MECH-8290-90 Computer-Aided Design (CAD)

Final Project Report

Design and Assembly of Hexacopter

Submitted by:

Group No. : 06

Name	Student ID
Sachin Jagdishkumar Kadia	110069256
Dipen Kavathiya	110072160
Rushabh Patel	110060917
Mohammed Adeel Ahmed	110078181
Kishan kumar Ghetiya	110069312

Submitted to:

Ahmed Azab, Ph.D., Peng

Date: December 12, 2022

Abstract:

Since robotic unmanned vehicles are being researched and developed more, new uses for these products and technology are emerging, and drones have been at the core of all of this. Drone technology has been used for anything from school projects and wedding photography to arial surveillance, farming, military applications. To execute the application easily and effectively along with the multifunction use, the focus is now on improving its design, capacity, and efficiency.
Various drone models have been created and built with certain functions, but the goal of this project is to create a drone that can be used for multiple functions more effectively and easily with the significant modifications in design.

All drones are developed with the applications, considering a number of aspects such payload capacity, battery, size, weight, and, last but not least, cost. We are modifying the design of drone components and introducing the new component while using general-purpose quad copter drone as a reference to make it more effective and versatile.
This study suggests upgrading the design of the quadcopter into a hexa-copter drone using computer-aided design techniques. The recommended proposals were modelled in 3D using Siemens NX software. The weight carrying capability increases as the dimensions are increased, enabling the drone to be used as a delivery drone. Additionally, we are redesigning the top plate and base plate to coordinate future advancements with applications. Furthermore, it may be utilized as a surveillance drone with the appropriate camera adjustments, preventing industrial accidents and preserving the security of the industry's workers and assets.

Siemens NX software was used to design the components of this hexa-copter before all the improvements were included. The camera stand and camera are then installed, taking into account the top plate and base plate measurements.
Using the same software, the final assembly was created by first creating the sub-assemblies, and then the final assembly of all the parts.

Table of Contents

List of Figures ... 3
List of Tables ... 5
1. Introduction ... 7
1.1 Overview ... 7
1.2 The Goals and Purpose of the Research ... 8
2. Literature review ... 9
3. Methodology and Principles ... 10
3.1 Working principle ... 10
3.2 Mathematical modelling ... 11
3.3 Design Methodology ... 19
4. Design and Modifications of Components ... 21
4.1 CAD Modelling of Components ... 23
4.1.1 Spider base ... 23
4.1.2 Spider top ... 23
4.1.3 Spider arm ... 24
4.1.4 Battery ... 24
4.1.5 Spinner ... 24
4.1.6 Spacer ... 25
4.1.7 Electric connector ... 25
4.1.8 Pillar ... 25
4.1.9 Fan ... 26
4.1.10 Motor ... 26
4.1.11 Distribution board ... 26
4.1.12 Electrical units 1 ... 27
4.1.13 Electrical unit 2 ... 27
4.1.14 Screw M6 ... 27
4.1.15 Screw arm ... 28
4.1.16 Bolt arm ... 28
4.1.17 Nut fan ... 28
4.1.18 Camera stand ... 29
4.1.19 Camera Screw ... 29

4.1.20 Camera screw pin ... 29
4.1.21 Camera lens ... 30
4.1.22 Baseplate arm nut ... 30
4.1.23 Camera ... 30
4.2 Subassembly of components ... 31
4.2.1 Arm subassembly ... 31
4.2.2 Electric board subassembly ... 31
5. Final assembly of the hexacopter ... 32
5.1 Exploded view ... 33
5.2 Exploded view with B.O.M ... 34
6. Drafting ... 35
7. CAM Modelling ... 37
8. Finite Element Analysis ... 38
8.1 Spider arm Analysis ... 38
8.2 Spider Base plate analysis ... 39
8.3 Camera stand analysis ... 40
9. CFD Analysis ... 42
10. Results ... 43
11. Future Scope: ... 43
12. Conclusion ... 44
13. References ... 45

List of Figures

Figure 1. Surveillance uav 7
figure 2. Videography drone 7
figure 3. Demand of drones: past, present, and future 8
figure 4. Forces acting on drones 10
figure 6. Block diagram of drone system 10
figure 7. Block diagram of drone system 12
figure 8. Geometry of hexacopter 16
figure 9. Rolling motion 16
figure 10. Pitching motion 17
figure 11. Yawing motion 17
figure 12. Top-down design methodology 20
figure 13. Product design considerations 20
figure 14. Components of drones 21
figure 15. Reference product 22
figure 16. Spider base 23
figure 17. Spider top 23
figure 18. Spider arm 24
figure 19. Battery 24
figure 20. Spinner 24
figure 21. Spacer 25
figure 22. Electric connector 25
figure 23. Pillar 25
figure 24. Fan 26
figure 25. Motor 26
figure 26. Distribution board 26
figure 27. Electrical unit 1 27
figure 28. Electrical unit 2 27
figure 29. Screw m6 27
figure 30. Screw arm 28
figure 31. Bolt arm 28
figure 32. Nut fan 28
figure 33. Camera stand 29
figure 34. Camera screw 29
figure 35. Camera screw pin 29
figure 36. Camera lens 30
figure 37. Baseplate arm nut 30
figure 38. Camera 30
figure 39. Arm subassembly 31
figure 40. Electric board subassembly 31
figure 41. Final assembly of hexacopter 32
figure 42. Exploded view of final assembly of hexacopter 33
figure 43. Exploded view with b.o.m 34
figure 44. Drafting sheet of electric board subassembly 35
figure 45. Drafting sheet of final assembly 36
figure 46. Spider arm displacement analysis 38

figure 47. Spider arm stress analysis.. 39
figure 48. Spider base plate displacement analysis.. 39
figure 49. Spider base plate stress analysis... 40
figure 50. Camera stand displacement analysis 40
figure 51. Camera stand stress analysis 41
figure 52. Propeller cfd analysis 42
figure 53. Propeller cfd analysis 42

List of Tables

Table 1. Components and their function..21
Table 2. Bill of material of hexacopter 34

Acknowledgements:

First and foremost, we would like to express our gratitude to Prof. Azab Ismail Ahmed and Graduate Assistant Syeda Marzia for his help in choosing the project. Under his guidance, we learned a lot about design software, which improved our comprehension of the scope of creating in mechanical engineering. In this group project, every team member worked effectively and efficiently, giving the project their complete attention and all of their creative suggestions. Therefore, we would want to thank one another for their ongoing work in our various fields of concern. Our staff has done a great job of creating uniformly dispersed pieces and components as well as writing and editing the necessary papers, such preparing reports and presentations. Everyone's design and sketching abilities have increased as an outcome of this cooperative effort, and they have all enjoyed learning new things.

1. Introduction

1.1 Overview

Since the science and technology is evolving at a tremendous space, the mobility of the products has become a great consideration. According to recent studies, interest in electrically driven unmanned aerial vehicles has risen dramatically over the past several years in both the aerospace engineering industry and academia. The enhancement of drones or UAVs (Unarmed Aerial Vehicles) is the primary topic of discussion everywhere from school projects to military organizations. Drones' capability to fly, carry an object, and be programmed to do a wide range of tasks has made this technology extremely beneficial in many different ways. Drones are helpful to people, industries, and government agencies. The use of drone technology has benefited a wide range of sectors. Social media promotes them for travel vloggers, the military wants them for contemporary defense and armament, and even the food sector is joining in to make meal delivery quicker and easier. Many professionals are finding it simpler to complete difficult jobs that are much better done with a drone, thanks to drone technology.

Figure 1. Surveillance UAV [1]

Figure 2. Videography drone [2]

Besides, considering the booming demand all over the world, the drone as a product can be a market taker for the industries who are designing and manufacturing the special purpose drone. According to states of Blue Wave consulting , the Asia-Pacific commercial drone market is anticipated to overtake all other markets worldwide. Possible runner-up would be North America. The value of the commercial drone market worldwide might reach 58.4 billion dollars in 2026. The market is anticipated to develop at a compound annual growth rate of roughly 16% between 2021 and 2026 [3].

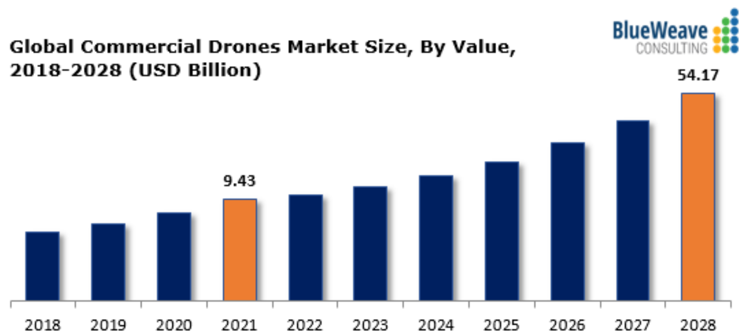

Figure 3. Demand of drones: past, present, and future [3]

The design of drones is constantly being improved, and thousands of leading manufacturers are constantly exploring innovative approaches for them in order to make them more versatile and ideal for a variety of special purposes. There are number of giant research and development organizations and manufacturers at work on this.

1.2 The Goals and Purpose of the Research

The primary goal of this project is to adapt a small general-purpose drone and make it versatile so that it can do a variety of tasks in an industrial setting. A quadcopter design was considered as a reference for this project, and many modifications and functional advancements have been made in its wake. There are certain delivery drone models are available outside, but the cost of purchasing and continuous maintenance is high and certainly is not best fit in the industrial environment. To solve this issue, general purpose drone can be converted to fulfil the several task in the industrial setup which will ultimately be cost redundant and effective for the application. The new hexagonal drone frame, which has twice the size of the quadcopter to enable it to carry things of a specific weight and size, is taken into consideration when it comes to design. A camera module is also in place, which may be used to monitor industry activity and also plays a crucial part in the pick-and-drop application to protect people and property from industrial mishaps. Additionally, given this significant market need, if extensive and rigorous research is done for this special application, it might radically alter the drone manufacturing sector.

A thorough research has been carried out on the existing drone designs in order to satisfy new design goals for according to application. On the basis of that investigation, the issues with the current design have been determined. The new 3D design is then created using CAD modelling, and Ansys is leveraged to conduct analysis and determine if the adjustments are actually viable or not.

2. Literature review

This Hexacopter is a VTOL (vertical take-off and landing) aircraft in the multirotor helicopter category. They differ from conventional helicopters in that their rotor pitch does not change while the blades revolve thanks to the use of rotors with fixed-pitch blades. Six rotors make up a hexacopter. De Bothezat may have been the first multirotor helicopter with fixed pitch rotors, but technology at the time was not advanced enough to make such a machine practical to build.

The primary issue was the vehicle's inherent instability and the resulting excessive pilot effort. Even though they were mechanically more complicated, standard helicopters [6] turned out to be more useful. The most significant barriers to this type of aircraft's controllability were later eliminated by technological advancement. Today's multi-copters aren't just radio-controlled toys; they're also reliable, simple helicopters with a payload capacity of almost two kilos [7]. Unmanned aerial vehicles, often known as aerial robots, have started to be employed, mostly for surveillance.

In terms of hexacopter design, different manufacturers have created hexacopters with varying design, material, and other physical characteristics. Reading the literature revealed that the parameters used to model the drones have a substantial effect on their capacity for controlling and carrying payloads. Considering the design, even hexacopter has variations according to the positioning of the arms and controlling method. In researching drones for this project, we discovered that hexacopters had more benefits than quadcopters, including the ability to fly for longer periods of time, the ability to withstand more faults than quadcopters, and the ability to carry more weight. Additionally, having several motors shortens the blades, minimizing structural and dynamical problems [10].

On the other hand, adding additional arms would result in increasing power usage. As a result, redesigning the power system is necessary to achieve more efficient functioning. Likewise, it will have an effect on the controller side. Also, after doing our research, we learned the significance of CFD considerations as well as the relevance of taking aerodynamics into account while designing.

The materials for the drone's body pieces can be chosen from a variety of options depending on the application requirements. Drones are constructed from a variety of materials, including thermoplastic, carbon fiber, aluminum alloys, and magnesium alloys. Most UAVs that are simply used for monitoring and surveillance are composed of carbon fiber. Aluminum and magnesium alloys are employed in situations where there are load-bearing requirements. Consider the DJI Inspire 2 with its carbon fiber arms and magnesium-aluminum body[8]. The diameter, pitch, and number of blades are the three major characteristics that define a drone propeller. In general, the greater they are, the more thrust is produced, but the motor is also subjected to more torque. However, it is known that long, slowly rotating, two-bladed propellers are more aerodynamically effective than short, quickly rotating, multibladed ones. The key factors affecting a propeller's properties are its rotating speed and the airflow velocity. The thrust, torque, and power only rely on the propeller speed if the air is static (at hover in still air) and the air density is constant. There are also more characteristics like mass and a geometric template that are stated as manufacturing series (e.g., Multirotor, Slow Flyer, Carbon, etc.) [9]. From material selection to mathematical modelling to the project's potential future upgrades, the literature research has been a huge assistance to us throughout the whole process. During the course of the project, all of the findings from the literature study were taken into account.

3. Methodology and Principles

3.1 Working principle

Newton's Third Law of Motion, which states that there is an equal and opposite response to every action, serves as the foundation for a quadcopter's flight. The propellers on a quadcopter force air downward. When this happens, a counteraction known as thrust propels the quadcopter up against gravity. Bernoulli's principle, which states that more push is produced by larger propeller blades and quicker rotation, is what causes air movement.

When the propellers rotate (for example clockwise), the quadcopter will tend to rotate anti-clockwise. Rotational force is called torque. Helicopters solve this by using a tail rotor. Quadcopters solve this by driving two diagonal propellers clockwise and the other two anti-clockwise. Thus, torque from one pair cancel that of the other.

Each diagonal pair of propellers will produce opposing thrusts when they revolve in opposing directions. It won't be possible for the quadcopter to lift off or fly. The solution is to have each diagonal pair of propellers' blades be an exact mirror copy of the other pair. Regardless of the rotational direction, all propellers will effectively push air downward [10].

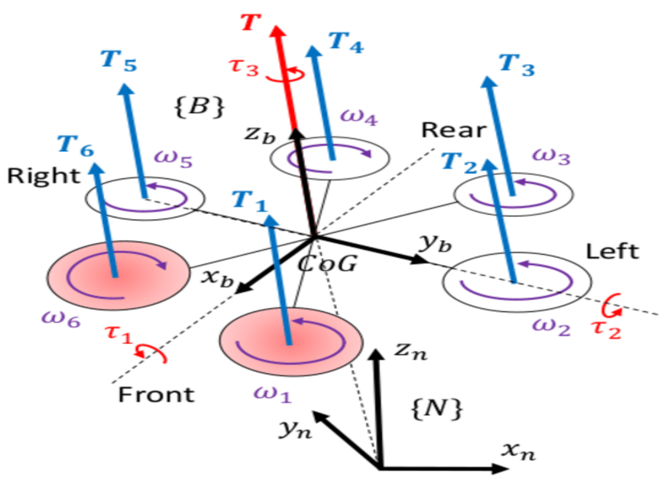

Figure 4. Forces acting on drones [11]

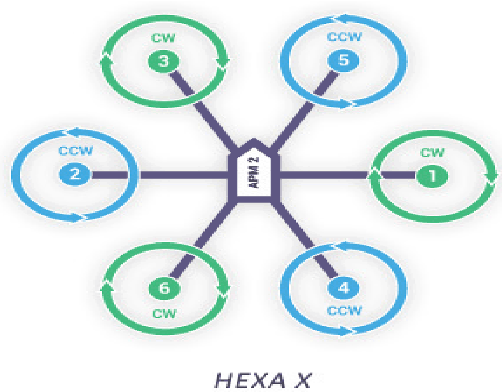

Figure 5. Hexacopter Type X [12]

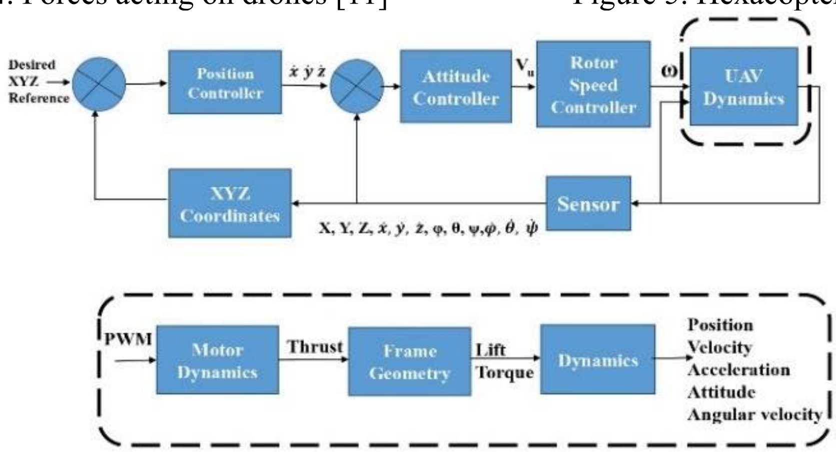

Figure 6. Block diagram of Drone system [13]

The drone which is considered as a reference has six DOF with four distinct movements:

1. Vertical: A quadcopter has the ability to ascend against the force of gravity or descend in controlled manner. The term "throttle or hover" or refers to these motions.
2. Rotational: Term Yaw is used for clockwise or counterclockwise rotations about the vertical axis.
3. Front-to-back Lateral: The quadcopter's nose dips or rises depending on how the lateral axis, also known as pitch, is tilted. This thus makes it possible to go forward or backward.
4. Left-to-right Lateral: Movement to the left or right is made possible by rolling along this axis.

3.2 Mathematical modelling

A mathematical model of the hexacopter has been developed after extensive research using sources such as research papers, journals, and engineering mathematical concepts. This model can be used to design the hexacopter and, in addition, it can be useful to develop the product and determine whether the actual dimensions of the product are accurate or not. Additionally, the drone controller may utilize it as an input to adjust the yaw, roll, and pitch values. This model may be used to create a control software with improved and added features.

Calculation according to Euler angles:

The techniques utilized to create the mathematical model for the hexacopter will be covered in this section. It discusses the coordinate frames and reference frame used to characterize the hexacopter's dynamics. The three angles (Roll, Pitch, and Yaw), also known as the Euler Angles, which control the hexacopter's flight, characterize the angular orientation of the aircraft. The ordered set of consecutive equations between the reference frame and the body frame is represented by these Euler angles[14].

The Euler angles were defined by Leonhard Euler [15]. The angular orientation of a stationary body in relation to a reference frame is described by these angles. The plane has the following Euler angles: Yaw (ψ), Pitch (ɵ), and Roll (ɸ). Yaw angle, which is perpendicular to the wings, is caused by the center of gravity. The center of gravity is where the pitch angle begins, and it runs parallel to the wingtip. The roll angle of the aircraft begins at the center of gravity and runs parallel to the wings.

The hexacopter's schematic is shown below. The hexacopter's motion may be described by two frames: the inertial or fixed frame and the body frame. An earth-fixed frame that is tangent to the earth's surface is important since an aircraft's motion is planned using geographic coordinates. The angular location of the Body frame with respect to the Inertial frame is specified by the Euler angles Yaw (ψ), Pitch (ɵ), and Roll (ɸ).

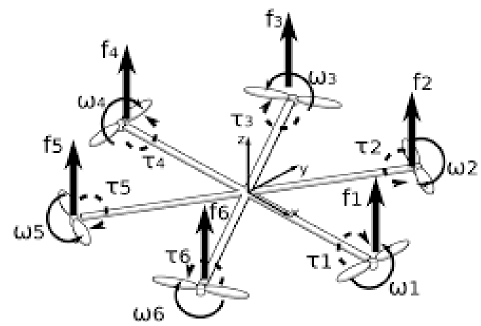

Figure 7. Block diagram of Drone system [14]

Let's use $X = [\, x\ y\ z]^T$ and $\eta = [\phi\ \theta\ \psi]^T$, respectively, to take the linear position vector and rotational position vector (Euler angle) in the inertial frame. As a result, the inertial frame's linear and angular velocities are, respectively, $\dot{X} = [\dot{x}\ \dot{y}\ \dot{z}]^T$ and $\dot{\eta} = [\dot{\phi}\ \dot{\theta}\ \dot{\psi}]^T$ [14]. Now, using the orthogonal rotation matrix R, we define the transformation from the body frame to the inertial frame. R is characterized by the rotation along the x, y, and z axes combined.:

\Rotation along the x-axis can be written as:

$$R_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\phi & -sin\phi \\ 0 & sin\phi & cos\phi \end{bmatrix}$$

Rotation along y-axis can be written as:

$$R_y = \begin{bmatrix} cos\theta & 0 & sin\theta \\ 0 & 1 & 0 \\ -sin\theta & 0 & cos\theta \end{bmatrix}$$

Rotation along the z-axis can be written as:

$$R_z = \begin{bmatrix} cos\psi & -sin\psi & 0 \\ sin\psi & cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Rotation matrix R = $Rx * Ry * Rz$

$$\mathbf{R} = \begin{bmatrix} cos\theta cos\psi & cos\psi sin\theta sin\phi - cos\phi sin\psi & cos\phi cos\psi sin\theta + sin\phi sin\psi \\ cos\theta sin\psi & cos\phi cos\psi + sin\theta sin\phi sin\psi & cos\phi sin\theta sin\psi - cos\psi sin\phi \\ -sin\theta & cos\theta sin\phi & cos\theta cos\phi \end{bmatrix}$$

$R^{-1} = R^T$ will be the transformation matrix from the inertial frame to the body frame.
We must acquire the transformation matrix for angular velocities [14] in order to maintain continuity in the system when it switches from the body frame to the inertial frame. The rotation is carried out in the order z-y-x, where the first rotation is about, which must undergo two rotations, R_x and R_y, to reach the body frame, the second is about, which must undergo rotation about R_x to align with the body frame, and the final rotation is about, which need not undergo any rotations.

The transformation laws are $\nu = \omega\eta\dot{\eta}$ and $\dot{\eta} = \omega_n^{-1}$ in which the angular velocity ν is defined by the vector $\nu = [p\ q\ r]^T$. ω_n^{-1} can only be defined if $\theta \neq \pi/2 + k\pi$ where k =($k \in Z$).

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + Rx \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + RxRy \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix}$$

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\phi & -sin\phi \\ 0 & sin\phi & cos\phi \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\phi & -sin\phi \\ 0 & sin\phi & cos\phi \end{bmatrix} \begin{bmatrix} cos\theta & 0 & sin\theta \\ 0 & 1 & 0 \\ -sin\theta & 0 & cos\theta \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix}$$

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & 0 & -sin\theta \\ 0 & cos\phi & cos\theta sin\phi \\ 0 & -sin\phi & cos\theta cos\phi \end{bmatrix} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

When angular velocities are transformed from the inertial frame to the body frame, the following arises:

$$\omega_\eta = \begin{bmatrix} 1 & 0 & -sin\theta \\ 0 & cos\phi & cos\theta sin\phi \\ 0 & -sin\phi & cos\phi cos\theta \end{bmatrix}$$

The following will be the transformation matrix for angular velocities between the body frame and inertial frame:

$$\omega_\eta^{-1} = \begin{bmatrix} 1 & sin\phi tan\theta & cos\phi tan\theta \\ 0 & cos\phi & -sin\phi \\ 0 & sec\theta sin\phi & cos\phi sec\theta \end{bmatrix}$$

The following describes the vector representing the overall rotational rate:

$$\omega = \dot{\phi} + \dot{\theta} + \dot{\psi}$$

Therefore, angular velocity vector will be

$\omega = \nu = \omega_\eta \dot{\eta}$

$$\nu = \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & 0 & -sin\theta \\ 0 & cos\phi & cos\theta sin\phi \\ 0 & -sin\phi & cos\phi cos\theta \end{bmatrix} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

We will now see the hexacopter in three dimensions as a solid body. The six electric motor dynamics and the blades' flexibility will be disregarded because of how quickly the motors move. Translational and rotational elements make up the motion of a rigid body. The Newton-Euler equations, which regulate both linear and angular motion, are taken into account to explain the dynamics of the hexacopter.

A matrix of inertia, the six arms of the hexacopter are thought to be symmetrically aligned with the body's x and y axis [14].

$$I = \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}$$

Calculations according to Newton-Euler equations:

The whole dynamics (rotational and translational) of a rigid body are described by the Newton-Euler equations. The Newton-Euler equations use matrices and column vectors to combine two equations—equations Newton's and Euler equations—into a single equation having six components [14]. These formulas connect the body's center of gravity to the total of all forces and torques. The Newton-Euler equations state that the external torque of the hexacopter is equal to the product of the angular acceleration of the inertial frame, the centripetal force, and the gyroscopic force. The Newton-Euler equations can be shown as follows with reference to the coordinate frame whose origin is the center of mass of the body:

$$m\dot{V}_B + \nu \times (mV_B) = \mathrm{F}$$

$$\mathrm{F} = \mathrm{F_g} + \mathrm{T_B}$$

where,

F= total force acting on the center of mass

m= mass of the body

F_g = gravitational force

T_B = total thrust

$\nu \times (mV_B)$ = centrifugal force

Translational dynamics:

Thrust force generated by motor 1 is given by:

$$\mathrm{T_{hi}} = \mathrm{k}\omega^2$$

Where,

k = lift constant

ω = angular velocity of the motor

T_{hi} = Thrust generated by each propeller

Now, since there are 6 motors and every motor generates a thrust, the total thrust will be:

$$\mathrm{T_B} = \sum_{i=1}^{6} T_{hi}$$

$$= \mathrm{k}\begin{bmatrix} 0 \\ 0 \\ \sum \omega_i^2 \end{bmatrix}$$

$$= \mathrm{k}\begin{bmatrix} 0 \\ 0 \\ \omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2 + \omega_5^2 + \omega_6^2 \end{bmatrix}$$

The total thrust will be:

$$\mathrm{F} = \mathrm{F_g} + \mathrm{T_B}$$

Where, F_g = Gravitational force

T_B = Total thrust

Total Thrust:

$$\mathrm{T_B} = \mathrm{k}\begin{bmatrix} 0 \\ 0 \\ \omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2 + \omega_5^2 + \omega_6^2 \end{bmatrix}$$

The linear motion in the body frame can be summarized as:

$$m\ddot{\mathrm{X}} = \begin{bmatrix} 0 \\ 0 \\ -mg \end{bmatrix} + \mathrm{T_B}$$

Taking m on the other side:

$$\begin{bmatrix}\ddot{x}\\ \ddot{y}\\ \ddot{z}\end{bmatrix} = \begin{bmatrix}0\\0\\-g\end{bmatrix} + \frac{TB}{m}$$

Now if we convert the body frame to inertial frame and integrate twice we can get the position:

$$\begin{bmatrix}\ddot{x}\\ \ddot{y}\\ \ddot{z}\end{bmatrix} = \begin{bmatrix}0\\0\\-g\end{bmatrix} + \frac{RTB}{m}$$

On integrating twice, we get $[\ x\ y\ z]^T$

Solving for $\frac{RTB}{m}$:

$$\frac{TB}{m} = \frac{k}{m}\begin{bmatrix}0\\0\\ \omega_1^2+\omega_2^2+\omega_3^2+\omega_4^2+\omega_5^2+\omega_6^2\end{bmatrix}$$

$$\frac{RTB}{m} = \frac{k}{m}\begin{bmatrix}0\\0\\ \omega_1^2+\omega_2^2+\omega_3^2+\omega_4^2+\omega_5^2+\omega_6^2\end{bmatrix}\begin{bmatrix}\cos\psi\sin\theta\cos\phi\ +\ \sin\psi\sin\phi\\ \sin\psi\sin\theta\cos\phi\ -\ \cos\psi\sin\phi\\ \cos\theta\cos\phi\end{bmatrix}$$

$$\ddot{x} = \frac{k}{m}\begin{bmatrix}0\\0\\ \omega_1^2+\omega_2^2+\omega_3^2+\omega_4^2+\omega_5^2+\omega_6^2\end{bmatrix}[\cos\psi\sin\theta\cos\phi\ +\ \sin\psi\sin\phi]$$

$$\ddot{y} = \frac{k}{m}\begin{bmatrix}0\\0\\ \omega_1^2+\omega_2^2+\omega_3^2+\omega_4^2+\omega_5^2+\omega_6^2\end{bmatrix}[\sin\psi\sin\theta\cos\phi\ -\ \cos\psi\sin\phi]$$

$$\ddot{z} = \frac{k}{m}\begin{bmatrix}0\\0\\ \omega_1^2+\omega_2^2+\omega_3^2+\omega_4^2+\omega_5^2+\omega_6^2\end{bmatrix}[\cos\theta\cos\phi] - g$$

Integrating twice the values of $(\ddot{x}, \ddot{y}, \ddot{z})^T$ $(x, y, z)^T$.

Calculating the Torques:

The drag equation from fluid dynamics gives us the frictional force:

$$F_D = \frac{1}{2}\rho C_D A\ v^2$$

ρ = Density
A = propeller area
C_D = dimensionless constant
v_2 = velocity of the propeller

hence torque on the tip of the propeller due to drag force:

$$\tau_D = \frac{1}{2} R\rho C_D A\ v^2$$

R = Radius of the propeller
$V^2 = \omega R^2$

$$\tau_D = \frac{1}{2} R\rho C_D A\ v^2 = b\omega^2$$

The complete torque about z-axis for a motor will be:

$$\tau_{zi} = b\omega_i^2 + I_{Mi}\omega_i$$

I_{Mi} = Inertia moment of the i_{th} motor
ω_i = Angular velocity for the i_{th} motor

from the geometrical structure of the hexacopter and from components of T_B and τ_{zi} we can get information on the roll, pitch, and yaw.

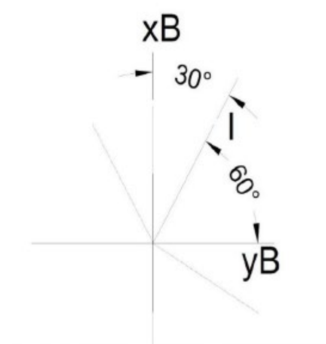

Figure 8. Geometry of Hexacopter

Roll: Only angular velocities w2, w3, w5, and w6 are active in rolling motion, with angular velocities 2 and 3 acting in one direction and w5 and w6 acting in the other direction. Changing the speed of the rotors on the right side while changing the speed of the rotors on the left side at the same time will cause a rolling motion. Figure 11 below describes rolling action. The red arrow indicates a decrease in angular velocity, the green arrow indicates an increase in angular velocity, and the black arrow indicates no change in angular velocity.

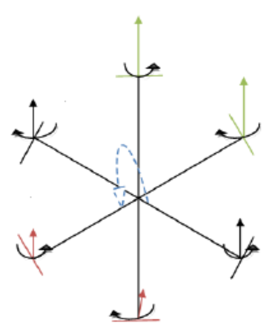

Figure 9. Rolling motion [14]

i = 2, 3, 5, 6
consider ‘l’ as the distance of arm:

$$\tau_\phi = \sum l * T_B = \sin 60^\circ kl(\omega_2^2 + \omega_3^2 - \omega_5^2 - \omega_6^2)$$

Pitch: In the case of pitch motion, angular velocities w1, w2, and w6 will act in one direction, but angular velocities w3,w 4, and w5 will act in the other direction. Rear rotor speed may be increased or decreased, and front rotor speed can be changed in the same manner to produce pitching movement. Figure 12 below describes pitch motion.

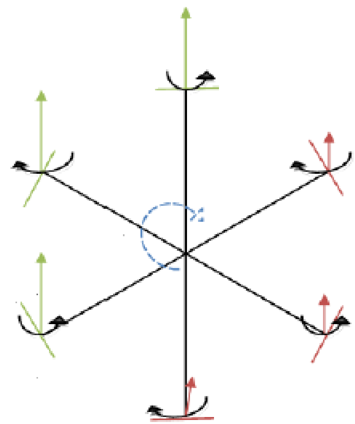

Figure 10. Pitching motion [14]

i = 1, 2, 3, 4, 5, 6

$$\tau_\theta = \sum l * T_B = kl(-\omega_1^2 - \omega_2^2/4 + \omega_3^2/4 + \omega_4^2 + \omega_5^2/4 - \omega_6^2/4)$$

Yaw: By changing the speed of the rotors rotating in the clockwise and counterclockwise directions, respectively, the total torque in the z-direction can be obtained. In other words, the angular velocities 1, 3, and 5 will act in one direction, while the angular velocities 2, 4, and 6 will act in the opposite direction. Figure 13 below describes the yawing action.

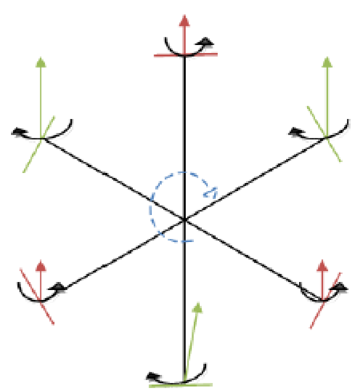

Figure 11. Yawing motion [14]

$$T_\psi = b(-\omega_1^2 + \omega_2^2 - \omega_3^2 + \omega_4^2 - \omega_5^2 + \omega_6^2)$$

Hence, the total torque applied to the body may be expressed as:

$$\tau_B = \begin{bmatrix} \tau\phi \\ \tau\theta \\ \tau\psi \end{bmatrix} = \begin{bmatrix} \frac{3}{4} kl(\omega_2^2 + \omega_3^2 - \omega_5^2 - \omega_6^2 \\ kl(-\omega_1^2 - \frac{\omega_2^2}{4} + \frac{\omega_3^2}{4} + \omega_4^2 + \frac{\omega_5^2}{4} - \frac{\omega_6^2}{4} \\ b(-\omega_1^2 + \omega_2^2 - \omega_3^2 + \omega_4^2 - \omega_5^2 + \omega_6^2) \end{bmatrix}$$

Rotational dynamics:

Rotational dynamics equation can be governed by:

$$I\dot{\nu} + \nu \times (I\nu) + \Gamma = \tau_B$$

Where,

ν = Angular velocity vector

$\dot{\nu}$ = Angular acceleration

I = Moment of Inertia vector

Γ represents the gyroscopic forces

τ_B is the external torque

$$\dot{\nu} = \Gamma^{-1}\left(\begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} - I_r \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \omega\Gamma + \begin{bmatrix} \tau\phi \\ \tau\theta \\ \tau\psi \end{bmatrix}\right)$$

$$\dot{\nu} = \begin{bmatrix} 1/I_{xx} & 0 & 0 \\ 0 & 1/I_{yy} & 0 \\ 0 & 0 & 1/I_{zz} \end{bmatrix} \left(\begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} I_{xx} \cdot p \\ I_{yy} \cdot q \\ I_{zz} \cdot r \end{bmatrix} - I_r \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \omega\Gamma + \begin{bmatrix} \tau\phi \\ \tau\theta \\ \tau\psi \end{bmatrix}\right)$$

$$\dot{\nu} = \begin{bmatrix} \frac{(I_{yy} - I_{zz})qr}{I_{xx}} \\ \frac{(I_{zz} - I_{xx})pr}{I_{yy}} \\ \frac{(I_{xx} - I_{yy})pq}{I_{zz}} \end{bmatrix} - I_r \begin{bmatrix} q(I_{xx}) \\ -p(I_{yy}) \\ 0 \end{bmatrix} \omega\Gamma + \begin{bmatrix} \tau\phi/I_{xx} \\ \tau\theta/I_{yy} \\ \tau\varphi/I_{zz} \end{bmatrix}$$

Where,

$$\omega\Gamma = -\omega_1 + \omega_2 - \omega_3 + \omega_4 - \omega_5 + \omega_6$$

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} \frac{(I_{yy} - I_{zz})qr}{I_{xx}} \\ \frac{(I_{zz} - I_{xx})pr}{I_{yy}} \\ \frac{(I_{xx} - I_{yy})pq}{I_{zz}} \end{bmatrix} - I_r \begin{bmatrix} q(I_{xx}) \\ -p(I_{yy}) \\ 0 \end{bmatrix} \omega\Gamma + \begin{bmatrix} \tau\phi/I_{xx} \\ \tau\theta/I_{yy} \\ \tau\varphi/I_{zz} \end{bmatrix}$$

$$\dot{p} = \frac{I_{yy} - I_{zz}}{I_{xx}} qr + \frac{I_r}{I_{xx}} q\omega\Gamma + \frac{\tau\phi}{I_{xx}}$$

$$\dot{q} = \frac{I_{zz} - I_{xx}}{I_{yy}} qr - \frac{I_r}{I_{yy}} p\omega\Gamma + \frac{\tau\theta}{I_{yy}}$$

$$\dot{r} = \frac{I_{xx} - I_{yy}}{I_{zz}} pq + \frac{\tau\psi}{I_{zz}}$$

Integrating once will give us $(p, q, r)^T$.

Writing all the equations of acceleration,

$$\ddot{x} = \frac{k}{m}\begin{bmatrix} 0 \\ 0 \\ \omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2 + \omega_5^2 + \omega_6^2 \end{bmatrix}[\cos\psi\sin\theta\cos\phi + \sin\psi\sin\phi]$$

$$\ddot{y} = \frac{k}{m}\begin{bmatrix} 0 \\ 0 \\ \omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2 + \omega_5^2 + \omega_6^2 \end{bmatrix}[\sin\psi\sin\theta\cos\phi - \cos\psi\sin\phi]$$

$$\ddot{z} = \frac{k}{m}\begin{bmatrix} 0 \\ 0 \\ \omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2 + \omega_5^2 + \omega_6^2 \end{bmatrix}[\cos\theta\cos\phi] - g$$

$$\dot{p} = \frac{I_{yy} - I_{zz}}{I_{xx}}qr + \frac{I_r}{I_{xx}}q\omega\Gamma + \frac{\tau\phi}{I_{xx}}$$

$$\dot{q} = \frac{I_{zz} - I_{xx}}{I_{yy}}qr - \frac{I_r}{I_{yy}}p\omega\Gamma + \frac{\tau\theta}{I_{yy}}$$

$$\dot{r} = \frac{I_{xx} - I_{yy}}{I_{zz}}pq + \frac{\tau\psi}{I_{zz}}$$

Integrating once will give us $(p, q, r)^T$.
Then using $\nu = \omega_\eta \dot{\eta}$ we can calculate $(\phi\ \theta\ \psi)^T$

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix}(\omega_\eta^{-1}) + \begin{bmatrix} p \\ q \\ r \end{bmatrix}\frac{d}{dt}(\omega_\eta^{-1}) = \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Integrating $[\dot{\phi}\ \dot{\theta}\ \dot{\psi}]^T$ we will get $[\phi\ \theta\ \psi]^T$.

Henceforth, we are considering this design equation and using these to design our model and will also use this for Finite element analysis.

3.3 Design Methodology

Design of the hexacopter was quite challenging because during this process not only the mechanical design parameters but all other parameters considering the drone as full-fledged finished product are also taken into account. Here, design is carried out using a top-down methodology, which involves working from the broadest possible level of a design concept to the most precise level of detail. A top-down design project is started with the basic project requirements in mind and collects that data in one location. The design process is improved by the distribution of the centralized information to the numerous components. Since we have comprehensive design knowledge as we have quadcopter as a reference , the top-down approach is the most effective way to carry out design. Top-down design (TDD) enables you to control the interrelationships between components such that any component that depends on the information changing at the system's core also changes. If properly done, we could manage the assembly from a single location. Moreover, the top-down approach is essential when we know the estimated output of the product and modify the design as necessary during the process.

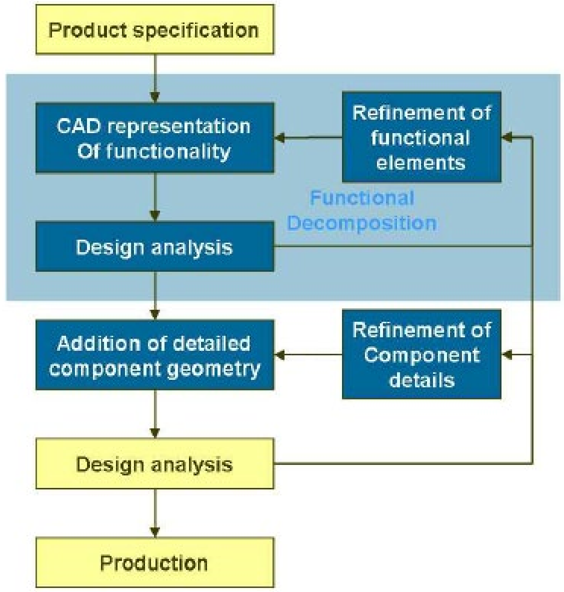

Figure 12. Top-down design methodology [16]

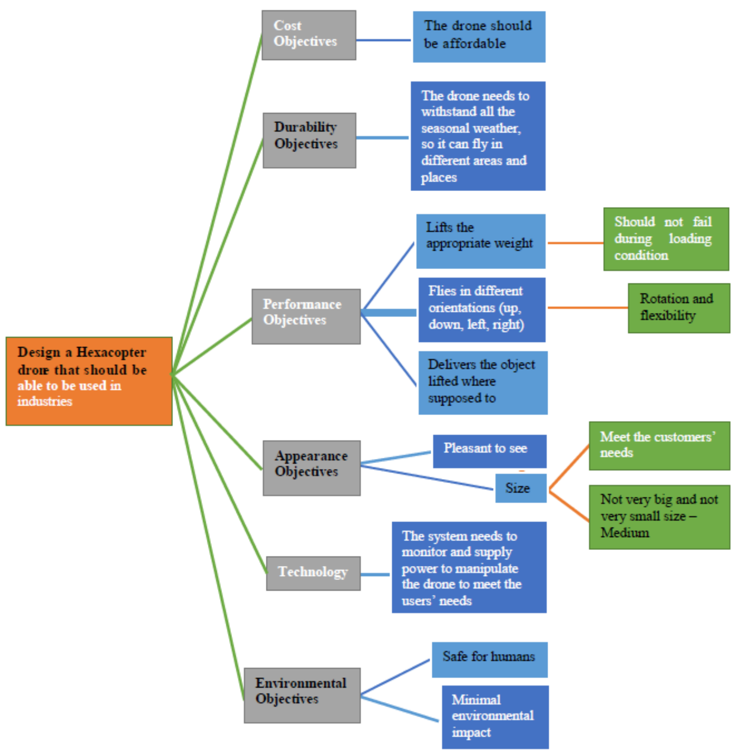

Figure 13. Product Design considerations

The goal of designing a hexacopter that is appropriate for an industrial setup involves many more design considerations because it must have some load carrying capacity, a camera for monitoring, compliance with size restrictions, safety, durability, and, last but not least, a reasonable cost per drone. We were able to complete the design after carefully reviewing the tree diagram above.

4. Design and Modifications of Components

The drones are mainly classified in four types namely, Multi-Rotor Drones, Fixed-Wing Drones, Single-Rotor Drones, Fixed-Wing Hybrid VTOL. Also, they can be classified in various categories according to the nature of applications such as Tactical Drones, Reconnaissance Drones, Large Combat Drones, GPS Drones, Photography Drones, Survey drones and Microdrones etc. The variety of components are used according to the applications but the basic components which are required to build any drone are [4],

Component	Function
Base Frame	Skeleton on which other parts are mounted
Motors	For the rotation of propellers
Electronic speed controller (ESC)	Controls motor speed, dynamic brake, distribute power
Flight Control Board	For takeoff, movement, and landing
Propellers	To create pressure difference and lift
Battery	Power source for drone
Electronics and power distribution cables	Power and signal transmission, control, and operation
Landing gears	Structure for safe landing
Camera	For the video surveillance
Radio Transmitter	Communication

Table 1. Components and their function

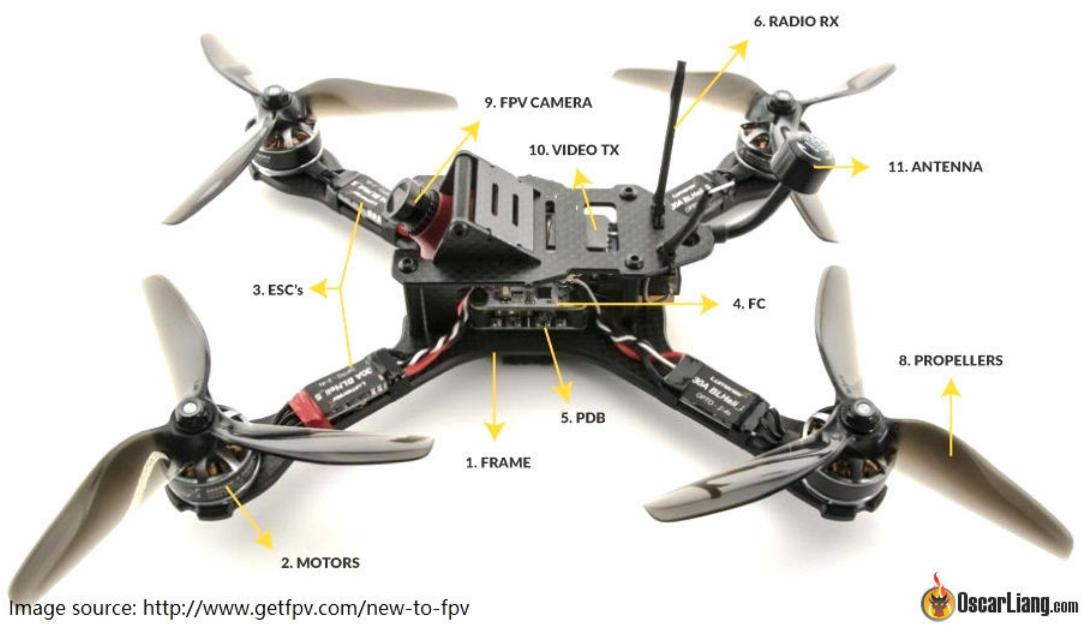

Figure 14. Components of drones [5]

For design of the hexacopter we have taken quadcopter as a reference and made certain modifications to it in order to achieve our objective.

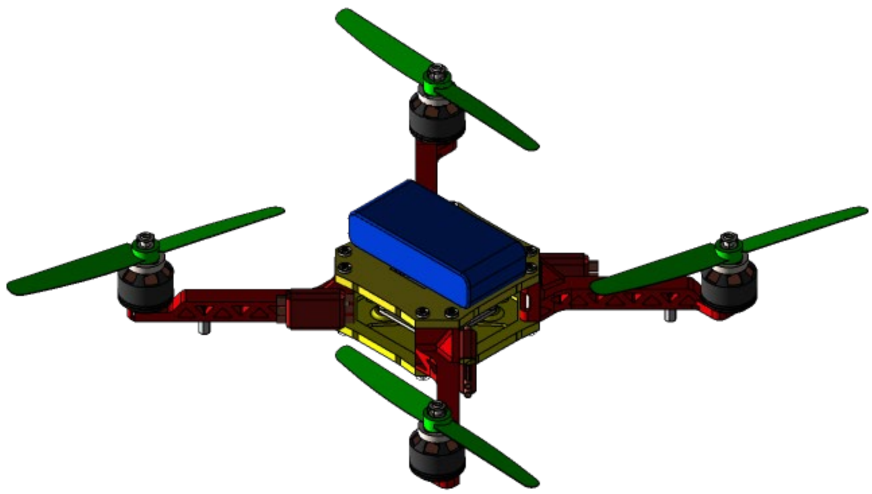

Figure 15. Reference product [17]

The reference product has several drawbacks as, it doesn't carry a camera so it can not be used as a surveillance drone. Besides, it has only 4 arms with 2 propellers, hence, cannot be used in pick and drop applications as its payload carrying capacity is too less and also doesn't have any clamping mechanism to carry the objects. The maximum wind resistance of this product is too low as 10m/s.

Modifications to the existing product:

1) Rather than using a quadcopter, we added an additional 2 arms to the drone, increasing its lifting capability, which is necessary for our applications.
2) Also, we added 2 more blades to provide the aforementioned function.
3) In order to support the drone's ability to lift weights and allow for future adjustments, we have scaled the dimension. We have also modified the top and baseplate which will increase the stability of the drone.
4) To clamp the objects we want to lift, position, and transport, we added stand to the base section.
5) Moreover, safety is the biggest concern when using drones for autonomous activities. We have also added a camera to the body so that we can monitor the drone's movements and operations to address this issue.

To accommodate these modifications, the design and dimensions of the reference product quadcopter is changed, and at some places new parts are designed and assembled to achieve the required function.

4.1 CAD Modelling of Components

Siemens NX v12.0 has been used to generate the CAD model for the parts and final product assembly below, taking into account all the modifications to dimensions and the incorporation of new parts.

4.1.1 Spider base

It is the most crucial component of the project since it serves as the foundation for the electrical unit. Additionally, each arm is joined to the base. It features a protrusion where a camera may be fastened. It should be sturdy and less aerodynamically resistant, with enough strength to support the propeller velocity and added weight for motors and other components as per requirement.

Modifications: Redesigned to hexagonal to accommodate the six arms. Dimensions are doubled

Commands Used: Extrude, Pattern

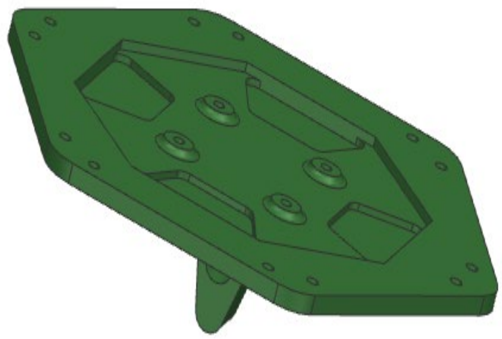

Figure 16. Spider base

4.1.2 Spider top

Arms, battery, and distribution is mounted on that, and it is connected with the base to make a rigid body and support whole assembly.

Modifications: Redesigned from the square base

Commands used: Extrude, Mirror

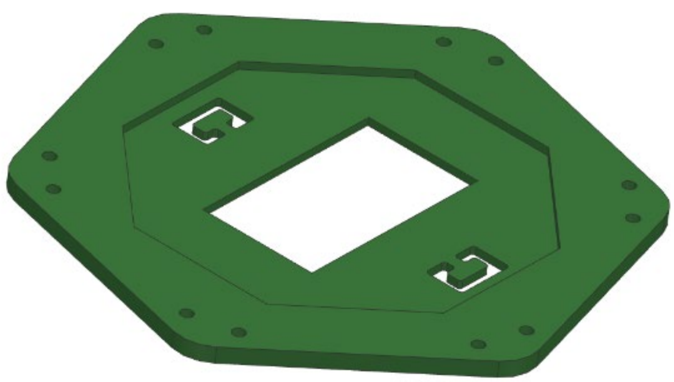

Figure 17. Spider top

4.1.3 Spider arm

Spider arm is a part of the drone frame which support the propeller and motor is mounted on that. Also, it increases the load carrying capacity if designed properly.

Modifications: Two additional arms are added, hole to fit pillar is added and dimensions are doubled

Commands used: Extrude, fillet, chamfer, pattern

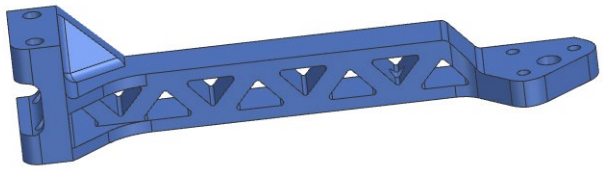

Figure 18. Spider arm

4.1.4 Battery

Most drones use high-power Lithium Polymer (LiPo) batteries. A 3S (3 cells) or 4S battery can be used (4 cells).

Modifications: Dimensions are doubled

Commands used: Extrude, Edge blend

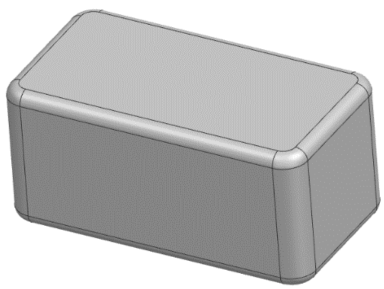

Figure 19. Battery

4.1.5 Spinner

It makes the smooth rotation of the motor and make efficient rotary motion transfer to the fan.

Modifications: Holes size increased from M3 to M6 and dimensions are doubled

Commands used: Hole, Revolve

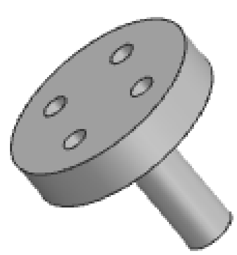

Figure 20. Spinner

4.1.6 Spacer

It is used to support and separate the top and the bottom base so the electrical unit can be housed in between.

Modifications: Dimensions are doubled

Commands used: Extrude

Figure 21. Spacer

4.1.7 Electric connector

It is used to create connections between the various parts of the drone to the electronic controller circuit.

Modifications: No modifications made since it is made with industry standards

Commands used: Extrude, Fillet, Project geometry

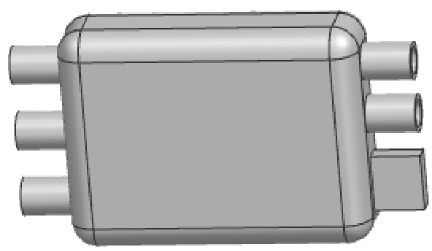

Figure 22. Electric connector

4.1.8 Pillar

Pillars are resting point of the drone and add a gap between drone body and ground.

Modifications: Made hollow to reduce the drone weight and dimensions are doubled

Commands used: Extrude, Revolve

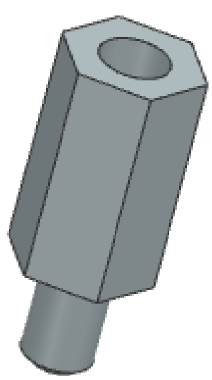

Figure 23. Pillar

4.1.9 Fan

Shape, size, and number of propellers all affect a drone's speed and capacity to lift loads. Long propellers provide enormous torque at low rotational speeds and are less responsive to changing rotational speed. Less weight is carried by short propellers. They require a high speed for higher thrust and often change rotational speeds.

Modifications: Increased number of propellers from 2 to 4 Dimensions are doubled

Commands used: Extrude, Pattern

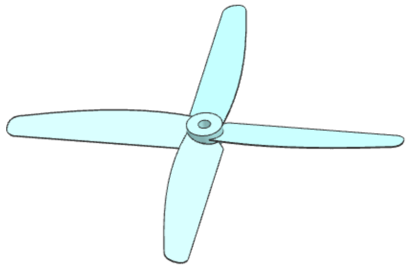

Figure 24. Fan

4.1.10 Motor

It is used to power the wing blades to provide a lift to drone to help it fly.

Modifications: Dimensions are doubled.

Commands used: Revolve, Extrude, Pattern

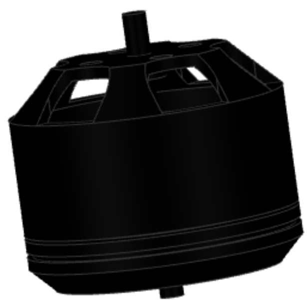

Figure 25. Motor

4.1.11 Distribution board

Electrical unit 1 and 2 are mounted on that and make sure that all of the circuits are fastened and work perfectly.

Modifications: Dimensions are doubled

Commands used: Extrude, project curve

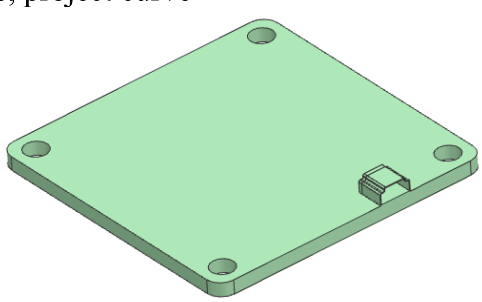

Figure 26. Distribution board

4.1.12 Electrical units 1

Electrical units containing the controllers of the drone to increase the speed, change motion od propellers etc.

Modifications: No modifications made since it is made with industry standards

Commands used: Extrude,

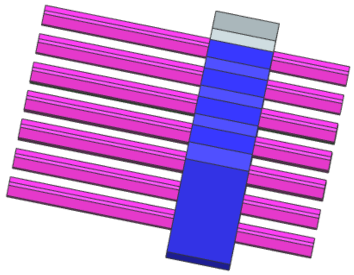

Figure 27. Electrical unit 1

4.1.13 Electrical unit 2

This part can be used to maintain the power supply throughout the power distribution board. The purpose of the Power distribution board in hexacopter is to transmit the power from the battery to electric connectors and generate power supply for multiple secondary or subsidiary electrical units with different voltage levels. Therefore, these secondary electrical components such as the electrical unit help to maintain the power supply within the distribution board.

Modifications: No modifications made since it is made with industry standards

Commands used: Pattern, Swept, Extrude

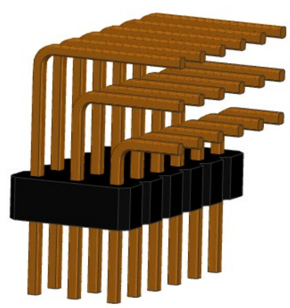

Figure 28. Electrical unit 2

4.1.14 Screw M6

They are used to mount the battery on the top plate

Modifications: Chosen the bolt from M3 to M6

Commands used: Revolve, Extrude, Threading

Figure 29. Screw M6

4.1.15 Screw arm

It fastens the motor to the spider arm

Modifications: Selected appropriate bolt size according to the assembly requirement

Commands used: Revolve, Extrude

Figure 30. Screw arm

4.1.16 Bolt arm

It fastened the arm, spider base and spider top

Modifications: Selected appropriate bolt size according to the assembly requirement

Commands used: Extrude, Revolve

Figure 31. Bolt arm

4.1.17 Nut fan

Added for the fastening purpose and make sure that body is perfectly tightened

Modifications: Appropriate nut is added to the assembly

Commands used: Extrude, Threading

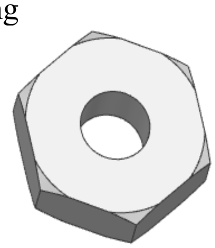

Figure 32. Nut fan

4.1.18 Camera stand

The purpose and application of this camera stand are to place the camera in the right place, and it will be placed from both sides of the camera which can also be used to pick up and drop certain small objects to desired places.
Modifications: Added this part to assembly
Commands used: Extrude, Edge blend

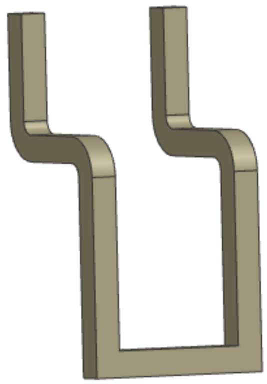

Figure 33. Camera stand

4.1.19 Camera Screw

Used to fix the camera to the base plate
Modifications: Dimensions are doubled and made sure that is perfectly fasten the camera
Commands used: Extrude, Revolve

Figure 34. Camera Screw

4.1.20 Camera screw pin

Used to fasten the camera to the baseplate.
Modifications: Added to the assembly
Commands used: Extrude, Edge blend

Figure 35. camera screw pin

4.1.21 Camera lens

To zoom in and zoom out for monitoring during operation
Modifications: Added to the Assembly
Commands used: Swept

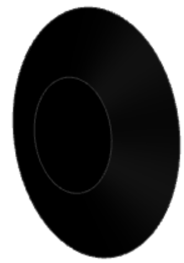

Figure 36. Camera lens

4.1.22 Baseplate arm nut

This is a hexagonal nut that is the most commonly used nut design. This nut design, in conjunction with bolts and washers, is used to fasten the arm with a base plate that prevents movement. This hex nut design allows for maximum torque and grip in a threaded fastener arrangement.
Modifications: Added to the assembly
Commands used: Revolve, internal threading

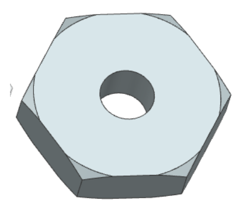

Figure 37. Baseplate arm nut

4.1.23 Camera

The purpose of a drone camera is to allow a vantage point that is impossible to see from the ground, and often in conditions that are inaccessible or dangerous to humans. Also used for surveillance.
Modifications: Added to the assembly
Commands used: Revolve, Mirror, Extrude, Edge blend

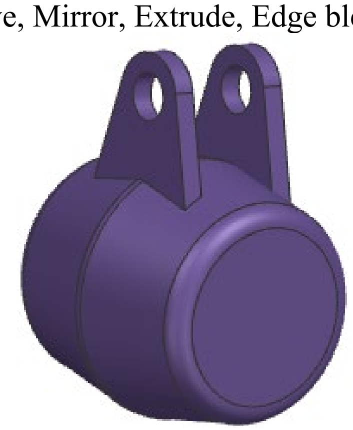

Figure 38. Camera

4.2 Subassembly of components

Here, all of the required components are design with Siemens NX. Now, before the assembly , it is always preferred to make subassembly of the components which will create the ease in doing the final assembly. In this process, we have designed two subassemblies before final assembly.

4.2.1 Arm subassembly

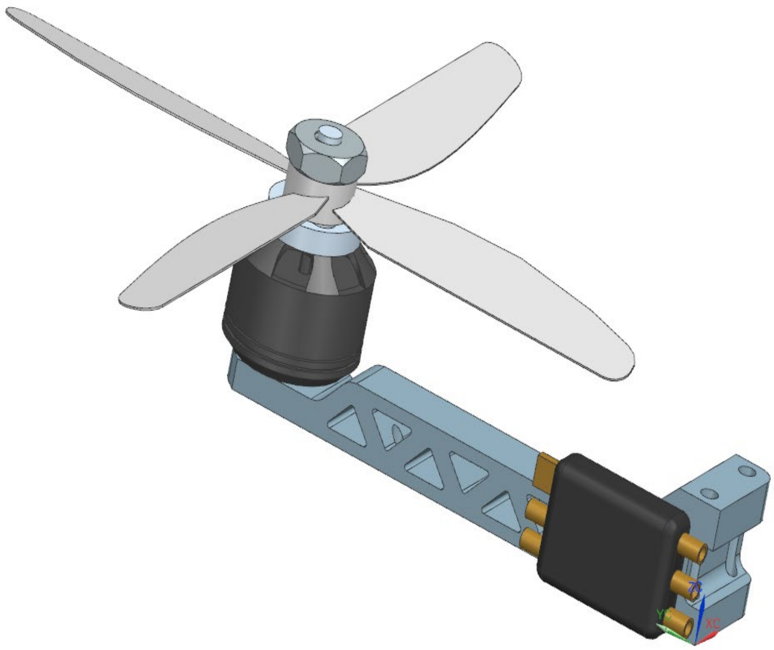

Figure 39. Arm subassembly

4.2.2 Electric board subassembly

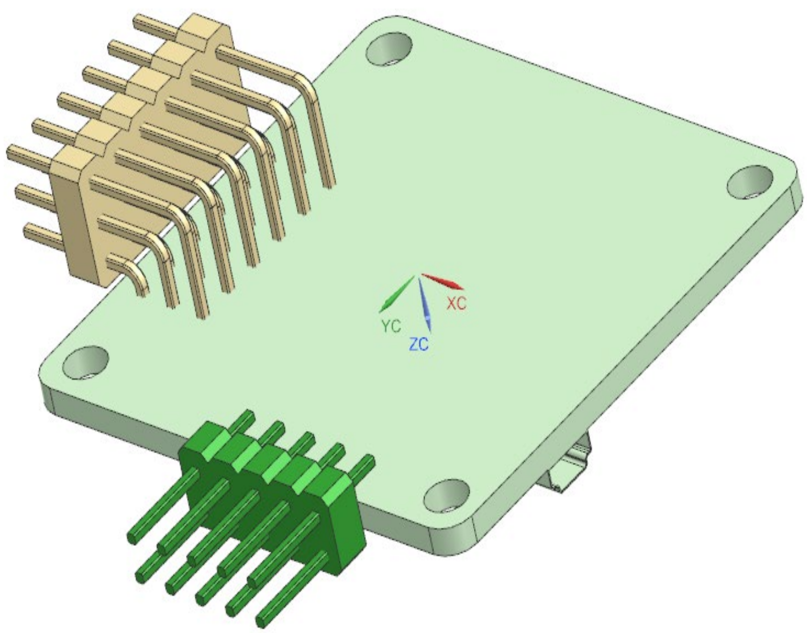

Figure 40. Electric board subassembly

5. Final assembly of the hexacopter

After creating the arm and electrical board sub-assemblies, we started assembling the entire drone, including all of its parts and sub-assemblies. We used the same Siemens NX software to assemble all of the models. After final construction, we gave the drone's various components a different colors for a better aesthetic view while still keeping in mind the aesthetic perspective. The hexacopter's full assembly is shown in Figure 41.
Total Dimension of the product after final assembly is : 750x750x250

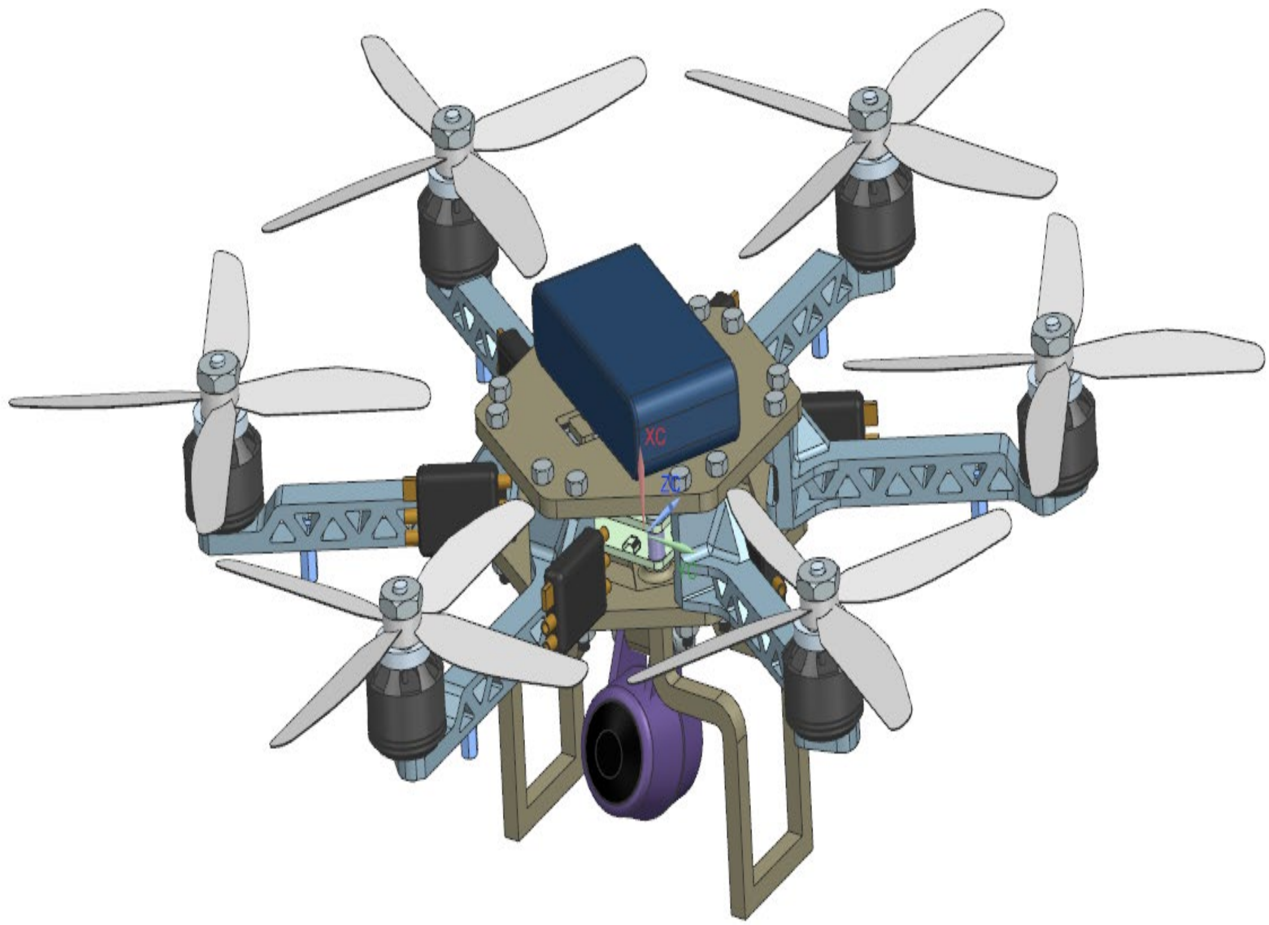

Figure 41. Final assembly of Hexacopter

5.1 Exploded view

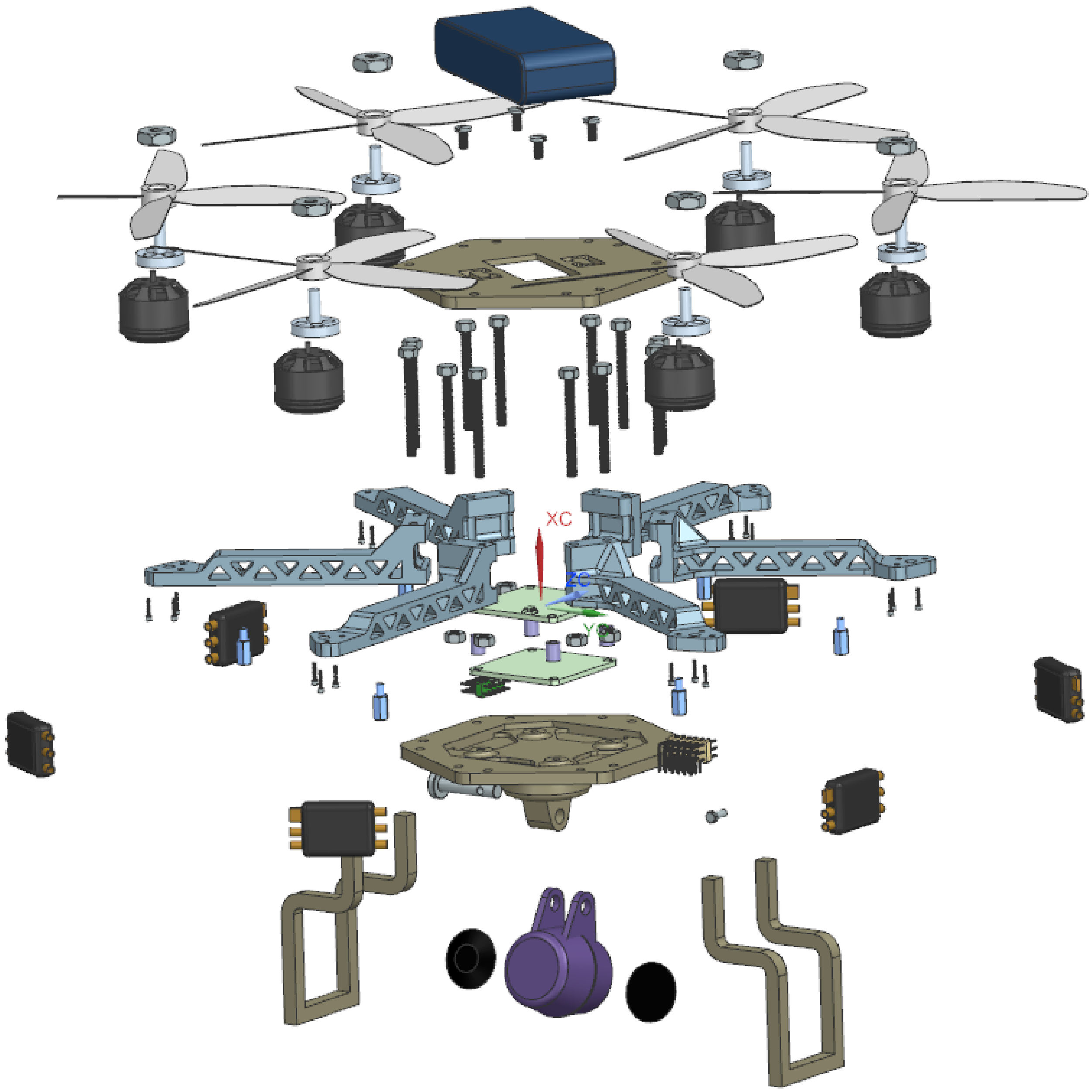

Figure 42. Exploded view of final assembly of Hexacopter

5.2 Exploded view with B.O.M

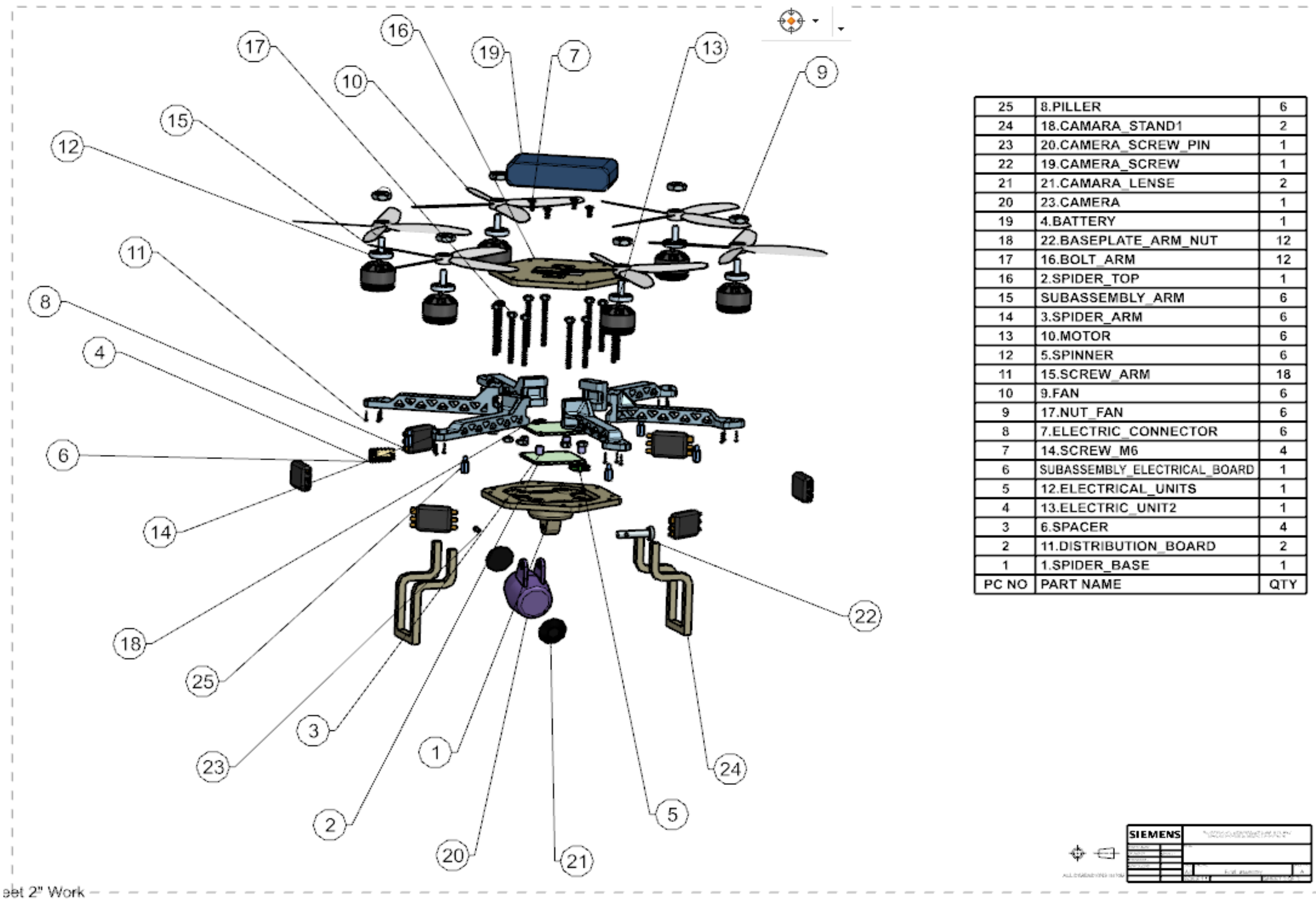

Figure 43. Exploded view of final assembly of Hexacopter with B.O.M

Sr No.	Part Name	QTY	Sr No.	Part Name	QTY
1	Spider base	1	**13**	Electrical units 2	1
2	Spider top	1	**14**	Screw m6	4
3	Spider arm	6	**15**	Screw arm	18
4	Battery	1	**16**	Bolt arm	12
5	Spinner	6	**17**	Nut fan	6
6	Spacer	4	**18**	Camera stand	2
7	Electric connector	2	**19**	Camera screw	1
8	Piller	6	**20**	Camera screw pin	1
9	Fan	6	**21**	Camera lens	2
10	Motor	6	**22**	Baseplate arm nut	12
11	Distribution board	6	**23**	Camera	1
12	Electrical units 1	1			

Table 2. Bill of Material of Hexacopter

6. Drafting

For technical, architectural, or engineering applications, drafting—also known as technical drawing involves the development of precise representations of objects, systems, or structural constructions. A drafter, design engineer, or draftsperson is a person who is proficient at drafting. Objects are drawn to scale in drafting and typically include several perspectives of the same object or structure. They are frequently employed for the construction or assembly of an object and can be quite comprehensive.

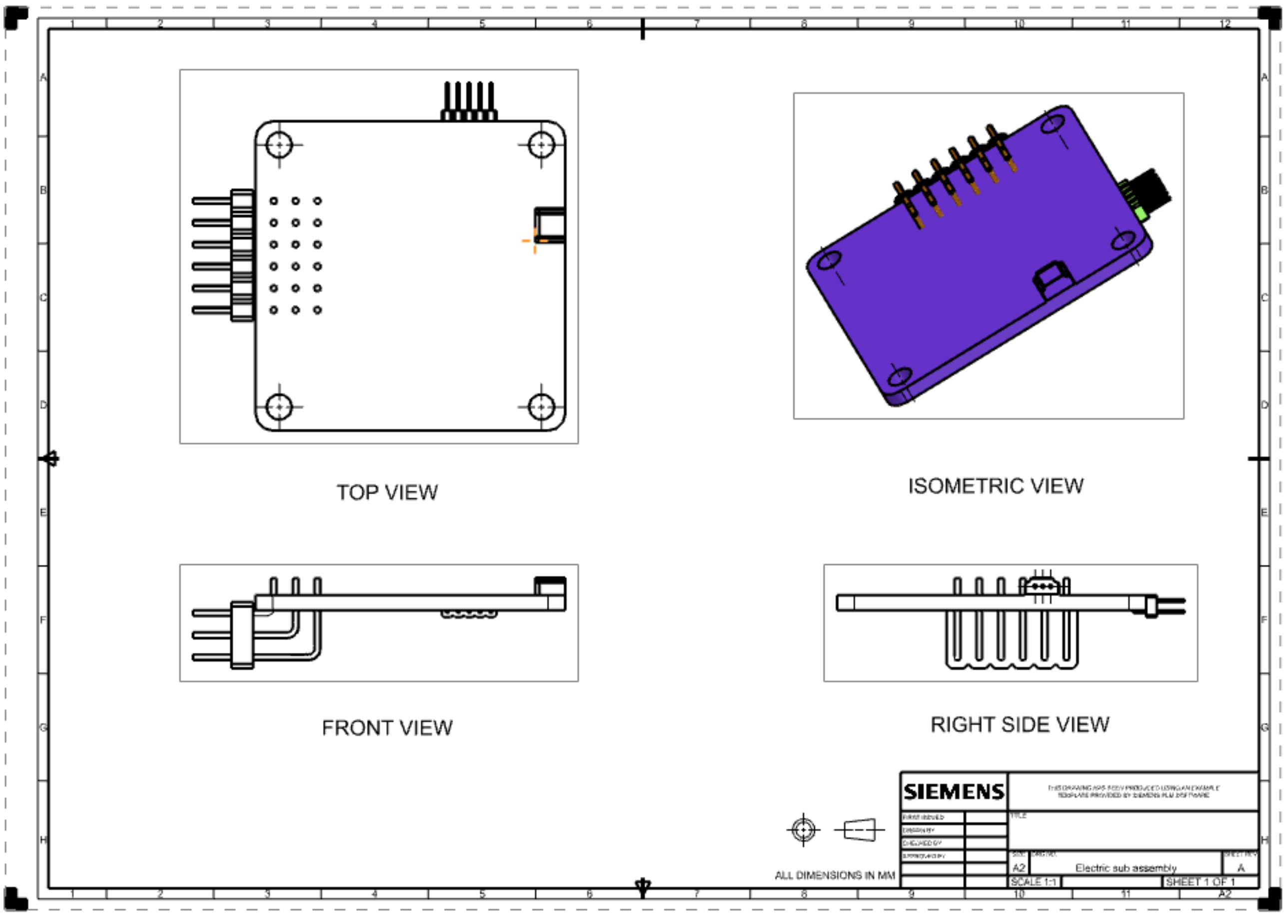

Figure 44. Drafting sheet of electric board subassembly

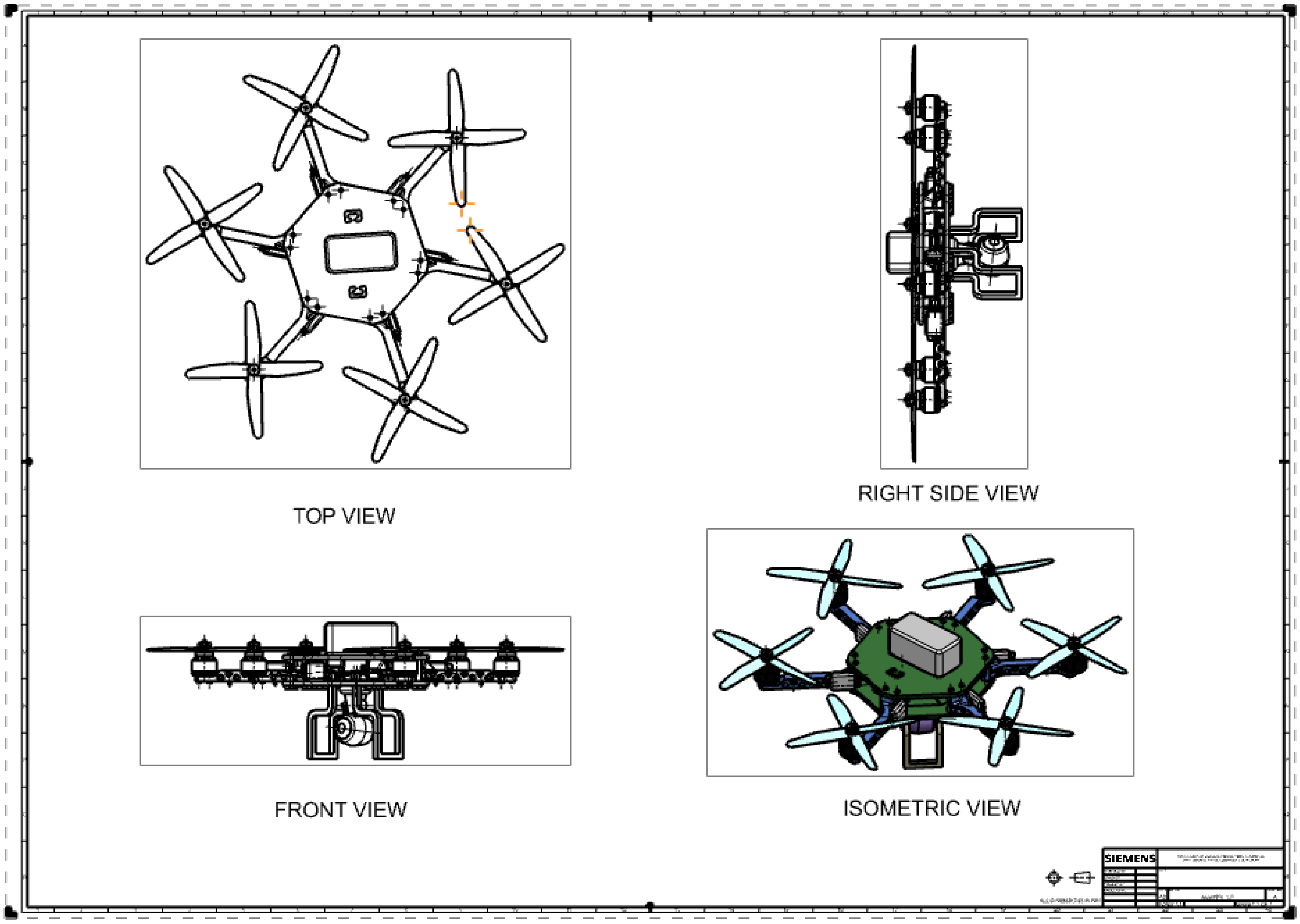

Figure 45. Drafting sheet of final assembly

7. CAM Modelling

```
(CREATED BY       : PROJECT GROUP 06                          )
(DATE             : 11.12.2022 , 16:13                        )
(PARTNAME         : SPIDER BASE_SETUP_1.PRT                   )
(CREATED BY       : KAVATHI                                   )
(DATE             : 11.12.2022 , 16:13                        )
(PARTNAME         : SPIDER BASE_SETUP_1.PRT                   )
N10 G17 G21 G94 G90

(DRILLING, TOOL : STD_DRILL)

N12 T00 M6
N14 G54
N16 G17 G0 G90 X97.923 Y-70.392 S200 M3
N18 G43 Z3. H0
N20 G94 G81 G99 Z-12.423 F250. R3.
N22 G0 Z24.629
N24 G81 X109.923 Y-49.608 Z-12.423 R3.
N26 G0 Z24.629
N28 G81 X12. Y-120. Z-12.423 R3.
N30 G0 Z24.629
N32 G81 X-12. Z-12.423 R3.
N34 G0 Z24.629
N36 G81 X-97.923 Y-70.392 Z-12.423 R3.
N38 G0 Z24.629
N40 G81 X-109.923 Y-49.608 Z-12.423 R3.
N42 G0 Z24.629
N44 G81 Y49.608 Z-12.423 R3.
N46 G0 Z24.629
N48 G81 X-97.923 Y70.392 Z-12.423 R3.
N50 G0 Z24.629
N52 G81 X-12. Y120. Z-12.423 R3.
N54 G0 Z24.629
N56 G81 X12. Z-12.423 R3.
N58 G0 Z24.629
N60 G81 X97.923 Y70.392 Z-12.423 R3.
N62 G0 Z24.629
N64 G81 G98 X109.923 Y49.608 Z-12.423 R3.
N66 G80
N68 M5
N70 M2
```

8. Finite Element Analysis

For several engineering and scientific issues, the FEA approach provides an approximation of the solution. It is primarily employed for issues for which there is no precise solution. It is a numerical approach as opposed to an analytical one. Finding the stresses and strains in engineering components under load was one of the initial uses of FEA. Any realistic model of an engineering component that uses FEA requires a lot of computing power.
We have done Finite element of analysis of the three main parts of the hexacopter body namely, arm, Spider base and camera stand.

Parameter chosen for analysis: -

- Analysis Type: Structural Analysis
- Material: Aluminum 6061
- Mass Density: 2.711e^{-06} kg/mm^3
- Mesh type: ctetra(4)
- Mesh size: 1 mm
- Force: 10N for Camera stand and Base plate, 5N for Spider arm

8.1 Spider arm Analysis

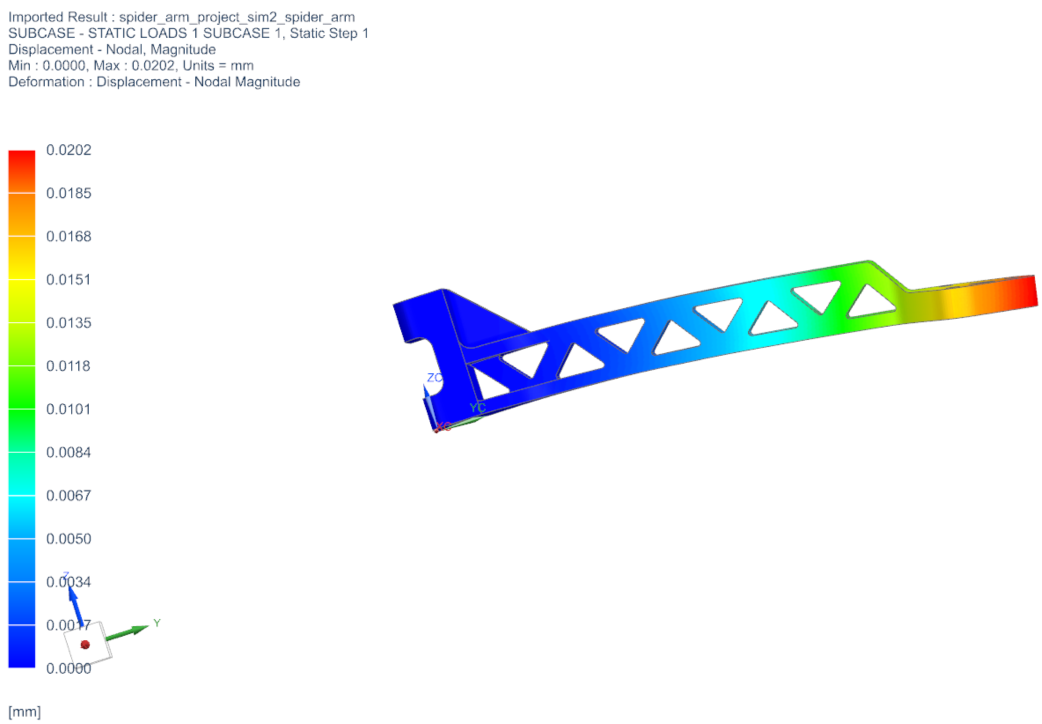

Figure 46. Spider arm Displacement analysis

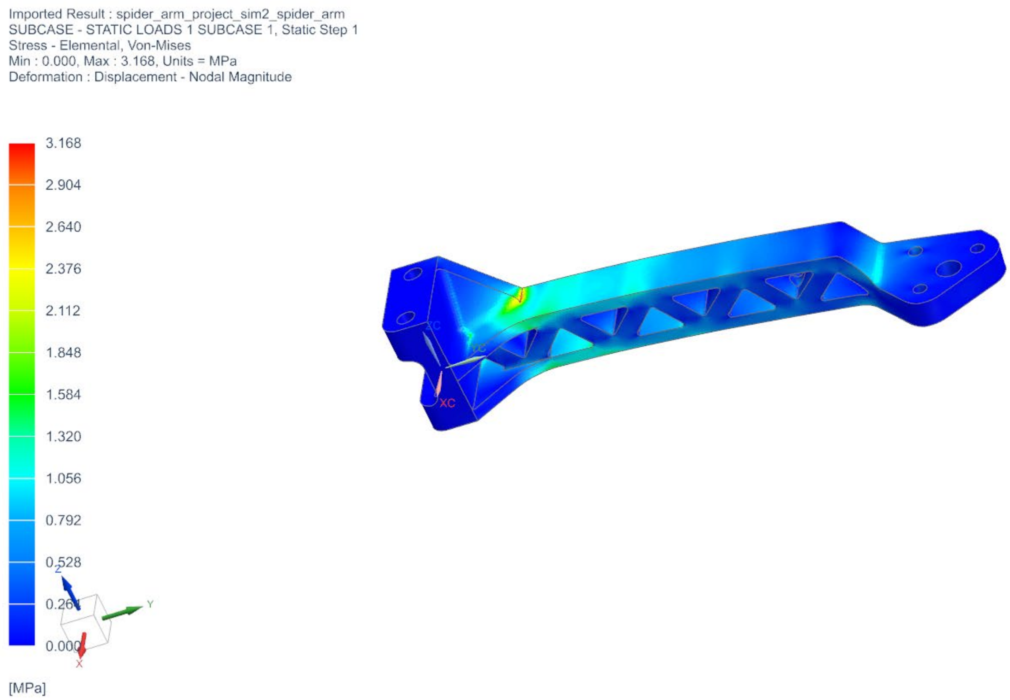

Figure 47. Spider arm Stress analysis

8.2 Spider Base plate analysis

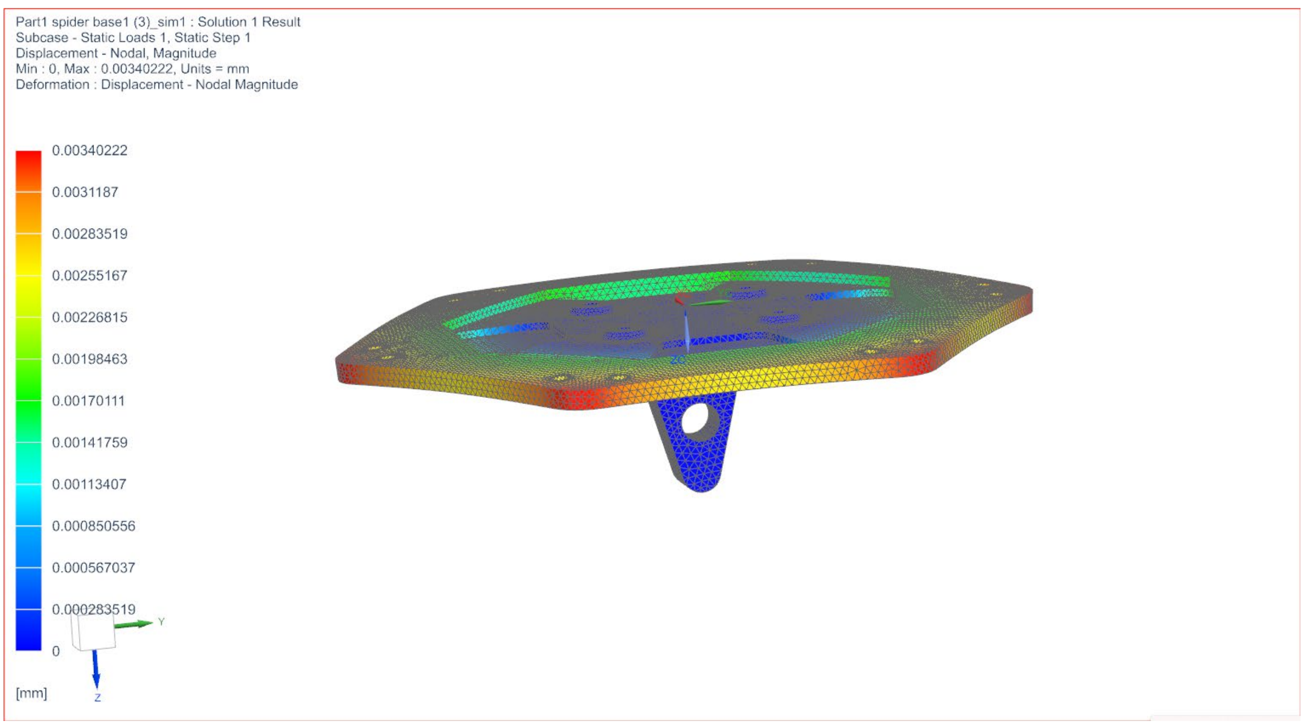

Figure 48. Spider Base plate Displacement analysis

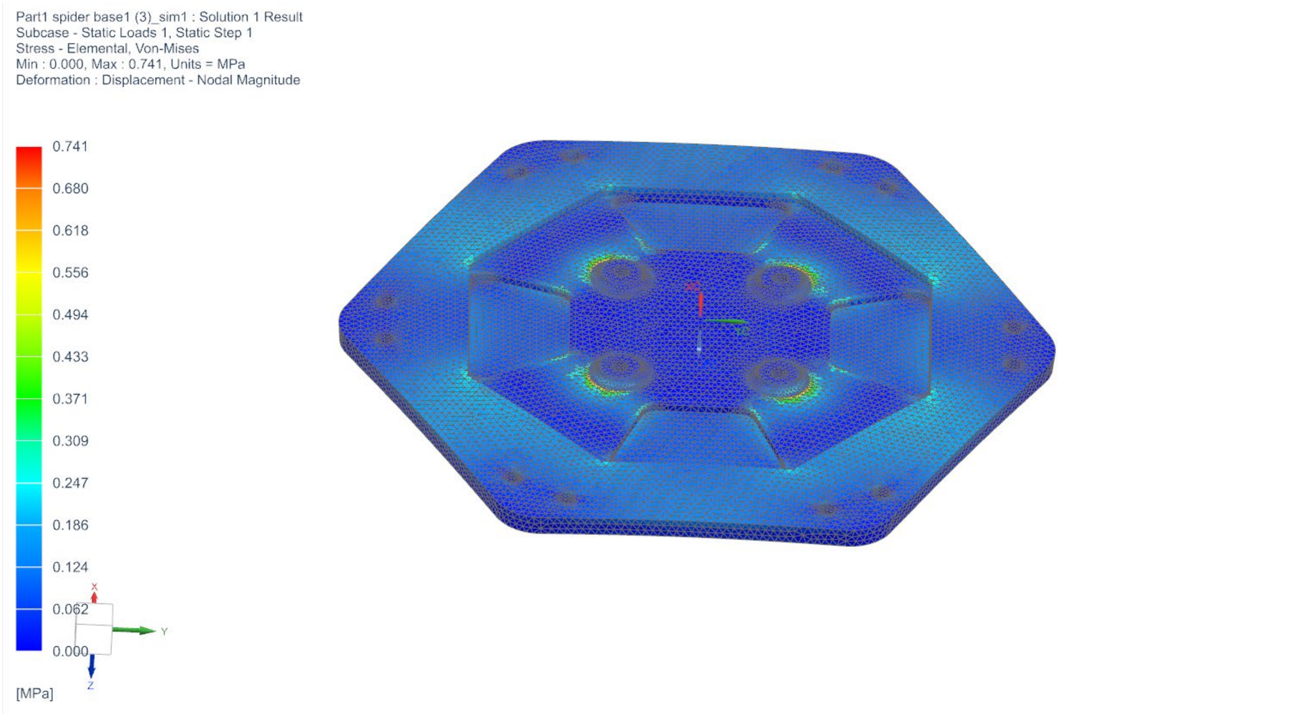

Figure 49. Spider Base plate stress analysis

8.3 Camera stand analysis

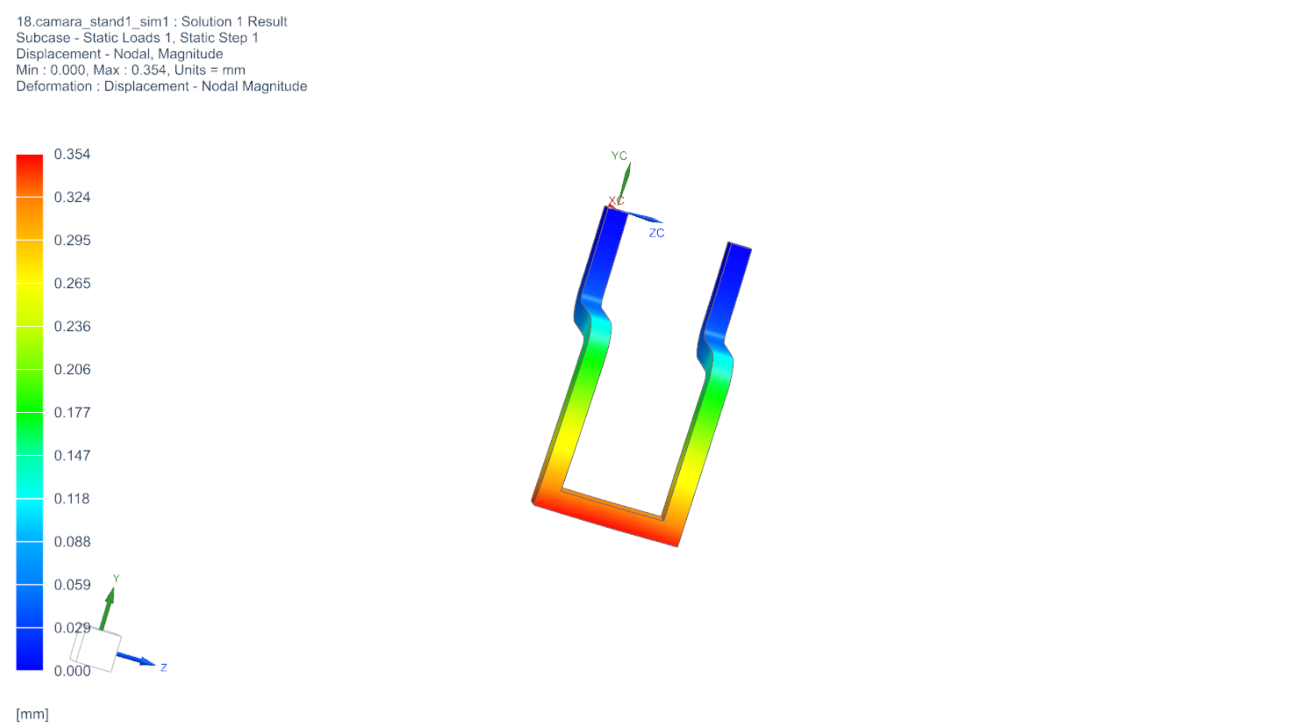

Figure 50. Camera stand Displacement analysis

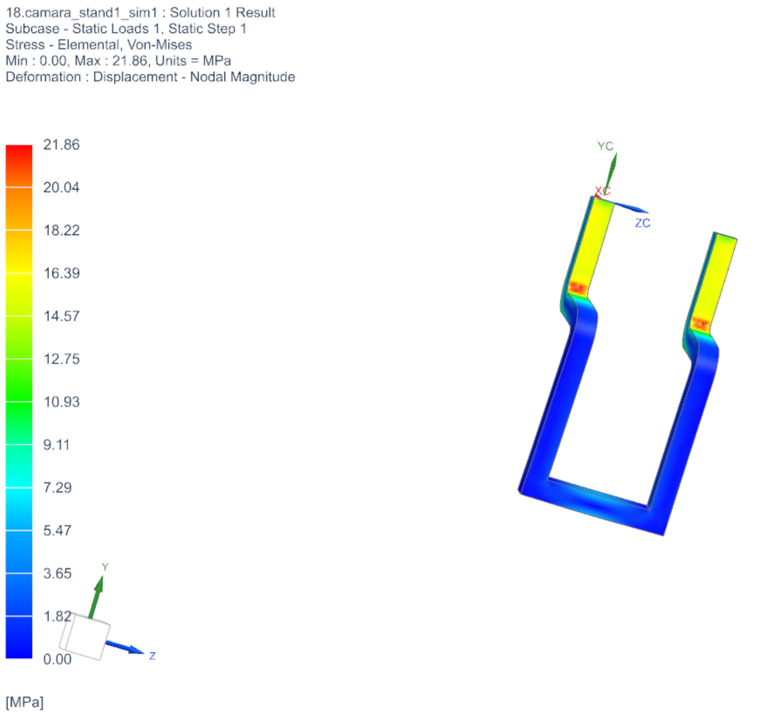

Figure 51. Camera stand Stress analysis

9. CFD Analysis

The forces acting on a drone's body are determined in part by fluid dynamics. The aerodynamics of the propellers or blades determine the size, shape, and speed of the drone. For the airflow dynamics above drones, computational fluid dynamics (CFD) modelling is helpful. To determine the amount of thrust produced by propellers, CFD modelling of motor is needed. For evaluating CFD data, wind tunnel testing of the drone's aero foil blade is still crucial.

Air seed considered for analysis in 20 m/s.

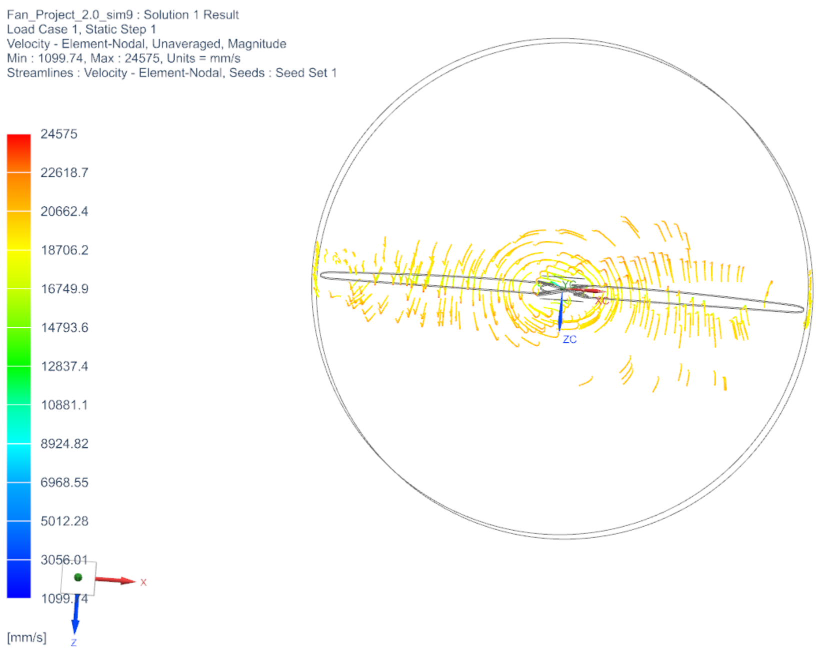

Figure 52. Propeller CFD analysis

Figure 53. Propeller CFD analysis

10. Results

The hexacopter we designed and assembled using Siemens NX shows that the concept is quite viable. Furthermore, Finite element study and CFD analysis support the fact that this model can withstand this specific loading situation. The proposed proposal is a feasible solution to the current drone-related predicament. By employing this method, general purpose drone may be transformed into a product that is adaptable, stiff, and more effective at performing tasks, which is what the present industrial settings require.

Additionally, there are a number of areas where we can make design and functionality enhancements. This device may be used as a reference by the drone manufacturing industries as they conduct research and development on multifunctional drones that are completely suited for industrial settings and can withstand those conditions while being economically viable. However, the drone business is facing obstacles such as a lack of infrastructure for air traffic control, which is in charge of safe flight operations in restricted airspaces. In addition to reducing operational difficulties, unified air traffic management can increase drone-related safety. These crucial elements are expected to prevent against property losses and environmental harm while supporting simultaneous drone operations in several places. However, by using the right strategy and effective techniques, these problems may be greatly overcome.

11. Future Scope:

For this project to be implemented in the market, which is its future aspect, simulation and adequate analysis are necessary. A part's stresses (structural and thermal) can be studied to determine whether or not it will fail and whether design changes are required to address possible issues. Design simulation enables manufacturers to validate and confirm the intended use of a product in development as well as the product's ability to be manufactured. Simulated engineering is frequently referred to as "simulation" in general (CAE). These issues will thus be the subjects of this project's future discussions. These tools enable the product to be improved and its efficiency to rise. Stress analysis helps in establishing the right dimensions and material to be chosen when modelling various sections and components.

12. Conclusion

Adding surveillance and object-transportation capabilities to an existing quadcopter model taught us how to develop our creativity in research and technology to find out alternatives for designing efficient and effective products by creating a multipurpose use to reduce cost and resources of the company.

Designing is a broad domain to explore, thus learning about design and working on this project in this field have expanded our perception of its vast breadth of area and value in the engineering sector. There are several purposes for both designing and drawing that contribute to accurately developing and effectively analyzing the final output. As we worked on this project, we encountered several technical and design challenges. These challenges stimulated our interest in learning how to address design challenges, which enabled us to complete the project. Additionally, we need to work on its design analysis, which we still need to understand, in order to launch this product on the market. To strengthen and improve our designing talents, we thus wish to learn how to undertake analysis in the near future.

Working on a team project always reveals the strengths and weaknesses of each participant, which may be useful when allocating tasks. The same way that some team members excel in modelling specific components while others do not, some excel at research work while others do not, some excel at creating reports and presentations while others do not, some excel at elaborating and communicating while others do not, and so on. Therefore, identifying each team member's strengths and weaknesses assists in allocating tasks, and everyone benefits from building on each other's weaknesses by learning from their strengths.

Overall, this project taught us how to use design software more productively. In large industrial and warehousing facilities where the safety of people and property is the biggest concern considering the drones as a moving vehicle. If the research and development is carried out while taking safety and security, drones will be the next game changer in the upcoming industry 4.0.

13. References

[1] Staff. “The Pros and Cons of Drones - Full Drone.” *Full Drone - the Wonderful World of Drones*, 2 June 2016, fulldrone.com/pros-and-cons-of-drones.

[2] “The Best Drones for Photos and Video.” *Wirecutter: Reviews for the Real World*, www.nytimes.com/wirecutter/reviews/best-drones. Accessed 26 Nov. 2022.

[3] Research Pvt Ltd, BlueWeave Consulting and. “Global Commercial Drone Market Size to Boom 5x to Touch USD 54.2 Billion by 2028 | BlueWeave Consulting.” *GlobeNewswire News Room*, 11 Oct. 2022, www.globenewswire.com/en/news-release/2022/10/11/2532136/0/en/Global-Commercial-Drone-Market-Size-to-Boom-5x-to-Touch-USD-54-2-Billion-by-2028-BlueWeave-Consulting.html

[4] “10 Drone Parts Everybody in Construction Should Know.” *Foundation Structure*, 26 Dec. 2016, www.foundationstructures.com/10-drone-parts-everybody-in-construction-should-know. Retrieved November 21, 2022, https://www.foundationstructures.com/10-drone-parts-everybody-in-construction-should-know/

[5] Oscar. “Quadcopter Hardware Overview - Every Component Explained - Oscar Liang.” Oscar Liang, 9 June 2018, oscarliang.com/quadcopter-hardware-overview, Retrieved November 13, 2022

[6] WAGTENDONK, WJ. Principles of Helicopter Flight. Newcastle, WA: Aviation Supplies & Academics, Inc., 2006. 304 p. ISBN 1-56027-649-5.

[7] POUNDS, P., MAHONY, R., CORKE, P. Modelling and Control of a Quad-Rotor Robot. In Proceedings of the Australasian Conference on Robotics and Automation, Auckland, New Zealand: Australian Robotics & Automation Association, Dec. 2006, p. 501-510.

[8] “What Are Drones Made of? Detailed Guide to Drone Anatomy [Consumer+Commercial] – the Corona Wire.”, www.thecoronawire.com/what-are-drones-made-of-detailed-guide-to-drone-anatomy. Accessed 30 Nov. 2022.

[9] Hindawi, and Marcin Biczyski. “Multirotor Sizing Methodology With Flight Time Estimation.” *Multirotor Sizing Methodology With Flight Time Estimation*, 20 Jan. 2020, www.hindawi.com/journals/jat/2020/9689604.

[10] Cherukuri, arvindpdmn, Jagannadha Rao. “Quadcopter.” *Devopedia*, 28 Feb. 2022, devopedia.org/quadcopter, Retrieved November 13, 2022, https://devopedia.org/quadcopter#:~:text=The%20main%20principle%20behind%20the,the%20quadcopter%20upwards%20against%20gravity.

[11] Pachputesharad, *Working Principle and components of drone · CFD Flow Engineering*. CFD Flow Engineering. Retrieved November 13, 2022, from https://cfdflowengineering.com/working-principle-and-components-of-drone/

[12] "Connect ESCs and Motors &Mdash; Copter Documentation." *Connect ESCs and Motors &Mdash; Copter Documentation*, ardupilot.org/copter/docs/connect-escs-and-motors.html. Accessed 5 Oct. 2022.

[13] Hegde, Navya & George, V. & Nayak, C. & Kumar, Kamlesh. (2020). *Transition flight modeling and robust control of a VTOL unmanned quad tilt-rotor aerial vehicle*. Indonesian Journal of Electrical Engineering and Computer Science. 18. 1252. 10.11591/ijeecs.v18.i3.pp1252-1261

[14] V. Artale, C. Milazzo and A. Ricciardello, *"Mathematical modeling of hexacopter"*, Applied Mathematical Sciences, vol. 7, pp. 4805-4811, 2013.

[15] E. Bekir, *Introduction to modern navigation systems*. Singapore: World Scientific, 2007, Accessed 5 Oct. 2022.

[16] Neutral reference model for engineering change propagation in global top-down modeling approach - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Top-down-modeling-approach_fig1_229040076 [accessed 09 Nov, 2022]

[17] *Free CAD Designs, Files & 3D Models | The GrabCAD Community Library*. (n.d.). Grabcad.com. Retrieved November 22, 2022, from https://grabcad.com/library/drone-581