Unmanned Vertical Lift for Medical Equipment Distribution

Final Design Review

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Executive Summary

This report provides a comprehensive methodical design of an autonomous flying vehicle, for the purpose of transporting medical supplies. Current medical supply transportation infrastructure lacks the ability to adequately service the rapidly growing industry, especially in times of crisis. To help solve this issue, this report details the design of an unmanned drone which can carry a fifty-kilogram payload for fifty kilometers, in twenty-eight minutes. The drone is also capable of transporting a fifty-kilogram payload for two hundred kilometers in seventy-five minutes or less, all while flying at an altitude of up to one thousand meters. Since the medical field often involves emergencies, the drone is designed to load and unload the payload quickly. Methods of analysis include the DMAIC approach, which was implored in order to proliferate the design process. TOPSIS analysis and flow simulation were analysis methods used as well. The final design is a VTOL craft, with a rotating wing design which allows the craft to take off and hover like a helicopter, but also fly horizontally like a traditional plane. The final weight of the craft is 198.56 kilograms, excluding the payload. The aircraft is electric and powered via lithium sulfur batteries. The aircraft carries the payload on the underside of the fuselage, via a system of brackets which raise and lower between the landing gear to drop off this payload at its destination autonomously. This design has the potential to completely change the way medical supplies is transported, and in turn increase efficiency in the medical field. While it is still just a design, this craft can be built, refined, and used in the real world with further optimization.

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1. Chapter 1:

1.1 Introduction

Autonomous vehicles provide a promising future in the world of personal convenience. Whether it be delivering packages or a daily bus route, removing the need for operators who can become fatigued after long hours and a hazard to the public is quickly becoming reality. With the recent outbreak of COVID-19, getting medical supplies from warehouses to hospitals and other locations has been a significant challenge and one that has resulted in more people contracting the disease from lack of proper medical equipment than current society should allow. Vertical lift technology, specifically vertical takeoff and landing (VTOL) aircraft is a promising approach to delivering medical supplies effectively to the communities in need. When paired with autonomous capabilities, medical supplies can be delivered to most urban areas and dropped off for safe and contactless distribution. Not only can this provide relief for the current pandemic, but future disaster relief can reap the benefits of this system and eventually lead to commercialization of autonomous delivery systems.

1.2 Overview

This document goes over the progress made towards making a VTOL aircraft that will carry medical supplies approximately 200 kilometers for distribution. Research has been done on various aircraft and methods of flight for the VTOL as well as designs for a payload carrier. The document has clear requirements the VTOL must be able to perform by April when the final product is needed. With the given requirements, the designing process for the VTOL is complete.

1.3 Objective

The purpose of this design project is to create an unmanned VTOL with the ability to hold approximately 50 kilograms of medical supplies in a rectangular payload and deliver it up to 200 kilometers away to various drop off locations for distribution. The VTOL must be able to reach its destination and drop off the payload and must be able to return to its launch site after delivering the payload to destination without reconfiguring the drone and completely autonomous.

1.4 Justification

Whether it be a natural disaster, war, or a health crisis, medical supplies are necessity for human survival that is not always readily available: roads may be flooded, borders may be closed, or disease may put deliverers in harm’s way. A VTOL aircraft can get around many of the logistical issues created when the terrain prevents medical supplies getting from point A to B by flying above the problems. The aircraft can go from the roof of a warehouse to the roof of a hospital without relying on an intact ground transportation network. Additionally, an autonomous aircraft can fly to a destination, drop off supplies, and return without any human interference. Not only does this reduce the chances of an untrained individual messing with the aircraft trying to unload packages, but it reduces the spread of communicable diseases. Designing an autonomous VTOL with greater range and payload capacity than current options reduce the time required to deliver supplies to people in need and may help to reduce the rate of infection for diseases such as COVID-19 when used for vaccine delivery.

1.5 Project Background and Problem Statement

Ground transportation is not always reliable in emergency situations, nor is traditional aircraft the safest option/logistically practicable for delivering medical supplies in certain situations. The outbreak of the COVID-19 virus has shown weaknesses in the modern delivery network used every day across the globe. Supplies and vaccines are arriving too late or too few are delivered to make an impact. Current delivery drones, with low payload capacity and short range, do not meet the need required by the current epidemic to help humanity.

Developing an unmanned vertical lift aircraft that can deliver payloads of 50kg to distances 200km away at high speeds is vital for helping COVID-19 relief and lessening the impact of future health crises.

2. Chapter 2: Literature Review

2.1 Vertical Takeoff and Land Aircraft

VTOL aircraft have the advantage of being able to take off and land from an area not much larger than the aircraft. The most common VTOL aircraft is a helicopter which comes in multiple variations (Figure 1), although each work on the same principle [1]. Single main rotor helicopters have a large rotor providing thrust and a secondary rotor on the tail providing secondary thrust perpendicular to the main rotor to counteract the spinning torque. A tandem rotor, or dual rotor, helicopter uses two equal sized rotors spaced horizontally apart from one another and spin in opposite directions to counteract the toque. This design requires a larger airframe to hold the rotors, but the rotors are smaller than the rotor of a single rotor helicopter [1]. Tandem rotor helicopters have a greater carrying capacity and speed since both rotors provide downward thrust compared to helicopters with tail rotors which have to waste thrust to counteract torque [2]. Intermeshing rotors are similar to tandem rotors except the rotors are spaced closer together and at an angle so they can intermesh without colliding. These helicopters have high load capacity and high stability [2]. Coaxial rotors also have two rotors rotating in opposite directions to cancel out torques, but they are mounted on the same shaft. This creates a large amount of drag from interference airflows between the rotors and reduces the overall cruising speed. Tilt-rotor aircraft look similar to conventional propellor driven airplanes except the rotors are at the wing tips and rotate up to provide thrust like a helicopter for takeoff/landing and rotate forward to provide thrust for horizontal travel. This design benefits from the efficiency of wings for distance travel while retaining the VTOL abilities of a helicopter. The fixed wings partially block the downward thrust of the rotors when vertical so there is an issue of propwash [3]. To overcome the thrust loss, tilt wing aircraft rotate the wing with the rotors (Figure 2). The tilt-wing is lighter, simpler, and more reliable than the tilt-rotor aircraft but has a high chance of stall during transition when the forward velocity is low, and the wing angle of attack is high [4].

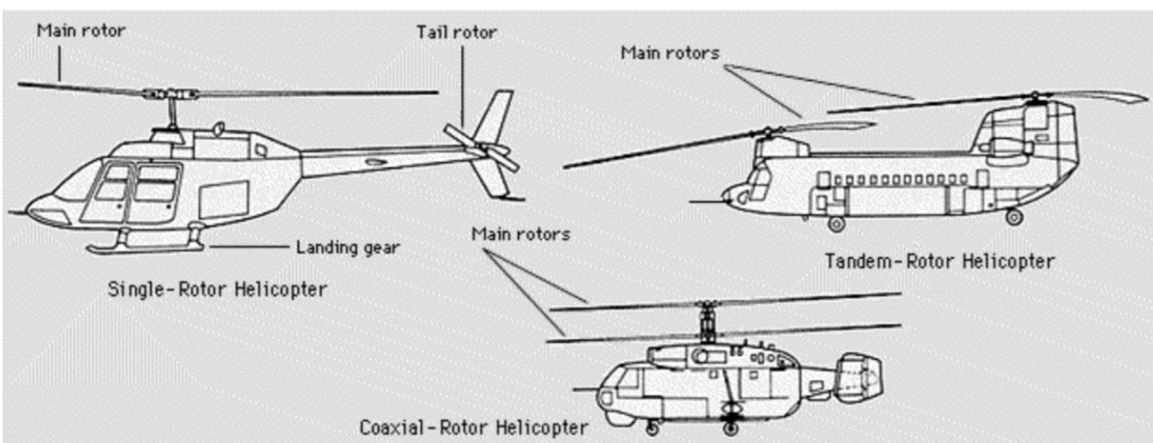


Figure 1: Helicopter Rotor Arrangements [5]

Quadcopters (or multi-copters) are quickly becoming the design choice for businesses involved in small delivery aircraft. A quadcopter has four propellors which spin at different rates to allow for pitch, roll, and yaw movements. Since this type of aircraft requires a high degree of control for each propellor, quadcopters were not very feasible with gas engines [4]. Smaller, lighter electric motors have allowed multi-copters to become useful for situations where small loads and precise control are required. Often times, multi-copters will use many smaller propellors to achieve the same thrust as a few large propellors since control relies heavily on changing prop speed and lower rotational inertia allows for faster response. For the same reason, quadcopters do not scale up easily and require a new airframe design to allow for more motors and propellors [4].

Figure 2: Bell Boeing V-22 Osprey Tilt-Rotor Aircraft [6]

2.2 Private Sector Approaches to Delivery Drones

Drones in the private aerospace sector have gained huge attention within the past decade for anything from amateur photography to land surveying. Drone delivery services have existed for decades in science fiction stories, but now there are multiple companies trying to deliver goods with drones. Amazon Prime Air uses quadcopters to deliver payloads of five pounds or less up to 15 miles away [7]. Alphabet's Wing uses a hybrid design, mixing a conventional fixed wing aircraft with the VTOL capabilities of a multirotor helicopter. The Wing drone is capable of flying at speeds up to 112km/h at 45m to deliver a 1.5kg payload in a 10km radius [8]. Wingcopter (Figure 3) uses a quad-tiltrotor

Figure 3: Wingcopter Tilt-Rotor Quadcopter Design [9]

design to travel at speeds of 150km/h at a 5000m ceiling height delivering payloads of up to 6kg anywhere from 20km to 60km away (distance varies with payload capacity) [9]. The company Zipline delivers medical supplies to rural hospitals in Africa using an autonomous plane up to 80km away [10]. The airplane launches from a catapult (Figure 4), delivers cargo via parachute, and is caught at the base with a capture wire (somewhat similar to how jets land on aircraft carriers). The aircraft is modular, allowing for quick repairs and maintenance without slowing down deliveries and battery packs are removed for charging to reduce aircraft downtime. The drone, limited to 1.3kg payloads, is commonly used for small but urgent medical supplies, such as blood bags [11].

Figure 4: Zipline drone after launch [11]

2.3 Previous VTOL Design Projects

Different projects from past design contests of VTOL's were observed to understand their methods of designing a VTOL. The main focus was to look for contest winners that focused on travelling far and also projects where the VTOL needed to carry a payload. A group from the University of Maryland decided to have a compartment to load their payload in the VTOL. There is a rack that allows more flexibility in the payloads stored and can be removed to change to different custom racks. However, another group from the University of Maryland decided that the payload would be hoisted from inside the VTOL that also controls the doors opening and closing for delivery.

Another design group located in Pakistan took another approach when it came to creating a VTOL. They thought incorporating the characteristics of conventional aerial vehicles and merging them with rotary wing designs would be the best way to have high levels of endurance and speed, while at the same time, having better stability during flight [12].

2.4 Delivery Methods

The horsefly drone (Figure 5) was an aircraft developed by AMP Electric Vehicles and researchers of the University of Cincinnati specifically for product delivery. The drone originally used a cage type method to deliver commercial product within a small radius. This was because at the time, they valued package safety over flight speed. Later, they partnered with UPS and improved their old method of delivering packages by getting rid of unneeded parts of the cage and incorporating a drop-roping design. This improvement increased the stability and increased delivery speed because there would be no need descend in order to complete a delivery. The 2020 horsefly drone (Figure 6) has fully autonomous flight and landing capabilities, with a maximum speed of 4.5 kg and maximum flight speed of 46 mph.

Figure 5: Horsefly 2015 version [12]

Figure 6: Horsefly 2020 version [12]

2.5 Use of Composite Materials for Drone Manufacturing

A Composite material is a material constructed of two or more types of fibers, which have been combined to create a material which is stronger than any one of the fibers making up the composite. The past three decades have seen a rapid increase in composite material technology and development. Composite materials are especially pertinent in the unmanned aerial vehicle's sector, given the demand for lighter and more durable materials.

A very common type of composite material, in the drone world, are fiberglass composites. Sought after for their attractive, stiffness to weight ratio. One of the first methods used to construct material composites, is known as the hand lay-up process. In this process, first a set of molds are created in the desired end shape. Once the molds have been created, their surfaces are treated to prevent the material from sticking to them. Then the desired fibers are cut to length and placed inside the mold, layer by layer, mixing resin in between fiber sheets. Pressure is applied to the fibers, via a roller, ensuring no air bubbles are trapped inside the structure. Then a gel coating may be applied to the surface of the material, ensuring consistency, smoothness, and strength of the surface. Once this is completed the mold is closed and left to cure. While more advanced methods of producing fiber composites exist, the hand lay-up can benefit low volume manufacturers, because of its simplicity and economic feasibility [13]. For example, Figure 7 shows a UAV created using composite materials.

Researchers at the University of Yogyakarta discovered a way to enhance the hand lay-up process, by implementing a method called vacuum bagging. Essentially just adding a vacuum packing curing process to the existing hand lay-up process. The addition of the vacuum packing process ensures a tough, stiff, smooth, and consistent makeup of the material.

Figure 7: UAV Composite [13]

2.6 Energy Systems

VTOL aircraft, which range from toy RC aircraft weighing a few ounces to the military multi-ton behemoths, need some sort of energy system to power the propulsion system. Most aircraft use fossil fuels because the energy density is one to two orders of magnitude greater than current battery storage technology and when weight is the difference between taking off and staying grounded, a highly energy dense fuel is the clear option [14]. Combustion engines are generally piston engines for general aviation and turbofan jet engines for commercial aviation. Piston engines have plateaued as far as efficiency is concerned whereas turbofan jet engines are constantly being improved to increase the energy extracted from each unit of fuel. Even so, engineers are developing alternatives to the traditional jet engine to help with efficiency. Electric propulsion (EP) and hybrid electric propulsion (HEP) are two emerging solutions to increase aircraft efficiency [15]. EP is a fully electric system using batteries or solar panels to power a motor. HEP falls between traditional engines and fully electric aircraft, often with the benefits of each [15]. HEP still relies on a jet turbine but the output power is used to drive a generator which then directly powers the motors or recharges batteries. The efficiency improves as there are fewer mechanical linkages in the system which are points of wasted energy transfer. EP can have efficiencies as high as 73% and a comparable turboprop engine may only have a 39% efficiency [14]. HEP systems often use electric propulsion for takeoff and landing to reduce noise pollution and jet turbine propulsion (either directly or to power the motors) for cruise where noise is not as much of an issue.

2.7 Social benefits of drones during COVID-19

The rise of COVID-19 has caused social distancing and reduced personal contact with others to become normalized throughout the world. This pandemic has shown the various flaws and inefficiencies in the current system. This seems the like the perfect scenario for drone technology to expand and reach global adoption for medical distribution. Use of drones for medical, parcel, and grocery deliveries would be enormously beneficial for America’s response to COVID-19 [16] and large demand is already being seen in highly concentrated areas.

3. Chapter 3: Project Management

3.1 Problem Solving Approach

One plan that is being used is the DMAIC (Define, Measure, Analyze, Improve, Control) process, which is an improvement methodology that is mainly used for six sigma projects. This is a great way to ensure that the project gets completed smoothly and effectively.

For the Define portion, the problem that needs to be addressed must be identified, which is creating a medical drone that meets the needs and requirements of the user base. The Drone’s purpose is to transport medical supplies efficiently in a timely order within suburban areas. For the measuring, the initial model must be drafted with the proper dimensions using Solidworks based on the proper requirements (shown in section 3.2). For analyzing, Solidworks needs to be used to examine metrics, like airflow, pressure, thrust, etc. For improving the system, increases in aerodynamic effectiveness/efficiency will be sought after during the simulation. And for control, the design will be finalized by making the proper alterations and looking at things like safety, observing environmental factors, and risk to reward aspects.

3.2 Expected Problems

As it stands, the VTOL drone is going to use a tilt-wing or tilt-rotor design. Analyzing the vertical portion of flight and the horizontal portion of flight should not cause any issues but the transition phase will require further research into tilt-wing/rotor aircraft aerodynamics. All analysis will have to be taken for accurate values as the team is not able to construct a prototype to test the design due to classes currently being held virtually. The design will have to be as cheap as possible since the market for medical drones is mostly government subsidized and relies on donations.

3.3 Requirements for Success

The unmanned vertical takeoff and landing aircraft will need to follow a list of requirements and specifications when created to solve the problem of a transport needed for medical supplies. The requirements are split between the functional and non-functional requirements necessary to complete the project. The functional requirements are that the VTOL:

- Must be able to carry 50kg (110lb) in a predefined 120cm x 80cm x 80cm container
    - Table 1 below shows the estimated weight of basic medical bundles. It was decided that carrying medicine and supplies (including insulin) of 50 kilograms would be ideal to carry on a single trip based on the Table 1 trends.
- Must reach and stop at 50km (31 miles)
    - Average radius between hospitals in theoretical suburban area.
- Must reach and stop at 200km (124 miles)
    - Average radius from warehouse in theoretical suburban area to site that needs medical supplies delivered.
- Must be autonomous
    - Only a single operator is allowed at a remote site to monitor the status of the VTOL without actively controlling it.

- Must be able to return to launch site or reach destination with full payload

On the other hand, the non-functional requirements, which are requirements not necessary to complete the main mission of this project but useful towards improving the design, are that the VTOL:

- Must not exceed 6.1m x 6.1m x 6.1m maximum size
- Must determine destination is safe to unload payload
- Must be able to load and unload payload quickly in time of emergency
- Must be able to arrive at destination 50km away in 28 minutes (200km away in 75 minutes) or less after takeoff.

Table 1: World Health Organization Disease Emergency Supply Recommendations [17]

Basic module	WHO Catalogue codes	Weight (kg)	Size (cm)	Volume (m3)
Module (1a): Medicines only, without cold chain insulin	KMEDNCD1BM1-A1	235	120x80x120	1.920
Module (1b): Medicines cold chain only, insulin	KMEDNCD1BM2-A1	10	120x80x80	0,768
Module (1c): Renewable	KMEDNCD1BR1-A1	21,8	60x40x42	0.1008
Module (1d): Supply for equipment	KMEDNCD1BS1-A1	141	120x80x87	0.8352
Module (1e): Equipment	KMEDNCD1BE1-A1	8,6	60x40x27	0.0648
Total		**416,4**		**3,689**

3.4 Gantt Chart/Schedule

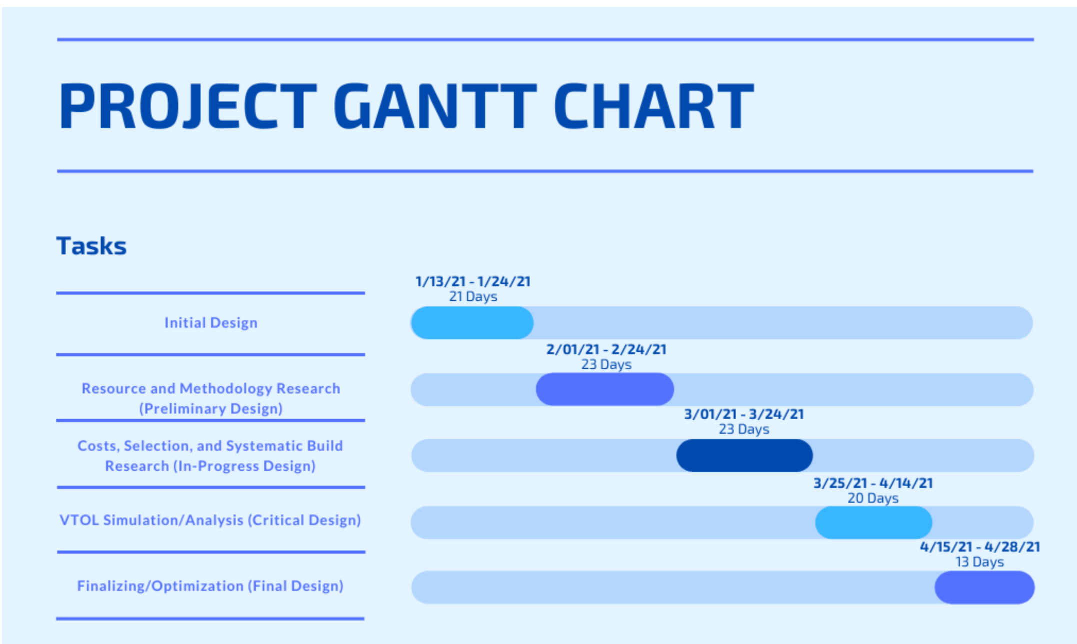


Figure 8: Gantt Chart

Table 2: Break down of each section of Gantt Chart

1	Initial Design				
1.1	Identify Design Requirements	Elijah M, Kyle N	01/13/21	01/24/21	
1.2	Identify Design Concepts	Everyone	01/13/21	01/24/21	
1.3	Group Discussion	Everyone	01/15/21	01/18/21	
1.4	Identify Design Alternatives	Everyone	01/15/21	01/24/21	
1.5	2nd Group Discussion	Everyone	01/20/21	01/24/21	
1.6	Finish IDR Report	Everyone	01/21/21	01/24/21	
2	Preliminary Design				
2.1	Scope and Goal Setting	Miles M, Elijah M	02/01/21	02/07/21	
2.2	Budget	Andrew P	02/02/21	02/07/21	
2.3	Project Planning	Miles M, Kyle N	02/04/21	02/11/21	
2.4	Risk Management	Elijah M, Kyle N	02/06/21	02/11/21	
3.4	Group Discussion	Everyone	02/18/21	02/23/21	
4.4	Consensus	Everyone	02/20/21	02/24/21	
5.4	Finish PDR Report	Everyone	02/17/21	02/24/21	
3	In progress				
3.1	Costs and Selections	Andrew P, Elijah	03/01/21	03/07/21	
3.2	Systematic Build / Build Design	Elijah M, Kyle N	03/01/21	03/07/21	
3.2.1	Configuration/ Analysis	Miles M, Kyle N	03/07/21	03/13/21	
3.2.2	Testing	Andrew P, Kyle N	03/07/21	03/13/21	
3.3	Group Discussion	Everyone	03/13/21	03/23/21	
3.3.1	Finish IP Report	Everyone	03/14/21	03/24/21	
4	Critical Design				
4.1	Design for Safety/Failure	Elijah M, Kyle N	03/25/21	04/12/21	
4.2	Analyze Effects	Kyle N, Andrew P	03/26/21	04/12/21	
4.3	Project Performance	Kyle N, Miles M	03/26/21	04/12/21	
4.4	Write CD Report	Everyone	04/10/21	04/14/21	
5	Final Design				
5.1	Design for Environment	Elijah M, Kyle N	04/15/21	04/22/21	
5.2	Reports and Predictions	Miles M, Andrew	04/15/21	04/22/21	
5.3	Group Discussion	Everyone	04/22/21	04/28/21	
5.4	Finalize Review Overall Report	Everyone	04/22/21	04/28/21	

The Table listed above is the breakdown of Gantt chart that the VTOL Squad plan on following throughout the design process of the medical drone. This gives a more detailed overview of the Gantt chart seen in Figure 8.

3.5 Flow Chart

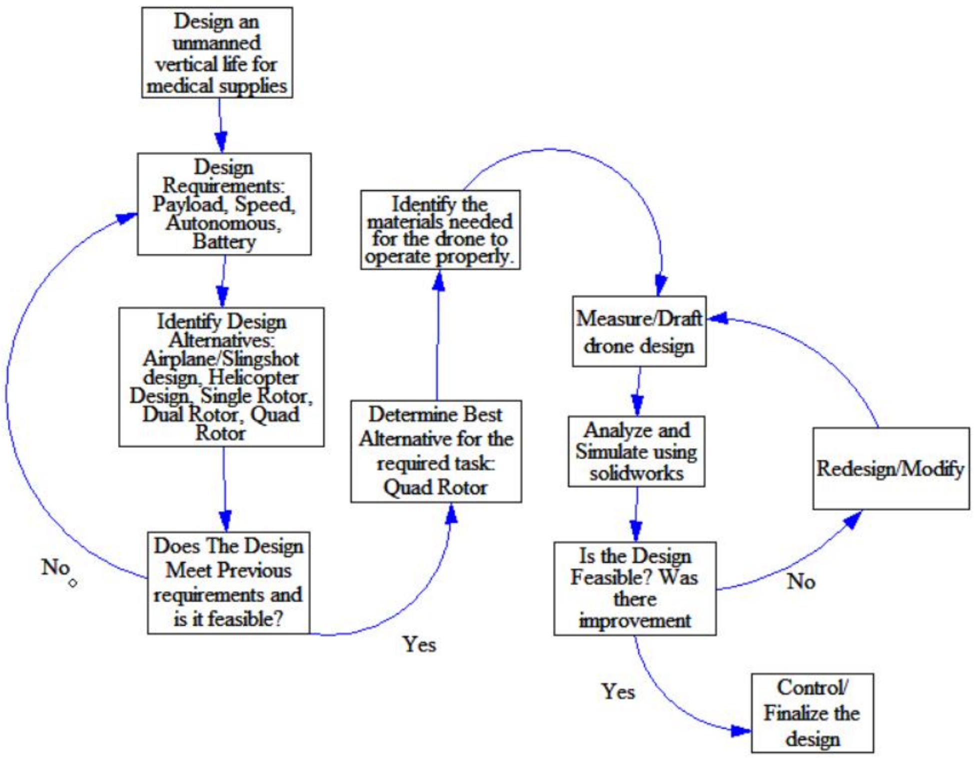
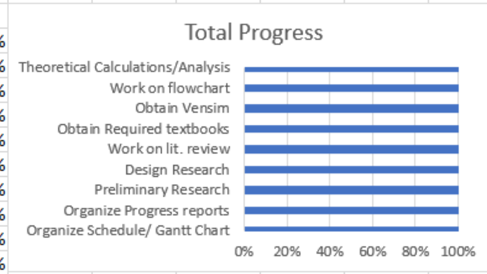


Figure 9: Flow Chart

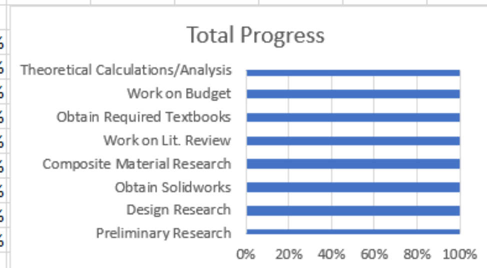
The flowchart above in Figure 9 is a brief walkthrough of the way the VTOL Squad plans on completing the project. It follows the DMAIC model design process, starting with defining the objective of the project, measuring/drafting the initial design, analyzing/simulating the design, improving the design, and controlling/finalizing the design. These steps are the core of the DMAIC design methodology. [18]

3.6 Responsibilities

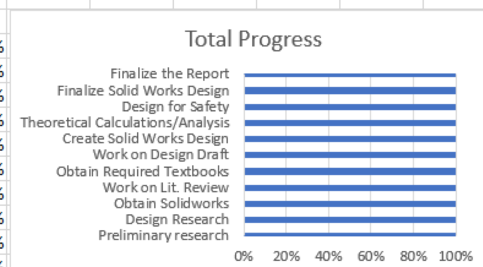
Team Member	
Miles	
Task	
Organize Schedule/ Gantt Chart	100%
Organize Progress reports	100%
Preliminary Research	100%
Design Research	100%
Work on lit. review	100%
Obtain Required textbooks	100%
Obtain Vensim	100%
Work on flowchart	100%
Theoretical Calculations/Analysis	100%
Finalize the Report	100%



Team Member	
Andrew	
Task	
Preliminary Research	100%
Design Research	100%
Obtain Solidworks	100%
Composite Material Research	100%
Work on Lit. Review	100%
Obtain Required Textbooks	100%
Work on Budget	100%
Theoretical Calculations/Analysis	100%
Finalize the Report	100%



Team Member	
Kyle	
Task	
Preliminary research	100%
Design Research	100%
Obtain Solidworks	100%
Work on Lit. Review	100%
Obtain Required Textbooks	100%
Work on Design Draft	100%
Create Solid Works Design	100%
Theoretical Calculations/Analysis	100%
Design for Safety	100%
Finalize Solid Works Design	100%
Finalize the Report	100%



Team Member	
Elijah	
Task	
Prelinary Research	100%
Design Research	100%
Obtain Solidworks	100%
Work on Lit. Review	100%
Obtain Required Textbooks	100%
Work on Design Draft	100%
Create Solid Works Design	100%
Theoretical Calculations/Analysis	100%
Design for Safety	100%
Finalize Solid Works Design	100%
Finalize the Report	100%

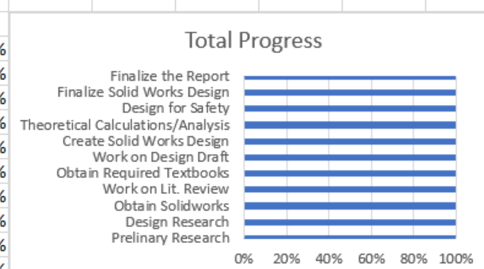


Figure 10: Individual Progress Reports

The figure above are the current responsibilities and total progress of each team member so far. The progress and tasks of each team member will be updated as time goes on until the deadline of the project.

3.7 Budget

Table 3: Proposed Budget for Materials

Budget	
Carbon Fiber	$1,600
Aluminum	$600
Styrofoam	$180
Epoxy	$400
Adhesive	$200
Vacuum Packer	$250
Nuts and Bolts	$175
Motors	$15,460
Electronic Speed Controllers	$10,000
Propellers	$720
Flight Controller	$500
Power Distribution Board	$350
Sensors	$900
FPV Camera	$900
Video Antenna	$50
Video Transmitter	$600
Battery	$4,000
Transmitter and Control Setup	$2,000
Design Software	$2,000
Labor, Equipment, Assembly	$15,000
Total Cost	**$55,885**

The budget, as seen in Table 3, presents the estimated cost of building a VTOL drone described in the following sections. The costs are estimated around the size of the craft and the required materials.

3.8 Material Required/Used

Below is a list of the materials and parts that are planned to be used to construct the craft

Wings:
- Carbon Fiber Sheets
- Styrofoam Molds
- Adhesive Solution
- Epoxy Solution
- Plastic Vacuum Packing Sheets
- Vacuum Packer

Fuselage:
- Aluminum Sheet Metal
- Screws and Bolts
- Epoxy Solution
- Carbon Fiber Sheets
- Adhesive Solution

Frame:
- Aluminum Sheet Metal
- Screws and Bolts
- Adhesive Solution
- Epoxy Solution

Propellers:
- Wiring
- Propeller System
- Nuts and Bolts

Flight Control System:
- Flight Controller
- Electronic Speed Controller
- Sensors
- FPV Camera
- Video Antenna
- Video Transmitter
- Adhesive Solution
- Nuts and Bolts
- Wiring

Ground Control System:
- Flight Control Monitor
- Flight Control Transmitter
- Flight Control Ground Computer
- Flight Control Software
- Video Antenna
- Flight Control Antenna

Design Resources:
- Design Software
- Labor
- Manufacturing Equipment

3.9 Resources Available

The following is a list composed of the resources available that will be used during this project. These resources are useful in determining the best method to design the VTOL and calculate its efficiency in practice.

- Vensim
- Solidworks
- Fusion360
- KSU Library
- Aircraft Design: A Conceptual Approach by D. Raymer (Sixth Edition)
- Elements of Propulsion: Gas Turbines & Rockets by Mattingly and Boyer (Second Edition)
- Project Management in Practice-John Wiley & Sons, Inc. (2017)
- Excel

4. Chapter 4: Sizing Analysis

4.1 Mission Profile

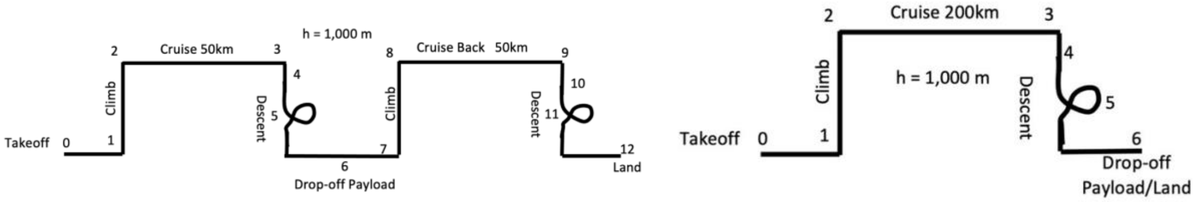


Figure 11: Left, Hospital Mission Profile; Right, Warehouse Mission Profile

Figure 11 shows the mission profile the VTOL must undertake to deliver medical supplies to the next hospital in a suburban area and a trip from a warehouse. As seen in the hospital mission profile, the VTOL will take a vertical takeoff and cruise 50km in 28 minutes to reach the hospital and drop the payload. After dropping the payload, the VTOL will perform another vertical takeoff and cruise back to its original destination for either recharging or collecting another payload. The mission profile for a trip from a warehouse is the same as the mission profile from hospital to hospital but has a longer range of 200km in 75 minutes.

4.2 Initial Sketches

4.2.1 Quadcopter Sketch

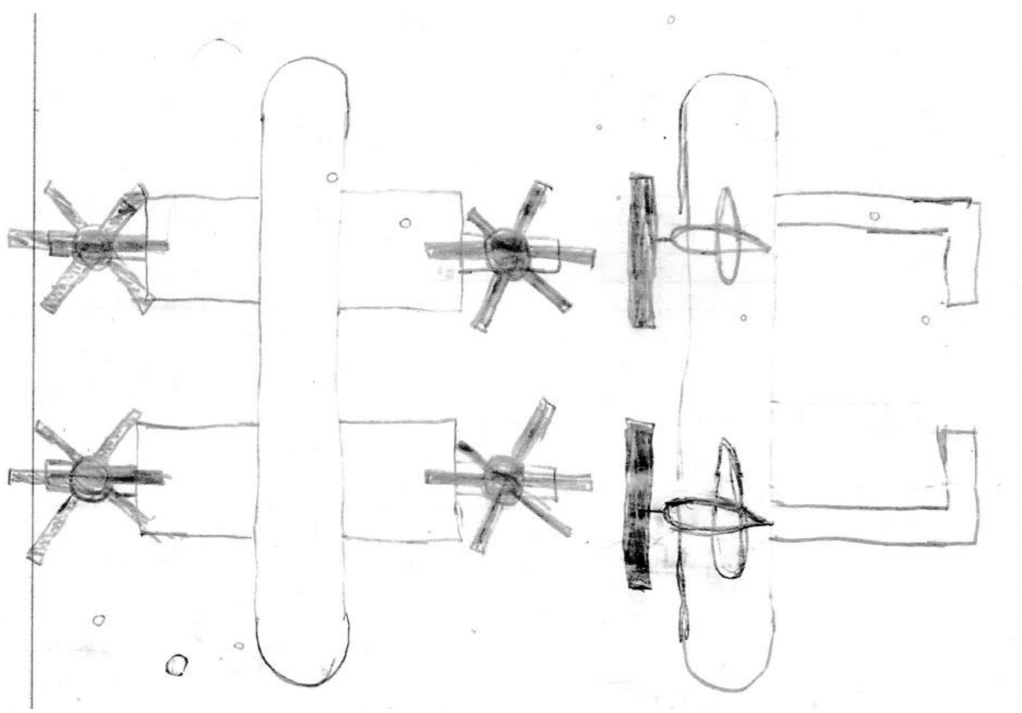


Figure 12: Quadcopter Design Sketch

The design from Figure 12 above utilizes four propellers and four wings to make the VTOL work. The design's VTOL is a tilt-wing aircraft where the tilting occurs at the halfway point of each wing. As seen in the sketch, the propeller is attached to the far end of the wing so that it will also tilt when necessary, for the VTOL to either takeoff or cruise to its destination. The payload would be secured by a claw that will withstand the aerodynamic forces acting upon it during flight. This design was ultimately not used due to the added complexity of four wings and the stall caused by half tilted wings.

4.2.2 VTOL Sketch

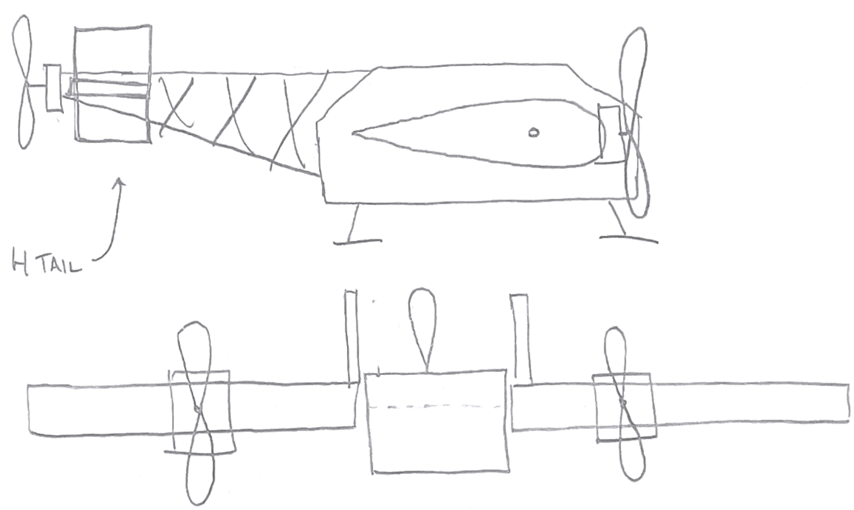


Figure 13: VTOL Sketch

The VTOL from Figure 13 Above uses three propellers, two in front and one on the tail, to provide lift and stability. The rear propeller works to counteract any moments created and adding forward momentum to the aircraft during the vertical to horizontal transition phases where stall is likely to happen. An H-tail is added to allow the rear propeller to interact with freestream air. For vertical flight, the wings rotate 90 degrees. The two front propellers are rotating in opposite directions to counteract torque. While not shown, the payload will be stored underneath the fuselage with a latch mechanism that can be autonomously operated.

4.2.3 Initial Design

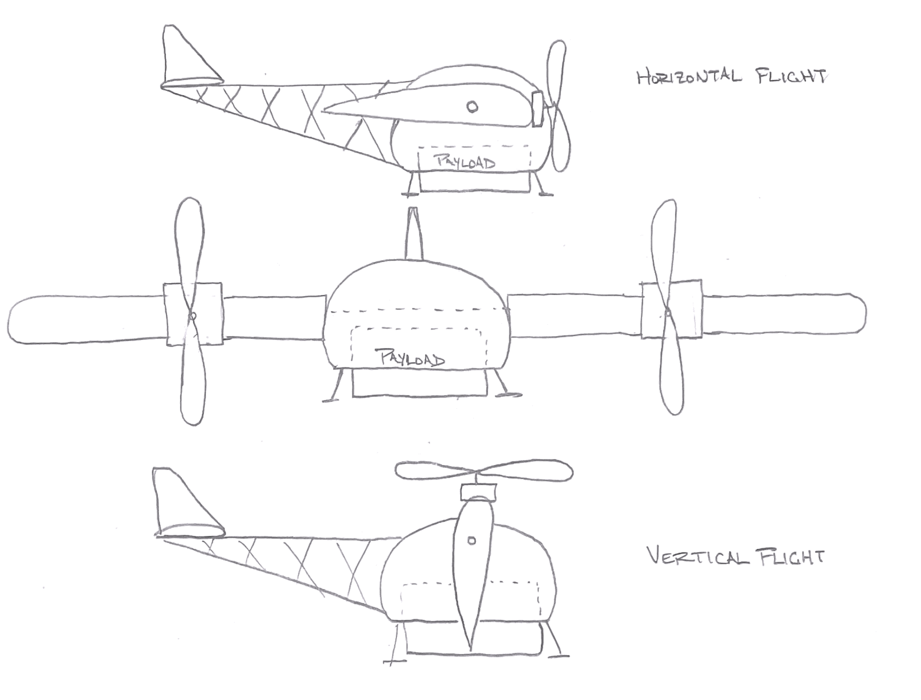


Figure 14: The Initial Design, Dash-1

The VTOL shown in Figure 14 above uses wings that can rotate 90 degrees to direct the thrust in the desired direction. Only two propellers are used to reduce the complexity, compared to three or four propellers. Control is reliant upon the two propellers and the conventional tail is for countering moments. The payload is stored underneath the aircraft similar to the first sketch with a claw latch.

4.3 Motor Selection from Trends

A motor for each propeller on the VTOL is selected from observing previous trends of electric powered aircrafts in Table 4 below. Table 4 is a simplified version of the table in Appendix E that describes the motor used in the aircraft, the payload it could carry, and its max speed.

Table 4: Electric Aircraft Classifications

Aircraft (Single Engine)	Motor (kW)	Payload Weight (kg)	Max Speed (km/h)
Alisport Silent Club	13	165	200
Pipistrel Taurus Electro	40	265	130
Rutan Long ESA		279	298
Pipistrel WATTsUP	50	236	194
Bye Aerospace eFlyer 2	90	200	250

From observing the data in Table 4, a selection of two 30kW motors is selected for the VTOL. This gives a total power of 60kW which should be more than enough for the payload of 50kg. The power is also on the higher end due to it being a tilt-wing VTOL that will need more power to vertically takeoff.

4.4 Power Loading and T/W

For VTOL's, the power loading is an important deciding factor on its capabilities and performance. Due to trends from other VTOL's and helicopters, a power loading is guessed for initial calculations. From Table 5, the power loading for this VTOL is approximately 2.1 kg/kW. With the power loading and total power provided from the motors, the takeoff gross weight is calculated using:

$$W_0 = \frac{W}{P} * P \quad (1)$$

The takeoff gross weight is calculated to be 126 kg.

Table 5: Typical VTOL Power Loading [4]

Aircraft Type	Typical W/P	
	lb/hp	kg/kW
Scout/attack helicopter	3–5	1.8–3.1
Transport helicopter	5–7	3.1–4.3
Civil/utility helicopter	3–8	1.8–4.9
Tilt rotor	4–5	2.4–3.1
Tilt wing (propeller)	~3.4	~2.1

With the initial power loading assumed, the thrust-to-weight ratio is calculated using the following equation:

$$\frac{T}{W} = \frac{(Propeller\ Efficiency)}{Speed} * \frac{P}{W} \quad (2)$$

The propeller efficiency is typically between a range of 82%-92% and thus 85% is chosen to represent the propellers on this VTOL. The speed is chosen from the requirements the VTOL must meet, reaching 50km in 28 minutes and reaching 200km in 75 minutes. The speed needed to reach the 200km is higher than the speed needed to reach the 50km and is chosen to represent the speed in the thrust-to-weight ratio. Calculating thrust-to-weight gave a value of 0.0091.

4.5 Airfoil Selection

The airfoil for both wings needs to be decided initially to further test the aircraft. To find an airfoil for this aircraft, the lift coefficient and thickness ratio (t/c) are required to choose a known airfoil. The lift coefficient was chosen to be 0.3 based on trends of similar aircrafts. The t/c can also be found from trends in Figure 15 below using the highest cruise Mach number.

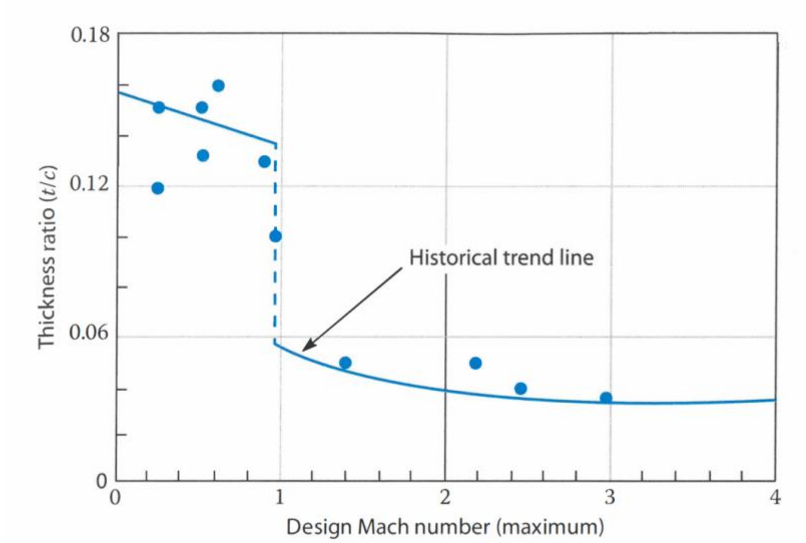


Figure 15: Thickness Ratio Historical Trend [4]

The Mach number of 0.132 gave a thickness ratio of approximately .155 or 15.5%. Due to the Mach number being below supersonic, a four or five series NACA airfoil can be selected. For the initial selection, a NACA 23015 was chosen as the airfoil for initial analysis.

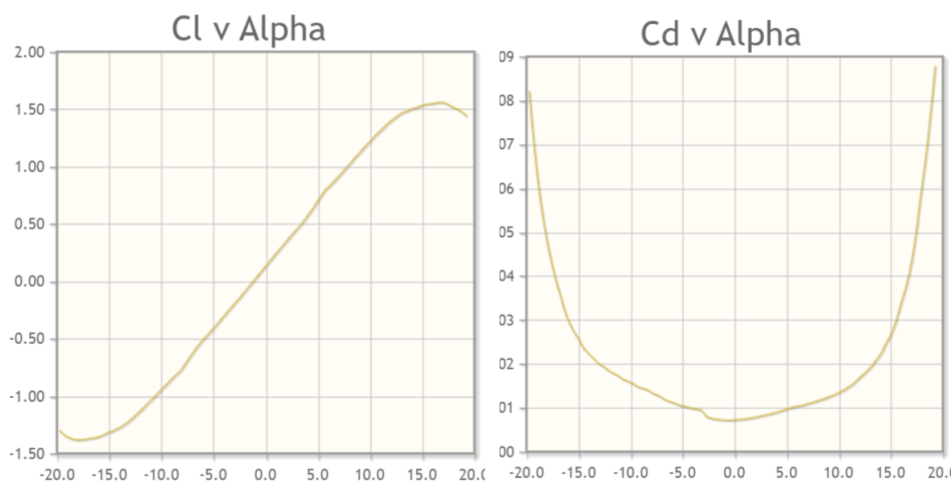


Figure 16: Left, Cl v Alpha; Right, Cd v Alpha [22]

Referring to Figure 16, the coefficient of lift is around 0.18 for the NACA 23015 airfoil at a zero angle of attack. Similarly, the coefficient of drag is about 0.08 at zero angle of attack. There is a positive moment coefficient at a zero angle of attack (Figure 17) so the airfoil will rotate about the quarter chord unless it is at an angle of attack around -7, -5, and 6. The coefficient of lift over coefficient of drag is about 1.25 for the airfoil.

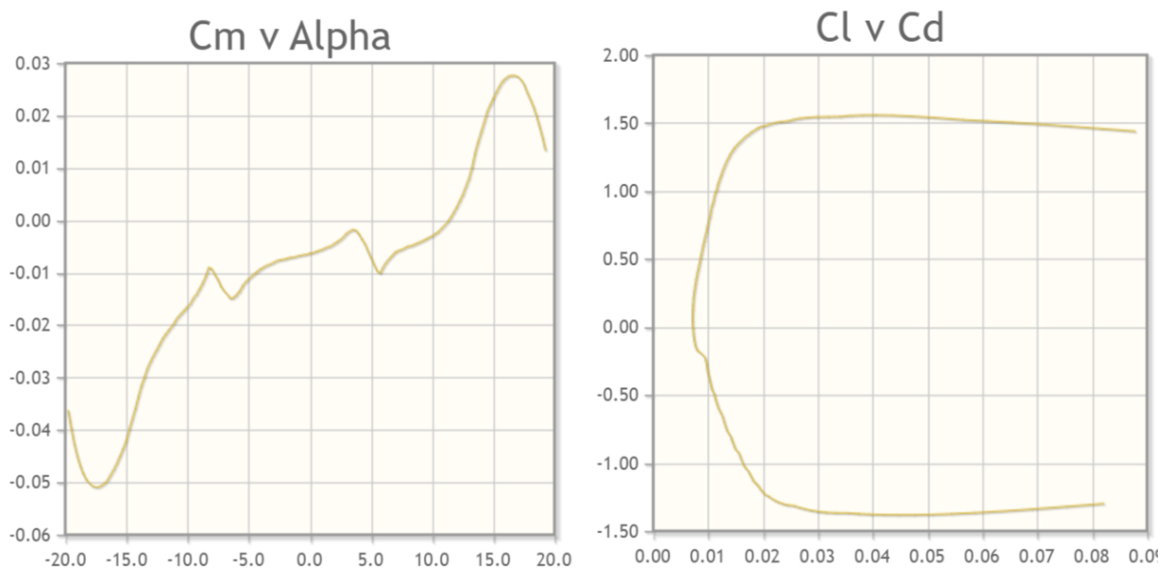


Figure 17: Left, Cm v Alpha; Right, Cl/Cd [22]

4.6 Initial Sizing in Airplane Configuration

Sizing the aircraft presents two issues: electric aircraft are relatively new and lack historical trends, and tilt wing VTOL aircraft are equally as uncommon and lacking information. Determining the empty weight of an aircraft usually involves using fuel fraction estimates to find the fuel weight along with historical trends for particular types of aircraft. The weight of an electric airplane is slightly less complicated since batteries do not become lighter as the energy is consumed unlike a jet engine plane. By looking at small one to two passenger electric aircraft, a trend appeared to show that the empty weight was 1.15-1.3 times the weight of the payload. With the required payload being 50kg, an estimated takeoff weight (using the 1.3 factor) is 115kg. The takeoff weight calculated using power loading returned a gross takeoff weight of 126kg, a difference of less than 10%.

The wingspan is limited to 6.1m (maximum) by the problem statement and that was reduced to 5.5m if an increase in size was later required. To find the ideal aspect ratio for the wingspan and selected airfoil, Solidworks Flow Simulation was used (see Appendix F, G, H) to compare a six, eight, and ten aspect ratio wing for various angles of attack at cruise. An aspect ratio of 6 provides the greatest lift for the NACA 23015 airfoil with a 5.5m wingspan (Figure 18). The initial sizing for the chord becomes 0.8403m, from the equations:

$$b = \sqrt{A \cdot S} \quad (3) \qquad , \qquad c = \frac{2S}{b(1+\lambda)} \quad (4)$$

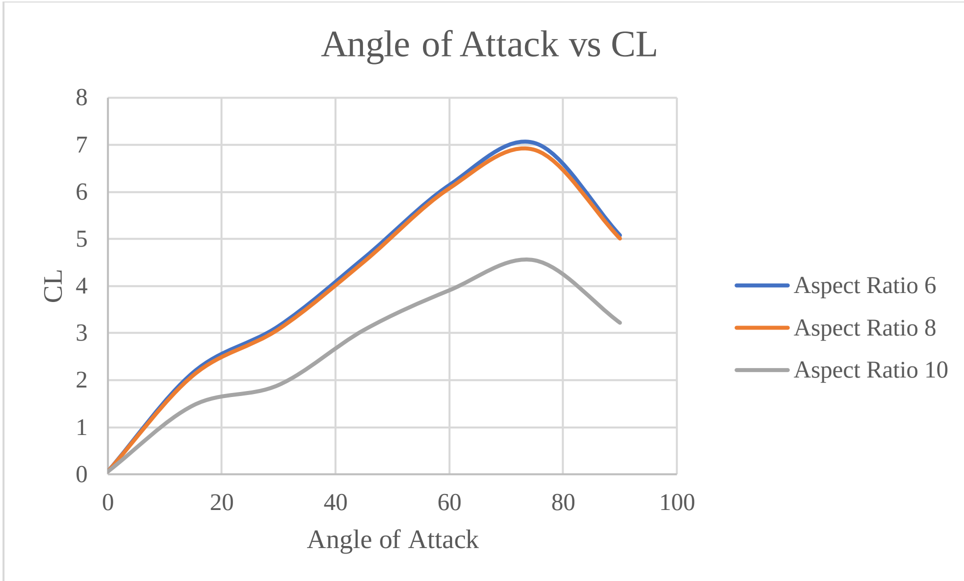


Figure 18: Coefficient of Lift vs Angle of Attack for a given Aspect Ratio

Wing loading is determined for stall, cruise, and loiter while in the plane configuration to calculate the design lift coefficient and some aspects of drag. Wing loading is calculated using the following equation:

$$\frac{W}{S} = \frac{Weight\ of\ Aircraft}{Reference\ Wing\ Area} \qquad (5)$$

For the initial design with a mass of 126 kg and reference area of 4.62 m^2, the wing loading is 27.3 kg/m^2. This value is an estimate based on past trends and a more accurate wing loading is calculated using more variables. The equation for wing loading based on stall is:

$$\frac{W}{S} = q_{stall} C_{L,max} \qquad (6)$$

Where: $q = \frac{1}{2}\rho V^2$

Usually V_{stall} is $V_{approach}/1.3$ but there is no $V_{approach}$ for this aircraft design (as it does not land in the conventional way) so V_{stall} was calculated as $V_{cruise}/1.3$ (V_{cruise} is 44.44m/s). $C_{L,max}$ was estimated to be 1.8 from Figure 19 for an aircraft with plain flaps and no sweep to the wings. $W/S_{,stall}$ becomes 119.30 kg/m^2. Cruise wing loading is solved similarly using the equation:

$$\frac{W}{S} = q\sqrt{\pi A e C_{Do}} \qquad (7)$$

Where e and C_{Do} are estimated values from [4], 0.8 and 0.03 respectively. $W/S_{,cruise}$ ends up being 75.34 kg/m^2. The final wing loading to calculate in the plane configuration is loiter, using the equation:

$$\frac{W}{S} = q\sqrt{3\pi A e C_{Do}} \qquad (8)$$

Using the same values as used for cruise, W/S,$_{loiter}$ becomes 130.5 kg/m^2. The lowest wing loading result is the value that should be used to calculate wing reference area; the lower the value, the larger the reference wing will be which ensures the aircraft is designed properly for every situation. Since cruise is the lowest airplane configuration wing loading, the reference wing area becomes 3.32 m^2. Applying Eq. 3 and 4, the span is 3.17 m and the chord is 0.528 m.

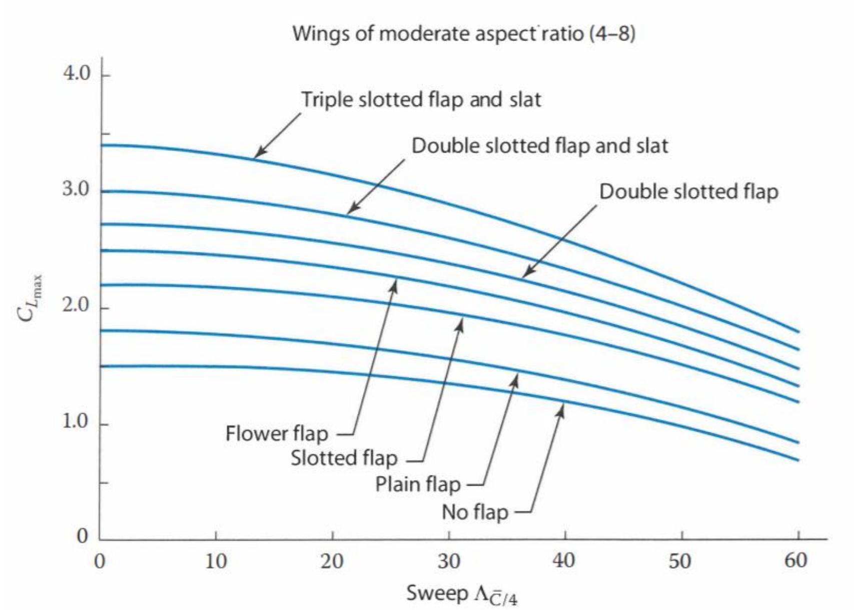


Figure 19: Maximum Lift Coefficient [4]

4.7 Initial Sizing in Helicopter Configuration

Based on historical trends, the disk loading for the propellers on the VTOL is 245 kg/m^2. The disk loading is useful for determining the takeoff weight and disk area required for flight; however, neither are officially known. However, the solidity of each propeller is calculated as 0.15915 after using Eq. 9 and deciding that each propeller should have three blades and an aspect ratio of 6. Using the solidity, the area of each propeller blade is found after calculating the disk area. The power required for the VTOL will be used to determine a takeoff weight to calculate the disk area of the propellers.

$$Solidity = \frac{n}{A_p * \pi} \quad (9)$$

Where: n = 3 blades

$A_p = 6$

Using Eq. 10 for hover momentum theory, the induced velocity at the rotor disk (V_1) is correlated to the thrust and power needed to keep the VTOL in hover. Eq. 11 below calculates V_1 using the thrust disk loading (T/S) of the VTOL. Typically, T/S should equal the disk loading, but due to the downwash acting on the aircraft, it will be increasing by 3% to 252.35 kg/m^2. As shown in Eq. 12, V_1 is used with thrust to calculate the ideal power for the VTOL. However, to gain an accurate reading of how much power is actually needed, the ideal power is divided by a Measure of Merit (*M*) of 0.7.

$$\rho V_1^2 S V_2 = \frac{1}{2}\rho V_1 S V_2^2 \qquad (10)$$

$$V_1 = \sqrt{(T/_S)/2r} \qquad (11)$$

Where: $r = 1.1117\ kg/m^3$

$$\frac{T}{S} = 252.35\ kg/m^2$$

$$P_{ideal} = Thrust\ x\ V_1 \qquad (12)$$

Due to the propellers not being completely efficient, the total power required for the VTOL is the actual power divided by the mechanical efficiency of 97%. With this, all the power needed for the VTOL can be calculated, but due to the thrust not being known yet, the power is interpolated until the guessed power is equal to the total power. Table 6 below shows the values guessed until a power of approximately 119 kW is calculated to be the total power. It also shows the takeoff weight, disk area, and thrust needed in helicopter configuration.

Table 6: Total Power Interpolation

P, guess	W/P	W	W/S	S	T/S	T	P,ideal	P, total
60	2.1	126	245	1.944	252.35	4808.67	160.37	236.2
80	2.1	168	245	1.458	252.35	3606.5	120.28	177.14
90	2.1	199.5	245	1.228	252.35	3037.05	101.29	149.17
120	2.1	252	245	0.972	252.35	2404.33	80.19	118.09
119	2.1	249.9	245	0.98	252.35	2424.54	80.86	119.09

With the total power calculated, the power necessary for the VTOL to climb up to the required altitude of 1000 meters is found using Eq. 13. From the equation, the power needed to climb to 1000 m altitude is 94.42 kW.

$$P_{climb} = \left[\left(\frac{1.3965*9.8*W_0}{0.7}\sqrt{\frac{1.3965*(W/S)}{2\rho}}\right) + \frac{9.8*W_0*V_{climb}}{2}\right]\left[\frac{P_{ideal}}{0.7*P_{total}}\right] \qquad (13)$$

Where: W_0 = 249.9 kg

W/S = 245 kg/m^2

V_{climb}= 30 m/s

P_{ideal} = 80.86 kW

P_{total} = 119.09 kW

Table 6 showed the final disk area (S) chosen for the propellers is 0.98 m^2 with each propeller having a disk area of 0.49. Using the disk area and the solidity calculated before, the area of each propeller blade is calculated using Eq. 14. The area of each propeller blade is 0.07807 m^2 with a radius of 0.395 m and chord length of 0.0658 m.

$$Blade\ Area = S_{per\ rotor} * Solidity \quad (14)$$

4.8 Adjusted Sizing

After determining the initial sizing for the VTOL in the helicopter configuration and the weight increasing compared to the plane configuration as a result (250 kg vs 126kg), the reference wing area is recalculated using the same wing loading equations as in Section 4.6. Since the variables are the same as before, the cruise wing loading is as it is still the lowest of the calculated W/S values. Utilizing Eq. 5, 3, and 4, the reference wing area is 3.32 m^2, the span is 4.46 m, and the chord is 0.744 m.

4.9 Geometry Sizing

4.9.1 Fuselage

The optimal fuselage fineness ratio, or the fuselage length compared to the diameter, is 3 for the lowest drag induced by the fuselage. The length of the fuselage can be estimated based on past trends using Table 7 the equation:

$$Length = aW_0^C \qquad (15)$$

Where:

Table 7: Length Equation Variables [4]

Type of Plane	a	C
Homebuilt-composite	1.28	0.23
GA-twin engine	0.366	0.42

The length is calculated as 4.56 m based on homebuilt factors and 3.72 m based on GA factors. Since this aircraft is somewhere between the two types, the average length is chosen for the fuselage length, 4.14 m. For the optimal fineness ratio, the diameter should be 1.38 m. For the VTOL, the diameter was rounded up to 1.40 m to ensure there is enough room around the cargo for structure and battery storage.

4.9.2 Tail

The tail is used to counter the moments created by the wings and provide stability and control. The horizontal and vertical tail reference wing area is found through the equations:

$$S_{HT} = \frac{c_{HT}\bar{C}_W S_W}{L_{HT}} \qquad (16)$$

$$S_{VT} = \frac{c_{VT} b_W S_W}{L_{VT}} \qquad (17)$$

Where C_{HT} is 0.65 and C_{VT} is 0.055, which are averaged from typical values for homebuilt and GA aircraft. S_W is the wing reference area, $\bar{C}_W$ is the mean wing chord, and b_W is the wingspan. Solving the equations, S_{HT} becomes 0.776 m^2 and S_{VT} becomes 0.393 m^2.

A lower aspect ratio is used on the tail than the wing to retain control of the aircraft in case of wing stall. For the initial design, an aspect ratio of 3 is used for the horizontal tail and 1.3 for the vertical. The taper ratio is the same for both horizontal and vertical at 0.4 (based on averages from [4]). The tail airfoil will be the same NACA 23015 airfoil used for the wing with a thickness-to-chord ratio of 0.15. With these values known, the same equations used for determining wing geometry can be used on the tail and result in the following values in Table 8:

Table 8: Horizontal and Vertical Tail Sizing Values

	Horizontal Tail	Vertical Tail
S	0.776 m^2	0.393 m^2
b	1.526 m	0.715 m
C_{root}	0.726 m	0.785 m
C_{tip}	0.290 m	0.314 m
$\bar{C}$	0.539 m	0.583 m
$\bar{Y}$*	0.327 m	0.306 m

* $\bar{Y}$ is doubled in the equation for vertical tails.

4.10 Motor Selection and Battery Estimation

4.10.1 Motor Selection

The power required for the vertical portions of the flight paths was determined in Section 4.7 to be 94.42 kW to climb to 1,000 meters and 119.09 kW in total. For the horizontal portions of the flight paths, while in conventional plane configuration, the power used for level, cruise flight is given by the equation:

$$P_{used}\eta_p = \frac{mg}{L/D}V \qquad (18)$$

Where η_p is the propeller efficiency (generally around 80%), L/D is 10.34 (further detail in Section 4.11), and velocity is 29.76 m/s or 44.44 m/s depending on the mission. The power required for level cruise is 8.81 kW when traveling at 29.76 m/s and 13.16 kW when traveling at 44.44 m/s.

Since the highest power usage – 120 kW – is the maximum power requirement, the motor will be selected based on that value. Two motors are being implemented in the VTOL design and as such, each motor should be rated for 60 kW. However, for most of either mission profile, the aircraft is in plane configuration and using much less than the maximum power requirement. The max power usage will only be needed for a few seconds as the aircraft climbs vertically from ground to 1,000 meters in under one minute. Each motor needs to be rated for 60 kW, but the continuous usage motor rating can be considerably less. An MGM Compro REB 60 motor fits the requirements with 60 kW peak power and 35-45 kW continuous power at 15.14 kg each [19].

4.10.2 Battery Estimation

Battery energy storage is available in various energy contents, or the energy per unit mass. The higher the energy content, the more ideal the battery is for aircraft. Estimating the necessary mass of batteries for a given mission is accomplished using the equation:

$$E = \frac{m_b E_{sb} \eta_{b2s}}{1000 P_{used}} \qquad (19)$$

Where E is endurance in hours, m_b is the battery mass (kg), E_{sb} is the battery specific energy (wh/kg), and η_{b2s} is total system efficiency (about 93%). Rearranging Eq. 19 for m_b during climb and substituting 0.00926 hours for E, 94.42 kW for P_{used}, and 500 wh/kg for E_{sb} returns a mass of 1.872 kg. 500 wh/kg is the energy density of some lithium sulfur (LiS) batteries. Battery mass needed for level flight can be calculated from the equation:

$$m_b = \frac{E \cdot m}{3.6\frac{L}{D}[E_{sb} \cdot \eta_{b2s} \cdot \eta_p / gV]} \quad (20)$$

Where *m* is the aircraft mass and V is the velocity in km/h. Solving for various mission segments, Table 9 presents the mass of batteries required for the segments.

Table 9: Battery Mass for Each Mission Segment

Battery Mass			
Distance (km)	Payload (kg)	Velocity	Mass (kg)
1, Vertical	50	30 m/s	1.87
50	0	107 km/h	7.08
50	50	107 km/h	8.85
200	0	160 km/h	28.31
200	50	160 km/h	35.36

For the 50 km legs mission profile, the total battery mass required is 23.42 kg. For the 200 km leg mission profile, the battery mass required is 39.1 kg. To ensure the aircraft can handle either mission at any moment, 40 kg of LiS batteries should be installed.

4.11 Aerodynamics

4.11.1 Lift

As stated in section 4.6, the maximum lift of the aircraft (C_L) is found to be 1.8 due to this VTOL having plain flaps and no sweep angle.

4.11.2 Lift Curve Slope

The equation for the lift curve slope used in Eq. 21 is due to this VTOL never achieving supersonic or transonic speed, which leads the lift curve slope to equal 5.611 per radian.

$$C_{L_\alpha} = \frac{2\pi A}{2+\sqrt{4+\frac{A^2\beta^2}{\eta^2}}} * \left(\frac{S_{exposed}}{S_{reference}}\right) * F \quad (21)$$

Where: A = 6

$\beta = 0.9825$

$\eta = 95\%$

$S_{exposed}/S_{reference} = 0.6867$

F = 1.8466

4.11.3 Parasite Drag

Parasite drag is the drag the VTOL will experience at zero lift. It is found using the skin friction coefficient and the ratio between the wing's wetted area and reference area as seen in Eq.22.

$$C_{D_o} = C_{fe} * \frac{S_{wet}}{S_{ref}} \quad (22)$$

The skin friction coefficient is found from Table 10 under the assumption that the VTOL is considered a twin-engine light aircraft.

Table 10: Aircraft Skin Friction Coefficient [4]

Aircraft	Cfe
Bomber	0.003
Civil transport	0.0026
Military cargo (high upsweep fuselage)	0.0035
Air Force fighter	0.0035
Navy fighter	0.004
Clean supersonic cruise aircraft	0.0025
Light aircraft-single engine	0.0055
light aircraft-twin engine	0.0045
Prop seaplane	0.0065
Jet seaplane	0.004

With a skin friction coefficient of 0.0045, S_{wet} of 4.685 m^2, and S_{ref} of 3.32 m^2, the parasite drag is calculated to be 0.0063502.

4.11.4 Lift to Drag Ratio

The lift to drag ratio (L/D) was used to determine the amount of power is needed for level flight. Using the lowest wing loading calculated and the parasite drag, L/D is calculated from Eq. 23.

$$\frac{L}{D} = \frac{1}{\frac{q*C_{D_0}}{W/S} + \frac{W/S}{q*\pi*6*0.869121}} \tag{23}$$

Where: W/S = 75.34 kg/m^2

q = 1097.98 Pa

Eq. 21 gives an L/D value of 10.34.

4.12 Weights

Using the equations in Appendix I and the values in Table 11, the weight for each component is calculated to find a more accurate empty weight for the VTOL. From the table, all the weights for each component are added together and the empty weight is found to be 195.86 kg. With the 50 kg payload included, the takeoff gross weight is 245.86 kg, which is very close to the initial takeoff gross weight of 249.9 kg.

Table 11: Empty Weight Calculations

Wing		British Units
W dg (N)	2449.02	550.56
Nz	10.5	10.5
Sw (m^2)	3.32	35.74
A	6	6
t/c	15%	0.15
Taper ratio	1	1
Sweep	0	0
Aileron Span/Wing Span	70%	70%
Aileron Span (m)	3.12	10.25
Aileron Chord/Wing Chord	0.15	0.15
Aileron Chord (m)	0.11	0.36
Scsw (m^2)	0.35	3.73
Dynamic Pressure (pascals)	1097.98	22.93
W wing (kg)	22.71	50.02
Horizontal Tail		British Units
Wdg	2449.02	550.56
Nz	10.5	10.5
Sweep ht	0	0
Ah	3	3
q	1097.98	22.93
Sht	0.78	8.35
Taper Ratio	0.4	0.4
t/c	15%	15%
W Hori Tail (kg)	2.29	5.05
Flight Controls		British Units
Fuselage Length (m)	4.14	13.58
Bw	4.46	14.64
Nz	10.50	10.50
Wdg	2449.02	550.56
W Flight Control (kg)	2.31	5.09

Vertical Tail		British Units
Ht/Hv	0	0
Nz	10.5	10.5
Wdg	2449.02	550.56
q	1097.98	22.93
Svt	0.39	4.23
t/c	15%	15%
A	1.3	1.3
Taper ratio	0.4	0.4
W Verti Tail	1.25	2.75
Fuselage		British Units
Sf	18.03	194.10
Nz	10.5	10.5
Wdg	2449.02	550.56
Lt	2.07	6.79
L	4.14	13.58
D	1.4	4.59
q	1097.98	22.93
W Fuselage	59.59	131.28
Installed Engine		British Units
Wen (N)	148.37	33.36
Nen	2	2
Motor Controller	82.32	18.51
W installed engine	67.71	149.17
Batteries		British Units
W Batteries (kg)	40	88.13
Empty Weight (kg)	195.86	

4.13 Loading and Unloading Payload Procedures

The drone's payload will be loaded manually before flight, via an open space on the bottom of the craft. The shape of the payload will always be a uniform box, as that is what the craft is designed to secure. The payload will be securely attached to a series of brackets, which will grasp the load from underneath the box as well as on the sides. Before takeoff someone will manually position the payload underneath the craft, and once in place, will trigger the brackets to secure the payload. While the loading process will be performed manually, the unloading process will occur autonomously. For the unloading process, a pre-determined drop off area will be chosen, and the craft will locate this area via GPS coordinates. The craft will land and approach this drop off area in the hover mode, positioning itself directly over top the drop-off area. Once in position the craft will touch down, and then allow the payload brackets to lower the package and release the box onto the ground. Once the box has been placed on the ground, the payload brackets will retract, and the drone will move onto its next scheduled position.

4.14 Final Sizing and Specifications

Table 12 below shows the summarized sizing of the unmanned VTOL. Using the sizing below, a final CAD model is shown later in section 5.3. Two MGM Compro REB 60 engines were chosen to power the aircraft and due to it being electric, there will be batteries stored in the fuselage to provide energy.

Table 12: VTOL Final Sizing

Final Sizing			
Propeller Sizing		**Tail Sizing**	
No. of Rotors	2	Horizontal Tail Aspect Ratio	3
No. of Blades	3	Horizontal Tail Area (m^2)	0.78
Prop. Aspect Ratio	6	Horizontal Tail Taper Ratio	0.4
Solidity	0.16	Horizontal Tail t/c	15%
Disk Area per rotor (m^2)	0.49	Vertical Tail Aspect Ratio	1.3
Propeller Radius (m)	0.40	Vertical Tail Area (m^2)	0.39
Propeller Chord (m)	0.07	Vertical Tail Taper Ratio	0.4
Propeller Blade Area (m^2)	0.08	Vertical Tail t/c	15%
Wing Sizing		**Fuselage Sizing**	
Reference Area (m^2)	3.32	Wetted Area (m^2)	18.03
Aspect Ratio	6	Length (m)	4.14
t/c	15%	Diameter (m)	1.4
Aileron Span (m)	3.12		
Aileron Chord (m)	0.11		
Control Surface Area (m^2)	0.35		

Table 13 and Table 14 provide the specifications this unmanned VTOL will have to successfully fulfill its purpose of transporting medical supplies. Table 14 shows that the empty weight of the aircraft being 195.86 kg and a payload of 50 kg will lead to a takeoff weight of 245.86 kg. However, Table 13 shows that the takeoff weight used is 249.90 kg. The extra weight allows more leeway that the VTOL will be able to carry and still fly.

Table 13: Aircraft Specs

Aircraft Specifications			
Desired Altitude (m)	1000	Power Loading (kg/kW)	2.1
Range (km)	200	Thrust (N)	2424.54
Takeoff Weight (kg)	249.90	Thrust-to-Weight Ratio	0.99
Payload Weight (kg)	50	Disk Loading (kg/m^2)	245
Cruise Speed (m/s)	44.44	Wing Loading (kg/m^2)	75.34
Stall Speed (m/s)	34.19	Parasite Drag	0.01

Climb Speed (m/s)	30.00	Aircraft Drag Coefficient	0.03
Induced Velocity (m/s)	33.35	Airfoil Lift Coefficient	0.30
Power for Hover (kW)	80.86	Aircraft Lift Coefficient	1.80
Total Power (kW)	120	Lift-to-Drag Ratio	10.34
Wing Airfoil	NACA 23015	Tails Airfoil	NACA 23015

Table 14: Final Empty Weight Analysis

Empty Weights	
Wing	22.71
Horizontal Tail	2.29
Vertical Tail	1.25
Fuselage	59.59
Installed Engine	67.71
Flight Controls	2.31
Batteries	40
Total Empty Weight	**195.86**

5. Chapter 5: Computer-Aided Design

5.1 Initial CAD Design

Figure 20 shows the first initial CAD design made for the VTOL. As seen, the VTOL has two propellers with two blades as well as the ability to tilt the entire wing depending on if it is taking off or cruising. Since it is unmanned, there is no space needed for passengers and the fuselage only has to hold the batteries, controls, and payload.

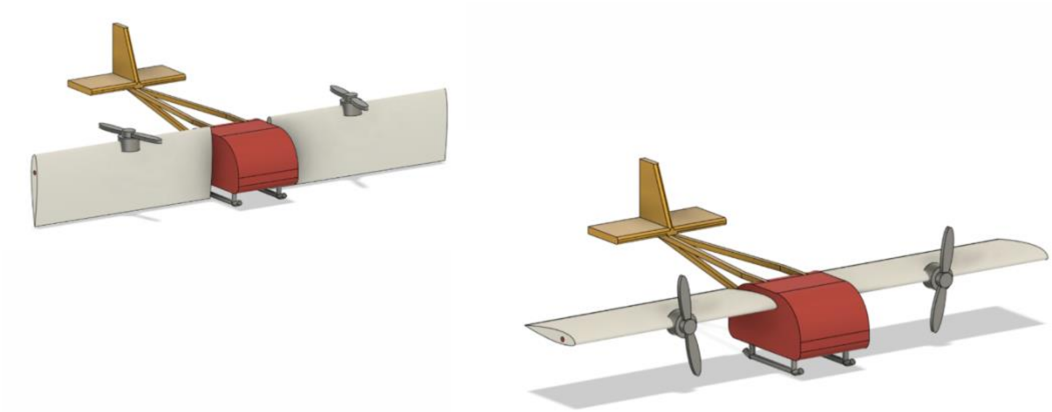


Figure 20: Initial CAD Design

5.2 Revised CAD Design

Figure 21 to Figure 25 show a revised CAD model of the VTOL. The main changes to the CAD model are adding the correct airfoil to the tail and attempting to streamline the fuselage for better aerodynamics. The fuselage length needed to be increased to allow for additional battery storage and more space for the cargo.

Figure 21: Revised CAD Design

Figure 22: Revised CAD, Front View

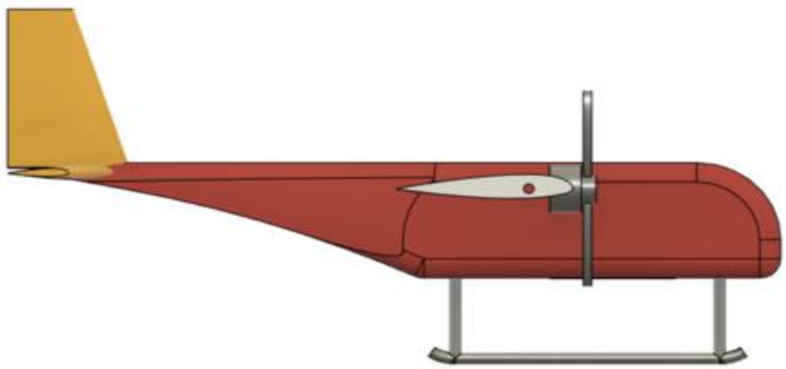


Figure 23: Revised CAD, Side View

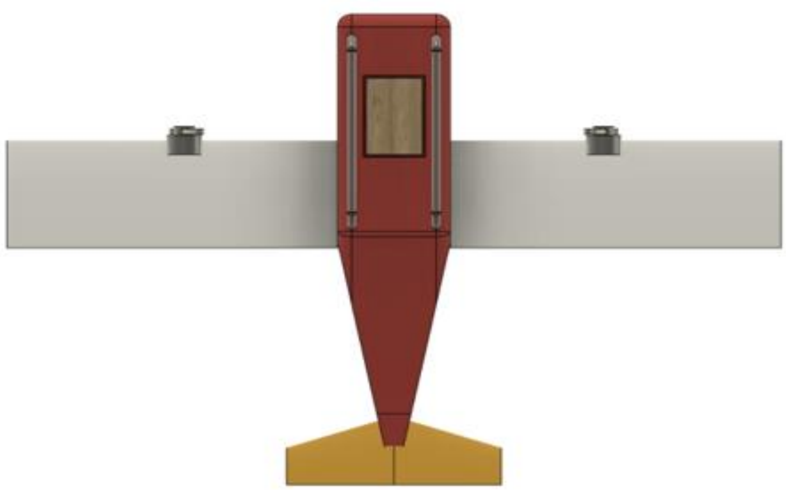


Figure 24: Revised CAD, Bottom View with Cargo Visible

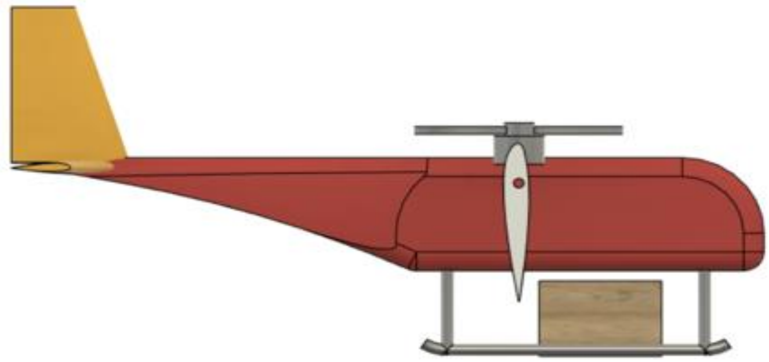


Figure 25: Revised CAD, Side View with Wings Tilted and Cargo Lowered

5.3 Final CAD Design

The final design (Figure 26 to Figure 29) changes the propellers from two blades to three. Besides the blades, the CAD design does not differ much from the revised design besides changing the color scheme of the VTOL to KSU colors and adding the KSU logo. Figure 30 is a render of the aircraft just after touchdown with the cargo lowered and the wings in the helicopter configuration.

Figure 26: Final CAD, Front View

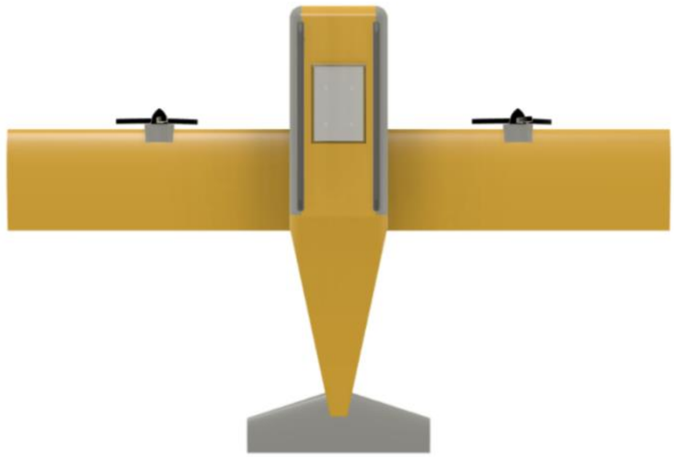


Figure 27: Final CAD, Bottom View

Figure 28: Final CAD, Side View

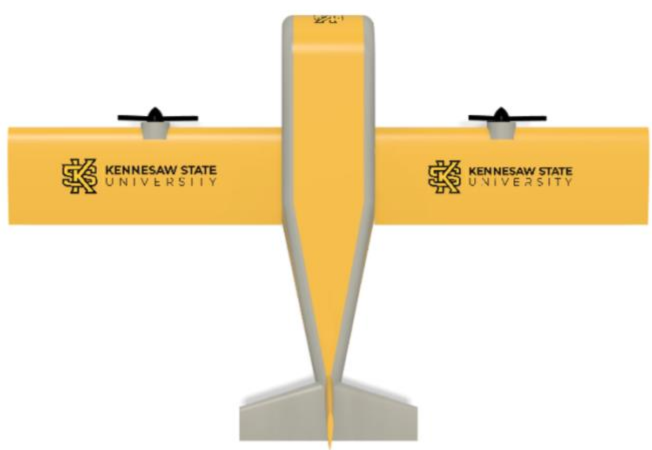


Figure 29: Final CAD, Top View

Figure 30: Final CAD Render in Helicopter Mode with Package Lowered

5.4 Flow Simulations

The Solidworks Flow Simulations reveal that the final CAD design could benefit from some future modifications to make the aircraft more aerodynamic. Figure 31 shows the simulated airflow velocity around the aircraft through the freestream air (shown as orange) at 44 m/s. The static propellors in the design caused the airflow to circulate (vortices, shown in blue) shortly behind the motor location but in practice the propellors should increase the airflow, not reverse it. The top of the aircraft appears to be more or less streamlined in level flight, but the bottom suffers from additional vortices caused by design choices. The fuselage portion from the cargo compartment to the elevators is slightly concave, leading to flow separation from the body and vortices which increase drag (Figure 32). Airflow going around the landing gear also separates and causes unwanted vortices, as seen in Figure 33.

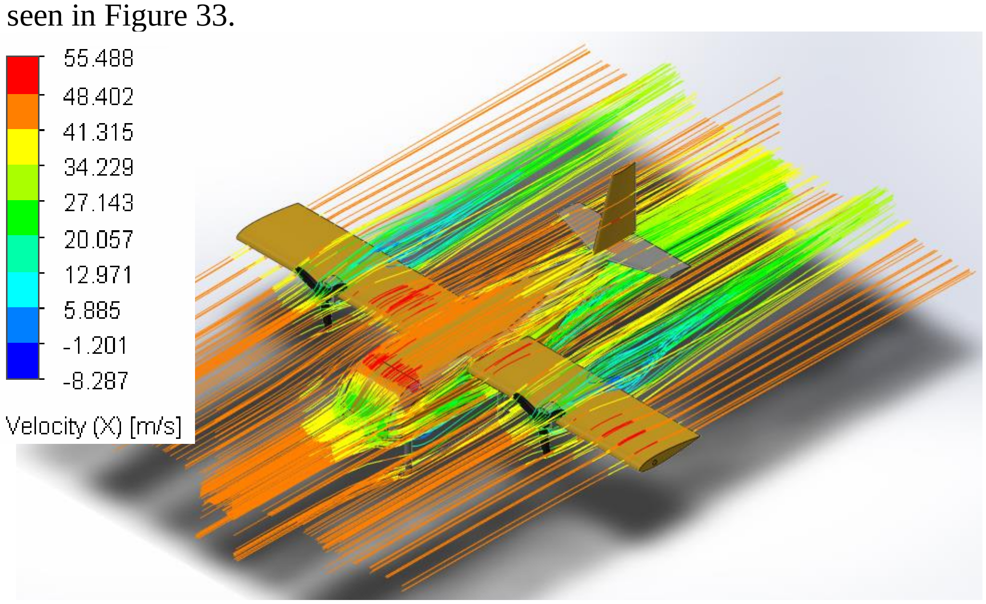


Figure 31: Flow Simulation of Forward Velocity (44 m/s) in Level Flight

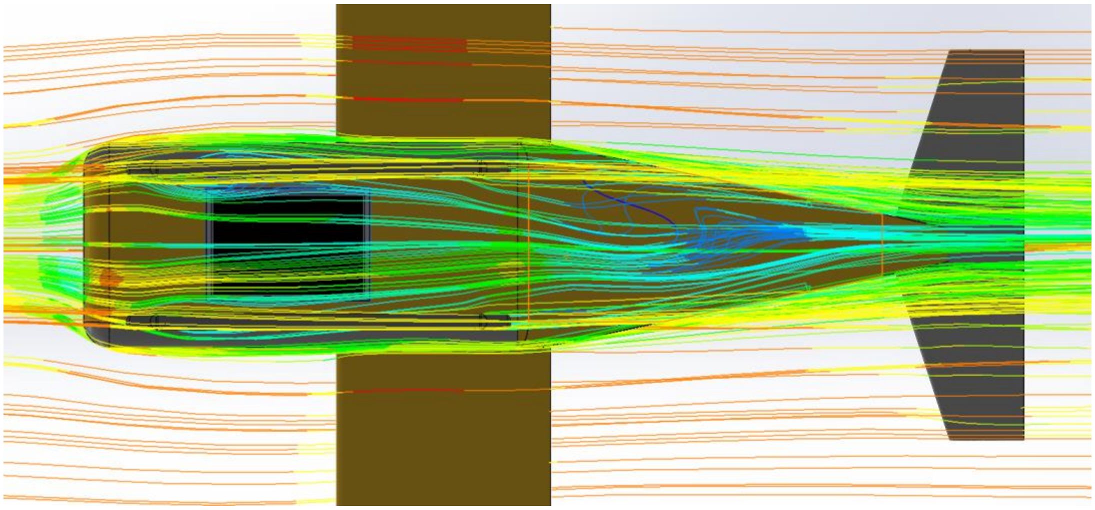


Figure 32: Bottom View of Flow Simulation in Level Flight

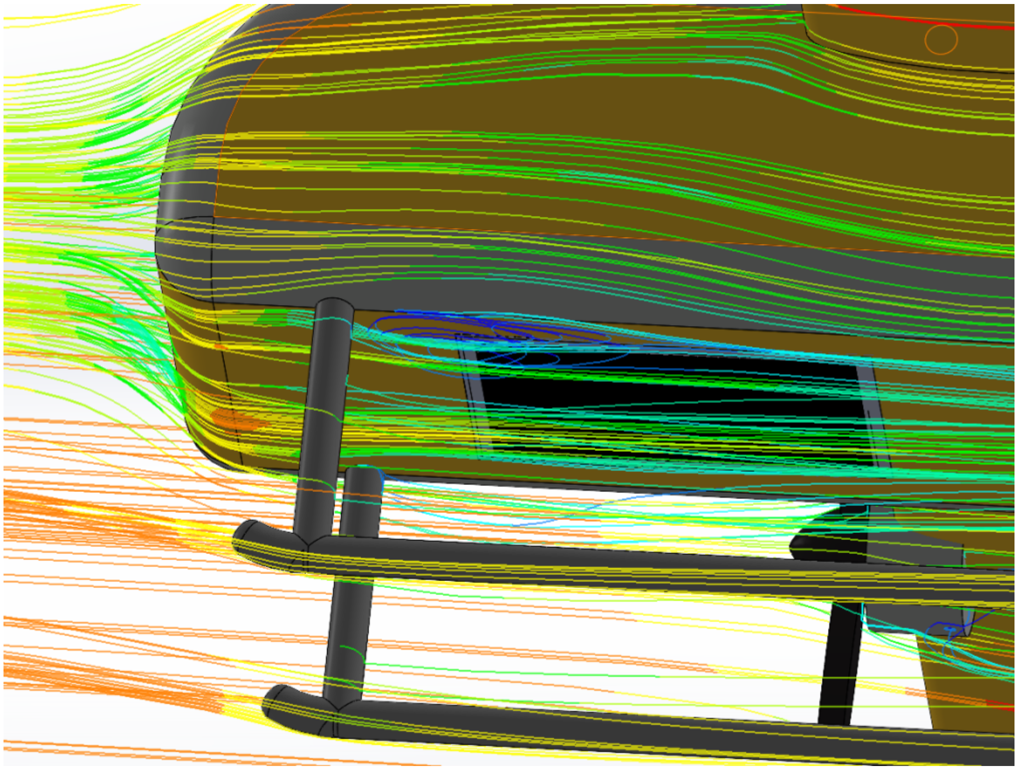


Figure 33: Flow Simulation around Landing Gear

During vertical flight in the helicopter configuration, the flow separation around the body is more severe than in level flight. As the aircraft rises at 30 m/s, the underside of the fuselage has a lower pressure (green arrows) than the upper surface (yellow arrows) which adds drag and increases the thrust needed (Figure 34). Similarly, when the freestream (blue) velocity encounters the aircraft, the flow goes around the body but there is significant airflow (red)towards the bottom of the fuselage and tail (Figure 35). The rising airflow interacts with the downflow and creates more drag inducting vortices.

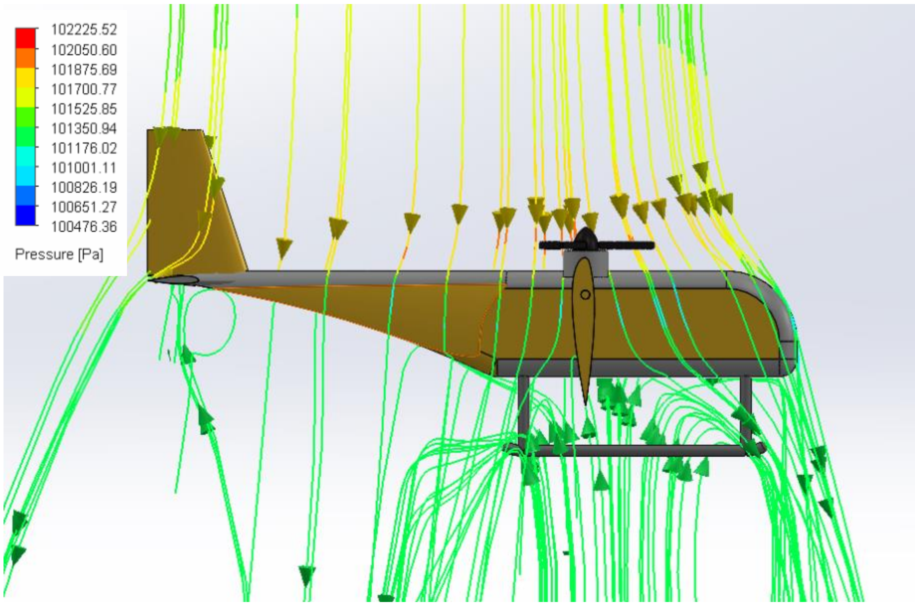


Figure 34: Pressure Flow Simulation in Vertical Flight

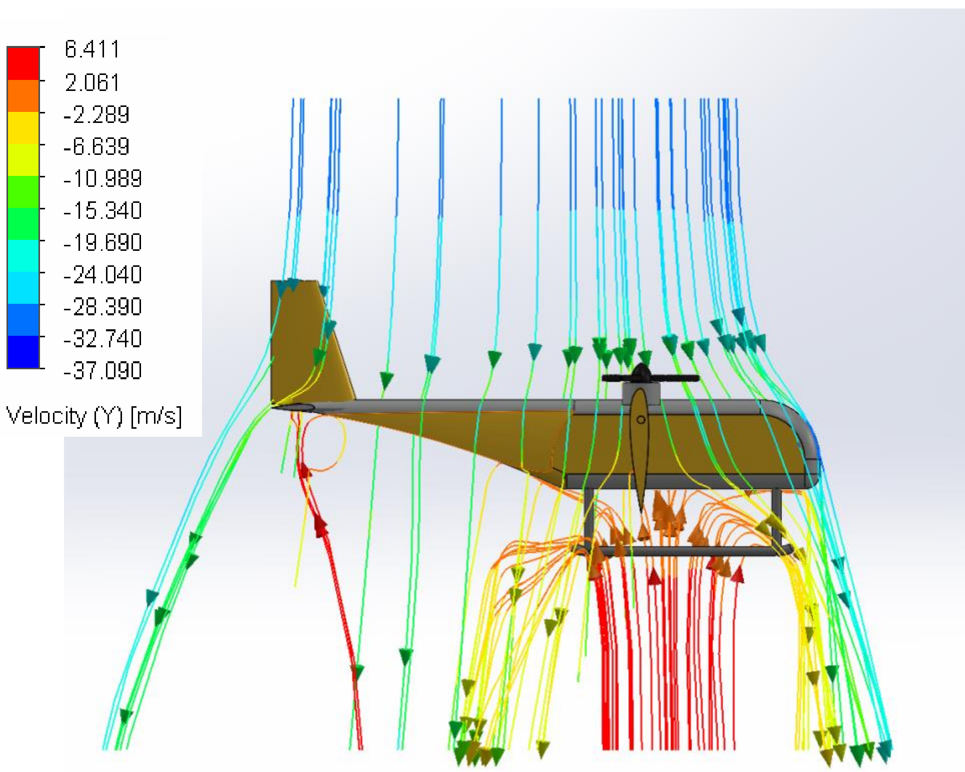


Figure 35: Airflow Velocity around Fuselage in Vertical Flight

6. Chapter 6: TOPSIS Analysis

6.1 TOPSIS

The TOPSIS method or Technique for Order Preference by Similarity to Ideal Solution is a decision-making methodology that is often used to find an ideal alternative based on certain criteria. We compared our model to various aircrafts using metrics like flight speed, payload, range, reliability, and maneuverability to determine which alternative could be seen as ideal, but range, reliability, and maneuverability can be seen as highly subjective. Since the weights placed on each criterion are highly subjective, they were determined by group consensus.

Table 15: Qualitative Scale

Qualitative Scale:	
Excellent	9
Above Average	7
Average	5
Below Average	3
Poor	1

Table 16: Decision Matrix

	Flight Speed(km/h)	Payload(kg)	Range	Reliability	Maneuverability
Our model	162.00	50	5	7	5
Wingcopter	150.00	6	5	5	7
Alphabet Wing	112.00	1.5	7	5	3
Zipline	100.00	1.75	9	7	3
Horsefly	74.00	4.5	3	7	9
F/Chretien Helicopter	40.00	170	3	7	3

$$DM = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_p \end{array} \begin{array}{c} \begin{array}{cccc} R_1 & R_2 & \cdots & R_q \end{array} \\ \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1q} \\ c_{21} & c_{22} & \cdots & c_{2q} \\ \vdots & \vdots & \ddots & \vdots \\ c_{p1} & c_{p2} & \cdots & c_{pq} \end{bmatrix} \end{array}$$

Figure 36: Initial Data Matrix [20]

l represents the alternative index (l = 1, 2, ..., q), while n is the number of potential alternatives and m represents the criteria index (m =1, 2, ..., p). The elements R_1, R_2, ..., R_q for the DM define the criteria while A_1, A_2, ..., A_p define the alternatives. [20]

Table 17: Normalized Matrix

NORMALIZED MATRIX

	Flight Speed	Payload	Range	Reliability	Maneuverability
Our model	0.5787	0.2819	0.3553	0.4463	0.3706
Wingcopter	0.5358	0.0338	0.3553	0.3188	0.5189
Alphabet Wing	0.4001	0.0085	0.4975	0.3188	0.2224
Zipline	0.3572	0.0099	0.6396	0.4463	0.2224
Horsefly	0.2643	0.0254	0.2132	0.4463	0.6671
F/Chretien Helicopter	0.1429	0.9584	0.2132	0.4463	0.2224

$$Normalized\ Decision\ Matrix = L_{lm} = \frac{c_{lm}}{\sqrt{\sum_{l=1}^{q} c_{lm}^2}} \qquad (24)$$

The equation above represents the relative performance of each alternative within the Normalized Decision Matrix.

Table 18: Criteria Weights

	Flight Speed	Payload	Range	Reliability	Maneuverability
Raw Weight	8	4.5	7	7	3.5
Weights	0.267	0.150	0.233	0.233	0.117

Table 19: Weighted Data Matrix

WEIGHTED DATA MATRIX

	Flight Speed	Payload	Range	Reliability	Maneuverability
Our model	0.1543	0.0423	0.0829	0.1041	0.0432
Wingcopter	0.1429	0.0051	0.0829	0.0744	0.0605
Alphabet Wing	0.1067	0.0013	0.1161	0.0744	0.0259
Zipline	0.0953	0.0015	0.1492	0.1041	0.0259
Horsefly	0.0705	0.0038	0.0497	0.1041	0.0778
F/Chretien Helicopter	0.0381	0.1438	0.0497	0.1041	0.0259

$$V = V_{lm} = W_m \times L_{lm} \qquad (25)$$

By multiplying the element for each column of the normalized decision matrix, the weighted decision matrix was determined.

Table 20: Ideal Solution Matrix

IDEAL SOLUTION MATRIX

	Flight Speed	Payload	Range	Reliability	Maneuvability
Positive Ideal	0.1543	0.1438	0.1492	0.1041	0.0778
Negative Ideal	0.0381	0.0013	0.0497	0.0744	0.0259

$$Positive\ Ideal\ Solution = I^+ = \{V_1^+, V_2^+, \dots, V_q^+\}\ where{:}\ V_m^+ = \{Max(V_{lm})\} \qquad (26)$$
$$Negative\ Ideal\ Solution = I^- = \{V_1^-, V_2^-, \dots, V_q^-\}\ where{:}\ V_m^- = \{Min(V_{lm})\}$$

The above table represents the positive and negative ideal solutions for flight speed, payload, range, reliability, and maneuverability. They can be identified by finding the lowest and highest possible values for each criterion or column in the weighted data matrix.

Table 21: Distance from Positive and Negative Ideal Solution Matrixes

DIST FROM POSITIVE MATRIX

	Flight Speed	Payload	Range	Reliability	Maneuverability	S*
Our model	0.000000	0.010298	0.004400	0.000000	0.001197	0.126073
Wingcopter	0.000131	0.019235	0.004400	0.000885	0.000299	0.157954
Alphabet Wing	0.002269	0.020305	0.001100	0.000885	0.002692	0.165079
Zipline	0.003488	0.020245	0.000000	0.000000	0.002692	0.162559
Horsefly	0.007027	0.019588	0.009899	0.000000	0.000000	0.191088
F/Chretien Helicopter	0.013506	0.000000	0.009899	0.000000	0.002692	0.161548

DIST FROM NEGATIVE MATRIX

	Flight Speed	Payload	Range	Reliability	Maneuverability	S-
Our model	0.013506	0.001682	0.001100	0.000885	0.000299	0.132185
Wingcopter	0.010980	0.000014	0.001100	0.000000	0.001197	0.115287
Alphabet Wing	0.004704	0.000000	0.004400	0.000000	0.000000	0.095414
Zipline	0.003267	0.000000	0.009899	0.000885	0.000000	0.118537
Horsefly	0.001049	0.000006	0.000000	0.000885	0.002692	0.068066
F/Chretien Helicopter	0.000000	0.020305	0.000000	0.000885	0.000000	0.145569

$$S_l^+ = \sqrt{\sum_{m=1}^{p}(V_m^+ - V_{lm})^2}\ ; l = 1, 2, \dots, q \quad (27)$$

$$S_l^- = \sqrt{\sum_{m=1}^{p}(V_m^- - V_{lm})^2}\ ; l = 1, 2, \dots, q$$

Where l = Alternative index

m = criteria index

The table above shows the separation distances from positive ideal solution and negative ideal solution of each alternative. The formula used is listed above.

Table 22: Final Rankings

	Closeness to Ideal
Our model	**0.511834**
Wingcopter	**0.421923**
Alphabet Wing	**0.366282**
Zipline	**0.421697**
Horsefly	**0.262648**
F/Chretien Helicopter	**0.473985**

$$C_l = \frac{S_1^-}{(S_1^+ + S_1^-)}\ , 0 \leq C_1 \leq 1 \quad (28)$$

The chart above shows that the VTOL model was closest to ideal when flight speed, payload, and reliability were made the heaviest weighted criteria. The formula above was used to determine the closeness to ideal for each criterion.

7. Chapter 7: Conclusions

The aircraft design process is very iterative and achieving even the simplest of goals becomes a grand undertaking in which solving one aspect will change another which in turn changes the original values which changes another…. On and on the process repeats until a semblance of an answer presents itself and the next part of the process can commence. Designing an aircraft is less of creating a finished product that is perfect and more of deciding when a design is good enough for the required needs of the job, even if more improvements could be made.

Based on the minimum success criteria, the VTOL designed and modeled in the preceding sections is a success. The aircraft has the capability to transport 50kg of medical supplies in a predefined 120cm x 80cm x 80cm container autonomously without human intervention excluding the initial loading of the package. It can vertically take off from a launch site up to 1,000 meters and transition to horizontal flight, like a traditional plane, to reach locations 50km away where it will return to the helicopter configuration to vertically descend. After unloading the supplies, the craft will reverse the process to get back to the initial launch site. For the secondary mission, the aircraft can also transport the same 50kg of medical supplies one way to warehouses and logistic centers 200km away from the launch site without recharging, in similar fashion to the previous mission.

Additionally, the aircraft satisfies the less vital criteria for success. The entire aircraft is within a 6.1m x 6.1m x 6.1m maximum size: the wingspan is 5.5m and the length is 4.14m. The loading and unloading process can be done quickly through the use of a latch system and the only human input is placing the package. Lastly, the aircraft can takeoff from dense urban centers by taking off vertically while also reaching destinations 50km away within 28 minutes and 200km away in 75 minutes by converting to a fast and efficient plane.

Although the minimum requirements have been met and the aircraft is sufficiently designed, there is room for optimization/improvement in the future.

- Aircraft Fuselage Design Optimization
  The aircraft fuselage could be optimized to reduce areas of flow separation to reduce drag. The landing gear could also be modified to retract which will allow for a more streamlined body. The fuselage is boxy as is and a round shape would be more ideal.
- Designing with Other Disciplines
  Discussing the design with other experts (electrical engineers, structural engineers, manufacturing engineers, etc.) will vastly improve the quality and overall design of the aircraft. Aerospace engineers and industrial systems engineers do not have all the knowledge needed for producing an aircraft from start to finish.
- Safety Requirements
  Increasing the safety of the system to achieve FAA approval for commercial use will allow for the aircraft to have the potential of being commercially viable. Medical suppliers will not want to send expensive supplies in an aircraft that may injure people or property.
- Building a Physical Prototype
  Allows regulatory approval and will lead to a more thorough analysis of the craft in the "real world."

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Appendix A: Acknowledgements

As a team**,** we would like to express our thanks Dr. Adeel Khalid for the time, energy, and guidance that he provided to us during our time in university and throughout the progression of this project.

We also would like to thank our friends and family who supported us throughout our academic careers.

Appendix B: Contact Information

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Appendix C: Reflections

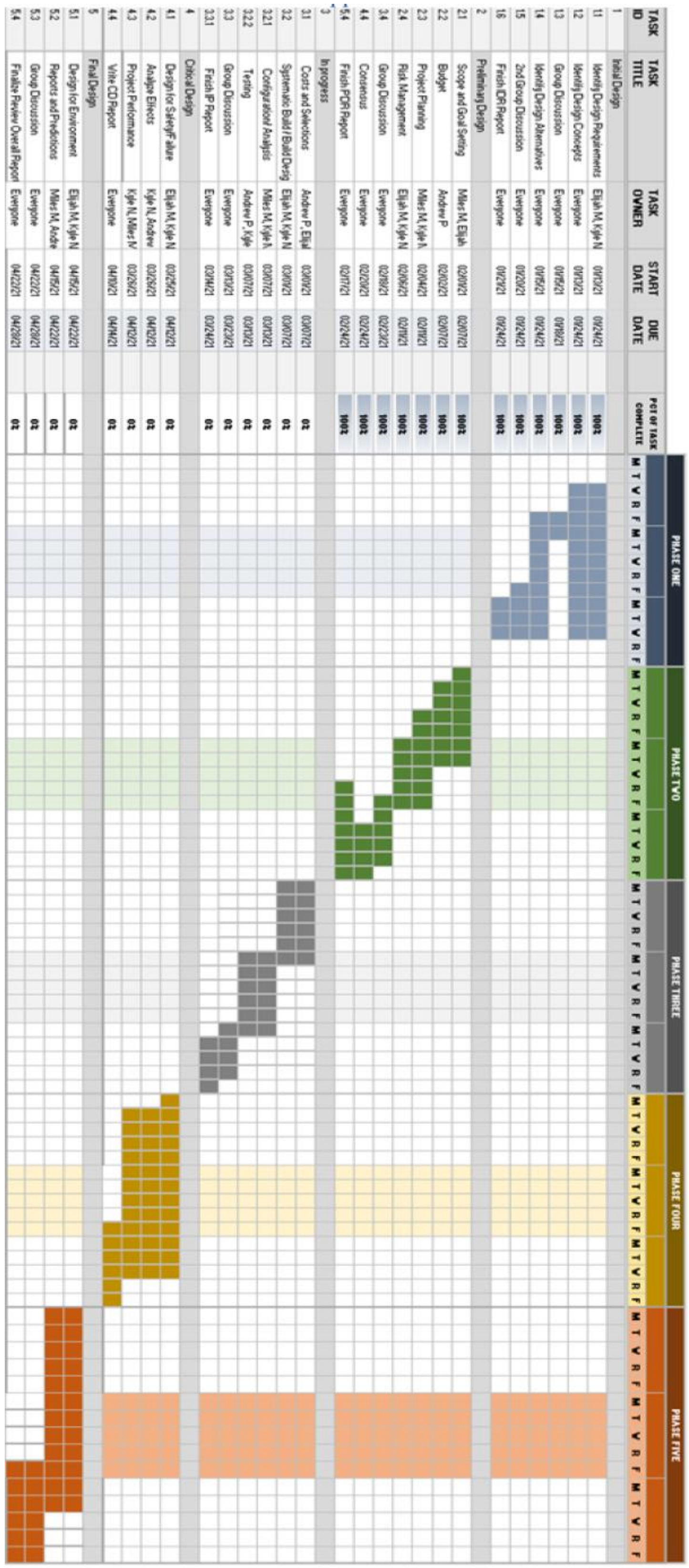
Throughout the design process, we were able to utilize different concepts and skills learned from each of our respective fields in order complete the project. Some large challenges that we faced were dealing with project management and not really being able to meet face to face due the COVID-19 Pandemic. Even so, we had to make the best of the unexpected situation. We overcame this problem by focusing on each team member having individual tasks and conveying our individual findings, calculations, and results weekly. (Miles Mack)

Throughout this project we exercised lots of different skills, and the project tested our competency. The area where I felt most challenged, was the project management side of things. It was difficult to imagine where to start the project. You start with a single goal, in this case designing a drone which can carry a payload of 50kg, and it branches out into all these intricate processes and problems. I now see how important it is, to have a clear vision of your goals. When you have a clear vision of what needs to be done, you can allocate all your time and energy into completing the task. (Andrew Payne)

A major problem that occurred was trying to complete this project during the pandemic. Without in person classes, it made it difficult to catch up with everyone and make sure we were consistently on the right track. I personally had difficulties keeping all of the calculations and formulas organized enough to actually gleam any information from them. It was also difficult working with electric VTOLs because it was something I didn't have a lot of knowledge on and allowed us to work outside my usual comfort zone. This project was a great learning experience on aircraft design and working in teams. (Elijah McDonald)

This assignment has made me appreciate aircraft designers much more than I used to. The amount of work that is involved with aircraft design is staggering and it is a wonder aircraft get designed when everything starts with estimations based on historical trends. When we started this project, I did not think about the complications of tilt-wing aircraft and the complications to designing electric, let alone them combined. Many of the equations and problem-solving approaches for this type of aircraft were not taught in a course so if there is a silver lining to picking a challenging aircraft, it is that I learned a lot of new information and how to apply it. Having more time to complete this project would have led to more refined results but there is only so much time in each semester. (Kyle Nottage)

Appendix D: Detailed Gantt Chart



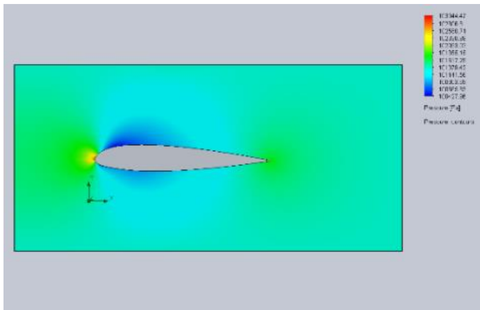
Appendix E: Electric Aircraft Specifications

Aircraft	Motor			Battery		Wingspan (m)	Wing Area (m^2)	Aspect Ratio	Empty Weight (kg)	Gross Weight (kg)	Payload Weight	Max Speed (km/h)	Capacity	Propellers	
	kW	hp	Weight (kg)	Weight (kg)	Power (kWh)									Blades	Diameter (m)
Alisport Silent Club	13	17		40	1.4	12	10.3	14	125	290	165	200	1	2	1.6
Pipistrel Taurus Electro	40	54				14.97	12.33	18.6	285	550	265	130	2		
Rutan Long ESA		258				7.96	7.617		322	601	279	298	2		
Pipistrel WATTsUP	50	67				10.5	9.51	11.3	314	550	236	194	2	2	1.8
Pipistrel Alpha Electro	60	80	11	126		6.5	9.51						2	2	
Bye Aerospace eFlyer 2	90					12	12		662	862	200	250	2	3	

Appendix F: NACA 23015 Pressure Plots @ Aspect Ratio 6

Angle of Attack:

0



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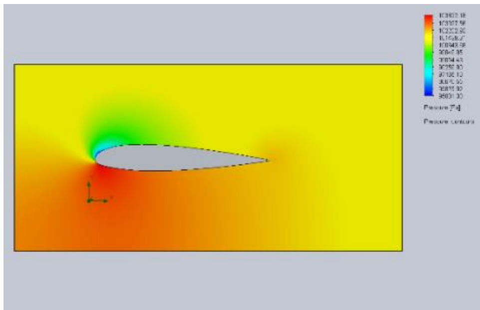

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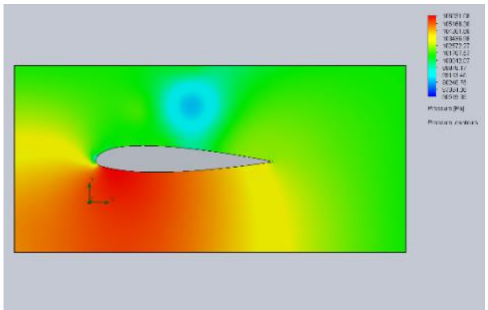

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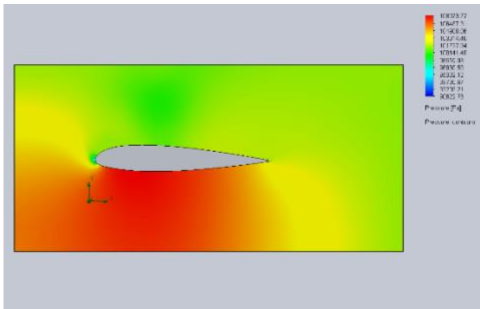

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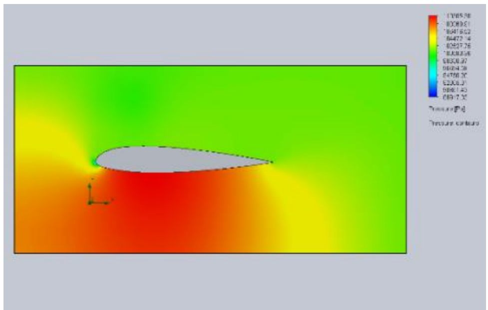

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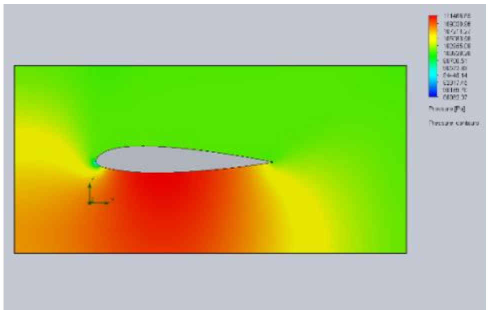

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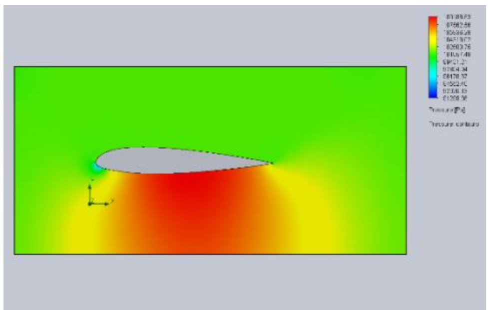
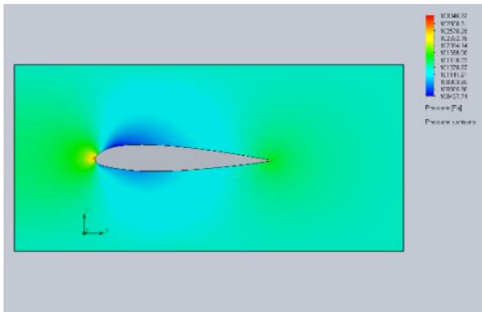


Appendix G: NACA 23015 Pressure Plots @ Aspect Ratio 8

Angle of Attack:

0



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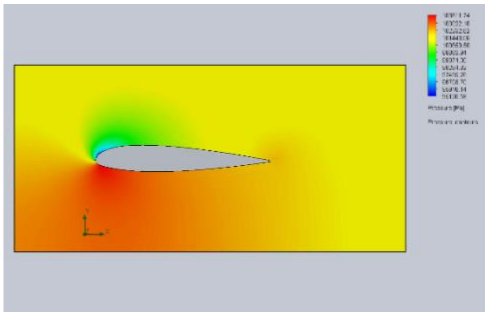

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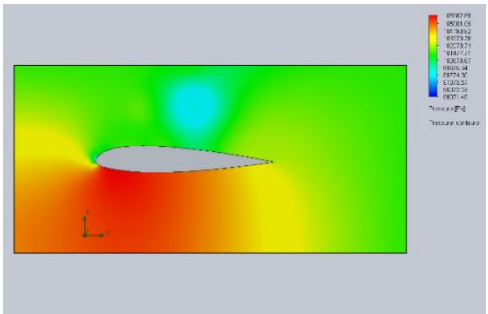

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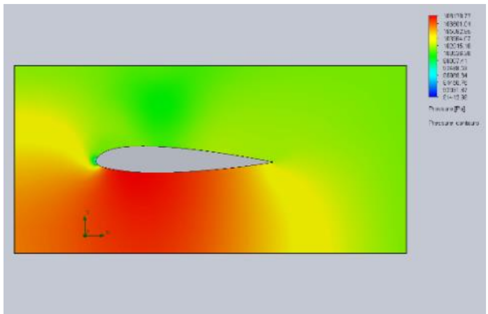

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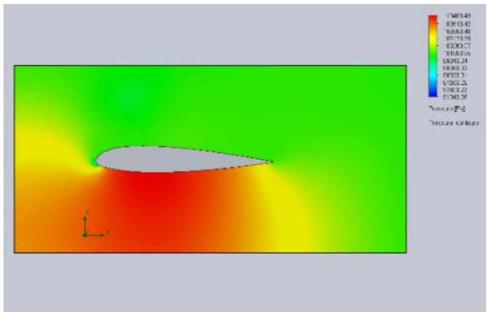

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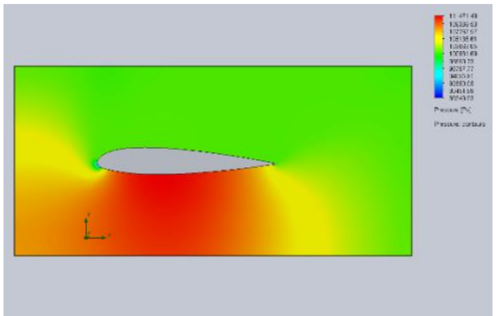

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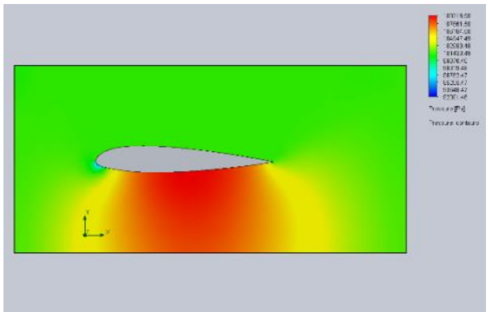
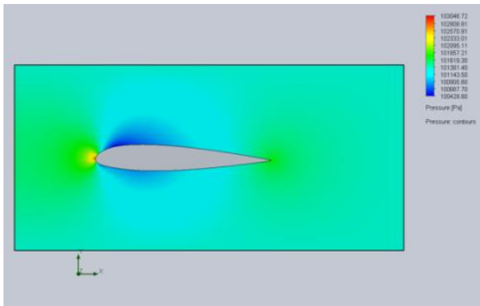


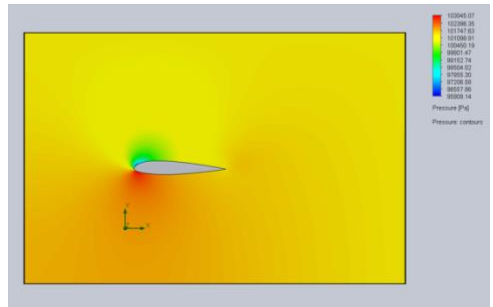
Appendix H: NACA 23015 Pressure Plots @ Aspect Ratio 10

Angle of Attack:

0



15



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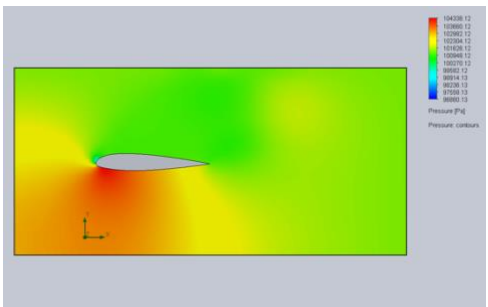

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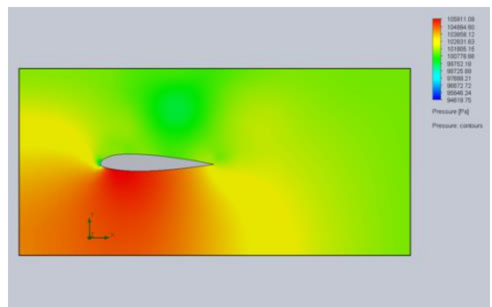

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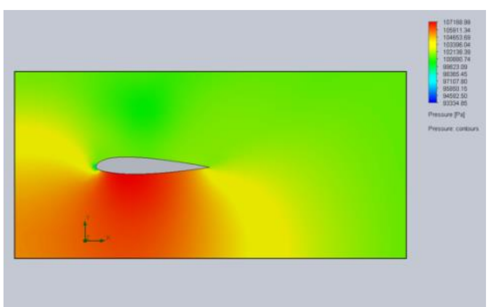

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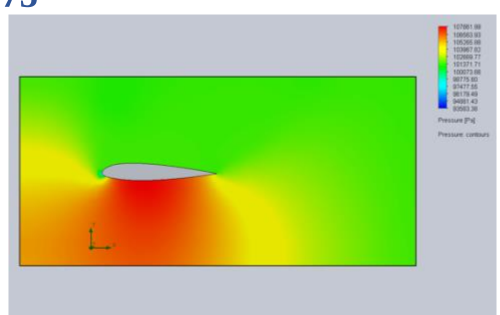

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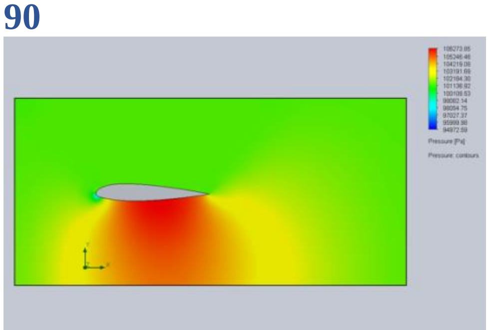

Appendix I: General Aviation Component Weight Equations [4]

$$W_{\text{wing}} = 0.036 S_w^{0.758} W_{\text{fw}}^{0.0035} \left(\frac{A}{\cos^2 \Lambda}\right)^{0.6} q^{0.006} \lambda^{0.04}$$

$$\times \left(\frac{100\, t/c}{\cos \Lambda}\right)^{-0.3} (N_z W_{\text{dg}})^{0.49}$$

$$(\text{ignore second term if } W_{\text{fw}} = 0) \qquad (15.46)$$

$$W_{\text{horizontal tail}} = 0.016 (N_z W_{\text{dg}})^{0.414} q^{0.168} S_{\text{ht}}^{0.896} \left(\frac{100 t/c}{\cos \Lambda}\right)^{-0.12}$$

$$\times \left(\frac{A}{\cos^2 \Lambda_{\text{ht}}}\right)^{0.043} \lambda_h^{-0.02} \qquad (15.47)$$

$$W_{\text{vertical tail}} = 0.073 \left(1 + 0.2 \frac{H_t}{H_v}\right) (N_z W_{\text{dg}})^{0.376} q^{0.122} S_{\text{vt}}^{0.873}$$

$$\times \left(\frac{100 t/c}{\cos \Lambda_{\text{vt}}}\right)^{-0.49} \left(\frac{A}{\cos^2 \Lambda_{\text{vt}}}\right)^{0.357} \lambda_{\text{vt}}^{0.039} \qquad (15.48)$$

(If λ_{vt} is less than 0.2, use 0.2)

$$W_{\text{fuselage}} = 0.052\, S_f^{1.086} (N_z W_{\text{dg}})^{0.177} L_t^{-0.051}$$

$$\times (L/D)^{-0.072} q^{0.241} + W_{\text{press}} \qquad (15.49)$$

$$W_{\text{main landing gear}} = 0.095 (N_l W_l)^{0.768} (L_m/12)^{0.409} \qquad (15.50)$$

$$W_{\text{nose landing gear}} = 0.125 (N_l W_l)^{0.566} (L_n/12)^{0.845}$$

(reduce total landing gear weight by 1.4% of TOGW if nonretractable) (15.51)

$$W_{\text{installed engine (total)}} = 2.575\, W_{\text{en}}^{0.922} N_{\text{en}} \qquad (15.52)$$

(includes propeller and engine mounts)

$$W_{\text{fuel system}} = 2.49 V_t^{0.726} \left(\frac{1}{1 + V_i/V_t}\right)^{0.363} N_t^{0.242} N_{\text{en}}^{0.157} \qquad (15.53)$$

$$W_{\text{flight controls}} = 0.053 L^{1.536} B_w^{0.371} (N_z W_{\text{dg}} \times 10^{-4})^{0.80} \qquad (15.54)$$

$$W_{\text{hydraulics}} = K_h W_{\text{dg}}^{0.8} M^{0.5} \qquad (15.55)$$

$$W_{\text{electrical}} = 12.57 (W_{\text{fuel system}} + W_{\text{avionics}})^{0.51} \qquad (15.56)$$

$$W_{\text{avionics}} = 2.117\, W_{\text{uav}}^{0.933} \qquad (15.57)$$

$$W_{\text{air conditioning and anti-ice}} = 0.265 W_{\text{dg}}^{0.52} N_p^{0.68} W_{\text{avionics}}^{0.17} M^{0.08} \qquad (15.58)$$

$$W_{\text{furnishings}} = 0.0582\, W_{\text{dg}} - 65 \qquad (15.59)$$

Appendix J: Individual Contributions

Table 23: Major Contributor(s) to Each Chapter

Section #	Section Name	Team Members
	Executive Summary	Andrew
	Chapter 1:	
1.1	Introduction	Kyle
1.2	Overview	Elijah
1.3	Objective	Elijah
1.4	Justification	Kyle
1.5	Project Background and Problem Statement	Kyle
	Chapter 2: Literature Review	
2.1	Vertical Takeoff and Land Aircraft	Kyle
2.2	Private Sector Approaches to Delivery Drones	Kyle
2.3	Previous VTOL Design Projects	Miles
2.4	Delivery Methods	Miles
2.5	Use of Composite Materials for Drone Manufacturing	Andrew
2.6	Energy Systems	Kyle
2.7	Social benefits of drones during COVID-19	Miles
	Chapter 3: Project Management	
3.1	Problem Solving Approach	Miles
3.2	Expected Problems	Miles
3.3	Requirements for Success	Elijah/Kyle
3.4	Gantt Chart/Schedule	Miles
3.5	Flow Charts	Miles
3.6	Responsibilities	Miles
3.6	Budget	Andrew
3.8.	Material Required/Used	Andrew
3.9	Resources Available	Miles
	Chapter 4: Sizing Analysis	
4.1	Mission Profile	Elijah
4.2	Initial Sketches	Elijah/Kyle
4.2.1	Quadcopter Sketch	Elijah
4.2.2	VTOL Sketch	Kyle
4.2.3	Initial Design	Kyle
4.3	Motor Selection from Trends	Kyle

4.4	Power Loading and T/W	Elijah
4.5	Airfoil Selection	Elijah/Kyle
4.6	Initial Sizing in Airplane Configuration	Kyle
4.7	Initial Sizing in Helicopter Configuration	Elijah
4.8	Adjusted Sizing	Kyle
4.9	Geometry Sizing	Kyle
4.9.1	Fuselage	Kyle
4.9.2	Tail	Kyle
4.1	Motor Selection and Battery Estimation	Kyle
4.10.1	Motor Selection	Kyle
4.10.2	Battery Estimation	Kyle
4.11	Aerodynamics	Elijah
4.11.1	Lift	Elijah
4.11.2	Lift Curve Slope	Elijah
4.11.3	Parasite Drag	Elijah
4.11.4	Lift to Drag Ratio	Elijah
4.12	Weights	Elijah
4.13	Loading and Unloading Payload Procedures	Andrew
4.14	Final Sizing and Specifications	Elijah
	Chapter 5: Computer-Aided Design	
5.1	Initial CAD Design	Kyle/Elijah
5.2	Revised CAD Design	Kyle/Elijah
5.3	Final CAD Design	Kyle
5.4	Flow Simulations	Kyle
	Chapter 6: TOPSIS Analysis	
6.1	TOPSIS	Miles
7	Chapter 7: Conclusions	Kyle/Miles

Table 24: Technical Contributions

Miles Mack	Created charts/ managed schedules for project. Edited video. Contributed to background research. Incorporated design techniques to assist design process. Created and calculated the TOPSIS diagrams/analysis and designed process charts.
Elijah McDonald	Lead all calculations for the VTOL in helicopter configuration. Calculated power necessary for flight, P/W, T/W, takeoff and empty weight, lift, and drag. Contributed to airfoil selection and defining project parameters. Lead most paper formatting and review.
Kyle Nottage	Lead calculations for the VTOL in plane configuration. Calculated required battery amount and determined the motors. Performed all computer-aided design and analysis. Helped with literature review.
Andrew Payne	Dealt with manufacturing processes, material selection, and budgeting. Contributed to literature review. Wrote executive summary.