, the UAV can return to the warehouse after delivering the package via the same 5 km route it took to reach the location.

The assigned Operational Pilot will monitor the UAV's current location via the 155-degree view of the Caddx Turtle V2 camera (Caddx Turtle V2, n.d.). With the use of city maps, the camera feed, and the Smartfly terrain feature, the Operational Pilot will determine the location via notable landmarks, such as buildings or unique terrain. Operational Pilots can still monitor UAV telemetry as total communication has not been lost. Based on the camera feed along with telemetry from the sensors, Operational Pilots can adjust accordingly to make sure that the UAV runs optimally and completes the mission.

3.3.2 Lost Communications

When communication is lost with a UAV and attempts to reconnect have failed, the UAV will continue to fly to the delivery location and go through the package delivery process (Refer to 3.1.3 Package Delivery). Once the package has been delivered, the UAV will wait for the Operational Pilot's signal to return home. Due to loss of communication, the UAV will remain at the delivery zone since the signal will not be received. As the UAV remains at the zone, a recovery team of two Aircraft Recovery Personnel will drive to the location.

In the event that communication is lost when the UAV is making a return flight, the UAV will follow its pre-existing flight path bringing it back to the warehouse. Once it returns, the UAV will loiter above the warehouse waiting for a signal to land, which it cannot receive. The UAV will loiter until its battery life reaches 10%. Once this occurs, the UAV will land on a clear area using its sensor system. The Company programmed the UAV this way to prevent UAVs from falling without enough power to initiate emergency procedures.

3.3.3 Obstacle Avoidance

Several sensors incorporated into the final design come with obstacle avoidance features. These systems were installed to prevent collisions with any surroundings a UAV might encounter, such as other aircraft or birds. Although a range of one meter was required, the Company decided to increase the range to give more time to evade obstacles. Additionally, sensors indicate when a UAV strays from the flight path and requires course correction. The Slamtec RPLIDAR A1M8 and SmartFly info TF03-100 both act as the active obstacle avoidance sensors. The Slamtec provides a full 360 view of the UAV at a range of six meters (Slamtech, n.d.) making it optimal for avoiding moving objects from the sides. The SmartFly acts as the forward facing sensor due to its 0.5-degree compared to the Slamtec. However, the Smartfly has a range of 100 m (SmartFly INFO, n.d.) giving pilots time to make evasive maneuvers in case of an obstacle in front of the UAV.

During flight, the UAV will fly at an altitude of 250 m: high enough to avoid buildings. In order to avoid other UAVs in the area, the Trig TT21 Class 2 Mode S (Mendelssohn Pilot Supplies, n.d.) acts as the transponder allowing the UAV to sense and communicate with other UAVs along with CUTC. Signals can be sent to and received (via transponder) from other UAVs and CUTC is able to send commands to the UAV if necessary.

With the combined features of the sensor system, the UAV will be able to detect obstacles at a range 6m. Thus allowing the Pixhawk (Refer to 3.3.1) to create a course to prevent a collision, but not far enough to stray from the flight path. The Pixhawk can then stabilize the UAV once all obstacles have been evaded.

3.3.4 Beyond Line of Sight

As most of the mission will require the UAV to fly Beyond Line of Sight (BLOS), multiple sensors were necessary to increase safety and coverage of the UAV's surroundings. Each Operational Pilot will monitor up to five UAVs that are in flight (Cummings et al., 2007). Camera feed from the Caddx Turtle V2 will be transferred via the FPV Triple Feed Patch Antenna attached to the UAV. With the camera feed, Operational Pilots are able to confirm the location of the UAV via distinct landmarks. Using the ThrustMaster T.Flight Hotas joystick, the signal gets sent to the flight controller then out to the multiplexer in order for the Operational Pilot to switch between the Pixhawk Autopilot to manual control. Manual control is only meant for emergency landings or in the event of autopilot failure.

The sensor system will monitor the UAV's altitude, speed, and distance. Pixhawk Autopilot will be the main guiding system for the UAV with its stabilization features and internal sensor systems. Additionally, its design allows for more accurate readings providing better flight performance.

3.3.5 One Engine Out Condition

Due to the UAV's hybrid fixed-winged design, each wing has two built-in rotors that assist in VTOL performance with two rotors at the rear assisting in horizontal flight. In the event of a rotor malfunction occurring in either wing during horizontal flight, flight speed will not be affected due to wing rotors only assisting in VTOL maneuvers. In the event a rotor malfunction occurs in either wing during VTOL maneuvers, the Operational Pilot will turn off the same rotor on the opposite wing causing the two remaining rotors to stabilize the UAV. The two remaining rotors can complete the delivery as they can provide the VTOL capabilities to land.

Two rear rotors assist in horizontal flight, a malfunctioning rotor will only decrease the speed of the UAV by half. To counteract this effect, the remaining rotor will maintain an RPM of 6200 to achieve 51 knots. The wings of the UAV will provide most of the lift throughout the flight, but the wing rotors will help maintain an altitude of 250 m throughout the remaining flight.

Depending on the location when the rotor fails, the Operational Pilot will provide different instructions. If UAV is closer to warehouse than delivery zone and even if the package is not delivered, pilots will bring the UAV back to warehouse and bring it to the warehouse for repairs, If UAV is closer to the delivery location than warehouse, pilots will bring the UAV back to the delivery location and wait for the recovery team to retrieve it.

3.3.6 Emergency Landings

In the event of a multi-rotor malfunction, wing damage, or major malfunction, the UAV enters the emergency landing protocols along with the assistance of the Nova and Mayday Parachute Launchers to launch the Iris Ultra 96 parachute capable of holding 50 lbs of weight (IRIS ULTRA 96" STANDARD PARACHUTE, n.d) with a fall speed ranging from 3.28 m/s to 4.33 m/s depending on if the UAV contains a package. With the parachute, the kinetic energy of a falling UAV ranges from 71.27 to 218.71 joules. To give a comparison, the UAV does not have enough force to break a bone nor the average car windshield (Biello, D., 2005; Expandusceramics, n.d.) even at the maximum falling speed with the parachute. The GM 16x10 Folding propeller blades in the rear of the UAV will retract into the motors to safely reduce blade exposure (Hyperflight, n.d). Once retracted, it stays retracted until the Operational Pilot sends a signal to the UAV through the microcontroller to open the blades again.

Assigned Operational Pilots will pass full control onto a Safety Pilot who will land the UAV. Depending on the altitude of the falling UAV, Safety Pilots are able to use Nova to manually deploy a parachute or use Mayday as an automatic deployment system (Figure 26). The Mayday automatic deployment system is able to detect up to 18 m of altitude when achieving a speed of 20 m/s with an auto-deployment at 3.35 m (Mayday & Nova, n.d.). Soon after the Safety Pilot will navigate the UAV to low population areas such as rooftops or vacant areas (parking lots and parks). Communication with city officials can provide the Company locations that UAVs are approved to land in during emergency landings.

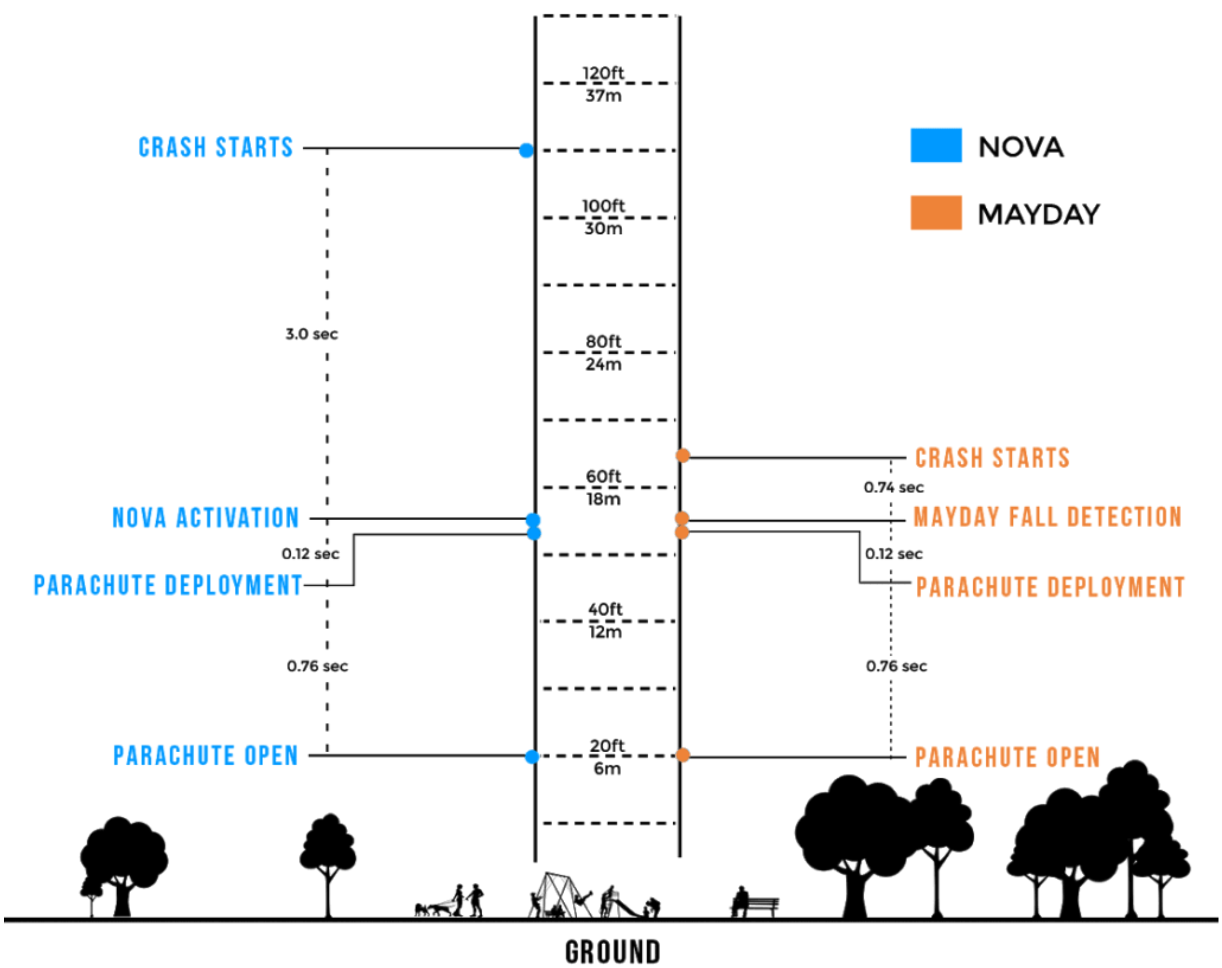


Figure 26. Mayday and Nova parachute deployments.

During the landing process, warning lights and sirens will begin to warn nearby pedestrians. The DJI Mavic Air/Pro Spark Phantom will act as the warning lights due to its strobe light feature and light distance of 100 m and brightness level of 130 LM (DJI Mavic Air/Pro Spark Phantom, n.d.). The VIFLY Finder V2 FPV Racing Drone will emit a warning at 110 dB (VIFLY Finder V2 FPV Racing Drone, n.d.). The DJI Mavic has a battery life of 20 hours while the Finder V2 FPV Racing Drone has 30 hours with both charge times being at 1.5 hours. This will help in both day, evening, and dark entries/exits to detect the UAV in both bright and dark light sources.

A pair of Recovery Personnel will leave the warehouse to retrieve the damaged UAV. Using a combination of sensor data before the crash and Short Message Service (SMS) signals from the Pixhawk 4, the pair will be able to locate the UAV. SMS signals can provide the location of the UAV via Google Maps. With the warning lights and sirens, the pair will be able to find the UAV upon entering its general vicinity.

3.3.7 Regulations and Additional Safety

Due to the challenge requirements, UAVs must operate BLOS in order to complete deliveries. This is in direct violation of FAA Regulation §107.31 which states that UAVs must operate in the visual range of the operator. The Regulation also requires UAVs to be seen by the operator with no equipment besides corrective lenses. To counter this violation, multiple sensor systems were added in order to account for various UAV logistics, such as altitude, speed, and directional heading, as well as act as obstacle avoidance systems.

Certain phases of the delivery occur in populated urban areas. This violates FAA Regulation §107.39, which dictates that UAS cannot operate over unwilling or unprotected pedestrians in case of a falling UAV. To counter this, multiple warning lights and sirens will activate once the UAV experiences a situation requiring an emergency landing. The parachute will activate and act as an additional visual cue.

The challenge's minimum flying altitude is 250 m, but FAA Regulation §107.51 states that no UAS can fly higher than 121.92 m. Due to 250 m being a requirement, the Company will accept the consequences brought on by the violation. Furthermore, the increase in altitude provides Safety Pilots more time to initiate emergency landing procedures. FAA Regulation §107.35 restricts UAVs to one per pilot. Company researchers determined that one Operational Pilot is capable of monitoring five separate UAVs without decreasing their job performance (Cummings et al., 2007). The Company is able to deliver a waiver to the FAA on the matter and provide justifications to the design in order to have it approved.

Part 135 certificate deals with the overall scope and type of the operation a company partakes in (Federal Aviation Administration, n.d.). Due to the number of UAVs that will be operating in the air in a given time, company operations do not fall in line with a 135 Basic certificate. However, company operations do fall under the Standard Part 135 certificate. Therefore, the Company will apply for the Standard Part 135 certificate to approve operations.

Additional safety measures have been set in place to act as redundancies in case the main system fails. Propeller covers were implemented in order to prevent damage coming to any of the UAV's surroundings. Rear propellers were chosen due to their ability to fold to reduce damage to the surroundings. A dual parachute system allows for both a manual and automatic release of the parachute during a fall. Sections of the FAA Part 107 Regulation where the Company is in no-compliance were listed (Table 13). The contracting city has given Pacific Projects the necessary permits for non-compliant sections of the regulation thereby allowing for Company operations.

Table 13. FAA Violations.

FAA Regulation	Description
§107.31	Operators must have a visual of UAV that is unaided by any device other than corrective lenses.
§107.35	A person may not pilot more than one UAV at the same time.
§107.39	Operations cannot occur over unwilling human beings.
§107.51	UAV altitude cannot exceed 400 feet or a speed of 87 knots.

4. Business Case

4.1 Cost Analysis

4.1.1 Operating Costs

Below is a breakdown of the total operating cost (personnel and electricity) for delivering all 156 packages in a single day (Tables 14; Table 15). Hourly labor cost is $970 with a day's cost equaling $12,320 including the additional hour before and after the flight window. The hourly cost of power is $0.12 with a day's cost being $9.87, resulting in a total operational cost of $12,329.87 per day.

Since a flight can only deliver one package, 156 flights would have to be made. A single flight uses 25.37% or 7,781.62 mAh of its 32,000 mAh battery charge (Refer to 3.2) The cost of a single flight was calculated by taking the daily operating cost and subtracting the pre-flight and post-flight hours. The new total was divided by the amount of packages delivered in a day. A single flight costs $74.68. The Company must pay a weekly rent of $25,000 for the warehouse. In a 28 day period, total operating costs equate to $445,512.72 including warehouse rent.

Table 14. Daily power consumption and cost.

Electrical Bill	kWh per day	Hours of runtime	Cost per day (US $0.12/kWh)
9 UAVs	40.81	12	$4.90
3 DUO Dual Multi-Charger	5.40	12	$0.65
3 Computer (CPU)	36.00	12	$4.32
Total Energy Cost per Day	**70.21**		**$9.87**

Table 15. Cost of Personnel.

Personnel	Number of Personnel	Work Hours	Pay Rate	Total Hourly Cost
Launch and Recovery Assistants	9	14	15	$135
Package Handler	9	14	15	$135
Operational Pilots	3	12	35	$105
Safety Pilots	3	12	35	$105
Air Traffic Manager	2	12	35	$70
Recovery Personnel	4	12	35	$140
Maintenance Technicians	5	12 (+2 hours for 2 Technicians)	35	$175 ($70 for pre and post flight hours)
Range Safety Personnel	3	12	35	$105
Total Hourly Cost				**$970 ($680 for pre and post flight hours)**
Total Personnel cost per day				**$12,320**

To maximize the 12 hour flight window, the Company decided to direct the ground crew to prepare UAVs for flight one hour beforehand. This allows for the first set of UAVs to launch once the flight window begins. Additionally, ground crew personnel will remain for an hour after the flight window ends to break down the staging areas and place UAVs back into the warehouse. The hourly cost for the pre- and post flight hours is $340 each with the total cost being $680.

Preparation for new flights follows a set process that personnel must follow (Refer to 3.1.5 “Post Mission”) and complete in eight minutes. When preparing a UAV, personnel will experience slack time in between tasks. Each personnel will have eight minutes of slack time between each UAV launch. Using a Program Evaluation and Review Technique (PERT) chart

(Figure 27), company Researchers were able to determine the time each task would likely take to be completed. The estimated average time to complete all six tasks to prepare new flights is four minutes and 50 seconds.

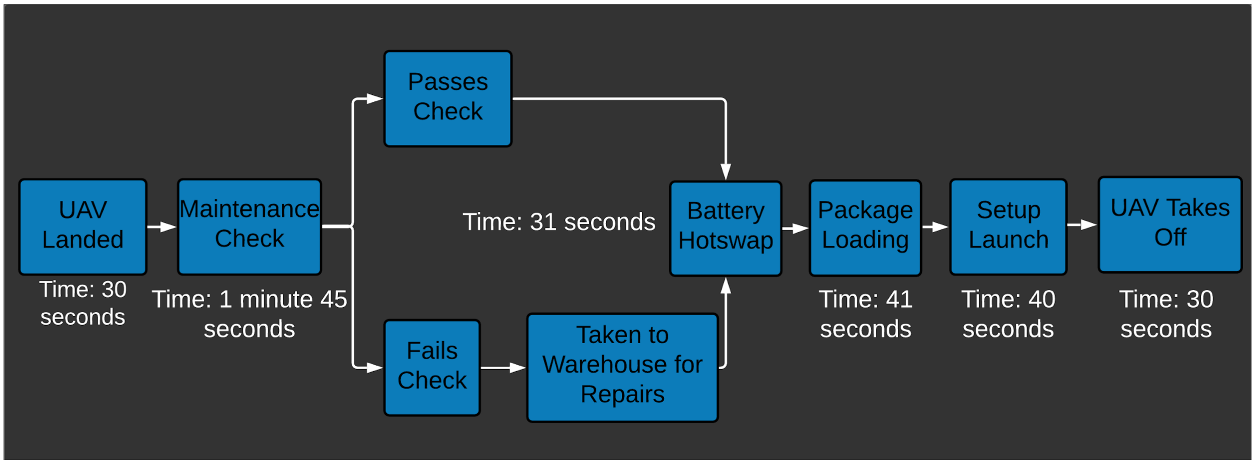


Figure 27. Pre-flight checks PERT chart.

4.1.2 Fixed Costs

Total fixed costs for all 12 UAVs (airframe and internal components), C3 components, and supporting equipment is $62,711.86. A full breakdown on component costs are provided in sections 2.3.1 (Table 4), 2.3.2 (Table 5), 2.3.3 (Table 7), and 2.3.4 (Table 8). The cost of a single UAV (includes airframe and internal components) is $4,589.79 while 12 UAVs cost $55,077.48. Total cost for C3 components is $6,743.20. Support equipment costs equate to $891.18.

4.1.3 Profit Analysis

Pacific Projects created the C21 Fantail with the intent of making a UAV that is safe, reliable, and able to complete the mission. Costs, weight, and ability to perform their tasks were traits used to help the Company choose components. With the finalized design, Pacific Projects guarantees a design with reliable performance that both completes its mission and is profitable to the Company. In the 12-hour flight window, with all packages being delivered provides a daily gross income of $23,400 with a net income of $11,070.13 after subtracting the expenses for personnel and energy. Total daily operating costs equate to $12,329.87. Within a week, the Company has a net income of $52,569.87 after paying the warehouse rent. Within a 28 day month, the Company's net income comes to $210,279.48.

To minimize slack time, the UAV launches will occur in sets of three with a 8-minute stagger between launches. Table 16 details the series of launches that will occur within three hours, which then repeats for the twelve-hour flight window. Flights are staggered so that a set will land soon after the previous set has been launched. With this launch pattern and the estimated time to prepare a flight (Refer to 4.1.1 “Figure 27.”), the personnel are given short rests before resuming the next task. During rests, personnel are allowed to go on break, eat their scheduled lunch, or use the bathroom. When an employee goes on break, the remaining personnel are still capable of completing the required tasks. When an Operational Pilot goes on break, the three UAVs will be divided amongst the two remaining Operational Pilots. One Operational Pilot can monitor up to five separate UAVs (Cummings et al., 2007) to take over for the pilot taking their break.

Table 16. UAV set launch pattern.

UAV	Return (8 Minutes)								
	Return	Loiters	Lands	Launches		Return	Loiters	Lands	Launches
1	6:17 AM	6:27 AM	6:27:30 AM	6:36 AM	1	7:27 AM	7:37 AM	7:37:30 AM	7:48 AM
2	6:17 AM	6:27 AM	6:27:30 AM	6:36 AM	2	7:27 AM	7:37 AM	7:37:30 AM	7:48 AM
3	6:17 AM	6:27 AM	6:27:30 AM	6:36 AM	3	7:27 AM	7:37 AM	7:37:30 AM	7:48 AM
4	6:27 AM	6:37 AM	6:37:30 AM	6:46 AM	4	7:37 AM	7:47 AM	7:47:30 AM	7:58 AM
5	6:27 AM	6:37 AM	6:37:30 AM	6:46 AM	5	7:37 AM	7:47 AM	7:47:30 AM	7:58 AM
6	6:27 AM	6:37 AM	6:37:30 AM	6:46 AM	6	7:37 AM	7:47 AM	7:47:30 AM	7:58 AM
7	6:37 AM	6:47 AM	6:47:30 AM	6:56 AM	7	7:47 AM	7:57 AM	7:57:30 AM	8:08 AM
8	6:37 AM	6:47 AM	6:47:30 AM	6:56 AM	8	7:47 AM	7:57 AM	7:57:30 AM	8:08 AM
9	6:37 AM	6:47 AM	6:47:30 AM	6:56 AM	9	7:47 AM	7:57 AM	7:57:30 AM	8:08 AM
	Return	Loiters	Lands	Launches		Return	Loiters	Lands	Launches
1	6:51 AM	7:01 AM	7:01:30 AM	7:12 AM	1	8:03 AM	8:13 AM	8:13:30 AM	8:24 AM
2	6:51 AM	7:01 AM	7:01:30 AM	7:12 AM	2	8:03 AM	8:13 AM	8:13:30 AM	8:24 AM
3	6:51 AM	7:01 AM	7:01:30 AM	7:12 AM	3	8:03 AM	8:13 AM	8:13:30 AM	8:24 AM
4	7:01 AM	7:11 AM	7:11:30 AM	7:22 AM	4	8:13 AM	8:23 AM	8:23:30 AM	8:34 AM
5	7:01 AM	7:11 AM	7:11:30 AM	7:22 AM	5	8:13 AM	8:23 AM	8:23:30 AM	8:34 AM
6	7:01 AM	7:11 AM	7:11:30 AM	7:22 AM	6	8:13 AM	8:23 AM	8:23:30 AM	8:34 AM
7	7:11 AM	7:21 AM	7:21:30 AM	7:32 AM	7	8:23 AM	8:33 AM	8:33:30 AM	8:44 AM
8	7:11 AM	7:21 AM	7:21:30 AM	7:32 AM	8	8:23 AM	8:33 AM	8:33:30 AM	8:44 AM
9	7:11 AM	7:21 AM	7:21:30 AM	7:32 AM	9	8:23 AM	8:33 AM	8:33:30 AM	8:44 AM
						Return	Loiters	Lands	Launches
					1	8:39 AM	8:49 AM	8:49:30 AM	9:00 AM
					2	8:39 AM	8:49 AM	8:49:30 AM	9:00 AM
					3	8:39 AM	8:49 AM	8:49:30 AM	9:00 AM

4.2 Cost/Benefit Analysis and Justification

The C21 Fantail is a UAV designed to be a safe, quiet, and reliable choice for deliveries. Compared to current delivery services, the C21 Fantail is an energy efficient design capable of enduring long distance flights. Its hybrid fixed-wing design allows both gliding and VTOL maneuvers. Its gliding capabilities reduce energy consumption for horizontal flights by using two propellers maintaining speed. In consideration for cost savings, the Company chose a straight wing. The flat underside increases internal component stability and reduces unneeded space. The H-tail fin design selected by the Company provides an aerodynamic airframe and shortens the fuselage.

During component selection, company researchers compared cost, anticipated performance during flights, and additional features making a component stand out. Components deemed more important during flights, such as sensors and transponders, were given special leniency in the cost to performance ratio as these components were vital to a successful flight. To balance out the costs of sensors, the Company opted to cut costs on motors, servos, trolley carts, and the racks and pinions: only selecting ones that could fulfill their tasks. The Company also chose to forgo launchers for take offs and opted for vertical take off.

The number of personnel selected by the Company was balanced between productivity and profitability. With this methodology, the warehouse and staging areas have enough personnel to effectively fulfill their tasks. Company personnel are able to perform tasks safely while not crowding the staging area.

Company operations save time by having no road traffic and reducing costs spent on fuel. Furthermore, the automated delivery system reduces the number of personnel by making individual drivers null. By making UAVs fly in sets with a 10-minute stagger, it creates a continuous loop of returning flights and UAV launches that shortens slack time between tasks.

Missions were vital to making a profit for the company with a day's net income being $11,070.13. Within the first eight days of deliveries, the Company will be able to pay for the 12 UAVs and the weekly rent for the warehouse. The Company's break-even point will occur within eight days of deliveries as the company will be able to pay off all fixed costs.

5. Conclusion

The C21 Fantail UAV is a safe, reliable, and cost-efficient solution for an automated aerial delivery service. The Fantail is capable of VTOL maneuvers and is able to complete three full flights before swapping out its battery. Deliveries are quick and quiet with each flight being under 30 minutes while causing minimal noise pollution in urban areas. Preparation for new flights reduces slack time allowing for more deliveries in a day while also giving personnel time for breaks. The sensor system, along with the GPS/autopilot, is capable of completing a mission in the event of total communication loss. GPS failure is circumvented with the autopilot's ability to connect to Wi-Fi and transmit telemetry. The C21 Fantail is able to fly even if a rotor malfunctions mid-flight. In the event of an emergency, landing equipment and procedures ensure the UAV is incapable of falling fast enough to damage car windshields or break bones. The emergency system is capable of alerting nearby pedestrians with distinct visual and audio cues. With a daily net income of $11,070.13, Pacific Projects will pay off all fixed costs within eight days.

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