REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE
Ministère de l'Enseignement Supérieur et de la Recherche Scientifique
Université 8 Mai 1945 – Guelma
Faculté des Sciences et de la Technologie
Département de Génie Electrotechnique et Automatique

Réf:……………/2025

MEMOIRE

Présenté pour l'obtention du **diplôme** de **MASTER Académique**

Domaine: Sciences et Technologie

Filière: Electromécanique

Spécialité: Electromécanique

Par: ARBA Haithem et HAMLAOUI Khawla

Thème

Modelling and Design of a Quadcopter Unmanned Aerial Vehicle

Soutenu publiquement, le 22/06 /2025, devant le jury composé de:

Mr. Moussaoui Abdelkrim	Professeur	Univ. Guelma	Président / Encadreur
Mme. Boucerredj Leila	MCA	Univ. Guelma	Examinateur
Mme. Chaabi Lilia	MCB	Univ. Guelma	Examinateur
Mr. Mentouri Zoheir	Maître de Recherche A	CRTI, Annaba	Co-Encadreur

Année Universitaire: 2024/2025

Acknowledgements

(فَاذْكُرُونِي أَذْكُرْكُمْ وَاشْكُرُوا لِي وَلَا تَكْفُرُونِ)

First and foremost, we express our deep gratitude to Almighty God, who granted us the patience, strength, and willpower necessary to successfully complete this project. We would like to extend our sincere thanks to our supervisor, Professor Moussaoui Abdelkrim, for his guidance, availability, valuable advice, and continuous support throughout this work. His rigorous and caring supervision greatly contributed to the success of this project. We also thank our co-supervisor Dr. Mentouri Zoheir for the precious advices. Without forgot to thank all the professors and members of the Electrical Engineering Department for the quality of the education they provided throughout our academic journey. Our gratitude also goes to our fellow students and colleagues for their support, collaboration, and encouragement. Finally, we express our heartfelt appreciation to our families for their moral support, constant encouragement, and patience throughout our studies.

Dedication

Without my family, I wouldn't be where I am today. Their unwavering love, endless support, and quiet sacrifices have carried me through every stage of this journey. To my dear parents your belief in me gave me the strength to persevere, and your values are the foundation of all I have achieved. To my wonderful friend and partner, Mayar despite your own responsibilities, you brought warmth, clarity, and joy into this experience. Without you, there wouldn't have been that inspiration to do better. Your presence turned challenges into opportunities and stress into something lighter. For that, and so much more, I thank you.

Dedication

I dedicate this work to myself for every step I took when it felt easier to stop, for the strength I found in silence, for the courage I built in solitude, and for continuing to show up even when it was hard this journey has tested me in ways I never expected but through it all, I remained true to myself. I am deeply thankful not only for the destination but for the version of me that refused to give up along the way.

And my deepest thanks go to my friend who was my greatest support through both the good times and the bad, through right and wrong, she was more than a sister to me.

I also extend my heartfelt thanks to the Hamlaoui, Arba, and Amraoui families. I hope you are proud of us on this day.

And finally i would like to end by saying this is only the end of an era but the start of an age ❤️.

Abstract

This project presents the complete design, 3D modelling, and aerodynamic simulation of a quadcopter drone using Autodesk Fusion 360. Starting from a structural concept, each component was modeled with technical precision and assembled into a unified airframe. Aerodynamic behavior was evaluated using Autodesk Flow Design, allowing for flow analysis and optimization of the geometry. The final design is simulation-ready and 3D printable, demonstrating real-world applicability.

Keywords :

Drone, Quadcopter, 3D Modelling, Fusion 360, Aerodynamic, 3D Printing, UAV (Unmanned Aerial Vehicle).

Résumé

Ce mémoire présente la conception complète, la modélisation 3D et la simulation aérodynamique d'un drone quadricoptère à l'aide d'Autodesk Fusion 360. À partir d'un concept structurel, chaque composant a été modélisé avec précision et assemblé dans une structure cohérente. Le comportement aérodynamique a été analysé via Autodesk Flow Design, permettant une optimisation des formes et des flux. Le design final est prêt pour la simulation et l'impression 3D, démontrant une applicabilité concrète.

Mots clés :

Dron/Drone, Quadricoptère, Modélisation 3D, Fusion 360, Simulation aérodynamique, Impression 3D, Véhicule aérien sans pilote (UAV).

ملخص

تقدم هذه المذكرة تصميمًا كاملاً، ونمذجة ثلاثية الأبعاد، ومحاكاة ديناميكية هوائية لطائرة بدون طيار رباعية المراوح باستخدام برنامج .Autodesk Fusion 360 انطلاقًا من مفهوم هيكلي، تم تصميم كل مكون بدقة وتجميعه في هيكل متماسك. تم تحليل السلوك الديناميكي الهوائي باستخدام برنامجAutodesk Flow Design ، مما يسمح بتحسين الشكل والتدفق. التصميم النهائي جاهز للمحاكاة والطباعة ثلاثية الأبعاد، مما يُظهر قابلية التطبيق في العالم الواقعي

الكلمات المفتاحية

طائرة بدون طيار , طائرة رباعية المحركات,النمذجة ثلاثية الابعاد,محاكاة ديناميكية هوائية,الطباعة ثلاثية الأبعاد ,مركبة جوية غير مأهولة

CONTENTS

List of Figures

Chapter 2: UAV Modelling

Chapter 3: Drone's Design

List of Abbreviations

UAV : Unmanned Aerial Vehicle.

CAD : Computer-Aided Design.

CAM : Computer-Aided Manufactruring.

CAE : Computer-Aided Engineering.

ESC : Electronic Speed Controller.

FPV : First-Person View.

GPS : Global Positioning system.

PDB : Power Distribution Board.

PLA : Polylactic Acid.

STL : Stereolithography (3D model file format).

PCB : Printed Circuit Board.

VTOL : Vertical Take-Off and Landing.

General Introduction

In recent years, Unmanned Aerial Vehicles (UAVs) more commonly known as drones, have emerged as powerful tools across a wide range of industries. Originally developed for military applications, UAVs have evolved into critical assets in sectors such as agriculture, logistics, surveillance, environmental monitoring, and aerial photography. Their ability to reach inaccessible areas, operate autonomously, and collect real-time data has made them an essential part of modern engineering and research solutions.

Among the various types of UAVs, multirotor systems—particularly quadcopters—stand out due to their mechanical simplicity, stability in flight, and ability to hover precisely. These characteristics make them highly suitable for both educational purposes and advanced engineering applications.

This master thesis focuses on the modeling; design and aerodynamic simulation of a quadcopter drone. The project integrates modern engineering tools such as Autodesk Fusion 360 for mechanical structure design and Autodesk CFD for fluid dynamics simulation. It also explores 3D printing using PLA material for rapid prototyping. The final goal is to produce a quadcopter frame that is modular, lightweight, and aerodynamically optimized.

Chapter I: Generalities on the drone

I.1. Introduction:

Unmanned Aerial Vehicles (**UAVs**), also known as **drones**, have traveled far from their military origins in World War I. From their initial development for surveillance and combat, UAVs now pervade civilian sectors—from agriculture to disaster response—driven by developments in miniaturization, autonomy, and sensors. Quadcopters, a dominant subclass of rotary-wing drones, are the focus of this chapter, and it discusses their technological foundations, applications, and flight control systems. By analyzing their design and their impact on society, this project bridges engineering theory with real-world application [1].

I.2. Definition:

A drone, or officially an Unmanned Aerial Vehicle (UAV), is a drone that flies without a human pilot inside. It is controlled by either:

- Remotely through a human pilot via ground control systems.
- Autonomously through pre-programmed flight paths or artificial intelligence.
- Major Characteristics:
- No Onboard Pilot: Emphasizes external control or autonomous systems.
- Payload Flexibility: Can carry sensors, cameras, or shipment packages.
- Aerodynamic Types: Includes fixed-wing (long-distance) and rotary-wing (e.g., quadcopters for hovering ability) [1].

I.3. Brief history of UAV's development:

The concept of flight has intrigued human beings for centuries, but the desire to fly without having a human being on board came from military technology. Unmanned Aerial Vehicles (UAVs), or drones as they are better known, began in the early 20th century and have undergone a revolutionary change driven mostly by military needs. Early Beginnings and World Wars [5].

The idea of UAVs first began taking shape during World War I, especially with the invention of the Kettering Bug in 1917, a precursor to flying bombs built by Charles Kettering [5].

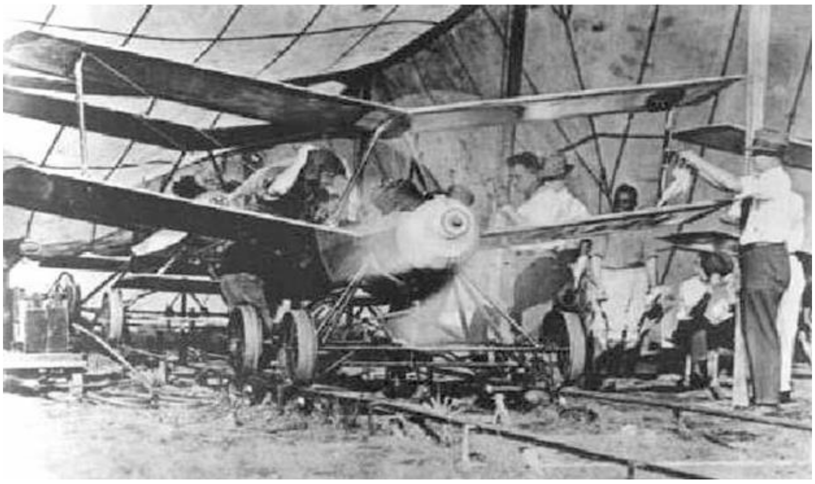


Figure (I.1). The Kettering Bug , an early unmanned flying bomb designed in 1917

Although it never had seen service, it was the beginning of pilotless flight technology. The second most significant event was the Queen Bee in the 1930s—a radio-controlled aircraft used by the British Royal navy for target training. Interestingly, the "drone" has been named after this model [5].

The Germans employed the V-1 flying bomb, the first cruise missile to be employed in combat, during World War II. Meanwhile, the United States was establishing its drone capability with the OQ-2 Radio plane, the first mass-produced UAV, produced by actor-turned-engineer Reginald Denny [5].

Figure (I.2). The OQ-2 Radio plane on ramp, the first mass-produced UAV.

Following WW2, the Cold War era was more concerned with strategic reconnaissance. The shooting down of the American U-2 reconnaissance plane over the Soviet Union in 1960 highlighted the risks of manned surveillance, accelerating the development of surveillance drones like the Ryan Ferebee series [5].

Figure (I.3). Ryan Model-147 UAV, a key reconnaissance drone during the Vietnam War.

They were loaded with cameras, jammers, and other payloads and were widely deployed during the Vietnam War [5].

- **Technological Boom (1970s–1990s)**

The 1980s and 1970s witnessed a technology revolution with advances in digital electronics and miniaturization. Israel was at the forefront of developing UAVs with significant systems like the Scout and Mastiff that provided real-time reconnaissance and jamming capability in local wars. Spurred on by Israeli progress, the United States developed and enhanced drones like the Pioneer UAV, which was extensively used during the Gulf War [5].

Figure (I.4) Predator UAV in Taszár, Hungary during the Balkan conflicts.

These UAVs demonstrated the strategic importance of real-time battlefield monitoring and coordination.

- **21st Century UAVs from Reconnaissance to Combat:**

The start of the century saw drones transitioning from support operations to combat operations. The arrival of the MQ-1 Predator and its successor, the MQ-9 Reaper, brought about the era of remotely controlled strike aircraft. These systems not only performed intelligence, surveillance and reconnaissance (ISR) missions but were also intended to provide precision guided ammunition, hence being potent asymmetric warfare assets [5].

Figure (I.5): British MQ-9 Reaper drone in active service over Afghanistan.

In addition to massive drones, small UAVs like the Black Hornet Nano were made available, offering tactical support for infantry forces undertaking urban warfare operations. Their extremely small size, stealthy operations, and live imaging capabilities made them central assets for contemporary militaries [5].

Figure (I.6). Black Hornet Nano palm-sized tactical micro-UAV used in urban reconnaissance.

I.4. Drone Types:

Alongside these combat and surveillance advancements, breakthroughs in materials, sensors, and autonomy paved the way for versatile rotary-wing drones, which became indispensable in both military and civilian applications:

- **Classic helicopter:**

single main rotor helicopters are the most common helicopter configuration They need an anti-torque system (tail rotor or some other anti-torque system) to counteract the twisting moment generated by the main rotor, powered by a single or more engines. In a single main rotor helicopter part of the power generated by the powerplants is utilized to counteract torque. The most common anti-torque mechanism is a tail rotor, which acts to counteract the torque generated by the main rotor [2].

Figure (I.7). Classic helicopter.

- **Coaxiale bi-rotor helicopter:**

A coaxial bi-rotor helicopter is a type of rotorcraft that features two main rotors mounted one above the other on concentric shafts, rotating in opposite directions. This design effectively cancels out the torque produced by each rotor, eliminating the need for a tail rotor to counteract rotational forces. The result is enhanced stability, improved hovering capabilities, and increased maneuverability, making coaxial helicopters particularly suitable for operations in confined spaces or challenging environments [2].

Figure (I.8). Coaxiale bi-rotor helicopter.

- **Bi-rotor helicopter:**

A tandem rotor helicopter or a bi-rotor helicopter is an aircraft that has two large horizontal rotors mounted at the two ends of the fuselage, one at the front and the other at the rear. These rotors rotate in opposite directions (counter-rotating) to cancel out their respective torque, thus eliminating the need for a tail rotor [2].

Figure (I.9). Bi rotor helicopter.

- **Multi-Rotor drones:**

Multirotor drones are a popular type of UAV that utilizes greater than one rotor to generate lift and stabilize. Their design may incorporate three (Tricopter), four (Quadcopter), six (Hexacopter), or eight (Octacopter) rotors, with each one having an equilibrium among control complexity, stability, and lifting power. Multirotor drones are ideally suited for applications requiring vertical take-off and landing (VTOL), precise hovering, and precise control in small spaces, making them ideal for aerial photography, inspection tasks, and research [2].

Figure (I.10). Hexacopter.

Figure (I.18). Octacopter.

Figure (I.19). Tricopter.

Quadcopters and other rotary-wing UAVs differ from fixed-wing UAVs in that they offer greater maneuverability and freedom of movement. One of the most important advantages of the quadcopter is its simplicity of control and relatively low cost. Its ability to hover over a single point and fly at low speeds makes it particularly well-suited to research and test uses. Quadcopters come in various sizes, ranging from coin-sized vehicles to bigger multi-meter-long systems. The smallest of these, micro-UAVs, also have features that are specialized for particular purposes. As one of the designs of multi-rotor UAVs, the typical quadcopter is made up of four main elements: four motors, a center frame or chassis, an electronic control board, and a radio receiver [2].

Figure (I.20). A typical quadcopter drone with four rotors.

I.5. Fields of use:

- **Agriculture:**

Drones in agriculture are used for crop monitoring, pesticide spraying, soil analysis, and precision farming, helping farmers optimize yield and reduce labor costs [3].

Figure (I.21). Agriculture drone.

- **Surveillance and Security:**

Used by law enforcement, border patrol, and private security, drones provide a bird's-eye view for monitoring activities and ensuring safety in large or dangerous areas [3].

Figure (I.22). Surveillance and Security.

➢ **Delivery Services:**

Companies like Amazon and DHL are piloting drone delivery systems to transport packages quickly, especially in hard-to-reach or rural areas [3].

Figure (I.23). Delivery Services.

➢ **Medical and Emergency Response:**

Drones deliver critical medical supplies, vaccines, and defibrillators in emergencies, offering fast and reliable delivery in disaster zones or remote locations [3].

Figure (I.24). Medical and Emergency Response.

- **Photography and Videography:**

A favorite among filmmakers and hobbyists, drones are used to capture stunning aerial images and videos from perspectives that were once inaccessible [3].

Figure (I.25). Photography and Videography.

I.6. General Components of the Drone:

Drones are complex systems that consist of several vital components that cooperate together to enable stable and efficient flight. Whether in professional environments or as a hobby, a proper understanding of the components is crucial for successful operation, maintenance, and modification. The following is an outline of the key elements in a generic multirotor drone.

- **Frame:**

The frame is the drone's skeleton. It holds all other components of a Drone together and provides structural integrity [7].

Figure (I.26). Quadcopter frame.

- **Motors:**

Motors are critical for propelling the drone into the air. They control the speed and stability of the drone by adjusting the propellers [7].

Figure (I.27). Quadcopter motor

- **Propellers:**

Propellers are the limbs of the drone, creating lift and thrust by spinning at high speeds [7].

Figure (I.28). Quadcopter propellers

- **Electronic Speed Controllers (ESC) :**

ESC’s control the speed of the motors based on commands from the flight controller. They regulate the amount of power that goes to the motors, helping to adjust the speed of each propeller [7].

Figure (I.29). Quadcopter ESC's

- **Flight controller:**

Considered the brain of the drone, the flight controller is responsible for every aspect of flight operations [7].

`**Figure (I.30).** Flight controller.

- **Battery:**

The battery provides the power needed for the drone to operate. Most drones use lithium-polymer (LiPo) batteries [7].

Figure (I.31). Drone battery.

- **Sensors:**

Sensors play a crucial role in the drone's ability to navigate and stabilize. The common types used are: Gyroscopes, accelerometers, and barometers which are standard sensors that help the drone understand its position and orientation [7].

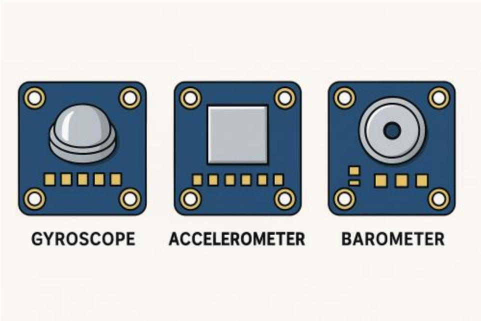


Figure (I.32). Approximate image of the sensors.

- **GPS module:**

GPS modules enhance the navigation capabilities of drones, allowing for precise positioning [7].

Figure (I.33):DJI GPS module.

- **Camera:**

Cameras are essential for drones used in photography and videography, providing real-time images and videos [7].

Figure (I.34). Camera module

Table (I.1). Summary of Drone Components and Their Importance

Component	Function	Importance
Frame	Holds all components	Structural integrity
Motors	Propel and stabilize the drone	Essential for flight
Propellers	Create / lift and thrust	Directly affects flight dynamics
ESC	Regulate motor speed	Precision control
Flight controller	Manages all aspects of flight	Brain of the drone
Battery	Powers the drone	Determines flight time
Sensors	Provide data on position	Navigation and stability
GPS module	Enhances navigation	Precise positioning

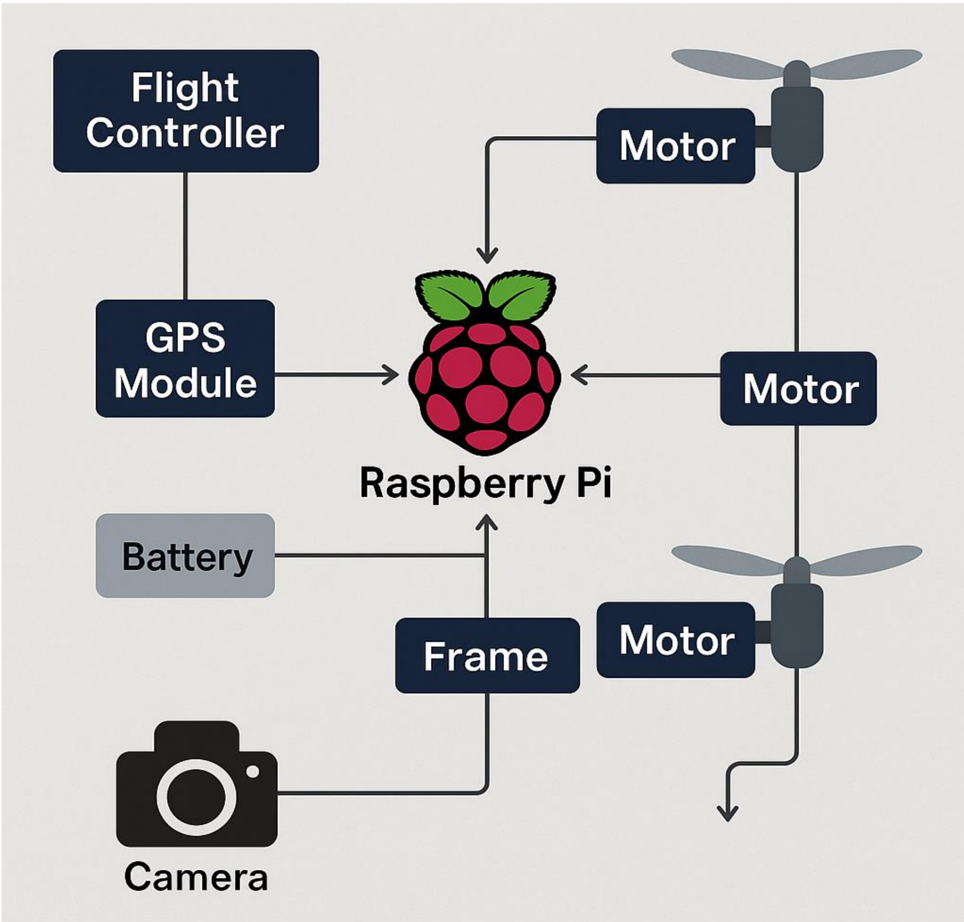


Figure (I.28): Drone system Diagram.

I.7. Conclusion:

In conclusion, the evolution of UAVs from basic military tools to complex, multi-functional devices is a significant step in engineering, design, and application. Quadcopters and various multi-rotor quadcopters are a culmination of miniaturization, control system, and artificial intelligence innovation. Their applications today cut across agriculture to search and rescue, testifying to their utility to society.

Chapter II: UAV Modelling

II.1. Introduction :

UAVs fly due to the lift forces generated by their wings, which are upward-directed forces acting on the UAV. When air flows around the wings, the wings alter the direction of the airflow. The wing has a specific aerodynamic shape capable of generating the force responsible for lifting the UAV, known as Lift Force. The wing's cross-sectional shape resembles an airfoil similar to the shape of an eyelid meaning it is cambered, with the upper surface longer than the lower surface.

Lift is primarily generated because the UAV’s wings deflect the passing airflow downward, and as a reaction, the air exerts an upward force on the wing. There is a parameter called the Angle of Attack (AoA), which is the angle between the wing chord line and the oncoming airflow. There is also a feature called the Leading Edge, which is the front edge of the wing facing the airflow, and the Trailing Edge, which is the rear edge where the airflow leaves the wing. In the wing's cross-section, both the leading and trailing edges are represented by two distinct points: one at the front and one at the rear of the airfoil.

II.2. Basic Principles of Mechanics :

When the UAV is in the takeoff phase or in level flight, the leading edge of the wing is positioned higher than the trailing edge. As the wing moves through the air, the angle of attack pushes the air downward beneath the wing. The airflow over the upper surface of the wing is also deflected downward due to the specially designed aerodynamic shape of the wing.

An increase in the angle of attack leads to an increase in the lift force acting on the wing, because it causes a greater deflection of the airflow downward. However, this increase has a limit beyond a certain point, the wing enters a stall condition, in which the airflow can no longer remain smoothly attached to the wing surface, resulting in a sudden loss of lift.

II.2.1 Newton’s Third Law of Motion :

Newton’s Third Law of Motion, formulated by the English physicist Isaac Newton, states that: *"For every action, there is an equal and opposite reaction."*In this context, the action is the wings pushing the air downward, while the reaction is the air pushing the wings upward. This reaction force is what generates the lift force acting on the UAV it is the upward vertical force that enables the UAV to remain airborne.

II.2.2 Bernouli principle :

Bernoulli's principle is a key concept in aerodynamics and explains how UAVs generate lift. According to this principle, when the speed of a fluid (like air) increases, its pressure decreases. UAV propellers or wings are designed so that air travels faster over the upper surface and slower underneath. This creates a pressure difference lower pressure on top and higher pressure below which produces lift and allows the UAV to rise.

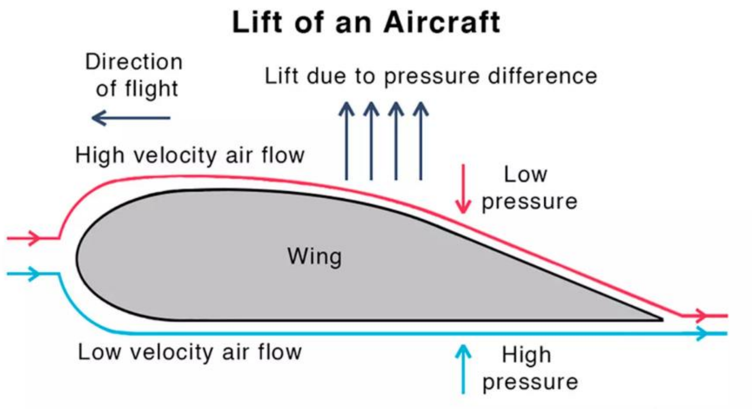


Figure (II.1). Bernouli principle

II.3. Flight Theory :

The ability to fly is, at its core, the ability to manage and balance the forces of gravity and motion. For a UAV (Unmanned Aerial Vehicle), flight is achieved by controlling the interaction of four fundamental aerodynamic forces: **thrust**, **lift**, **drag**, and **weight**. Each of these forces plays a crucial role in the UAV's stability, maneuverability, and overall performance in the air.

II.3.1. Thrust :

Thrust is the forward force generated by the UAV's propulsion system typically by engines and propellers. It results from pushing air backward, producing a reaction force in the opposite direction (Newton's Third Law). Thrust serves two key purposes:

- Initiating or altering the UAV's motion.
- Overcoming the opposing force of drag to maintain or increase speed.

Thrust can also be defined as:

- The component of the resultant aerodynamic force parallel to the propeller axis, or
- The total force generated by jet or rocket propulsion in more advanced UAVs.

The amount of thrust required depends on the UAV's design and flight conditions, including altitude, speed, and drag.

Thrust equation :

$$F = \dot{m} \times V_e + (P_e - P_0) \times A_0 \tag{2.1}$$

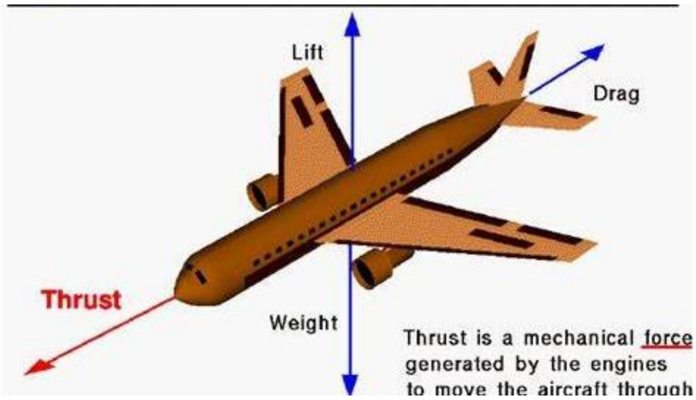


Figure (II.2). Thrust

II.3.2. Lift :

Lift is the aerodynamic force acting perpendicular to the direction of the relative wind and within the UAV's plane of symmetry. It is the force that elevates the UAV into the air, counteracting gravity. Lift increases with forward speed and depends on the shape of the UAV's lifting surfaces, such as wings or rotor blades.

The generation of lift is primarily explained by Bernoulli's principle, which relates pressure and velocity in a fluid flow. A specially designed airfoil the cross-sectional shape of the wingis crucial for lift production:

The upper surface of the airfoil is curved, making air travel a longer path over it. To meet the air at the trailing edge simultaneously, the air on top must move faster than the air below.

Faster airflow above means lower pressure, while slower airflow below results in higher pressure, generating an upward force lift.

This pressure differential is the core mechanism behind flight. As long as lift equals or exceeds weight, the UAV can maintain or gain altitude.

Lift equation :

$$L = C\,\iota\,(\tfrac{1}{2}\rho v^2)A \qquad (2.2)$$

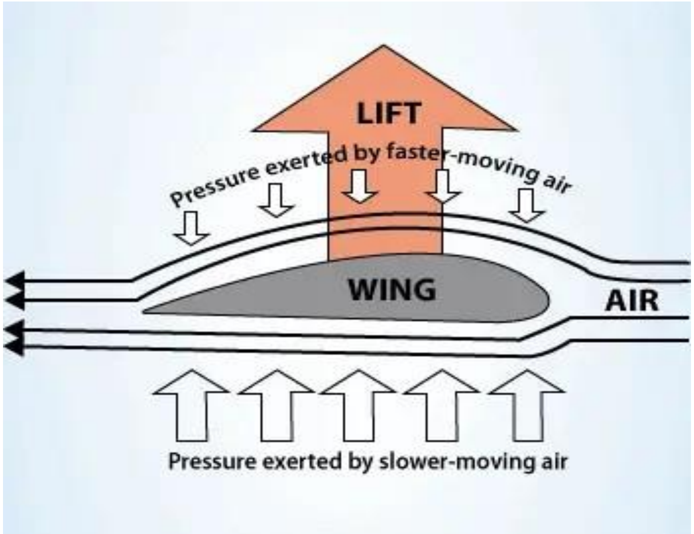


Figure (II.3). Lift

II.3.3. Drag

Drag is the aerodynamic resistance force that acts opposite to the UAV's motion. It is aligned with the direction of the relative wind and reduces forward speed. Drag is composed of two main components:

Parasitic drag: Caused by the shape of the UAV and surface friction.

Induced drag: A byproduct of lift generation, mainly due to airflow vortices at the wingtips and pressure imbalances.

Together, these components resist motion through the air. Efficient UAV designs aim to minimize drag while maintaining sufficient lift to reduce energy consumption and extend flight time.

Drag equation :

$$D = \tfrac{1}{2} \times S \times V^2 \qquad (2.3)$$

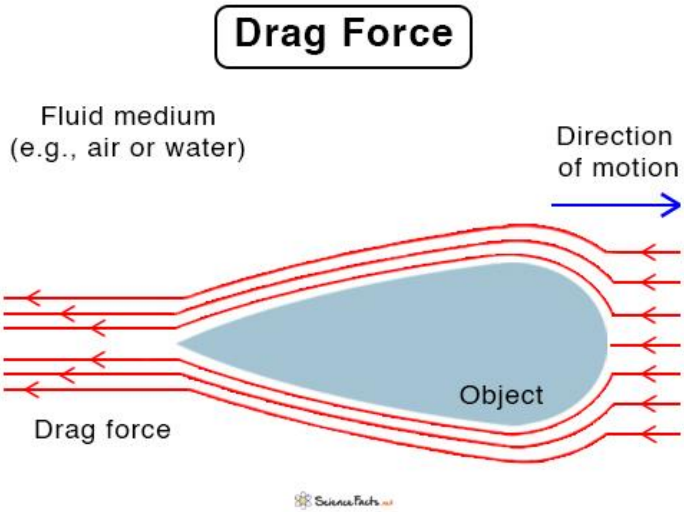


Figure (II.4). Drag Force

II.3.4. Weight :

Weight is the gravitational force acting on the UAV due to its mass. It is directed toward the center of the Earth and is typically represented by the maximum takeoff weight, which is the upper limit at which the UAV must meet all its performance and safety criteria.

To achieve stable flight:

- Lift must balance or exceed weight to prevent descent.

If lift equals weight, the UAV flies at constant altitude (vertical equilibrium).

$$W = m \times g \tag{2.4}$$

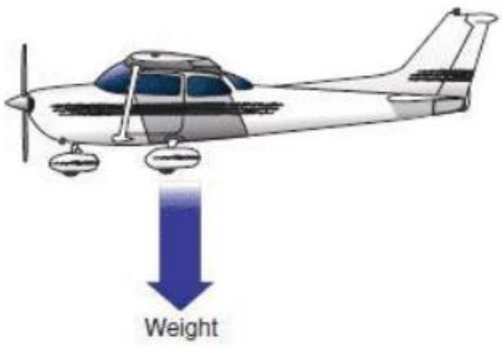


Figure (II.5). Weight

II.3.5. Force Balance in Flight :

The UAV's flight condition is determined by the balance of the four forces:

When lift = weight, the UAV remains in steady level flight (no vertical acceleration).

When thrust = drag, the UAV maintains a constant horizontal velocity.

An increase in thrust over drag results in acceleration, while an increase in lift over weight results in ascent.

The dynamic balance between these forces allows the UAV to climb, descend, turn, or hover, depending on the flight system and design.

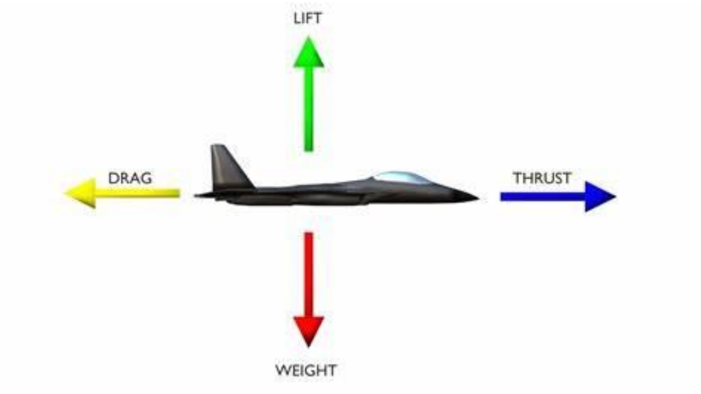


Figure (II.6). Forces balance

II.3.6. Airfoil and Lift Mechanics :

The airfoil is the aerodynamic shape of a wing or blade that enables efficient lift generation. Its design is critical to UAV performance:

A cambered upper surface increases the path length of airflow, causing it to move faster.

According to Bernoulli's Law, this faster movement creates lower pressure, leading to lift due to the pressure difference across the wing surfaces.

II.3.7. Angle of Attack (AOA) :

The Angle of Attack is the angle at which relative wind meets an Aerofoil. It is the angle formed by the Chord of the aerofoil and the direction of the relative wind or the vector representing the relative motion between the aircraft and the atmosphere.

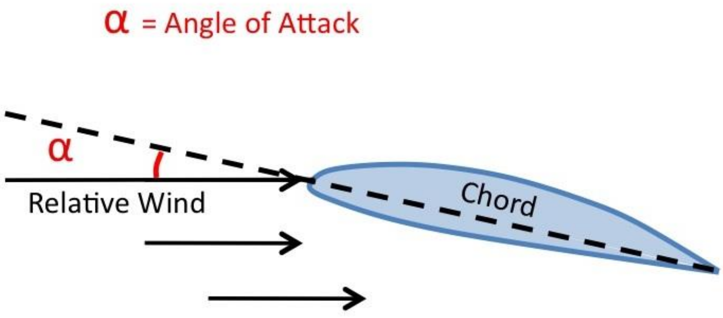


Figure (II.7). Angle of attack

The following figure illustrates all of these elements combined :

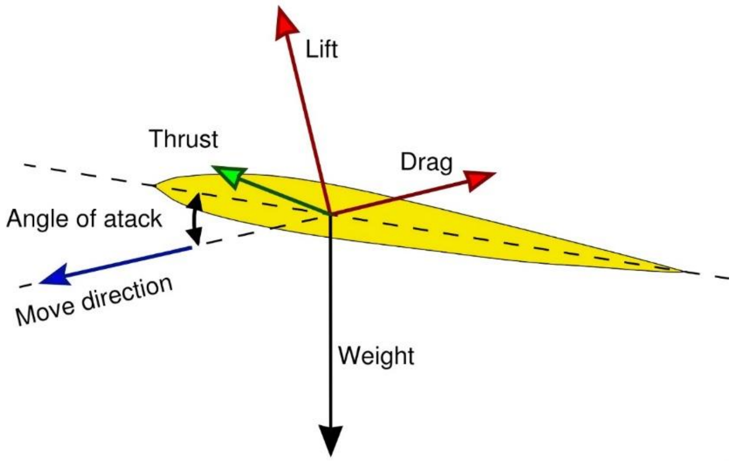


Figure (II.8). all forces combined

II.4. Mathematical model of a Quadcopter :

The kinematics and dynamics of a quadcopter can be clearly understood by considering two frames of reference: earth inertial frame { O } and body fixed frame { B }. The earth inertial frame is defined with gravity pointing in the negative z direction, and the coordinate axes of the body frame are along the arms of the quadcopter. 4 DC motors are placed at the extremities of all the arms, with a propeller mounted on them to provide the required thrust. In the structure shown in figure 3, Motors 1 and 3 rotate in the counter-clockwise direction with angular velocities ω_1 and ω_3, whereas motors 2 and 4 rotate in the clockwise direction ω_2 and ω_4.

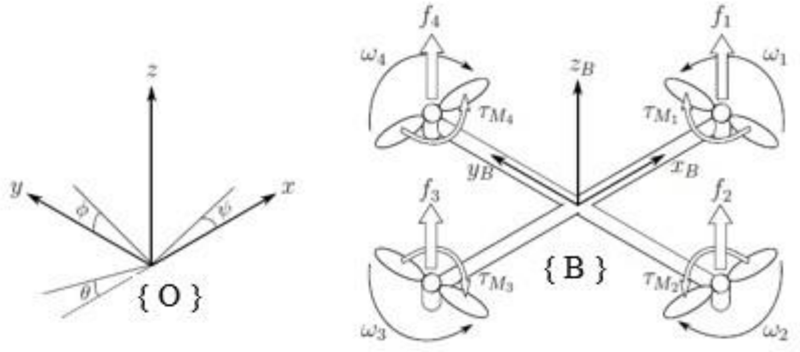


Figure (II.9). body frames of a quadcopter

The absolute position of the center of mass of the quadcopter is expressed in the inertial frame as : $\varepsilon = [\ X \ \ Y \ \ Z\ ]^T$. The attitude or the angular position is defined in the inertial frame with the

'roll-pitch-yaw' Euler angles $\eta = [\ \Phi \ \ \theta \ \ \Psi\ ]^T$. The linear velocities $V_B = [\ V_X \ \ V_Y \ \ V_Z]^T$ and angular velocities $\nu = [\ P \ \ Q \ \ R\ ]^T$ are defined in the body frame.

The relationship between these two frames is expressed using the rotation matrix R_1

$$R_1 = \begin{bmatrix} C\Psi C\theta & C\Psi S\theta S\Phi - C\Psi CX\Psi & C\Psi S\theta C\Phi + S\Psi S\Phi \\ S\Psi C\theta & S\Psi S\theta S\Phi + C\Psi C\Phi & S\Psi S\theta C\Phi - C\Psi S\Phi \\ -S\theta & C\theta S\Phi & C\theta C\Phi \end{bmatrix} \qquad (2.5)$$

Where $C_\theta = cos(\theta)$ and $S_\theta = sin(\theta)$. R_1 is orthogonal, which implies $R^{-1} = R^T$ which is the rotation matrix from { B } to { O }.

Since all the motors are identical, the derivation is explained for a single one. The thrust acting on the quadcopter by a single motor-propeller system is given by momentum theory:

$$T_i = C_D \rho A r^2 \omega_i^2 \qquad (2.6)$$

Where C_D is thrust coefficient of the motor, ρ is the density of air, A is the cross-sectional area of the propeller's rotation, r is the radius of rotor and ω_1 is the angular speed of the rotor. For simple flight motion, a lumped parameter approach is considered to simplify the above equation to

$$T_i = K \omega_i^2 \qquad (2.7)$$

Combining the thrust from all the 4 motor-propeller system, the net thrust in the body frame Z direction is given by:

$$T = K \sum \omega_i^2 \qquad (2.8)$$

Therefore, the net thrust acting on the quadcopter in the body frame is:

$$F^B = [0 \quad 0 \quad T]^T \qquad (2.9)$$

In addition to thrust, a drag force also acts on the quadcopter which is a resisting force. It has components along the coordinate axes in the inertial frame directly proportional to the corresponding velocities. The drag force is given in the component form as

where A_x, A_y and A_z are the drag coefficients in the x, y and z directions.

If all the rotor velocities are equal, the quadcopter will experience a force in z direction will move up, hover or fall down depending on the magnitude of the force relative to gravity. The moments acting on the quadcopter cause pitch, roll and yaw motion. Pitching moment M_Φ occurs due to difference in thrust produced by motors 2 and 4. Rolling moment M_θ occurs due to difference in thrust produced by motors 1 and 3.

$$M_\Phi = L\,(T_4 - T_2) \qquad (2.10)$$

$$M_\theta = L\,(T_3 - T_1) \qquad (2.11)$$

in which L is the distance between the center of propeller and the center of quadcopter.

Yawing moment M_Ψ is caused by the drag force acting on all the propellers and opposing their rotation. Again from the lumped parameter approach,

$$\tau_{Mi} = B\,\omega_i^2 + I_R\,\dot{\omega}_i \qquad (2.12)$$

where τ_{M1} is the torque produced by motor 1, B is the torque constant, I_R is the inertia moment of rotor. The effect of $\omega\,\dot{i}$ is very small and can be neglected.

$$M_\psi = B\,(-\omega_1^2 + \omega_2^2 - \omega_3^2 + \omega_4^2) \qquad (2.13)$$

The rotational moment acting on the quadcopter in the body frame is:

$$M^B = [M_\Phi \;\; M_\theta \quad M_\psi]^T \qquad (2.14)$$

There is also a rotational drag which is a resistive torque that acts on the body frame which is proportional to the body from angular velocities. The rotational drag is given by:

$$M^R = [A_r P \quad A_r Q \quad A_r R]^T \qquad (2.15)$$

where A_r is the rotational drag coefficient.

The model presented here has been simplified by ignoring several complex effects like, blade flapping (deformation of blades at high velocities and flexible materials), surrounding wind velocities etc.

Newton-Euler formulation is used to derive the dynamic equations of motion for the quadcopter. The quadcopter is assumed to have a symmetrical structure, so the Inertia matrix is diagonal and time-invariant, with $I_{XX} = I_{YY}$.

$$I = \begin{bmatrix} I_{XX} & 0 & 0 \\ 0 & I_{YY} & 0 \\ 0 & 0 & I_{ZZ} \end{bmatrix} \qquad (2.16)$$

In the body frame, the force producing the acceleration of mass $m\,\dot{V_B}$ and the centrifugal force $v \times (m\,V_B)$ are equal to the gravity $R^T G$ and the total external thrust F^B and the aero dynamical drag force $R^T F^D$.

$$m\,\dot{V_B} + v \times (m\,V_B) = R^T G + F^B - R^T F^D \qquad (2.17)$$

In the case of a quadcopter, it is convenient to express the dynamics with respect to a mixed frame { M } with the translational dynamics with respect to the inertial frame and { O } and the rotational dynamics with respect to the body frame { B }.

In the inertial frame, centrifugal effects are negligible. The only forces coming into play are the gravitational force, thrust, drag and acceleration of the mass of quadcopter.

$$m \times \ddot{\varepsilon} = G + R \times F^B - F^D \qquad (2.18)$$

Rewriting this,

$$\begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ -g \end{bmatrix} + R \times \frac{F^D}{m} - \frac{F^B}{m} \qquad (2.19)$$

Making the following substitution and taking the component form gives the dynamic equation for translational motion:

$$\begin{bmatrix} x \\ \dot{y} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} u \\ v \\ w \end{bmatrix} \qquad (2.20)$$

$$\dot{U} = (\sin\Phi \ \sin\Psi + \cos\Phi \ \sin\theta \ \cos\Psi) \times \frac{T}{m} - \frac{Ax}{m} \times U \qquad (2.21\text{ a})$$

$$V^{\cdot} = (-\sin\Phi \ \cos\Psi + \cos\Phi \ \sin\theta \ \sin\Psi) \times \frac{T}{m} - \frac{Ay}{m} \times V \qquad (2.21\text{ b})$$

$$W = -g + (\cos\Phi \ \cos\theta) \times \frac{T}{m} - \frac{Az}{m} \times V \qquad (2.21\text{ c})$$

Again, considering the rotational dynamics in the body frame, the angular acceleration of the inertia $I\dot{v}$, the centripetal forces $v \times (I\ v)$ and the gyroscopic forces $\Tau$ are equal to the external torque M^B and the torque generated due to aero dynamic drag.

$$I\ \dot{v} + v \times (I\ v) + \Tau = M^B - M^D \qquad (2.22)$$

Rewriting this equation,

$$\dot{v} = I^{(-1)} \left(\begin{bmatrix} P \\ Q \\ R \end{bmatrix} \times \begin{bmatrix} I_{XX} \times P \\ I_{YY} \times Q \\ I_{ZZ} \times R \end{bmatrix} - IR \begin{bmatrix} P \\ Q \\ R \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \times \Omega + M^B - M^D \right) \qquad (2.23)$$

Where $\Omega = -\omega_1 + \omega_2 - \omega_3 + \omega_4$ and I_R is the rotational inertia of each motor. Writing in

$$\dot{P} = \frac{I_{XX} - I_{YY}}{I_{zz}} QR - \frac{I_r}{I_{XX}} Q\Omega + \frac{M_\Phi}{I_{XX}} - \frac{A_r}{I_{XX}} P \qquad (2.24\text{ a})$$

$$\dot{Q} = \frac{I_{zz} - I_{XX}}{I_{YY}} PR - \frac{I_R}{I_{YY}} \Omega \frac{M_\theta}{I_{YY}} - \frac{A_r}{I_{YY}} Q \qquad (2.24\text{ b})$$

component form,

$$\dot{R} = \frac{I_{XX} - I_{YY}}{I_{ZZ}} PQ + \frac{M_\Psi}{I_{zz}} - \frac{A_r}{I_{zz}} \qquad (2.24\text{ c})$$

Transformation of angular velocities from body frame to inertial frame is given by:

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\Psi} \end{bmatrix} = \begin{bmatrix} 1 & sin\phi \times tan\theta & cin\phi \times tan\theta \\ 0 & cos\phi & -sin\phi \\ 0 & \frac{sin\phi}{cos\theta} & \frac{cos\phi}{cos\theta} \end{bmatrix} \begin{bmatrix} P \\ Q \\ R \end{bmatrix} \qquad (2.25)$$

Using the equation of thrust and torque mentioned in dynamics of quadcopter and the above four equations of thrust and torques, the values of the angular velocities at each of the four rotors are obtained and shown in Equation :

$$T = K\,(\omega_1^2 + \omega_3^2 + \omega_4^2) \qquad (2.26)$$

$$\begin{pmatrix} m\phi \\ m\theta \\ m\psi \end{pmatrix} = \begin{pmatrix} K & K & K & K \\ 0 & KL & 0 & -KL \\ -KL & 0 & KL & 0 \\ -B & B & -B & B \end{pmatrix} \begin{pmatrix} \omega1\text{^}2 \\ \omega2\text{^}2 \\ \omega3\text{^}2 \\ \omega4\text{^}2 \end{pmatrix} \qquad (2.27)$$

Taking inverse of the above matrix, the following equations are obtained for individual rotor speeds :

$$\omega_1^2 = \frac{T}{4K} - -\frac{m\psi}{4b} \qquad (2.28\ a)$$

$$\omega_2^2 = \frac{T}{4K} - \frac{m\phi}{2KL} + \frac{m\psi}{4b} \qquad (2.28\ b)$$

$$\omega_3^2 = \frac{T}{4K} + \frac{m\theta}{2KL} - \frac{m\psi}{4b} \qquad (2.28\ c)$$

$$\omega_4^2 = \frac{T}{4K} + \frac{m\phi}{2KL} - \frac{m\psi}{4b} \qquad (2.28\ d)$$

These ω are then used to calculate the current states of the quadcopter as mentioned before. This model is used to develop both the attitude and trajectory controller along with implementation of the trajectory airplane.

II.5. Conclusion :

In this chapter, we have explored the fundamental principles of UAV flight, including aerodynamic forces such as lift, drag, thrust, and weight, and how they interact to enable stable and controlled flight. We also introduced the core flight theories Bernoulli's and Newton's laws that support UAV operation. Finally, we have presented a simplified mathematical model of a quadcopter, highlighting the dynamics and mechanisms involved. This foundation is crucial for understanding UAV behavior and serves as a basis for the design and simulation.

Chapter 3: Drone's Design

III.1. Introduction:

Designing a drone frame isn't just about drawing shapes — it's about turning ideas and requirements into something real, something that works. In this chapter, we walk through the entire design process of a drone airframe using Autodesk Fusion 360. Every step is approached with practicality in mind keeping the frame lightweight, strong, and modular. The final goal? A design that not only looks good on screen but can also be 3D printed and tested in real-world conditions or simulations.

III.2. Autodesk Fusion 360:

III.2.1. Definition:

Autodesk Fusion 360 is a cloud-based 3D design and engineering software developed by Autodesk. It combines computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), and printed circuit board (PCB) design in a single platform. This integration allows users to design, simulate, and prepare parts for manufacturing within the same environment, making it especially valuable in engineering and prototyping workflows. Fusion 360 is widely used in product development, robotics, mechanical design, and education due to its accessibility and versatility [8].

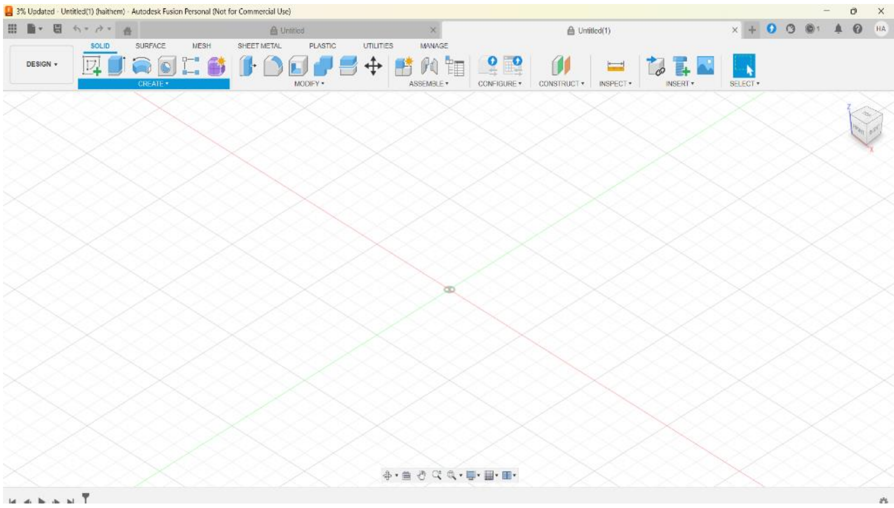


Figure (III.1). Autodesk Fusion 360 interface.

III.3. Key Applications:

III.3.1. Parametric and Freeform 3D Modeling:

- Fusion 360 allows users to design components using both parametric constraints (precise dimensions and features) and sculpted, organic shapes.
- **Example***:* Designing the structural frame of a drone by defining precise dimensions and constraints between parts [9].

III.3.2. Simulation and Analysis (CAE):

- Users can perform static stress analysis, thermal simulations, and motion studies to evaluate the performance of their models before production.
- **Example***:* Testing the strength of a drone arm under load to identify weak points and optimize geometry [9].

III.3.3. Computer-Aided Manufacturing (CAM):

- Fusion 360 provides built-in tools to generate CNC toolpaths for machining and supports additive manufacturing workflows such as 3D printing.
- **Example***:* Creating G-code to mill an aluminum motor mount or exporting an STL file for 3D printing a drone frame [9].

III.3.4. Electronics and PCB Design:

- Fusion 360 includes a full suite of tools for designing and routing custom PCBs, integrating them with mechanical models.
- **Example:** Designing a custom power distribution board (PDB) to fit precisely into a compact drone chassis [9].

III.3.5. Collaboration and Cloud Storage:

- All project files are saved in the cloud, enabling version control, real-time collaboration, and access from any device.
- **Example***:* Collaborating remotely with a team on a drone design, where each member can access, comment, or update the model in real-time [9].

III.4. Advantages of Using Fusion 360 in the Drone Project:

Autodesk Fusion 360 offers several key advantages that make it particularly suitable for drone design and prototyping. Firstly, its integrated platform combines CAD, CAM, and CAE functionalities, enabling a seamless transition from design to simulation and manufacturing without switching between different software tools. This integration reduces development time and potential errors during file transfers between systems.

- Secondly, Fusion 360 supports parametric modeling, which allows design changes to be made easily by adjusting parameters rather than redrawing components from scratch. This feature is especially useful in iterative drone design, where small adjustments in frame dimensions or mounting structures are often required based on simulation results or component constraints.
- Additionally, Fusion 360's cloud-based collaboration enables real-time file sharing and version control, which is beneficial for team-based academic projects or remote collaboration with supervisors. The built-in simulation environment also allows for stress and thermal analysis, which can help validate structural integrity before 3D printing the drone components.
- Finally, Fusion 360 is free for students and educators, making it accessible without budget constraints, and includes comprehensive online support, tutorials, and a strong user community ideal for learning and problem-solving in an academic context.

➢ **Why Fusion 360 Was Chosen for This Project:**

- Fusion 360 was selected for this drone project due to its versatility, cost-effectiveness, and strong integration of design and simulation tools. Compared to other CAD software such as SolidWorks or CATIA, Fusion 360 offers a more accessible learning curve while still providing professional-grade tools. Its cloud-based nature enables easy access from multiple devices and ensures automatic version tracking, which is particularly useful for academic work and team collaboration.
- Moreover, its compatibility with 3D printing workflows through built-in STL export and direct integration with slicing software makes it an ideal choice for projects that require rapid prototyping. As the project involved designing custom drone components such as the frame, motor mounts, and camera supports, Fusion 360's parametric and assembly modeling features proved essential for building and testing accurate prototypes before physical fabrication.

➢ **How Fusion 360 Was Used in This Project:**

- In this master project, Fusion 360 was primarily used for the 3D modeling of the drone's mechanical structure. The tool was utilized to design the drone frame, propeller guards, landing gear, camera mounts, and battery holders. Each part was modeled as a separate component and then assembled into a complete digital drone model using the Assembly workspace.

- Additionally, motion simulation was used to test the range of movement for the camera mount and landing gear mechanisms. Before 3D printing, the models were exported as STL files, allowing for compatibility with slicing software like Ultimaker Cura. The built-in rendering tools were also used to generate realistic images for the master project visuals and presentation.
- Throughout the project, Fusion 360's parametric design tools made it easy to adjust dimensions as needed, which was crucial during the iterative design process. The project also benefited from Fusion 360's cloud saving and backup, ensuring secure version history and recovery during development.

III.5. Defining the Quadcopter Frame Specifications:

The conception of our quadcopter drone begins by setting clear parameters for the drone. The goal is a 210 mm "X" frame, optimized for strength, weight, and aerodynamics. The design will be fully 3D printable and tailored around standard components such as motors, a PDB, and a camera

III.6. Bottom Plate Design Process:

III.6.1. Creating the Motor Mount:

- We start a new sketch on the bottom plane,
- We draw a 210 mm center diameter circle,
- We add vertical, horizontal, and 45° construction lines,
- At the 45° line, we draw a 25 mm motor mount circle,
- Inside it, we add a 5 mm hole for the motor shaft,
- We add slot holes for mounting screws,
- We use the circular pattern to complete motor mount.

- Step 1 : we start a new sketch on the bottom plane.

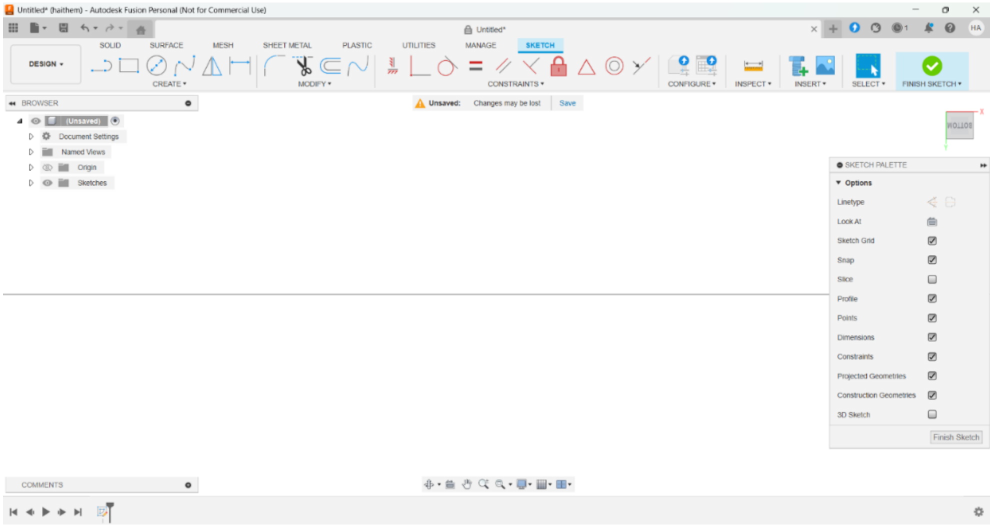


Figure (III.2). The sketch's bottom plane

- Step 2 : we draw a 210 mm center diameter circle.

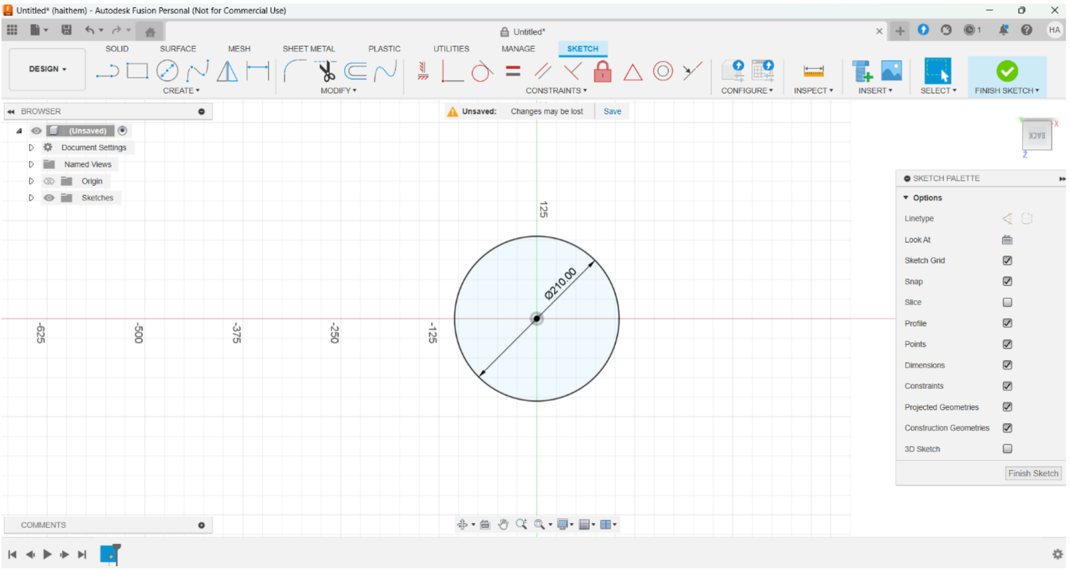


Figure (III.3). The 210mm centre diameter circle

- Step 3 : we add vertical, horizontal, and 45° construction lines.

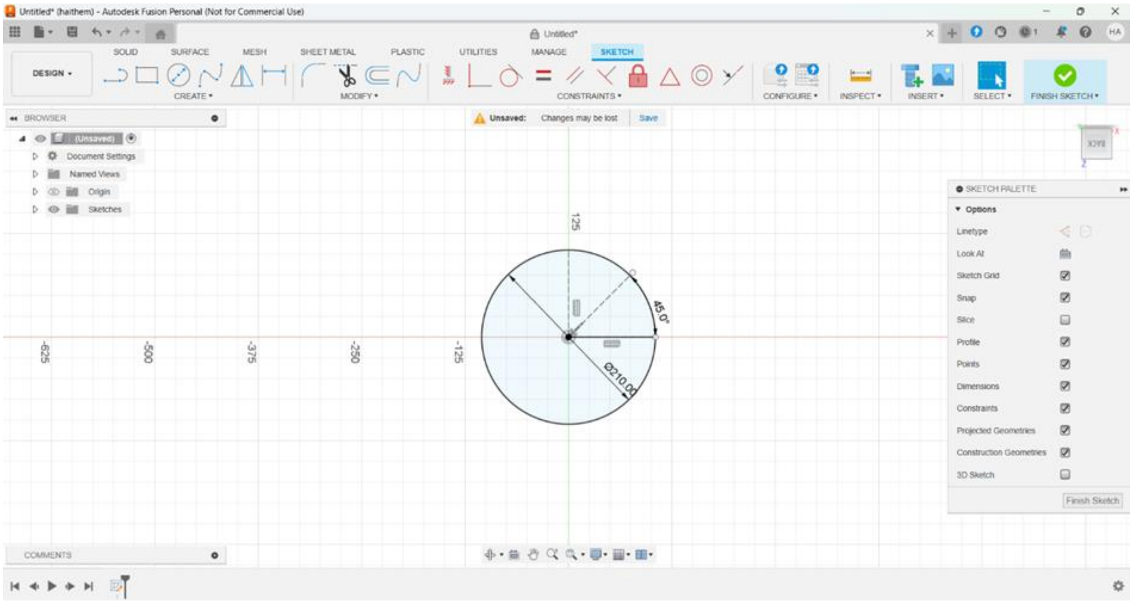


Figure (III.4). The vertical,horizontal and 45 degree onstruction lines

- Step 4 : at the 45° line, we draw a 25 mm motor mount circle,

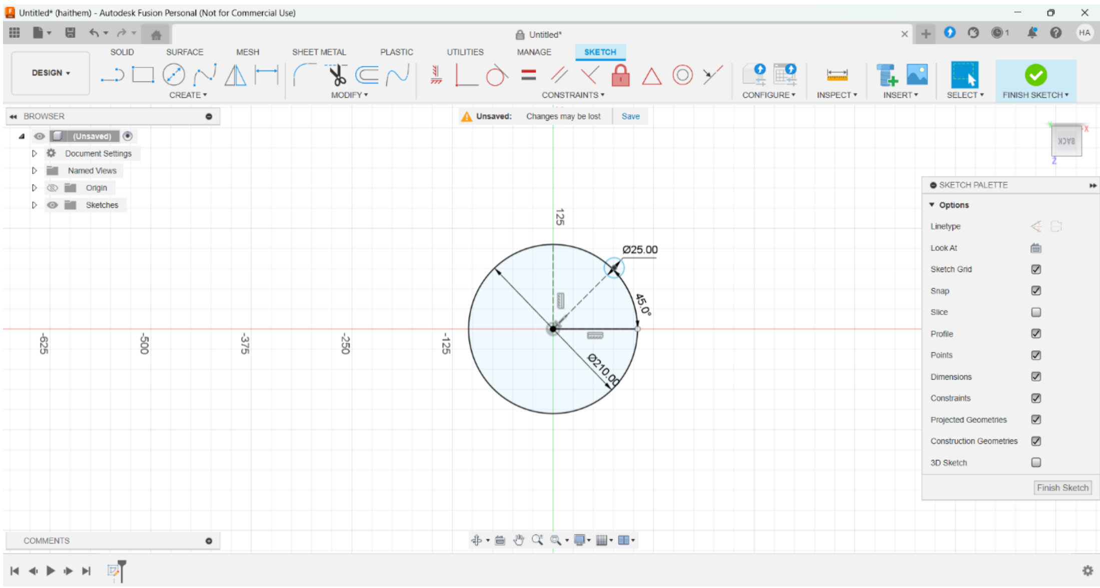


Figure (III.5). The 25 mm circle

- Step 5 : inside it, we add a 5 mm hole for the motor shaft,

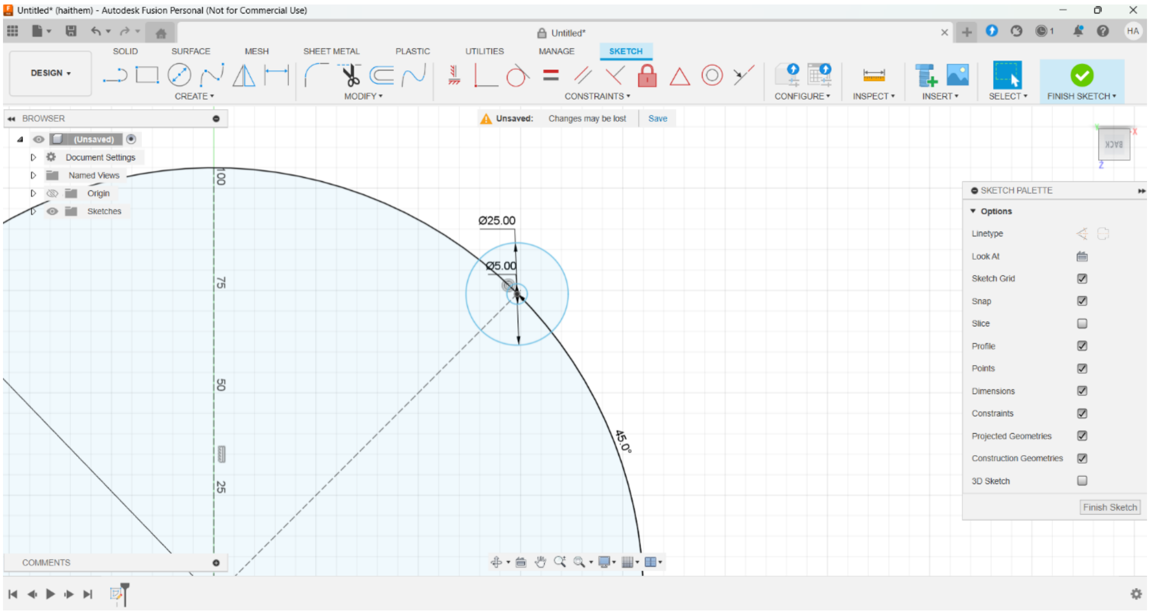


Figure (III.6). The 5 mm hole

- Step 6 : we add slot holes for mounting screws.

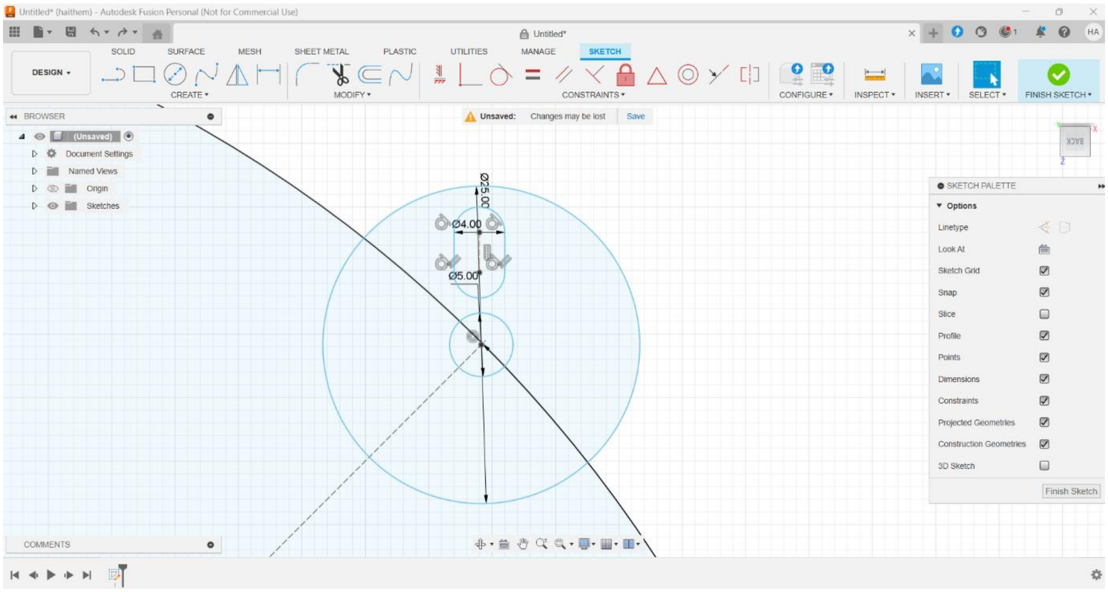


Figure (III.7). The Slot holes

- Step 7 : we use the circular pattern to complete motor mount.

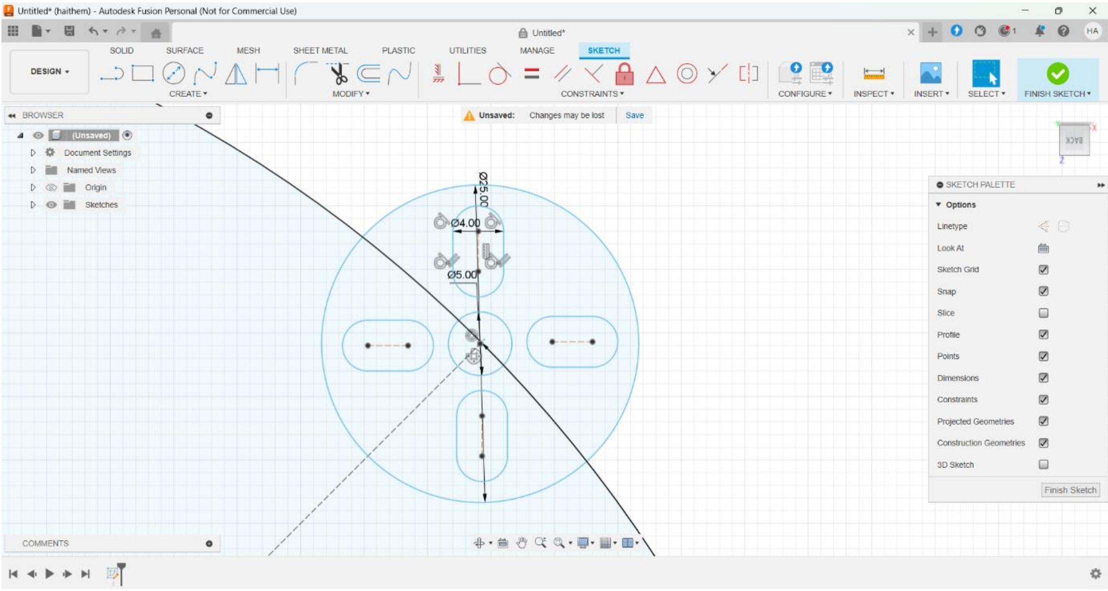


Figure (III.8). The Motor mount

III.6.2. Applying a Circular Pattern:

- We select the complete motor mount,
- We use the Circular Pattern tool to duplicate the geometry around the center point,
- We set quantity to 4 motor mounts.

- Step 8: we select the complete motor mount.

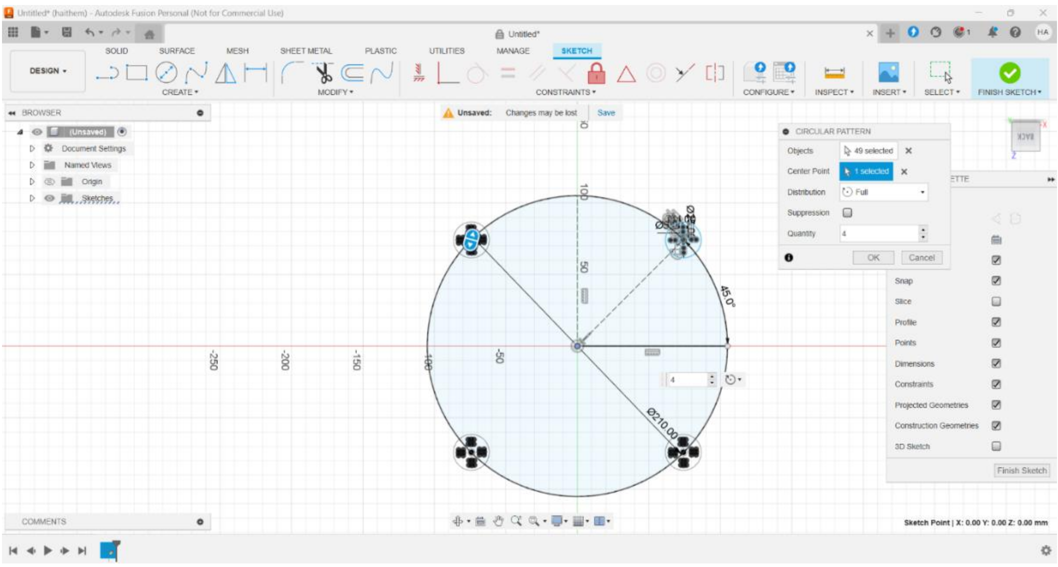


Figure (III.9). Application of the circular pattern

- Step 9 : We use the Circular Pattern tool to duplicate the geometry around the center point and we set quantity to 4 motor mounts.

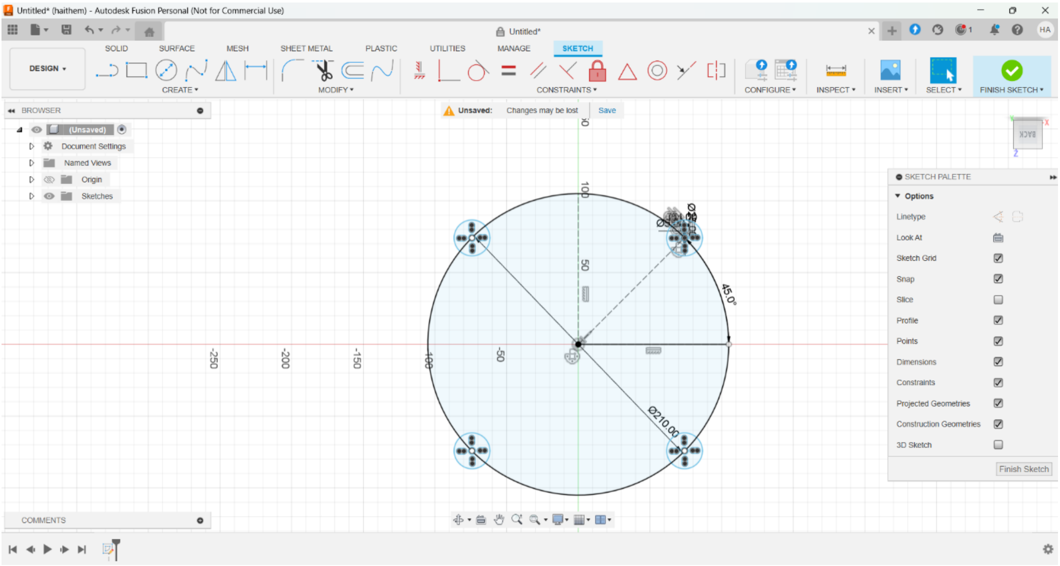


Figure (III.10). The Circular pattern

III.6.3. Sketching the Component Plate:

- We use the Center Rectangle tool to draw a 160 mm × 45 mm central plate.
- We use arcs to connect each motor mount to the rectangle.
- We apply Tangent Constraint to ensure smooth connections.
- We set the width of the booms to around 12 mm.

- Step 10 : We use the Center Rectangle tool to draw a 160 mm × 45 mm central plate.

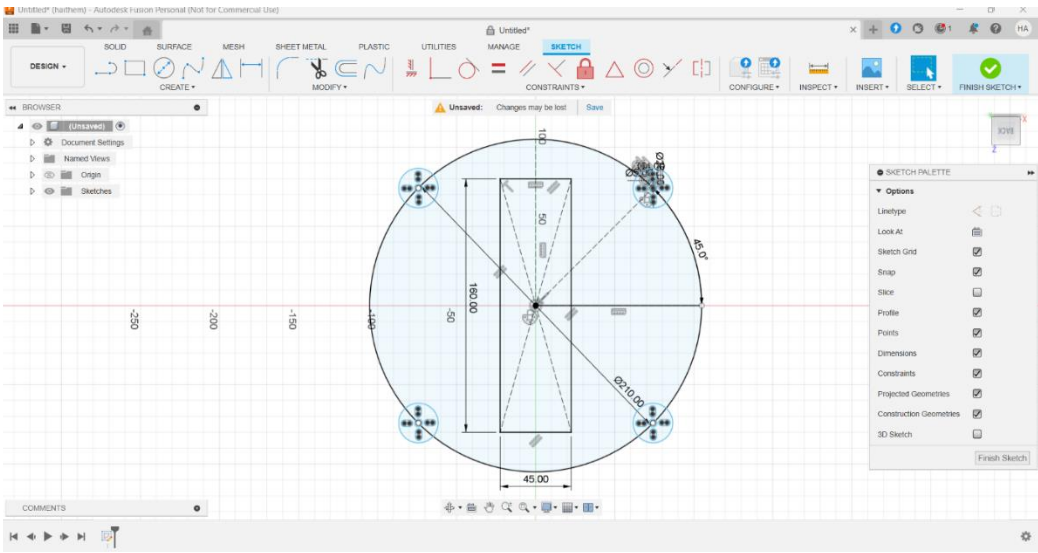


Figure (III.11). The rectangle Centering

- Step 11 : we use arcs to connect each motor mount to the rectangle and we make sure to ensure smooth connections using Tangent constraint tool.

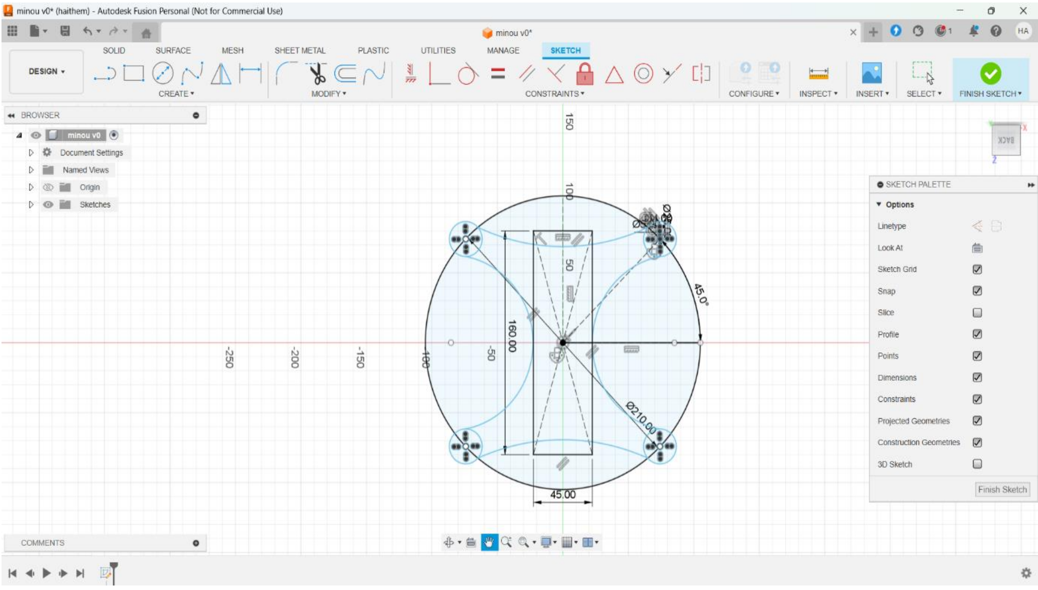


Figure (III.12). Connection of motor mounts to the rectangle

III.6.4. Integrating the Power Distribution Board (PDB):

- We create a 30.5 mm × 30.5 mm square,
- We add 4 mm holes at the corners,
- We make a construction Square.

- Step 12 : we create a 30.5 mm × 30.5 mm square.

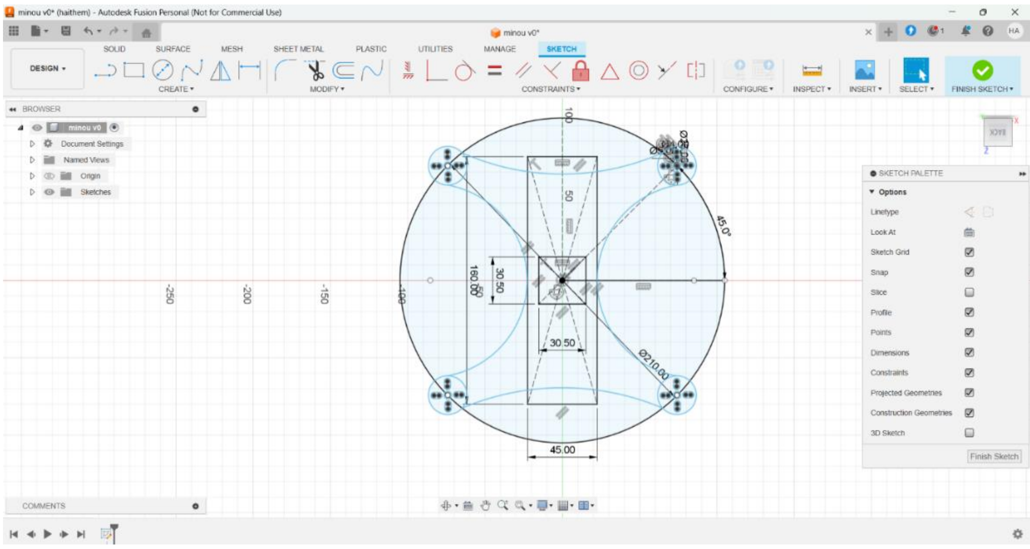


Figure (III.13). Square of dimensions 30.5*30.5 mm

- Step 13 : we add 4 mm holes at the corners.

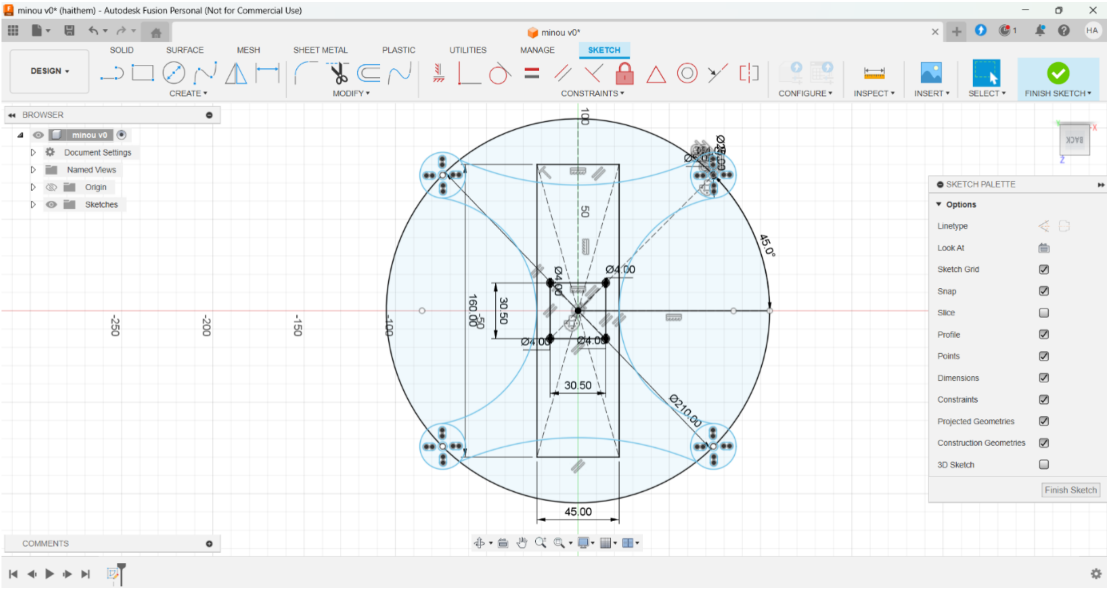


Figure (III.14). The Square corner holes

- Step 14 : we make a construction Square.

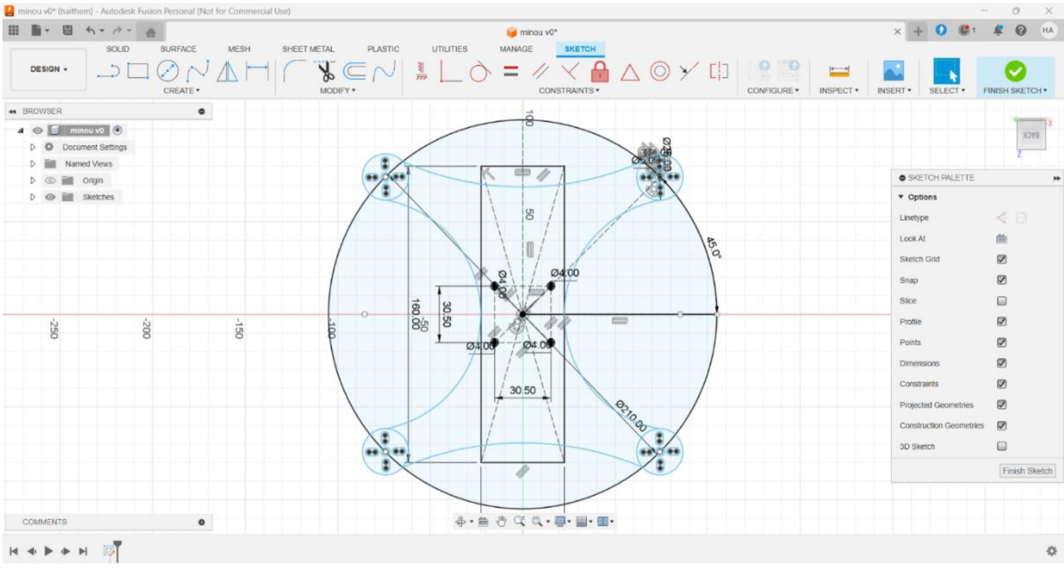


Figure (III.15). The Square Construction

III.6.5. Adding Stand-Off Holes:

- We create a 145 mm × 35 mm construction rectangle for standoff mounting,
- We add 4 mm holes at the corners,
- We use Rectangle Pattern tool to repeat the holes.

- Step 16 : we create a 145 mm × 35 mm construction rectangle for standoff mounting,

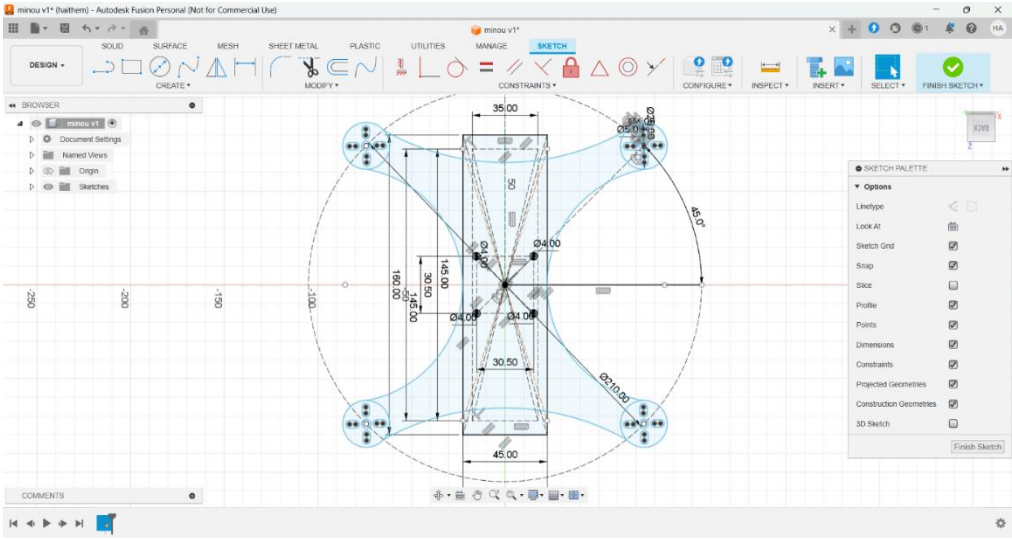


Figure (III.16). Rectangle Construction

- Step 17 : we add 4 mm holes at the corners then we use Rectangle Pattern tool to repeat the holes.

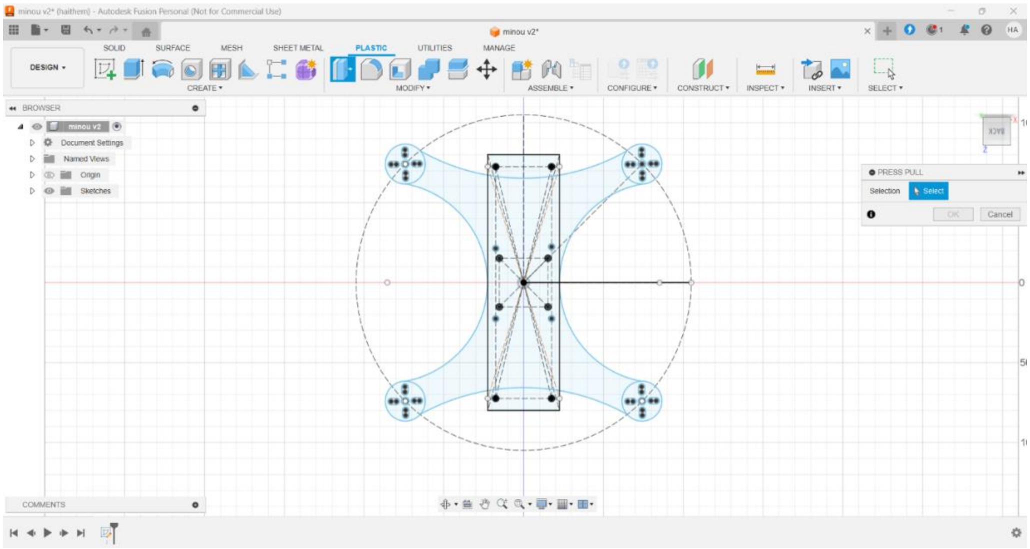


Figure (III.17). The Stand-off holes

III.6.6. Extruding the Component Plate:

- We use the Press Pull tool to extrude the full sketch 3 mm,
- We keep all holes unselected to remain open.

- Step 18 : we use the Press Pull tool to extrude the full sketch 3 mm.

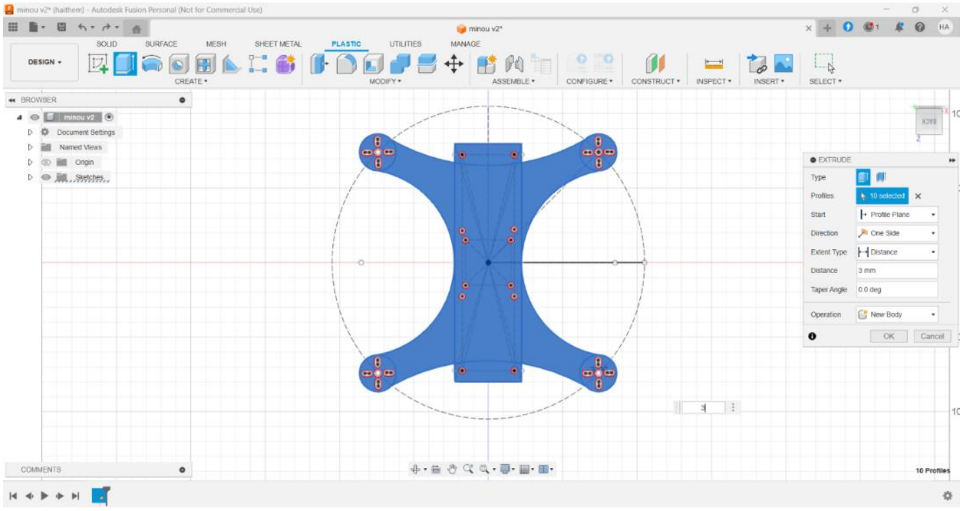


Figure (III.18). Press pull tool layout

- Step 19 : We keep all holes unselected to remain open.

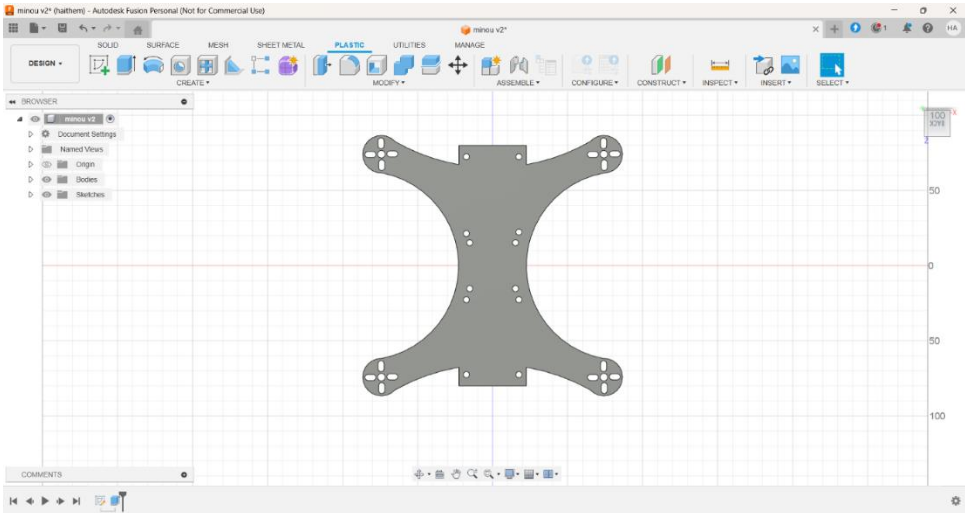


Figure (III.19). The Quadcopter bottom plane

III.6.7. Applying Fillets:

- We use the Fillet tool (F) on boom corners and plate corners,
- We apply a 5 mm radius fillet to smoothen edges.

- Step 20 : we use the Fillet tool (F) on boom corners and plate corners to smoothing the edges.

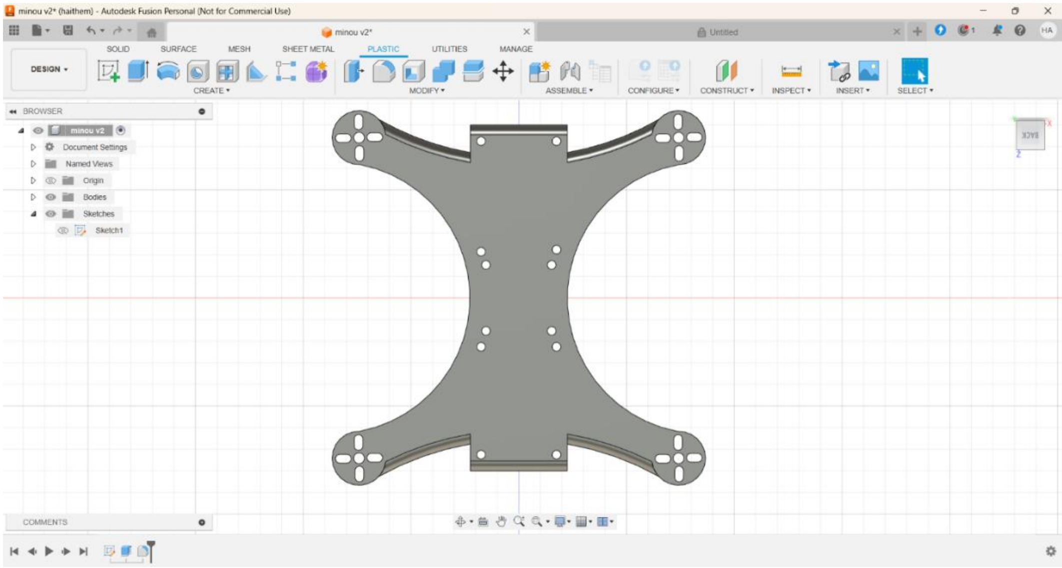


Figure (III.20). Applying fillets

III.7. Creating the Top Component Plate:

- We copy the bottom plate sketch,
- We Remove unneeded holes and we add:
  - FPV camera bracket slot (1.5 mm),
  - Battery strap slots (2 mm × 30 mm),
  - Antenna hole (6 mm).
  - 25 mm × 25 mm cutouts (to reduce airframe mass).
- We extrude the top plate to 1.5 mm and move it 25 mm above.

- Step 1 : we copy the bottom plate sketch and draw the FPV vamera bracket slot.

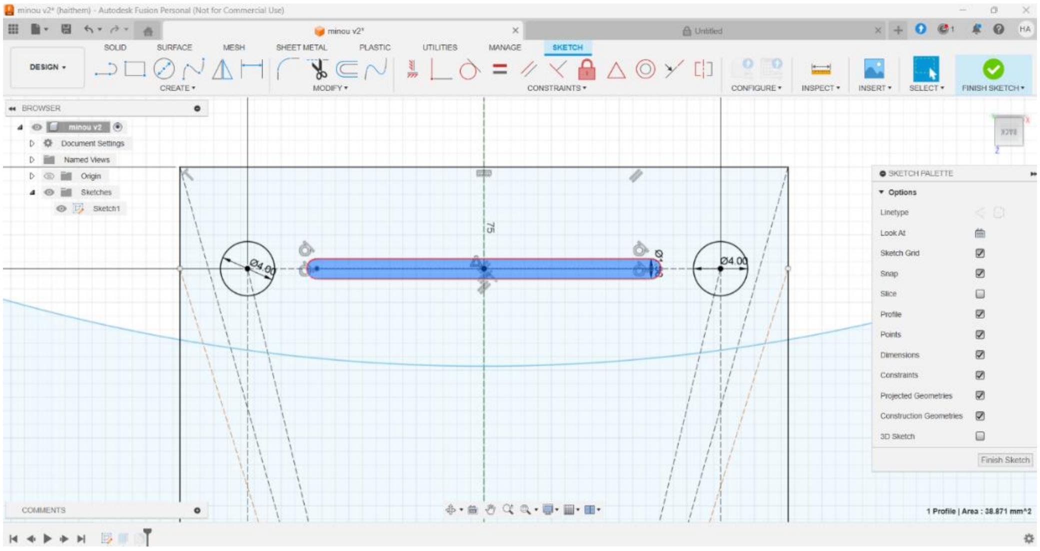


Figure (III.21). FPV camera bracket slot

- Step 2 : We add battery strap slots (2 mm × 30 mm).

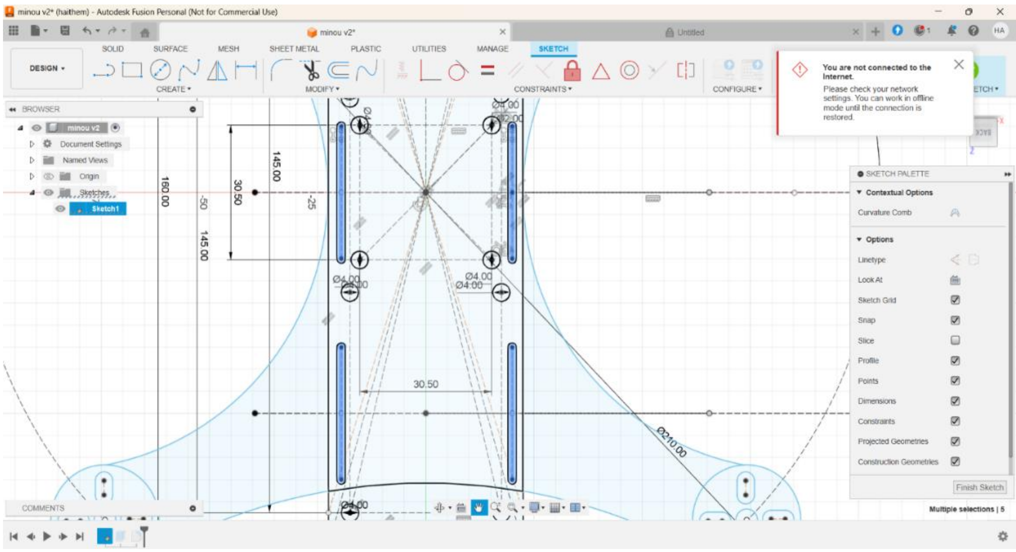


Figure (III.22). Battery strap slots

- Step 3 : Antenna hole (6 mm).

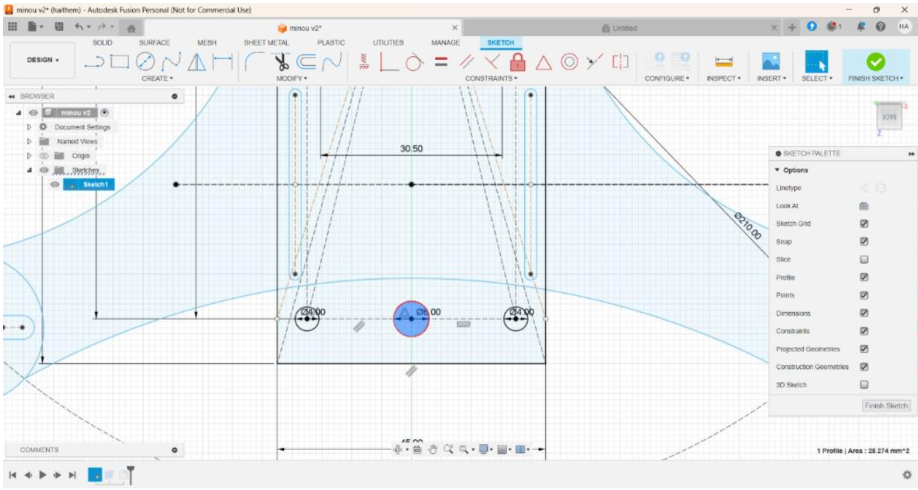


Figure (III.23). Antenna hole

- Step 4 : 25 mm × 25 mm cutouts (to reduce airframe mass).

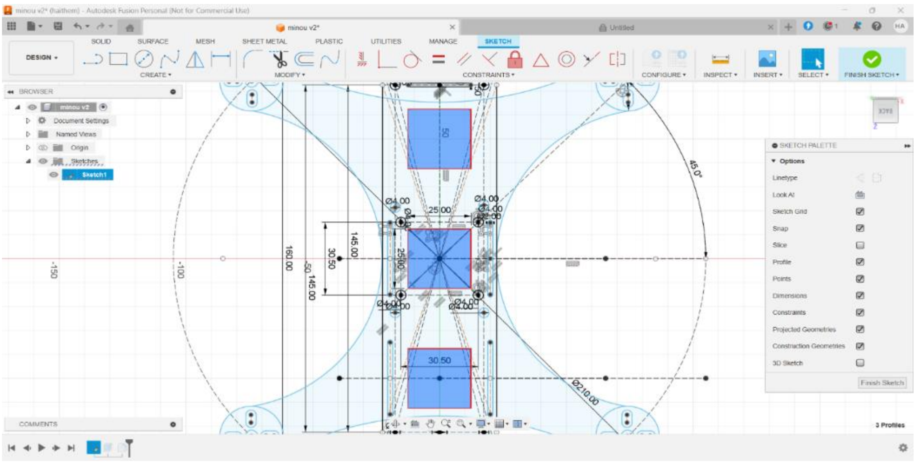


Figure (III.24). Cutouts

- Step 5 : we turn our sketch into 3D model.

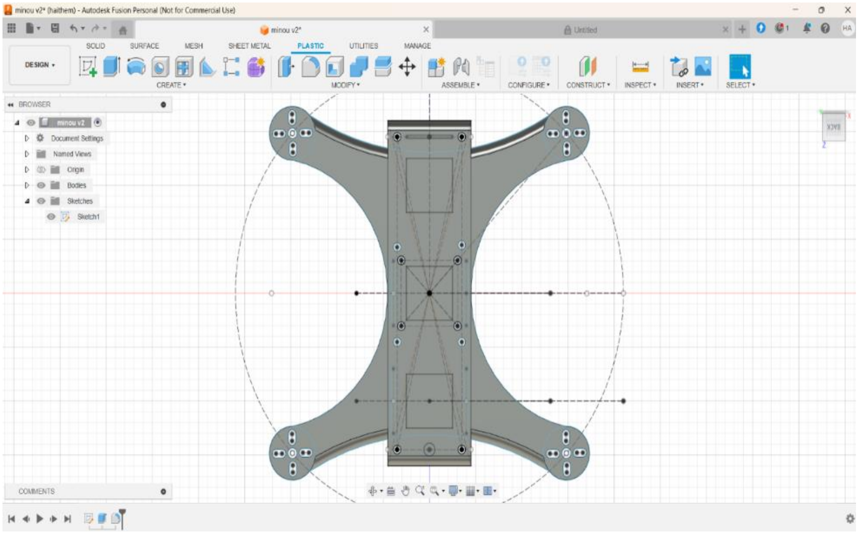


Figure (III.25). Top plane extruding

- Step 6 : we extrude the top plate to 1.5 mm and move it 25 mm above.

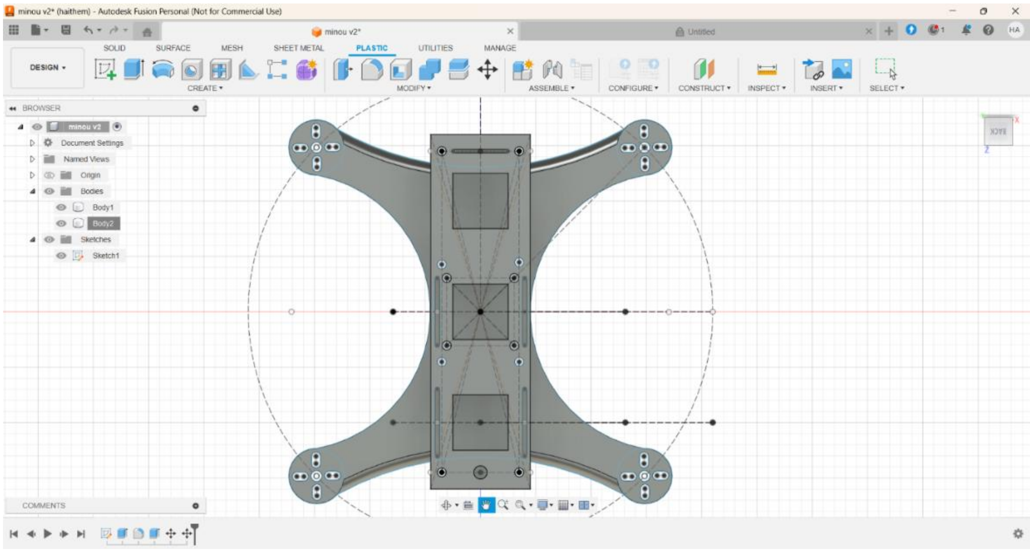


Figure (III.26). Top plane moving

A different angle of our bottom frame :

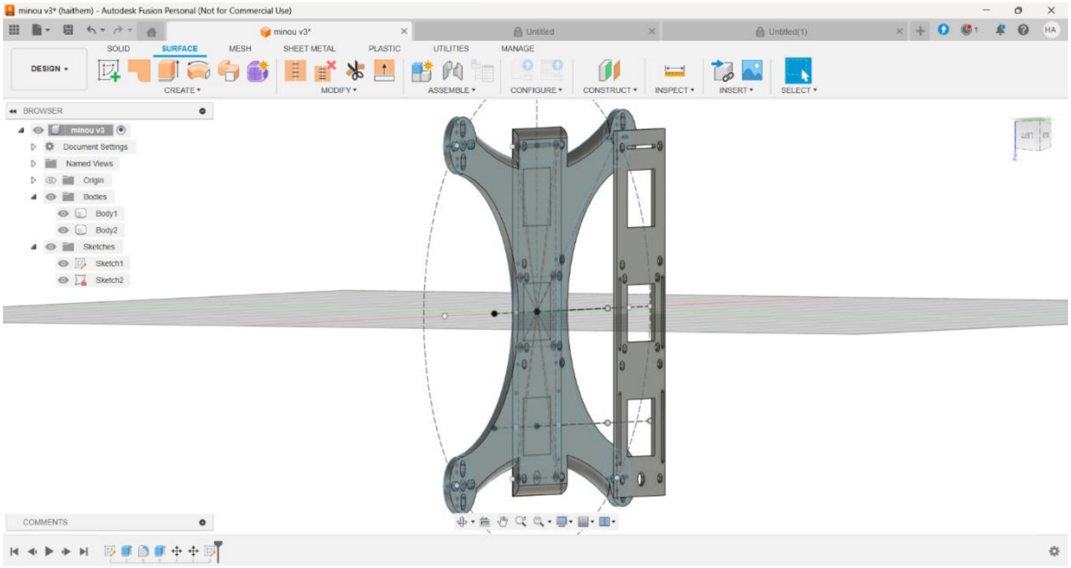


Figure (III.27). Drone's body different angles

III.8. FPV Camera Bracket Design:

- We sketch a 23 mm × 27 mm rectangle,
- We add a 16 mm center circle,
- We add small rectangles for camera arms,
- We extrude 1.5 mm,
- We move into bracket slot area.
- Step 1 : We sketch a 23 mm × 27 mm rectangle.

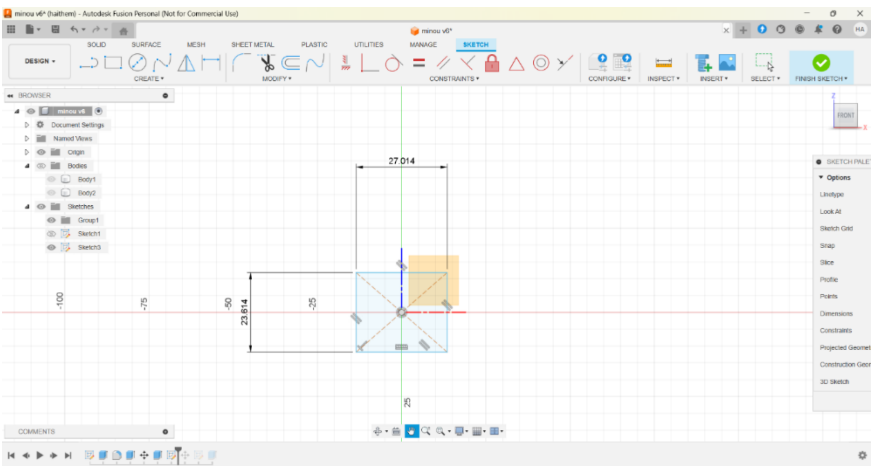


Figure (III.28). Adding a 23*27 mm rectangle

- Step 2 : We add a 16 mm center circle.

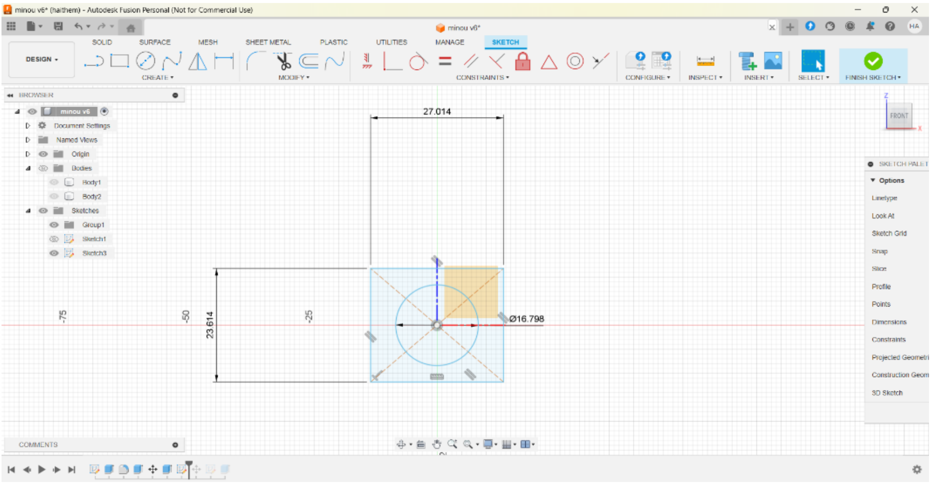


Figure (III.29). Centring the circle

- Step 3 : We add small rectangles for camera arms, then we extrude them by 1.5 mm,

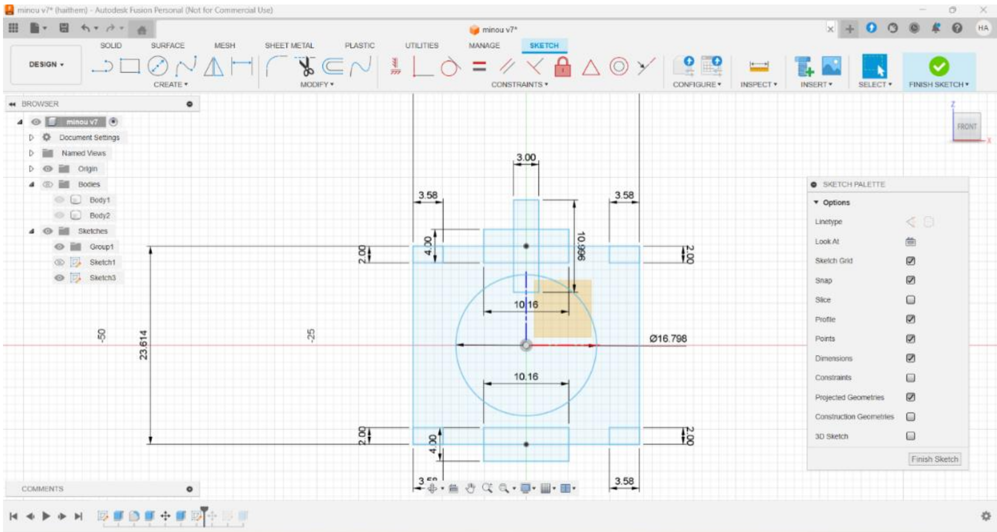


Figure (III.30). Add rectangles for camera arms

Now we have our camera bracket slot ready :

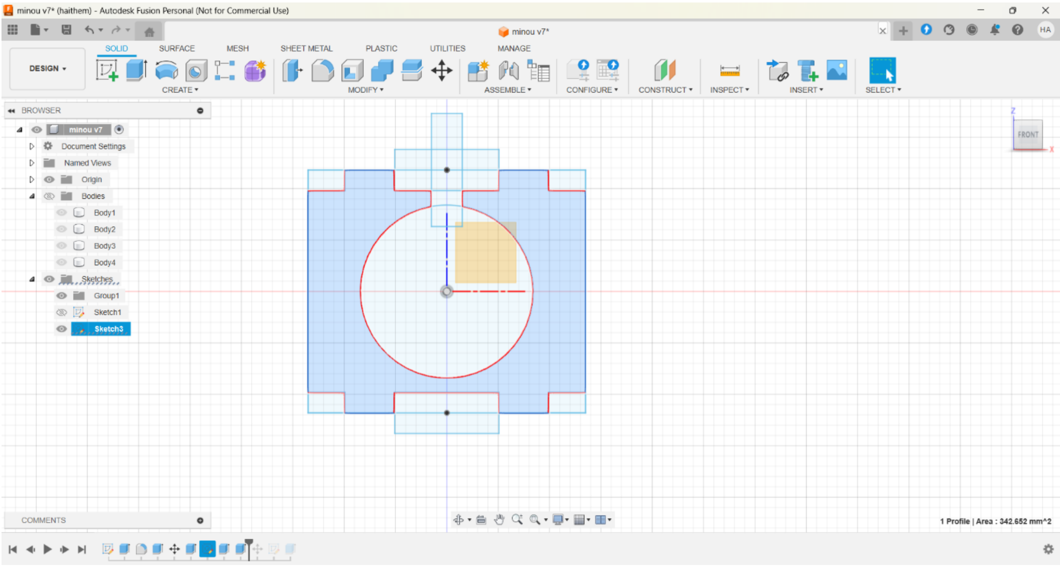


Figure (III.31). The Bracket slot

III.9. Assembling the plates:

- For the camera bracket we use the move tool and put it in its proper place
- We add screws:
    - We go to insert > Mcmaster-Carr component,
    - We select the type of screw we need,
    - We shoo the size, length, thread and head type,
    - We save it as 3d step file,
    - We download it,
    - Now we use the copy/move to make another screws/put them in its places [9].

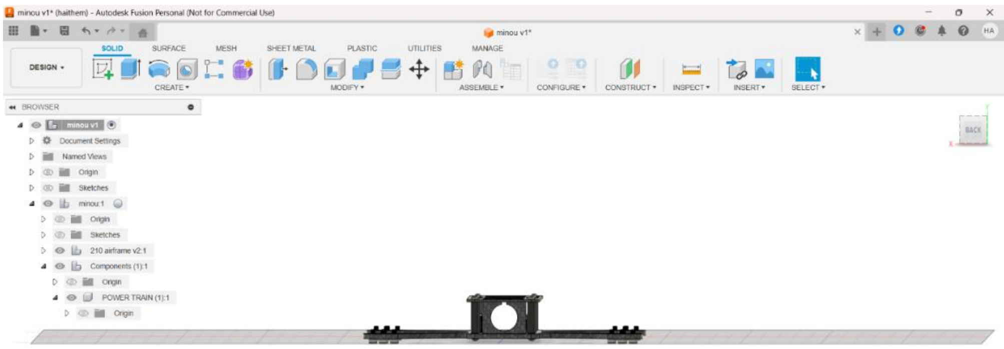


Figure (III.32). The Camera bracket slot

Final frame design :

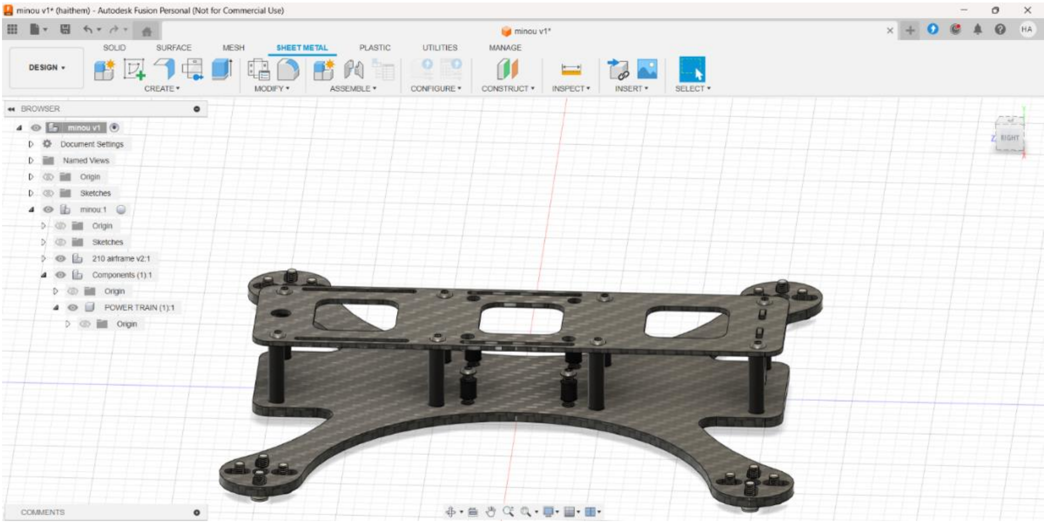


Figure (III.33). The Full Quadcopter frame

III.10. Propellers:

To design a basic drone propeller, we follow the following steps step by step:

- we click on start a new sketch,
- we choose the right plane,
- we draw a line of 7.5 mm and 45 degrees,
- we create a three-point arc slot at the edges of the line we drew,
- we adjust our slot using the dimension tool,
- we click on finish sketch,
- we go to construct and construct the offset plane from the right by 20 mm,
- now we create a sketch on the new plane,
- we draw a line of 15 mm and 20 degrees,
- now we use the dimension tool to adjust the new line based on the previous one to get the shape we want,
- we create a Centre to Centre slot of 5 mm,
- we click on finish sketch,
- we do another construction plane from the right plane by 80 mm,
- we draw a line of 6 mm,
- we adjust it using the dimension tool,

- we create a 0.1 mm Centre to Centre slot at the new line edges,
- we click on finish sketch,
- we use fit point spline tool to draw across the different planes,
- we use the loft tool to create a 3d solid ,
- we got our half blade,
- click on finish sketch ,
- we create a sketch on the top plane,
- we click on circle diamond circle,
- we draw a circle of 12.5 mm,
- we draw a 6 mm circle ,
- we extrude it to 6 mm up and 2 mm down (we got our motor mount),
- now we select the motor mount as origin + copy the half blade by 180 degrees,
- we use the project all to project our area inside the motor mount,
- we extrude the inside area to cut it and remove the inside objects,
- to modify the propeller area, we use the scale tool .

- step 1 : we choose the right plane.

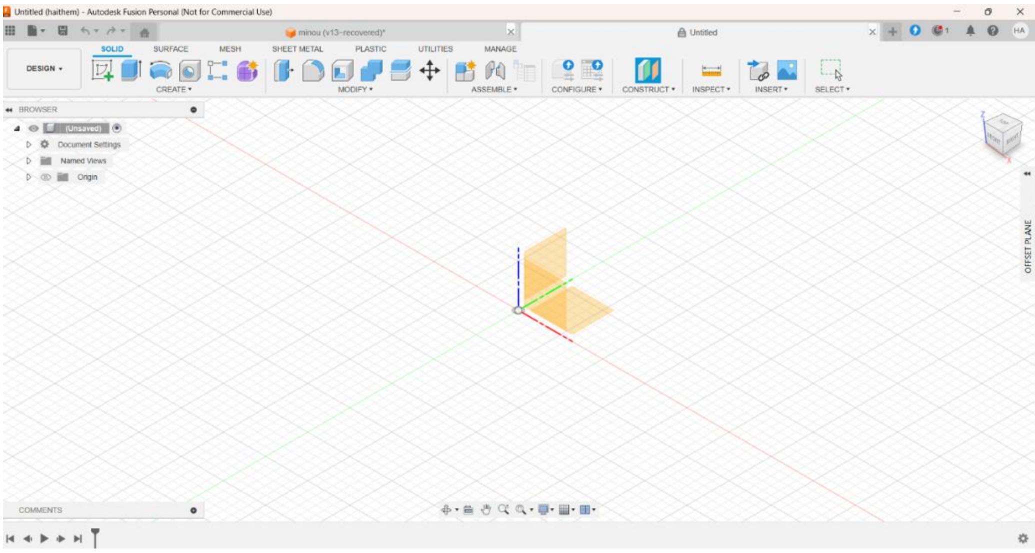


Figure (III.34). Start a sketch

- Step 2 : we draw a line of 7.5 mm and 45 degrees.

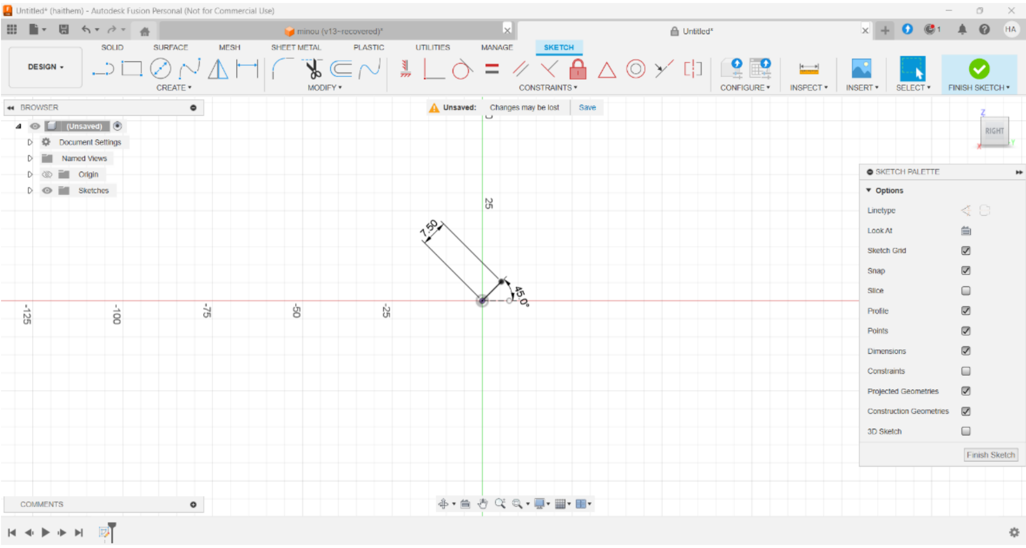


Figure (III.35). Draw a 7.5 mm line

- Step 3 : we create a three-point arc slot at the edges of the line we drew.

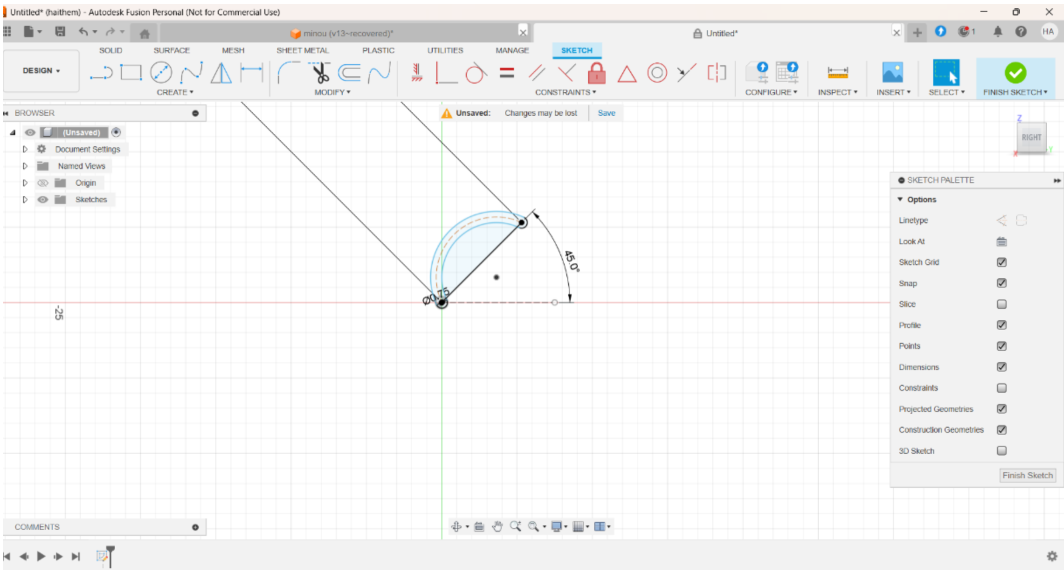


Figure (III.36). Create a slot

- Step 4 : we adjust the ling using the dimenssion tool

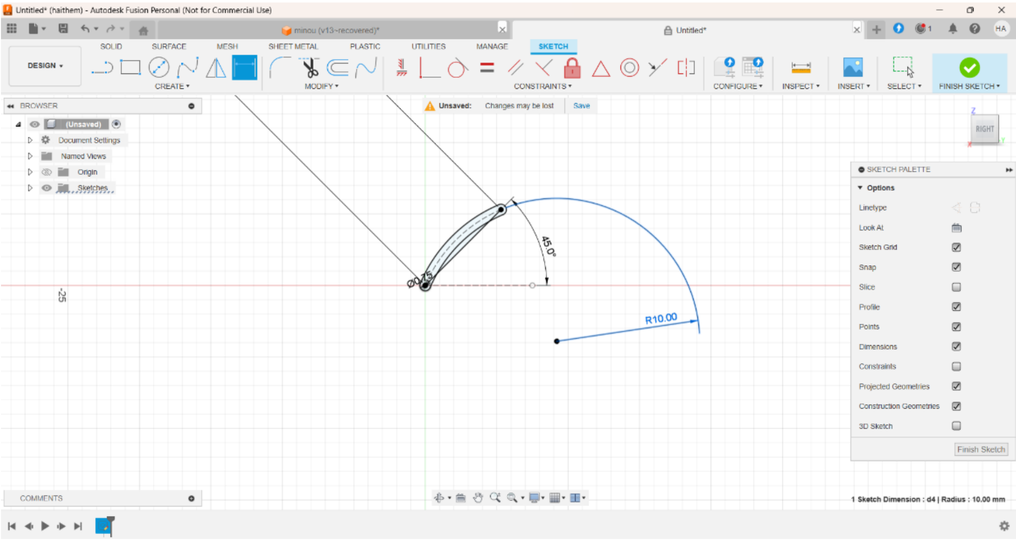


Figure (III.37). Adjust the line

A look at the normal origine planes.

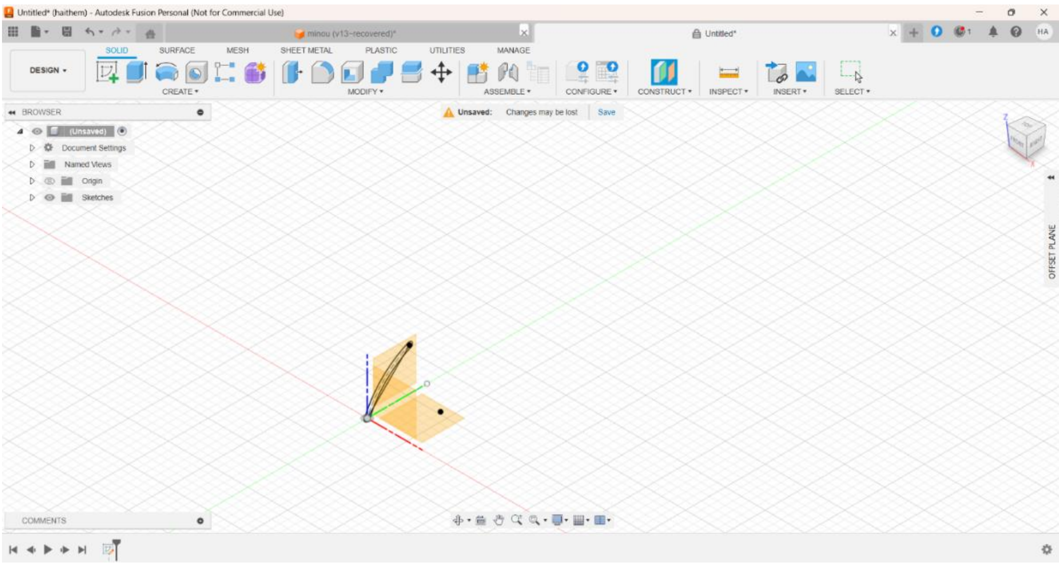


Figure (III.38). The origin planes

- Step 6 : we construct an offset plane by 80 mm.

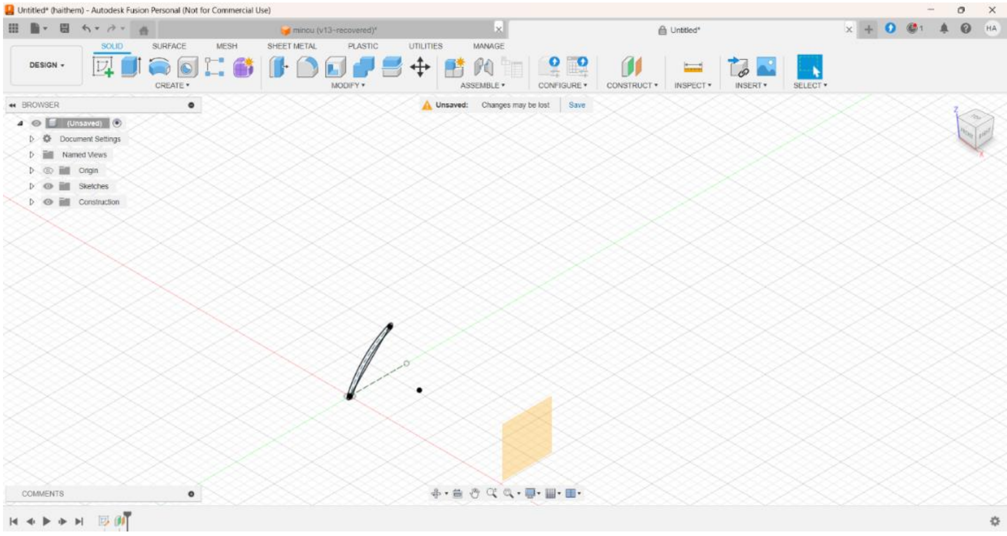


Figure (III.39). Construction of an offset plane

- Step 7 : we choose the new plan , then we draw a 15 mm line.

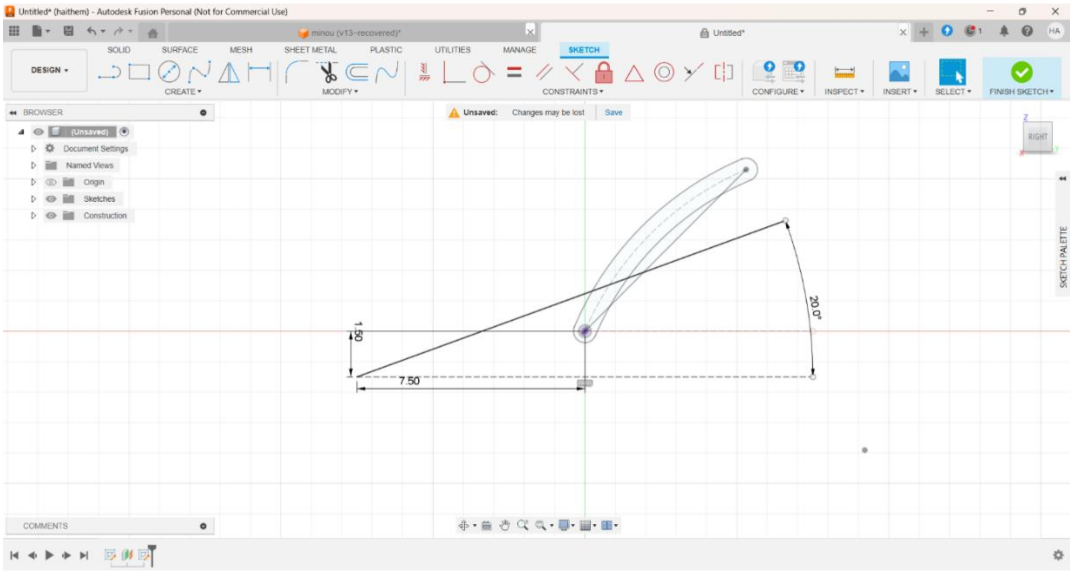


Figure (III.40). The 15 mm line

- Step 8 : We create a slot.

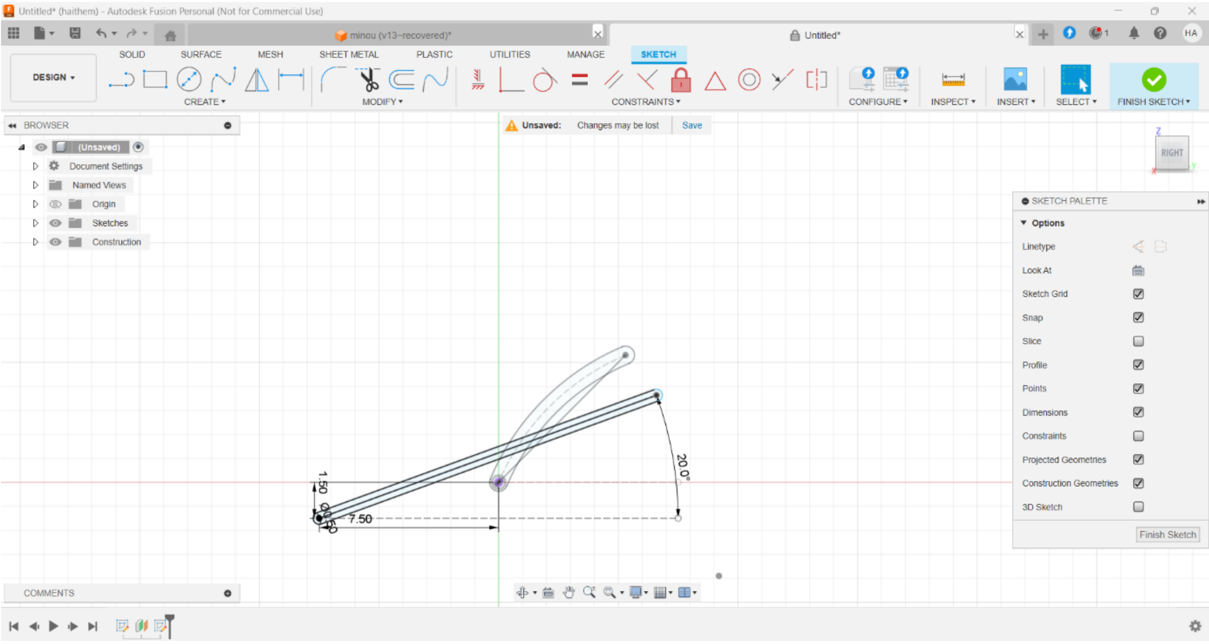


Figure (III.41). The slot creation

- Step 9 : Construct a 60 mm plane.

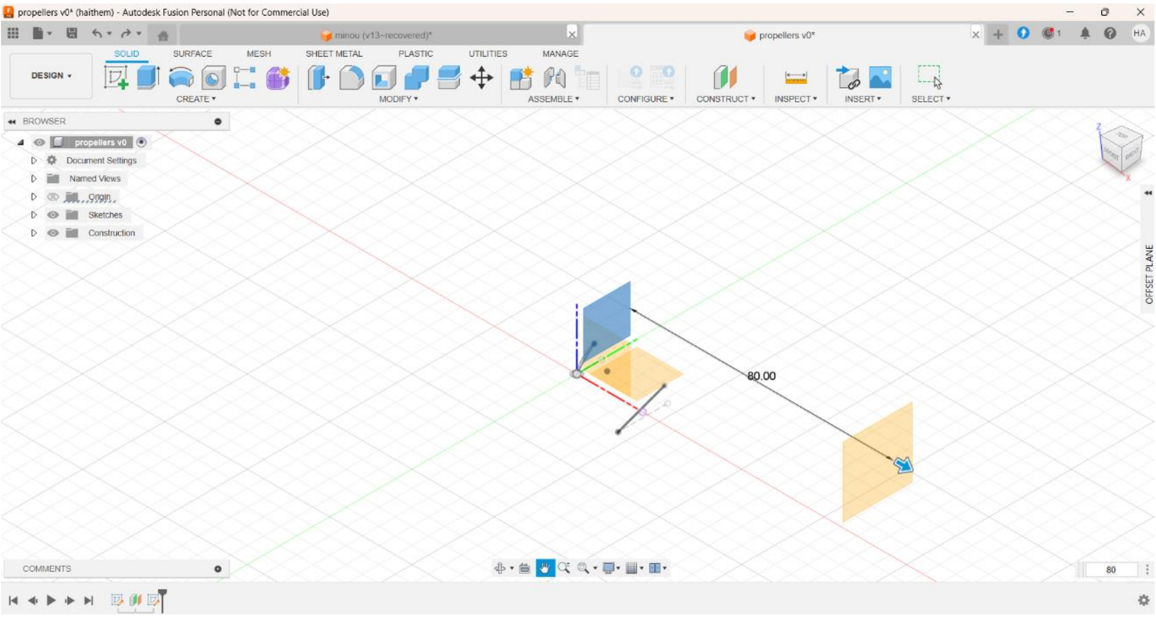


Figure (III.42). The offset plane construction

- Step 10 : On the new plan we draw a 6 mm line.

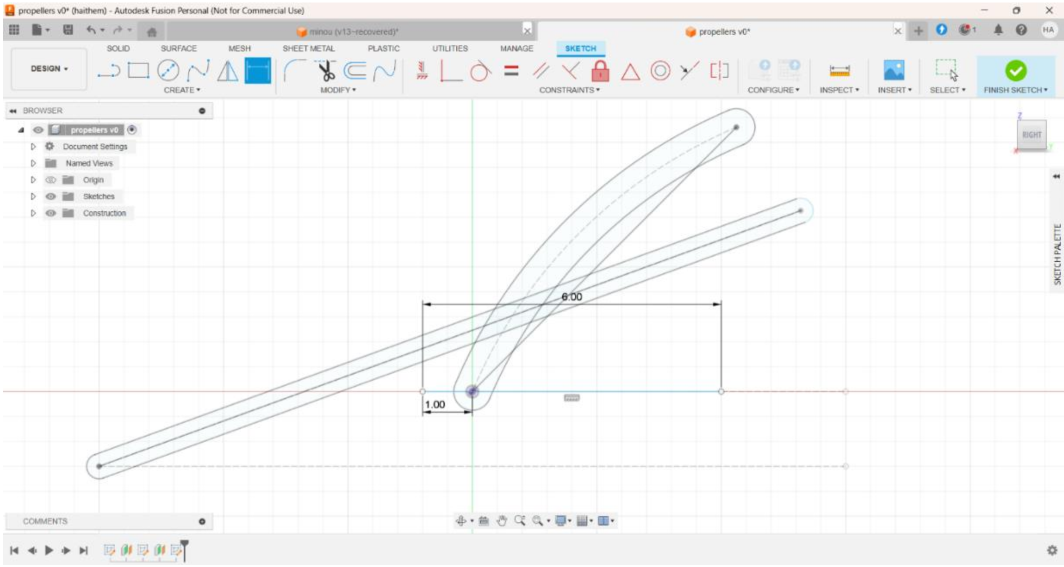


Figure (III.43). the 6 mm line drawing

- Step 11 : we creat a slot.

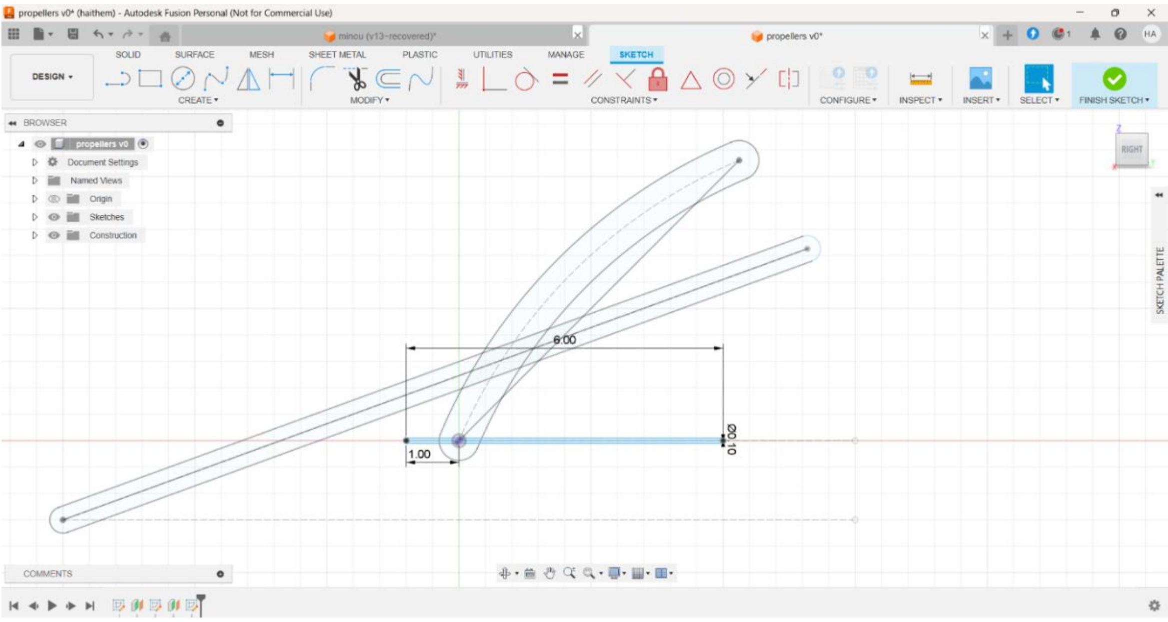


Figure (III.44): The slot creation

- Step 12 : we finish the sketch.

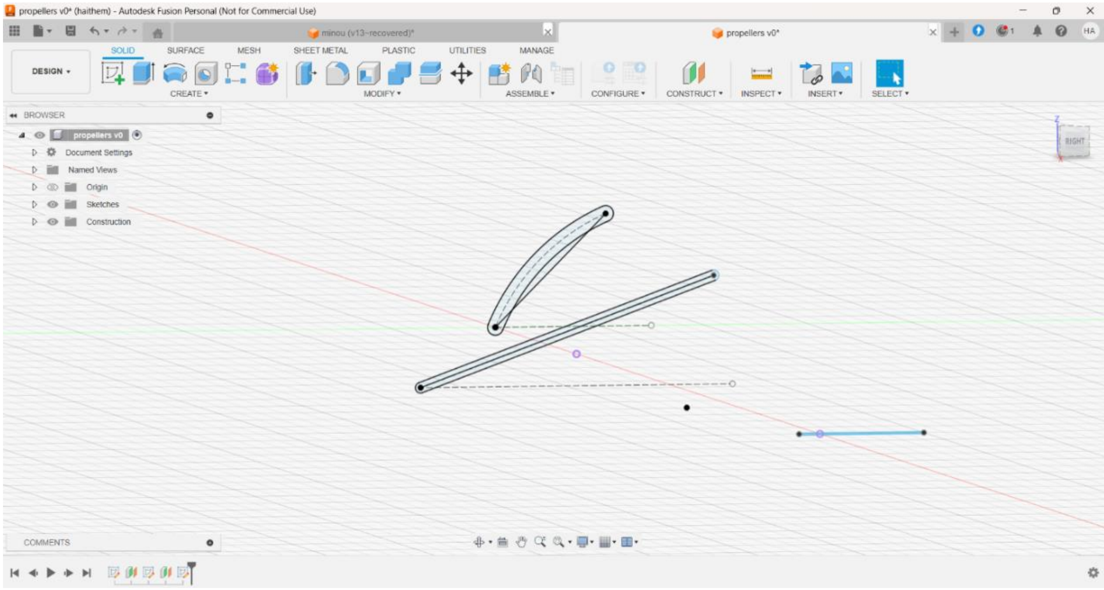


Figure (III.45). The sketch

- Step 13 : we connect the points.

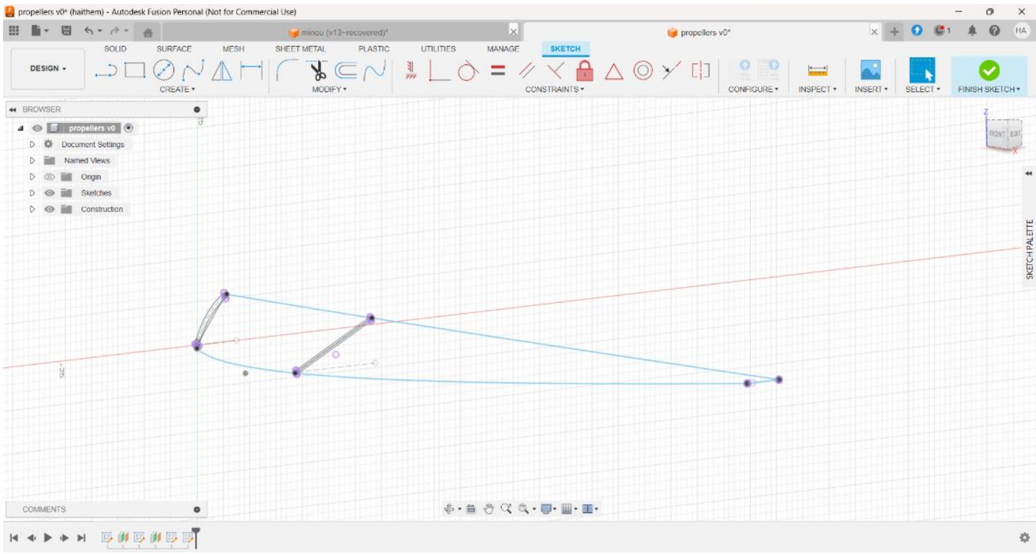


Figure (III.46). Connect fit points

- Step 14 : We turn our sketch in a 3D model.

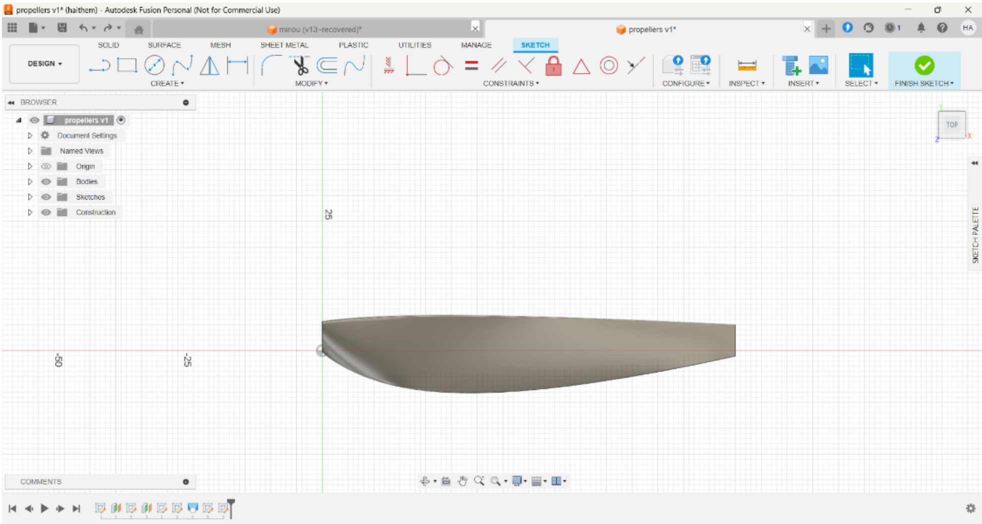


Figure (III.47). The half blade

- Step 15 : We create diamond circles .

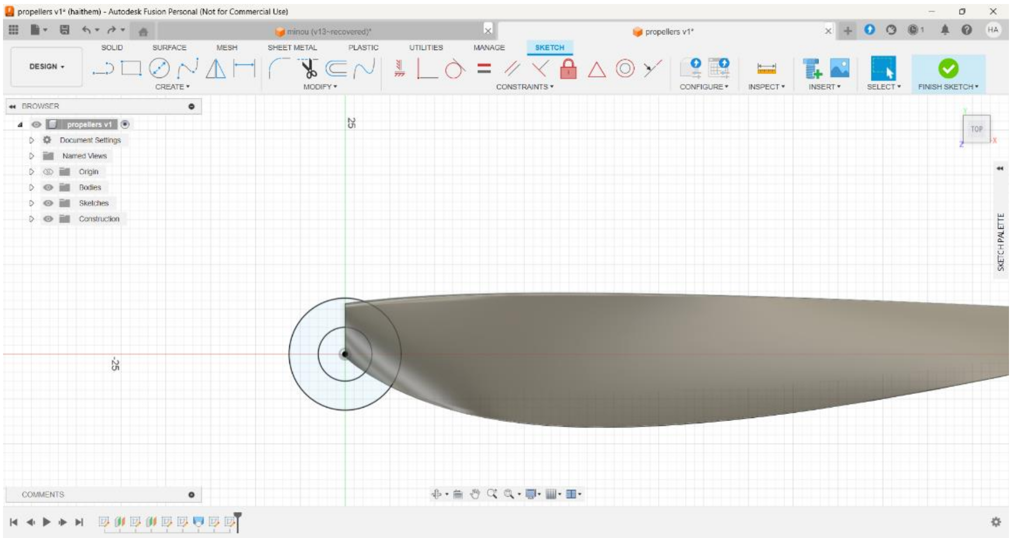


Figure (III.48). Diamond circles creation

- Step 16 : We turn our diamond circle into 3D model.

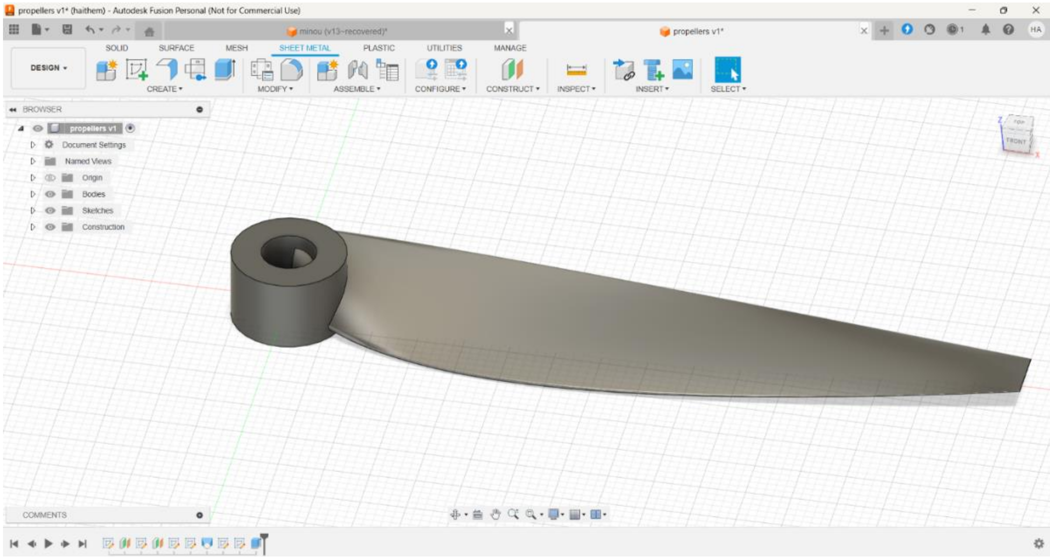


Figure (III.49). The motor mount

- Step 17 : we use the copy/move layout to copy the half blade.

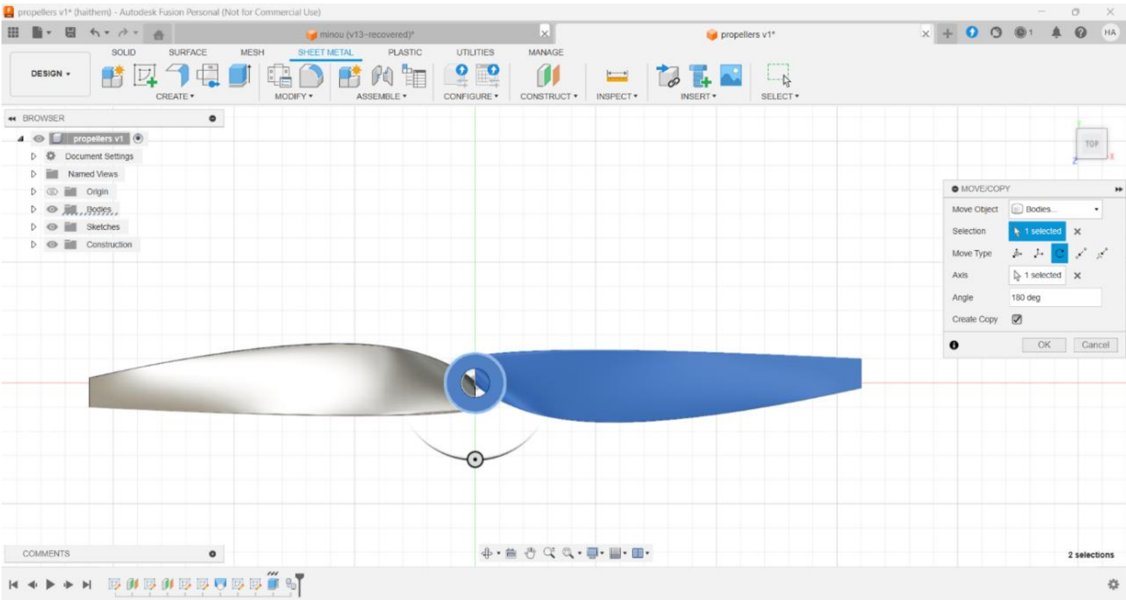


Figure (III.50). The half blade copy

- Step 18 : We select the inside object to cut them off.

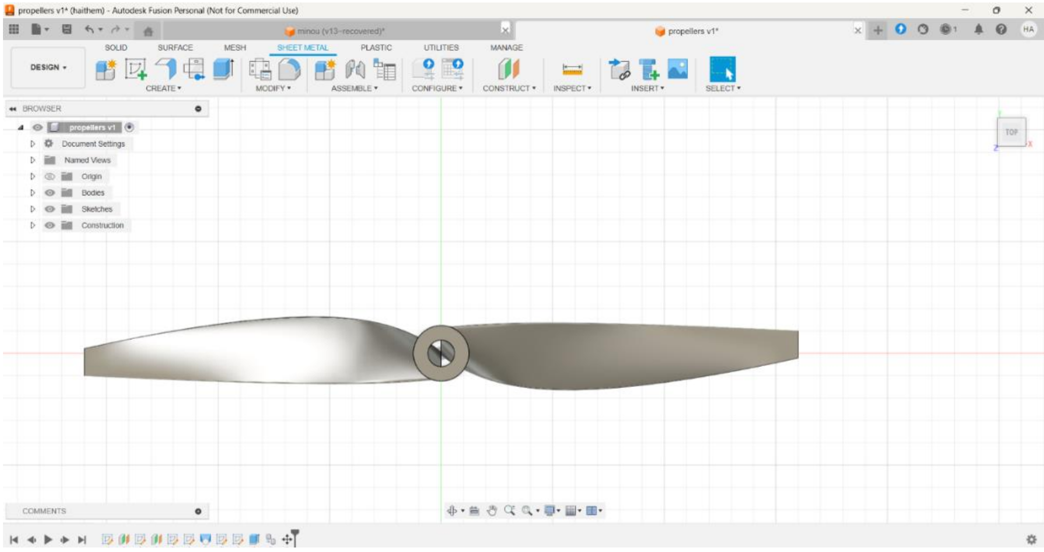


Figure (III.51). The inside object cutting

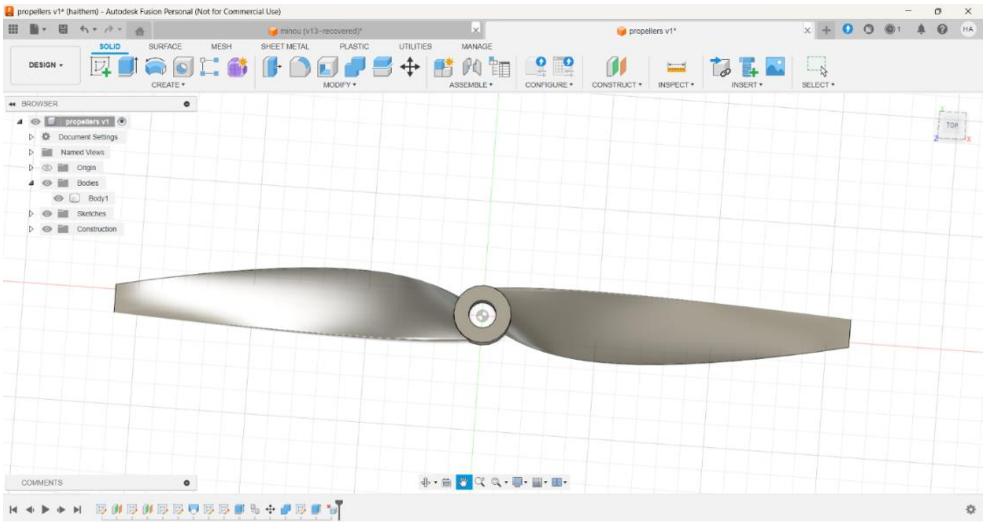


Figure (III.52). The full Propeller

III.11. Material Selection for 3D Printing:

Choosing the appropriate material for 3D printing is essential to ensure the drone frame meets performance and durability requirements. For this project, PLA (Polylactic Acid) was selected due to its ease of use, dimensional accuracy, and sufficient strength for prototyping applications. PLA is a biodegradable thermoplastic derived from renewable

resources like corn starch. It offers good tensile strength and stiffness, making it a suitable material for producing drone frames where high loads are not expected during flight. Additionally, PLA is less prone to warping during printing, ensuring accurate builds for interlocking
parts and assembly components such as motor mounts and camera brackets. While materials such as ABS and PETG offer improved impact resistance and thermal tolerance, they typically require higher print temperatures and heated enclosures, which were not available during this project. Since the initial goal of the drone is prototyping and educational use, rather than high-performance outdoor flight, PLA was determined to be the most practical and accessible choice.
Future iterations may explore alternative materials like carbon-fiber-reinforced nylon or PETG for increased durability and resistance to mechanical stress in demanding environments [8].

III.12.Final Airframe Assembly:

- Organize all bodies.
- Export each body using **Make** > **3D Print** tool as STL files.

III.13. Conclusion:

In conclusion, the conception and design phase of the drone project has provided a strong foundation for the technical and functional realization of our prototype. Using Autodesk Fusion 360, each mechanical component was carefully modeled with precise dimensions to ensure compatibility and structural integrity. The design process involved critical considerations such as motor alignment, propeller clearance, center of gravity, and frame weight distribution. Additionally, attention was paid to printability and real-world constraints to ensure the design could be physically realized using 3D printing technologies. This chapter represents a significant step toward a fully functional aerial platform, paving the way for further integration, simulation, and physical testing in the following phases.

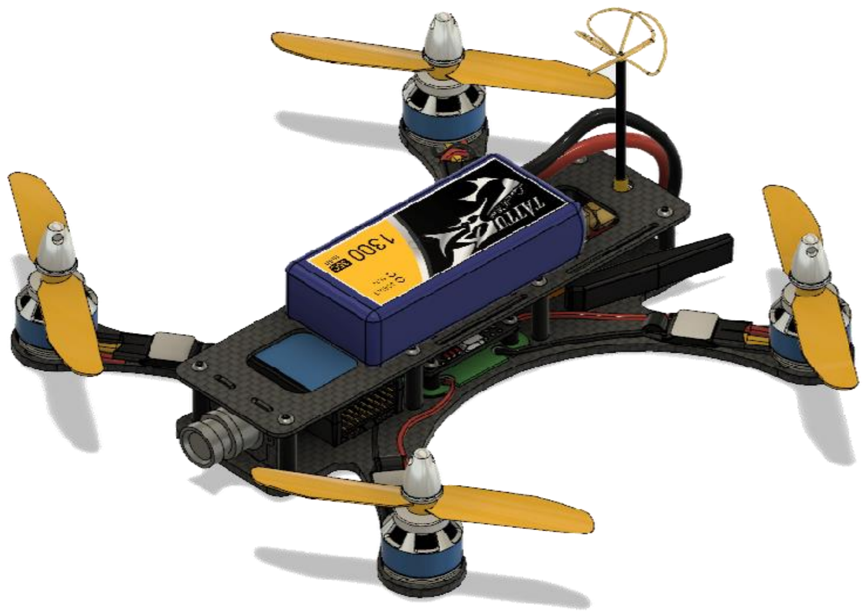
Chapter 4: Aerodynamic Simulation

IV.1. Introduction:

The purpose of this chapter is to evaluate the aerodynamic behavior of the designed drone using Autodesk Flow Design. Wind tunnel simulation helps visualize airflow patterns, identify turbulence zones, and guide iterative refinements for optimal flight efficiency. This simulation focuses on the assembled quadcopter airframe without internal electronics, prioritizing geometry-based aerodynamic performance.

IV.2. Model Preparation for Simulation:

The assembled 3D model, exported from Fusion 360 as an STL file, must be pre-processed to ensure it is watertight and free of unnecessary features that could interfere with simulation results. Screws and small non-aerodynamic components were hidden prior to export to simplify meshing and reduce noise in the simulation.



Figur(IV.1). Assembled 3D Quadcopter model

IV.3. Import and Setup in Autodesk Flow Design:

Autodesk Flow Design allows for real-time wind tunnel simulation using simplified boundary conditions and airflow visualization **[8]**.

After launching Flow Design, the drone model is imported and oriented properly using:

- **Z-Axis**: set to 90°
- **Y-Axis**: set to 90°

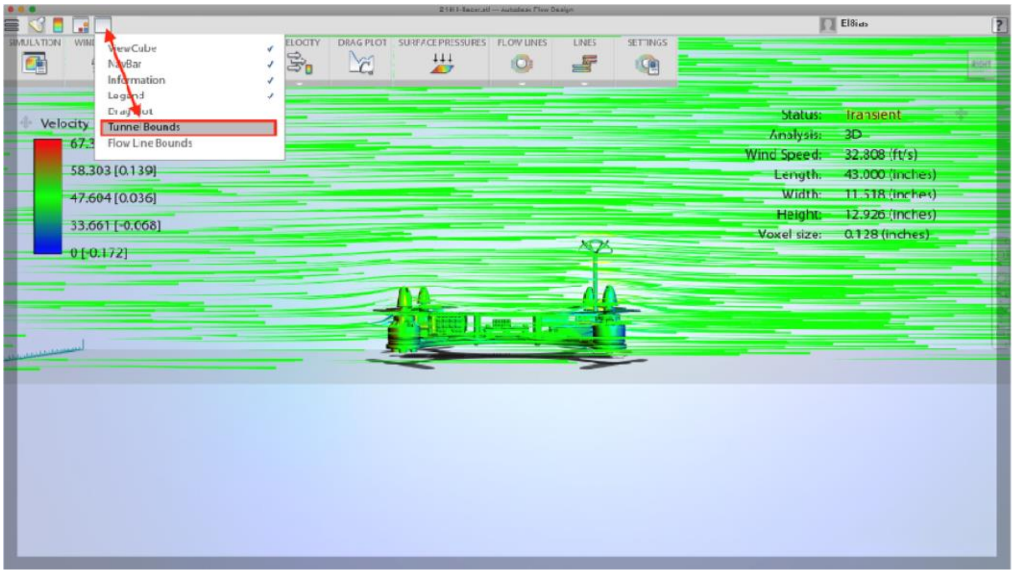


Figure (IV.2). Tunnel bound

This ensures the drone faces forward, simulating real flight posture.

IV.4. Configuring Wind Tunnel Parameters:

After importing the model, a bounding tunnel box is generated to define the airflow space. Adjustments include:

- Enlarging the bounding box to extend beyond the drone
- Lowering the bounding floor to simulate elevated flight
- Simulation accuracy improves when flow lines and cross-sections are clearly visualized. Activating **Dark Mode** enhances contrast and makes velocity lines easier to interpret.

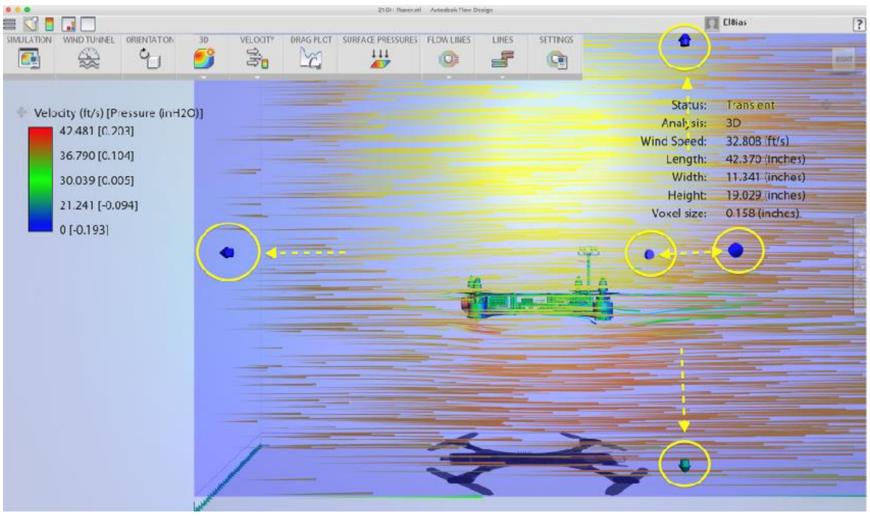


Figure (IV.3). Velocity streamlines and pressure Distribution

IV.5. Viewing and Interpreting Flow Results:

IV.5.1. Airflow Lines:

Flow Design immediately simulates airflow upon model load. In the horizontal flight configuration, streamlines indicate the velocity field around the drone. High turbulence is often observed behind the motor arms.

IV.5.2. Forward Tilt Configuration:

A second simulation was performed with the drone tilted forward by 30° to mimic real flight posture during forward movement. This exposes additional turbulence near the arm joints.

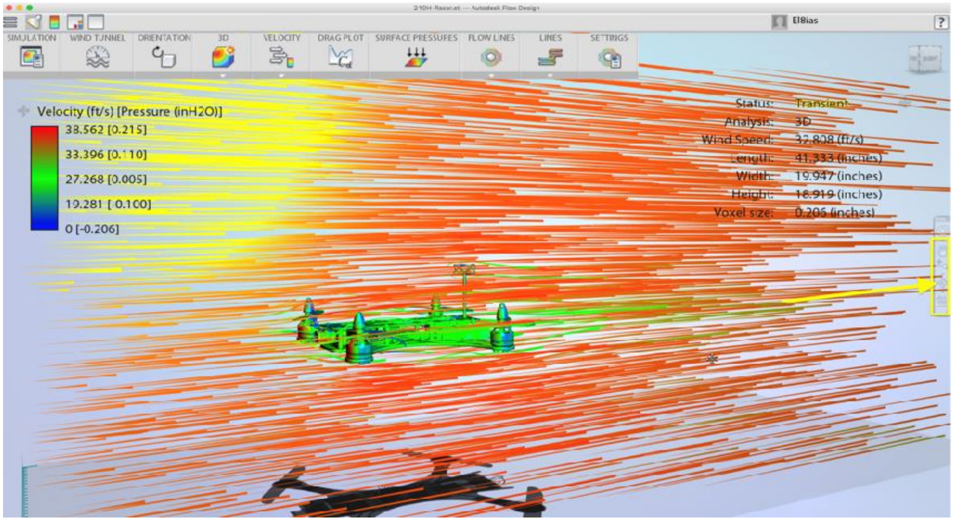


Figure (IV.4). Rear perspective of streamline velocity

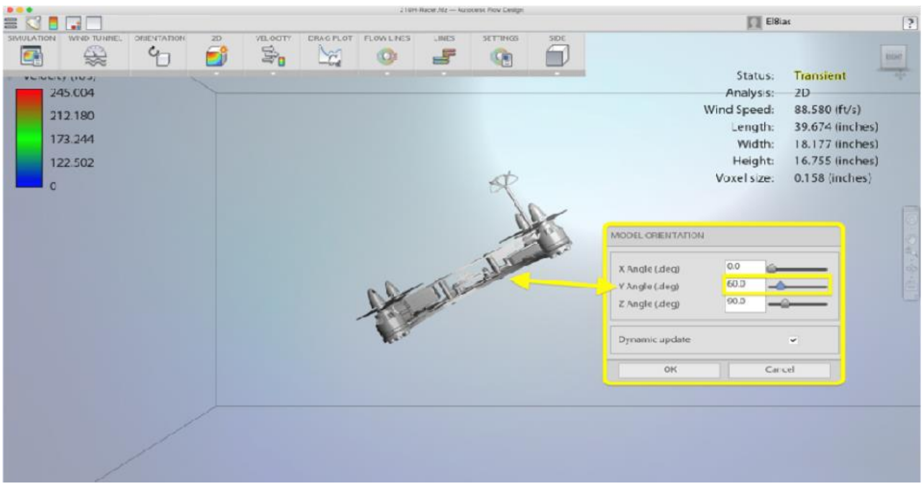


Figure (IV.5). Forward tilt configuration

IV.6.2 D Plane Analysis:

Flow Design includes a feature to slice the airflow view using a 2D vertical plane. This plane is moved to pass directly through the drone's center, allowing clear observation of lift and drag forces as well as pressure gradients [9].

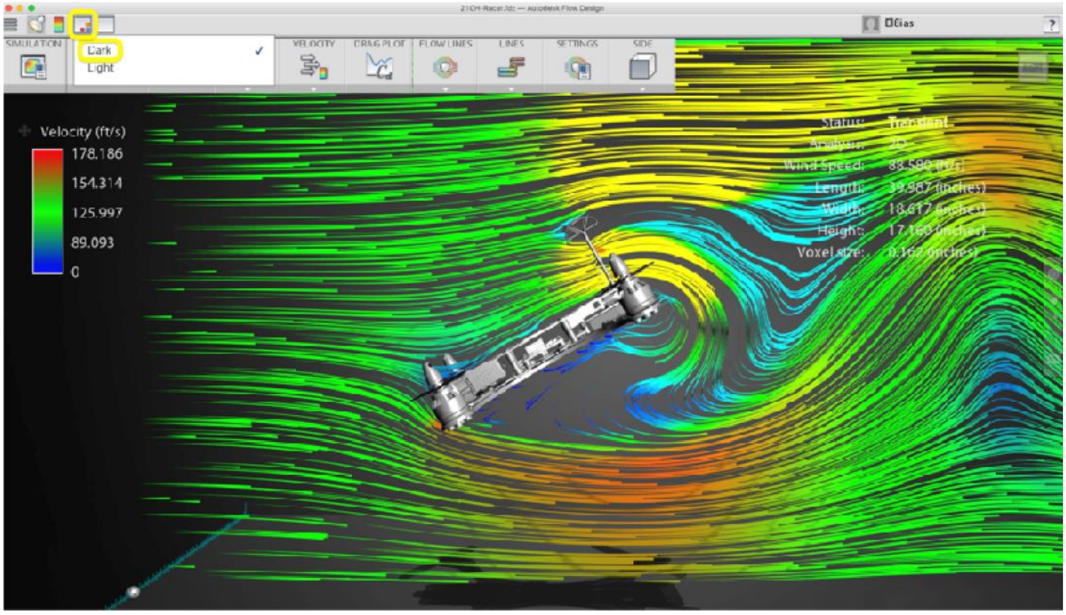


Figure (IV.6). Wind tunnel simulation

IV.7. Conclusion:

In this chapter, we have presented a comprehensive study on the design and aerodynamic evaluation of a quadcopter drone, combining modern 3D design techniques with fluid dynamics simulation. Through the use of Autodesk Fusion 360, a lightweight and modular drone frame was successfully modeled with attention to structural stability, manufacturability, and integration of standard UAV components. The design process emphasized parametric control, which allowed for rapid modifications and adaptation to prototyping constraints. Simulate airflow behavior around the drone structure, offering insights into the aerodynamic efficiency of the frame. This step is crucial for understanding how design choices, such as edge geometry, component placement, and surface area, impact performance factors such as drag and lift. Though primarily focused on educational and prototyping applications, the simulation phase lays the groundwork for future iterations involving advanced materials and flight controllers.

GENERAL CONCLUSION

This master thesis has presented a comprehensive study on the modeling, the design and the aerodynamic evaluation of a quadcopter drone, combining modern 3D design techniques with fluid dynamics simulation. Through the use of Autodesk Fusion 360, a lightweight and modular drone frame was successfully modeled with attention to structural stability, manufacturability, and integration of standard UAV components. The design process emphasized parametric control, which allowed for rapid modifications and adaptation to prototyping constraints.

The simulation of airflow behavior around the drone structure has offered insights into the aerodynamic efficiency of the frame. This step was crucial for understanding how design choices, such as edge geometry, component placement, and surface area, impact performance factors like drag and lift.

The results of this project demonstrate the effectiveness of integrating design and simulation in early-stage UAV development. It reduces development time, minimizes prototyping costs, and improves the performance of the final product.

This project highlights the synergy between computer-aided design and engineering analysis in the evolving field of drone technology.

Future work may include the incorporation of flight stabilization algorithms, field testing, and exploration of alternative materials like PETG or carbon-fiber composites for improved durability and flight performance.

Bibliography

[1]. *Austin, R. (2010). Unmanned Aircraft Systems: UAVS Design, Development and Deployment*. Wiley.

[2]. *J. Valavanis & G. Vachtsevanos (2015). Handbook of Unmanned Aerial Vehicles. Springer.*

[3]. Floreano, D., & Wood, R. J. (2015). Science, technology and the future of small autonomous drones. Nature, 521(7553), 460–466.

[4]. Tymrak, B. M., Kreiger, M., & Pearce, J. M. (2014). Mechanical properties of components fabricated with open-source 3-D printers under realistic environmental conditions. Materials & Design, 58, 242-246.

[5]. DeLia, E., Stein, T., Heventhal, B., Sohi, P., & Wake Field, M. (2016). *Racing-Drone Design Fundamentals with Fusion 360*. Autodesk University

Website links :

[6]. History of unmanned aerial vehicles - Wikipedia

[7]. All Components of a Drone: A Detailed Guide - Drone Universities

[8]. Autodesk. (n.d.). *Fusion 360: Integrated CAD, CAM, CAE & PCB Software Platform*. Retrieved from https://www.autodesk.com/products/fusion-360

[9]. Autodesk. (2023). *Fusion 360 Overview*. Retrieved from https://www.autodesk.com/products/fusion-360