AERODYNAMIC ANALYSIS OF A QUADCOPTER DRONE FOR HEAVY LOAD LIFTING

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by

Rayyan Abdulaziz Bin Yasir
Muhammad Arham Khan

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EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by:

Rayyan Abdulaziz Bin Yasir 356792

Muhammad Arham Khan 356925

Titled: "AERODYNAMIC ANALYSIS OF A QUADCOPTER DRONE FOR HEAVY LOAD LIFTING" be accepted in partial fulfillment of the requirements for the award of BE MECHANICAL ENGINEERING degree with grade B

Supervisor: Dr. Syed Maaz Hasan, Professor, SMME, NUST	Dated: 29 Jul 24
Committee Member: Rehan Zahid, Assistant Professor SMME, NUST	29 Jul 24 Dated:
Committee Member: Dr. Emad Ud Din, Professor SMME, NUST	Dated: 29/7/24

(Head of Department) 05-8-24 (Date)

COUNTERSIGNED

Dated: 5-8-24

(Dean / Principal

ABSTRACT

In recent years, the use of drones for package delivery has gained significant attention due to their potential to transform logistics and transportation. However, one of the major challenges in drone delivery systems is the limitation on the payload capacity of individual drones. This project focuses on exploring the formation of drones for lifting heavier loads, utilizing various formations and components to optimize the delivery process. Different drone formations including Vee, Front, Column, and Echelon are studied to determine their efficacy in lifting heavier loads. The project also researches into the main components of drones such as motors, frames, and propellers, selecting appropriate specifications to meet the requirements of heavy load transportation. By leveraging the collective strength of multiple drones in formation, this project aims to overcome the payload limitations of single drone deliveries and enhance the efficiency and effectiveness of package delivery systems.

ACKNOWLEDGMENTS

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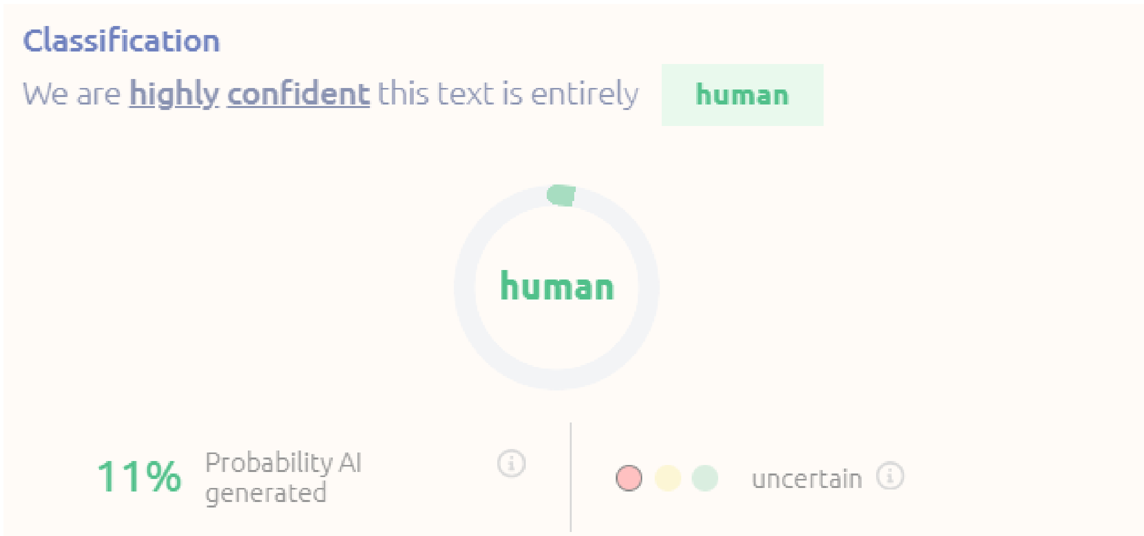
ORIGINALITY REPORT



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ABBREVIATIONS

CFD	Computational Fluid Dynamics
UAV	Unmanned Aerial Vehicle
RPM	Revolutions per minute
CCW	Counter Clockwise
CW	Clockwise

<u>CHAPTER 1: INTRODUCTION</u>

1.1 Background

While the idea of lifting heavy things has been around for thousands of years, modern engineering and robotics have taken it to new heights. Drones, with their precision and efficiency, can now handle much heavier payloads than ever before.

The main goal of this project is to devise a drone configuration appropriable to be used in the transportation of heavy loads. The use of 2 vertically aligned drones for load lifting will potentially decrease the transportation costs as well as emissions in terms of carbon footprint. This allows us to progress towards a greener environment.

Example uses: delivery of foods or groceries are done via cars or more commonly, bikes. The use of drone formations will help decrease the carbon emissions that the bike otherwise would have produced.

The other goal of using drones for heavy lifting is to tackle tasks that are tough for humans or traditional machines, such as reaching remote areas easily. But there are challenges. Drones have limits on how much they can carry, how much power they need, and how stable they can stay. However, ongoing research and advancements are tackling these issues, making drones more capable and reliable.

One promising solution is using formations of drones. By coordinating the movements of multiple drones, we can spread out the load and use energy more efficiently. This maximizes how much weight the drones can carry and makes operations more flexible.

Today, there are many different formations and setups for drones, each designed for specific tasks and constraints. Advanced control algorithms and communication systems help drones work together smoothly, lifting heavy loads with precision and stability.

In summary, using drones for heavy lifting is a major step forward in technology. By using drones smartly and coming up with innovative strategies, we can change the way heavy things are moved and delivered, opening up new opportunities in areas like logistics, construction, and disaster relief.

1.2 Motivation

Big names like Amazon, FedEx, and UberEats are always looking for new ways to make delivering packages faster and cheaper. Using drones for delivery is something they're really interested in because it could be super fast and efficient. But there are still some hurdles to overcome.

That's where our team comes in. We're working on a project to figure out how to use drones to carry heavier stuff. By teaming up with AlphaCube, we're aiming to tackle the challenges and come up with new solutions in drone technology. Our goal is to make drone delivery systems better and more reliable, so they can be used on a larger scale.

1.3 Problem Statement

Our task, given by AlphaCube, is to make drone delivery systems work better. We're focusing on how drones can work together in formations to carry heavy things more efficiently. By studying how drones fly in formations, we want to come up with new ideas to make them work better and carry more weight. Our goal is to make it easy for drones to fit into the way things are already done with deliveries.

1.4 Objectives

A list of the objectives has been formulated according to the available project time and resource. These are the deliverables of the project;

- CFD study of vertical drone formation
- Demonstration and Validation of swarms for lifting heavy loads.
- Framework of drone for lifting heavy loads

CHAPTER 2: LITERATURE REVIEW

The use of Unmanned Aerial Vehicles (UAVs), or drones, has become widespread due to their versatility in various fields. This literature review aims to give an overview of different types of UAVs, focusing on their classifications, what they can do, and where they're used.

2.1 Types of Drones

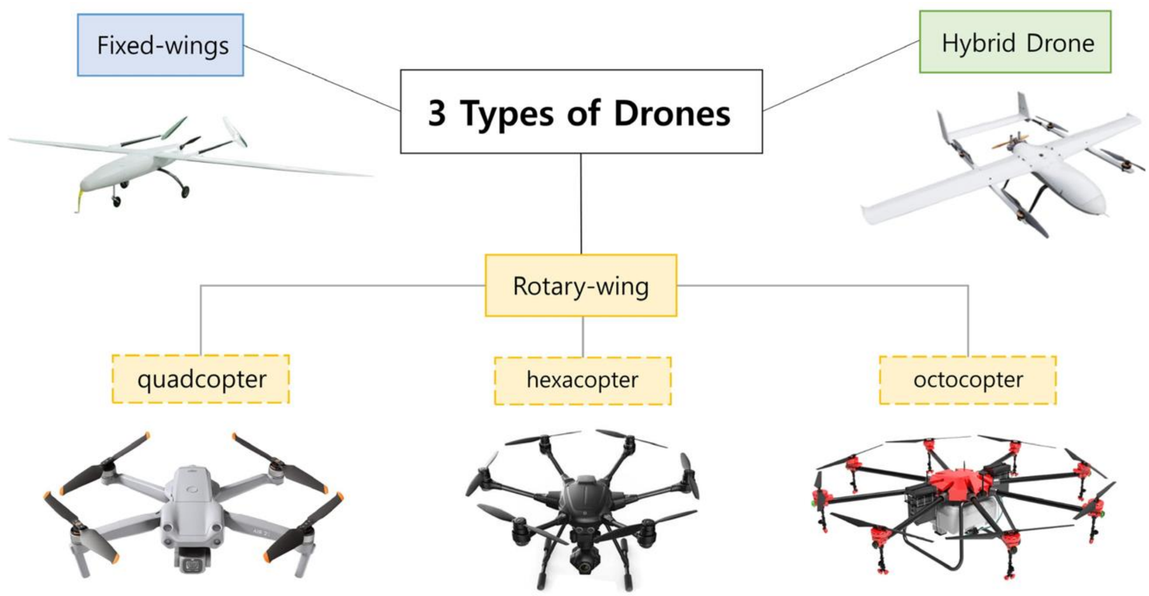


Figure 1: Types of Drones

2.1.1 Fixed-Wing Drones

Fixed-wing drones are like small airplanes, with wings that don't move. They're great for flying long distances efficiently but need a runway to take off and land. These drones are often used for things like making maps from the air, keeping an eye on crops, and watching over large areas for a long time. Their ability to stay in the air for a long time makes them perfect for tasks where they need to cover a lot of ground or watch over big fields.

2.1.2 Multirotor Drones:

Multirotor drones, including quadcopters, hexacopters, and octocopters, feature multiple rotors arranged in a symmetric configuration. These drones are highly maneuverable and capable of vertical takeoff and landing (VTOL) without requiring a runway. Multirotor drones excel in tasks that demand precise control and hovering capabilities, such as aerial photography, videography, and inspection of infrastructure. Their versatility and ease of operation make them popular choices for hobbyists, filmmakers, and commercial operators alike.

2.1.3. Single-Rotor Helicopters

Multirotor drones, like quadcopters, hexacopters, and octocopters, have several rotors arranged in a symmetrical pattern. They can take off and land vertically, so they don't need a runway. These drones are really good at moving around precisely and hovering in one spot, which makes them perfect for things like taking photos and videos from the air, inspecting buildings, and flying indoors. They're easy to use, so lots of hobbyists, filmmakers, and businesses use them.

2.1.4 Fixed-Wing VTOL Drones

Fixed-wing VTOL drones are a mix of fixed-wing airplanes and multirotor drones. They can take off and land vertically, just like multirotors, but they also have the efficiency and endurance of fixed-wing aircraft. Because they don't need a runway, they're great for tasks like surveying remote areas, delivering cargo to hard-to-reach places, and patrolling over water. They combine the best of both worlds, making them really useful for a wide range of applications.

2.1.5 Hybrid Drones

Hybrid drones bring together different types of propulsion systems, blending the strengths of fixed-wing and multirotor designs. They can switch between vertical and horizontal flight modes, which makes them really versatile. These drones are used for all sorts of things, from keeping watch over areas and gathering information to helping with farming and keeping an eye on the environment. Because they can change how they fly based on what's needed, they're really useful in situations that keep changing.

2.2 Components of Drones

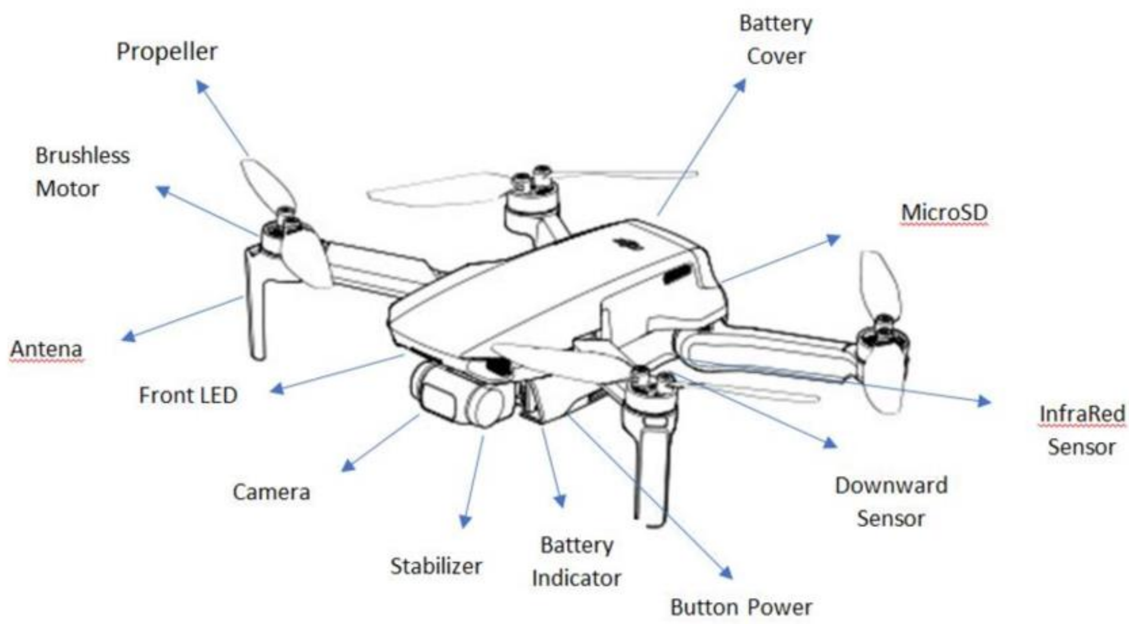


Figure 2: Drone Parts

2.2.1 Motor

This exploration dives into how motors drive drones forward. We're looking at details like the size of the stator and how much power the motor has, and how these affect how well the drone performs, especially when it needs to carry heavy things. We'll talk about how to choose the right motors, thinking about things like how much force they can make and how quickly they respond to different loads.

2.2.2 Frame

Choosing the right frame is super important for making sure drones can handle heavy loads without falling apart. We're looking at things like what materials the frame is made of, how big it is, and what it looks like, all to make sure the frame can handle different sizes of loads while still flying smoothly through the air.

2.2.3 Propeller

Propellers are crucial for making drones move forward. We're diving deep into propeller design, looking at things like how big they are, how steep the blades are, and how well they work. We're also paying close attention to picking the right propellers for lifting heavy things. We'll think about stuff like how much thrust they make compared to how heavy the drone is, how evenly they lift things, and how efficiently they use power, all to make sure the drone works great in different situations.

2.3 Load Carrying Capacity

2.3.1 Determination of load carrying capacity

Investigating the approaches utilized to establish the highest load a drone can carry is significant. This thorough examination involves various factors like the ratio of thrust to weight, energy usage patterns, and constraints related to structure. By delving into these aspects, we aim to gain a complete understanding of how they interact and impact the drone's ability to carry loads.

2.3.2 Analysis of payload limitations

Another facet of in-depth investigation into factors limiting payload capacity will emerge, addressing crucial aspects such as battery capacity, motor power capabilities, and aerodynamic constraints. Additionally, strategic approaches for alleviating these constraints will be suggested, encompassing advancements in battery efficiency and aerodynamic enhancements aimed at improving payload capabilities while ensuring operational reliability.

2.3.3 The propulsion system

The propulsion system comprises the propeller, motor, and any arrangements within the setup. It generates the necessary thrust for the UAV to hover, accelerate, or decelerate. The report discusses the utilization of two propellers mounted on a single motor. This configuration doubles the thrust compared to a single propeller setup. Consequently, the UAV can successfully carry a greater load.

2.3.4 Coaxial Propeller Systems

A creative strategy for boosting the lift generated by the lower drone involves employing coaxial propellers. This method involves utilizing two propellers driven by a single motor, enabling the generation of greater thrust. Coaxial rotor technology takes advantage of the lower propeller's ability to utilize the wake generated by the upper propeller, thereby enhancing its thrust.

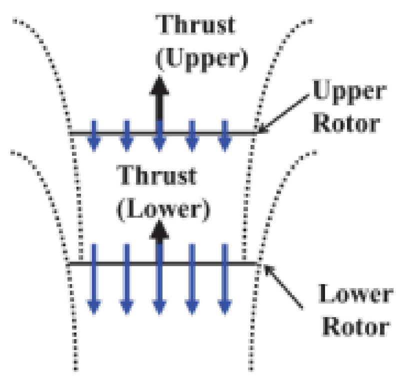


Figure 3: Coaxial Rotor

However, a problem arises wherein the drone requires the two propellers to rotate opposite to each other (i.e. one rotates CCW and the other must rotate CW). This can be achieved using the science behind helicopter aerodynamics[6], using a gearbox system to change the rotations of the two propellers. Two possible configurations are;

1. Bevel Gear Gearbox
2. Spur Gear Gearbox

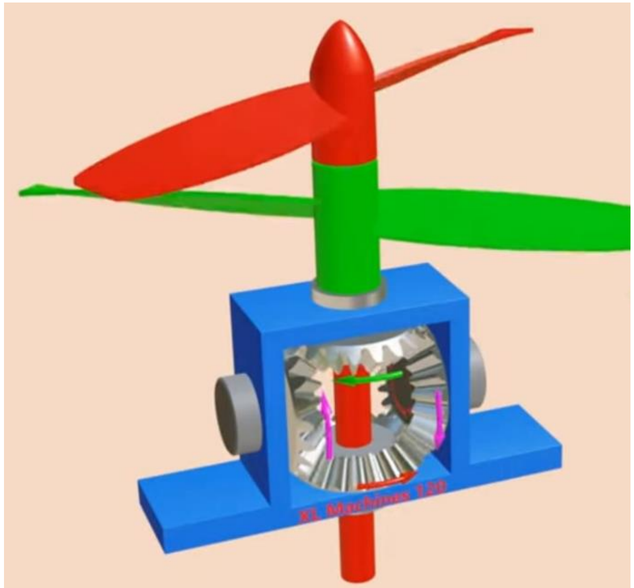


Figure 5: Bevel Gear Gearbox Configuration

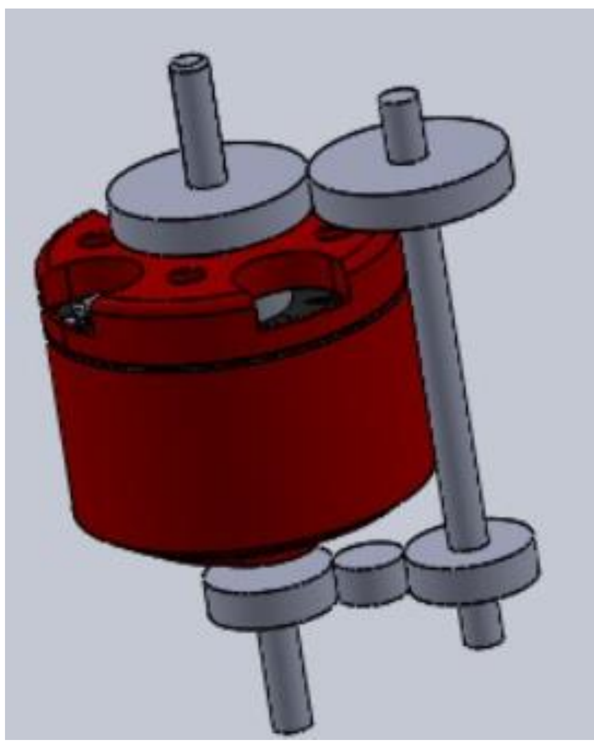


Figure 4: Spur Gear Gearbox Configuration

While these two configurations would generate the required thrust, they are dismissed as viable options. This is due to the need for 2 or 4 gears per coaxial propeller in the system. Consequently, the weight of the drone would significantly increase, offsetting the thrust enhancement provided by the coaxial propellers, thus defeating the original purpose. Unless a lightweight and innovative solution is identified, the payload capacity of the drone cannot be effectively increased.

2.3.5 Introduction to using multiple drones

One solution to the problem involves the innovative concept of harnessing the combined power of multiple drones organized in coordinated formations to surpass payload restrictions and strengthen load-carrying capability. Detailed discussions will outline the inherent benefits and obstacles linked with formation-based strategies, such as improved load distribution, efficient energy usage, and increased operational adaptability across various environments.

2.4 Formation-Based Load Lifting

2.4.1 Design and implementation of formation-based strategies

Precisely outlining the intricacies of designing and executing formation-based strategies tailored for lifting heavier loads is essential. Key focus areas include identifying optimal formation shapes, creating advanced coordination algorithms, and establishing reliable communication protocols to ensure smooth integration and synchronized operation of drones within the formation.

2.4.2 Testing and validation

Describing experiments and validation procedures is crucial to ensure the effectiveness of the formation. Tests will aim to empirically evaluate the feasibility of load lifting strategies based on formations, with a focus on the vertical (column) setup. Thorough testing regimes will evaluate performance metrics including load distribution, stability, and operational efficiency. Ultimately, validation of the proposed strategies will occur in the natural environment conditions.

2.4.3 Drone formation types

There are multiple formations that can be opted in order to increase the load carrying capacity of a drone system. The Vee and Echelon formations are relatively complex in their shapes and their testing regimes will be even more complex to do so. The formation studied in this project is the vertical (column) formation. It has multiple identical drones aligned perfectly on top of each other.

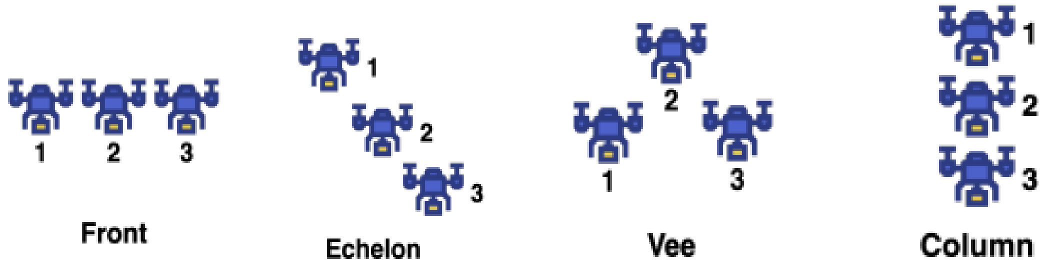


Figure 6: Drone Formations

CHAPTER 3: METHODOLOGY

A design methodology serves as a systematic approach for transforming requirements into a product that fulfills those requirements. In this work, which involved Computational Fluid Dynamics (CFD), the design methodology primarily focused on CFD design processes. This methodology follows a highly iterative approach, where certain steps may be repeated multiple times to enhance the design and meet its requirements. The steps of this methodology are illustrated in Figure 7.

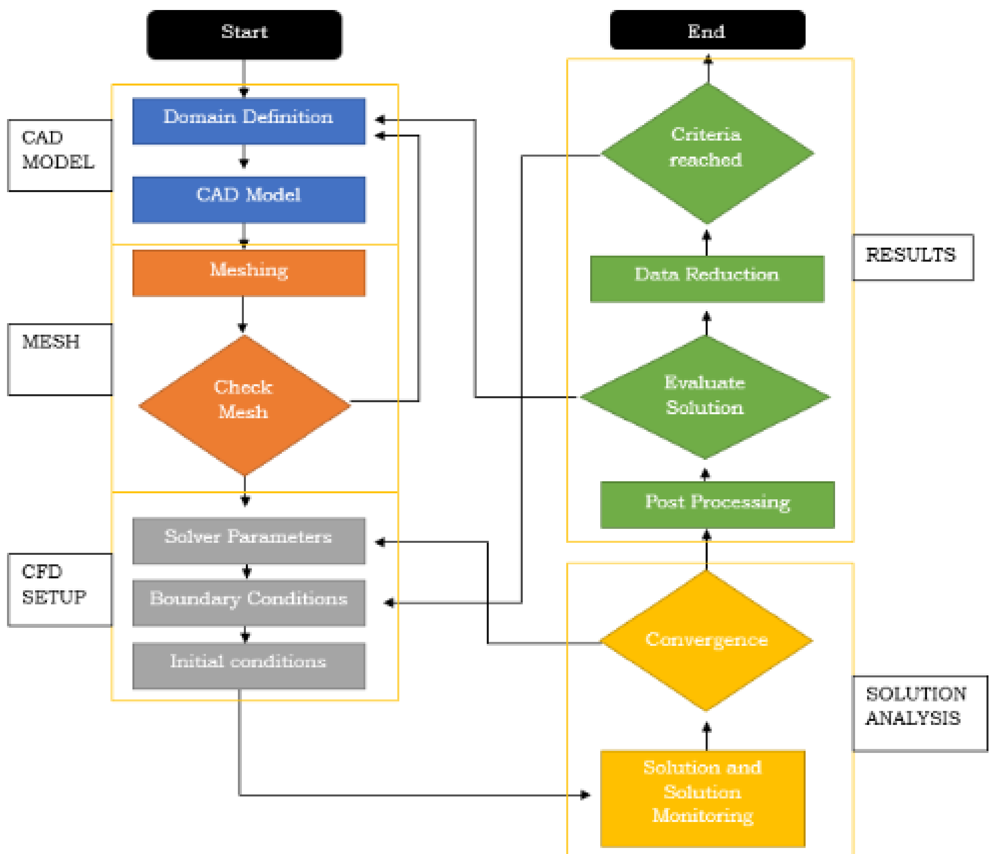


Figure 7: Design Approach for Simulation

Background research on the problem was covered in Chapter 2 of this thesis report. Design considerations and requirements derived from the background research, concept generation and development, and evaluation of the derived solution will be discussed in this chapter.

3.1 Design Considerations

The main aspects that need to be considered in the development of the drone are as follows;

1. Aerodynamic body
2. Lift generation

The aerodynamic body can be explained by looking at the general shape of the fuselage.

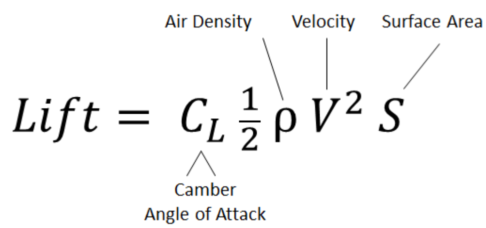
> **The general shape of the fuselage:** While propellers are the beating heart of drone flight, the fuselage, often a sleek, streamlined body, plays a crucial but subtle role in generating lift. Its shape is not only aesthetically appealing; it is also carefully designed to interact with and optimize airflow, contributing to a drone's overall efficiency and performance.

Lift generation can be further divided into 3 aspects:

1. **Propeller selection:** Several key factors influence a propeller's effectiveness:
   - Material: Popular choices include nylon, carbon fiber, and wood, each offering distinct advantages in terms of strength, weight, and flexibility.
   - Size and Pitch: Smaller propellers with lower pitch angles prioritize agility and responsiveness, while larger propellers with higher pitch provide greater stability and load-carrying capacity.
   - Number of Blades: The number of blades influences efficiency and noise generation. Tri-blade and quad-blade designs offer a balance between performance and noise, while higher blade counts prioritize efficiency.
2. **Number of Propellers:** The number of blades significantly impacts several crucial aspects of flight, making it a carefully considered design choice. Lift arises

from the pressure difference created by a propeller blade acting like a mini airfoil. Each blade pushes air downwards, generating an upward force on the drone. The 2 main factors of lift generation are; the total blade surface area and the efficiency of blade to utilize the motor's rotation

3. **Motor Rpm:** Lift generation in UAVs is mainly based on the principle of Bernoulli's equation. As the motor propels the blades of a propeller, they act as little airfoils. Increased RPM results to faster airflow over the blades, creating a region of low pressure above and high pressure below, resulting in an upward lifting force.



However, maximizing lift isn't as straightforward as simply increasing the RPM. Trade-offs must be considered:

- Diminishing Returns: Beyond a certain threshold, the increase in lift per additional RPM diminishes due to factors like blade stall and compressibility.
- Power Consumption: Higher RPM necessitates more power draw from the battery, negatively impacting flight time and potentially leading to motor overheating.
- Noise Generation: Faster-spinning propellers create more noise, posing limitations in noise-sensitive environments.
- Modal imbalance: high RPM will result in greater vibration of the drone, which will need to be accounted for by using a controller.

Other worth mentioning design criteria are ease of attachment, cost, appearance, and weight.

3.2 Design Requirements

The design requirements, enlisted in Table 1, are derived based on the background research conducted in Chapter 2, with the aim of developing a lift enhancing upper chassis.

Table 1: Design requirements

Requirement	Qualitative Description
Easy to Attach	The upper chassis should be easy to attach onto the lower chassis of the drone
Weight	The weight of the upper chassis must be as low as possible so that it does not add to the payload.
Durability	The upper chassis has to be durable, in order to allow for long time usage.

3.3 Design

After conducting thorough research on drone aerodynamics and establishing design goals and specifications, designs for each component, such as the upper chassis and _, were developed using SolidWorks. Furthermore, ANSYS was employed to conduct Computational Fluid Dynamics (CFD) analysis on the designs. The materials chosen for each component are also detailed and discussed.

3.3.1 Propeller

While flight control systems and onboard sensors often receive significant attention, the basic technology enabling UAV ascent and maneuverability resides in the seemingly uncomplicated structure of the propeller. This paper delves into the technical aspects of propellers, emphasizing their crucial role in producing lift, enabling maneuverability, and impacting overall UAV performance. The primary function of a propeller relies on aerodynamic principles. As the propeller spins, its airfoil-shaped blades interact with the air around them, resulting in high pressure below and low pressure above the blades.

Figure 8: 10x45 propeller

Calculation for the required thrust for flight is shown in Table **2.**

Table 2: Mass of Drone

	Component	**Approximate Mass**
1	A2212/10T 1000kV Motors	72g*4 = 288g
2	Frame	270g
3	Battery	185g
4	10x45 Propeller	28*4 = 112g
Total		905g = 8.878 N

For thrust to weight ratio of 1.5, the thrust provided by the propellers must be

8.878 * 1.5 = 13.317N

13.317/4 = **3.32N per propeller**

At least 3.32N should be produced by the selected propeller.

The thrust calculations for the 10x45 propeller are as follows;

$$motor\ kV\ rating = 930kV$$

$$Voltage\ supplied = 11.1V$$

$$motor\ maximum\ RPM = 930 * 11.1 = 10323\ rpm$$

$$\frac{kgThrust}{motor} @100\%throttle = 0.8kg$$

$$0.8kg * 9.81 = 7.845N$$

$$max\ thrust = 7.845N\ * 4 = 31.4\ N$$

The propeller is optimum for the application as it is capable to produce more than the required force to lift the drone. Therefore, the 10x45 propeller is chosen and the proposed RPM is 8000rpm, since it is the rpm at which the motor performs most efficiently.

$$propeller\ proposed\ rpm = 8000\ rpm$$

$$motor\ throttle\ \% = \frac{8000}{10323} = \mathbf{77.5}\%$$

3.3.2 Motor

The A2212/10T 1000 KV brushless motor is a popular choice for powering a variety of small, multi-rotor Unmanned Aerial Vehicles (UAVs), commonly known as drones. Its compact size, decent power output, and relative affordability make it a versatile option for hobbyists and enthusiasts alike. Let's delve into the specifications and characteristics of this motor to understand its strengths and potential applications.

Table 3: Technical Specifications of Motor A2212/10T 1000KV

Motor Size	A2212 (22 mm diameter, 12 mm stator length)
KV Rating	1000 KV (Rpm per Volt applied)
Number of turns	10T (refers to the number of windings in the stator, influencing torque and speed)
Max efficiency current	6 – 12 A
Maximum Current	16 A

3.3.3 Drone Chassis

The chassis of a quadcopter drone acts as its structural foundation, offering stability for vital components like motors, propellers, flight control systems, and payload. In this comprehensive document, we'll explore the design journey of a quadcopter drone chassis, highlighting three main stages: initial prototype, refined prototype, and topology optimization. The design process was conducted using SolidWorks, a prominent computer-aided design (CAD) software.

1. Initial Prototype

During the initial prototype stage, the focus was on conceptualizing the fundamental structure and arrangement of the quadcopter drone chassis. Key factors considered included weight distribution, structural robustness, and ease of assembly. The design process commenced with outlining the basic shape and dimensions of the chassis, taking into consideration the size and positioning of components like the flight controller, battery, and motor mounts.

Using SolidWorks, 3D models of the chassis components were developed based on the initial sketches. These models were then assembled to visualize the complete design and identify any potential conflicts or fitting issues. Iterative adjustments were implemented to enhance the design, ensuring optimal placement of components and overall equilibrium.

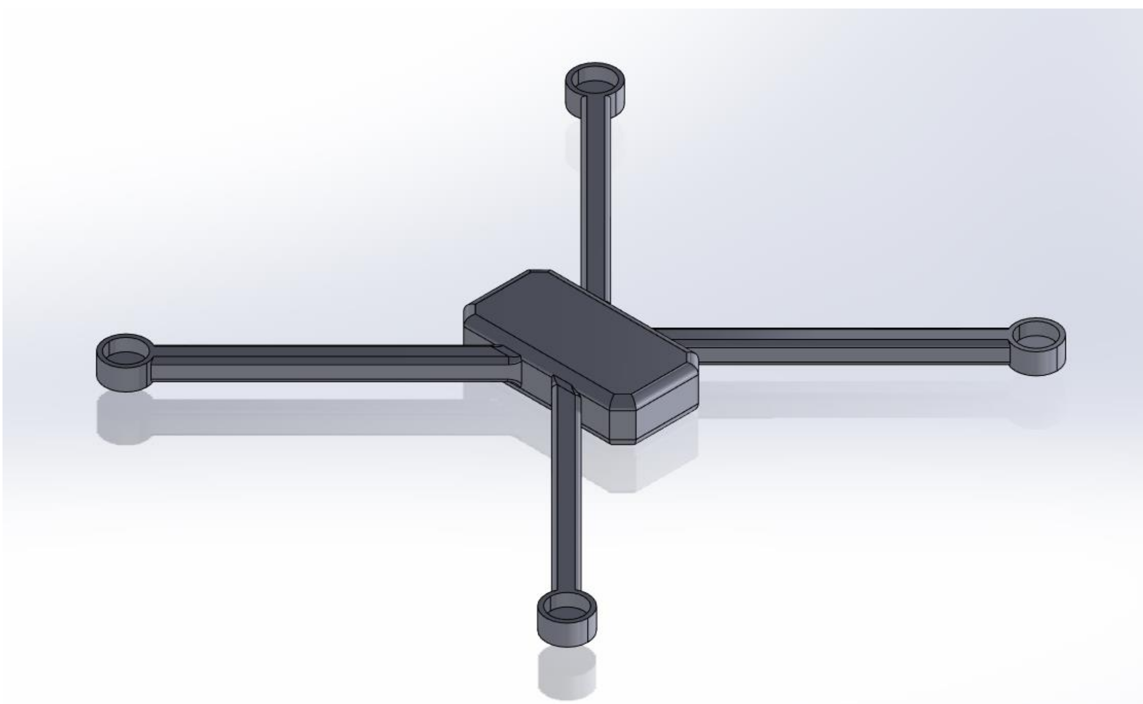


Figure 9: initial Prototype

2. Refined Prototype

During the refined prototype stage, the emphasis shifted towards enhancing the structural integrity and functionality of the chassis design. This involved fine-tuning the dimensions, incorporating reinforcement features, and optimizing material usage to strike a balance between weight and durability.

Subsequently, the refined prototype underwent virtual testing within SolidWorks, simulating various flight conditions and load scenarios to validate its performance and durability. Any necessary design iterations to address identified weaknesses or enhance performance were implemented before progressing to the final stage.

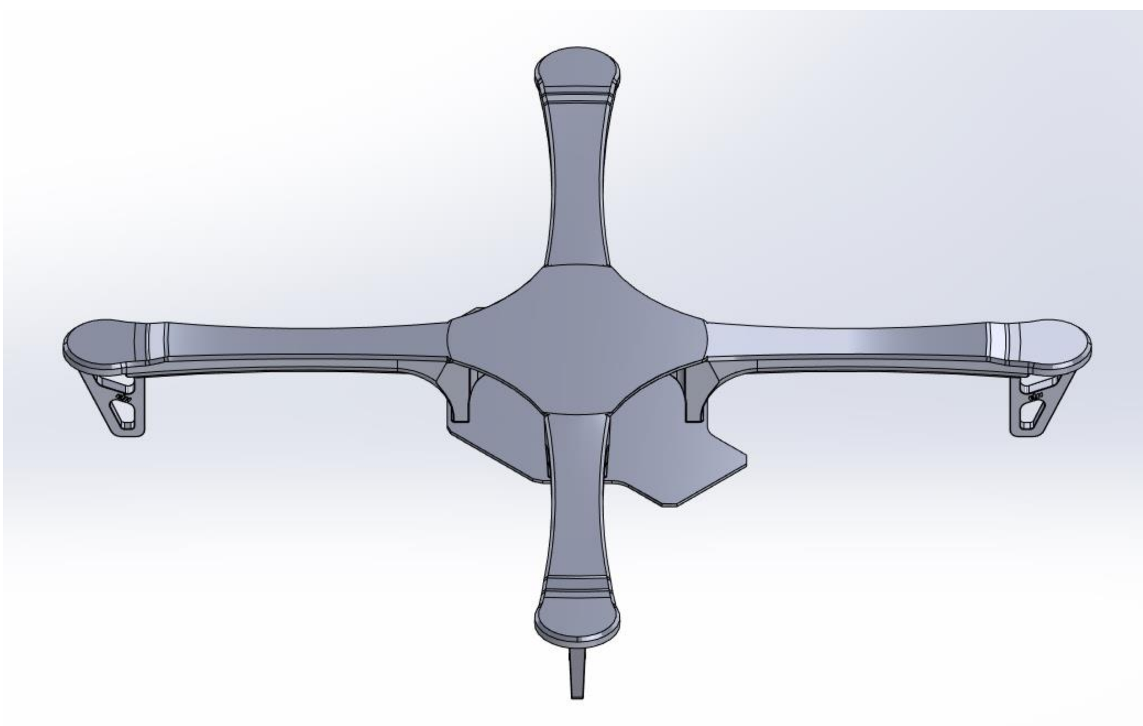


Figure 10: Refined proptotype

3. Topology Optimization

In the topology optimization stage, advanced engineering principles and computational tools were leveraged to further enhance the design for weight reduction and structural efficiency. Topology optimization algorithms within SolidWorks were utilized to iteratively eliminate material from non-essential areas of the chassis while preserving its structural integrity.

The process commenced by defining the design space and loading conditions, and specifying constraints such as maximum allowable stress and displacement. The software then generated a series of optimized designs by systematically removing material from regions identified as less critical for load-bearing purposes.

The resulting topology-optimized chassis design showcased a more organic and lightweight structure, with material distributed strategically to minimize weight while upholding structural strength. The final design underwent additional FEA simulations to validate compliance with performance requirements and safety standards.

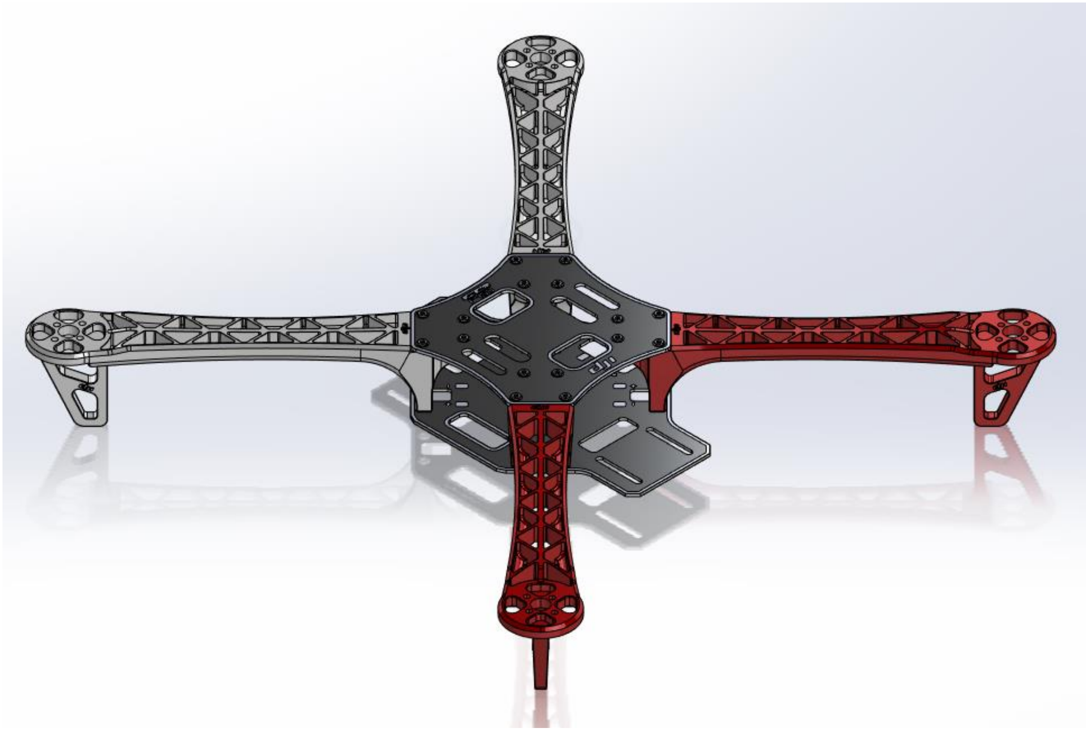


Figure 11 Topology Optimization

3.3.4 Battery Selection

The chosen battery pack is the 2200mAh Li-Po Battery

- **Capacity:** 2200mAh - This refers to the amount of electrical charge the battery can store, measured in milliampere-hours (mAh). Higher capacity batteries can provide longer flight times for drones or power electronic devices for longer durations.
- **Voltage:** 3S - This indicates that the battery consists of 4 cells connected in series, resulting in a nominal voltage of 11.1 volts (3 .7 volts per cell). This voltage is

suitable for powering many multi-rotor drones and other applications that require a higher voltage source.

Figure 12: 2200mAh Li-Po Battery

3.3.5 Material Selection

In recent years, drone technology has undergone significant progress, with a diverse array of materials being employed in constructing drone components. The selection of materials is pivotal in shaping the performance, longevity, and overall functionality of drones. This document aims to delve into several materials frequently utilized in drone construction, with particular attention given to PLA (Polylactic Acid) and ABS (Acrylonitrile Butadiene Styrene) plastic for 3D printing purposes.

1. Aluminum

Aluminum is a prevalent choice in drone construction owing to its lightweight yet robust characteristics. It boasts an impressive strength-to-weight ratio, corrosion resistance, and thermal conductivity, rendering it suitable for structural elements like frames, arms, and landing gear. Aluminum components are commonly machined or CNC milled to exact specifications, ensuring superior performance and dependability.

2. Carbon Fiber

Carbon fiber is highly valued for its outstanding strength and stiffness-to-weight ratio, making it a top choice for high-performance drones. Carbon fiber components are frequently employed in frames, propeller blades, and reinforcement structures, delivering superior rigidity and durability compared to conventional materials. Despite being relatively expensive, carbon fiber offers unparalleled performance in demanding applications.

4. PLA (Polylactic Acid) Plastic

PLA, a bioplastic derived from sources like corn or sugarcane, naturally decomposes over time. Its popularity in 3D printing stems from its ease of use, affordability, and widespread availability. PLA is lightweight, sturdy, and maintains its shape effectively, making it suitable for producing various drone components such as frames or covers. Although it may not withstand heat or impact as robustly as certain materials, PLA excels in rapidly prototyping concepts and implementing design modifications.

5. ABS (Acrylonitrile Butadiene Styrene) Plastic

ABS, known for its strength and durability, is a resilient type of plastic that withstands impact and abrasion without readily breaking. It is commonly utilized in 3D printing to create drone components such as motor holders, propeller protectors, and sturdy covers. ABS parts maintain their form effectively and exhibit greater heat resistance compared to PLA, rendering them suitable for outdoor applications and environments with elevated temperatures. ABS plastic is the preferred material for constructing the chassis of the drone in this scenario.

3.3.6 Upper Chassis

The project aims to maximize the lifting capacity of vertically stacked drones while minimizing aerodynamic losses.

It can be done in two ways,

a. adjusting the vertical distance between drones
b. Optimizing the fuselage design to reduce drag and wake region.

When drones accelerate vertically, they encounter drag and aerodynamic inefficiencies due to the high RPM of their propellers. To address this, we can optimize the spacing between drones or modify the fuselage design to enhance aerodynamic efficiency based on our existing design. Drawing inspiration from the sleek and minimalist design of commercially available drones like the DJI Phantom 4, we aim to minimize the wake region and encourage smoother airflow by promoting prolonged air adherence to the body. This strategy enables us to enhance the overall aerodynamic profile of our drone configuration, leading to improved lifting capacity and performance.

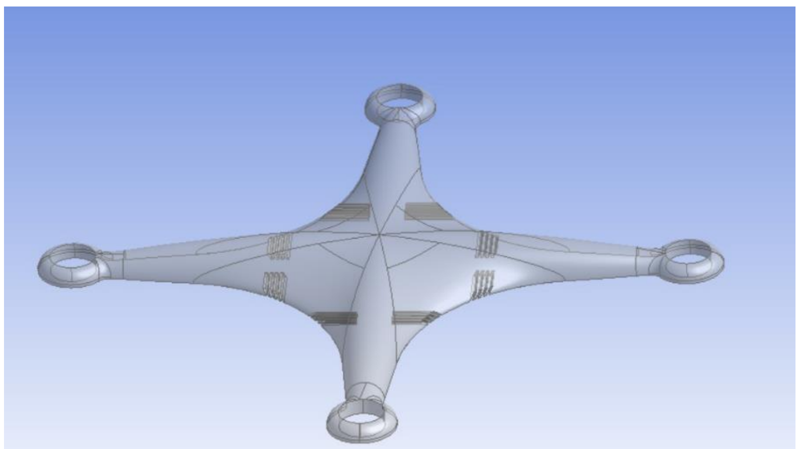


Figure 13: Upper Chassis

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Propeller Analysis

4.1.1 Meshing

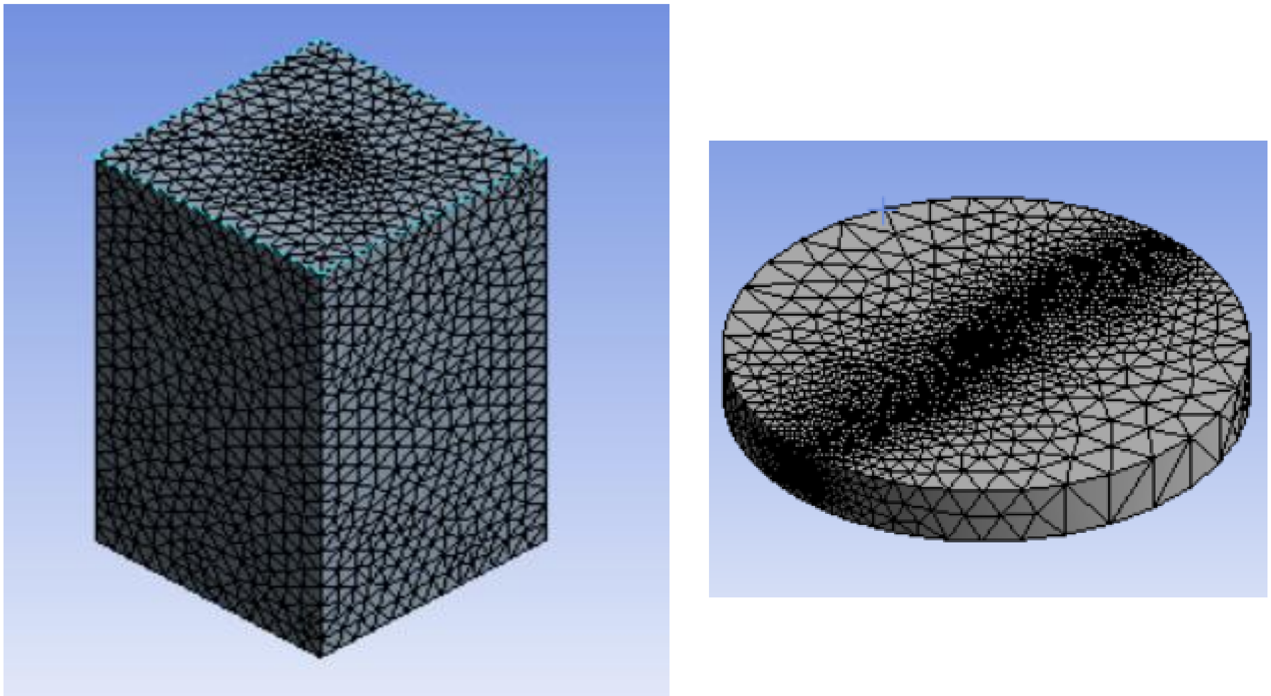


Figure 14: Meshing

	Mesh 1	Mesh 2
Element Quality	0.70963	0.70806
Orthogonal Quality	0.71255	0.7156
Skewness	0.28596	0.28277

Table 4: Mesh Statistics

4.1.2 Results of Simulation

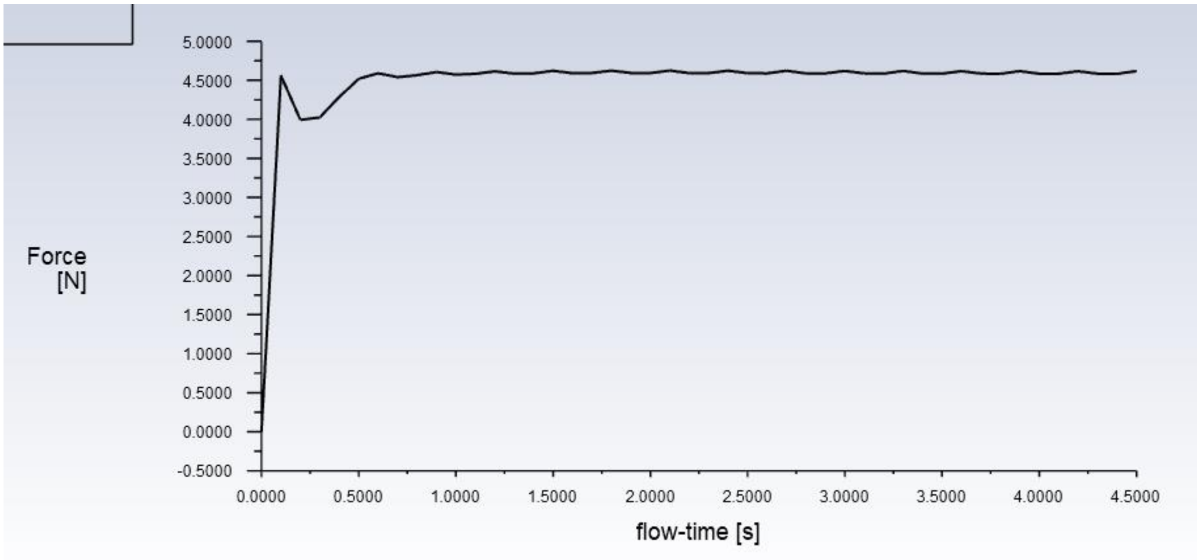


Figure 15: Lift Force plot

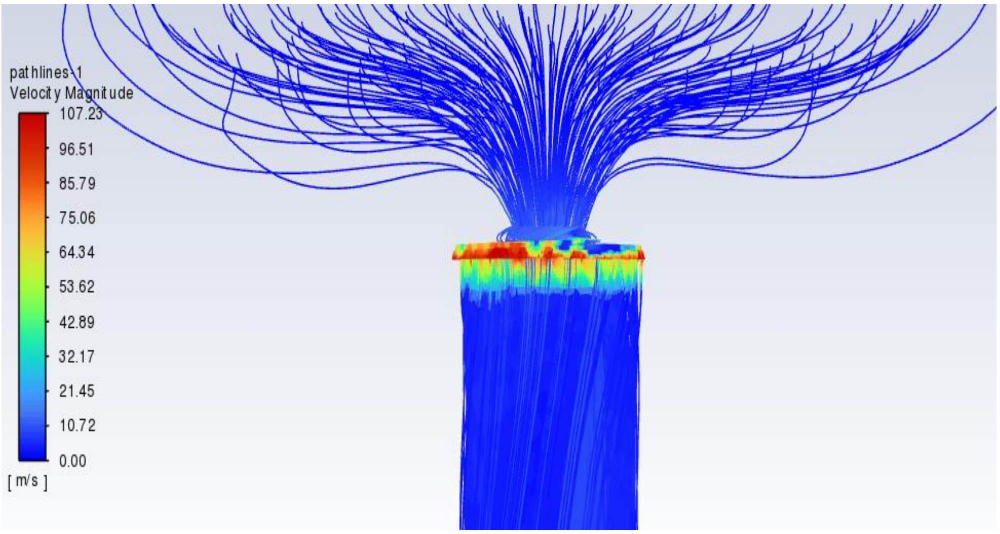


Figure 16: Velocity Streamlines

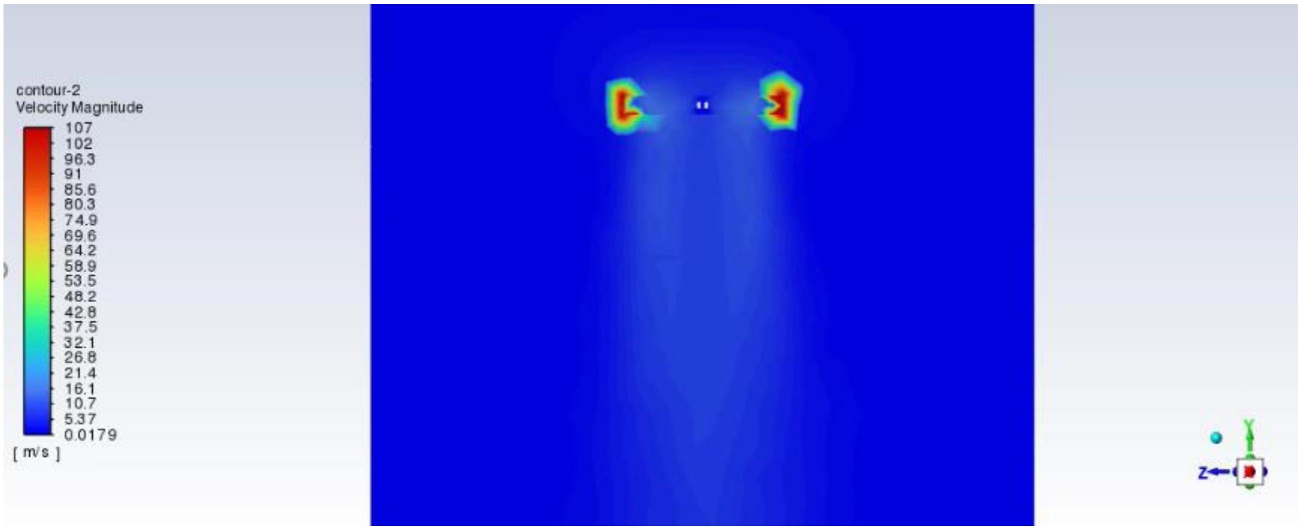


Figure 17: Velocity Contour

4.1.3 Discussion of result

The simulation shows that the single propeller produces about 4.5 N of force. For a quadcopter, the combined force produced by the 4 propellers is the algebraic sum of each propeller's lift produced. Therefore, the total lift = 4 * 4.5 = 18 N

4.2 Chassis Analysis

4.2.1 Mesh

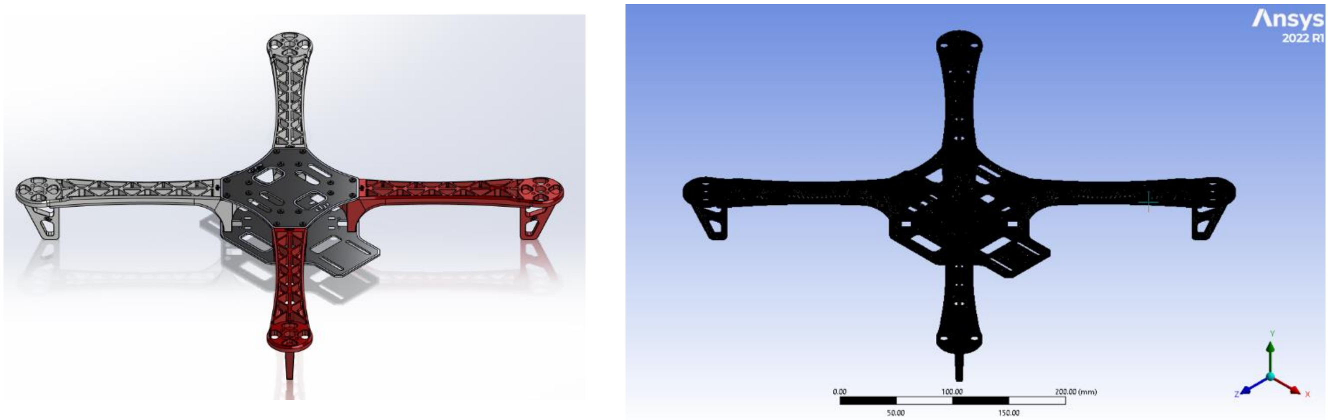


Figure 18: Drone Chassis and its Mesh

4.2.2 Static Simulation result

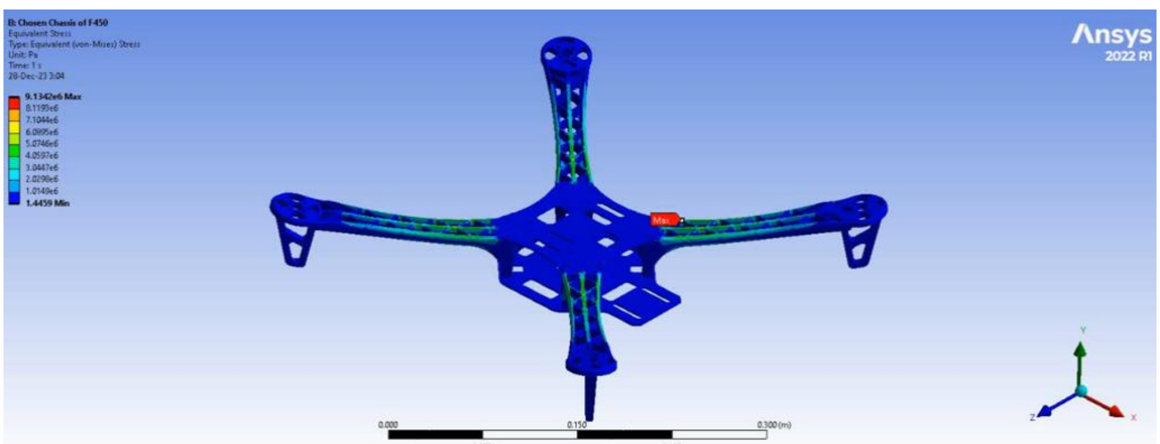


Figure 19: Stress Analysis on Chassis

4.2.3 Discussion

The simulation shows the maximum stress generated on the chassis is about 9.2 MPa. Moreover, the rigidity of the model is proven by the fact that the vertical deformation of the chassis is just 4 mm.

4.3 Upper Chassis

4.3.1 Model

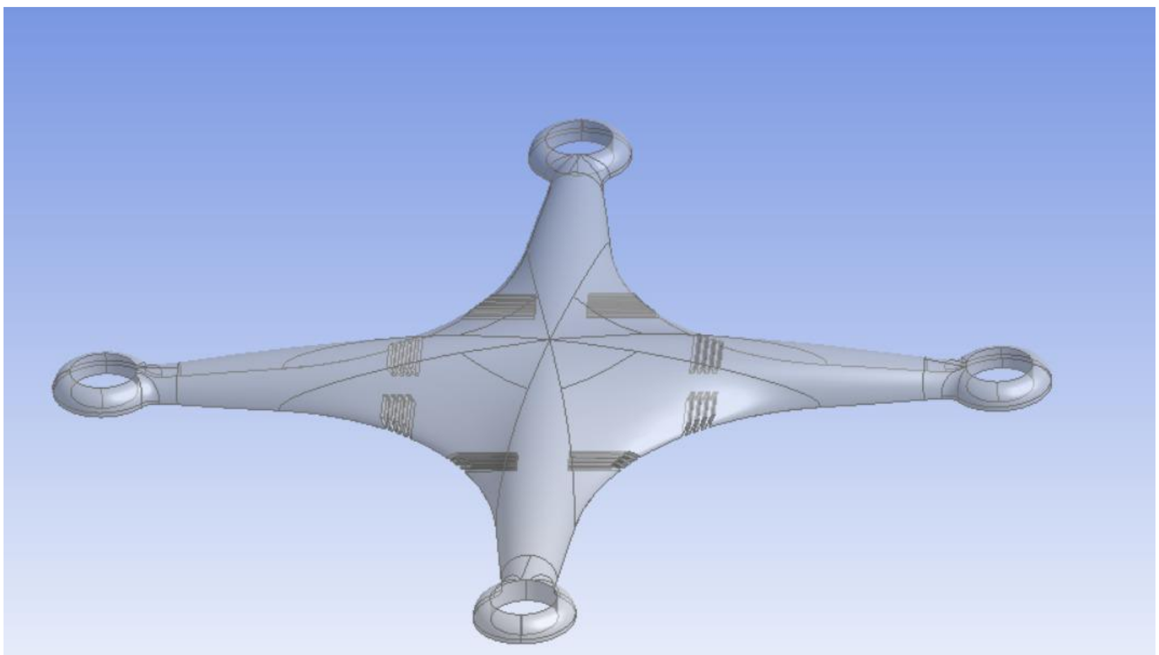


Figure 20: Model Chassis

4.3.2 Simulation Result

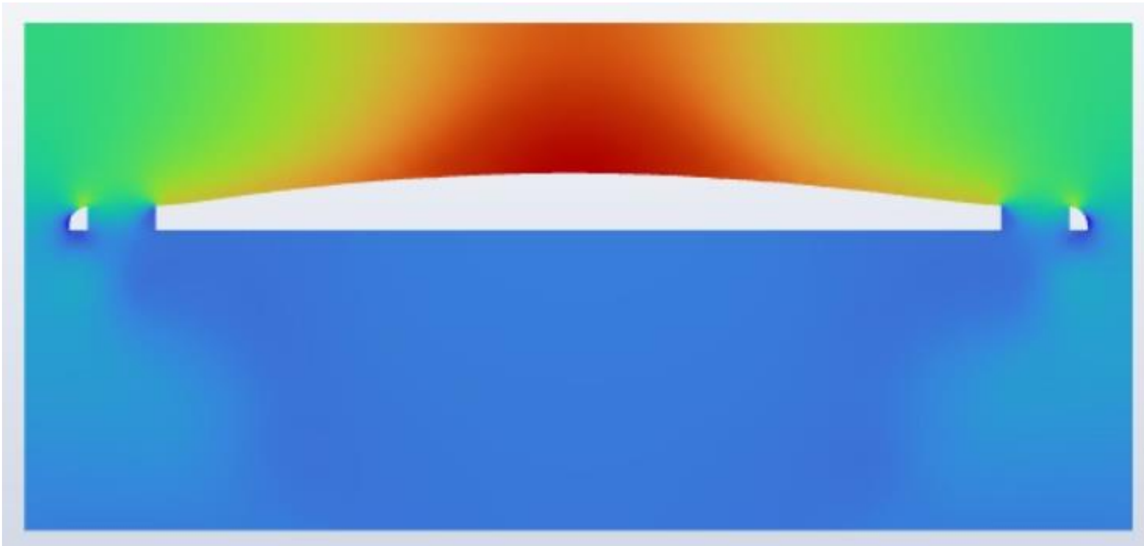


Figure 21: Pressure Contour

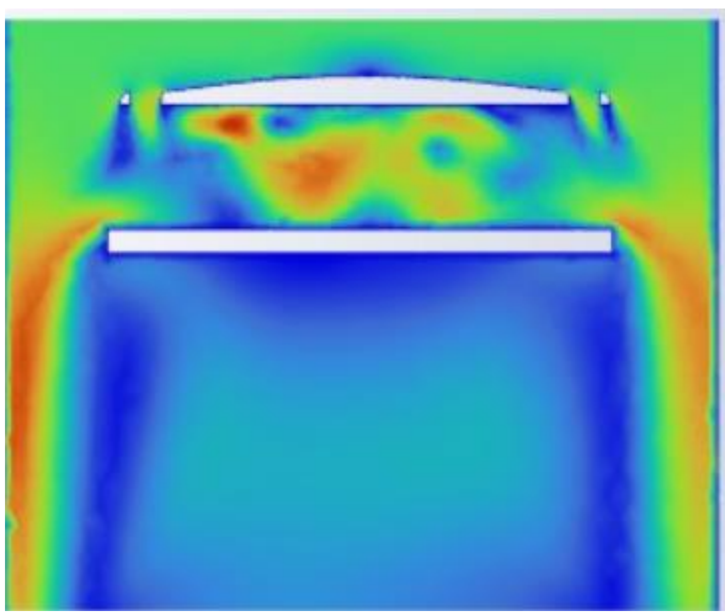


Figure 22: Velocity Contour of the two drones in

close proximity at low Re

4.3.3 Discussion of simulation

This simulation shows how the upper chassis distributes the pressure. This decreases the impact on the lower drone in the Vertical drone formation.

4.4 Experimental validation

An experiment was setup in order to verify the simulation results. The details of the experiment are broken down in terms of objective of the experimentation, apparatus used, procedure, objectives (i.e. readings) and results. One major thing to note in the experiment is that an assumption was used. The assumption was that since the drone is symmetrical, and the two drones are identical to each other, the analysis can be simplified by analyzing one propeller of the top drone, and the subsequent propeller of the lower drone. This allowed the experiment to be performed in a safer manner, since two drones operation would risk injuries. Two experiments were performed, one with the propellers at 611 mm apart and the other with the propellers at 200 mm apart

4.4.1 Objective of the experiment

The objective of the experiment is to empirically find the lift forces produced by the two propellers in vertical formation.

4.4.2 Apparatus used

- A frame-like structure was built such that its width was longer than the diameter of the 10x45 propeller.

Figure 23: Frame Structure

- A weight balance was used to measure the lift force.

Figure 24: Weight Balance

- Motors were used to rotate the propellers.
- ESCs were used to control the motor speeds.
- Battery was used to supply power needed

4.4.3 Procedure

1. Ensure the crossbeams are securely fastened to the frame
2. Attach the propellers to their respective motors
3. Ensure wiring is done correctly as to have both propellers rotate in the same direction
4. Mount the motors to the crossbeams

5. Place the framework on the weight balance
6. Make sure the framework is balanced on the weight balance.
7. Tare the reading. Any lift produced by the propellers will cause a negative force reading on the balance.
8. Start motors at lowest throttle using the remote
9. Take reading at the lowest throttle
10. Increase the throttle position and take readings

4.4.4 Observations

<u>Experiment 1: 611mm apart</u>

Table 5: Experiment 1 readinsgs

throttle position	lift force generated (g)
1	60
2	124
3	203
4	263
5	274
6	288

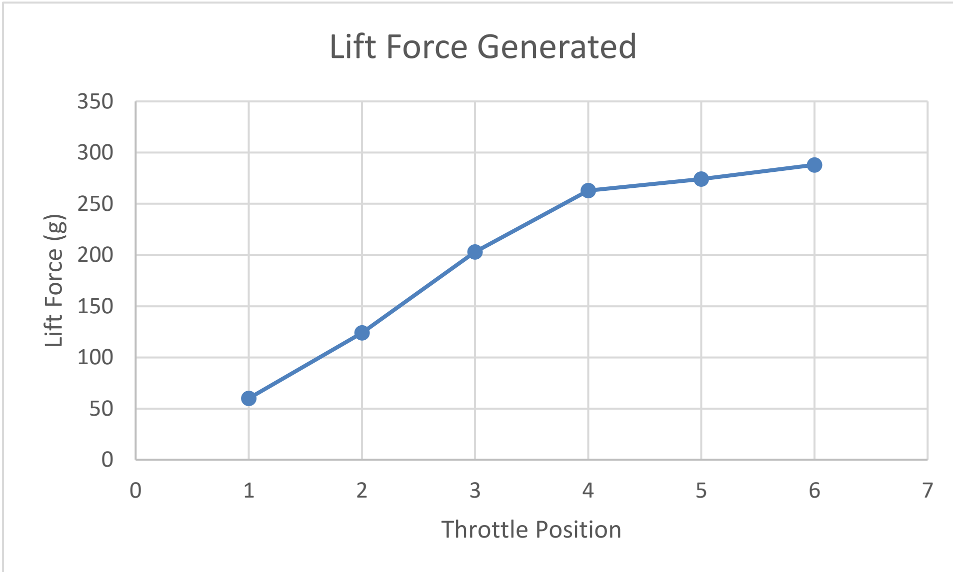


Figure 25: Lift vs Throttle position graph for Experiment 1

Experiment 2: 200 mm apart

Table 6: Experiment 2 readings

throttle position	lift force generated (g)
1	47
2	109
3	184
4	203
5	176
6	148

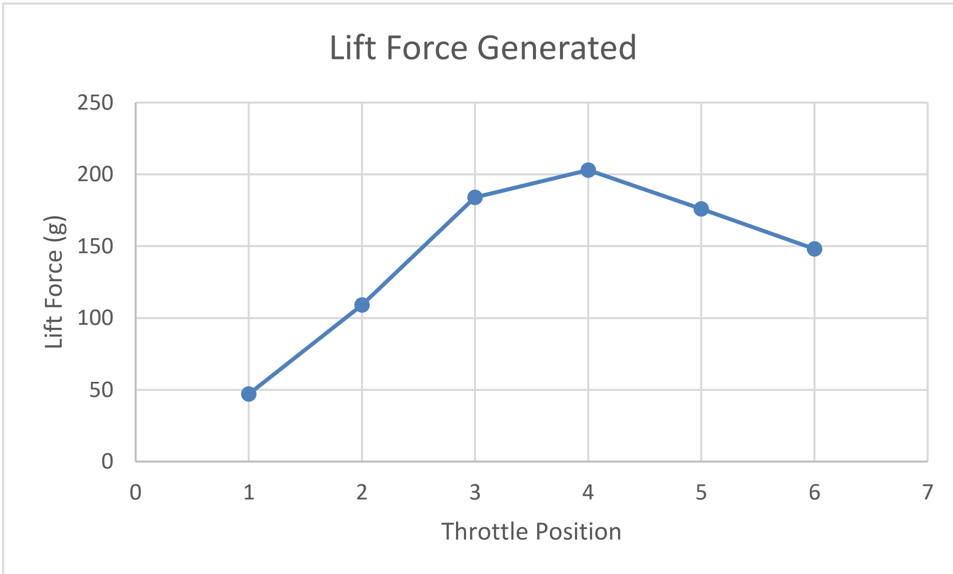


Figure 26: Lift vs Throttle position graph for Experiment 2

4.4.5 Results and discussion

The experiment shows that when the propellers are far apart, then the combined lift produced is larger than when they are in close proximity to one another. This proves our hypothesis, which was that the lift produced of the lower drone will be impacted by the thrust produced by the propellers of the upper drone, more so when they are close to each other. The maximum thrust produced in experiment 1, when the propellers were far apart was recorded to be 288 g force, whereas the maximum lift generated in experiment 2 was only 203 g force. Another thing to note is that the propellers appear to stall after throttle position 4 in experiment 4, and then decrease. This can be explained by the downwash effect.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

The aim of this project was to study and improve the vertical lift capability of 2 drones in vertical formation by adding an aerodynamic accessory to its chassis. This was done in order to optimize drones so that they can work together in a vertical formation in close proximity to each other.

5.1 Discussion

The reasoning behind this project originated from the increasing demand for drones across various industries, spanning logistics, agriculture, infrastructure inspection, and emergency response. Drones offer unmatched versatility and accessibility, serving as a viable solution for tasks previously challenging or inaccessible. However, a persistent limitation encountered in many drone applications is the constraint on payload capacity, particularly when transporting heavy loads over significant distances.

Recognizing this limitation as a potential bottleneck hindering the widespread adoption and effectiveness of drones, the project team focused on enhancing the drone's vertical lift capabilities. By prioritizing improvements to the propulsion system, which generates lift and maneuverability, the project aimed to increase the drone's capacity to carry heavier payloads while maintaining operational efficiency and safety standards.

Enhancing the propulsion system involved a multifaceted approach, including optimizing motor performance, refining propeller design, and implementing advanced control algorithms. Each component played a critical role in augmenting the drone's lifting capacity, aiming for a significant improvement in payload capabilities without compromising stability or flight endurance.

To achieve these objectives, the project team conducted a comprehensive analysis of existing propulsion technologies, performance metrics, and fuselage improvement options. Through iterative design iterations and rigorous testing protocols, they refined and optimized the drone's fuselage to maximize efficiency and effectiveness in lifting heavy loads.

Furthermore, the project emphasized compatibility and scalability, ensuring that the enhancements could be seamlessly integrated into existing drone platforms with minimal retrofitting. This approach facilitated adoption by drone manufacturers and operators while allowing for future advancements and upgrades to further enhance the drone's capabilities over time.

5.2 Recommendations

Although the upper chassis contributes positively to the overall lift of the body, the impact is marginal. Further enhancements could be achieved through topological optimization of the upper chassis, refining the design to improve aerodynamic performance and structural integrity. One intriguing approach could involve using a charged material as a surface coating for the upper chassis, reducing the coefficient of lift and drag during flight. Leveraging advanced computational tools like finite element analysis (FEA) and computational fluid dynamics (CFD), engineers can systematically explore various design configurations to strike a balance between weight, strength, and aerodynamic efficiency.

The next phase of the study entails gathering experimental data to validate and refine the computational models, providing a comprehensive understanding of the flow dynamics around the drone. Understanding wake region optimization is crucial for mitigating aerodynamic drag and reducing energy consumption. This involves employing fluid mechanics techniques to manipulate airflow, minimizing the formation of low-pressure zones beneath the drone that can affect stability and maneuverability.

To observe and analyze airflow over the drone accurately, researchers can use techniques such as smoke visualization and high-speed imaging with slow-motion cameras. By visualizing flow patterns generated by the propellers and fuselage, engineers can identify areas for improvement and devise effective strategies for optimizing aerodynamic performance.

Rapid prototyping techniques enable engineers to iterate quickly on design concepts and implement modifications based on insights gained from experimental testing. By creating scaled-down prototypes using methods like 3D printing, engineers can evaluate numerous design variations and assess their impact on aerodynamic efficiency. This iterative process allows for the rapid exploration of the design space, leading to optimized configurations that maximize performance while minimizing undesirable aerodynamic effects.

Furthermore, the great quantity of experimental data generated through rapid prototyping can validate and calibrate analytical models, ensuring accuracy and reliability. By comparing results from experimental testing with predictions from analytical methods, engineers can verify the effectiveness of design optimizations and gain confidence in predicting the drone's aerodynamic behavior under different operating conditions.

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APPENDIX I: INFORMATION ON UAVS AND QUADCOPTERS

1. Unmanned Aerial Vehicles (UAVs)

Definition: Unmanned Aerial Vehicles (UAVs), commonly known as drones, are aircrafts that operate without a human pilot onboard. They can be remotely controlled or fly autonomously based on pre-programmed instructions or dynamic inputs.

Applications:

- Military and Defense: UAVs are mainly used for surveillance, reconnaissance, target acquisition, and aerial combat missions by military forces worldwide.

- Civil and Commercial: UAVs are increasingly being utilized in various civilian and commercial applications, including aerial photography and videography, agriculture, infrastructure inspection, search and rescue operations, environmental monitoring, and package delivery.

- Scientific Research: UAVs are employed in scientific research for data collection, mapping, and monitoring of environmental phenomena, wildlife populations, and geological features.

Regulations and Safety:

The operation of UAVs is subject to regulations imposed by civil aviation authorities in different countries. These regulations govern aspects such as registration, pilot licensing, airspace restrictions, and safety guidelines to ensure the safe and responsible operation of UAVs.

2. Quadcopters:

Definition: Quadcopters are a type of rotary-wing UAV characterized by four vertically oriented propellers arranged in a cross configuration. They rely on differential thrust generated by the propellers to control pitch, roll, yaw, and altitude.

Components: Key components of a quadcopter include the frame (chassis), motors, propellers, electronic speed controllers (ESCs), flight controller, battery, and various sensors (e.g., gyroscopes, accelerometers, barometers).

Flight Characteristics: Quadcopters are known for their agility, stability, and ease of control. They are capable of hovering in place, performing rapid maneuvers, and flying in confined spaces due to their compact size and versatile design.

Applications: Quadcopters find widespread use in aerial photography and videography, recreational flying, educational purposes, research and development, and various commercial applications such as aerial surveying, mapping, inspection, and surveillance.

Design Considerations: Designing a quadcopter involves considerations such as frame material and construction, motor and propeller selection, payload capacity, flight time, stability and control algorithms, and overall aerodynamic efficiency.