МІНІСТЕРСТВО ОСВІТИ І НАУКИ
НАЦІОНАЛЬНИЙ ТЕХНІЧНИЙ УНІВЕРСИТЕТ УКРАЇНИ
«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ ІМЕНІ ІГОРЯ СІКОРСЬКОГО»
Інститут аерокосмічних технологій
Кафедра авіа- та ракетобудування

Дипломний проєкт

на здобуття ступеня бакалавра

за освітньо-професійною програмою «Літаки та вертольоти»
спеціальності 134 «Авіаційна та ракетно-космічна техніка»
на тему: « Транспортний мультикоптер »

Виконав (-ла): студент (-ка) IV курсу, групи ВЛ-72
Бетхаї Атефехсадат
Керівник: Асистент , кандидат технічних наук
Козей Ярослав Сергійович

Київ – 2021

					ВЛ7215.2500.000			
Изм.	*Лист*	*№ докум.*	*Подпись*	*Дата*				
Разраб.		*Бетхай А.*			« Транспортний мультикоптер »	*Лит.*	*Лист*	*Листов*
Провер.		*Козей Я.С.*					*1*	*2*
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Н. Контр.								
Утв.								

Національний технічний університет України
“Київський політехнічний інститут імені Ігоря Сікорського”

Інститут (факультет) *Аерокосмічних технологій*
(повна назва)

Кафедра *Кафедра авіа- та ракетобудування*
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Рівень вищої освіти – перший (бакалаврський)

Напрям підготовки 134 Авіа- та ракетобудування
(код і назва)

ЗАТВЕРДЖУЮ
В. о. завідувача кафедри
______ *В.В. Кабанячий* (підпис)
(ініціали, прізвище)

«___» ________ 2021 р.

ЗАВДАННЯ
на дипломний проект студентці

Бетхаї Аті
(прізвище, ім’я, по батькові)

1. Тема проекту: *Транспортний мультикоптер*

керівник проекту Козей Ярослав Сергійович, к.т.н.
(прізвище, ім’я, по батькові, науковий ступінь, вчене звання)
асистент кафедри АРБ

затверджені наказом по університету від «___» _______ 20*21* року №______

2. Термін подання студентом проекту: *11 червня 2021 р.*

3. Вихідні дані до проекту:

3.1 Характеристики: сучасних акумуляторів, безколекторних електродвигунів, повітряних гвинтів, матеріалів, компонентів

4. Зміст пояснювальної записки:

4.1. Аналіз літератури по темі важких мультикоптерів та існуючих варіантів технічної реалізації транспортних мультикопткрів. Постановка завдання.

4.2. Розрахунок масово-енергетичних характеристик.

4.3. Математична модель динаміки польоту.

4.4. Створення візуально-просторової моделі мультикоптера.

4.5. Собівартість та монетизація важкого мультикоптера.

4.6. Розробка технічної документації

Изм.	Лист	№ докум.	Подпись	Дата	ВЛ7215.2500.000	Лист 2

5. Перелік графічного матеріалу (із зазначенням обов'язкових креслеників, плакатів, презентацій тощо):

5.1 Аналіз аналогів та постановка завдань на дипломний проект.
5.2 Розрахунок масово-енергетичних характеристик.
5.3 Математична модель динаміки польоту.
5.4 Візуально-просторова модель мультикоптера.
5.5 Собівартість та перспективи розвитку.

6. Консультанти розділів дисертації

Розділ	Прізвище, ініціали та посада консультанта	Підпис, дата	
		завдання видав	завдання прийняв

7. Дата видачі завдання: *25 лютого 2021 р*

КАЛЕНДАРНИЙ ПЛАН

№ з/п	Назва етапів виконання дипломного проекту	Термін виконання етапів проекту	Примітка
1.	*4.1. Аналіз літератури по темі важких мультикоптерів та існуючих варіантів технічної реалізації транспортних мультикопткрів. Постановка завдання.*	*до 29.03.2021 р.*	
2.	*Розрахунок масово-енергетичних характеристик.*	*до 12.04.2021 р.*	
3.	*Математична модель динаміки польоту.*	*до 30.04.2021 р.*	
4.	*Розрахунок навантажень що діють на мультикоптер*	*до 5.05.2021р.*	
5.	*Визначення основних характеристик мультикоптера.*	*до 15.05.2021 р.*	
6.	*Візуально-просторова модель мультикоптера..*		
7.	*Собівартість та монетизація мультикоптера.*	*до 27.05.2021 р.*	
8.	*Оформлення пояснювальної записки та графічних матеріалів*	*до 10.06.2021 р.*	
9.	*Перевірка на плагіат*	*до 13.06.2021 р.*	
10.	*Захист*	*з 14.06.2021 р. по 30.06.2021 р*	

Студентка ____________ *Аті БЕТХАЇ*
(підпис) (ініціали, прізвище)

Керівник проекту ____________ *Ярослав КОЗЕЙ*
(підпис) (імя, прізвище)

Пояснювальна записка

до дипломного проєкту

на тему: « Транспортний мультикоптер »

Київ – 2021

АНОТАЦІЯ

Проект представляє дипломну роботу бакалавра "Важкий транспортний мультикоптер", проект містить 70 сторінок, 40 малюнків , 3 таблиці.
Квадрокоптер може стабільно досягати вертикального польоту і використовуватись для моніторингу або збору даних у певному регіоні, наприклад, при завантаженні маси. Технологічні досягнення знизили вартість і збільшили продуктивність мікроконтролерів малої потужності, що дозволило широкому загалу розробити власний квадрокоптер. Метою цього проекту є побудова, модифікація та вдосконалення квадрокоптера для отримання стабільного польоту, збору та зберігання даних GPS та виконання автокоманд, таких як автоматична посадка. В проекті використовується поточний квадрокоптер, який може належним чином стабілізувати себе, визначити своє місце розташування GPS, а також зберігати та реєструвати дані Більшість цілей у цьому проекті були досягнуті, що призвело до стабільного та маневреного квадрокоптера. КЛЮЧОВІ СЛОВА Дрон / квадооптер, передавач і пульт, пропелери, електродвигуни, акумулятор

ABSTRACT

The project presents the bachelor graduation thesis “ Heavy transport Multicopter “ , the project contains 70 pages , 40 figures and 3 tables.

A quadcopter is a vehicle which fly vertically and has to be stable . with flying it will collect data for many reasons and also it can carry masses for different usages . the main goal of designing projects is to determine the highest performance with the lowest cost of the projects . This project tried to lead to build , modify and make the improvement of quadcopter with the highest capabilities . quadcopter can determine it’s position by satellite and GPS data and also stabilized itself with the controllers . In this project the stability , cost and maneuverability of a quadcopter has been studied .

1. *Analysis of the literature on the topic of heavy multicopters (drone) and existing technical options , implementation of transport multicopters.*

1.1 general information and history

A drone, in technological terms, is an unmanned aircraft. Drones are more formally known as unmanned aerial vehicles (UAVs) , unmanned aircraft systems (UASes)
,
Remotely Piloted Aerial System (**RPAS)** or Small Unmanned Aircraft System **(SUAS) .** Essentially, a drone is a flying robot that can be remotely controlled or fly autonomously through software-controlled flight plans in their embedded systems, working in conjunction with onboard sensors and GPS.
For our purposes, technologies in the drone sector will be broken down into two categories: drones that require a human operator to guide its missions and autonomous drones, which do not.
On Earth, drones are often used for military purposes because they don't put a pilot's life at risk in combat zones. In addition, drones don't require rest, enabling them to fly as long as there is fuel in the craft and there are no mechanical difficulties.

Technically speaking, space borne drones could include cargo spacecraft, satellites and machines that leave Earth, although they aren't usually referred to as such.

The history of drones

Many trace the history of drones to 1849 Italy . In July 1849, the earliest known recording of an unmanned aerial vehicle being used in warfare was the Austrian incendiary balloon attack on Venice. Around 200 balloons (each carrying a 25 to 30 pound bomb) were launched from land and then dropped onto the city using a time fuse. The marked the beginning of drone warfighting in history.
The first pilotless radio-controlled aircraft were used in World War I. In 1918, the U.S. Army developed the experimental Kettering Bug, an unmanned "flying bomb" aircraft, which was never used in combat.
The first generally used drone appeared in 1935 as a full-size retooling of the de Havilland DH82B "Queen Bee" biplane, which was fitted with a radio and servo-operated controls in the back seat. The plane could be conventionally piloted from the front seat, but generally it flew unmanned and was shot at by artillery gunners in training. The term drone dates to this initial use, a play on the "Queen Bee" nomenclature.[1]

UAV technology continued to be of interest to the military, but it was often too unreliable and costly to put into use. After concerns about the shooting down of spy planes arose, the military revisited the topic of unmanned aerial vehicles. Military use of drones soon expanded to play roles in dropping leaflets and acting as spying decoys.

Military drone use solidified in 1982 when the Israeli Air Force used UAVs to wipe out the Syrian fleet with minimal loss of Israeli forces. The Israeli UAVs acted as decoys, jammed communication and offered real-time video reconnaissance.

Drones have continued to be a mainstay in the military, playing critical roles in intelligence, surveillance and force protection, artillery spotting, target following and acquisition, battle damage assessment and reconnaissance, as well as for weaponry. [1]

Figure 1.1.1 . Winston Churchill and the Secretary of State for War waiting to see the launch of a de Havilland Queen Bee radio-controlled target drone, 6 June 1941

Who Made the First Drone?

The world’s first-known quadcopter was created back in 1907 by two brothers named Jacques and Louis Breguet. They were working side-by-side with the controversial Nobel Prize winner Professor Charles Richet at the time. An exciting discovery indeed, it was also plagued with problems off the get go. It required four men to steady it and it could only fly two a mere two feet off the ground .

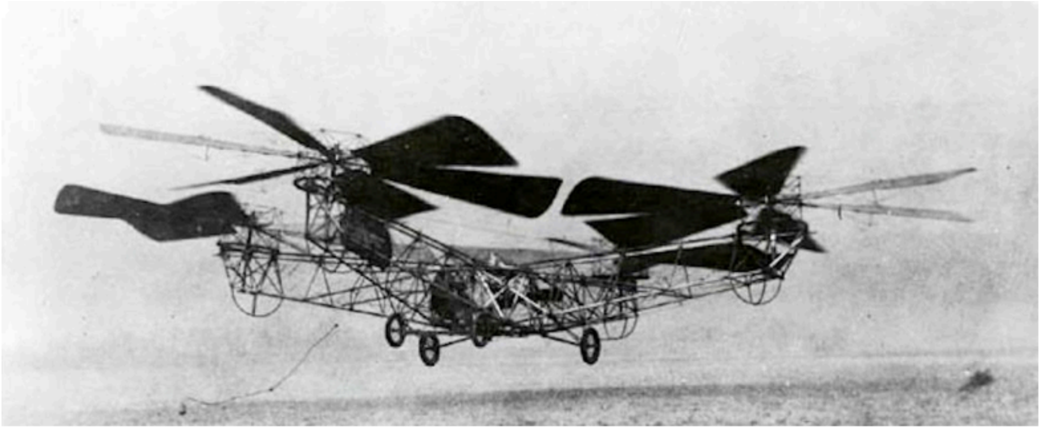


Figure 1.1.2 . Quadcopter designed by George De Bothezat, making descent at McCook Field after remaining airborne for two minutes, 45 seconds. Picture from Edison National Historic Site archives.

The first military drone was launched in 1917 during World War 1 and known as the *Ruston Proctor Aerial Target*. It was the first unmanned, radio-controlled aircraft in history and based upon Nikola Tesla’s RC technology. It was designed to act as a flying bomb that could be safely piloted into enemy territory. Ultimately, it was never used in combat but led to the creation of *The Kettering Bug* to be used later in the war.

In World War 2, Reginald Denny created the very first remote controlled aircraft. It was called the *Radio plane OQ-2* and was the first massed produced drone made in the United States. This was a major milestone in the manufacturing of drone for the military. A follow-up version called *the Radio plane OQ-3*later became the most widely used drone in the history of the United States service. Over 9,400 were built during World War 2 . [2]

Different Types of Drones & classifications *:*

And while the fact that there are so many different types of drones out there may seem overwhelming to some, the truth is, that’s a good thing.

Having a wide variety of options available on the market means you’re bound to find one that fits your needs perfectly – all you need is a little help figuring it out.

And while the most common drone classification is according to the **type and number of propellers** they have, there are a few more factors worth mentioning here:

- Size
- Range
- Abilities

1. *Types of Drones According To Aerial Platforms*

Since this is the most common – and arguably, the most important – classification of drone types, we're going to take our sweet time and go into details of these **four main types of drones according to the aerial platform** they use [3] :

1) Single-Rotor

As the name suggests, these units only feature one fairly large rotor (not counting the small one at the tail, of course), and strongly resemble a real-life helicopter in both their structure and design.

And because they're more efficient at generating thrust than their multi-rotor counterparts, they're suitable for longer flight times, which can further be increased by using a gas-powered motor. With two large rotor blades, there's a much higher risk of serious injury in case you find yourself on their path or lose control over them – and the fact that they're not as stable as multi-rotor drones don't help their case, either.
With two large rotor blades, there's a much higher risk of serious injury in case you find yourself on their path or lose control over them – and the fact that they're not as stable as multi-rotor drones don't help their case, either.

Figure 1.1.3 . single rotor drone

2) Multi-Rotor

Multi-rotor drones are, by far, the most common types of drones used by both hobbyists and professionals alike – and out of the four main drone types discussed in this category, they are the cheapest option available, too .

While you're most likely to call them "drones," there are alternative names you should get yourself familiar with, based on the **number of rotors they have on the aerial platform**:

- Multicopters, which serves as an "umbrella term" that covers all multi-rotor drone types
- Tricopters

- Quadcopters - Our specialty
- Hexacopters
- Octocopters

As they give the user so much control over positioning and framing, they're perfect for perfect for aerial photography, and generally getting an eye in the sky .

How ever they have some few downsides . Although they keep improving, they're still rather inefficient regarding flight time and speed – most can only stay airborne for around 20 to 30 minutes. **The more rotors you add, the less flight time you get.**

3) ***Fixed-Wing***

These types of drones use the same principle as airplanes – using wings to generate lift, rather than vertical-thrust-generating rotors.

Fixed-wing drones only need energy to keep the forward motion going, while the wings generate vertical lift as they go, which makes them much more efficient at covering longer distances, mapping broad areas, and staying close to their point of interest as long as the energy source allows it.Some models can even be gas powered, which allows them to stay airborne for up to 16 hours at a time!

However, they aren't able to hover in one place, which makes launching and landing quite problematic – only small models can be launched by hand, while also surviving a "belly landing." Plus, you can pretty much rule them out as a means of taking aerial photos and videos.

Figure 1.1.5 . Fix Wing , SkyCruiser A22

4) Fixed-Wing Hybrid

By bringing together the benefits of fixed-wing drones with the ability to hover seen in rotor-based models, a new type of drones was born – fixed-wing hybrids.

And although they all have one thing in common – vertical take-off and landing – they come in several variations:

- A fixed-wing design paired with a vertical-lift motor
- Tail-sitting aircraft that point vertically for take-off, then pitch over to fly horizontally
- Tilt-rotor models that feature rotors or wings that can swivel from pointing upwards to a horizontal position

The concept was initially tested back in the 60's – but only the new-gen sensors, such as gyros and accelerometers, managed to breathe new life into the idea.

2. ***Types of Drones According To Their Size*** :

1) **Very Small (Nano/Micro) Drones** – The very small UAV class applies to UAVs with dimensions ranging from the size of a large insect to 30-50 cm long. The insect-like UAVs, with flapping or rotary wings, are a popular micro design. They are extremely small in size, are very light weight, and can be used for spying and biological warfare. Larger ones utilize conventional aircraft configuration. The choice between flapping or rotary wings is a matter of desired maneuverability. Flapping wing-based designs allow perching and landing on small surfaces. Examples of very small UAVs are the Israeli IAI Malat Mosquito (with wing span of 35 cm and endurance of 40 minutes,) the US Aurora Flight Sciences Skate (with wing span of 60 cm and length of 33 cm), the Australian Cyber Technology CyberQuad Mini (with 42x42 cm square), and their latest model, CyberQuad Maxi.

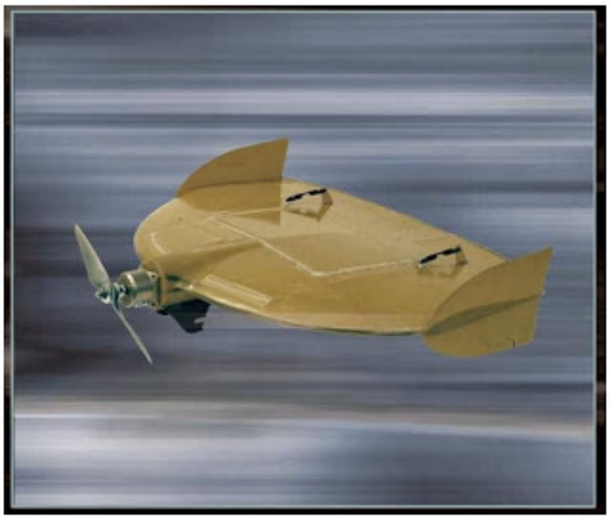


Figure 1.1.7 . Israeli IAI Malat Mosquito

2) **Small Drones** – The Small UAV class (which also called sometimes mini-UAV) applies to UAVs that have at least one dimension greater than 50 cm and no larger than 2 meters. Many of the designs in this category are based on the fixed-wing model, and most are hand-launched by throwing them in the air . Examples of this small UAV are : 1 meter long RQ-11 Raven, by US Aero Vironment with a wingspan of 1.4 m or US Army RQ-7 Shadow .

Figure 1.1.8 . RQ-11 Raven

3) **Medium Drones** – The medium UAV class applies to UAVs that are too heavy to be carried by one person but are still smaller than a light aircraft. They usually have a wingspan of about 5-10 m and can carry payloads of 100 to 200 kg. Examples of medium fixed-wing UAVs are (see Figure 1.6, below) the Israeli-US Hunter and the UK Watchkeeper. There are other brands used in the past, such as the US Boeing Eagle Eye, the RQ-2 Pioneer, the BAE systems Skyeye R4E, and the RQ-5A Hunter. The Hunter has a wingspan of 10.2 m and is 6.9 m long. It weighs about 885 kg at takeoff. The RS-20 by American Aerospace is another example of a crossover UAV that spans the specifications of a small and medium sized UAV. Many other medium UAVs can be found in the reading assignment. There are also numbers of rotary-based medium sized UAVs.

Figure 1.1.9 . RQ-2 Pioneer

4) **Large Drones** – The large UAV class applies to the large UAVs used mainly for combat operations by the military. Examples of these large UAVs are the US General Atomics Predator A and B and the US Northrop Grumman Global Hawk .

Figure 1.1.10 . General Atomics Predator B

3. *Types of Drones According To Their Range: The Further, The Better*

The drone’s range is determined by how far away it’s capable of flying before the signal breaks, and you lose control over your aircraft, at which point a crash-landing is inevitable.

Of course, the bigger the range, the better – but keep in mind that not all of these drone types are available to the general public.

1) **Very Close Range** – The very-close-range category usually only includes the so-called toy or hobby drones, which have a range of around 3 miles or so, and can stay in the air for about 20 to 45 minutes, depending on the batteries.

2) **Close Range** – These can fly approximately 30 miles away from the user (a significant improvement compared to very close range drones), and their batteries allow them to stay airborne for up to six hours.

3) **Short Range** – Being able to stay airborne for approximately 8 to 12 hours, with a maximum range of a little over 90 miles (which gives them an edge over their close-range counterparts), short-range drones are most suitable for spying and surveillance purposes.

4) **Mid-Range** – These high-speed drones are capable of covering areas of up to 400 miles, which makes them suitable not only for surveillance purposes but for gathering scientific data (especially meteorological data), as well.

5) **Endurance** – The most notable thing about this type of drones is that they can go beyond the 400-foot threshold, reaching heights of up to 3000 feet, and staying up in the air for hours on end.

4. Types of Drones According To Their Abilities & Equipment

And according to their „special powers," drones can be split up into the following categories:

1) **GPS Drones** – These drones link up to satellites via GPS and use that as a means of mapping out the direction of their flight, and automatically returning to their base in case they're running low on battery power, or they go outside your reach.

2) **RTF Drones** – Ready-to-fly (RTF) drones are ideal for beginners because they require little to no assembly – all you need to do is charge up the battery, and you're ready to take it for a spin .

3) **Trick Drones** – Mostly used as toys, these drones are usually only 10 inches long and weigh no more than a few ounces. Their size allows them to pull off lots of different maneuvers, such as barrel rolls and flips, while they're up in the air.

4) **Racing Drones** –These light and agile drones are stripped of any additional features and excess weight, which allows them to achieve speeds of around 60 miles per hour easily – although it often costs them their range and flying times.

5) **Photography/Video Drones** – Simply put, photography/video drones have cameras attached to their body, allowing you to get a bird's eye view of the world.

6) **Waterproof/Underwater Drones** – While most drones can't handle getting wet, others will gladly go for a swim – their electronic components are entirely sealed off, so that water can't reach them.

7) **Alternative-Powered Drones** – It may come as a surprise, but not all drones use batteries – there are types of drones that use alternative power sources, or, rather, fuels, such as gas powered or nitro fuel, to run.

8) **Delivery Drones** – is an unmanned aerial vehicle (UAV) used to transport packages, medical supplies, food, or other goods. Delivery drones are typically autonomous.

In this paper we are going to discuss and design specially the Quadcopter :

Quadcopters have the qualities of different helicopters. Helicopters are either pitched or co- axial. While pitched ones are agile and wind resistant, co-axial ones, which depend on two layers of rotors, are more stable. Quadcopters are a comfortable blend of both. Three-axis gyro technology enhances their stability. Pilots control the quadcopter with the joysticks on a remote-controlled transmitter. A receiver on the quadcopter processes the pilot's instructions. The pilot's signals combine with output from the quadcopter's altitude sensors. The flight controller then signals the Electronic Speed Controllers (ESCs), which in turn move the quadcopter's motors.

Newton's law of motion states that for every action, there is an equal and opposite reaction. The four rotors, two moving clockwise and the other two, counter-clockwise, negate any force or torque on the fuselage. They stabilize movement and function.

Ways to use quadcopters :

1) ***Research***

University researchers, who work in various fields, use the quadcopter as a research tool. They gather information needed for work on robotics, flight control and real-time systems. Quadcopters make suitable test platforms, as they are relatively cheaper and smaller. Anyone can fly them, which makes them convenient tools for researchers.
Apart from this, these durable little devices can survive harsh environments. They can go into dangerous places on behalf of researchers. This helps solve many difficulties with cost and logistics.

2) ***Military, law enforcement and community agencies***

Military scientists in different countries invented quadcopters for combat and reconnaissance
purposes. They still serve these functions.
Law enforcement agencies use them in search and rescue operations as well. These little aerial vehicles scour inaccessible areas for disaster survivors. Agencies also use them to uncover criminal activity. One of these drones is the Aeryon Scout, developed by Canadian Company Aeryon Labs. It has helped uncover drug trafficking rings in Central America.

Figure 1.1.11 . Aeryon Scout micro drone Gopro Hd Hero2

3) ***Commercial use and aerial photography***

Amateur pilots and enthusiasts love quadcopters as their dazzling aerial stunts make excellent
conversation topics.

These days, many use them to capture aerial images and videos. Three-axis gyro technology stabilises many of the latest quadcopters, allowing them to capture these images without a shaky, “jello” effect.
Expert pilots regard Go Pro cameras as the best ones to use with quadcopters. Pilots of Walkera, Blade and DJI quadcopters can make use of their Go Pro cameras, the Go Pro channel and the Go Pro application on the smart phones. They can easily attach these cameras to their quadcopters for filming. The DJI Phantom Vision 2 and the DJI Phantom 2 Vision Plus have wonderful filming capabilities. Three-axis gimbals allow them to capture smooth videos. Pilots can capture more stunning images by loading quadcopters with Go Pro cameras.

Figure 1.1.12 . DJI Phantom Vision 2

4) *Augmented Reality Games*

Apart from being able to use them with cameras, pilots can play augmented reality games with their quadcopters as well. Augmented reality gives them a perspective of the real world, with a few thrilling enhancements. The real-world simulation makes the games enticing for older children and teens. Mission Helicopter is one such game. Pilots simply need to push items through obstacle courses without “blowing up” their quadcopters. Ideal for younger players, the graphics are eye-catching and the controls, easy to manipulate.

5) *Solving problems with motion*

Athletes and those with disabilities often encounter problems with movement. Quadcopters may help ease their burdens.

Raffaella D'Andrea, a scientist at Ted Global, explained how quadcopters can complete difficult, physical tasks human beings cannot. In a demonstration, he balanced a wine glass filled with water on top of a quadcopter. The device flew without spilling water out of the glass. The high speed of the quadcopter negated the aerodynamic effects and gravitational pull on the water. What helped further was that the quadcopter's propellers pointed upwards, in the same direction as the glass.
Such findings help athletes, who can develop greater speeds and better posture to overcome problems with gravity and aerodynamics.

6) Delivering food and medicine

Quadcopters, being minute, can reach places humans cannot. In future, community agencies may use them to deliver food and medicine to inaccessible areas where roads are completely cut off. Andreas Raptopoulous, a researcher at Matternet, explained how the quadcopter can transport about 2Kg (4.41 pounds) of medicines to these areas in about 15 minutes. He introduced Matternet, a system of flying vehicles and landing stations, controlled by routing software.
Quadcopters can navigate into ground stations, in safe areas, to deliver food and medicine. The routing software guides the quadcopters through adverse weather. This will help people in hard-to-reach areas recover and progress.

1.2Processing of statistical data

1) DJI Mavic 2 Pro

The Mavic 2 Pro from DJI is a drone that balances power, portability, and professional-quality visuals with the inclusion of a 20MP Hasselblad L1D-20c gimbal camera. The camera delivers a 1" CMOS sensor with an adjustable f/2.8 to f/11 aperture, support for a 10-bit Dlog-M color profile, and 4K 10-bit HDR video capture.

The Mavic 2 Pro utilizes a low-drag aerodynamic body design for achieving speeds up to 47.7 mph, a four-cell LiPo battery for up to 31 minutes of flight time, and low-noise propellers for filming without being distracting. This power and performance are coupled with a variety of dynamic shooting modes and other capabilities that help you achieve cinematic results.[4]

Figure 1.1.13 . DJI Mavic 2 Pro

2) PC-1 Multipurpose Quadcopter

PC-1 lightweight, vertical take-off and landing (VTOL) multi-rotor helicopter is currently operational with the Armed Forces of Ukraine, and manufactured by Ukrainian drone maker, Ukrspecsystems.
Capable of carrying a variety of payloads, the quadcopter can be used for a wide range of military and tactical missions, including intelligence, surveillance, reconnaissance, detection and tracking of ground targets, and search-and-rescue.
In addition to military operations, the unmanned helicopter can be used for special forces missions such as emergency response, inspection and monitoring. The drone has the ability to conduct missions in complex urban environments. [5]

Figure 1.1.14 . PC-1

3) IF750 Enterprise Quadcopter Drone Platform

The ultimate tool for industrial UAV applications, the IF750 quadcopter couples payload adaptability with robust architecture to bring operational efficiency to the next level. The IF750's flexibility enables multiple full-

stack solutions, facilitating physical asset inspections, geospatial applications, defense applications, and much more. This system is an optimal OEM solution for organizations to integrate their specific technology into an open-source UAV ecosystem.
The IF750 can be provided as one of several complete industrial drone solutions, or as the ideal vehicle to integrate and field your organization's custom technology. With a proven, reliable modular drone platform to incorporate into you or your customers' workflows, you can focus on your strengths and the vital deliverables of your missions. [6]

Figure 1.1.15 . IF750 Enterprise Quadcopter

4) GRIFF 135 Quadcopter

Redefining the world of Unmanned Aerial Systems. The GRIFF 135 is built on the GRIFF 2.0 Master Design, the new modular design which enables rapid, easy swapping of payload and batteries in mere seconds. The GRIFF 135 has been built to the demands of the market - it can a 30kg (66 lb) payload for 45 minutes yet can lift a maximum of 75kg (165 lb). It comes ready to fly with a dual battery set that can be charged in just one hour. With an optional second pack, you'll be able to fly continuously. Its compact folded dimensions make transportation a breeze - it measures just 77cm wide x 144cm long in this state, with a height of 47cm. The GRIFF 135 expands to ready-to-fly dimensions of 226cm x 241cm x 47cm. [7]

Figure 1.1.16 . Griff 135 quadcopter

Table 1.1

Comparative data

parameters	*DJI mavic 2 pro*	*PC -1*	*IF 750*	*Griff 135*
Dimension (mm)	83*83*198	530*480*130	965*965*415	226*241*47
Max takeoff weight (kg)	0.907	5.6	6.2	135
Payload capacity (kg)	0.400	1	2	30
Max horizontal ground speed(m/s)	20	20	10	25
Max Altitude (m)	5000	1000	3500	4000
Flight time (min)	31	38	15-30	25-30

1.3 Design method of quadcopter

Quadcopter is aerial vehicles with 4 propellers that produce a vertical thrust similar to a helicopter, but unlike a helicopter, no tail rotor is required for stability. The Quadrotor's attitude (aircraft orientation relative to the vehicle's center of gravity) is completely controlled by four propellers and a control system programmed on a microcontroller. Figure 1.1.17 shows the three axes of rotation on which the aircraft's attitude is defined.

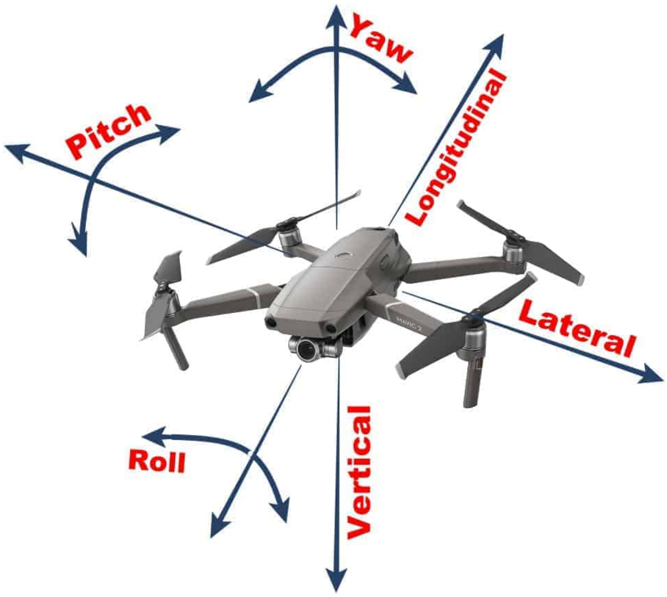


Figure 1.1.17 Quadcopter attitude axes

Roll, pitch, and yaw are controlled by increasing and decreasing the thrust produced by sets of motors. Figure 3 shows the top view of AirWolf II along with the rotational direction of the propellers and the associated motor numbers .

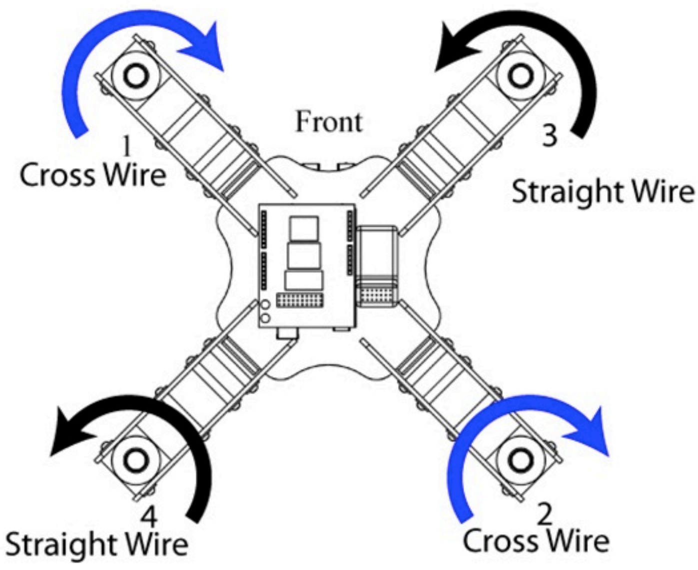


Figure 1.1.18 Motor numbers and propeller rotational direction

A right side roll of the aircraft is performed, for example, by increasing the thrust produced by motor set 1 and 4 while decreasing the thrust produced by set 2 and 3. Similar logic is applied to explain the control of pitch. While the explanation of roll and pitch are fairly straight forward, the explanation of how yaw is controlled is more interesting. The control of yaw is explained by the resulting torque produced by a motor. When the motor applies a torque to a propeller, a counter torque is applied to the aircraft. This counter torque phenomenon is the reason why a standard helicopter must have a tail rotor to compensate for the torque produced by the main engine. Quadcopters, on the other hand, use the torque produced by sets of propellers/motors to control yaw. For example, increasing the torque produced by motor set 1 and 2 while decreasing the torque produced by set 3 and 4 will cause a counter-clockwise rotation about the yaw axis.

Now that a primary understanding of quadrotor helicopters has been established an analysis of the aircraft can be performed. The next section of this report covers static thrust and its relevance to quadcopters.

References and Sources :

https://internetofthingsagenda.techtarget.com/definition/drone [1]
https://tipsfordrones.com/the-history-of-drones-milestones-you-have-to-know/ [2]
https://buybestquadcopter.com/drone-types/ [3]
https://www.bhphotovideo.com/c/product/1430449-REG/dji_cp_ma_00000019_01_mavic_2_pro.html [4]
https://www.airforce-technology.com/projects/pc-1-multipurpose-quadcopter [5]
https://inspiredflight.com/if750-quadcopter/ [6]
https://griffaviation.com/the-griff-fleet/ [7]
https://www.aeroexpo.online/prod/griff-aviation-north-america/product-185460-40807.html [8]

2. *Calculation of mass and energy characteristics*

2.1 Mass Estimation

For determining the suitable motor and propeller which is needed for powering the quadcopter we should have an estimation of mass of the rotor craft . so for this matter we need to calculate the average mass of each component because every component make it's own loading and load factors which leads to creating the lift by each of them . Table 2.1.1 shows us the weight of any part of quadcopter with regarding to the quantity which will be used in project and also a total weight .
Quadcopter uses four motors , four blades or propellers that pair of them rotate clockwise and another pair rotate counter clockwise for making the flight stable . the speed which rotates the motors considers the direction control and the movement control of the drone . so as the speed of the motor increases the thrust force will increase which make the drone to fly . For position finding quadcopter uses the GPS data and other parts like Gyroscope and flight controller , transceiver . Batteries and DC motors and also the main frame of quadcopter took in to account too .

Table 2.1.1

First iteration of masses calculation			
Name	Mass, kg	Q-ty	Total, kg
Motor	5,2	4	20,8
Controller	1,5	4	6
Propeller	1,2	4	4,8
Control System	0,5	1	0,5
Batteries	25	4	100
Fuselage	28	1	28
35 kg of useful load	35	1	35
		Total	195,1

2.2Static Thrust Calculation

For selecting the best motor and propeller we should calculated the thrust force or better to say static thrust . static thrust is amount of thrust which is rotating but it is stationary to the earth . quadcopters also fly with low speed relative to earth so this calculation is so important . static thrust has a wide effect in many phase of flight . in the calculation the values are just estimated .

In accordance to the newton laws any action has it's own reaction so in propulsion system when a vehicle accelerates even in the air or water produced a force which has the reaction force in opposite direction . when a propeller accelerate it creates force by throwing the air toward the direction of flying and in the reaction case there will produce a force against it . we call this force thrust . the acceleration in propeller take place in two spaces : half of it at the front of it and the other half at the behind .

Power – Thrust by using the Momentum Theory

The thrust of a multi copter produced by changing the momentum of the force which created from downward air . This system of forces make the helicopter to fly by making the lift . two factors should be consider first rotor area and then the speed of the air . The rotor area can be small but we need more air speed or it can be large as enough and we can have a lower air speed .
In Fluid dynamics thrust force is proportional to the volume of the fluid we have , it can be water or air which accelerate per the unit of time . In this section we should calculate the power which is required too . The power can be explained as the kinetic energy changes of the air kinetic energy which is divided by time interval .

$$P = \frac{\rho A v^3}{4} (2.2.1)$$

$$P = \frac{\rho A v^3}{4} = \frac{1{,}225\ .\ 1{,}32\ .27}{4} = 10{,}91\ W \approx 11\ W$$

For this equation we consider the propeller area as below :

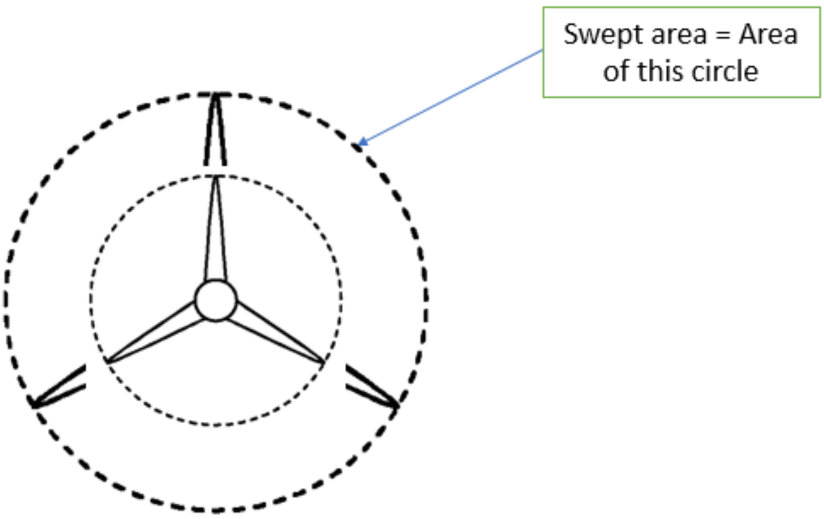


Figure 2.2.1

The next step is to determine the thrust produced by a propeller. Equation 2.2.2 gives thrust based on the Momentum Theory.

$$T = \frac{\pi}{4} D^2 \rho v \Delta v \ (2.2.2)$$

$$T = thrust\ [N]$$

$$D = propeller\ diameter\ [m]$$

$$v = velocity\ of\ air\ at\ the\ propeller\ \left[\frac{m}{s}\right]$$

$$\Delta v = velocity\ of\ the\ air\ accelerated\ by\ propeller\ \ [m/s]$$

$$\rho = density\ of\ air\ [1{,}225\ kg/m^3]$$

In common we consider the velocity of the air at the section of propeller by the following formula : $v = \frac{1}{2}\Delta v$ which calculated by the total change of air velocity .

$$T = \frac{\pi}{8} D^2 \rho (\Delta v)^2 \ (2.2.3)$$

$$T = \frac{\pi}{8} . (1{,}3)^2 . 1{,}225 . (6)^2 = 29{,}06\ \ N\ \approx 30\ N$$

Equation 4 gives us the power which received from the motor by a propeller . Equation 2.2.5 obtained by solving the 2.2.4 equation for Δv and substituting it into equation 2.2.3. With this process we determined the Δv and now we can have the torque value too .

$$P = \frac{T\Delta v}{2} => \ \Delta v = \frac{2P}{T} \quad (2.2.4)$$

$$\Delta v = \frac{2P}{T} = \frac{2 . 11}{30} = 0{,}73\ m/s$$

$$T = \ \left[\frac{\pi}{2} D^2 \rho P^2\right]^{1/3} \quad (2.2.5)$$

$$T = \left[\frac{\pi}{2}(1{,}3)^2 \cdot 1{,}225 \cdot (11)^2\right]^{1/3} = 7{,}18 \approx 7\ N$$

2.3 Selection of electrical equipment

2.3.1 Selection of Motor

The important point which should carefully be studied is that for choosing a best motor for project we should choose the one that can lead the quadcopter too fly in hover phase for at least half an hour , it means that by choosing the appropriate motor for our rotor it should produce half percentage more thrust that the whole mquadcopter .

According to our calculations we have to choose the right Motor which can meet the requirements of designed quadcopter . the following table contains the characteristics of Motor which selected :

Table 2.3.1

Producer	*Rotex Electric*
Model	*REX 30-5*
Engine type	*Outrunner*
kV	*54*
Max number of cells	*15S*
Power output, Watt	*18000*
Motor weight, kg	*5,2*
Voltage	*63*
Motor RPM in cruise	*2500*
Diameter mm	*74*
Length mm	*216*
Mass kg	*5,2*

Motor REX 30 is designed for aircraft and other aplication with 1.3m propeller. Due small dimension and high torque can provide continuous power 15Kw and 18Kw for shor time.
Motor have integral Hall and temperature sensor and is designed as air cooled for air aplications. Ideal for this motor is 2200-2500RPM at 50V.

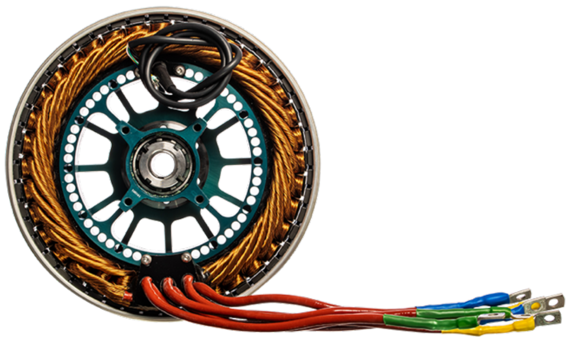


Figure 2.3.1.1. REX 30-5 Motor

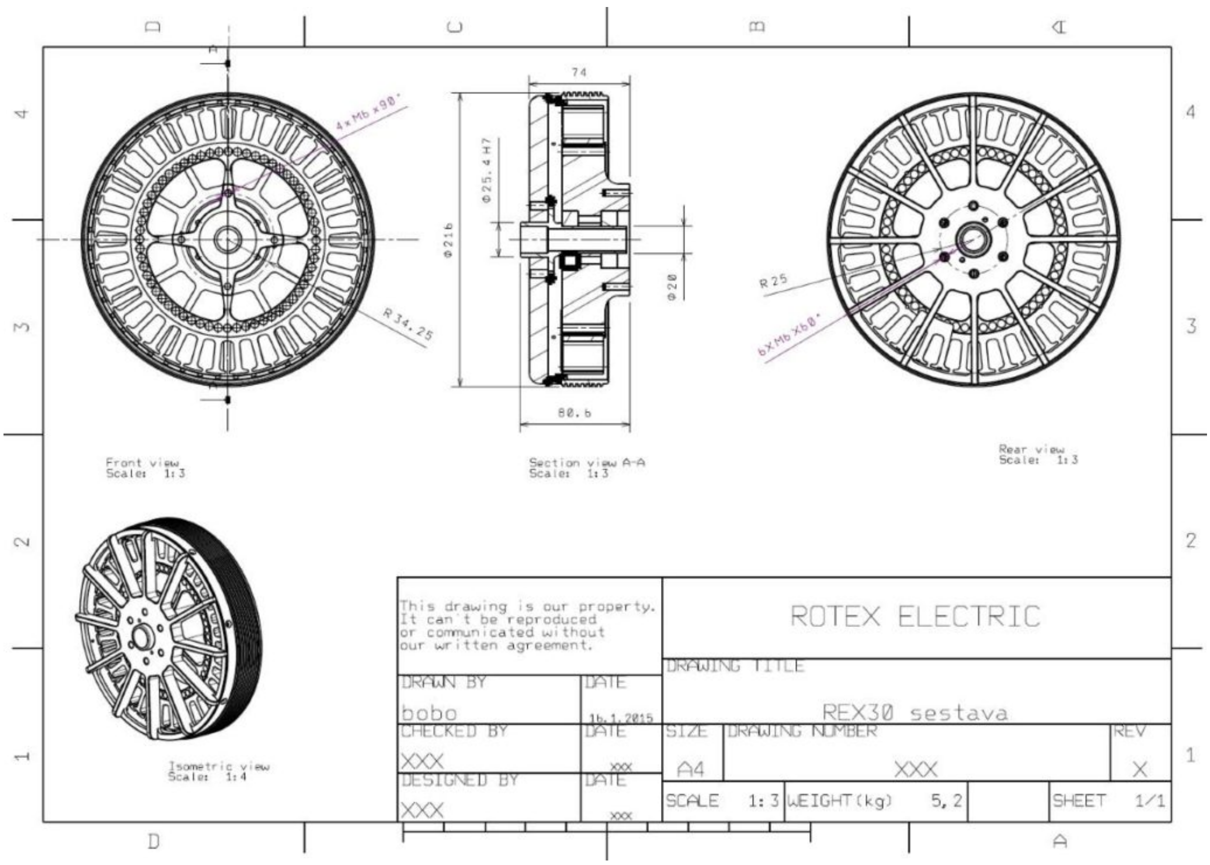


Figure 2.3.1.2. REX 30-5 Motor

- ***Selection of Motor Controller :***

For motor control system **MOTOR CONTROLLER MGM Compro TMMHBC-280120-3-E** has been choosen . This motor controller provides smooth and quality control of the motors. The controller has the following specifications :

- voltage - 16 - 120 В
- max continuous current - до 280 А

- max short term current - 400 A
- controller power supply external, 14 - 35 B

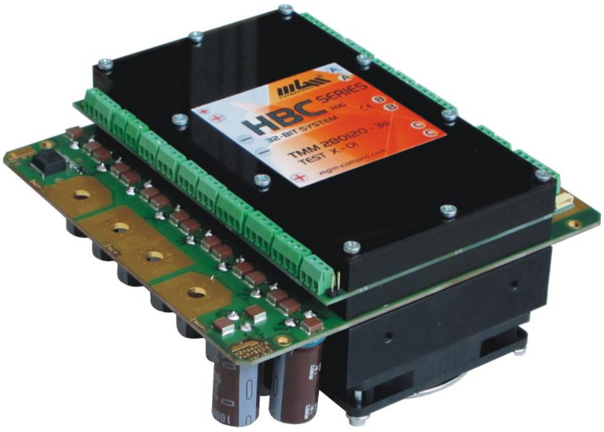


Figure 2.3.1.3. CONTROLLER MGM Compro TMMHBC-280120-3-E

- ***Selection of autopilot system :***

Dronee Cockpit autopilots provide a complete integrated avionics solution that includes the flight control processor, inertial sensors, GPS receiver, secondary compute module and datalink radio. For this design we selected the MicroPilot . MP2128HELI-LRC2 Enclosed helicopter UAV autopilot (2.4GHz).

2.3.1.4. MP2128HELI-LRC2 Enclosed helicopter UAV autopilot

The specifications are as below :

Servos

• Elevon, flaperons, 4 servo flap/aileron, separate flaps, v-tail, x-tail, split rudders
• 12 servo outputs
• 50 Hz servo update rate
• Separate servo and main battery power supply
• Separate voltage monitor for main and servo battery power supplies

• Integrated RC override
• 11 bit servo resolution

Control System
• 30 Hz PID loop update rate
• Gain scheduling for optimum performance
• Rudder aileron feed forward for improved turn performance
• Aileron/elevator feed forward for improved altitude hold during turns
• Autonomous takeoff and landing
• User definable PID feedback loops
• User definable table lookup functions
Navigation
•4 Hz GPS update rate
•Move servo at waypoint
•Change altitude at waypoint
•Change airspeed at waypoint
•User definable holding patterns
•User definable error handlers
•RPV and UAV modes
•Supports GFPS accuracy
•1,000 waypoint command buffer Telemetry, Datalog and Video
• Telemetry (100 user definable fields transmitted each second)
• 5 to 30 Hz telemetry update rate
• Onboard datalog: 52 standard fields, 24 customizable, 69 MB
• 5 or 30 Hz datalog update rate
• Can record for approximately 58 hours at 5 Hz

Sensors
• Airspeed max speed: 500kph
• Altimeter max altitude 12,000m
• 5 g, 3-axis accelerometers
• 300°/s, 3-axis rate gyro

Physical Characteristics
• Embedded long-range data communication link, frequency-hopping, spread spectrum 2.4 GHz, 900 MHz, other frequency optional
• 8 high current drivers,
• 8 analog sensor inputs to be displayed on the GCS
• 2 control modes
 - Autopilot mode (UAV/RVP)
 - Manually piloted mode for emergency response
• Wide range of input voltage (6.5-30 v)
• Weight 413 g
• 146 mm x 81.7 mm x 46 mm
• Failsafe watchdog timer

- ***Transmitter hardware :***

JETI Duplex DC-24 Multimode 2.4GHz

2.3.1.5. DC-24 Multimode transmitter

The specifications are as below :

Transmitter hardware:
- New: Multi-mode control stick
Determination of joystick positions via Hall sensors (without potentiometers)
Control path resolution 4096 steps
Color display, back lit
- Rotating joystick units
Vollaluminiumsteuerknuppel-/ emergency, length adjustable, ball bearings
- Internal Memory
- Integrated Antennas
- Built-in Li-ion rechargeable battery for long operating time
Charger
- Aluminum carrying case
Voice output
Headphone jack
- Digital trimmings

Transmitter software (anticipated):

2.4 GHz DUPLEX EX
- 24 control channels
- Customizable menu guidance
- Almost unlimited setting options
- Almost unlimited number of model memories
Firmware update via USB

Ultra fast control responses
Power management system for longer operating time
PC-interface
- 4 adjustable model types (Aircraft/heli/function model; multirotor helicopter)
- 4 languages (EN/DE/CZ/FR)

Telemetry functions:

Speech output of telemetry warnings and telemetry values
Display of the telemetry data in real time on transmitter display
- Recording of telemetry data
PC transfer, storage and processing of the telemetry values
- Store (Backup) the model data and transmitter settings on the PC

2.3.2 Determining the appropriate propeller

Selecting the right propeller is so important for designing a quadcopter because it has a direct influence on power and in stability of the drone . many factors should be considered like weight , diameter and the result is the flight efficiency of it .

When we want to select propeller blades, we should pay attention to the following factors:

- ***Number & Size of Blades***

The platform view of our design will lead us to choose the number of blades which is required for us . Depending on the usage for example small diameter blades used for racing designs and they have been combined with small motors that have high KV ratings . These blades are measured as less than 8 inches .
Blades with the size of over than 8 inches have been used with low KV rating motors and for transport heavy drones like the one in our project . These kind of drones used for carrying cargo and for example mapping purposes .

- ***Pitch***

Pitch is the factor which has the direct relation to the frame of quadcopter too . pitch in general is the distance which traveled by a propeller per a revolution of it .

Propellers with low pitch rate used for the conditions with low turbulence than lift production and with high rate of torque . This condition results to more flight time of drone and motors have less consumption energy from the batteries because they should not work a lot .

Propellers which have more pitch rate can move more air also but directionally the produce more turbulence and low amount of torque .

- ***Diameter***

As we know propeller with large diameter can move the large amount of air too . this matter has the most important relation with flight efficiency which means that the changes in propeller diameter make significant changes on flight efficiency of our quadcopter . For hovering flight phase the large diameter gives us the more stable flight that the small ones .
As mentioned before high pitch propellers used for racing and acrobatic maneuvers in addition we can say that small diameter in combination with high pitch give us the best drones for high maneuvers conditions of flight .

- ***Other factors that should be considered include:***

- Blade material
- Power
- RPM
- Air density
- Maximum noise

So in accordance to this paper requirments , the 2 blades propeller selected with the following diameter :

$$d = \sqrt{\frac{4N_{max}}{\pi n_{blades} P_{blades}}} \quad (2.3.1)$$

$$d = \sqrt{\frac{4 \,.\, 2{,}4}{\pi \,.\, 2 \,.\, 1}} = 1{,}2363\ M$$

Where :

- N_{max} is power output for engine which is equal 18000 W or 2,4 mechanical horsepower ,
- n_{blades} is number of blades that equal 2 ,
- P_{blades} 1e hp/m^2

So the propeller selected with 1,3 diameter .

3. mathematical dynamic model

The Quadcopter maneuverability is high so we need a system which should be accurate for controlling . Quad mean four so we have four motors and for rotors which in accordance to the frame located with equal arms or better to say distances from the center of it . For stability we should consider this center as a center of mass of the whole parts of drone . By rotating these rotors the produced force make the drone to fly which is the result of thrust forces .

In this section, information about the quadrotor mathematical model and control system is given.

3.1 The Description of Quadcopter

As we can see in Figure 3.1.1 in order to moving of the quadcopter from point A to B , the changes in speed to the certain combination will allow the quadcopter to tilt . the changes in propeller speed directly changes the acceleration .

Figure 3.1.1

This acceleration also depends on mass , size and shape of quadrotor . In accordance to the previous figure 3.1.1 for example for transforming from B point to I_3 the quadcopter should decelerate and for this mean we have to use the moment of inertia Matrix .

As we know moment of inertia is the quantity which determines that how much moment is required for an given angular acceleration about some velocity axes , and it depends on mass distribution and rotation axes .

For balancing the torques of rotors as we have 4 rotors here they should rotate by pair , it means that as we have power like f_i = 1,2,3,4 , for example 1 ,3 and 2,4 should rotate similarly , first pair clockwise and second pair counter clock wise .

In Quadcopter flight dynamic there are two coordinate systems which shown in Figure 3.1.2

Those systems are :

- Inertial (Earth) Fixed Frame
- Body Fixed Frame

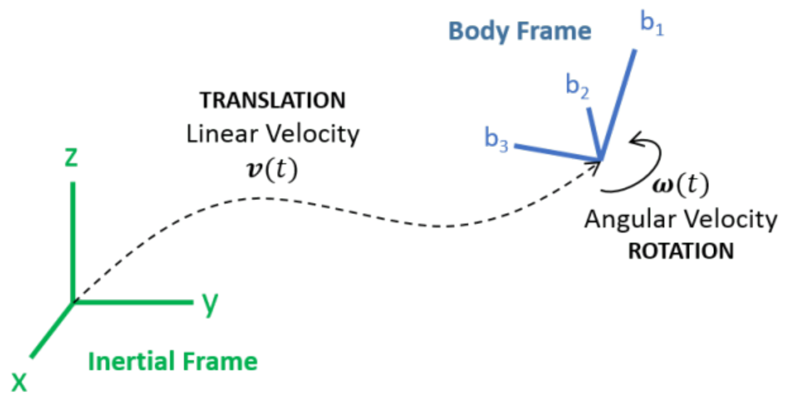


Figure 3.1.2 Quadcopter Coordinate Systems

Transformation in quadcopter moving contain two motions which are rotation and translation .

From classical flight dynamics we know that the force which exerted on a propeller or which

we call lift is directly proportional to the square of angular velocity of the propeller .

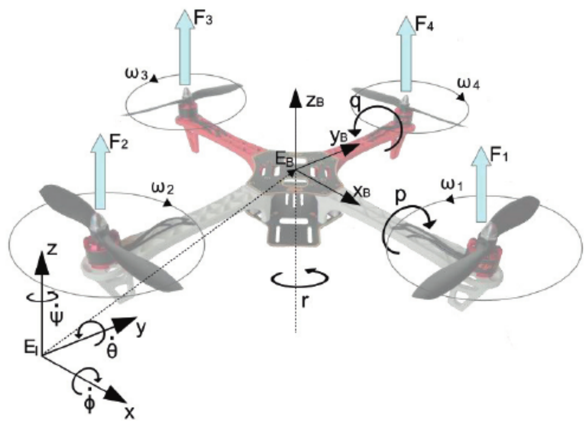


Figure 3.1.3 angular velocity and moment

Yaw moment is the moment which make the drone to rotate around the vertical axis which is positive for right turning and it is negative in left turning conditions , we calculate the yaw moment with countering torque between each propeller . angular velocity for each rotor is equal and by that the net here is equal to zero ,

but for each pairs the angular velocities are different and that's why it makes the drone to yawing negatively or positively .
The forward or backward movements have relation with pitch angle which is θ . This angle can be increased by back thrust of rotor or can be decreased by front thrust of rotor .
At the end also we have side ways movements which have relation with roll and it's angle is φ , this movement can be increased by increasing the thrust of left rotor or decreased by decreasing the thrust that produced by right rotor .
Figure 3.1.4 shows the movements of a quadrotor by changes in rotor speeds.

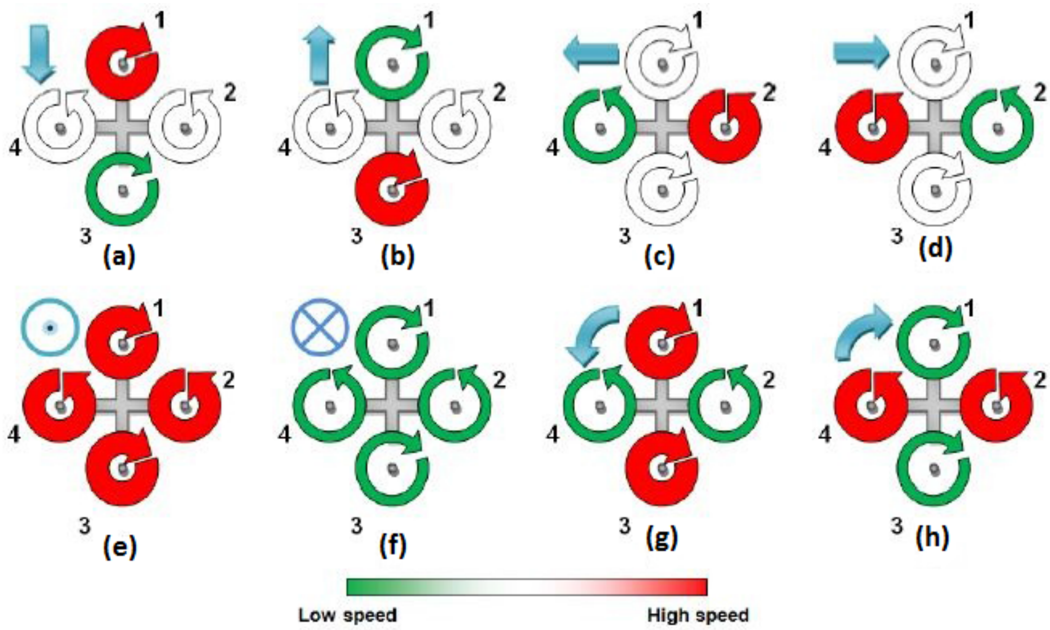


Figure 3.1.4 Quadcopter Movement

3.2Quadcopter Kinematic Model

In Quadcopter flight dynamic there are two coordinate systems which shown in Figure 3.1.2

Properties as roll ,pitch and yaw angles or angular velocities are physical characteristics which have been measured in accordance to the inertia coordinate system and the properties like acceleration have been measured in body fixed coordinate system .

By taking in to account the Euler's approach angles about the x , y and z axes which in another hand is rotations like roll , pitch and yaw we will write the rotation matrix R that obtained between the inertia earth fixed frame and body fixed fram .

The calculated R matrix is as follows :

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

T is a matrix for angular transformations :

$$T = \begin{bmatrix} 1 & \sin(\phi)\tan(\theta) & \cos(\phi)\tan(\theta) \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \frac{\sin(\phi)}{\cos(\theta)} & \frac{\cos(\phi)}{\cos(\theta)} \end{bmatrix}$$

3.3Quadcopter Dynamic Model

The Newton – Euler approach used to obtain dynamic model of quadcopter , Newton – Euler approach considers the following:

- the structure is rigid and symmetric,
- the propellers are rigid,
- the thrust and the drag are proportional to the square of speed,
- ground effect is neglected

We consider the velocities of the propellers as expressed by f_i, the total thrust generated by the four propellers is defined by f_i as following :

$$T = \sum_{i=1}^{4} f_i$$

where f_i is :

$$f_i = 4{,}392399 * 10^{-8}.RPM.\frac{d^{3,5}}{\sqrt{pitch}}(4{,}23333 * 10^{-4}.RPM - V_0)$$

RPM that is abbreviation of propeller rotations per minute; pitch is propeller pitch, in meters; d is propeller diameter, in meters; and V0 is the forward airspeed, freestream velocity, or inflow velocity , in m/s.

By applying some inputs we can control the behavior of quadcopter

For example the applied torque is difference between the torque from each propeller one by one. The values of the input forces and torques are proportional to the squared speeds of the rotors :

$$\begin{cases} f_t = U_1 = b(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2) \\ \tau_x = U_2 = bl(-\Omega_1^2 - \Omega_2^2 + \Omega_3^2 + \Omega_4^2) \\ \tau_y = U_3 = bl(\Omega_1^2 - \Omega_2^2 - \Omega_3^2 + \Omega_4^2) \\ \tau_z = U_4 = bl(\Omega_1^2 - \Omega_2^2 + \Omega_3^2 - \Omega_4^2) \end{cases}$$

Here l is the arm of system or the distance between every rotors and the center of the quadrotor (center of mass) , b is the thrust factor and d is the drag factor. Here, lift and drag factors of the propeller blade (b and d respectively) are calculated from the Blade Element Theory .

Blade element theory describes the behavior of blade by cut it to smaller sections and parts along it’s length and studies the forces applied and balance of them in each section itself . then this method measures the thrust and torque of each section separately .

The full quadrotor non-linear dynamic model with the x,y,z motions respectively for a pitch, roll and rotation is as follows :

$$\begin{cases} \dot{x} = w[s(\phi)c(\psi) + c(\phi)c(\psi)s(\theta)] - v\big[c(\phi)s(\psi) - c(\psi)s(\phi)s(\theta) + u[c(\psi)c(\theta)]\big] \\ \dot{y} = v[c(\phi)c(\psi) + s(\phi)s(\psi)s(\theta)] - w\big[c(\psi)s(\phi) - c(\phi)s(\psi)s(\theta) + u[c(\theta)s(\psi)]\big] \\ \dot{z} = w[c(\phi)c(\theta)] - u[s(\theta)] + v[c(\theta)s(\phi)] \\ \dot{\phi} = p + r[c(\phi)t(\theta)] + q[s(\phi)t(\theta)] \\ \dot{\theta} = q[c(\phi)] - r[s(\phi)] \\ \dot{\psi} = r\frac{s(\phi)}{c(\theta)} + q\frac{s(\phi)}{c(\theta)} \\ \dot{u} = (vr - wq) + gs(\theta) \qquad \dot{v} = (wp - ur\dot{)} - gc(\theta)s(\phi) \\ \dot{w} = (uq - vp) - gc(\theta)s(\phi)\frac{u_1}{m} \\ \dot{p} = \frac{I_y - I_z}{I_x}qr + \frac{U_2}{I_x} \\ \dot{q} = \frac{I_z - I_x}{I_y}pr + \frac{U_3}{I_y} \\ \dot{r} = \frac{I_x - I_y}{I_z}pq + \frac{U_4}{I_z} \end{cases}$$

3.4 Space Model of Quadcopter

With state space modeling we have advantages like modeling of multiple-input and multiple-output system .

The equations of a system under control is nonlinear so it is necessary to write them as linear system .For making state space mathematical model we use a set of outputs , inputs and variables which have relation with first order of equation. The space model is shown as follows:

$$\dot{x} = Ax(t) + Bu(t)$$

$$y = Cx(t) + Du(t)$$

Where x(t) state vector, u(t) control or input vector, y(t) output vector, A system vector, B input vector, C output vector and D feed forward vector.

If the non-linear equations given in previous equation are linearized, the following equations will be obtained:

$$\left\{\begin{array}{c} \dot{\phi} = p \\ \dot{\theta} = q \\ \dot{\psi} = r \\ \dot{p} = \dfrac{\tau_x}{I_x} \\ \dot{q} = \dfrac{\tau_y}{I_y} \\ \dot{r} = \dfrac{\tau_z}{I_z} \\ \dot{u} = -g\theta \\ \dot{v} = g\phi \\ \dot{w} = \dfrac{f_t}{m} \\ \dot{x} = u \\ \dot{y} = v \\ \dot{z} = w \end{array}\right\}$$

$[x\ y\ z\ \phi\ \theta\ \psi]^T$ is the vector has the linear and angular position of the quadrotor in accordance to earth inertia frame coordinate and $[u\ v\ w\ p\ q\ r]^T$ is the vector has the linear and angular velocities in accordance to the body frame coordinates and u is input or control vector: $u = [\ f_t\ \tau_x\ \tau_y\ \tau_z\ ]^T$

By making the linearization compeleted we can obtained the input matrix, the previous equation is divided into two parts. The first part coresponds the longitudinal flight x, z, u, w , q , θ and the second part is the y, v, p, r, ϕ and ψ values showing the lateral flight. With previous information we can have the longitudinal and lateral space models .

Longitudinal flight model:

$$\begin{bmatrix}\dot{x}\\ \dot{z}\\ \dot{u}\\ \dot{w}\\ \dot{q}\\ \dot{\theta}\end{bmatrix}=\begin{bmatrix}0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & -g\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0\end{bmatrix}\begin{bmatrix}x\\ z\\ u\\ w\\ q\\ \theta\end{bmatrix}+\begin{bmatrix}0 & 0\\ 0 & 0\\ 0 & 0\\ 1/m & 0\\ 0 & 1/I_y\\ 0 & 0\end{bmatrix}\begin{bmatrix}f_t\\ \tau_y\end{bmatrix}$$

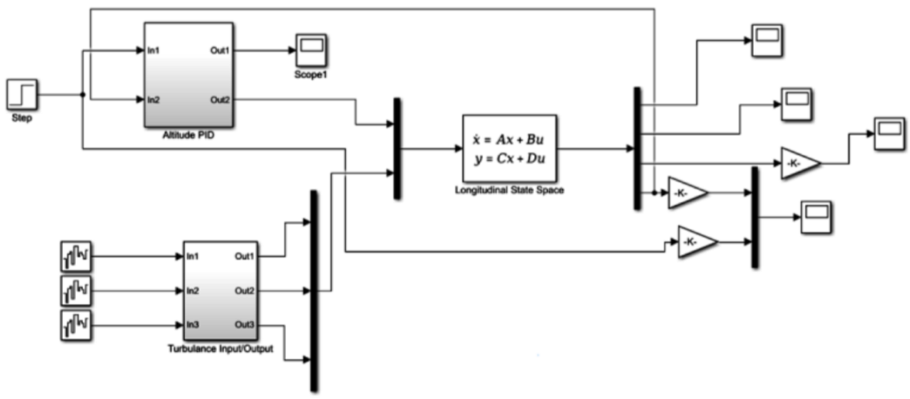
$$y=\begin{bmatrix}1 & 0 & 0 & 0 & 0 & 0\\ 0 & 1 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}x\\ z\\ u\\ w\\ q\\ \theta\end{bmatrix}$$

Lateral flight model:

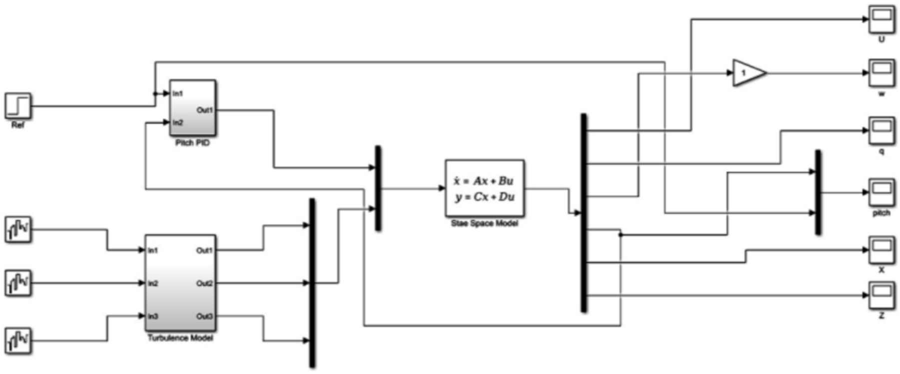
$$\begin{bmatrix}\dot{y}\\ v\\ \dot{p}\\ \dot{r}\\ \dot{\phi}\\ \dot{\psi}\end{bmatrix}=\begin{bmatrix}0 & 1 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & g & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 0 & 0\end{bmatrix}\begin{bmatrix}y\\ v\\ p\\ r\\ \phi\\ \psi\end{bmatrix}+\begin{bmatrix}0 & 0\\ 0 & 0\\ 1/I_x & 0\\ 0 & 1/I_z\\ 0 & 0\\ 0 & 0\end{bmatrix}\begin{bmatrix}\tau_x\\ \tau_z\end{bmatrix}$$

$$y=\begin{bmatrix}1 & 0 & 0 & 0 & 0 & 0\\ 0 & 1 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}y\\ v\\ p\\ r\\ \phi\\ \psi\end{bmatrix}$$

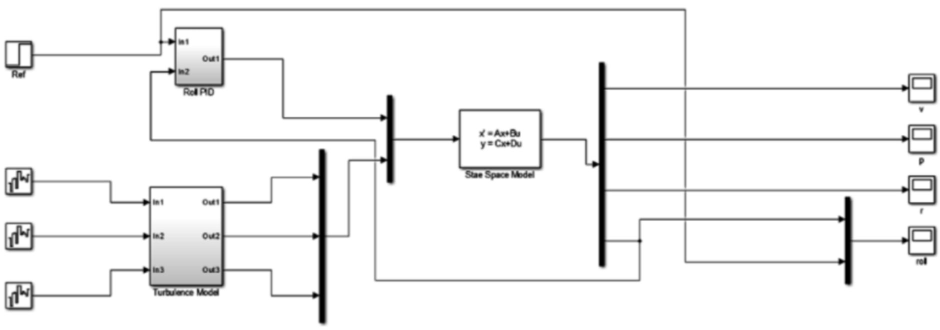
Depending on the model and parameters quadrotor hover, longitudinal and lateral flight simulink models are as follows, respectively.



Hover flight

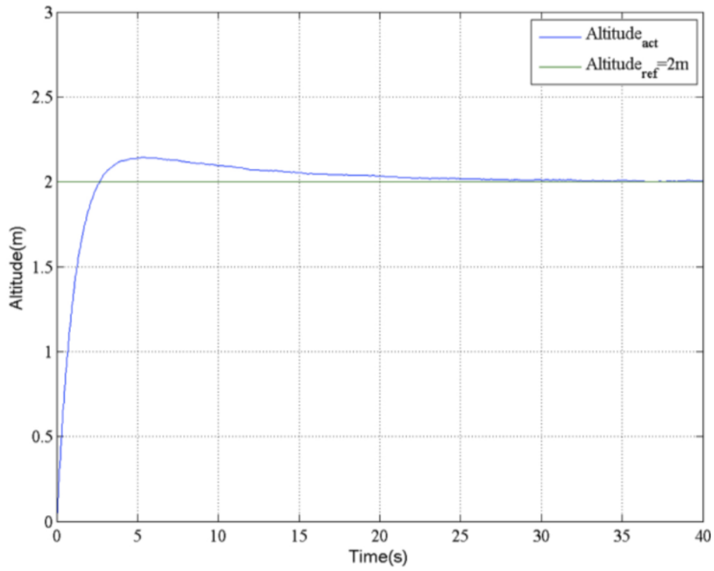


Longitudinal flight

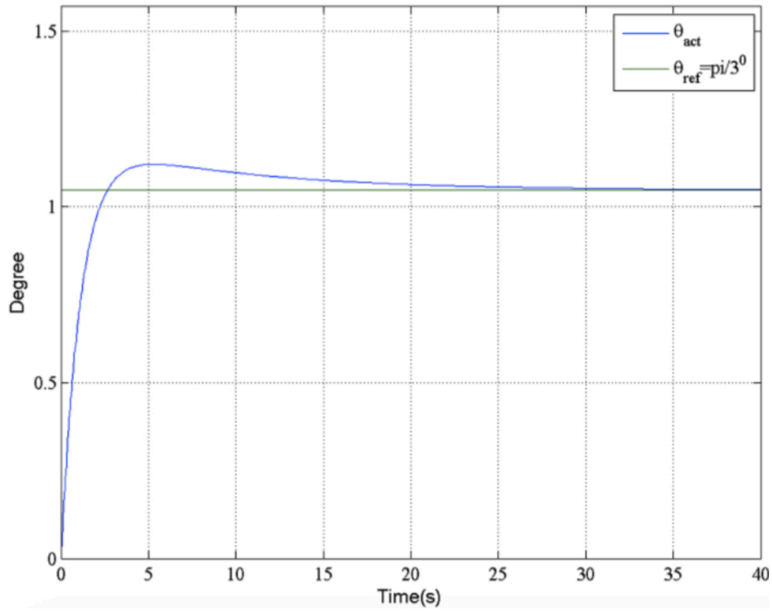


Lateral flight

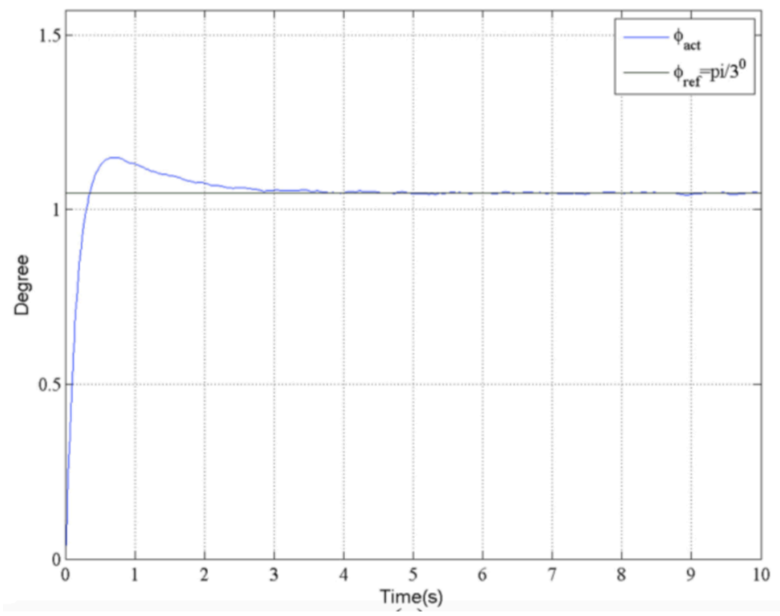
The following graphs are obtained for each flight mode according to the simulation results.



hover flight



longitudinal flight



lateral flight

In this study, longitudinal, lateral and hover flight of quadrotor is discussed. Quadrotor model was created in Fusion 360 program and data obtained from it was made with Simulink model.

4.4. Creating a visual-spatial model of a multicopter

The 3D model can be draw and produce by using 3D printers that form 2D layers of the model with three-dimensional material, one layer at a time. Without a 3D model, a 3D print is not possible. 3D modeling software is a class of 3D computer graphics software used to produce 3D models.

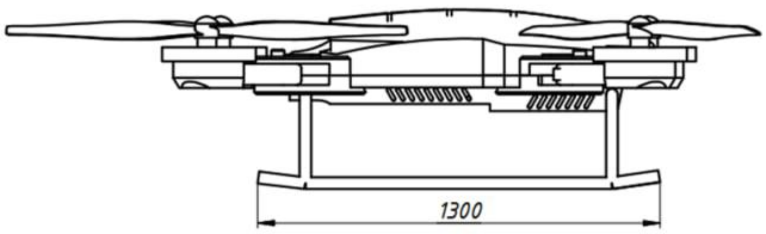


Figure 4.4.1

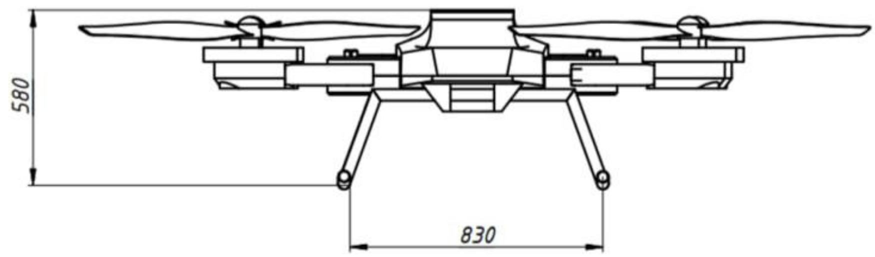


Figure 4.4.2

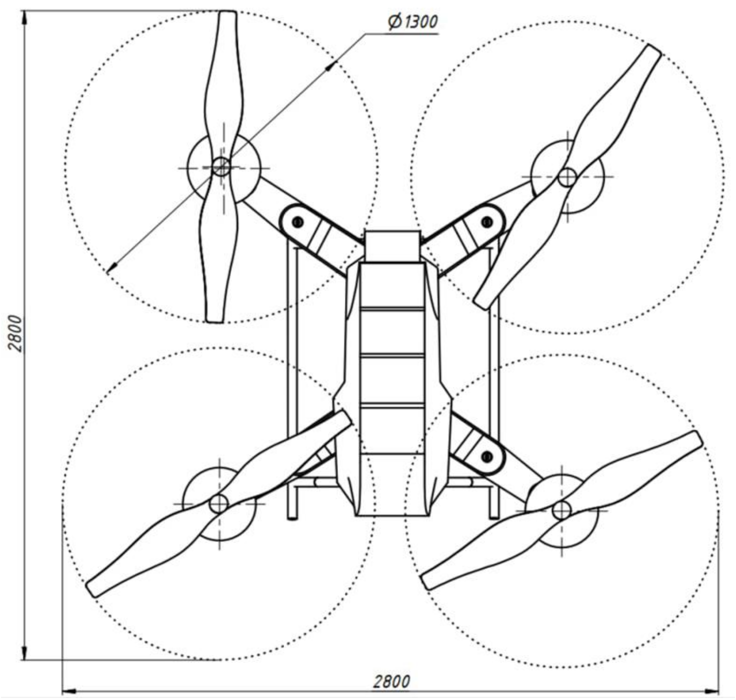


Figure 4.4.3

Then with the help of Fusion 360 the 3D models has been created :

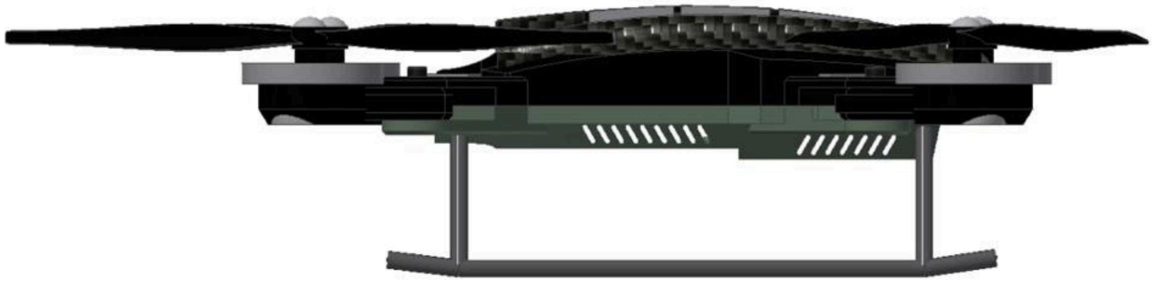


Figure 4.4.4

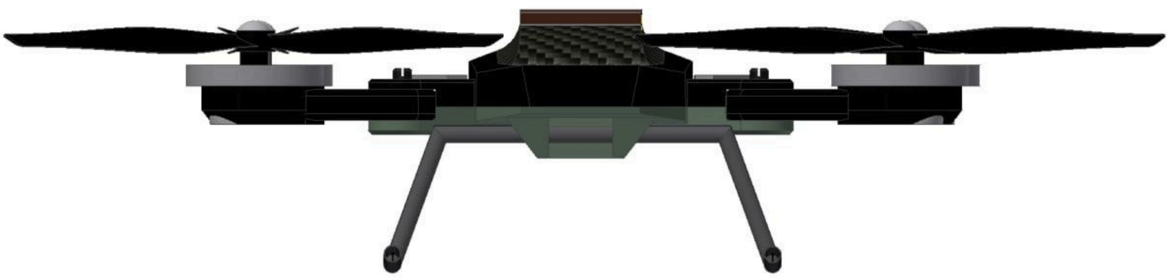


Figure 4.4.5

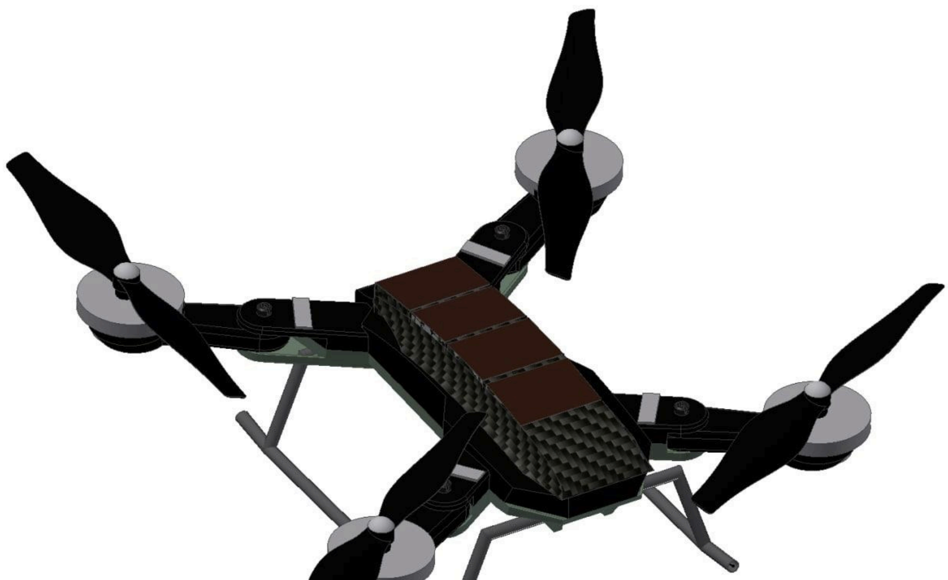


Figure 4.4.6

Also it can has a place for cargo carriage :

Figure 4.4.7

4.5. Cost and monetization of a heavy multicopter

UAVs are demonstrating to be effective in many fields , so it is so important to take in to account the costs of it's design so we have to consider every parts of quacopter cost .

Airframe :

Airframe is the same robot frame on which different parts are installed. Airframes are available in the market at different prices depending on the material of the body, the total weight of the frame, as well as the ability to install gimbal and the best airframes are air frames that are made of carbon fiber. Carbon fiber, in addition to being very light in weight, also has a very high resistance.

Brushless motors:

To build a drone, when buying an engine, you must be very careful whether the engine is compatible with other parts such as flight control, etc .

Electronic Speed Controller (ESC) :
Another component that plays a key role in the quadcopter is the electronic motor controller, which controls the speed and amount of current it can continuously supply to the motors in Amps in flight. These multi-rotor speed controllers monitor the efficiency of the motors and the torque they produce to prevent any damage to the motors.

Propellers :

Propellers are another component needed to build a drone is to play a key role in providing a controlled flight. When buying a quadcopter propeller, note that the purchased model is compatible with the desired engine, because the size and type of impellers compatible with it are mentioned in the engine data sheet or specifications sheet. To increase the efficiency of these licenses, the user sees two options in front of him. The first can use propellers with more blades or increase the length of the blades, which in many cases increases the length of the blades, causing the multi-rotor frame to collapse and cause a certain irregularity. Therefore, you can use three-bladed propellers to increase efficiency and production torque.

Batteries :

The battery is one of the other components needed to build a quadcopter, and when buying a UAV battery, you should calculate the consumption of all motors and LEDs so that you can buy a battery with compatible voltage and current. The power supply for the motors and all the electrical components of a UAV is a lithium battery that can be recharged and has a long life cycle so that after one charge, it can keep the bird suspended or moving in the sky for a good time. A quadcopter battery is made up of one or more lithium-ion cells that generate the required voltage to propel the propellers, causing the aircraft to land. To increase flight continuity, you should consider more batteries or high-capacity batteries, which, however, still increase the weight of the bird's takeoff, and as a result, this weight gain will affect the flight duration. When buying a drone battery, you should pay attention to its voltage, current and other details.

Quadcopter radio transmitter :

The transmitter or remote control is actually the most important part of a bird control system that transmits the necessary instructions through the frequencies of 2.4 and 5.8 GHz. This remote control actually transmits your commands to the receiver that you install inside the quadcopter, where the bird changes direction after processing your command. The direction and speed sticks are the two main levers on the remote that with the slightest hint of them, you will see the position of the bird change. A typical transmitter has 4 channels through which four basic axes can be controlled. But using more channels can increase the efficiency of a transmitter. Of course, know that the more channels a remote control has, the higher its price.

Quadcopter radio receiver :

Another part needed to build a drone is its radio receiver or receiver, which appears in the role of complement to the controller and processes and executes all sent instructions. When choosing a remote, you can provide the receiver with it, but some receivers are supplied separately.

Battery charger :

When buying a UAV battery charger, make sure you have a battery-compatible input and output charger that protects the battery from dangerous voltages while charging.

Voltage regulator :

Precisely to describe this part, it can be said that it is a balancing device for all electrical parts such as flight control, motors and speed control motors that prevent the connection of strong currents. This part is also one of the peripherals of the quadcopter that must be purchased along with the main parts.

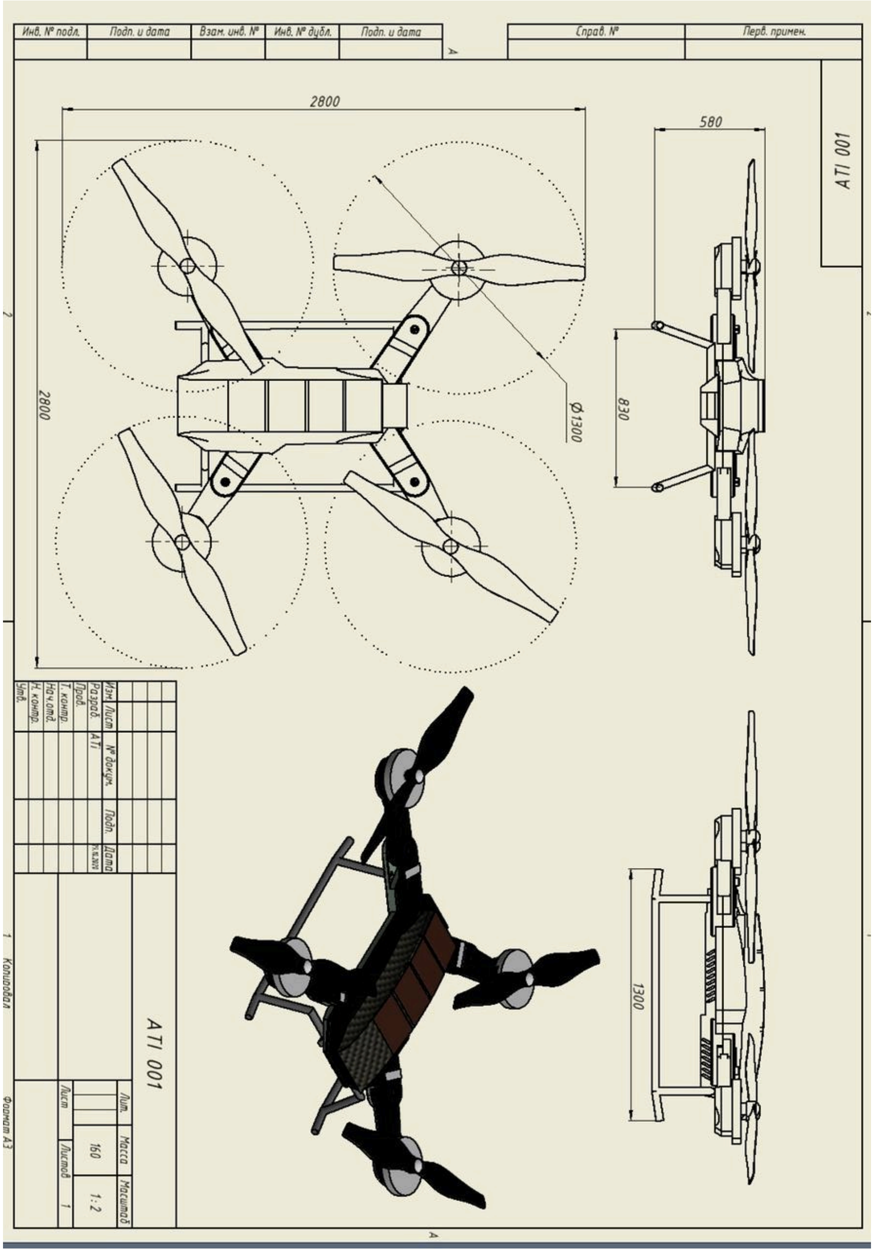
Also we have some optional parts that we can add to the quadcopter .

The following table 4.5.1 shows our designed quadcopter costs :

Table 4.5.1

Estimated cost of components, US$			
Name	UDC Prototype	Q-ty	Total
Motor	$3 155	4	$12 620
Motor controller	$4 874	4	$19 495
Propeller	$1 200	4	$4 800
Autopilot	$8 000	1	$8 000
Control System	$2 013	1	$2 013
Regular charger	$1 000	1	$1 000
Fast charger	$4 000	1	$4 000
Batteries	$1 500	4	$6 000
Fuselage	$7 000	1	$7 000
Misc components	$2 000	1	$2 000
		Total	$66 928

4.6. Technical documentation



References :

- *Teppo Luukkonen*

Modelling and control of quadcopter , School of Science Mat-2.4108 Independent research project in applied mathematics

- *Modeling, Design and Experimental Study for a Quadcopter System Construction by Øyvind Magnussen Kjell Eivind Skjønhaug*

- Gain scheduled linear quadratic control for quadcopter , M Okasha, J Shah, W Fauzi et al.

- Dynamics and control of quadcopter using linear model predictive control approach , M Islam *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* 270 012007 .

- Theoretical development and study of takeoff constraint thrust equation for a drone , Conference Paper · December 2017 .