C-25 Sigma

Submitted in Response to the Real World Design Challenge 2022

Submitted by:

Indus-Luft Dynamics

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Executive Summary

Delivery services are becoming increasingly ubiquitous and fundamental to city life. Owing to this ever-increasing demand, they are also becoming more profitable. The food industry, with the likes of DoorDash, Uber Eats, and Postmates, reflects the same trend: staggering revenues generated by facilitating convenient deliveries at minimal costs. During the pandemic, delivery companies were one of the few to see substantial growth. All businesses increased their digital presence and focused heavily on door to door deliveries. This is a testament to the resilience of the delivery sector and proves that it is only set to grow exponentially in the near future.

The conventional model for door to door logistics involves hiring delivery agents who use vans or trucks. Unmanned Aerial Vehicles (UAVs), however, offer a more efficient, convenient, and eco-friendly solution for quickly delivering smaller volumes of packages over relatively large distances while reducing the overall cost of labor as compared to a conventional delivery system. Our company, Indus-Luft Dynamics, proposes the C-25 Sigma as an innovative solution optimized to be a part of a pilot program in a city in the USA testing how to safely integrate Unmanned Aerial Systems (UAS) in the National Airspace System (NAS).

Completing a 30km round-trip demands considerable endurance from a UAV. Thus, due to its range and payload carrying capacity, a single rotor design has been chosen as the base for our UAV. Further research led us to the Gyrodyne, an inspiration from the vintage “Fairey" Rotodyne. Accordingly, the UAV has a hybrid design that maximizes efficiency while retaining Vertical Takeoff Or Landing (VTOL) capabilities. With crucial assistance provided by the various technical simulations conducted, the team has finalised a 3D Model. A propulsion system, with six propellers, has been chosen in accordance. This system keeps the sound levels in check as well as allows the aircraft to perform conventional takeoffs or landings in emergency situations.

In addition to its innovative design, C-25 Sigma is also equipped with state-of-the-art avionics and control systems. A comprehensive company-operated network system, placed along all flight corridors, mediates communications between any two UAVs within range of each other, facilitating obstacle avoidance. Obstacles are dealt with by using a combination of methods that aid in navigation. In case of any untoward event, emergency signals can be sent out via a pre-programmed protocol. All these systems improve the C-25 Sigma’s reliability.

To move the UAV with ease on ground, a thorough missions plan was chalked out. From minimizing slack time to increasing the number of packages delivered per day, all steps were calculated and sorted with precision. A detailed warehouse plan was also made in order to ensure the smooth running of in-house operations. In addition, a comprehensive analysis of the flight profile was performed whilst ensuring all safety requirements and FAA guidelines were complied with. High levels of kinematics and trigonometric calculations were involved throughout the Flight Profile Analysis.

The business case has been designed in a manner that makes our service affordable for target clients and profitable for our company. Materials, components, and systems have been chosen to extract the best quality while keeping costs low. The proposal has been formulated on the basis of thorough calculations and is centred around the idea of expanding service volumes while keeping highly competitive profit margins. A synergy between automated and manual operations has resulted in a highly profitable and yet affordable proposal. The company has also incorporated appealing strategies such as rewarding regular clients with discounts and low cost service to acquire a large and diverse clientele.

As a synopsis, the C-25 Sigma is a versatile and efficient UAS that strives to solve current delivery challenges with as much attention to detail and rigour as possible. We are confident that the proposed UAS is a competent contender in this up-and-coming industry and will lead the way for the integration of UAVs into commercial airspace in the near future.

Specification Table

Criteria	Value	Met (yes/no)	Section #, page #
General			
Takeoff weight including single package	25Kg		2.5, p.49
Wingspan (fixed-wing) or max width (other)	3m		2.6, p.50
Aircraft only carries single package (weight of 5 kg and dimensions of 0.5 m by 0.5 m by 0.25 m)		Yes	2.3.1, p.30
UAS Airfield			
All 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.55
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.55
Takeoff/Landing ● Vertical takeoff/landing take place at single 3 m X 3 m zone that is 10 m away from staging areas ● Horizontal takeoff/landings use the UAS Airfield runway		Yes	3.1.1, p.55
Flight Corridors			
Flight speed within 35 kt and 87 kt		Yes	3.2, p.60
Flight altitude within 200 ft (61 m) and 400 ft (122 m)		Yes	3.2, p.60
Aircraft can climb from airfield to flight corridor within 150-m horizontal distance		Yes	3.2, p.60
Aircraft can descend from flight corridor to airfield within 500-m horizontal distance		Yes	3.2, p.63
Aircraft can stay in holding zone (radius of 500 m) at 200-ft altitude above airfield and delivery location until given clearance		Yes	3.2, p.63
Package Delivery			
Aircraft can climb/descend between delivery location to flight corridor within 100-m horizontal distance		Yes	3.2, p.60,63
Aircraft capable of landing at a single 3 m by 3 m delivery zone. Vertical landing/takeoff only.		Yes	3.1.3, p.57
Aircraft lands to deliver packages. Engines shut down.		Yes	3.1.3, p.57
Package is removed by hand		Yes	2.3.1, p.30
UAS Command, Control, and Communication			
Up to a maximum of 20 aircraft in air at a single time		Yes	3.1.1, p.54

Redundant systems		Yes	3.3, p.66-71
Aircraft has transponder to identify itself and provide current speed, heading, and altitude to CUTC		Yes	2.3.3, p.41
Aircraft continuous monitor by personnel at airfield		Yes	2.3.4, p.46
Aircraft capable of receiving new commands while in flight and modify flight pattern accordingly		Yes	2.3.2, p.33
Human pilot available to take manual control if necessary		Yes	2.3.4, p.46
Aircraft capable of BVLOS		Yes	2.3.2, p.34
Aircraft does not rely on global navigation satellite systems		Yes	2.3.2, p.35
Detect and Avoid (DAA)			
Aircraft must detect static and dynamic obstacles		Yes	2.3.3, p.37
Aircraft must avoid conflicts		Yes	2.3.3, p.37
DAA system architecture must fit with C3 capabilities		Yes	2.3.3, p.36
Lost Link Protocol			
Aircraft must have protocols in case of partial loss of communications		Yes	3.3.1, p.66
In case of total loss of communication, aircraft must be capable of safely returning to the UAS Airfield.		Yes	3.3.1, p.66

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1. Team Engagement

1.1 Team Formation and Project Operation

Aadil Faisal Saiyed (Project Manager/ Design Engineer) is the team lead for this project due to his previous record of holding cross-functional leadership roles. He is in his senior year, in the STEM field studying Mathematics, Physics, Computer Science and Chemistry. He has an immense interest in Aviation as well as Aerospace, with Aircraft Design, Human Spaceflight and Mechanics being the specific junctures of his passion. Aadil has been an active member of Aeross (the school's extremely prestigious and selective Aerospace Society) where he has broadened his experience and knowledge of Aerospace. Due to his innate inclination, he is keen on pursuing Aeronautical/Aerospace engineering in the future.

Avihan Jain (Co-Project Manager, Business and Cost Analyst) is managing the project given his past experience of leading the school in various ventures. He is currently pursuing Physics, Mathematics, Chemistry and Economics in high school. He is a part of various societies in DPS RK Puram, including the entrepreneurship and physics club. He is also a prospective member of the Aerospace Society. He has contributed greatly in research and strategizing due to his past experiences of engineering, innovation and leadership. He always looks forward to finding solutions to various challenges and problems he observes in his surroundings that could help enhance people's lives.

Amartya Bagchi (Director of Operations, Business Deputy) is a member of the prestigious Aerospace Society of DPS RK Puram. As a sophomore in highschool, he has a keen interest in STEM-related fields and computers. With a budding passion for aviation and aerospace, he is participating in the Real World Design Challenge for the second time. Previously, he has been to the final round of the World Scholar's Cup, an international competition based on science and other fields. His desire to learn more, combined with his prior experience, proved to be extremely beneficial to the team; and helped create a comprehensive proposal. He intends to pursue STEM in the future for the greater good of society.

Pradyun Rudra Patra (Physicist, Mechanisms Developer) is a member of Aeross, The Aerospace Society, DPS RK Puram's highly selective and prestigious aerospace society. He has a history of being involved in aerospace related competitions and helping out wherever he can. He has been working with space settlement design and aerospace/aviation competitions for his club and school for years. He is keen to keep up his enthusiasm in the field and continue his participation in STEM related competitions and events.

Shaurya Gambhir (Avionics Engineer, Sketch Artist) is a prospective member of the Aerospace Society, DPS RK Puram. He is in 10th grade and plans to take up STEM further. Having deep knowledge and fascination in the field of Electronics, Aerospace engineering, Mechanical engineering and AI, Shaurya is fluent in using a plethora of softwares ranging from graphic design and illustrations to simulation. It is his first representation in a major competition and has been a paramount and substantial asset to the team.

Mana Sharma (CAD Specialist, Mathematician) is a member of the Aerospace Society, DPS RK Puram. She is in 10th grade and plans to pursue STEM further. She has a deep interest in 3D modeling and has provided many great contributions to the team. Mana has also participated in SSDC securing first position in the INSSDC onsites. She is adept at using both Blender and Fusion 360.

The entire team committed itself to a strict regimen, where everyone was assigned a certain amount of work daily in order to meet their targets. In addition to this, work was divided very clearly, so as to avoid confusion of jurisdiction. The team also perfected every piece of information that was put in this document before it was finalized. Following a strict schedule and a premeditated plan was the team’s strategy to achieve its goal of winning RWDC. The team also emphasized on its collaborative effort, not only between participants, but with the mentors as well. The team was always collectively open to criticism and change, this greatly contributed to the quality of this proposal, and gave it the required winning edge.

1.2 Acquiring and Engaging Mentors

The team was formed even before the Challenge Statement was released and during the very first meeting, a common understanding that all members had was the importance of mentors and the need to reach out to them as early as possible. This was a result of learnings from other Aeross teams which had done RWDC and struggled to find mentors as by the time they started their research, all mentors were occupied with other teams. Once the Mentors list for this year was released, the team identified 5 mentors with the right competencies and scrambled to send out email within hours of the release.

The team got a quick reply from Mr. Robert Sprayberry who agreed to be their mentor. Mr. Sprayberry is an Aerospace Engineer and works at The International Civil Aviation Organization (ICAO). His expertise in structural design as well as operations was of massive

help to the team throughout the competition. Apart from having an industry professional as our mentor, the team also reached out to senior members and alumni of Aeross to be advisors for the team. Aryan Goel, a member of Aeross, had participated in RWDC last year as part of team Blazing Kryptonite, the national winners and 3rd Internationally, became an advisor to the team. His experience in aerospace related competitions, especially RWDC, was quite helpful for the team. The President of Aeross, Siddhansh Narang, was also very much willing to be an advisor to the team. He is a member of over 30 Virtual Airlines and Virtual Organizations. He was also part of Samaritan Aerospace which became the first Indian Team to win RWDC in 2020. His expertise in CAD, Simulations and Flight Profile Analysis was of great aid to the team.
The team would also like to thank former members Raghav Chaudhary and Khushi Mishra for their immense contributions to the project before they had to part due to personal reasons.

Overall, the mentors proved to be an excellent resource for the team in completing the project. The mentors contributed their different backgrounds and years of work experience to assist the team in solving the difficulties presented by this assignment. After winning the State Challenge, the team met with the mentors to discuss the judge’s comments on our notebook, and used their constructive feedback advantageously.

1.3 State the Project Goal

This year’s challenge required the team to design an Unmanned Aircraft System (UAS) to deliver packages (5kg, 0.5m×0.5m×0.25m) in a city within the United States. Moreover, the delivery zones are located 15km away from the warehouse/hub. While the UAV can carry only one package at a time, it must perform vertical takeoff and landing (VTOL). The authorities have provided a list of requirements that the company must fulfill. These requirements are made keeping in mind the safety and comfort of local residents, and companies must meet these criteria to be able to operate in the city. In addition to this, a warehouse will be leased by the company (as provided by the Challenge) which will serve as the base of operations for conducting flights in the flight corridor. The UAV must have a detailed design that must meet all the necessary requirements, whilst adhering to the required safety protocols. Flights will be planned in compliance with the guidelines of the FAA and the clearance of the respective airspace that will be operated in, and the operations must be conducted in a systematic and organized manner. There must be an effective means for Obstacle-Avoidance along with a reliable detection-and-avoidance system, and the system must include other important mitigation measures as well. A comprehensive business strategy with the goal to maximize revenue is also required, with the primary objective being to increase the number of deliveries while keeping the cost as low as possible. The company must prove that the system is profitable, and has significant advantages over competitors. The daily revenue should exceed the daily operating cost to ensure a profit. Therefore, the goal of this project is to make a UAS that successfully meets all necessary requirements and safety guidelines while also maintaining profitability.

1.4 Tool Setup/Learning/Validation

Google Workspace: This is a collection of Google's cloud computing and collaboration tools. The team predominantly made use of Google Docs (for documentation, formatting and typesetting), Google Meets (for team meetings), and Google Drive (for storing all the documents systematically in folders). It allowed the team members to collectively work in real-time while also having the option to assign tasks and suggest changes, all via the internet due to the restrictions on physically meeting up caused by the COVID-19 Pandemic.

Autodesk Fusion 360: Fusion 360, being one of the first CAD, CAE and CAM software, assists professionals and students to bring their ideas to life. As it is a widely utilized software and the CAD specialist had prior experience with it, modeling was done on Fusion 360 solely.. The simulation workspace of Fusion was used for performing the static stress test on the model to find out weaker sections of the aircraft. Also, the Center of Gravity was graphically determined in this workspace.

Discord: Discord is an instant messaging and digital distribution platform where the concept of "servers" and "channels" makes it easier for teams to collaborate. A server is created which is followed by the addition of channels (subsections) within the server. This tool also provides for Voice Channels which leads to faster and efficient cross communication. The team used Discord for daily communication, work assignments, research logs and cross communication. In addition to this, the team's near peer mentors were added to the server, thus resulting in faster doubt resolution.

Fig. 1: Discord Voice and Channels

Adobe Illustrator: Illustrator is a vector graphics editor and drawing program used to create anything from single element designs to complete sketches. This tool was majorly used to make all the 2D sketches along with labeling the 3D model with proper dimensions.

Ansys: Ansys is a multiphysics engineering simulation software for product designing. The team had used Ansys for Computational Fluid Dynamics (CFD). These CFDs were done for the specific airfoils chosen, which helped us better understand how a certain airfoil acts under a specific angle of attack and velocity. It also provided the lift and drag related values of the airfoils chosen. This further helped the team during Flight Profile Analysis.

Airfoil Tools: Airfoil tools is a website which contains information about thousands of airfoils. It contains scripts which are used to plot these airfoils in softwares such as Ansys and Autodesk Fusion 360. This website helped the team by providing airfoil plots, comparisons and search functionality, which assisted the team in choosing and selecting airfoils.

1.5 Impact on STEM

Although members of the team did not have a lot of prior experience at par with the standard of international competitions, their willingness to learn and adapt pushed them throughout the competition. In addition to this, the curiosity, level of ideation and research involved in a STEM rooted competition really grasped the attention of all. With team members hoping and working hard to pursue their career in the STEM fields, they all saw this as a massive learning curve and as their first major step inside the industry.

Aadil says, “I have always had an abiding curiosity for aircrafts. I clearly remember, as a very young child, identifying airline logos and being thrilled to hear the roar of planes. As I grew up, this inquisitiveness turned into a hunger to learn the science involved in the aviation industry. Hence in the future, I am keen to make a career in the aeronautical domain. RWDC has really given me a platform to express my passion and learn with equally passionate fellow members.” Pradyun comments, “RWDC is an excellent method to let our imaginations run wild and improve our knowledge and abilities in the fields of STEM. The research and design process greatly helped me stoke my interest in aviation. RWDC does a great job in developing teamwork and soft skills too.” Shaurya remarks, “Pursuing RWDC has been a great journey for me. I have gained immense knowledge in the field of aviation. It has also helped me develop team management skills which will help me in all my future endeavors.” Avihan remarks, “RWDC has introduced me to a holistic view of integrating engineering and business. It has broadened my vision from conventional systems to innovative horizons.” Amartya states, “I have always had a passion for aviation, and RWDC truly helped me realize the extent of opportunities that this field offers. It integrates STEM with innovation to offer a challenge that is like no other.” Mana adds, “This competition provided a great opportunity for me to expand my knowledge in aviation, and also greatly helped open new doors in the future for me in STEM.”

Being part of an education system that promotes little to no practical application and extra curricular activities, this competition has not only opened up new horizons for the team members but has inspired juniors in the school to test out their learnings from the classroom at a national/international level.

2.System Design

2.1 Engineering Design Process

An engineering design process is a systematic approach deployed by engineers or project teams to resolve a problem. It can be a highly iterative or cyclic process, that necessitates going back and repeating segments of the process multiple times until an efficient and desirable solution has been reached. Our team recognised early on the importance of creating our own design process to ensure smooth and methodical workflow. The figure gives a general idea of the team’s engineering design process.

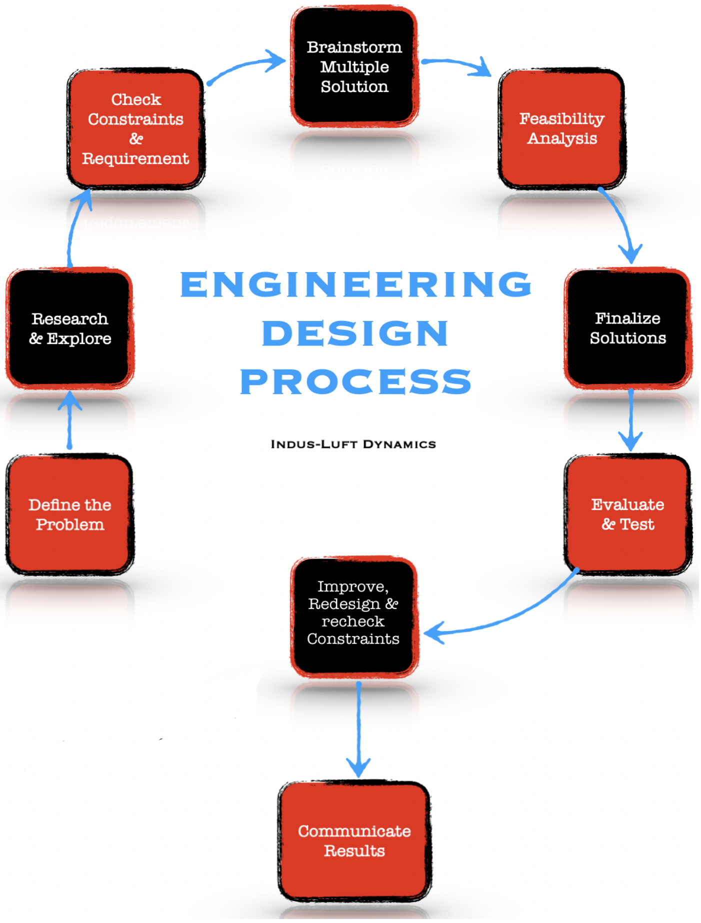


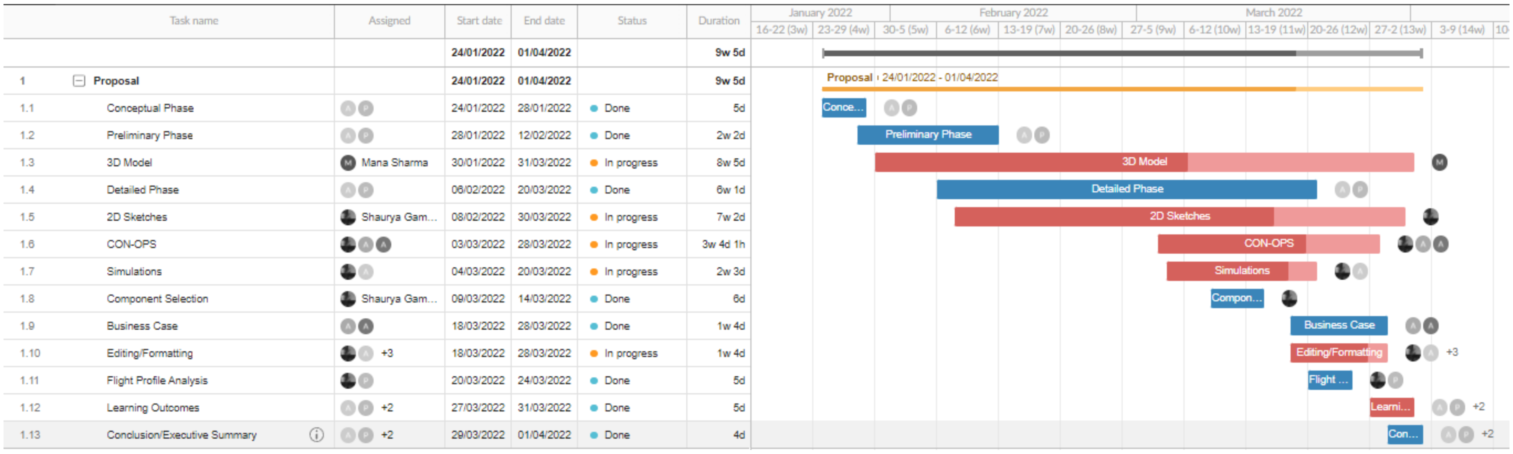
Fig. 2: Engineering Design Process

Conceptual Design: In this phase, there was a heavy emphasis on each team member’s general understanding of the prompt and what it demanded. A lot of ideas regarding various elements of our design were thought of, many of them quite experimental, all in an effort to filter out the most appropriate ideas for the given challenge. The team aimed to gain a wider perspective rather than an in-depth understanding of the topics researched, hence a wide variety and large quantity of information was gathered. It was also during this phase that each team member explored which design area they are most comfortable and interested in working with.

Preliminary Design: In many ways, the preliminary design phase was the filtration process. In this phase, the best ideas from the conceptual phase were researched in greater depth, with greater specificity. The aim was not to finalize things, but to rather research more on the shortlisted topics. . The aim was to take certain decisions regarding which topics shall be delved into with even greater detail in the detailed phase of the design process. Most general decisions such as the general structure of the airframe, the navigation system and so on were taken in this phase. Simultaneously, ideas that seemed far-fetched, for instance, the idea of a fan-in-wing aircraft, were filtered out.

Detailed Design: By this phase, all major decisions were already taken. The team knew exactly what it was aiming for and what it needed to achieve, the only purpose of this phase was to go into as much depth as possible with the research and documentation of the final design of the aircraft. All design details and the 3D model of the UAV were finalized in this phase. Simulations and tests were also conducted using different softwares.

2.2 Project Plan



	Task name	Assigned	Start date	End date	Status	Duration
			24/01/2022	**01/04/2022**		**9w 5d**
1	⊟ **Proposal**		**24/01/2022**	**01/04/2022**		**9w 5d**
1.1	Conceptual Phase	A P	24/01/2022	28/01/2022	● Done	5d
1.2	Preliminary Phase	A P	28/01/2022	12/02/2022	● Done	2w 2d
1.3	3D Model	M Mana Sharma	30/01/2022	31/03/2022	● In progress	8w 5d
1.4	Detailed Phase	A P	06/02/2022	20/03/2022	● Done	6w 1d
1.5	2D Sketches	Shaurya Gam...	08/02/2022	30/03/2022	● In progress	7w 2d
1.6	CON-OPS	A A	03/03/2022	28/03/2022	● In progress	3w 4d 1h
1.7	Simulations	A	04/03/2022	20/03/2022	● In progress	2w 3d
1.8	Component Selection	Shaurya Gam...	09/03/2022	14/03/2022	● Done	6d
1.9	Business Case	A A	18/03/2022	28/03/2022	● Done	1w 4d
1.10	Editing/Formatting	A +3	18/03/2022	28/03/2022	● In progress	1w 4d
1.11	Flight Profile Analysis	P	20/03/2022	24/03/2022	● Done	5d
1.12	Learning Outcomes	A P +2	27/03/2022	31/03/2022	● Done	5d
1.13	Conclusion/Executive Summary ⓘ	A P +2	29/03/2022	01/04/2022	● Done	4d

Fig. 3: Gantt Chart with Dates

A project plan helped the team approach the project systematically. Overall team management was done by the Project Manager and Co-Project Manager. Moreover Discord was used as the main source of communication, bi-weekly meetings were scheduled to deliberate on the progress of the team and the work assigned to each member. Collective and individual work schedules were subsequently posted on Discord, easily accessible to all members, with a proposed deadline for the same to check the delayed completions. Designing a Gantt chart helped visualize and affirm timelines pertaining to the completion of the project. The Gantt chart being easy to interpret, increased overall clarity.

The team followed a system of work-assignments on Discord which were pre-discussed in team meetings. Furthermore, research logs were added with various subchannels making it easier to communicate on a certain topic without creating confusion. A certain topic, when completed, had its channel moved into a completed work category.

Team members were also divided into different categories such as “Electronics”, “Design”, “Missions”, “Business”, “2D/3D artists” to follow a more systematic way of communication. Individual team meetings were held between the people of a category to discuss their specific topic of work which was later reviewed by other team members.

2.3 Subsystems

2.3.1 Air Vehicle

Conceptual Design Phase

The challenge for this year was to design a UAV capable of safe and efficient package delivery missions within an urban airspace. The team looked at various aircrafts, manned and unmanned, for initial design inspiration. To ensure that the best possible airframe designs were selected, it was necessary to have a uniform set of parameters for comparing all the options. To that end, five evaluation metrics were established. They are, respectively: Payload Capacity, Range, Endurance/Efficiency, Complexity, and Noise.

All designs considered during the conceptual phase were compared on these five key aspects. It is important to note, however, that these degrees of freedom are strongly interlinked, and the improvement of one can often adversely affect other parameters. Throughout the design process, the team strove to achieve an equitable tradeoff between various factors to come up with a robust, affordable and efficient UAV that would be convenient for mass adoption. The following initial designs were considered:

Multirotors: These use more than two rotors with fixed-pitch spinning blades that provide thrust, thus generating lift and offering VTOL.

These multiple-rotors do not allow high cruise speeds; Hence covering shorter distances due to inefficient energy consumption requiring constant refueling. They generally have low

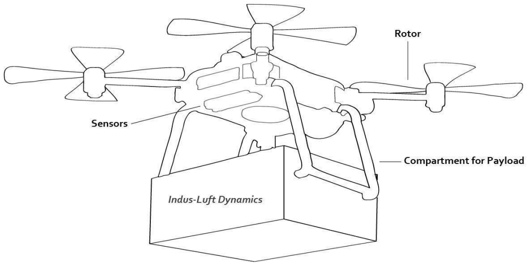


Fig. 4: Multirotor Conceptual Sketch

payload capacity, and the heavy-lift multirotors have significantly lesser flight times (Multirotor drones, n.d.). This design simply did not meet the standards of other types of aircraft that are more feasible for the team's purpose.

Tiltrotors: UAVs utilize multiple, variable-pitch propellers to generate both lift (to perform VTOL) as well as thrust during cruise flight.

In the initial stages of researching tiltrotors, a typical Osprey-like airframe was considered. This offered considerable advantages, such as its ability to perform complete VTOL and transition from cruise to hover flight, higher speeds and a high degree of maneuverability. However, the disadvantages associated with tiltrotors were primarily the high degree of complexity in mechanical design and unstable flight performance at low speeds. Additionally, in comparison to single-rotors, tiltrotors would prove more costly to design and maintain and less efficient during hover flight. Therefore, tiltrotors were not considered further.

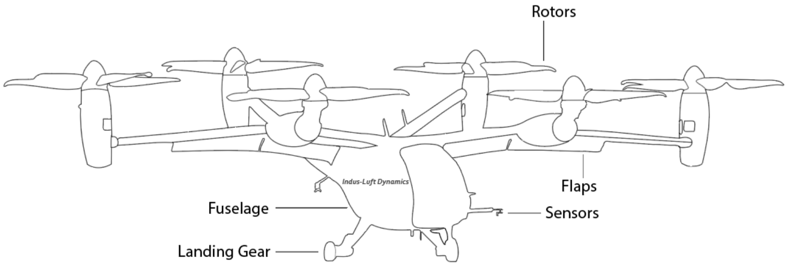


Fig. 5: Tiltrotor Conceptual Sketch

Single Rotor: These UAVs have a single large rotor for lift and a smaller rotor for stabilization and steering on their tail. (Herrick, 2017) Such aircraft are capable of performing a vertical take-off and landing (VTOL) within the 3x3m area assigned. Due to the single rotor, they can also hover and pivot on a vertical axis. Additionally, they have a higher payload to empty weight ratio which allows transport of heavier goods, making it more energy-efficient as compared to other UAV types.

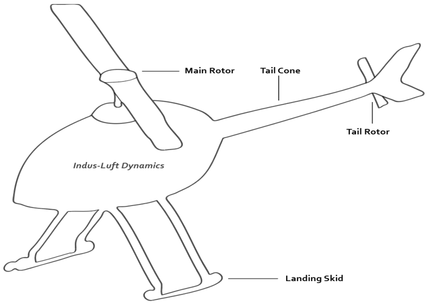


Fig. 6: Single Rotor Conceptual Sketch

Moreover, their high stability, maneuverability, and reasonable cruise speed makes them perfect for an urban setting. However, single-rotor helicopters have significantly more vibration than multi-rotor UAVs. (KDEdirect, 2021) To overcome these problems the team researched more and looked into Gyrodynes.

Gyrodynes: Gyrodynes rely on the concept of translational flight. A gyrodyne consists of a top-mounted single rotor for VTOL, and has several propellers mounted on the wings to provide forward thrust during cruise. This design, thus, theoretically combines the efficiency of a fixed-wing airframe, whilst also allowing for Vertical Takeoff or Landing. All in all, Gyrodynes had a major influence on our design, as it motivated us to pursue a hybrid design to maximize efficiency and take this further.

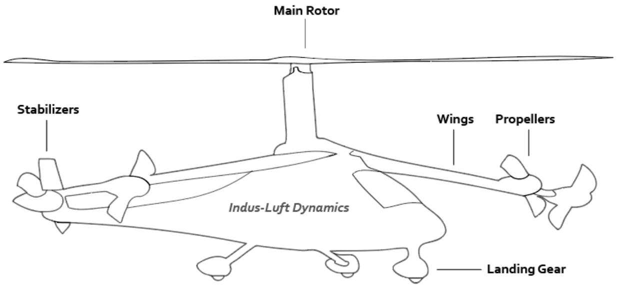


Fig. 7 Gyrodyne Conceptual Sketch

Preliminary Design Phase

Airfoils

There are mainly two types of airfoils: Symmetrical and Asymmetrical, this comparison provides us a groundwork of the specific airfoils that will be chosen for our UAV. Since our design is a Gyrodyne type design, airfoils needed to be chosen for the wings, rotor blade, propellers and the stabilizers.

Criteria	**Symmetrical**	**Asymmetrical**
Design	Same shape on both sides of the centerline	Upper and lower surfaces are different
Lift and Efficiency	No lift at 0° AOA, less efficient by 5%-7%	Greater lift, some lift at 0°AOA
Pressure on Blade	Low pressure on blades	Twisting force is exerted on the blades
Costs	Lower costs, ease of construction	Higher costs, strengthening required to the blades
Center of Pressure	Maintained at different AOA	Center of pressure changes with the AOA
Lift-Drag Ratio	Lower L/D ratios	Higher L/D ratios
Stall Characteristics	Undesirable	Desirable

Table 1: Symmetrical vs Asymmetrical

As evident above, there are a few disadvantages in using the asymmetrical airfoils but currently, these have been overcome with advancements in technology. Asymmetrical airfoils were not commonly used previously due to the difficulty in manufacturing, higher costs, and the high change in center of pressure every time the AOA changed, this affected the stability but this has been taken care of with the help of sturdy materials like CFRP. Taking all these points in mind, Asymmetrical airfoils were chosen due to greater L/D ratio.

Materials

In order to fly, UAVs must be able to generate enough upward thrust to overcome their own weight, so the selection of materials in an aircraft is dominated by minimizing its mass without compromising strength of the airframe. Every gram of material used to make a UAV costs energy to lift, and every gram that can be saved leads to increased payload capacity, extended flying time and improved maneuverability (coderman, 2021). The team researched possible materials such as Titanium, Aluminum Alloys (2024,6061,7075) and Carbon Fiber. These materials were compared on the basis of important aspects such as tensile strength, density, elongation, and strength-weight ratio keeping cost in mind as well.

Aluminum Alloys: This is an economical option that offers excellent weight-to-strength ratio at a relatively low price. It is a dependable, strong metal with great fracture toughness and corrosion resistance. (Admin, 2019). Aluminum, one of the most proven materials used in the Aviation Industry, has a relatively low weight and high thermal conductivity.

Titanium: It is widely used in high stress/temperature areas. Titanium's high melting point and tensile strength benefits allows it to be used in aerospace engine components, landing gears, springs and wings etc. Although it is stronger than Aluminum, it weighs just two-thirds as compared to it. Unfortunately, its melting point is so high that it is difficult to process it. That is a big reason why it is more expensive than other metals (2021, Protolabs).

Carbon Fiber: When individual strands of carbon are woven together, they form an ultra-strong mesh-like material, which is carbon fiber (Monroe, 2021). This material is frequently used in aircraft because it is extremely lightweight, robust, and more resilient than steel, titanium and even aluminum. This allows for a better fuel economy and design flexibility (Kaspersky, 2016). Of the three materials, this has the lowest density, highest tensile/compressive strength and temperature tolerance. Moreover, it is durable in corrosive environments.

After thorough research, the team decided to eliminate Titanium due to its high weight and cost. Carbon Fiber and Aluminum Alloys were chosen. A Static-Stress Simulation of the model was performed in order to identify the high-stress areas and assign materials accordingly.

Material	Tensile Strength (MPa)	Density (g/cc)	Strength-Weight Ratio (MPa/g/cc)	Elongation (%)
Aluminum	315	2.7	115	17
Carbon Fiber	5407	1.79	3026	1.75
Titanium	620	4.45	140	14

Table 2: Initial Material Comparison

Detailed Design Phase

Wing Design

While the UAVs major airframe components were being finalized, the team pursued research on optimal wing configurations, with a view to improve efficiency. Potential wing configurations were adjudged based on the following parameters:

- ➔ Aerodynamic Performance
- ➔ Effect on Takeoff and Landing Distances
- ➔ Ease and Cost of Production

Along with utilizing conventional fixed wings, other types of wing configurations were explored namely box wings and propulsive wings.

Boxed Wings: Box wings are an iteration of the closed-wing concept. The aircraft is essentially dual-winged and both the wings are structurally merged at the tips. Box wings are a topic of renewed interest as the aviation industry is seeking to move towards sustainability and carbon-neutrality. Due to the distribution of uplift requirement between two lifting surfaces, a box wing would lead to increased payload capacity without increasing the wingspan. The potential increase in lifting capability and reduction in induced drag without fundamentally increasing the UAVs dimensions made box wing an attractive option.

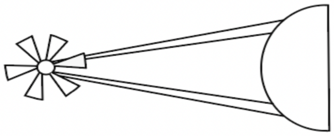


Fig. 8: Boxed Wing

Integrated Propulsive Wings: In distributed propulsion systems, the propulsive units are distributed about the wings or fuselage. A key point of difference is the synergistic integration of the propulsion system and airframe, as opposed to the traditional decoupled design. This concept was explored further by the team due to its numerous evident benefits. This includes enhancement of overall propulsive efficiency, elimination of additional control surfaces and increased performance in terms of range, noise abatement, shorter take-off and landing field length and safety. As lithium-based batteries had been chosen and were being concurrently researched, the team focused on distributed electric propulsion.

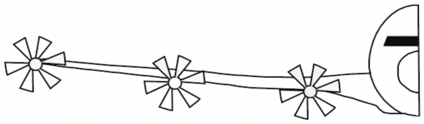


Fig. 9: Integrated Propulsive Wing

The propulsion system of the NASA X57 Maxwell aircraft concept was looked at due to favorable low-speed performance. The X57 was created with the aim of reducing noise and emissions and improving efficiency.

In conclusion, due to greater efficiency gains, and an overall better-adapted system for electrical power, the team decided to model an integrated propulsive wing, as opposed to using box wings, which were also an attractive option. Reduced wing weight and lower complexity also contributed to the decision.

As far as the airfoil for the wing was concerned, asymmetrical airfoils were the main target. Airfoils which operate at high Reynolds number (500,000-1,00,000), high Cl v Cd (which depict higher efficiency) and low AOA's were considered, namely NACA 2412, NACA 2410 and NACA 4415. Upon comparison in Airfoil Tools, the following the results were observed:

Airfoil	Max Cl/Cd	Thickness
NACA 2412	101.4 at α=4.5°	12%
NACA 2410	98.5 at α=3.75°	10%
NACA 4415	119.4 at α=5.5°	15%

Table 3: Wing Airfoil Comparison

As evident from the table, both the NACA 2412 and NACA 4415 offer high Cl/Cd with low angles of attack, their performance is also similar. However, due to better stall characteristics and prior application NACA 2412 was our airfoil of choice. Along with this, Computational Fluid Dynamics (CFD) for the airfoil was done on Ansys. This analysis provided the team with the lift and drag values for NACA 2412 at a velocity of 40 m/s. **Lift - 222.36 N, Drag - 42.36 N**, The L/D ratio for NACA 241 was calculated to be **5.2:1.**

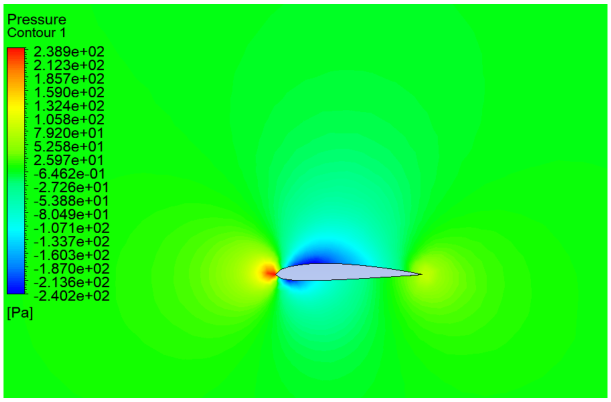


Fig. 10:CFD of NACA 2412

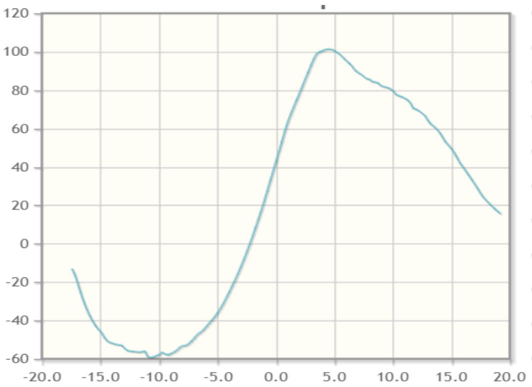


Fig. 11: Cl/Cd V Alpha Graph of NACA 2412

Ducted Propellers

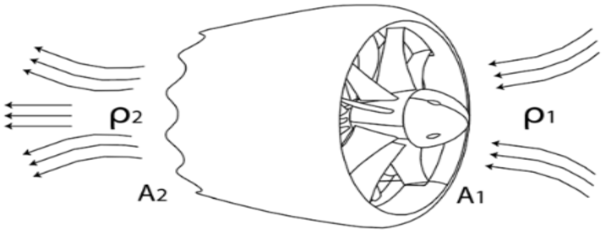
Since the chosen design is Gyrodyne based, the propellers solely control the horizontal thrust and acceleration of the aircraft. The vertical movement can be completely ignored for this phase as the main rotor maintains altitude. The horizontal thrust requirements for the initial phase will be to accelerate to the cruise speed after which the thrust will be reduced to just combat the drag that the aircraft will face during flight. Through simulations, it was calculated that the drag acting on the aircraft will be about 115N. The thrust during cruise will be maintained at exactly this level. Moreover, the maximum thrust that the propellers will have to generate during the acceleration phase will be 296N.

As for the configuration, there are two different sizes of propellers, one with a blade radius of 0.379m the other with 0.253m. Pelz et al. (2009) derived an optimization model according to which the optimal number of propellers is proportional to the aircraft mass to the power of 0.29 ($M^{0.29}$). Using this rule, it was found that the optimal number of propellers for our aircraft is 2.54. Hence, the team assigned three propellers per wing, one big and two small. The bigger propellers are placed closer to the main body of the aircraft than the small ones, because the stress on the region where the wings are attached to the body increases significantly if heavier motors are placed further away from the body. Essentially, while looking into propeller placement, the aim is to maximize efficiency in terms of the thrust generated as well as practicality in terms of the design. Such a configuration achieves both of those aims well.

The maximum thrust requirements from the propellers is 42.28N from the smaller propellers and 63.42N from the bigger propellers; the maximum power requirements are 0.771kW and 0.945kW for the small and big propellers respectively.

In the National Challenge, the C-25 Sigma was equipped with conventional fixed pitch propellers but for the International Round, the team's Design Engineer researched better propulsion concepts which brought about the Ducted Propellers.

At first, it would appear that ducts have a large entrance so as to provide greater airflow, but at a larger scale, it is more like a narrow pipe. Bernoulli's principle shows that as the radius of a pipe decreases, the liquid flowing through it speeds up, and its pressure drops. Since the duct is like a small pipe, the air which is forced into the duct accelerates. This means that a propeller with a greater pitch can be installed to keep up with the speed of the airflow, and not demand more power from the motor. Alternatively, a less powerful motor could be used to swing a larger propeller. In comparison, a ducted fan produces significantly greater thrust than an open rotor of the same diameter, thus the upgrade. In both instances, the improved efficiency is immensely beneficial.



ρ – Density
m – Mass
Vol – Volume
V – Velocity
A – Area
L – Length
M' – Mass Flow Rate

$$\rho = \frac{m}{Vol}$$

$$m = \rho \times Vol$$

$$m = \rho \times A \times L$$

$$M' = \rho \times A \times \frac{L}{dt}$$

$$M' = \rho \times A \times V$$

As Mass Flow Rate is constant, $\rho \times A \times V$ is also constant.

Hence $\rho_1 \times A_1 \times V_1 = \rho_2 \times A_2 \times V_2$

If the fluid is incompressible, $\rho_1 = \rho_2$

$A_1 \times V_1 = A_2 \times V_2$ - Equation of Continuity

Therefore, the mass flow-rate remains constant across the given control volume.

Fig. 12: Derivation for Equation of Continuity

Another significant benefit of ducted fans is that they have very low tip losses since there is no place for a tip vortex to form. The duct, which stops it from happening in the first place, is a very practical and efficient option. Furthermore, ducted fans are far quieter than propellers because the ducts cover the noise produced by the blades while also limiting the tip speed, which may contribute to even more noise. Lastly, ducted fans are safer when running on the ground since the ducts screen and conceal the propeller blades, reducing the risks of the blades colliding with any personnel or objects.

Another key aspect that was discussed was the noise profile of the ducted propellers. Keeping in mind the comfort of city residents, it was deliberated that reducing noise produced whilst preserving efficiency was of utmost importance. Pursuing this chain of thought, the team encountered chevrons (like those found on Boeing 787,737 MAX and 747-8) and found it to be a perfect contender for reducing the noise produced by our propellers. Thus, the chevrons were included in our duct design, reducing the overall noise generated by the UAV. A diagram of our final ducted propeller design is shown in the figure.

To meet the power and thrust requirements, the team sought to use powerful brushless DC motors. For this purpose, we selected four KDE600XF-1100-G3 Brushless DC Motors and two KDE600XF-530-63 Brushless DC Motors. These motors offered additional features like improved cooling and other efficiency improvements, thus making them ideal for our UAV.

Propeller Airfoils

High speed asymmetrical airfoils were looked at for the propellers. Lift production at a 0° was also a deciding factor.

Airfoil	Max Cl/Cd	Thickness
Göttingen 417	127.2 at α=5°	6%
Eppler 63	235.2 at α=1.25°	4.3%
Clark Y	114.8 at α=6.75°	11.7%

Table 4: Propeller Airfoil Comparison

Eppler 63's Cl/Cd was too high for the purpose hence it was eliminated from selection. The Clark Y having a higher coefficient of lift, a positive Cl/Cd ratio from 0° to 15° (it is able to generate lift over a wide range of AOA) and its peak Cl/Cd ratio being lower than the Göttingen 417, all these reasons accounted for it being chosen.

A spinning blade and a fluent flow CFD was conducted on this with the same boundary condition as for the main rotor. It gave a **lift** value of **195.50N** and **drag** of **26.42N** resulting in a **L/D ratio** of **7.4:1.**

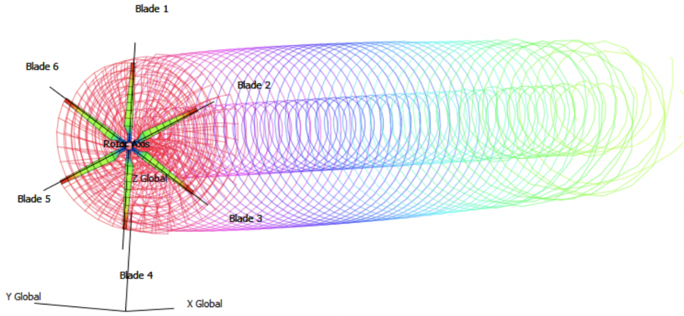


Fig. 13:Propeller Blade CFD

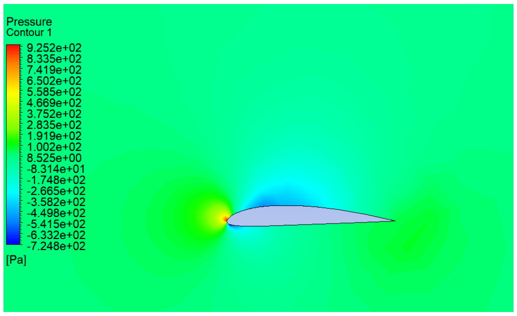


Fig. 14: Clark Y CFD

Rotor Head

There are many factors that were taken into consideration while designing the rotor. Choosing the number of rotor blades is a problem to which there is no perfect solution. Results vary greatly, depending on the situation. A number of factors were looked into while choosing the number of rotor blades.

Blade Tip Speed - The tips of the rotor blade travel at a very high speed. This speed can even cross the sound barrier, causing a lot of vibrations and instability. This is a situation to be avoided, and designers must keep in mind that rotor blade tips must travel at a reasonable speed.

Blade Droop - The longer the blades are, the more they will droop, and drooping blades are a technical hazard. Fewer the blades, the longer they will have to be and the more they will droop.

Stress/Strain on the Rotor - The size and weight of the rotor system must not be very high because the greater the weight of the system, the greater will be the centrifugal force in it causing a lot of stress and strain on the rotor head.

Vibrations - The resonating frequency of a helicopter is what decides how much it will vibrate. The higher the resonating frequency, the smoother and quieter the ride. This is achieved by a higher number of blades, because when the size of the blades is reduced and the RPM is increased for each blade, the resonant frequency increases too.

Rotor Blade Loading - The load that the rotor blade has to bear during flight is known as rotor blade loading. Most designs limit rotor blade loading to 6-9 kgm^-2. There is smaller rotor blade loading in aircraft with higher number of rotor blades, but larger numbers of blades do come with their own set of problems.

The UAV that will be used in this project is not very heavy or carrying a large payload. Hence it does not make sense to have a very large number of rotor blades, given the amount of weight, complexity and maintenance cost that additional blades add. At the same time, having just two rotor blades will make the drone very unstable, the vibrations will be intense and could put the package in danger. Thus, three rotor blades seems ideal for this situation. Having three blades gives the rotor a stable center of gravity and makes it more mechanically balanced. Also, the natural vibration of the rotor goes down sharply as the number of blades increases, since more blades divide the lift into smaller per-blade loads, and at higher frequency, both of which make vibration of many-bladed helicopters much lower and easier to treat in the end. Hence the team concluded that a three bladed configuration is better than two blades. As for four blades and above, our payload and drone size does not demand such a configuration and those will unnecessarily increase the complexity of the system.

Once the number of rotor blades has been finalized, the next step involves selecting a rotor head configuration. Out of articulated, semi-rigid and rigid, semi-rigid was instantly eliminated because our rotor has three rotor blades, which is not supported by a semi-rigid system. The choice between rigid and fully articulated was a complicated one. An articulated rotor system is one where each of the blades is mounted on a hinge that allows them to flap, lead/lag and move completely independent of the other blades. This configuration is the most complicated and allows for the most movement in the blades but is also the most stable in flight and reduces vibrations very effectively. While a rigid system causes more vibrations, it brings simplicity to the table. While it includes a reduction in the drag of the rotor hub, it also is lighter as compared to other configurations. Additionally, rigid rotor systems are easier to maintain over long periods of time and much more reliable. On the whole, due to the simplicity, maintainability and superiority in terms of drag /weight reduction, a 3 blade rigid rotor system was finished as the rotor head design of the C-25 Sigma.

Rotary wing aircrafts surely do call for Newton's 3rd Law of Motion. This brings us to the

Anti-Torque Conundrum.

"Every action has an equal and opposite reaction and the action-reaction forces act on two different bodies". The movement of the rotor causes a torque effect to be created on the helicopter, causing it to spin in the opposite direction of the movement of the rotor. Every helicopter design must include a system that counteracts this force and allows the helicopter to move normally without spinning out of control. For such a system the team went to inspiration from existing rotary wing aircrafts. The twin rotor systems of the Boeing CH-47, Kamov Ka-50 and the HH-43 Huskie were researched. A twin rotor system utilizes two rotors that spin in opposite directions, hence counteracting each other's torque and eliminating the need for a separate anti-torque system.The most common twin rotor systems: coaxial, intermeshing and tandem, provide certain advantages in eliminating the "dissymmetry of lift". This configuration is also known to add a high degree of stability and powerful lift capability. However, the immense mechanical complexity, added weight and costly maintenance were the major reasons which made the team look for other options.

It was soon realized that as the C-25 Sigma has an integrated propulsive wing, the distributed propulsion system could function as the anti-torque system as well. After deliberation, it was decided that by making the propellers rotate in the direction opposite to the direction of the main rotor blade and adjusting the power, the propellers would be capable to counter the torque without the need for a tail rotor, fenestron or even "no tail rotor" (NOTAR) which otherwise make use of the Coandă effect. In essence, this design will use a single rotor configuration and the distributed propulsion system with support from the stabilizers will act as the anti-torque mechanism.

Rotor Blade Airfoil

Rotor blade airfoils encounter a wide range of operating conditions, the airfoil at the particular section is exposed to a variety of aerodynamic environments. The main properties that were aimed for were a good lift-drag ratio and suitable stall characteristics.These characteristics were not achieved by a single airfoil all along the length of the rotor blade hence, a relatively thicker airfoil for the inboard sections and progressively thinner one for the outboard was the approach. The airfoils which met the desired properties included NACA 23012, Gottingen 600 and Eppler 209.

Airfoil	Max Cl/Cd	Thickness	Max Camber
VR-7	125 at α=5.75°	12%	3.1%
NACA 23012	96.8 at α=8.75°	12%	1.8%
Gottingen 600	99.6 at α=3.5°	13.1%	1.9%
Eppler 209	121.6 at α=6°	13.7	1.6%

Table 5: Inboard Airfoil Comparison

Out of these the lowest camber and highest Cl/Cd was achieved by Eppler 209, hence it was selected for the inboard section. A CFD was then done for the Eppler 209. The result: **Lift - 386.58 N** and **Drag - 31.56 N**. These values show that the Eppler 209 produces high lift and low drag making it suitable for the rotor blades. The L/D ratio was then calculated to be **12.2:1**.

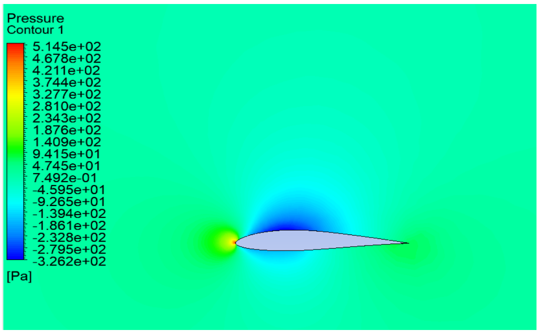


Fig. 15: Eppler 209 CFD

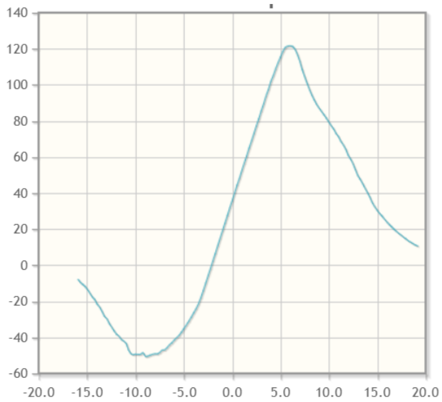


Fig. 16: Cl/Cd v Alpha Graph for Eppler 209

For the outboard section, retreating blade stall was one of the major deciding factors as it limits a helicopter's top forward speed. The angle of attack increases to maintain equal lift. When the critical AOA is reached the blade stalls at the outboard section.The NACA 0008 and 0012 were both attractive choices because of their low thickness, and AOA.

Airfoil	Max Cl/Cd	Thickness
NACA 0008	69.9 at α=7.5°	8%
NACA 0015	77.9 at α=9°	15%
NACA 0012	75.6 at α=7.5°	12%

Table 6: Outboard Airfoil Comparison

Symmetrical airfoils also are more stable as the AOA changes which in our case is exactly what the retrieving blade is experiencing. After comparisons in Airfoil Tools, NACA 0012 was chosen due to a higher L/D ratio and desirable stall characteristics.

As the main rotor is a very crucial component of a Gyrodyne, a spinning rotor blade CFD was also performed to observe the performance of the main rotor under real world conditions. The air velocity at the inlet was set at 78 kts with a turbulent intensity of 5% and a turbulent viscosity ratio of 10.

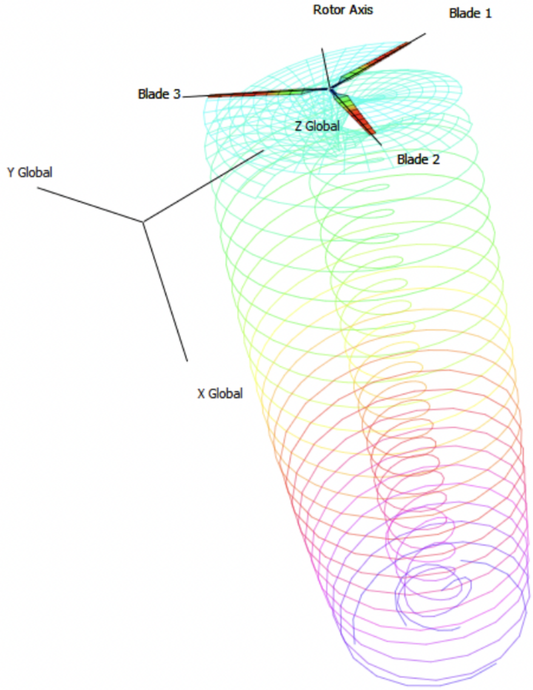


Fig. 17: Rotor Blade CFD

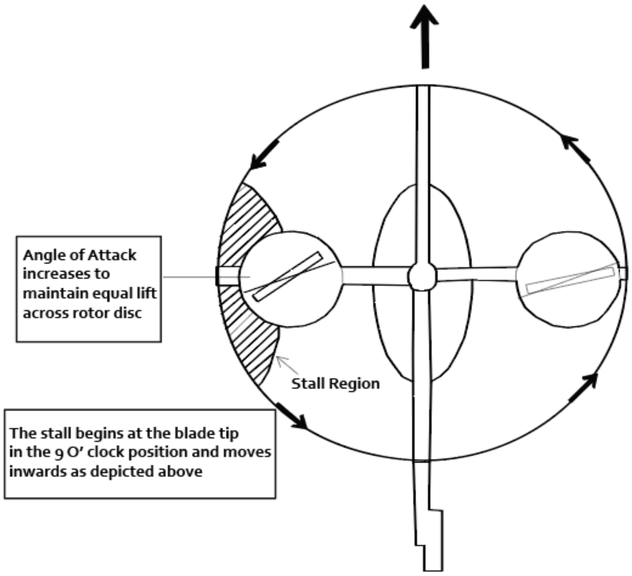


Fig. 18: Rotor Blade Stall Region

Main Rotor Components

Three Blades with Radius-1.616m. As discussed previously, the configuration that was decided upon was a rigid rotor head configuration. In this system, the hub does not consist of any hinges and it instead uses aerodynamics to mimic the functioning of a fully articulated system through the bending of the blades.The swash plate in the hub translates the inputs into actual movements in the helicopter blades. It is one of the most important parts in the functioning of any helicopter. It consists of a stationary swashplate and a rotating swashplate. The stationary swashplate is connected to the controls and is able to tilt and move vertically as well. The rotating swashplate rotates with the main rotor mast and is mounted on the stationary swashplate through a bearing. The flybar, which is located in the hub as well, acts as a stabilizing mechanism for the rotor. This bar has a weight/paddle at each end to assist in maintaining a constant plane of rotation. Through mechanical connection, it merges with the movement of the swashplate to dampen internal and external forces on the main rotor, such as wind.

Last, as the weight of the drone is 25 kg the minimum hover thrust is rounded to 250N. The main motor chosen was a KDE700XF-295-G3 (8MM) brushless DC Motor. This is a powerful and lightweight motor that generates a high RPM rate of 295 RPM/V.

Wingtips

While an aircraft is in flight, the magnitude of air pressure is higher under the wing than on top. This high-pressure area creates lateral airflow outwards from the main body towards the wing's trailing edge near the wingtip, where comparatively lower air pressure above the wing tends to spill and swirl around the wingtip, leading to the formation of vortices. These vortices reduce the aerodynamic efficiency due to the creation of an additional drag force, namely, "induced drag" or drag due to lift. (theflyingengineer, 2013)

Induced drag can be reduced in a lot of ways, such as twisting the wing or changing the airfoil cross-section; mainly, it is done by either increasing the wingspan or using wingtip devices. Having longer wings results in the wingtip vortices being further apart, thus influencing a smaller portion of the wing. On aircraft with smaller wings, a larger portion of the wing is near the wingtips and, therefore strongly influenced by the wingtip vortices. However, a larger wingspan needs to carry higher bending loads, so longer wings are heavier than shorter wings in order to have increased structural strength. In addition to this, having longer wings was not feasible due to the 3x3m area constraint. Therefore, the concept of wingtip devices was preferred. Using wingtip devices, induced drag is reduced by modifying the wingtip geometry exclusive of the remaining wing.

There are three major categories of this, **Hoerner Wingtips**, **Wing Endplates** and **Winglets**.

The **Hoerner wingtip** is just a downward curved wingtip with a sharp trailing edge; such a shape causes the wingtip vortex to move outward and away from the wing, this has the effect of reducing the downwash near the wing tip and therefore reducing the induced drag.

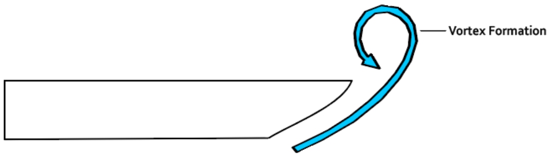


Fig. 20: Hoerner Wingtip Sketch

Whereas, **Wing endplates** are surfaces mounted at the wingtip that serve to block the flow of air around the wingtip therefore reducing induced drag. However, they add to the weight and increase parasitic drag. In addition, the trade-off of higher weight and parasitic drag for lower induced drag is not worth it.

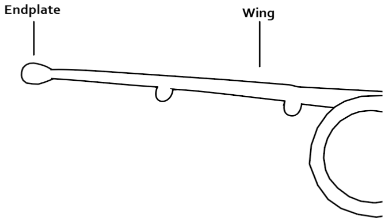


Fig. 21: Endplate Wingtip

Winglets have got their inspiration from birds as they curl their tip feathers upward when in need of high lift.(theflyingengineer, 2013.) The wingtips work on the mechanism of spreading the vortices along the trailing edge. Thus reducing the induced drag and increasing the lift. These also have additional advantages such as improved handling and safety, greater economy, lower emissions, and a significant reduction in vibrations and noise.(Aaron, 2017)

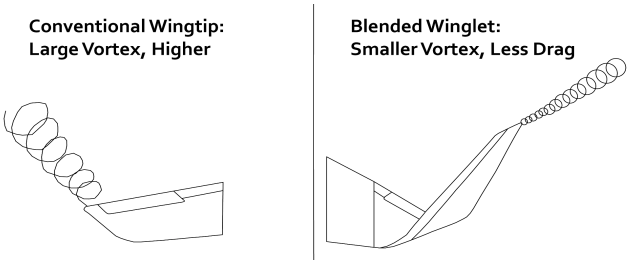


Fig. 19: Vortex Comparison

On comparison of different types of winglets such as Canted (used on A330, A340, B747-400), Raked (used on B787, B777, B747-8), and Blended Wingtips (used on the B737NG series), it was found that on the one hand, Raked wingtips are more suited for long-range operation while on the other, Canted wingtips are slowly going out of service as they are being replaced with more efficient Blended wingtips. For example, the A330-200/300 are fitted with a Canted wingtip, but the newer version, the A330neo, has a more efficient blended/ curved wingtip therefore, Blended wingtips were selected. However, on further research of Blended Wingtips, the Dual Blended wingtips, also known as the Split Scimitar Winglet, was looked into as it is a newer variant of the currently existing Blended Winglet. "The Split Scimitar Winglet redefines the aerodynamics of the existing Blended Winglet on the Boeing 737NG family. The combined aerodynamic elements of the ventral strakes, scimitar tips, and trailing edge wedges provide a drag reduction, and corresponding range increase, of two per cent or more for long-range missions." (Prabhakar, 2021). For all the stated reasons, Split Scimitar Winglets are used on our aircraft.

Materials-Static Stress Simulation

After CFRP and Aluminum were decided as the main materials, it was thought best to look for the exact aluminum alloy that would be suitable for our aircraft. Aluminum 7075 is one of the strongest aluminum alloys with a yield strength of 483 MP. Additionally, it has a density of 2.81 g/cm3 making it heavier as compared to other alloys. Although Aluminium 6061 has moderate yield strength (275MPa), it weighs less with a density of 2.69g/cm3. The low cost and adaptability of 6061 aluminum alloy are its main features. It is weldable, with good machinability and high corrosion resistance (Thomas, 1999) hence 6061 Aluminium has been selected.

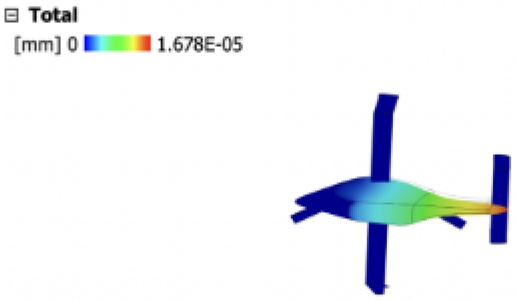


Fig. 22: Total Stress Test

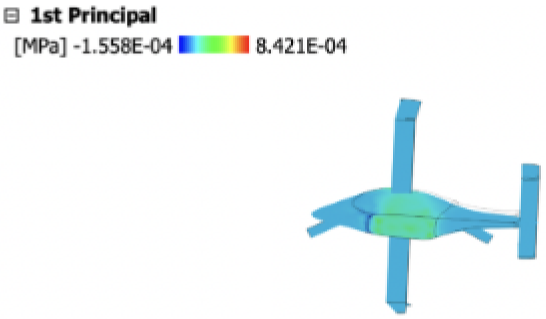


Fig. 23: 1st Principal Stress Test

Fig. 24: Safety Factor Stress Test

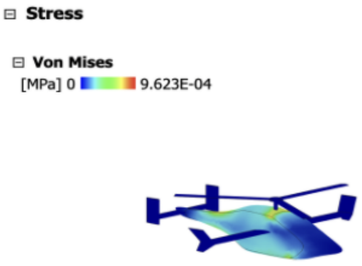


Fig. 25: Von Mises Stress Test

To decide the distribution of these materials on the aircraft, a Static Stress Simulation was conducted on Fusion 360. A structural load with magnitude 80N(X Angle 180 deg) was added to the undercarriage to account for the weight of the package and other components placed above it. Furthermore, constraints were added to the front part of the fuselage, wings, axle, rotor

blades and parts of the wings including winglets. Aluminum 6061, being the weaker material as compared to Carbon Fiber, was used as the main material for the simulation. This was because using a weaker material would help better in identifying the high stress areas.
Significant parts of the fuselage as well as the tail boom were observed to have the highest amount of stress hence CFRP, being the stronger material, was chosen for these parts.

In the rotor blades, as an asymmetrical airfoil is being used, (undergoes additional pressure as compared to symmetrical airfoils) the inboard sections use CFRP whereas the outboard sections are made of Aluminum. The wings, vertical stabilizers and axle are made of aluminum.

C-25 Sigma has a rating of 15.0 on Fusion 360's safety scale (0-15). When subjected to the imposed loads, the safety factor indicates whether a design is likely to survive undamaged, bend, or break. The safety factor for a specific material, manufacturing method, and application is influenced by a variety of variables and concerns.(Autodesk, 2020) For reference, any model with a rating below 1.0 has a very high chance of failing. Our model successfully cleared the stress test, proving safe for flight.
The weight of each material was calculated using (in SI units):
Surface Area x Density x Thickness = Mass
Aluminum 6061 (White) = 3.022 x 2700 x 0.001 = 8.159kg
CFRP (Black) = 4.211 x 1700 x 0.001 = 7.158kg
Weight: 8.159 + 7.158 =15.317 Kg


Fig. 26: Material Distribution

Loading/Unloading Mechanism

For this year, the challenge statement clearly mentioned that the package would be removed by hand at the delivery location, contrary to last year when the package had to be delivered while in air. To counter this challenge, the team looked into different loading/unloading systems on existing cargo planes, this included the upwards nose lifting mechanism of the Antonov 225/124 and the sideways opening tail section of the Boeing Dreamlifter. After collective ideation, it was thought best to avoid implementing the nose lifting and tail opening techniques as these sections contain intense circuitry, electrical components and

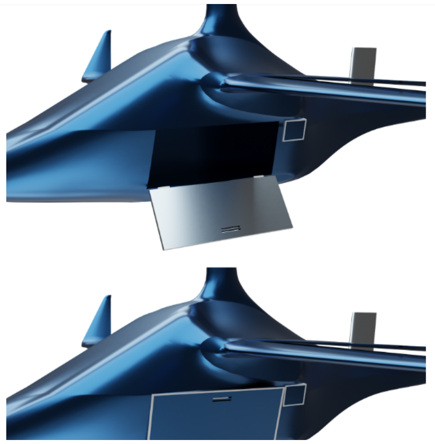


Fig. 27: Hatch Opening

overall, mechanical complexity. Instead, the company decided to go with an inbuilt hatch opening under the left wing of the aircraft. This location was chosen because it is easily accessible for the package handlers and does not interfere with any other components. The hatch has a handle, which when unlocked opens it outwards making package loading/unloading mechanism simple and practical.

Powerplant and Battery

The powerplant of the UAV was thoroughly debated upon. Given the requirements of the challenge, and the logistics provided, it was deemed that a fossil-fuel-based generic combustion engine would neither be effective nor efficient. This was because of the size-based limitations and economical inviability of having a fossil-fuel powered aircraft for the given application. Solar Power and Hydrogen-based technologies, although offering sustainable alternatives, were rejected as well due to the fact that these systems are still under development, and haven't been implemented commercially yet . As a result, an electric power plant was chosen as the final power source.

Batteries are the core of any mobile electronic system. The two primary contenders for our final battery-type were Lithium-ion (Li-Ion) and Lithium-Polymer (Li-Po) batteries. Out of Li-Ion and Li-Po batteries, Lithium Polymer batteries were deemed to be the better choice due to a lighter overall weight, as this meant that a bigger capacity could be achieved as compared to a Li-Ion battery of the same weight.

After calculating the final power draw of our aircraft, it was found that the UAV needed 2.733 kWh of power. Additional research showed that a battery pack of three MaxAmps 12S 22Ah 44.4V Lithium Polymer Batteries would easily satisfy our requirements for the entire flight profile, with more than enough extra energy accounting for a potential margin of error. Depleted batteries will be swapped with fresh charged batteries after flights through a special battery hatch door, which will be integrated into the fuselage of the aircraft.

Landing Gear

Fig. 28: Landing Gear

For the Landing Gear, it was important to first identify our requirements. Taxiing ability and CTOL as an emergency maneuver were the top requirements. Two configurations were considered: skid and nose-wheeled tricycle.

Skids were rejected only because they are incapable of taxi as well as landing in situations of main rotor failure when the aircraft needs to land on the runway conventionally. In the nose-wheeled tricycle, the debate was between a fixed and a retractable configuration. Fixed configuration, although known for its simplicity and lower maintenance, was rejected due to high values of parasite

drag. The trade-off of higher drag just for simplicity was deemed unreasonable. Thus, a retractable nose-wheel landing gear was deemed to suit our purpose. Some advantages of this include, greater flexibility for ground operations such as taxiing and turning, being capable of performing a full fledged conventional landing.Lastly, the most often quoted benefit of a retractable gear is an increased climb performance and higher cruise airspeeds as cleaning up the underwing reduces drag significantly. The landing gear placement of this aircraft is based on crashworthiness considerations. When the wheels are fully lowered in a vertical crash situation, the main gear will not penetrate the cargo hold and the nose gear will avoid important instrumentation.

Furthermore, our aircraft does not have conventional landing gear doors, instead we make use of wheel wells, a concept originating from the Boeing 737.

Doors were rejected as they take up space within the undercarriage, increase complexity of the design and add significant weight to the aircraft. (Low, 2021) Lastly, tubeless tyres are used.

2.3.2 Command, Control, and Communications (C3) Selection

Cloud Servers

There have been vast improvements in the field of cloud computing. A comparison was drawn between the perks and demerits of using physical and cloud servers.

	Physical Server	Cloud Server
Flexibility & Scalability	Limited functionality. More hardware resources required for expansion. Installing software requires manual set-up and involves higher pricing	Unlimited storage space and server resources. Full capability to install software (at a lower price)
Automation	Requires heavy administrative tasks Dedicated IT experts are necessary for effective functioning	All storage tasks are managed and supervised by cloud server provider Dedicated professionals are not required

Running Costs	Additional purchases and maintenance costs. Scalability is very costly	Consumers pay only for the resources being used.
Security	Personal hardware, hence easier to monitor users Implementing security features is however very expensive and time intensive	External storage site, hence less security However, trustworthy providers like Microsoft Azure, AWS are very secure

Table 7: Physical vs Cloud Server

Based on these results, Microsoft Azure's 'Hot' plan was chosen which offered 'pay-as-you-go' storage services at the low price of $0.018 per GB per month.

Navigation

While deciding the form and functioning of the C3 setup, the factors which were taken into account were: Degree of automation, Safe GPS system, Lightweight and power efficient, and Security features. Autonomous navigation capabilities are integral to the UAVs Guidance, Navigation & Control (GNC) system. These entail being able to calculate its own location, velocity, and altitude both in absolute measurements as well as relative to the airfield, landing pad, and any other communication towers on the way. The output from the navigation system functions as input for the flight controller.

Approach

Most navigation devices use major techniques such as ToA, TdoA, AoA, Triangulation, etc. The team has used a mix of these technologies, in an attempt to foolproof the UAV. The following technologies were used:

Enhanced GPS

GNSS based navigation was established as the default mode of BVLOS flight due to advantages such as ease of access, implementation, low cost, and reliability. However, urban locales present a unique set of challenges for GNSS-dependent vehicles, particularly as satellite signals can sometimes be blocked by high-rise buildings leading to insufficient signal sources to estimate position. Urban canyon phenomenon, signal attenuation, and multipath error can contribute to the degradation of GNSS signals and reduce accuracy in low-altitude urban areas, where high accuracy is needed the most.

This necessitates the use of backup navigation systems to ensure functionality in the event of a GNSS mishap.

GPS Navigation

INS

An Inertial Navigation System is a type of dead reckoning system that utilizes data from inertial sensors onboard the craft to provide three-dimensional position, velocity and orientation estimations. It is a completely self-contained unit and fuses altitude data from the IMU sensors with coordinate data from the GPS to provide real-time robust navigation. The flight controller on the UAV will use data from the GPS to provide coordinates of where the UAV is at a particular point in time and operate the UAV accordingly.

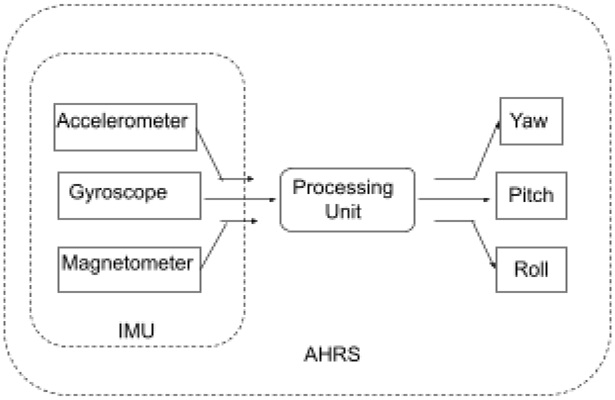


Fig. 29: IMU

Sensor Fusion

Sensor fusion involves taking multiple sensor measurements and combining them using mathematical models. The outputs from the accelerometer, gyroscope and magnetometer must be fused together in order to deliver meaningful orientation data. A Dynamic ANFIS model has been used to improve performance of GPS-INS systems In the absence of new GPS coordinates, ANFIS can generate predictions similar to a conventional neural network but with faster processing time and real-time realization.

Real Time Kinematics (RTK)

RTK utilizes two GNSS receivers, a Base Station Receiver and a Rover Receiver. To set up RTK positioning for our UAV fleet, firstly a GNSS receiver will be set up at the UAS Airfield. The exact coordinates of this receiver are known. The method involves the base station receiver first computing its location using satellite signals, and then computing the error in this obtained location by comparing it with its known coordinates. This data is then sent to the Rover Receiver, installed aboard the UAV. The rover receiver calculates its position using both its own received GNSS signals, as well the positional data from the base station receiver. This is done in real-time and the UAV can navigate itself with centimeter-level accuracy.

Mathematically, RTK follows an elegantly simple principle, known as code-based pseudoranging. The TDOA (time difference of arrival technique) is used to greatly enhance accuracy. The BSR receives a PRN code from a satellite. A PRN, or pseudorandom noise code allows the BSR to uniquely identify the individual satellite the code is from. Upon reception, it internally generates its own code. The time difference between the generation on the two codes multiplied by the speed of light gives us the Range, or the distance between the satellite and BSR.

$$R = c \times \Delta t$$

VANET

As part of an intelligent transportation system, a VANET (vehicular ad-hoc network) is a spontaneous wireless network of automobiles that is used to enable V-V (vehicle-to-vehicle) and V-I (vehicle-to-infrastructure) communication. An arbitrary vehicle can broadcast signals to other surrounding vehicles through V-V, including vehicle speed and turning direction. Vehicles are outfitted with an on-board unit (OBU) in a vehicle ad hoc network (VANET), and infrastructure units called road-side units (RSU) are installed along the UAVs path to keep the GCS constantly updated. At the back end, a trusted authority (TA) or GCS and application servers are installed which constantly monitors the information and assesses it in case of failures.

Each vehicle consists of mobile nodes. These nodes are a connection point in a network which send, receive, send, create, or store data. Each node requires you to provide some form of identification to receive access to the information, like an IP address. Technologies like WiFi, Zigbee, Bluetooth are used for V-V communication. Short range communication is most prominent in these applications.

During the state challenge, wifi based backup navigation systems were explored in detail before settling on the RSSI based method of wifi fingerprinting.However, this method has some significant flaws. You need multiple APs to be strategically set up around the city, these APs also need to be installed by the company thus significantly increasing the cost of initial setup. These APs also demand regular survey operations, not just for initial radio maps but also for any changes occurring in the macro environment. Due to these major drawbacks, this method was eliminated. Instead of the RSSI based method of wifi fingerprinting, a perfect candidate for the criterias was found in dedicated short range communications technology (DSRC) . DSRC is a set of short and medium range wireless technologies designed specifically for automotive use. Three technologies were considered and selected for further research : ZigBee, Bluetooth, and WIFI

Name	Frequency	Range	Latency	Data Rates
Wifi	2.4 GHz	20m-250m	<5ms	Up To 600mbps

Bluetooth	2.4 GHz	40m-200m	3ms	2mbps
Zigbee	2.4 GHz	1600m (outdoors)	15ms	250kbps

Table 8: DSRC Comparison

ZigBee technology is widely used in applications that require long battery life, low data rates, and secure networking. It operates in an unlicensed spectrum, it can be easily deployed and quickly scaled up. It is a low power, low cost, low data rate alternative to other personal wireless networks such as bluetooth and wifi. It has a 1600m outdoor range (clear line of sight) depending on obstacles and other environmental factors. Its advantages are security and long battery life. After taking into account the three technologies, Zigbee was decided to be applicable to the VANET systems (V-V systems). Zigbee offers a stable data rate as well as relatively low latency.

A ZigBee network has exactly one ZC device (GCS). The ZRs (RSUs) build a network between themselves through which packets are exchanged. The ZEDs (UAVs) are connected to the ZR. The ZEDs communicate with the ZRs, updating them about their location from time to time. These ZRs then transmit this data to the ZC through wireless communication. The UAV will encounter many RSUs along the way to the delivery location. Exchange of information will take place at these encounters with the RSUs.

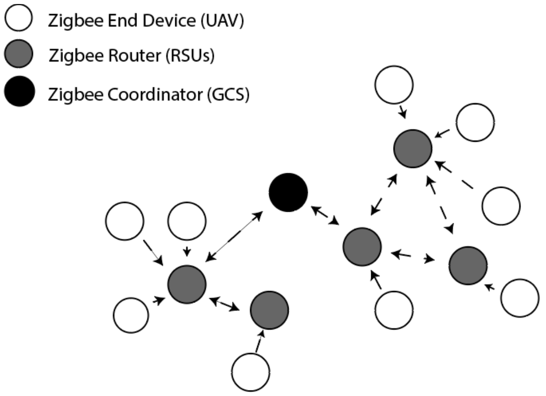


Fig. 30: Zigbee Network Devices

Communications

LTE: This ability of remote command and control can significantly enhance the safety and operation of UAVs. UAVs are required to send back live telemetry data, pictures, or videos for data communication. This data communication requires up to 50 Mbps data rate and packet error rates lower than 0.1% (Lin, 2018)

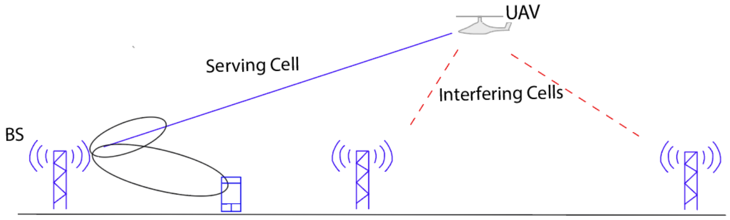


Fig. 31: Interfering Cells

The major disadvantage of using LTE was interference from other neighboring cells. Our UAV flying at the altitude of 61m and 122m, is not obstructed by buildings, and trees hence the UAV experiences better data propagation conditions.

A few methods have also been adopted to mitigate these interferences:

- Receiver techniques such as interference rejection. Comparing the sizes of small UAVs to the sizes of smartphones, it is more feasible to equip small UAVs with more antennas, which can be used to cancel or suppress the interfering signals from more ground BS (Base Station).
- Using dedicated cells for the UAVs, where the antenna patterns are pointed towards the sky instead of down-tilted towards the ground. These dedicated cells are particularly helpful in UAV hotspots where frequent UAV takeoffs and landings occur (Lin, 2018).

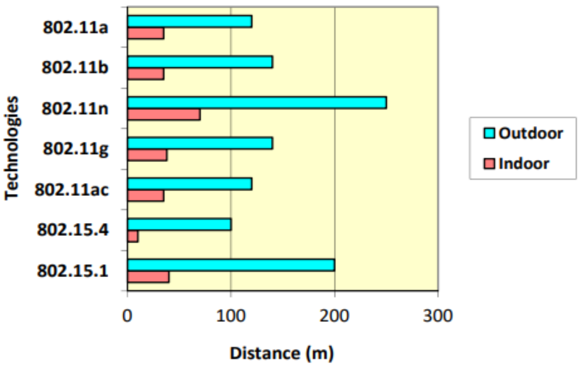


Fig. 32: WI-FI technologies

Wi-Fi

Wi-Fi is a short-range communication technology that consists of a set of standards for designing WLAN (Wireless Local Area Network) in the following radio bands: 2.4 GHz, 3.6 GHz, 5 GHz, and 60 GHz. In summary, based on the transmission characteristics, the team considered short-range communication technologies for landings. There are several reasons for choosing these technologies - they operate in the unlicensed spectrum, they do not require strict LOS, while offering reasonable coverage and data rate.

Moreover, they can be easily integrated with small UAVs. Furthermore, due to the significant improvements in speed, power consumption, capacity, and coverage, LTE is the best option amongst the long-range wireless technologies. However, in order to utilize the best features, Wi-Fi is integrated with LTE in our proposed approach.

While the aircraft is coming in to land, the transfer from LTE to Wi-Fi takes place at an altitude of 61m while the aircraft is performing hover.

2.3.3 Detect and Avoid (DAA)

The drones will have to face many obstacles in their everyday functioning, such as birds, other drones or unforeseen projectiles. Systems need to be developed to avoid collision with such obstacles and keep the drone safe from any possible damage. Such a system would need to be simple yet effective under any circumstance. Different solutions for obstacles will be discussed in detail in this section. The following sensor systems were researched:

Lidar: Lidar is a very strong contender when it comes to collision avoidance. It projects lasers into its environment and senses the light that gets reflected back to detect obstacles. This system has high accuracy and precision, and has been used extensively in self-driving vehicles. It does have some drawbacks: it is relatively more expensive than the other options and consumes a lot of energy. However, the strong results that it provides cannot be ignored.

Radar: Radar projects radio waves into the environment and then catches their reflections from the surrounding objects. Highly accurate information about both the position and velocity of moving objects in the drone's surroundings can be obtained. It has a very long range and remains largely unaffected by weather phenomena. These factors make it one of the best options for collision avoidance.

Cameras: Camera based detection techniques are broadly divided into monocular vision and stereovision. Monocular vision involves the use of a single camera. Stereo vision consists of using a pair of cameras for viewing the environment. Stereovision is more suitable for three dimensional environments as it enhances depth measurement and hence the position of any object in the 3D environment can be determined more accurately. It was agreed that the use of cameras was indispensable as they make it possible to switch to manual piloting of the UAV. Moreover, the development in deep learning has made it possible to optimize the predictions made by a camera. The functionality of cameras can be extended to even identifying the nature of obstacles and ultimately taking the appropriate steps to avoid a collision.

Ultrasonic sensors: They evaluate the objects near it by sending out short, ultrasonic impulses which are reflected back to the sensors. Ultrasonic sensors are compact, do not require any moving parts, and are unaffected by light or weather. they have been considered to provide a better overview, more efficient, and safe landing system, these sensors were found to be the most appropriate. These sensors will be placed at the bottom of the UAV (see section 2.5). These sensors help provide an exact distance between the UAV and the landing area, with information being provided to the onboard processor it strategically plans its descent, while learning and processing this information in the machine learning software.

Comparison Metric	Lidar	Radar
Range	Upto 250 m	Upto 250 m
Accuracy	Very high	Very high

Update Speed	Very High	Very high
Weight and Size	Quite Bulky	Light and small
Cost	Very High	Moderate
Power	High	Low
Computational Requirements	High	Moderate

Table 9: DAA Comparison Table

Machine Learning For Improving Visual Sensing

The concept of implementing machine learning to optimize visual sensing has become very popular in the autonomous vehicle sector. The readings of the RADAR sensors, which are highly accurate, will be used to get the actual distance and relative speed between the UAV and the obstacle. This data will be fed to the machine learning model as the labeled dataset. At the same time, the cameras will make estimations of the distance and relative velocity of the obstacle, which although accurate, are still not as credible as RADAR measurements. Based on the cameras' predictions and the actual readings of the RADAR, a neural network will be set up with the aim of gradually improving the cameras' accuracy. Furthermore, there were plans to switch from a combination of RADAR and cameras to solely using cameras for obstacle avoidance when the accuracy of the cameras is at par with the requirements. However, this thought has two major drawbacks:

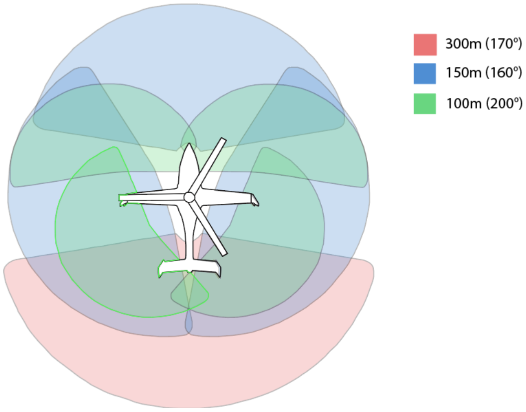


Fig. 33: Sensor FOVs

Collection of Datasets: Manufacturers of land based vehicles have access to much larger datasets to improve their models.

Advantage of RADAR in poor visibility conditions: RADAR sensors are immune to poor weather conditions. Plus, they are able to detect obstacles even in case of poor visibility or dark lighting. However, a camera is seldom capable of detecting and avoiding objects if the visibility is compromised. As a result, a combination of RADAR and cameras was agreed upon for detecting and avoiding obstacles.

Cooperative and Non-Cooperative Obstacles:

VANET (Section 2.3.2) provides an innovative mechanism for communication between vehicles. Therefore, vehicles are capable of communicating and identifying each other's presence in a particular area. Other than VANET, transponders have also been fitted on our UAV for transmission of data.

Algorithms for Obstacle Detection and Avoidance:

Local Path Planning Method

In this algorithm the UAV is guided with one straight line from the starting point to the target point which is the shortest path and the UAV follows it till it senses an obstacle. The UAV then performs obstacle avoidance by deviating from the planned path. This is done while updating the information such as new distance from current position to the target point.

A number of different algorithms were analyzed for obstacle avoidance. A list of these algorithms along with their advantages and disadvantages is given below:

	Merits	**Demerits**
Bug 1	It is a complete algorithm i.e., in finite time, it finds a path if such a path exists or terminates with failure if it does not.	Large memory and computation are required which results in lesser efficiency It is an exhaustive search algorithm.
Bug 2	It is a greedy search algorithm i.e., it takes the first thing that looks favorable. It requires less computation and is also easy to implement.	In some cases, it does not exhibit completeness.
Distance Bug	It traverses less distance than Bug 1 and Bug 2 algorithms to reach destination Efficient use of data from range sensors	It thinks about obstacle only when it encounters one and starts circumnavigating it whereas Tangent bug starts moving tangentially to obstacle showcasing precognitive behavior
Tangent Bug	It tries to minimize the heuristic distance so that the vehicle has to move minimum to reach the desired location.	It is not a self-sufficient approach. While moving on a tangential path when distance starts increasing, it starts acting as a bug algorithm by following the edge of the obstacle.
Artificial Potential Field	It is a simplistic approach which is easy to implement	Vehicle stops when it encounters a point of local minima. It cannot detect passage between closely spaced obstacles

Table 10: DAA Algorithms (Bhavesh, 2015)

The tangent bug algorithm can be integrated with artificial potential field to create an improved tangent bug (ITB) algorithm for multi-vehicle path-planning. This eliminates the situation when the UAV (using artificial potential) stops after encountering the local minima. Unlike the Tangent Bug Algorithm (used for static environments), the ITB Algorithm is capable of working effectively in dynamic as well as static environments. Therefore, the team finalized on adopting an ITB algorithm, which consists of the following two modes:

Motion-to-Goal Mode: If an obstacle is blocking the vehicle's path to the goal, the algorithm finds the edges of the obstacle. Then, the vehicle moves past the edge (which gives the shortest path to the goal) tangentially.

Boundary-Following Mode: The shortest distance between any point on the obstacle and the goal is noted. The algorithm also checks if there is any point to move to which is closer to the goal than any point on the obstacle. If there is, the vehicle moves towards this point and the boundary-following mode is terminated. If no such point is visible, the vehicle continues to move around the obstacle in the direction of the last motion-to-goal movement. (Mohamed et al., 2011)

Transponder System

They are small receiver-transmitters interrogated with particular radio pulses, transmitting a pulsed reply (W.H. Harman, 1989). A transponder system is used to increase airspace awareness between UAVs, greatly reducing the risk of collision.

The transponder transmits information about the UAVs location, speed, and direction. This information is received by all the other UAVs in the area and the CUTC, allowing the DAA system to make an informed decision about the collision avoidance. To maintain the probability of failure (Denoted by P), within the required constraints, both the internal system factors (denoted by X) , this includes transmitter and receiver parameters like strength of the signal, and frequency as well as external factors (denoted by Y) external factors Y are physical capabilities of UAVs, transmissions by other UAVs clogging the channel, as well as any other frequencies from other sources are considered. The decision should be made by the system at an appropriate distance to assess the best and worst case distances to avoid a collision. Therefore, it is important to maintain P, given Y, by finding appropriate X

A model needs to be created to simulate different encounter scenarios, with the purpose of identifying X, by iteratively adding more and more external factors, Y.

Aircraft state	Path	Explanation
Both aircrafts moving, both responding	Head on	Aircrafts on the same path heading towards each other at maximum speed

	Intersect	Aircrafts on intersecting paths, with a possibility of collision
Both aircraft moving, only one responding	Head on	Aircrafts on the same path heading towards each other at maximum speed
	Intersect	Aircrafts on intersecting paths, with a possibility of collision

(Lancovs, 2016).

Table 11: Physical Iteratives

These iterations produce d_{min} (minimum distance) and d_{max} (maximum distance) for safe encounters (distance at which the encounter does not end in a crash). These d_{min} and d_{max} are used in the next iteration, this final iteration produces a set of X which guarantees the probability of failure P<10^-9. If P exceeds allowed limits, X and Y parameters are adjusted to keep P within permitted range. These values are finally used for the implementation of the cooperative, infrastructure-independent collision system.

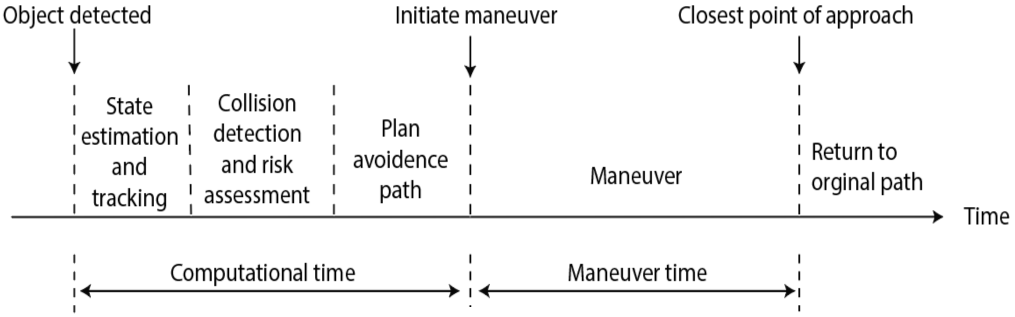


Fig. 34: DAA Plan

The transponder system also has 3 modes: Mode A/C and Mode S. These are different configurations of the transponder which allow it to selectively communicate between UAVs and transmit the data which each mode is capable of

Mode A/C

Mode A is usually combined with mode C to provide a better overview of the aircraft. Mode A is a 4 digit octal code that provides temporary identity of the aircraft. This code is broadcasted when the transponder receives an interrogation request from the CUTC. Mode C individually provides pressure, and altitude information about the aircraft which is an integral part of a transponder.

Mode S

The FAA developed a new system which allowed a unique identity, selective communication as well as single response. Furthermore it provided much larger datasets than simple identification, altitude, and pressure. It also provides backward compatibility with Mode A/C since they use the same frequency band for interrogation and responses for this reason.

The Mode S is paired with our DAA sensor and transponder system which provides an independent and cooperative detect and avoid system. Incase of failure of transmission between the UAVs the DAA sensor system is more than adequate to prevent a collision. This configuration was felt to be appropriate for our cause.

Ground Control Station Description

The company has built up a proprietary VANET network consisting of comm towers or RSUs along the flight corridors as well as the UAVs themselves. The RSUs built alongside the flight path of the UAV will provide the data to the GCS through a wired connection to eliminate other frequencies and interferences. This RSU will also transmit this data to the other UAVs in the area through the Zigbee protocol. A joystick is also provided to the pilots, which helps them take full control over the UAV including pitch, roll, yaw, and altitude. The necessary receivers and transmitters are provided both on-board and in the GCS. The joysticks and the hardware chosen will greatly assist in times of manual control when the pilot needs to take over.

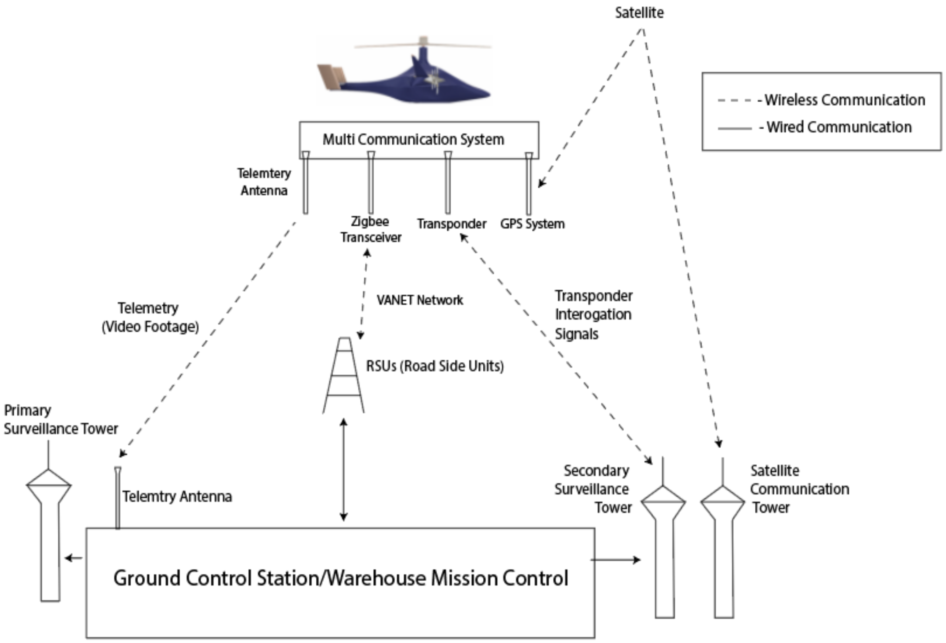


Fig. 35:GCS

The GCS will contain three main communication towers: Primary surveillance radar and secondary surveillance radar. The primary surveillance radar will be used to measure the distance of targets such as UAVs through deflected radio waves and radar sensors. The secondary surveillance radar will be used to send interrogation signals to the UAV transponders to obtain identity and altitude of cooperative airplanes. With the primary and secondary radar, this system allows safe air traffic flow. The GCS will also contain a satellite communication tower to communicate with the UAV during GPS navigation.

C3 Components

5.8GHz 48CH FPV AV Receiver (RC832) : The telemetry footage will be received by this component from the transmitter mentioned above. Instead of audio, video footage will be received.

Eachine TS832 Boscam FPV 5.8G 48CH 600mW 7.4-16V Wireless Transmitter : The video footage of all the cameras in our UAV will be transmitted from the UAV to the GCS through this.

Ping20S Mode S Transponder :It is one of the lightest and smallest Mode S transponders, it allows drones, UAVs, and aircrafts to respond to Mode S radar interrogations by the ATC. It assists the detect and avoid system of our UAV.

Zigbee S2C : It is one of the most effective Zigbee OBUs on the market. It operates on 2.4 GHz with data rates up to 250 kbps which is sufficient for interUAV communication.

Turnigy T6A-V2 AFHDS Mode 2 2.4GHz 6Ch Transmitter with Receiver along with TBS Crossfire micro Tx Rx bundle : This controller is used alongside the TBS crossfire, it has a large range of communication of about 40km. This would mainly be used by the safety pilots to control the UAV in uncertain situations. This is paired with the Logitech joystick for ease of control.

HUAWEI 4G Dongle E3372 : with a 4G LTE sim and data plan allows us to transfer sufficient amounts of data which is required to transmit a live video footage to the base station. This modem is capable of transmitting data at 150Mbps.

CubePilot Here+ GNSS Module with integrated RTK: This bundle includes - One GNSS Receiver (on board), One V2 RTK Rover (on board), One RTK Base (Installed at BS), One GPS Port connecter, and One Base USB connecter.

Simple Pack 4.0 Plus Wi-Fi Tracker: It offers a 3D accelerometer (motion, vibration, tilt, and shock).

Bosch 0263009637 Ultrasonic sensor: is a state of the art ultrasonic sensor in terms of robustness, reaction time, and object detection. It is not affected by dirt, ice, environmental conditions and other ultrasonic systems make it an appropriate choice for our UAV.

Texas Instruments AWR2944 Single-Chip 76- and 81-GHz FMCW Radar Sensor: This particular RADAR sensor was chosen because of its light weight and low battery consumption (2.09W) . It is a part of the latest generation of automotive RADAR sensors and has a long range.

OV48B (used in Xiaomi Redmi Note 10): The OV48B is one of the most popular CMOS sensors by OmniVision. It offers 48 MP resolution at 15 frames per second and upto 4k resolution at 30 frames per second. Furthermore, 'night mode' functionality can also be extended to improve the camera's performance. These sensors will be used to detect and avoid obstacles.

AKASO V50X Native 4K: This is the UAVs main camera. It will be positioned at the front. The camera is capable of delivering high quality 20MP resolution videos at 30fps (4k) / 90 fps (hd). Furthermore, the device's light weight and low battery consumption make it optimum for use.

Nvidia Jetson TX2: is a very popular choice for onboard computers in autonomous vehicles. It is the fastest, most power-efficient embedded AI computing device available. The low power consumption of 7.5 W loaded with 8GB of memory and 59.7GB/s of memory bandwidth make it ideal for executing obstacle avoidance algorithms and other flight related programs.

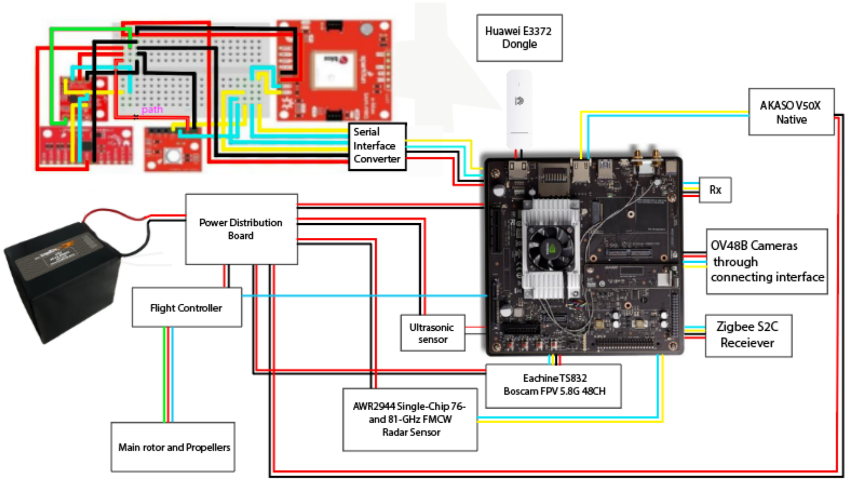


Fig. 36: Circuit Diagram

2.3.4 Ground Support Equipment

High grade equipment such as the Dell Inspiron 15 Touchscreen Laptop, Galaxy Tab S7 FE, Logitech Extreme 3D Pro Gaming Joystick, Conveyor Belts, and Storage Bots were utilized in our warehouse. Our custom and highly innovative storage bots promise to revolutionize the present state of package management by offering reliable and efficient transportation.

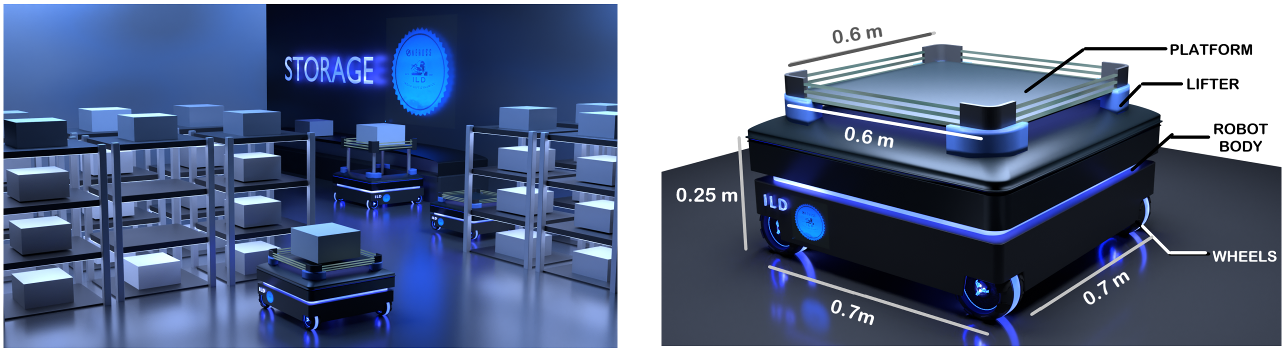


Fig. 37: Storage Bot

Ground Personnel

Human Resource Management is a key contributor to the success of any company. An overburdened workforce can prove to be very detrimental in the long run, and thus having proper designated roles was considered to be of major importance.

Hence, the company, understanding the true value of human resources, settled on choosing the following roles. Their wages and descriptions have been provided as well.

Operational Pilot [$35/hr] (5 employees): Operational Pilots are the pilots responsible for monitoring the state of aircraft and adjusting flight path as and when needed. This pilot will spend most of the operation time looking at a screen from the Ground Control Station, monitoring the assigned aircraft's telemetry and making changes to the flight programming as required.

Air Traffic Manager [$35/hr] (3 employees): This person is responsible for coordinating the taking off and landing of aircraft from the Warehouse. They must ensure that no two UAVs collide with one another during takeoff and landing, and prioritize departures and arrivals respectively as needed. In case of an emergency, they reroute/reschedule other flights to accommodate the concerned aircraft's arrival..

Supervisor [$31/hr] (1 employee): A supervisor is responsible for ensuring that each respective department is functioning as intended. They ensure that all operations are running as planned, and they micromanage tasks at their own level.

Electrician/Technician [$17/hr] (1 employee, visit once a week): The Electrician/Technician will visit once a week to ensure that all electrical components and technical aspects of the warehouse are functioning as intended. They will also confirm that UAVs are in an operable state.

Emergency Responders [$15/hr] (2 employees): These personnel will be tasked with tackling emergencies and urgent unforeseen situations, and any situations where a UAV may require prioritized attention.

Safety Pilot [$35/hr] (2 employees): This pilot is responsible for bringing in aircraft safely for recovery. In case any major flight-related issues occur, the Safety Pilot will be in charge of taking over command of the aircraft and bringing it safely to the Warehouse.

Payload Operator [$35/hr] (2 employees): This person is required when payload data is telemetered from the aircraft. This person will usually sit at a ground station, and coordinate the payload operations in real time. This person will be required for drop-offs not involving an automatic package release mechanism for the aircraft.

Range Safety/Aircraft Launch & Recovery [$35/hr] (2 employees): This individual can be assigned multiple non-concurrent roles, and is typically a highly qualified technician. Range Safety includes ensuring frequency deconfliction. They will also be responsible for coordinating with air traffic management personnel before the operation to ensure that the airspace remains free throughout, and confirming that appropriate airspace restrictions are communicated to piloted aircraft operating in the area.

Launch and Recovery Assistants/Package Handlers [$15/hr] (3 employees): This person will help with the movement of the UAV while on the ground. They will also be responsible for replacing batteries and reloading packages onto the UAV.

Janitor [$85/shift] (1 employee): The janitor will ensure the sanitary upkeep of our warehouse premises and will assist in miscellaneous tasks throughout a 6 hour shift.

In conclusion, our staff will consist of 22 hired individuals, with 21 regular employees working for the company on a daily basis, and 1 employee (the Electrician/Technician) visiting the Warehouse once per week to perform maintenance as and when needed.

2.4 Lessons Learnt

The design phase taught the team a lot of valuable lessons. It put forth many challenges and sparked many constructive debates within the team over design choices.

Several discussions on choosing an airframe and analyzing various solutions were one of the first challenges the team faced. The team contemplated different types of airframes and closely examined their merits and demerits. After establishing that a single-rotor design was the best choice available, the team realized a few shortcomings of single-rotors, and researched further to find the concept of “Gyrodynes”, which are a fixed-wing hybrid with a single rotor. The team settled on making a final design based on Gyrodynes due to their advantages. Another point of contention was the dilemma between having a boxed wing and a conventional wing design. The higher lift promised by boxed wings clashed with the lower drag offered by conventional wings. With thorough deliberation, the team decided to choose a conventional wing design.

Several other design decisions were driven by the goal of increasing efficiency. One of these was the decision to include shrouds on the propellers, i.e. choosing ducted propellers over conventional propellers. This choice, while improving the overall performance of our aircraft, also improved the safety of the UAV.

Whenever a problem was encountered or a roadblock was faced, the team took a step back and logically analyzed the issue. This simple yet comprehensive approach was the core of our design process, and is what defined our design at the end.

The most important lesson that was learnt out of all of these was the true value of finding appropriate solutions to a problem, and to back it up with research. The determination of the team to cover every aspect of the design phase, with encouragement from mentors, proved to be a fabulous learning opportunity in itself.

2.5 Component and Complete Flight Vehicle Weight & Balance

While deciding the placement of the electrical components, center of gravity (COG) was kept in mind, and the aim was to keep the COG along the center line above the landing gear, near the package. Thus all components had to be distributed equally across lines of symmetry down the length of the fuselage. To determine the coordinates graphically, the center of gravity analysis on Autodesk Fusion 360 was used; the COG obtained is shown below in the figure.

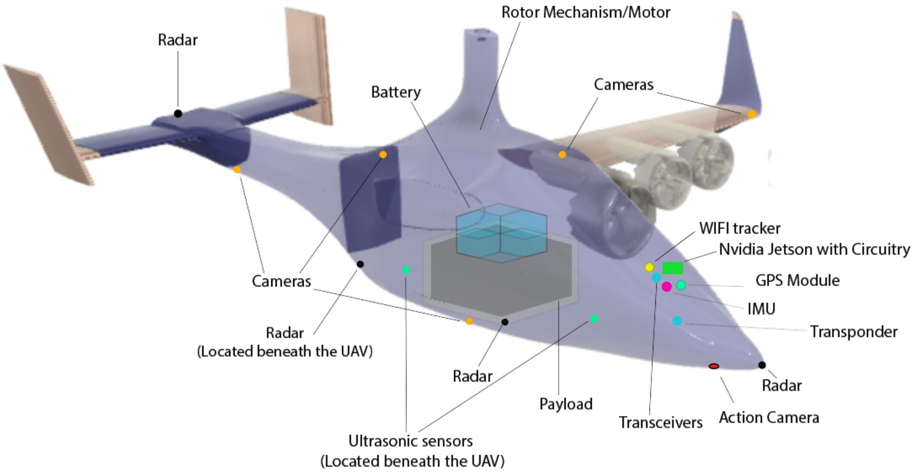


Fig. 38: Component Placement

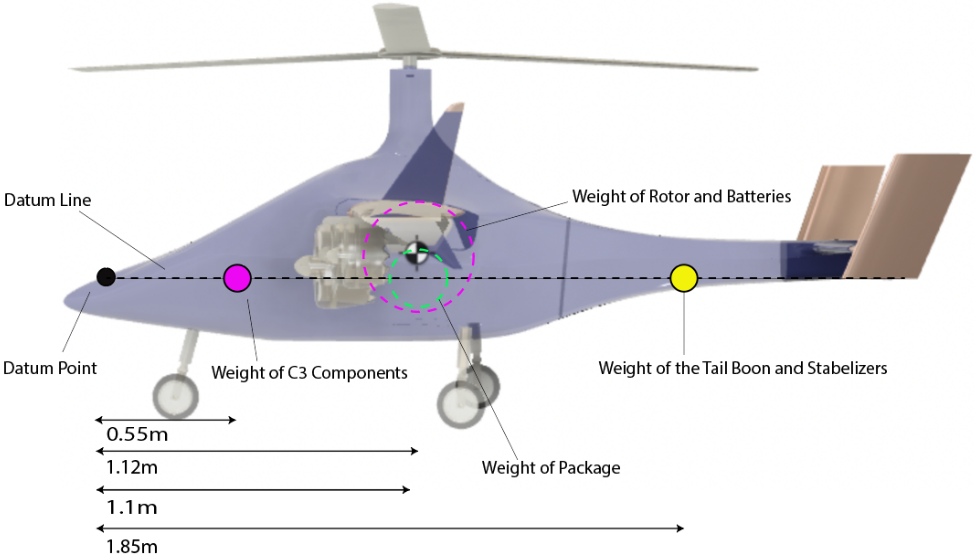


Fig. 39: COG Analysis

Component	Weight (W)	Distance from Datum Point (R)	Moment (WxR)
Fuselage and Package	9.03kg	1.12	10.08
Rotor and Batteries	8.69	1.10	8.9
Components	1.46	0.55	0.48
Tail Section	5.82 **Net**= 25 Kg	1.85	8.51 **Net**= 26.27

Table 12: Numerical Derivation of COG

To back this up, COG was numerically proven using a weight-moment relation. Here, the black point is taken as the datum point and the datum line is drawn from it through the body of the aircraft. The distance of the components from the datum point were noted and multiplied by their respective weights to obtain the moment. The total moment is then divided by the total weight of the UAV.

$$COG = \frac{Net\ Moment}{Net\ Weight\ of\ the\ UAV}$$

$$= \frac{26.2}{21.5} = 1.1 \pm 0.07m$$

On calculation, the COG came out to be at 1.1m from the datum point with an error margin of 0.07m. This result reaffirms the COG point obtained graphically from Fusion 360.

2.6 Final Design Drawings: C-25 Sigma

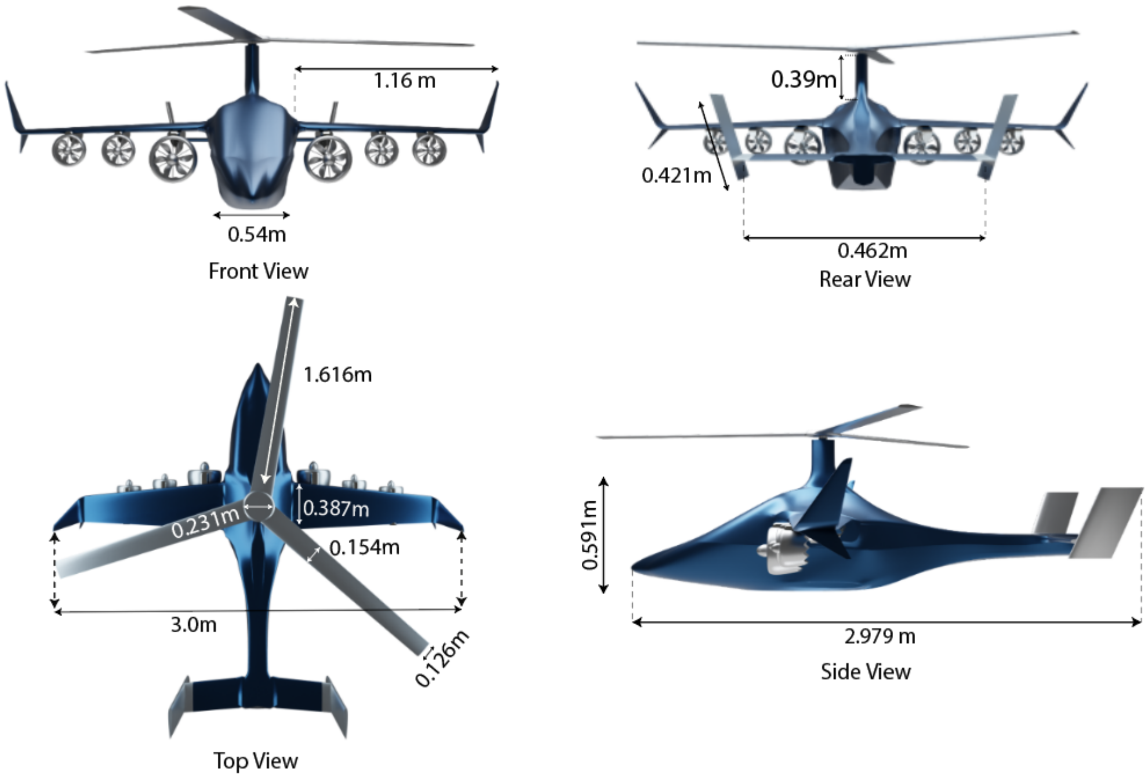


Fig. 40: Final Design Images

3. Missions

3.1 Concept of Operations

3.1.1 Pre-Mission

Our UAS will operate from 0700 hours to 1900 hours each day, thus allowing a daily operational window of 12 hours. However, flights will only be conducted between 0730 hours to 1830 hours, during an 11 hour flight window. From 0700 hours to 0730 hours each day, the warehouse will be prepared for operations. Personnel will set up their workstations, and other important tasks will be performed during this time. From 1830 hours to 1900 hours each day, the warehouse will wrap up operations, and personnel will conclude their tasks.

The clients would be required to download the company's mobile application (or use the company's website) beforehand to check the status of their package. This application will be available 24x7 to the clients, wherein they can communicate through a chat service pre-programmed to handle frequently asked questions. The client is required to confirm availability one day prior to the actual delivery via the same means. In case the chat service is not able to answer the query, a response team (overlooked by the supervisor) will take over and communicate with the client. There will also be a provision for a feedback system in our app/website. This will result in the enhancement of the chat service, and our services in general.

A warehouse management system called **NetSuite** will optimize warehouse operations such as task and inventory management, mobile receiving, mobile picking, return authorization, barcode scanning, and cycle count plans by streamlining them. (Oracle NetSuite, 2021). This helps minimize manual costs and enables us to run our warehouse efficiently.

The company also made several decisions to help improve the overall efficiency of operations. For example, a crucial point would be the company's demarcation of one of the takeoff/landing areas as the "takeoff" area, and the other takeoff/landing area as the "landing" area, to allow for a more efficient traffic flow of the UAVs.

Before Flights:

The packages, delivered by trucks, will arrive at the warehouse by 0700 hrs. These packages will be manually unloaded and stored in the warehouse. Any packages that arrive after this time will be accommodated for the next operational day. A payload operator will stick printed barcode stickers (which will be pre-determined for each staging area) onto each package and manually scan these codes. This scanning will result in the sending of an automated message to the clients informing them that their package has been received by the warehouse, and is being prepared for dispatch. An example of a barcode has been given below.

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Simultaneously, at 0700 hours in the morning, an automated system guided by air traffic managers will create flight plans and charts using **Lido Flight 4D** for each UAV for that day. These flight maps will be generated in accordance with City UAS Traffic Control (CUTC). Weather information, air traffic reports, terrain, altitude, clearance, and other crucial information will be taken into account while generating these flight routes. Using Lido Flight 4D, which is a free flight planning software by Lufthansa, routes will be optimized concerning fuel consumption, costs or flying time (Lufthansa Systems, n.d.). A flight plan will look similar to the one given in the figure.

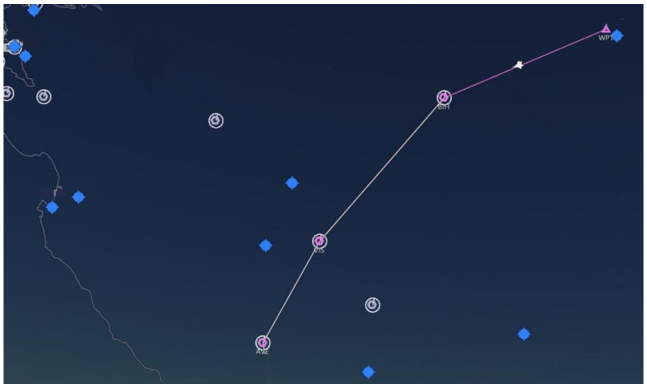


Fig. 41: Flight Path

Meanwhile, the launch and recovery assistants will be setting up equipment ensuring that the warehouse and staging areas are ready for operations. Mandatory pre-flight inspections will also take place for all the UAVs in the hangar by maintenance personnel.

1) Preparing Packages:

Before the flights, packages will be loaded onto a conveyor belt by a designated package handler at the storage area. There will be a conveyor belt system within the warehouse. This conveyor system will further have subdivisions (mainly three, in line with three different staging areas) and packages will be sorted into these three sub-belts based on a pre-programmed barcode-based sorting system and an omnidirectional belt. The barcodes on each

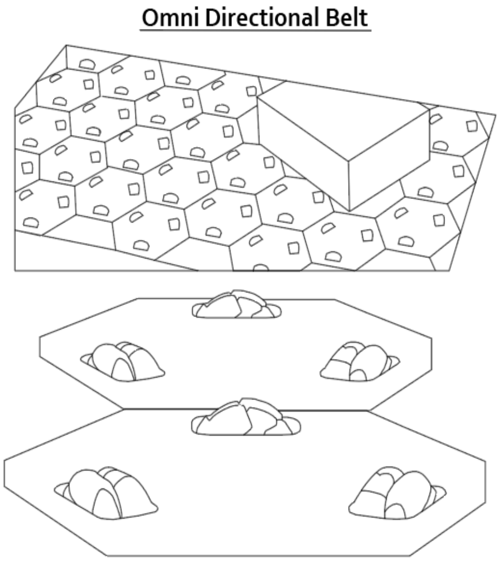
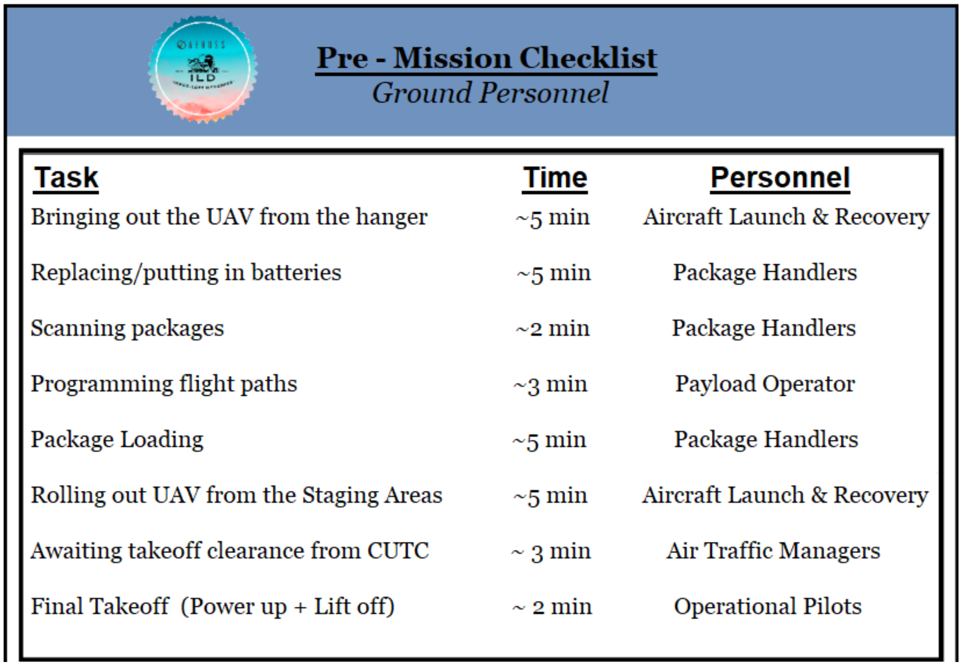


Fig. 42 : Omni Directional Belt

package are scanned and sorted for each staging area by an omnidirectional belt (refer to the figure). Packages will arrive at their respective staging area before departure and will be kept in a Holding Bay until then.


Pre - Mission Checklist
Ground Personnel

Task	Time	Personnel
Bringing out the UAV from the hanger	~5 min	Aircraft Launch & Recovery
Replacing/putting in batteries	~5 min	Package Handlers
Scanning packages	~2 min	Package Handlers
Programming flight paths	~3 min	Payload Operator
Package Loading	~5 min	Package Handlers
Rolling out UAV from the Staging Areas	~5 min	Aircraft Launch & Recovery
Awaiting takeoff clearance from CUTC	~ 3 min	Air Traffic Managers
Final Takeoff (Power up + Lift off)	~ 2 min	Operational Pilots

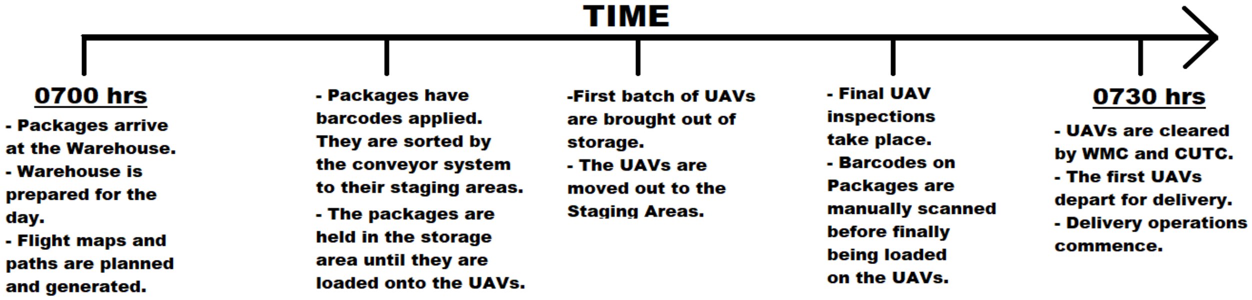
Fig. 43 : Pre Mission Checklist

2) Preparing UAVs:

Once the staging areas are ready for operations, the first departing batch of UAVs will be brought out from the warehouse hangar to the three staging areas by Aircraft Launch and Recovery staff. This will be done before 0730 hours, to ensure timely operations and to avoid delays. Once the UAVs arrive at the staging area, Launch and Recovery Assistants/Package Handlers begin by putting fresh batteries into the UAVs, checking the charge, and completing the final safety and environment checks of the aircraft. Final flight paths are also programmed on the UAV. They will perform a second round of manual scanning before the package is finally loaded onto the UAV. This will notify the clients that their package is about to depart.

After all pre-flight checks are completed at the staging area, the UAV, with guidance and clearance from the CUTC, the Air Traffic Managers, and the Warehouse Mission Control (WMC), proceeds to the “takeoff” area to perform a vertical takeoff. A checklist like the one given, helps give an idea of the approximate time it would take for each task to be completed.

The entire timeline has been summarized in the flowchart given below:



0700 hrs
- Packages arrive at the Warehouse.
- Warehouse is prepared for the day.
- Flight maps and paths are planned and generated.

- Packages have barcodes applied. They are sorted by the conveyor system to their staging areas.
- The packages are held in the storage area until they are loaded onto the UAVs.

-First batch of UAVs are brought out of storage.
- The UAVs are moved out to the Staging Areas.

- Final UAV inspections take place.
- Barcodes on Packages are manually scanned before finally being loaded on the UAVs.

0730 hrs
- UAVs are cleared by WMC and CUTC.
- The first UAVs depart for delivery.
- Delivery operations commence.

Fig. 44: Timeline Flowchart

Overview of all Flights:

Calculating total cycle time for one UAV:

$$Total\ Flight_{time}(F_t) = DeliveryFlight_{time}(Ascent + Cruise + Descent) + ReturnFlight_{time}(Ascent + Cruise + Descent)$$

$$F_t = 791.98\ (rounded \rightarrow 792)\ seconds$$

$$One\ Cycle\ Time\ (C_t) = F_t + 2(LoiterTime) + TurnaroundTime + DeliveryZoneTurnaroundTime + LeewayTime$$

$$C_t = 792 + 2(600) + 600 + 300 + 154\ seconds$$

$$C_t = 3046\ seconds$$

$$C_t = 50\ minutes\ 46\ seconds\ (50.76\ minutes\ approx)$$

Calculating number of flights per UAV per day:

$$Number\ of\ Flights\ per\ UAV\ per\ day\ (N_{flights}) = \frac{Total\ Flight\ Window\ in\ one\ day}{Cycle\ Time\ (C_t)}\ minutes$$

$$N_{flights} = \frac{660}{50.76}\ minutes$$

$$N_{flights} = 13\ (approx)$$

Calculating the UAV fleet size:

With two Takeoff/Landing areas, we chose to have 19 UAVs in the air. (< 20 limit)

$$\therefore Number\ of\ UAVs\ in\ air\ (UAV_{air}) = 19$$

$$Active\ Fleet = UAV_{air} + 3\ (Maximum\ UAVs\ at\ Staging\ Areas)$$

$$Active\ Fleet = 19 + 3$$

$$Reserve\ Fleet = 2$$

$$Size\ of\ Fleet\ (Fleet_{size}) = Active\ Fleet + Reserve\ Fleet$$

$$Fleet_{size} = 22 + 2$$

$$Fleet_{size} = 24$$

$$\therefore Size\ of\ Fleet = 24$$

Calculating number of packages per day:

$$Number\ of\ Packages\ per\ day = Number\ of\ Total\ Flights\ per\ day\ (N_f)$$

$$(N_f) = Number\ of\ Active\ UAVs \times Number\ of\ Flights\ per\ UAV\ per\ day$$

$$(N_f) = 22 \times 13$$

$$(N_f) = 286$$

$$\therefore Number\ of\ Packages\ per\ day = 286$$

Fig. 45: Overview of all Flight

After thorough calculations in conjunction with the Flight Profile Analysis (section 3.2), as depicted in the figure, the team determined several key variables:

1. The total time for one ideal UAV flight + turnaround cycle was found to be about 50.76 minutes.

2. The total fleet size, i.e. the total number of aircraft used, would be 24.
3. The number of flights per UAV per day was calculated as 13.
4. There will be 19 aircraft in the air at one time. (Under the 20 limit as per the challenge.)

Out of the total fleet, 22 would be a part of the Active fleet and two would serve as the Reserve fleet just in case any UAV of the active fleet is unable to operate normally. To prevent the Reserve fleet from losing its operable status after being kept in storage for long durations of time, the two UAVs will be swapped with any two of the Active Fleet, to ensure that all UAVs remain in an operable state.

Warehouse Layout:

The Warehouse Layout was planned with great detail. The package shall be moved consistently and systematically from its supply locale to its demand locale. All important parts of our Warehouse have been marked in the legend along with their respective dimensions.

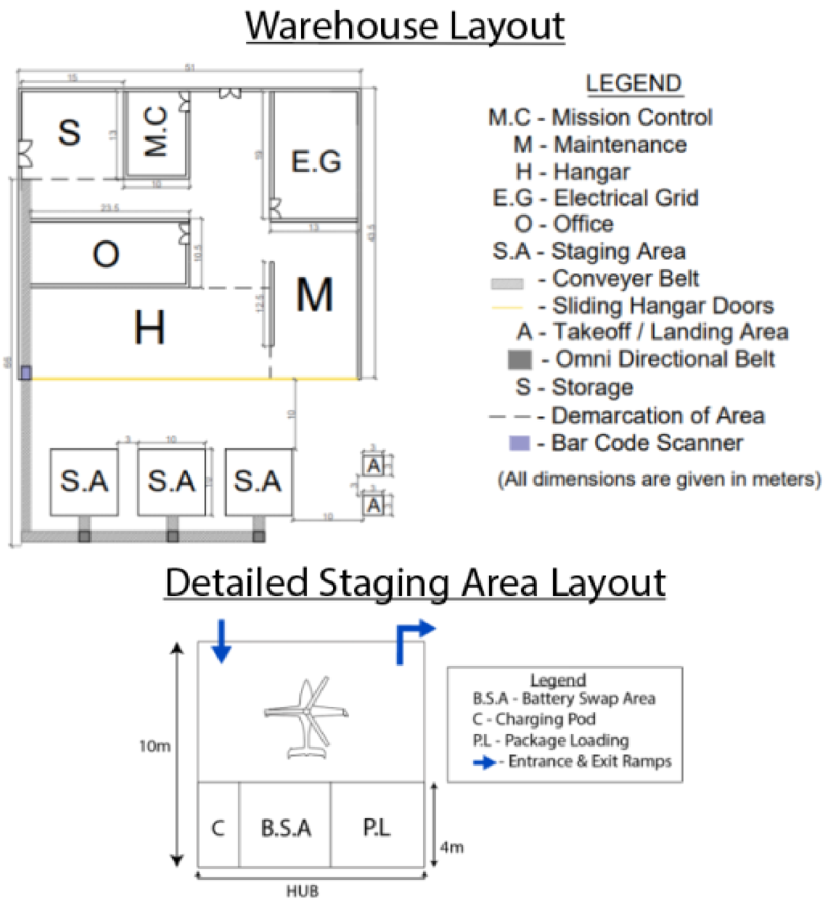


Fig. 46: Warehouse and Staging Area Layout

Our staging area is composed of multiple sub-sections namely, the Battery Swap Area, the Package Loading area, and the Charging Pod. UAVs will be moved in a systematic and organized manner with a pre-determined efficient workflow. A UAV will be brought in from either the warehouse or the landing area (i.e. after a flight) and will arrive at the Battery Swap Area, where the used battery pack of the UAV will be swapped with a fresh one. The used battery packs will be charged by chargers at the Charging Pod. Meanwhile, the UAV, now with fresh batteries, will have the package loaded onto it. A simultaneous set of thorough checks will take place after which the UAV will proceed to the takeoff area for another flight. This “turnaround” process will take approximately 10 minutes and will be comparable to the function of a complex pit stop.

3.1.2 Flight to Delivery Location

Pre-Flight

Several parameters must be met before the flight commences.

1) The Customer must have acknowledged the delivery operation via the company’s app/website and confirmed their presence for receiving the package.
2) All technicians must have given the “All Clear” signal for their respective systems.
3) The UAV must have received clearance to proceed to the Takeoff/Landing area.
4) Permission and clearance should also be received from the CUTC (City UAS Traffic Control), including approval of flight paths and weather information, relayed to each UAV via the Warehouse Mission Control. Once all these criteria are successfully met, the UAV will finally perform a vertical takeoff.

Flight

The UAV will perform a vertical takeoff. Forward airspeed will remain zero until the UAV has reached an altitude of 61 meters, after which the UAV diagonally ascends to the flight corridor altitude of 122 meters (400 feet). At the cruise altitude, the UAV begins accelerating to its cruising speed of 40 m/s(well within the required range of 35-87 knots). The Warehouse Mission Control will have predetermined procedures for managing departing aircraft. The UAV thus enters the cruise phase. The flight maps will have the necessary information for all known obstacles, like buildings, on the flight path. The UAV is also provided with data concerning the positions of other UAVs in the air at that time, hence ensuring that there is sufficient horizontal separation between two UAVs.

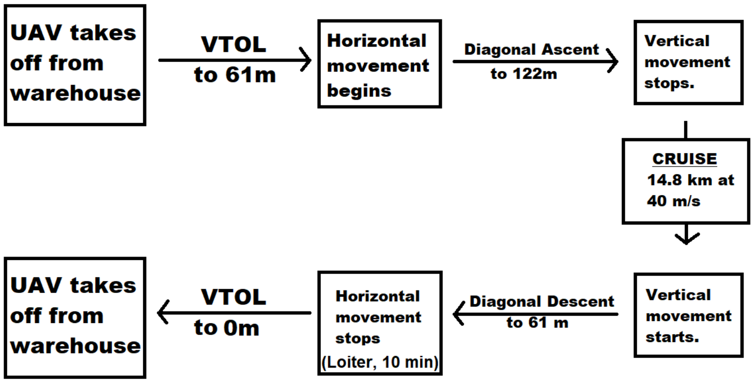


Fig. 47: UAV Path Flowchart

Keeping in mind that there might be unknown moving obstacles in the flight path, the UAV makes use of a comprehensive obstacle avoidance system in detecting such obstacles. A

Safety Pilot is always on standby, ready to take control over from the operating pilot in case of any emergency situations.

The UAVs sensors and cameras are constantly providing real-time feedback as to the position and state of the UAV. The UAV is functioning autonomously during normal flights to the delivery location as per the pre-programmed flight plan, whilst being supervised by the operating pilot. The UAV will travel the 15 km distance in about 6 minutes and 8 seconds at a speed of 40 m/s.

3.1.3 Package Delivery

As the UAV approaches the delivery area, the UAV gradually slows down and descends diagonally to an altitude of 61 m (200 ft). It then enters a “loiter” phase, wherein the UAV hovers above the delivery area until given permission to land. This shall be done within a holding area with a radius of 500 meters. After loitering for 10 minutes and once it is cleared to land, the UAV, upon receiving confirmation of the customer’s availability to receive the package (done via the Company’s website/app), performs a vertical landing at the delivery zone, whilst providing audible signals to alert any city residents in the vicinity as to the landing. Inputs from various sensors combined will ensure a proper landing phase. The entire diagonal descent and landing phase will be carried out within a 100 m horizontal distance from the delivery area.

In the scenario that any of these clearances are not provided, or an emergency occurs, the UAV will abort the landing procedure, and will either continue to loiter for longer or, if necessary, return to the warehouse. Upon having successfully landed at the 3 x 3 m delivery area, the engines will power down. The customer will then proceed to unload the package from the UAV by opening the package bay hatch. The customer shall then confirm the delivery via the company’s website/app, from where this information will be relayed to the UAV. The customer shall then proceed to clear the delivery area. After receiving the “All Clear” signal, the UAV will start its engines, and after being cleared for takeoff by the CUTC, it will perform a vertical takeoff. Thus, the return flight commences.

3.1.4 Return Flight

The UAV, after takeoff, will vertically ascend from the delivery zone up to the flight corridor to an altitude of 61 m, before diagonally climbing to a cruise altitude of 122 m (400 ft) (after following a similar ascent as performed while departing the warehouse) whilst staying within 100 m from the delivery zone horizontally (as required by the challenge). The UAV then enters forward flight, cruising at a speed of 77.75 knots (40 m/s).

While airborne, the UAV is constantly communicating with Warehouse Mission Control (WMC), providing location data and relaying other necessary information to the WMC. The same information is also shared by the warehouse with the CUTC. The UAV will also autonomously communicate with other UAVs, and its obstacle and collision avoidance systems will ensure that adequate horizontal separation is maintained from other UAVs in the region. The CUTC and warehouse will help ensure that the flight path is free of any known obstacles and that the UAV is correctly following the flight route.

Similar to the flight to delivery location, a standard flight plan is followed. Operating Pilots are always supervising the UAV's flight. Safety Pilots shall also remain on standby. As the UAV will no longer have the package (assuming the package was successfully delivered), the weight of the UAV will be significantly lighter. Thus, it will reduce power consumption, and more importantly, allow for a more efficient flight. As the UAV approaches the warehouse, it begins its descent to the loiter altitude of 61 m and loiters for 10 minutes, whilst staying within a holding area. This holding area will also have a radius of 500 meters. The CUTC and the WMC will relay approach directions and vector information, along with clearance data as to when to land at the landing area. Ground personnel, in coordination with WMC, will ensure that the landing area is cleared before the UAV's arrival. In the unlikely circumstance that the landing area is not available due to unforeseen reasons, the UAV will be commanded to loiter/hold above the warehouse until another landing area is available. The UAV will descend from the flight corridor to the loitering altitude with a horizontal distance of 166 meters, well below the 500 meters distance required by the challenge.

Upon receiving final clearance to land from the CUTC, and after being certified to do so by the WMC, the UAV will descend from its loitering altitude and then perform a vertical landing at the landing area. After a successful landing, the UAV will be moved off the landing area and brought to a staging area.

3.1.5 Post-Mission

After Each Flight

After landing and shutting down, the launch and recovery assistants will roll the UAV off the landing area to allow for other UAVs to perform landings. The UAV is then brought over to the staging area, where checks are done on the UAV by launch and recovery assistants. These checks will ensure that all systems and sensors are functioning and are ready to go. If all checks yield no issue, the UAV undergoes the procedures of the pre-mission (highlighted in section 3.1.1) again. Used batteries will be replaced with freshly charged batteries, and used batteries will be placed on the Charging Pod to be recharged. There will be a time difference of about 10 minutes from the UAV touching down to it departing again.

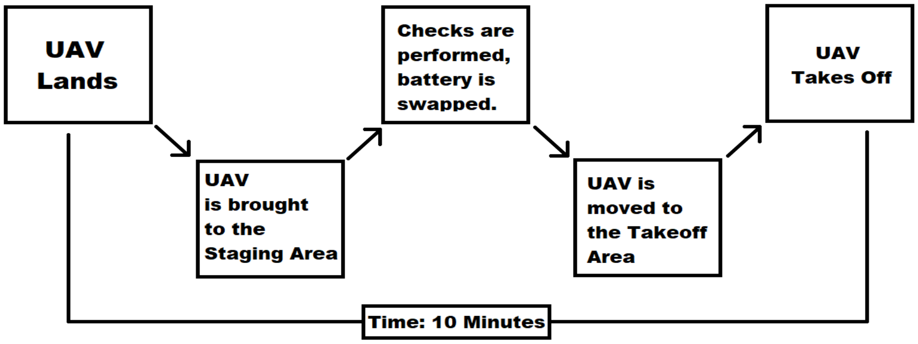


Fig. 48: After Flight Process

After Operating Hours

At the end of operations, all UAVs will be brought to the hangar for overnight storage. Once the last UAV of the operating fleet is brought in, the staging areas and workstations will wrap up operations. Thorough checks and inspections on all UAVs will then be conducted. Undelivered packages will be brought back to the package storage area and will be accommodated for the next operating day. All batteries will be removed from the UAVs for the night.

UAVs that are deemed to require repairs will be operated on by Maintenance personnel. In case the time needed for repairs exceed working hours, the repairs will be continued on the next working day. Once a week, Electricians and Technicians will also visit the warehouse to ensure proper upkeep of all warehouse systems.

Four major levels of repairs will be performed on the UAVs:

Check Type	Frequency	Description
Category 1	Performed after every flight.	These checks ensure that the UAV is in an ideal operating condition.
Category 2	Performed at the start and end of each operational day.	These will be more thorough checks performed to ensure that the operating fleet is ready to go and that there are no UAVs in need of repair.
Category 3	Performed after a UAV encounters an emergency/requires repairs.	Reserved for emergency situations where UAVs are involved in an emergency situation, and require urgent repairs/maintenance after an incident.
Category 4	Performed at the beginning of each month.	These checks will be a complete internal analysis of each component of the UAV fleet and will evaluate the overall status of the fleet.

Table 13: Types of Repairs

3.2 Flight Profile Analysis

Flight profile analysis is a crucial part of flight operations. This year in the challenge statement no map for delivery locations was given, so it was assumed that deliveries were made to locations in a 15km radius. As given in the challenge statement the company is required to keep our speed between 35 - 87 knots, an average speed of 40m/s was chosen (77.75 knots). After taking off from the warehouse, the UAV will ascend to 122m in two phases - Vertical Takeoff and Diagonal ascent.

“Delivery Flight” Phase

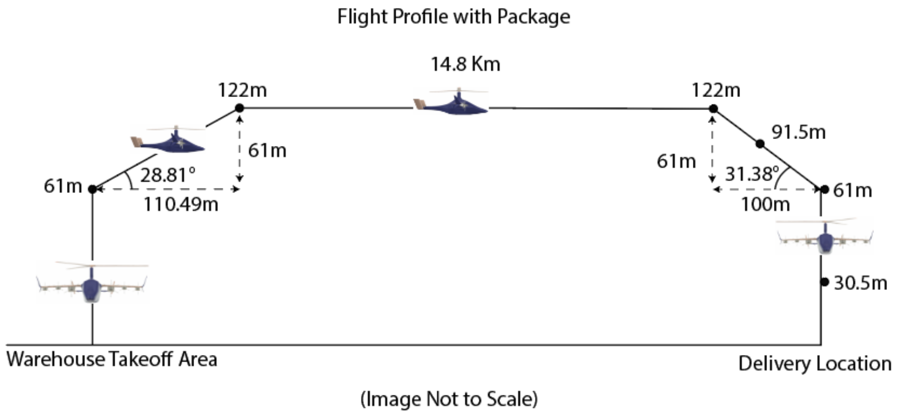


Fig. 49: Delivery Flight

Vertical Ascent

The UAV will vertically take off from the takeoff and landing area located in our warehouse and will ascend to an altitude of 61m. This will be done solely using the main rotor. The main rotor thrust will be fixed at exactly 345N for the entire period. An advantage of having a gyrodyne type design is that the vertical component of the UAVs motion is completely taken care of by the main rotor and the horizontal component is completely dependent on the propellers. Hence, the design doesn’t have to pitch at an angle, instead, the horizontal component of the UAVs movement can be calculated separately and has no bearing on the speed of ascent that was already reached during the initial takeoff.

Diagonal Ascent

Vertical Ascent - At exactly 61m, the thrust delivered by the main rotor will be reduced to 145N. This is exactly 100N less than the minimum hover thrust of 245N, this is to account for the fact that the UAV will have a high initial velocity at 61m, and simply reducing the thrust to hover-thrust levels wouldn’t help, as the UAV would overshoot the target altitude of 122m. To deal with this problem, the power must be reduced before we reach 122m, to below the hover thrust to ensure that the downward force is enough that when the UAV reaches 122m, the velocity of the UAV is exactly 0m/s.Then we will bring the thrust back to 245N at that exact moment to hover at 122m. According to this calculation, both the ascents from 0m to 61m as well as 61m to 122m will take 5.52 seconds each. That brings the total time taken for ascent to 11.04 seconds.

Horizontal Movement - The horizontal movement while ascending only begins at 61m altitude. The calculations done were based on the time it took for the vertical movement from 61m to 122m, and the required final horizontal velocity of 40mD/s. So, in the time that the drone reaches 122m altitude from 61m, it simultaneously reaches its target velocity of 40m/s. This entire process takes exactly 5.52 seconds. The acceleration during this time was calculated to be 7.24 m/s², which means that the total propeller thrust (accounting for drag) would be 296N.

Angle of Ascent

$$\tan\theta = \text{Vertical Distance} \div \text{Horizontal Distance (Perpendicular} \div \text{Base)}$$

$$\tan\theta = \frac{61}{110.34}$$

$$\theta = 28.81°$$

Cruise

The aircraft will have reached a cruise velocity of 40m/s. For the cruise phase the thrust will be reduced significantly since the objective is not to accelerate any further but just to maintain the UAVs velocity at 40m/s. The thrust will be adjusted to just counter the drag force on the UAV, hence the propeller thrust in this phase will be 115N.

Diagonal Descent

1. Horizontal Deceleration- While it starts descending vertically from 122m to 61m, the UAV will also simultaneously have to reduce its velocity from 40m/s to 0m/s horizontally. For this, the propeller power will be turned off and air brakes will be engaged to increase the drag by 85N. By drag force, the UAV will come to a stop at the required destination after continuing to cruise at a decelerating pace for 100m. Hence, the UAV reaches the loitering altitude with a horizontal velocity of 0m/s and vertical velocity of 0m/s, thus hovering at an altitude of 61m. It will take 5 seconds for the horizontal movement of the UAV to come to a stop.

2. Vertical Descent - The UAV will descend from 122m to 61m and loiter there for 10 min, after that it will make the final descent to the ground for package delivery. There are two phases in the vertical descent, first the thrust is reduced to 145N till the UAV reaches 91.5m altitude, at this point, the rotor thrust is increased to 294.75N so that it comes to a stop at exactly 61m , where the thrust is maintained at 245N to loiter. A similar thrust reduction and subsequent increase pattern is followed in the descent from 61m to 0m, where the altitude where the thrust is changed becomes 30.5m instead of 91.5m. By this method, the velocity of the UAV reaches exactly 0m/s at 0m altitude. The vertical movement of the UAV from 122m to 61m as well as 61m to 0m takes 8.3 seconds each. Since the time taken for vertical movement from 122m to 61m is slightly more than the horizontal movement, the vertical movement will continue for a few seconds, even after the destination is reached horizontally.

Main Rotor Power Calculations for Vertical Ascent

For a 25 Kg UAV the minimum hover thrust was calculated to be 245N. It was found through calculations that the ideal thrust at which the UAV shall ascend is 345N, which would give a thrust to weight ratio of about **7 : 5**

$$P = K.M^{3/2}/r$$

The table below shows the mathematical representation of different thrust levels and accelerations the UAV would reach and the power that it would consume:

Thrust	Acceleration	Power consumption
115N	0m/s²	0.186 kW - Small Propeller 0.228 kW - Big Propeller
145N	-4m/s²	0.76 kW
245N	0m/s²	1.68 kW
294.75N	1.99m/s²	2.22 kW
296N	7.24 m/s²	0.771 kW - Small Propeller 0.945 kW - Big Propeller
345N	4m/s²	2.82 kW

Table 14: Thrust values for Delivery Flight

“Return Flight” Phase

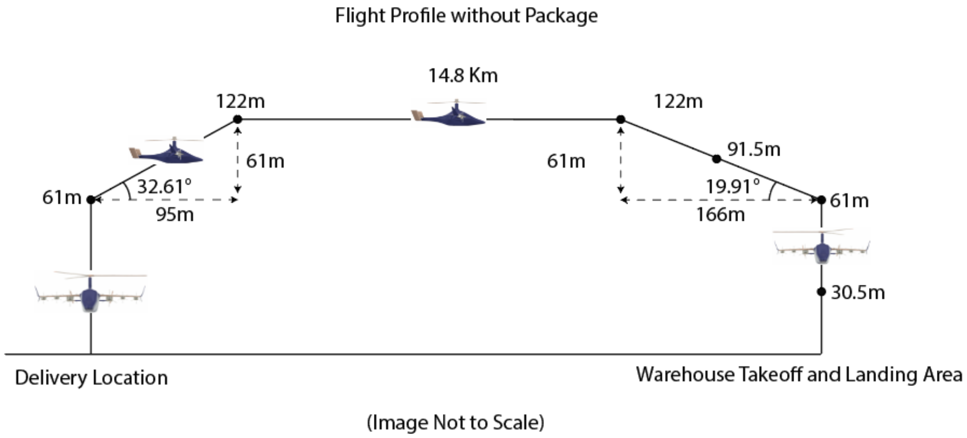


Fig. 50: Return Flight

Vertical Ascent

Same as last time, the UAV will initially lift off from the delivery zone vertically to 61m and then begin its horizontal movement. This time, since the UAV weighs 5 kilograms less, the hover thrust is reduced to 196.13N. 304.13N of thrust is generated during vertical ascent to generate an upwards acceleration of 5.4m/s².

Diagonal Ascent

1. *Vertical Ascent* - At exactly 61m, the thrust delivered by the main rotor will be reduced to 88.13N. This is exactly 108N less than the minimum hover thrust of 196.13N. According to this calculation, both the ascents from 0m to 61m as well as 61m to 122m will take 4.75 seconds each. That brings the total time taken for ascent to 9.5 seconds.
2. *Horizontal Movement* - The horizontal movement while ascending only begins at 61m altitude. The calculations done were based on the time it took for the vertical movement from 61m to 122m, and the required final horizontal velocity of 40m/s. So, in the time that the drone reaches 122m altitude from 61m, it simultaneously reaches its target velocity of 40m/s. This entire process takes exactly 4.75 seconds. The acceleration during this time was calculated to be 8.42m/s², which means that the total propeller thrust (accounting for drag) would be 283.4N.

Angle of Ascent

$$\tan\theta = \text{Vertical Distance} \div \text{Horizontal Distance (Perpendicular} \div \text{Base)}$$

$$\tan\theta = \frac{61}{95}$$

$$\theta = 32.61°$$

Cruise

The cruise phase without the package will be identical to the previous one.

Diagonal Descent

Vertical Descent - The UAV will descend from 122m to 61m and loiter there for 10 min, after that it will make the final descent to the ground for package delivery. There are two phases in the vertical descent, first the thrust is reduced to 116.13N till the UAV reaches 91.5m altitude, at this point, the rotor thrust is increased to 235.75N so that it comes to a stop at exactly 61m , where the thrust is maintained at 196.13N to loiter. A similar thrust reduction and subsequent increase pattern is followed in the descent from 61m to 0m, where the altitude where the thrust is changed becomes 30.5m instead of 91.5. By this method, the velocity of the UAV reaches exactly 0m/s at 0m altitude.

Horizontal Descent - While it starts descending from 122m to 61m, the UAV will also simultaneously have to reduce its velocity from 40m/s to 0m/s horizontally. For this, The propellers will stop and air brakes will be engaged to increase the drag by 85N. By drag force, the UAV will stop at the required destination after decelerating for 166m. This will take exactly the same time as it does for the UAV to go from 122m to 61m. Hence, the UAV reaches the loitering altitude with a horizontal velocity of 0m/s and net vertical velocity of 0m/s, coming to a stop at an altitude of 61m.

Both the descent processes from 122m to 61m, and 61m to 0m take 8.3 seconds each, bringing the total descent time to 16.6 seconds.

Main Rotor Power Calculations for Vertical Ascent

For a 25 Kg UAV the minimum hover thrust was calculated to be 196.13N. It was found through calculations that the ideal thrust at which the UAV shall ascend is 304.13N, which would give a thrust to weight ratio of about **7 : 5**

$$P = K.M^{3/2}/r$$

Thrust	**Acceleration**	**Power consumption**

115N	0m/s²	0.186 kW - Small Propeller 0.228 kW - Big Propeller
88.13N	-5.4m/s²	0.55 kW
196.13N	0m/s²	1.2 kW
235.75N	4.82m/s²	1.59 kW
283.4N	8.42m/s²	0.634 kW - Small Propeller 0.778 kW - Big Propeller
304.13 N	5.4 m/s²	2.02 kW

Table 15: Thrust values for “Without Package” Phase

Loiter Phase/Crosswind

After descending from 122m to 61m, the UAV will loiter for 10 minutes at an altitude of 61m. As per the challenge, there is a 10kt (5.14m/s) crosswind perpendicular to the aircraft’s arrival direction to the holding area in the loiter phase of the flight. To counter this crosswind the team thought and finalized on a new system to counter crosswind during this loiter phase. The team decided that the UAV would be equipped with wind speed and ground speed sensors, which are utilized with a doppler radar based system to calculate the drift angle of the UAV while countering the crosswind. This whole system works based on an algorithm which detects the 10kt winds and commands an automated correction of the deviation of the UAV by hard yawing, which is done by utilizing the rudders and ailerons. With the help of this system, the UAV, upon being cleared, will perform a landing while countering the crosswind.

Similar to how an MCAS system is used to lower the angle of the Boeing 737 Max if it goes into a high pitch-up situation, our system, instead of dealing with pitch, efficiently deals with yaw movement while countering the crosswind.

According to calculations it was found that to counter the effect of the wind on the fuselage about 15N of thrust will have to be exerted. Through this measure the UAV will be able to maintain its position without drifting or moving vertically.

After the power calculations, the team found that the UAV had a power requirement of 2.733 kWh including all onboard sensor components. The power used by the propellers for the anti-torque system is included in the highest power used by the propellers. With the calculations, it was computed that the UAV would require a battery that could provide at least 61.55 Amp Hours. (refer to the figure)

The team deemed a battery pack of three MaxAmps 12S 22Ah 44.4V batteries to be the most viable option, as these are capable of being fast charged, and having three of them adequately satisfied our power requirements. The three batteries together provide 66 Ah, which is more than the 61.5 Ah requirement that was computed by the team.

With these batteries, it was concluded that the UAV could fly for 50.76 minutes. An EV-Peak A9 12S DC Balance Charger could charge each of these batteries in 40 minutes. The weight of one battery is 1000g, and thus the entire battery pack weighs three kilograms per UAV.

3.3. Safety Requirements

3.3.1 Lost Link Protocol

A constant communications link shall be maintained between Warehouse Mission Control (WMC) and the UAV. Any discrepancies in this link will be promptly noticed due to the interconnectedness of our system.

In the case a partial loss of communication is experienced, the UAV will “realize” so due to a clear absence of acknowledgements from WMC. It will try to self-diagnose the problem and attempt to re-establish the link with WMC. The aircraft operator/air traffic manager, upon being first notified of this disruption (likely due to the disrupted data feeds) will ensure that the CUTC is immediately informed. The UAV’s situation will be quickly evaluated, and technicians will try their best to troubleshoot issues with the aforementioned link. Meanwhile, the UAV will compute the coordinates of the Last Known Position (LKP) at which the UAV had an established link. This information will also be available to WMC and will prove to be helpful in the event of a coordinated search-and-rescue operation. The UAV will continue flying as it was before the communication was lost for a predetermined safety period. In most cases, the link will be re-established by the end of this phase itself.

If the link cannot be re-established or the UAV cannot be communicated with altogether, the UAV will be considered to have undergone a total loss of communication. Based on the previously determined LKP data, the UAV will calculate which end-point (either the delivery area or the UAS Airfield) is closer. Simultaneously, the UAV will perform a self-diagnosis of all systems and will try to broadcast an emergency signal with status information via VANET if possible (as described in section 2.3.2). Other UAVs in the vicinity will be able to detect this “lost” UAV (which will be a part of the DAA model as explained in section 2.3.3), and will subsequently relay any new information to the WMC. After the safety period elapses and the emergency signal has been successfully broadcasted and acknowledged, the UAV will follow a pre-programmed route to the closest destination, assuming that all systems are functioning.

During a total and complete loss of communication (and no emergency signal being broadcasted/the signal not being acknowledged), the UAV will abort the delivery and attempt an emergency return to the UAS Airfield, provided that a safe flight is still possible. It is important to note that this “lost” UAV will gain priority status over other UAVs, and will be able to bypass loitering times to ensure a safe landing. If the airworthiness of the UAV is compromised altogether, it will perform an emergency landing as highlighted in section 3.3.3. WMC will attempt to locate the UAV using any information available, and based on its evaluation, will dispatch a recovery team if the UAV is considered completely untraceable. A flowchart illustrating this process is given below:

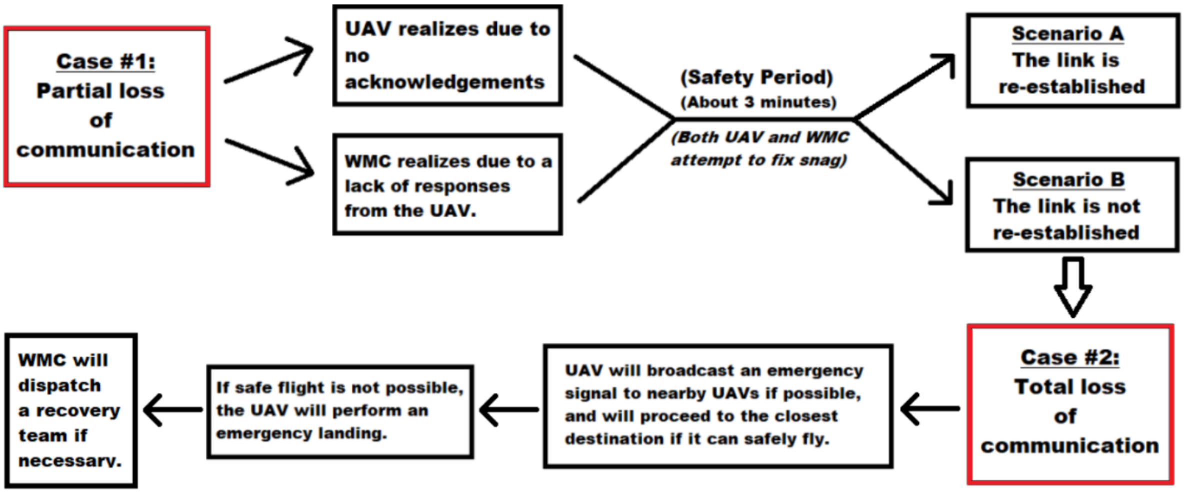


Fig. 51: Lost link Protocol

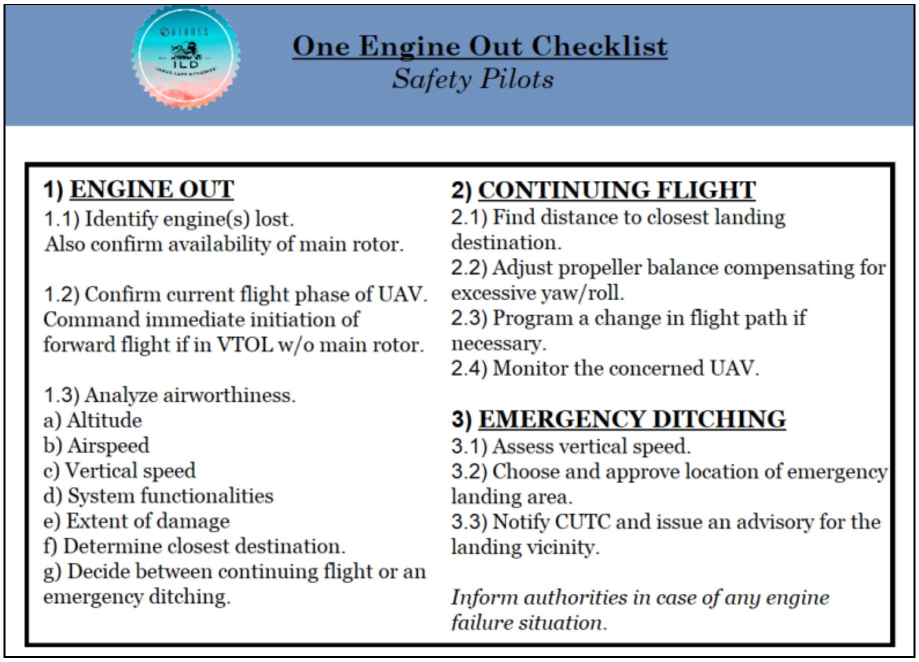
3.3.2 One Engine Out Condition

As the C-25 Sigma has six propellers and a fixed-wing design, the team believes that there are enough redundancies in our system to prevent a one engine out condition from affecting the airworthiness of the UAV. A variety of scenarios were considered systematically to ensure that our aircraft were prepared for as many situations as possible. In the case that one engine experiences failure, other engines will begin compensating.

Acknowledging that an engine failure may occur at any flight phase, in most cases, the UAV will be able to resume routine flight without any major issues and will be able to return to the UAS airfield safely. If the aircraft experiences an engine failure before the halfway point during any flight, it will return to the location where the flight originated from. If the aircraft has passed the halfway point, it will continue to its original destination.

If more than one engine fails and maintaining flight becomes impractical, the UAV will begin gliding and gradually descend. If the main rotor is available, it can assist in this process by generating lift until the UAV is low enough to enter a semi-powered/unpowered glide. If the main rotor is unavailable, the UAV will immediately enter a powered glide provided that all propellers are functioning.

Another scenario that was thoroughly examined was the failure of the main rotor during the VTOL phase. Assuming there will be a sufficient altitude, all propellers would fully engage providing forward thrust, to prevent the UAV from entering an uncontrolled free-fall. If the main rotor fails during the loiter phase, the UAV will employ a similar procedure as described for the VTOL phase and will enter a powered glide. If a safe landing cannot be guaranteed, and, in that case, will perform an emergency landing instead.



One Engine Out Checklist
Safety Pilots

1) ENGINE OUT
1.1) Identify engine(s) lost.
Also confirm availability of main rotor.

1.2) Confirm current flight phase of UAV.
Command immediate initiation of forward flight if in VTOL w/o main rotor.

1.3) Analyze airworthiness.
a) Altitude
b) Airspeed
c) Vertical speed
d) System functionalities
e) Extent of damage
f) Determine closest destination.
g) Decide between continuing flight or an emergency ditching.

2) CONTINUING FLIGHT
2.1) Find distance to closest landing destination.
2.2) Adjust propeller balance compensating for excessive yaw/roll.
2.3) Program a change in flight path if necessary.
2.4) Monitor the concerned UAV.

3) EMERGENCY DITCHING
3.1) Assess vertical speed.
3.2) Choose and approve location of emergency landing area.
3.3) Notify CUTC and issue an advisory for the landing vicinity.

Inform authorities in case of any engine failure situation.

Fig. 52: One Engine Out Condition Checklist

In all scenarios, the UAV will notify the air traffic managers (Mission Control) at the Warehouse, who shall initiate emergency protocols if required. Safety Pilots will take over control from the operational pilots and will begin guiding the UAV. A safety checklist to be followed by the Safety Pilots has been provided in the adjoining figure. An emergency landing will follow (as explained in section 3.3.3)

3.3.3 Emergency Landings

Emergency landings serve as a last resort, and such a situation will only arise when the airworthiness of the UAV is completely compromised. If an emergency landing is required due to any issues with the aircraft, the operational pilot will immediately be notified. As the proposed design is a fixed-wing based design, the aircraft will be capable of gliding. Ensuring that the UAV does not injure any people on the ground was deemed to be paramount. The UAV and the Safety Pilot will actively ensure that no people or obstacles are in the way by using the information from the various cameras and sensors while performing the descent/landing.

The emergency landing procedure will commence right after the UAV has either been approved/commanded to do so or has suffered sufficient damage to require one urgently, and will only be the final resort for the UAV. It will have scouted a predetermined landing area, which it shall aim for beforehand. This will be based on a variety of factors like the distance from the warehouse, and the population of the area the UAV is flying over.

The UAV commences its emergency landing by initially gliding in a gradual descent. The main rotor, if available, will provide lift until the altitude of the UAV is less than 10 meters, after which the main rotor will shut down and will be stopped completely by an internal mechanism. The UAV will finally pitch its nose up to reduce its speed about five meters before touchdown to avoid damaging the surroundings and its fuselage by crash-landing at a high speed. Our ducted propeller design will ensure that the blades, which will be turned off and thus not spinning before touchdown, do not strike the landing surface or any objects on the ground. Other solutions like parachutes were initially considered as a safety measure but were subsequently rejected due to their physical impracticality.

Once the UAV has finally touched down, the recovery team will be instructed to retrieve the aircraft. The UAV will continue to give out auditory and visual signals until the UAV has completely stopped moving. The subsequent recovery process will be prioritized by the recovery team and will be done urgently to prevent unauthorized personnel from accessing the aircraft while it is unattended.

Emergency Components

To alert anyone in the vicinity of a UAV performing an emergency landing, the team decided to add components for providing clear auditory and visual cues.

Name	Cost	Weight	Description
YoungRC JHE20B Buzzer	$5	2 grams	This loud buzzer will emit an auditory signal at 100 db, alerting people in a 125-meter radius.
Lume Cube Strobe Light	$40	10 grams	This is a powerful strobe light providing visual cues with a one-hertz fast strobe, visible for long distances.

Table 16: Emergency Components

3.3.4 Regulations and Additional Safety

Our UAS' compliance with the Federal Aviation Administration (FAA)'s current regulations has been summarized in the table below:

FAA Regulations (Part 107)	Satisfied (Yes/No)	Additional Information
The unmanned aircraft must weigh less than 55 lbs. (25 kg)	Yes	Our UAV weighs under 25 kgs.
Regulation § 107.25: Operations not under a covered structure.	Yes	Our UAS will function outdoors. No operations (flights) will be conducted within a covered structure or a covered stationary vehicle.
Regulation § 107.29: Daylight-only operations, or during civil twilight.	Yes	Operations will be conducted during daylight hours only.
Regulation § 107.37(a): Right of Way must be yielded to other aircraft.	Yes	The UAV shall yield right of way to other aircraft as and when required.
A maximum altitude of 400 feet above ground level (AGL).	Yes	The UAV will cruise at the highest permissible altitude as per the challenge (i.e. 400 feet).
Requires preflight inspection by the pilot in command.	Yes	The aircraft will be thoroughly inspected before flights by multiple personnel, including the pilot in command (operating pilot).
At all times the small unmanned aircraft must remain close enough to the pilot such that the pilot can control the aircraft with unaided vision.	No	As required by the challenge, at 15 km away, it is not physically possible to view the UAV with unaided vision.

Table 17: FAA Regulations

FAA Regulations Part 135

Our UAS also complies with Part 135 of the FAA's regulations, as the company owns the warehouse. Our aircraft will be solely used by our company and there is a workforce with designated roles for management personnel. Maintenance requirements are also adhered to, with frequent inspections conducted as prescribed in the Department of Transport's General Operations Manual and General Maintenance Manual. An aircraft flight manual will also be provided by the company as required by Part 135's standards. A minimum equipment list, as stated in the FAA guidelines, will be provided as well.

Additional Safety Measures

Several additional safety measures have been integrated into our design. The UAV combines the safety protocols of a multirotor design and the functionalities of a fixed-wing aircraft. Some other salient features are:

Multiple Propellers/ Distributed Propulsion: Having more motors means a lower probability of all forms of propulsion failing.

Collapsible Landing Gear: The Landing Gear will collapse upon impact, thus saving the fuselage from direct impact and subsequent damage.

4. Business Case

4.1 Cost Analysis

4.1.1 Operating Costs

Tasks	Description	Cost Per Day
Cost of Wages	There are over 20 employees coming daily. Human Resources have been selected keeping in mind all tasks.	$6675.5
Cost of Fuel	Cost of buying electricity from the conventional source/government on average was $0.125/kWh. Electricity has been accounted for all flight operations throughout the day.	$88.82
Cost of Communications	T-mobile Magenta MAX plan is chosen, which provides unlimited 4G LTE data service at the cost of $40/line for five lines. Pricing for 25 lines would be $2.73 per day.	$2.73
Cost of Hub/Maintenance	565m² (including hub, staging areas, UAVs etc) at $17.22/m²/year. (FSP's Average Client Facility Costs (n.d))	$26.68
Inventory Management System	NetSuite Inventory Management System is used to operate systematically. $99/month is spent to access this. (CPA, 2021)	$3.33
Miscellaneous Budget	These account for unprecedented situations and rise in costs of raw materials.	$20.00
Total Cost	Cost of Wages + Cost of Fuel + Cost of Communications + Cost of Hub/Maintenance + Inventory management System + Miscellaneous budget	**$6817.06**

Table 18: Operating Costs

Cost of Wages

Roles	Number of Employees	Duration Per Day	Wages Per Day
Air Traffic Manager	3	11 Hours	$1155
Supervisor	1	12 Hours	$350
Operational Pilot	5	11 Hours	$1925
Electrician/Technician	1	1.5 Hour	$25.50
Emergency Responders	2	11 Hours	$330
Safety Pilot	2	11 Hours	$770
Payload Operator	2	11 Hours	$770
Range Safety/Aircraft Launch & Recovery/Maintenance Recovery	2	11 Hours	$770
Launch and Recovery Assistants/Package Handlers	3	11 Hours	$495
Janitor	1	6 Hours	$85
Total	22	-	**$6675.5**

Table 19: Cost of Wages

- ➔ The operating cost per day is **$6817.06**
- ➔ Human resources is one of the most crucial areas of the plan. The company does not want to compromise on our services due to a sudden shortage of employees in unprecedented situations. Thus, sufficient employees have been kept to ensure smooth operations of the hub and the sub-systems, (Salaries, 2021).
- ➔ Operating Costs per Delivery:

  286 deliveries are made per day (as explained in section 3.1.1).

  The operating costs per delivery = $\frac{Total\ operating\ cost\ per\ day}{Number\ of\ deliveries} = \frac{\$6817.06}{286}$ = $23.83

4.1.2 Fixed Costs

Equipment	Description	Cost
Airframe Costs*	Includes the materials, batteries and motor used per UAV.	$4078.03
Delivery Mechanism Costs*	A hatch will be used as a delivery mechanism, which has already been accounted for in the material cost.	(included in material cost)
Sensor Costs*	Includes all the sensors of the UAV (detection and obstacle avoidance sensors).	$1071.30
Command Control Communication Costs (C3)#*	Includes onboard and offboard equipment that is used to communicate between the controller and the aircraft.	$1041.58
Support Equipment Costs #	Includes additional equipment required for our system such as conveyors.	$12013.00
Emergency Equipment Costs*	The emergency components include a buzzer and a light that will assist in alerting bystanders of the UAVs emergency landing.	$45.00

Table 20: Fixed Costs

** These costs correspond to one single UAV.*

 # These costs correspond to the entire operational setup.

- ➔ The cost per UAV is **$6235.91**
- ➔ With a fleet of 24 UAVs, the total cost for the UAVs is **$149,661.84**
- ➔ The net cost for support equipment is **$12,013.00**
- ➔ Total fixed cost is $149,661.84 + $12,010.00 = **$161,674.84**

4.2 Amortization

This section provides an overview of the final costs for the company as well as the clients.

Number of Deliveries Annually = Number of deliveries per day × Total number of days

= 286 × 365 = **104,390 deliveries**

- ➔ **Operating Cost per Year** = Operating cost per day × Total number of days

  = 6817.06 × 365 = **$2,488,226.90**

- ➔ **Fixed Cost** = Cost of 24 UAVs + Cost of support equipment

  = $149,661.84+ $12,010 = **$161,671.84**

➔ **Total Cost for the Year** = Fixed cost per year + Operating budget per year

= **\$161,671.84** + **\$2,488,226.90** = **\$2,649,898.74**

➔ **Amortized Cost** = $\frac{Fixed\ Cost}{365 \times No.\ of\ flights\ per\ day}$ + Operational budget per delivery

= $\frac{\$161{,}671.84}{365 \times 286} + \$\,23.83$ = **\$25.38**

Hence, it will cost the company **\$25.38** to fly each mission.

4.3 Pricing

The team calculated the amortized cost and discussed various potential profit margins. Furthermore, the team imposed a suitable profit margin that was in accordance with a round figure selling price for the service.

➔ **Profit Margin** = **18.16%**

➔ **Profit per Delivery** = $\frac{\%\ Profit}{100}$ × Amortized cost

= 0.1816× \$25.38 = **\$4.61**

➔ **Total Cost for a Delivery to a Customer** = Amortized cost + Profit per delivery

= \$25.38 + \$4.61 = **\$29.99**

➔ **Net Revenue for the First Year** = 104,390 x \$29.99 **\$3,130,656.10**

➔ **Net Profit for the First Year** = Profit per delivery × Number of deliveries

= \$4.61 × 104,390 = **\$481,237.9**

Despite a low profit margin, our net profit for the first year is high. We approached a strategy of decreasing our costs and increasing our volume. Since the fixed costs would already have been accounted for in the first year, supplemented by greater business outreach, the profit margin would increase substantially with time. With a highly fast delivery service at a relatively much lower cost, we believe that our model will stand out

4.4 Justification of Price and Cost/Benefit Analysis

4.4.1 Pricing Justification and Comparison

Walmart has partnered with DroneUp to deliver food items and childcare essentials in Arkansas. This service charges a delivery fee of \$10 for a 1.8kg package (heaviest item available) (Hollister, 2021).

Our company is not limited to any range of products and can deliver packages of 5 Kilograms to a large distance of 15km for $29.99. Whereas, the above-mentioned company charges highly for just a small weight to a limited clientele. It can also be seen that there will be profit distribution in the two partner companies. By keeping its profits independent, the company will be more profitable.

Company *Biryani* is a UAV delivery enterprise that delivers general packages to clients. They charge $150 per delivery for a 5 kg package at a maximum range of 5 km within Orlando, Florida. The company offers deliveries up to thrice the distance (15km versus 5km) at a fifth of the cost ($29.99 versus $150).

Although our company has a much lower profit margin, such competitive pricing will result in a higher volume of customers purchasing these services. Hence, in the long run, our company will be more profitable than Company *Biryani*.

The following gives information on why our company would be preferred over traditional delivery companies:

The rates of traditional delivery offered by Clementine Couriers, Inc. were calculated for the five boroughs of New York City with Manhattan as the starting point. The cost of a single 1-hour delivery (weight: 5 kilograms) lies between $45 and $75 ($1 per zone crossed in Manhattan; $4 per mile covered in the outer boroughs; plus an additional $25 for deliveries via The Manhattan Bridge). (Rates, n.d.)

The charges for Parcelmonkey, a well known traditional delivery company, were calculated for a package weighing 5 kilograms with dimensions of 0.5m×0.5m×0.25m for a distance of around 15 km. The company was charging the customer $20.85 for delivering the package within 1-5 working days. (parcel monkey, n.d.)

As observed, there is huge variability in the prices of the traditional delivery market. In most of the companies, either the costs are high for fast deliveries or the costs are low but the delivery speed is slow. Whereas, the company delivers packages within 50.76 minutes and has a comparatively lower and competitive cost of just $29.99.

It is important to note that there are additional costs that need to be paid by the courier service companies due to the involvement of drivers in their delivery operations. In the case of deliveries using UAVs, this expenditure is null.

The team believes that the following strategies would make customers prefer our company:

- ➔ The team calculated, analyzed, and considered various profit margins ranging from 5% to 150%. Although some options were very lucrative and luring, the team decided to go with a **relatively low and extremely competitive profit margin** of **18.16%**.

This was done in order to keep the service attractive and accessible to potential business partners/clients of various capital sizes and backgrounds.

There is growing competition and lots of potential in the commercial drone delivery market, and thus decided to keep a low, yet highly competitive profit margin. Additionally, **this strategy would enable us to acquire more clientele** as compared to our competitors. This will lead to an increase in the volume of production and hence, expansion of business.

The company has also incorporated a strategy of **rewarding frequent clients**. It has been elaborated upon further in the proposal. (Refer to section 4.4.2)

As compared to the current drone delivery systems, the cost of $29.99 is highly affordable. There likely is a large proportion of the market that is willing to pay this price.

4.4.2 Cost/Benefit Analysis and Justification

The core of the UAV is composed of Carbon fiber, a premium material, to ensure maximum safety. However, keeping costs in mind, a large portion of the UAV is also composed of Aluminum. It is durable and relatively much cheaper than other materials. Since a considerable portion of the budget was spent on Carbon fiber, the electrical components were chosen accordingly. In addition to fixed costs, the team aimed to reduce variable costs as much as possible as they were largely adding to our cost price per delivery. An equilibrium was sought out keeping in mind the quality of our service.

Furthermore, there were also a few tactical strategies incorporated:

Rewards to Regular Clients

The team planned to initiate a system of rewarding our clients based on the number of deliveries to their accounts. This is a tactic to attract large scale businesses towards the company's services. A frequent client will be rewarded with discounts on deliveries after successfully completing a particular number of orders with the company.

Conventional Electricity Supply Over Solar Panels

Present-day solar panels offer an efficiency of around 11-15%. This suggests that solar cell technology has a large scope for improvement. It was also calculated that the investment in solar panels will be compensated by the savings generated after a period of six and a half years. It was estimated that the cost of installing solar panels would be around $350,000 to $400,000 + maintenance costs. This would be an uneconomical choice for our power source.

Drone Insurance

A company like ours, with high returns on investment and apt safety measures, would be more suited to self-insuring drones. Thus, the company would not require any external UAV insurances, which are often very costly and unnecessary as the probability of our UAVs failing is quite low.

Maximizing Drone Deliveries

The team calculated an optimal way to plan, spread, and maximize drone deliveries over working hours (refer to section 3.1.1). Furthermore, the company minimized slack time altogether by ensuring that all UAVs have a low, yet adequate time difference between two delivery cycles. This enabled us to carry out 286 deliveries per day, enabling us to increase profits substantially. This would help us break even at an early stage.

5. Conclusion

Indus-Luft Dynamics firmly believes that the C-25 Sigma is a game-changing UAS solution for all package delivery needs in urban areas. As technology advances, the world is coming closer together, and our UAV aims to facilitate this. By making deliveries more efficient, our design aims to revolutionize the delivery industry.

We’ve streamlined systems and reduced time between operations. We’ve maximized the number of packages we can deliver within a certain span of time. The true value of the fusion of human resources and technology has also been realized, resulting in an effective workflow. The team has also deliberated on a unique business model with an extremely competitive pricing strategy whilst having significant profits. Various innovative choices have been made to maximize profits, be it the usage of a conveyor system, or the usage of Carbon Fiber in materials. The comfort of city residents has also been kept in mind, with a higher cruise altitude ensuring that noise levels are not high. Having an electric system also minimizes our impact on the environment, and is a step towards lower carbon emissions.

Furthermore, contingencies have been added wherever required using state-of-the-art obstacle avoidance systems and various detection-and-avoidance measures. Safety is our top priority, and thus the quality of the components and systems has been carefully chosen. The result is a thorough and reliable flight profile. Key elements of the design have been chosen in accordance with our project goals: A Gyrodyne based design is implemented as it offers a perfect balance between the functionalities of a helicopter and a fixed-wing design, improving efficiency whilst also demonstrating significant VTOL capabilities. The inclusion of ducted propellers has improved performance as they offer more thrust per revolution and thoroughly comply with safety requirements. In addition, Split Scimitar Winglets have been chosen because these drastically improve the range of the flight by reducing induced drag, thus, helping us to achieve our 15 km flight target.

Ease of use of the UAS is a priority for Indus-Luft Dynamics. The company's app/website aims to bridge the divide that exists between delivery services and clients while remaining intuitive and easy to use.

Our simple yet highly innovative solution to the roadblocks that plague delivery services worldwide, promises to usher in a new era of drone deliveries and can adapt to almost all urban layouts. Given the significant advantages of our system, it would not be far-fetched to imagine a future where almost all deliveries are unmanned, and an age where transportation systems will be more connected by UAVs than ever.

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