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Master's degree in Applications and Technologies for Unmanned Aircraft Systems

MASTER THESIS

TITLE: EVTOL Concept Design

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Abstract

This master thesis consists of a research and development project’s documentation about Electrical Vertical Take off and Landing (EVTOL) technology.

The main target is providing an investigation about this technology, reviewing its history since its origins to the future lines, understanding how it works by revising all the technical aspects such as the mechanical part, hardware components, software systems, structural stress design…

In addition, a market study is carried out around this technology to come up with a first prototype. Based on a research for the applications and utilities that it can offer regarding the future problems that humanity is facing.

Furthermore, this thesis documents the analog and digital methodologies that are being used throughout the entire creative process combining design and engineering workflows in order to achieve the proposed objectives.

The project’s value resides on the creative design aspect, therefore all the content is based from the pre-production design perspective. As the most technical part involving the product production such as the stress design aspect to select the right components, or quality validation process would be carried out on further stages by the engineers.

CONTENTS

INTRODUCTION

In “Victor Papanek” words, *Design, if it is to be ecologically responsible and socially responsive, must be revolutionary and radical*.

The Earth planet is currently facing difficult times where unexpected, drastic and contrasting natural phenomena happen in the order of the day. Polluted skies, toxic water and food, microplastics in newborn animals, storms, droughts, heavy rains hit the biosphere and provoques damaging hard consequences.

These situations are mainly caused by humans, one simple Earth's animal species that evolved with ego and ambition exponentially since they began using technology and carried on a symbiotic relationship with it. Technology has provided humans the capabilities to dominate everything around the planet, its actions influence all ecosystems.

Humanity’s quotidian lifestyle, traditions and conduct unstabilize Earth’s equilibrium. That’s why it is very important to be clever when using technology to take the next steps of humanity and planet evolution. Whilst that, the majority of the population live in overpopulated cities where people move constantly, following fast routines, so we need fast, green and organized mobility systems.

That’s why in the next couple of years flying sustainable ships will begin to appear in the skies of the largest megacities. As Avionics International (2021) stated in his EVTOL market study, “a lot of companies and new start ups are fighting for the opening trillion dollar market developing their own designs and ecosystems” (par. 7) {2}.

EVTOL (Electrical Vertical Take-off and Landing) aircraft is a disruptive technology that proposes a new method of transportation way cleaner, cheaper and safer than the current ones. It is a sustainable and powerful solution that satisfies the need for new aerial technologies for urban air mobility program that enable quieter and greener flights.

Objectives

In this master thesis, it can be found a research and development project involving EVTOL technology driven from the pre-production design process and a creative perspective. The main objectives of it are:

- Carry on a research about the EVTOL technology.
- Analyse it to understand how it could be a solution to face up the urge for greener aerial technologies.
- Use engineering and design methodologies to come up with an EVTOL conceptual prototype that could be a solution to a problem.

Document structure

To structure this multidisciplinary project it has been divided into 5 chapters. Chapter 1 consists of the technology's introduction, its concept, history and market situation are exposed to contextualize.
At the Chapter 2 it can be found the analysis of it, hardware and software aspects are treated to understand better the technology. In addition, there is also a comparative between EVTOL and traditional aviation.
In Chapter 3, drone's (and EVTOL) regulation is explained and exemplified with the study of the necessarily permits to carry on a flight operative in a certain area.
At Chapter 4 it is documented the whole EVTOL's conceptual prototype design process. As from the creative techniques like design direction, sketching, 3D production and more, to the engeenering ones as flow and structural forces simulation applied on the Solidworks CAD programm.
Finally, Chapter 5 covers the visual representation of the results (renders) and a an explanation about the concept prototype's whole functioning.

CHAPTER 1. EVTOL Technology

First of all, to approach this master thesis and achieve one of the main targets which is designing an EVTOL prototype concept (Fig. 1.1). It's important to contextualize the technology therefore the design process can be carried out with better knowledge. On this first chapter it can be found an introduction into EVTOL technology where the main subjects of it are handled such as the concept, its history and the market situation.

Fig. 1.1 A series of EVTOL aircraft. *Source: {1}*

1.1. A solution to sustainable mobility

Electrical VTOL is a revolutionary technology that is born as a mobility solution to live in a better and sustainable world. This newborn transportation technology consists of an electric battery powered aircraft, known by the special fact that it lands and takes off vertically.

It is designed to fly short-mid distances and carry from one to six people inside. Despite that it is also a very efficient tool to transport not only humans but cargo, packages and logistics. As this techonolgy, unless the traditaional aviation, doesn't require infrastructure to operate as it can land and take off vertically from everywhere. In addition their fixed wing configuration provides them the capacity to cover large distances.

Is very similar to a drone or a helicopter because it hovers but as you can see on the image (Fig. 1.1) on top, they also have wings as a plane does. This spec in combination with the rotor technology makes them the most versatile aircraft and provides nice flight capabilities.

Therefore, it can be said that an EVTOL is a small and simplified aircraft way more efficient, safer and cheaper which combines the best specs of UAS (Unmanned Aircraft Systems), helicopter and plane technologies compromised with Earth's sustainability, therefore its future…

1.2. History

In order to understand this technology it is needed to know its background. This section approaches from his very first steps to the future ones.

EVTOL's are a very recent technology that has just begun writing its first pages of history, but it has a huge future projection because of the urgent need of sustainable solutions.

This new type of aviation was made possible thanks to the development of electric propulsion and drones which are the main driving forces. Electric motors, battery density, fuel cells have evolved a lot in the recent decades.

As of the end of 2021 only a few companies had achieved a full sized working aircraft and are already running demo flights, but nowadays a lot of companies are presenting their aerial vehicles concepts. There are also start ups being born trying to make their first prototype fly. Joby Aviation is currently in the lead, setting the range record for EVTOL with a flight time of 1 hour and 17 minutes, range distance of 155 miles (Joby Aviation, 2021) {3}.

This EVTOL aircraft first appeared as a concept idea by NASA in the late 2000's (2009), proposing a sustainable aerial transportation for a single passenger use. It was not until 2011 when it began to rise the interest and several companies presented their own prototype. Since then, startups have been appearing all around the world presenting and evolving their prototypes to the point that these small companies have become the leaders of the industry showcasing great advances on fairs, workshops and congress….

In 2017 this emerging technology captivated the interest of the big aerial manufacturers companies such as Boeing, Airbus, Bell Textron who presented their technology prototypes.. These last steps precisely consolidated a simple concept idea to becoming an emerging and promising industry that day by day increases its interest and brings us evolution to our world…

It had escalated so quickly that governments and competent authorities had been forced to create and present their regulation around vehicles like drones and EVTOL to ensure they can operate in a safer and controlled environment. For instance, European governments developed the U-space concept regulatory framework which applied in February 2023. It consists of a controlled and organized space segregated by low, medium and high areas (Skybrary, 2021) {4}.

This allows the safe control from multiple and simultaneous operations of UAS and EVTOL's. That creates a perfect climate for EVTOL and drone industries.

Currently, in 2023 we found ourselves in a situation where there is a very competitive environment around EVTOL technology, it evolves every day. A lot of big companies are showing interest in the technology and they are developing their own prototypes via current manufacturers or even delegating it through new startups created intentionally for it.

A few of them are: Honda, Uber, Tesla, Spacex, Amazon, Airbus, NASA, Archer Aviation, Vertical Aerospace, Volocopter, and more...

During the last 8 years chinese companies like XPeng and EHang presented their products successfully hitting the market. Their aircrafts are already flying through Chinese skies as the government presented a law which regulates them. So we can ensure that China is a step forward from everyone else in this industry and helps keep a competitive, promising and evolving environment.

There have already came out some patents as some engineers and their companies came up with powerful improvements, some of them are the following ones:

- KaremAircraft: EVTOL Aircraft using large, variable speed tilt rotors
- Opener: Electrically powered aerial vehicles ad flight control methods
- Joby Aviation: Aerodynamically efficient lightweight vertical take off and landing aircraft with pivoting rotors and stowing rotor blades (Fig. 1.2)

Fig. 1.2 Joby Aviation EVTOL and its patented pivoting rotors technology. *Source: {5}*

1.3. Market Situation

This section covers an analytical report of the market evolution of EVTOL as well as the best components and the different system's technologies in which companies invest the most.

First of all we must approach UAS's market history record in order to understand EVTOL market evolution, as it branches out from UAS technology. To brief a bit, UAS technology has grown a lot this last decade (Fig.1.3) as its cost has become more affordable. The industries related to the materials used to produced them have standarized economically. In addition, this technolgy has been driven by a growing demand for agriculture, construction, law enforcement, logistics, media and entertainment, military and defense sectors. As UAS are a rapid and cost effective deployment tool.

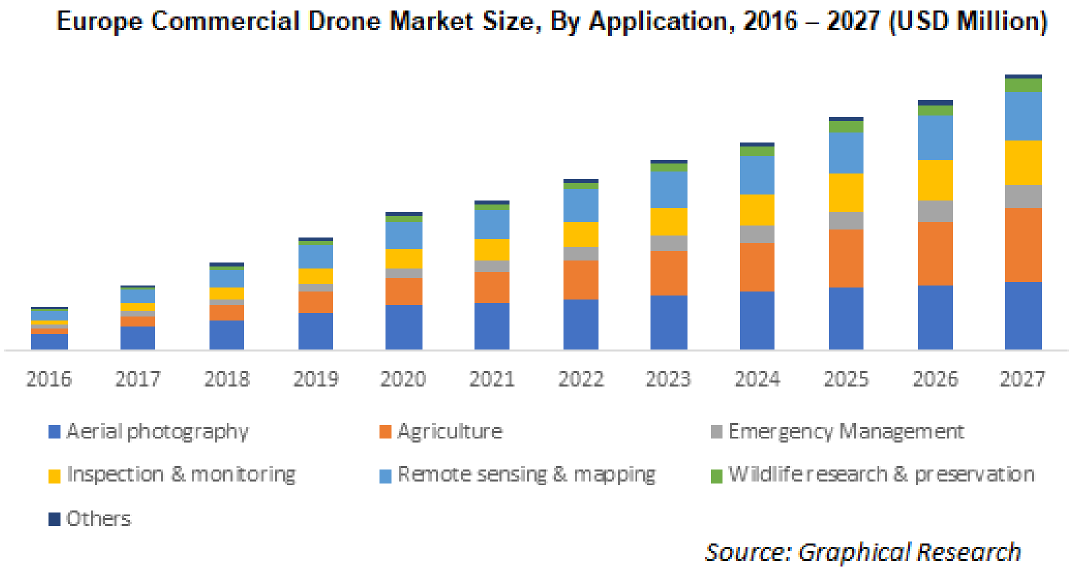


Fig. 1.3 European UAS market size evolution. *Source: {6}*

When it comes to EVTOL aircraft market, its growth is mainly driven by the urgent need for environmentally friendly aviation technology, a noise-free aircraft, the growing transportation congestion, the use of EVTOL's for cargo applications and increasing demand for an alternative mode of transportation.

A series of factors created a helpful and very promising scenario for this technology. It is the perfect one in the search for a greener mobility system, therefore a better future. Combines sustainability, safety, low maintenance infrastructure and low noise while providing similar advantages as traditional aircraft. The cost of producing it and using it is much more effective compared to a helicopter.

Last years in aviation history have been decisive, since air transport traffic has increased 5% yearly and its expected to grow so on. The industry is more aware of the impact of aviation on the environment and governments are making efforts to reduce emissions.

In addition, governments are investing in advanced mobility systems as the population in urban areas is rising exponentially.

Market's studies highlighted that the Global EVTOL Aircraft Market achieved revenue growth of USD 8.20 billion in 2021 and it is projected to reach around USD 23.4 billion by 2030, growing at a 14.90 CAGR (Compound Annual Growth Rate) (Fig. 1.4).

Fig. 1.4 EVTOL market table. *Source: {7}*

Advancements in software and hardware tech such as autonomous flight systems and electric propulsion respectively, are enabling a fast growing market to become a solid reality.

For instance, the new application of Hydrogen electric propulsion technology dominated the EVTOL market with more than a 30% of the market share. This type of electric power system provide by far larger autonomy and enable logistics to support operations without requiring separate charging stations.

Short range operations are expected to be the main fuel contributing to the growth of multirotor EVTOL aircraft, since the market share in 2021 was 79%. Multirotors are pretty stable and are used for applications such as passenger transport and emergency services to recreational activities like aerial photography.

Besides that, the lift plus cruise technology is also expected to grow during the forecast period as leading manufacturers are adopting it because it is less complex and enables long-range travel with stability.

Talking about software, this category commanded with more than a 21.75% of the market share. It is projected to generate the highest CAGR during the 2021-2030 period.

Technological companies are investing and deploying new aviation software which enhance operational efficiency, automates processes, increases safety and improves aircraft reliability.

EVTOL tech is growing and generating interest everywhere around the world. But North America is in control of the market share with more than 38%, it has contributed the most due to the presence of leading aviation companies and military applications. The United States aviation industry has compromised in growing greener technology to protect Earth.

In conclusion, it seems that North America or China would be the best place for a company to launch their EVTOL product as powerful investors and aviation companies are from these places. They helped standarized the materials to produce aircrafts making it by that more economically afforadable. In addition the country's competent authorities aim for greener aerial technologies and are in the race to able the perfect environment for EVTOL as soon as possible.

CHAPTER 2. Technology Analysis

In order to understand better the technology therefore we can find the most suitable strcuture, configuration and components for the EVTOL prototype concept. In this second chapter it can be found an in-depth analysis of the technology at issue. Also, there is a subsection dedicated specifically to the comparison between EVTOL and traditional aviation, to find out why it is the perfect solution for the future aerial mobility systems.

It is important to mention that the finality of this chapter is only to analyse the technology. In Chapter 4 which has to do with the beggining of the design process, it will be justified the selection of the prototype's specifications.

As it has been stated in the beginning of this document, EVTOL's are a revolutionary new aerial transportation method, it has close structural similarities to the current aircrafts but with the remarkable characteristic that is potentially more sustainable. It's a multifacet technology that will evolve the aviation industry and human civilization.

EVTOL's are an evolutionary step forward of VTOL (Vertical Take-Off and Landing) technology, which came into existence when it was needed for an aircraft that could operate in little space areas and work faster.

In general terms, because of its unique design and powerful structure EVTOL's have greater benefits than the other aircraft. First of all they are much quieter because their rotor speed is lower, they produce less noise when flying because their forward flight movement is using wing-borne lift.

They are more robust and have increased safety, its structure is powered by 4, 6 or 8 rotors so if one of those fails the aircraft can still fly in good condition. Same thing happens with the energy system, as they have several packs of batteries, it doesn't no matter if one of them fails, the other will back it up and the ship can still fly correctly.

The most known application for it at the moment is to be a "flying taxi" service. It is yet to determine the cost of using it, at the moment it seems to be an elite limo service but it would be very useful as a mass product service for any social class of people so they can pair it with other mobility services, thereby reducing emissions and traffic congestion. It has other applications such as package delivery and cargo transportation, it is thought that these last two will be the most common and useful.

At the moment all the talking has been about pros but as all, it also has unfavorable factors. The most notable aspect is its autonomy range which affects carrying capacities, it is very limited compared with other aircraft systems. So applications that need those capabilities such as search and rescue missions or long range package delivery are really limited. Not often, electrical batteries and other components are evolving and help solve these kinds of problems.

Also there are ongoing research and development programs focusing on other propulsion systems like hydrogen powered motors and batteries which are very promising and can solve greater as expected performance and autonomy problems.

2.1. Hardware

The technology of an EVTOL can be deployed in so many ways: big structure with six motors, little chassis and few rotors, fully electric, hybrid propulsion… Its final design totally depends on the application the aircraft is aimed for.

In the following table we have segmented the technology in the different key aspects that a design can be defined:

Table 2.1 EVTOL Technology classification

ASPECTS	DETAILS
By Technology	• Vectored Thrust • Multirotor • Lift plus Cruise
By Propulsion	• Fully Electric • Hybrid Electric • Hydrogen Electric
By Range	• <= 200 km • > 200 km
By Application	• Air Taxis • Air Shuttles • Private Transport • Cargo Transport • Air Ambulance & Medical

	Emergency ● Last Mile Delivery ● Inspection & Monitoring ● Surveying & Mapping ● Surveillance ● Special Missions
By End Use	● Commercial ● Defense ● Private ● Other
By Mode of Operation	● Autonomous ● Piloted
By MTOW	● <100 kg ● 100 - 1000 kg ● 1000 - 2000 kg ● > 2000 kg

2.1.1. Types of structure

Aircraft structure, materials and technology implemented depends on the ship's purpose and utility. As we can see on the figure (Fig. 2.1) below, the most common structural configurations are the following ones:

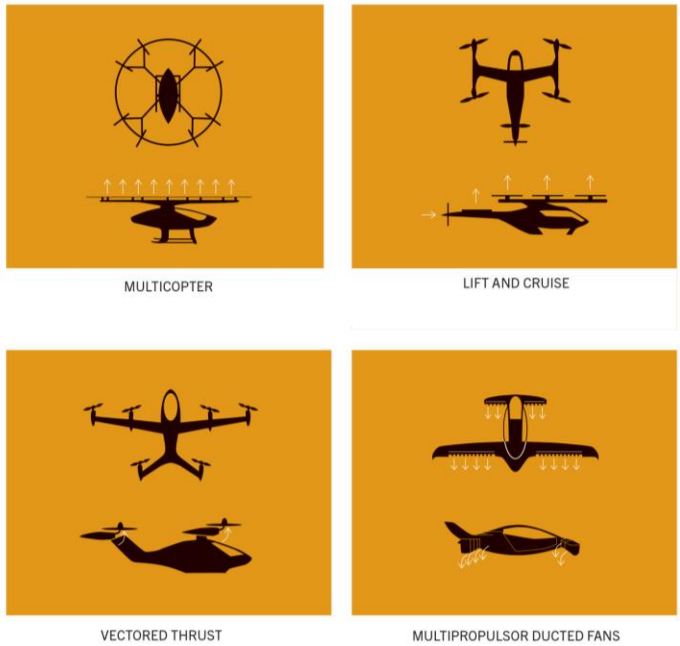


Fig. 2.1 EVTOL design configurations. *Source: {8}*

- Tilt Rotor: Vectored thrust systems, for instance Joby Aviation Lilium jet, this configuration is very efficient but too complex and expensive to produce. As main spec we find that the propulsors they use have the capacity of tilting so the aircraft can move with accuracy in any direction. They help transition the aircraft from lift off thrust to forward thrust, and wings boost cruise energy efficiency.

- Ducted Vectored Thrust: Multi propulsor ducted fans configuration consists in the same as the before mentioned tech, the electric fans are vector-able, they can also tilt and are covered by ducts reducing by that the noise. Wings boost cruise flight.

- Wingless: The most common wingless known aircraft are multicopters, Volocopter or eHang are examples of the market. Lifting rotors are arrayed around the circumference of a carbon ring. This kind of configuration are low cost ships, but low speed, small range and are not too comfortable as they have large slope flight trajectories.

- Lift and cruise: Autoflight startup prosperity one, easy to manufacture and maintain configuration, meets the highest safety requirements. This design provides alternative landing solutions as extra safety measures. Fixed wing glide landing and Whole aircraft parachute. And is the easiest EVTOL to design when aiming for a great long range capacity.

  One group of vertical rotors lift the aircraft and another kit provides forward thrust, wings also boost cruise efficiency. Very stable flight, the more rotors we have the more stable and safer it is. Because rotor failure consequences are avoided when increasing rotor number. When it comes to the engineering data, lift and cruise seem to be the most aerodynamicallly efficient, with a great autonomy and flight performance.

2.1.2. Components

As in every vehicle, there are a lot of important different pieces that compose the machine, those components are the ones needed for its utility and application, each one with its own necessary function.

When it comes to EVTOL aircraft there is no difference, in this section we will briefly expose the most important so we can understand how the technology works.

In the following list there are highlighted the main components of an EVTOL:

- Batteries: Electrical batteries are the propulsion system implemented. There are different types of it but the most commonly used nowadays is the Lithium-Ion battery, because unlike chemical systems it is more mass-efficient. It requires very little mass to accelerate a spacecraft. Not often these provide a short range of autonomy which is the main problem of EVTOL. That's why other propulsion methods are being considered, such as hydrogen propulsion that can be done fueled or battery celled.

  This technology is very powerful, efficient, and way greener removing carbon dioxide emissions entirely. They provide a higher power-efficiency-autonomy ratio thereby solving the autonomy problems.
  In the following graph (Fig. 2.2) we can see the environmental impact of each technology visually represented.

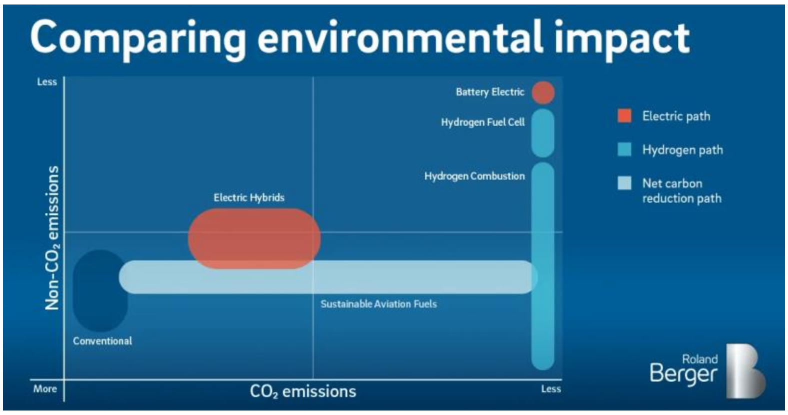


Fig. 2.2 Environmental impact comparative graph between electrical and hydrogen batteries. *Source: {9}*

Also, relative to batteries, hydrogen ones have more energy density when focusing on gravimetric and volumetric criteria. On the image (Fig. 2.3) below it can be seen a comparative between several propulsion technologies focusing on energy density.

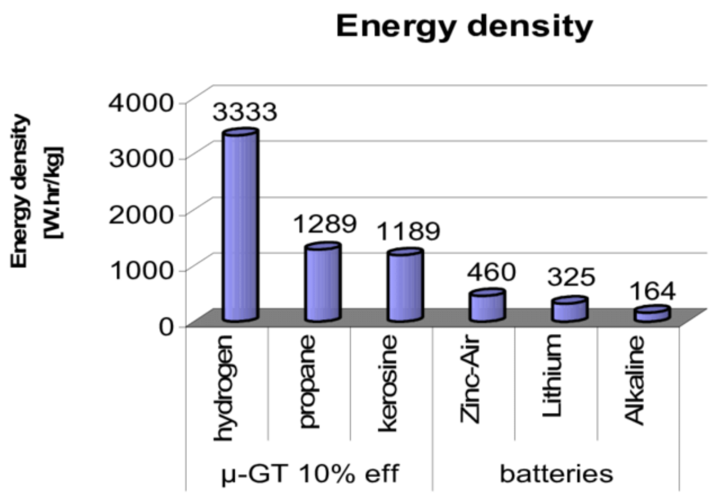


Fig. 2.3 Energy density comparative graph between different propulsion technolgies. *Source: {10}*

Hydrogen propulsion has greater advantatges and capacities. Despite that, the main problem of it to becom a reality is the extraction and distributing processes. The market situation related to this method is not yet established but will do for the nearer future as industries like aerospace, automotive, drone and much more have already research programs ongoing as they have seen the full potential of it.

This could speed up the storage systems and development of fuel cells, create infrastructure and push down supply chain costs..

In conclusion, the only problem for now is the money barrier. It has a high cost producing it and distributing it, but that must change from now on as a lot of industries know the advantages and are willing to implement it…

- Motor: Electric brushless rotor engines are the most used because they are more energy-efficient than brushed ones, since they don't contain brushes that lose energy because of friction. So they have larger battery life and require less maintenance.

- Propellers: Esch rotor has attached a propeller that can have two, three or more blades from a large range of lengths depending on the aircraft's type of configuration.

- Chassis: Metallic structures, carbon fiber and thermoplastics technologies are implemented together to build up aerospace vehicle's. As they offer the best quality-economical ratio while providing great performance on resistance and lightweight capacities.

2.2. Software

One of the main benefits that EVTOL technology has it's their ease of use. Which is provided by software tools that along with other systems upgrade its capabilities and ensures safety.

In the following section there are explained the main software tools that it can found on an EVTOL aircraft.

2.2.1. Systems

- Flight controller: This system is composed of different electronics that have the function to enable the aircraft working autonomously. Thanks to the preflight instructions implemented on its microcontroller's software and its communication with the hardware onboard, sensors and surface controllers.

  Between these electrical components that ensure the safety control of the aircraft we find; fly-by-wire, electric motors, actuators, servos, brakes, autopilot, and so on… The autopilot is one of the most important components, it's a software tool which manages the aircraft heading using the vehicle's mechanical, hydraulic and electronic systems along with the flight controller…

  These kinds of aircraft are operated via computerized flight control systems, that means that you don't totally control its actions and movements. The controller movements order instructions to the system, and this one processes the information contrasting it with its sensory data and deciding by itself the best and safer move.

- GPS: Global Positioning System is a satellite navigation tool used for obtaining positioning data in real time such as time, compass, and x&y axis position. It is a great solution to provide aircraft's geotagged data and keep its track on the traffic radar. Along with the barometer which provides pressure data therefore altitude, they both constantly communicate with the flight controller microprocessor to help stabilize the aircraft during the flight.

- LiDAR: This sensor contains a transmitter and a receiver to read the light laser shooted to the ground. By that it measures the distance to it and helps leveling and keeping the aircraft's altitude.

  It's also useful to detect obstacles and avoid a collision along with the flight controller by recorrecting the fly trajectory. Thanks to the laser technique it can also provide a real time 3D scan of the area's terrain.

- Radio: Constituting the aircraft there is also a radio system, with their own antennas functioning as transmitter and receiver, which enable the communication between the crew onboard to the exterior of it in order to interact with any type of necessary information such as traffic management, emergency messages, flight data, telemetry control…

  Wi-fi or 5g are other ways of communicating all types of information between aircraft and ground control stations. These methods also allow the possibility of not just exchanging valuable data but managing the aircraft itself.

- Camera: RGB or thermal, they are used to get visual data. As for surveillance, audiovisual or inspection. They are also a great tool to scan by carrying on the photogrammetry technique and obtain a textured tridimensional digital model of objects, buildings, landscapes…

- Proximity sensor: This little component is an essential one whose function is emitting and receiving radio waves. In order to detect nearby obstacles and avoid collisions by communicating it to the flight controller so the aircraft's trajectory gets recorrected. Thanks to the radio waves it can also bring out a real time 3D scan of the area's morphology.

- Other sensors: Temperature, humidity, barometer, microphone, gyroscope sensors…

2.3. EVTOL vs Traditional Aviation

People often think at first sight that EVTOL’s are the same as a helicopter, they are not that wrong.

This technology has so many similarities with other known aerial transport methods, in fact, VTOL’s and EVTOL’s are just UAS that mix the specs of multirotor and fixed wing technologies.

In this section we focus on comparing EVTOL with the most popular aircraft in order to solve this stigma.

2.3.1. UAS (Unmanned Aerial Systems)

In addition to what it has been stated before, UAS are the structural base of EVTOL’s. There are different UAS structures; fixed wing, tricopter, quadcopter, hexacopter, single rotor, and VTOL. This last one is the fundamental structure of EVTOL’s.

Same as EVTOL, VTOL aircraft is a hybrid drone, it mixes the stability of multirotor tech with the fixed wing, reducing by that aerial drag and so increasing its autonomy. Its wingspan dimensions emanate from 70 centimeters to 3 meters or more depending on its application.

The little ones VTOL’s are mainly used for photogrammetry, mapping and surveying, search and rescue missions, low payload cargo transport operatives, photography and videography… Therefore the materials used for their production tend to be lightweight such as, boat wood, fiberglass, foam. etc.

When the applications for VTOL’s require heavier payloads like cargo transport or aerial taxis, we have to scale the aircraft to a bigger structure and electrify them with more battery cells and more powerful rotors. That's the case when we are talking of EVTOL’s. These heavy payload applications require harder and more resistant materials like metallic structures, the ones used in planes and helicopters.

Not only are they similar in hardware but in the software aspects too, a great characteristic that EVTOL’s shares with drone technology has to do with the software aspects (Fig. 2.4). Systems like the computerized flight controller that offers an autonomous flight, fly by wire technology, autopilot, radio communication, GPS...

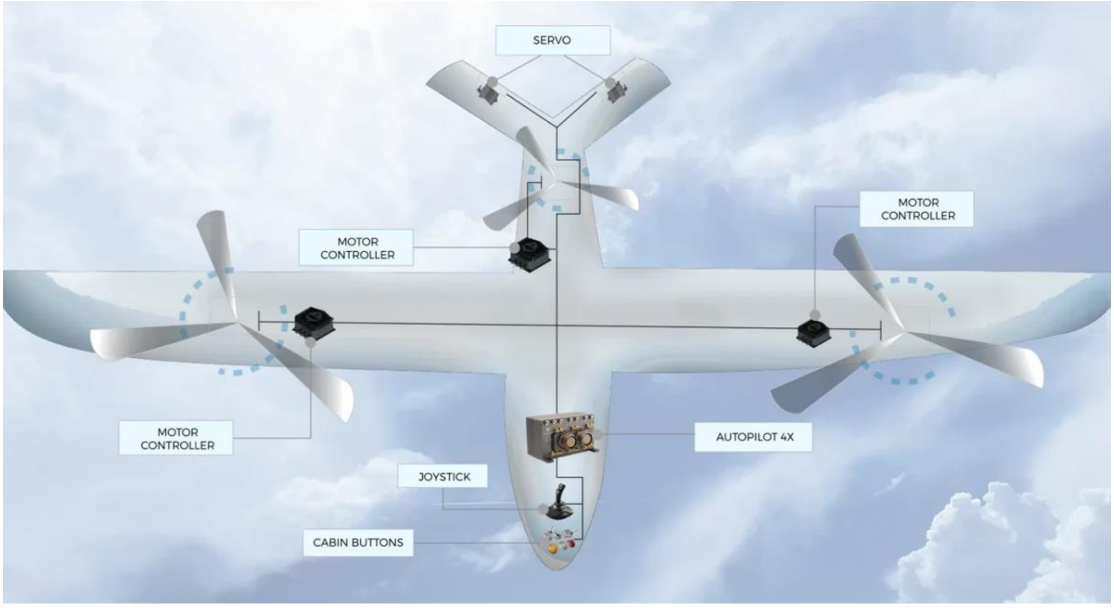


Fig. 2.4 EVTOL software tools. *Source: {11}*

All these have been integrated on them improving their practicality and ensuring safety by that. It allows the aircraft to ensure a safe flight by revising each of the pilot's controller movements with its components sensors, gyroscope, LiDAR, surface controllers, servos, actuators, etc… It kind of automates the pilot's instructions. This spec is very helpful as the majority of EVTOL's customers are non-trained pilots.

In conclusion, EVTOL's are like big drones, to be more exact they are big VTOLS with the same virtuous flying specs but with more powerful components and structure as they have to adapt to its utility and application.

2.3.2. Plane & Helicopter

Helicopters and planes are very noisy and cost too much to operate. EVTOL is a quieter mobility method with fewer emissions as they use electric propulsion.

According to Gandhi in his study states that eVTOL's are quieter because much of their forward flight is using wingborne lift which pushes the aircraft forward once it achieves certain velocity. Also, as their rotor speed is lower compared to helicopters, noise levels are reduced.

They are potentially safer than conventional aviation because they use the typical plane wing like structure to reduce drag and energy waste, therefore increase autonomy. And combine it with the multirotor technology that allows the perfect stability and movement precision at any direction.

As Michael Liskinen, president of the United Airlines Ventures, told CNBC that “the main reason eVTOL’s cost less to operate is because electrification makes the aircraft safer, safe aircraft also becomes less costly to maintain” he said.

In addition, as they have several rotors and batteries, in case of a rotor failure they do not totally depend on one, two or four motors. They can still fly correctly and avoid a collision if various rotors fail, the more we increase the number of rotors in an EVTOL, the safer it will be.

Electrical VTOL’s do not mandatorily require building infrastructure for them to operate, so we avoid wasting materials, occupying space and polluting to produce them. They have the ability of landing anywhere, even in little spaces. To summarize the comparison, here’s a list of the main benefits:

EVTOLs vs Traditional Aviation are:

- safer
- greener
- less noisy
- more maneuverability
- more precise
- more stable
- do not requiere infrastructure
- do not cost too much to operate
- less maintenance

Definitely EVTOL’s are a huge evolution from traditional avaition as they are way more greener. They ask for zero infrastructure to operate them and the noise pollution they produce is so much quiter. In addition they are safer as there are several rotors on them and can be automatedly piloted, eliminating human factors such as errors caused by fear or fatigue.

CHAPTER 3. Regulation and law aspects

With the aim of figuring out whichever legal limitations would be applied to the prototype concept. This chapter consists of the regulation involving drones, as currently there isn't still a framework that regulates EVTOL at all.

EVTOLs are a relatively newborn type of aircraft, they only have taken to the skies to carry on its testing. That is why there is not a fulfilled regulation that allows them to fly yet, at least for the bigger ones that exceed the certified class.

According to industry's specialists, there are ongoing negotiations between EVTOL companies and competent aerial authorities to apply a regulated public operable environment in the coming months. But before that, it is necessary that manufacturers prove and secure their systems and develop recovery plans to face mechanical failures…

In the regulation aspect, China is also a level ahead of everyone, several manufacturers had carried out a lot of testing. Some of them like EHang and Aerofugia have gotten their certification by CAAC, allowing them to fly commercially in the near future.

Europe has also taken some steps forward developing and applying a regulatory framework called the U-Space concept, which organizes and regulates all types of aircraft in the aerial space. Aside from helicopters, planes and other traditional aerial transports, drones and EVTOLs have been taken into account.

When it comes to aerial regulation it all depends on the type of aircraft, and its type of use or application. The characteristics of an aircraft such as its payload, dimensions and weight have a lot of importance because it determines the amount of damage (measured in kinetical energy) its impact can cause.

It is also needed to solve problems like where do you land these aircrafts, how do you control them, noise regulation, which is the procedure in case of accident, assurances, authorizations and all that stuff…

That's why professionals of the industry say that one way to get EVTOLs in the sky quicker is by certifying them for personal use. This certification process is less rigorous than commercially intended because by doing that you avoid having the problems mentioned before. You can land safely in any private property you want if you have owner's authorisation.

For instance, AIR's AIR ONE EVTOL is currently awaiting its certification from the FAA (Federal Aviation Administration) that allows them to operate in personal or private uses.

This EVTOL has got nearly 300 preorders, and according to its manager, the majority of customers are from the United States ensuring that USA is the easiest market to break into and maybe one of the first places where EVTOL will take to the skies.

When it comes to commercial use, we find out that there may appear infrastructure problems. If you want to escalate this technology, someday it will need a vertiport where you can land and charge its batteries. Also some default fire suppression system would be necessary, as batteries in some rare scenarios tend to get fire and are risky to its nearby.

In conclusion, there’s still a gap to fulfill when it comes to EVTOL regulation. A lot of aspects and problems have to be solved related to its structure, intended use, control systems, maintenance, infrastructure and much more…

But it seems that companies see a promising future in this sector and governments are working hard to enable the needed environments.

3.1. UAS Regulation

In this subsection and in the following one, it is covered a brief explanation of the regulatory framework involving UAS in order to understand how to properly actuate when using any type of drone or an EVTOL.

When flying a drone there are several things to take into account in order to do it correctly. First of all you must know that it is an aircraft and it is required to have a drone piloting license, which can be achieved by studying a course and passing its exams. Having all the knowledge that a drone involves is very important because ensuring safety in a flight operation is a must. We have not to forget that it doesn't matter the size of it, we are flying a “little” thing in the same aerial space where a lot of aerial operations coexist such as commercial planes, medical helicopters, airplanes, and so on…

Drone pilots have to be very careful because in case of a collision to another aircraft, for instance the rotor engine of a helicopter, you can cause a lot of damage to the crew and passengers including a mortal accident. Even if you hit a plane’s wing with a little drone you create a hole which will begin to get bigger because of air resistance. Difficulting by that the stabilization and proper manage of the aircraft therefore consequenting a potential crash.

That is why there are protocols and methodologies that have to be followed as of environmental factors too. Weather conditions like the illumination, wind, temperature, visibility, rain and so on, affect the flight capacity.

The drone regulation criteria depends mainly on the way a drone is defined. It is considered that an aircraft is a drone if it has a camera onboard. If not, it is defined as a toy, meaning that it has not to comply with any regulation. So this little aircraft can fly anywhere while his specs allow it. If an aircraft has a camera everything changes, we now have a drone that when operated the pilot must comply with identity, privacy, and aerial space laws.

Drones are less or more regulated depending on their mass (Fig. 3.1), their maximum take off mass (MOTM), and its kinetical energy in case of impact. Focussing on its mass we found them classificated in different class's; sub 250g, 2kg up, 25k

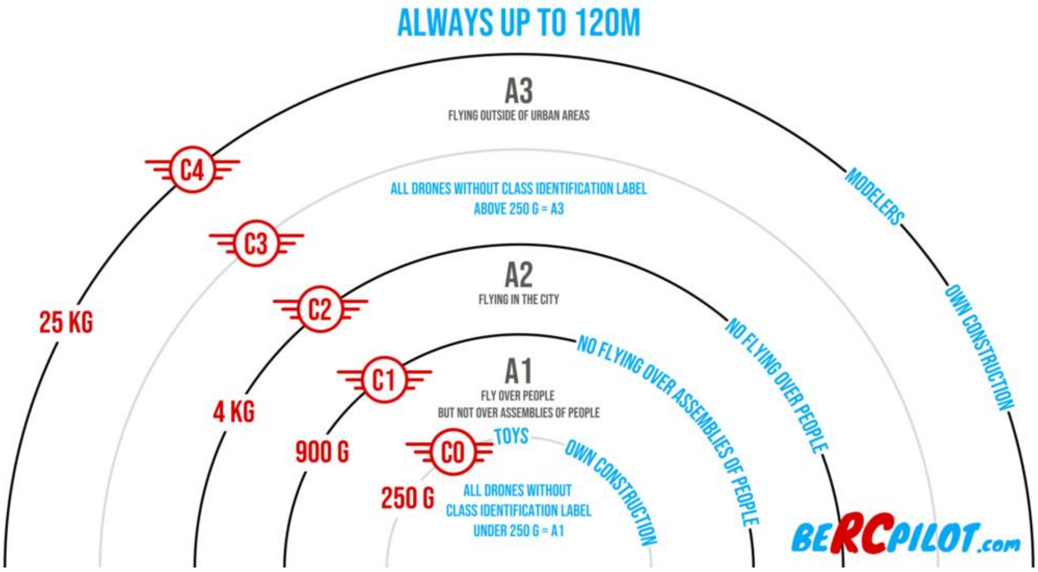


Fig. 3.1 Drone regulation class's classification. *Source: {12}*

In addition, another thing that affects flying a drone besides the specs of it, is the risk intrinsic to the operation, aerial and terrestrial (Fig. 3.2). It is not the same to fly in a rural or natural area where there are less obstacles, less population and less air traffic than flying in an urban area where there are many more factors and variables increasing the damage possibility.

Following this criteria we found 3 different types of scenarios; open, specific and certified. Respectively more dangerous thereby more restricted.

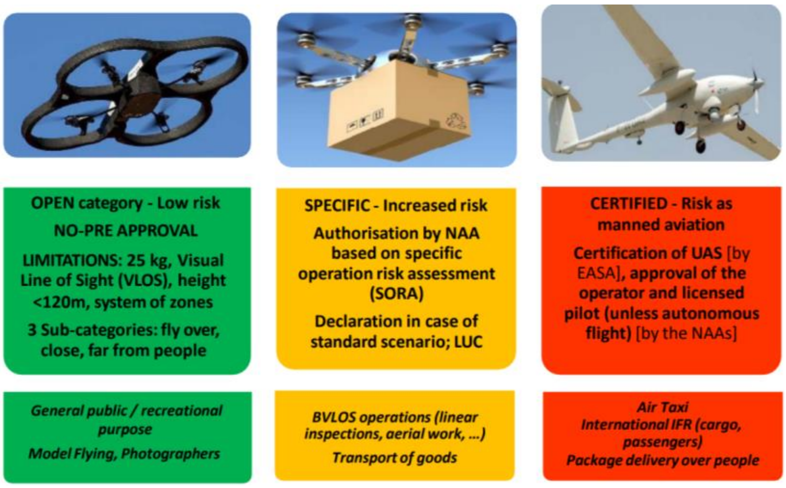


Fig. 3.2 Dron regulation scenarios by aerial and terrestrial risk. *Source: {13}*

To conclude, different restrictions are applied based on the drone's class and the scenario in which you aim to fly. So the drone operator will have to follow the correct protocols and methodologies to ensure a safe operation in order to carry on the flight.

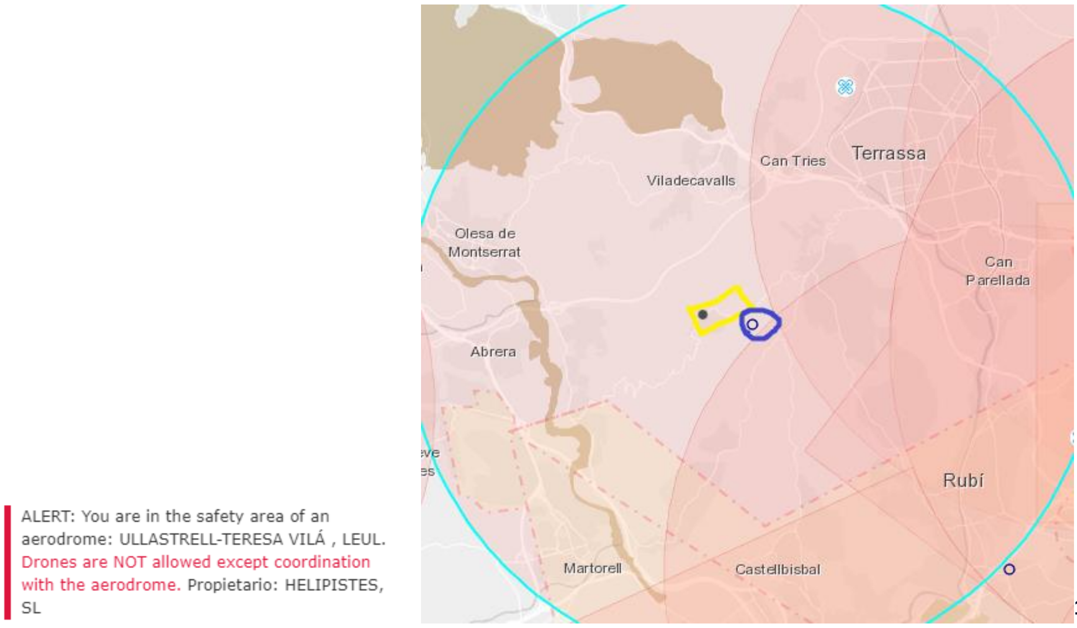
3.1.1. Flight Plan

For instance, here's a flight plan that is made to carry on a flight operation in the area of Ullastrell, Terrassa. This is an interesting example because despite it's a rural location, the urban areas of Barcelona, Sabadell, and Terrrassa are close to it so the airspace nearby is pretty much restrictedly controlled by airports and heliports.

Mission objective: Offer drone audiovisual footage about a real rally motorsport competition.

Location: Ullastrell, Carretera "el suro", 41°31'15.8"N 1°57'21.5"E

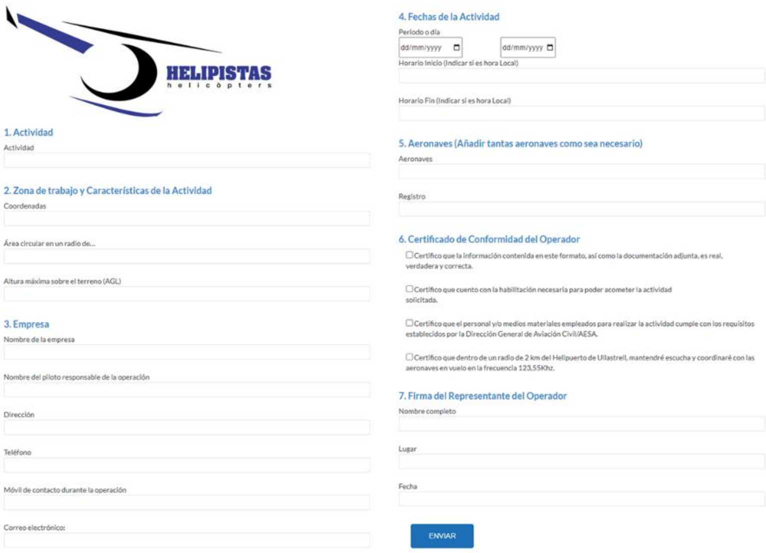
Air space regulation: As we can see in the figure below (Fig. 3.3), the air space zone where it is pretended to carry on this drone operation is controlled by an heliport. So we have to communicate with them in order to ensure safe flight conditions in the controlled airspace area.



[1]

Fig. 3.3 Airspace restricted zones, provided by ENAIRE Drones. *Source: {14}*

That is why we must declare our drone operation to ULLASTRELL-TERESA VILÁ, LEUL via its official form (Fig. 3.4). Also we must not forget to send them a flight plan 48 hours before the operative. On it there must be all the information requested and the operation features such as date, hour, altitude, location, duration, drone information...


HELIPISTAS
helicòpters

1. Actividad
Actividad

2. Zona de trabajo y Características de la Actividad
Coordenadas
Área circular en un radio de...
Altura máxima sobre el terreno (AGL)

3. Empresa
Nombre de la empresa
Nombre del piloto responsable de la operación
Dirección
Teléfono
Móvil de contacto durante la operación
Correo electrónico:

4. Fechas de la Actividad
Periodo o día
dd/mm/yyyy dd/mm/yyyy
Horario Inicio (Indicar si es hora Local)
Horario Fin (Indicar si es hora Local)

5. Aeronaves (Añadir tantas aeronaves como sea necesario)
Aeronaves
Registro

6. Certificado de Conformidad del Operador
☐ Certifico que la información contenida en este formato, así como la documentación adjunta, es real, verdadera y correcta.
☐ Certifico que cuento con la habilitación necesaria para poder acometer la actividad solicitada.
☐ Certifico que el personal y/o medios materiales empleados para realizar la actividad cumple con los requisitos establecidos por la Dirección General de Aviación Civil/AESA.
☐ Certifico que dentro de un radio de 2 km del Helipuerto de Ullastrell, mantendré escucha y coordinaré con las aeronaves en vuelo en la frecuencia 123,55Khz.

7. Firma del Representante del Operador
Nombre completo
Lugar
Fecha

ENVIAR

Fig. 3.4 LEUL (Helipistes SL) UAS flight permission form. *Source: {15}*

---

[1] Yellow = Ullastrell village, Blue = Heliport, Turquoise = LEUL controlled radius airspace

In addition, it's a must to make the use of radio the day of the flight to be coordinated with them at any moment throughout the entire operation.

On the other hand, 10 working days before this one takes place the drone operator must had requested the petition to carry out the drone operative to Mossos d'Esquadra through the their web application (Fig. 3.5). As some of the flights fit into the specific conditions scenario; the operator is flying a drone at less than 150 meters away from an industrial zone. The requirements requested to be able to make a petition are having a drone operator license, AESA's authorization and personal identifier document (DNI).

Fig.3.5 Mossos d'Esquadra's web link to comunicate the flight permission. *Source: {16}*

To be continued, here are descriptied the several type of flights to be done during the flight operation.

Type of flights:

- Zenital view VLOS

- Drone type: DJI mini2, 245g weight (camera included)
- Scenario: Class 0, A1 Open category
- Flight movements: high altitude (from 15m over the ground to 110m), simple movements in a straight line, from left to right, forward, diagonal, vertically, hovering, static.

- (b) Chasing view BVLOS

- Drone type: FPV 3.5 inch cine whoop, 574g weight (camera included)
- Position: moving at low height, fast movements to chase up the target closely over the road and between trees

- (c) General view VLOS

- Drone type: DJI mini2, 245g weight,
- Scenario: Class 0, A1 Open category
- Flight movements: high altitude (from 15m over the ground to 110m), simple movements in a straight line, from left to right, forward, diagonal, vertically, hovering, static.

**Notice that as we have a camera mounted on each drone, we must be aware that we need to register as a drone operator.*

As flight type (a) and (c) are in VLOS conditions and the drone is C0 and A1 scenario classified. We don’t need any authorisation and so to appeal for a SORA document in order to fly. We just have to respect the 120 maximum height and the 15m maximum distance over the public.

But in the case of flight (b), as it is BVLOS conditions and we are flying FPV manners at low height close to the car over the road nearby people, we have to make a SORA in order to declare and mitigate risks. For instance, in this case we found ourselves in the situation in which we are flying near an assembly of people that cannot escape in case of an accident.

This is the SORA that we must declar:

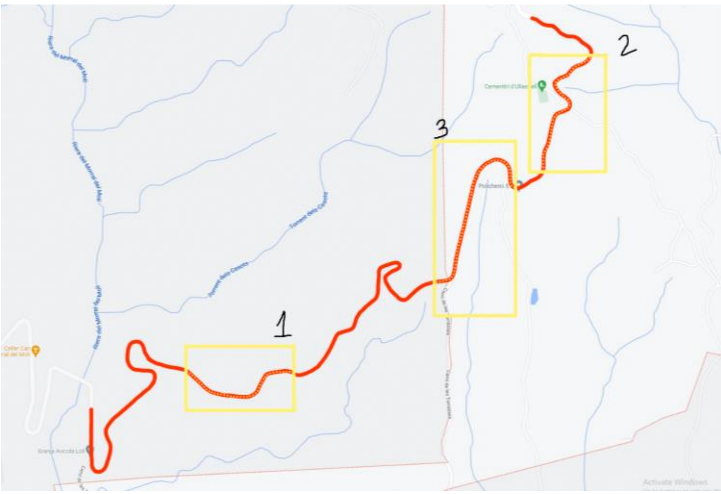
SORA (Specific Operation Risk Assessment)

Flight case (b) Chasing view BVLOS:

- Drone type: FPV 3.5 inch cine whoop, 574g weight (camera included).
- Position: moving at low height, fast movements to chase up the target closely over the road and between trees.
- Date:04/09/2023
- Flying intermittently in sectors 1,2 and 3 from 8:00h to 13:00h.
- We have 4 batteries, each battery flight time is 6 minutes = 3 car chases.
- The FPV drone will fly 4 times per hour, 24 minutes in total = 12 car chases.

<u>Trajectory:</u>

It has been decided to divide the zones in 3 different sectors (Fig. 3.5) in order to have a more controlled operation, this technique is called segmentation.



[2]

Fig. 3.5 Road itinerary segmentated by sectors to ensure safety

In each sector there are two radio operator observers, one of them situated at the beginning and the other one at the final part. The pilot will be in the middle of the sector at a elevated zone to achieve good radio coverage.

<u>Road zones description:</u> Wide road with mountain at both sides and trees at 5-10 meters away. The good point is that people are not allowed to be exactly on the side of the road, there are specific areas designated for the public to watch the race.

Sector 1: Lowest risk, No assembly or person allowed (Fig. 3.6)

Fig. 3.6 Sector 1

---

[2] Red = road/race itinerary Yellow Rectangle = segmented flight sectors Yellow points = drone trajectory

Sector 2: Highest Risk, Assembly of people at 10 horizontally and elevated meters of the side of the road in one specific turn, Cementiri turn (Fig. 3.7).

[3]

Fig. 3.7 Sector 2

Sector 3: Low risk, No assembly or person allowed (Fig. 3.8).

Fig. 3.8 Sector 3

<u>Risk mitigations measures applied:</u>

- Parachutes installed on both drones
- Cine Whoop guards
- Segmented type flight of the zones where we fly to ensure public safety
- Observers and pilot with radio devices coordinated between them and with heliport
- The drone of flight (b) will only fly over the road while there is public presence
- Both drones will not fly at the same time in the same zone
- Drones will land on the floor if a helicopter or other aircraft is present in the flight zone.

[3] Yellow = assembly of people

3.2. U-Space Concept

European governments developed the U-space concept regulatory framework which applied in February 2023 in order to move onto a sustainable smart mobility system aiming for safety and efficiency.

In general terms, this framework helps us control the aerial space and organizes it by segregating areas by class's as low, medium and high layers (Fig. 3.9). This allows the safe control from multiple and simultaneous operations of UAS and EVTOLS.

Also, it provides the safe integration of the drone sector into the traditional airspace by clarifying the responsibilities of Air Traffic Management (ATM)/U-Space and piloted aircraft versus UAS.

Fig. 3.9 U-space segregated zones. *Source: {17}*

The main pillars of U-Space are the services that everyone flying have to comply with these are:

Network identification:

- Serial number of the Unmanned Aircraft and real time flight data of the UAS
- Registration number of the UAS operators
- To manage aerial traffic information, the competent authorities can share and contrast the UAS operational data based on the information provided by the operators.

Geo-Awareness:

- Update UAS geographical position every 30 minutes, 30 seconds or daily (depending on the type of operation and its urgency).
- This service together with the Flight authorisation one aims to support UAS operators on providing relevant information about operational conditions, airspace constraints and any performance requirements prior and during flight…

Traffic Information:

- This service provides information to UAS operators about other air traffic that is present by proximity to its position.
- Supports situational awareness. It shows position, intended route.. Not only UAS but also manned aircraft traffic.
- When a manned aircraft needs to cross a U-space airspace, they would need to contact USSPs in order to provide their operational information so they can coordinate with CISPs and ATS to ensure a safe situation.

Flight Authorization:

- This service is in charge of providing authorisation to UAS operators based on the traffic within the same U-Space airspace.
- The activation of a flight initiates the use of other known services like, network and remote identification, traffic information, geo awareness…
- UAS Flight Authorisation Request (Mandatory information)
    - Unmanned aircraft serial number
    - Registration number of the UAS operator and of the unmanned Aircraft
    - Mode of Operation
    - Type of Flight
    - Category of UAS operation (‘Open’, ‘Specific’, ‘Certified’), UAS aircraft Class
    - 4D Trajectory
    - Identification Technology
    - Expected Connectivity Methods

- Endurance
- Applicable emergency procedure

3.3. Certification and Safety Requirements

EVTOL is a recently newborn technology, that's why for this type of aircraft, there aren't still any special certification or safety standards at the moment. As with any aircraft, they must have an airworthiness certificate to demonstrate that they meet the necessary safety standards before they may be used for public purposes.

Active VTOL Crash Prevention Limited is a member of the team developing the EUROCAE/EASA safety standards for eVTOL aircraft with specific responsibility for developing it for both eVTOL Active Safety Systems and for Stroking Crashworthy seats.

Since 2018, the European Union Aviation Safety Agency (EASA) has been working on the certification of such aircraft.

Using accident statistics from helicopters as a starting point, Loss of Control-Inflight and System (Powerplant) malfunction rank as the two leading causes of accidents, with Low Altitude Operations and Collision also being included.

In an emergency, fixed-wing aircraft automatically deploy a parachute that slows the drop. These are called "Whole aircraft recovery systems", and are becoming more common in many general aviation airplanes as they have already saved more than 500 lives worldwide.

In aviation safety is a must, protocols and methodologies have to be premeditated to prevent risks of collision aside from active systems. EVTOL aircraft's design and use carries certain risks:

- There won't be any typical lift beneath any wings during vertical takeoff and landing phases since there won't be any forward momentum, and there won't be any rotating effect, which helicopters utilize to manage emergency descents.

- The increased number of takeoffs and landings will result in additional stress for pilots, airframes, and engines. Pilots will need to take into account potential traffic, obstacles, and wildlife in all 6 directions constantly.

- The risk to people on the ground as well as to animals and property is increased by the use of eVTOL aircraft above towns and cities.

- If an emergency landing is necessary or the aircraft hits an obstruction, electrical power trains and the lithium batteries used to power the aerial vehicle are more likely to catch fire or explode.

- The increased use of the eVTOL aircraft's low-altitude operating environment where the incidence of bird strike is higher due to the greater density of birds.

- Safety measures will need to take into account a far wider variety of factors, such as weights, sizes, and the excitement of passengers, since eVTOL aircraft are expected to appeal to a wider audience than regular helicopters and small planes.

As a result, it has become clear that different strategies are needed for eVTOL aircraft as opposed to the current Emergency Descent Arrest Systems created for fixed wing and rotary aircraft.

In particular, Justin Littell's paper from the NASA Langley Research Center on "Challenges in Vehicle Safety and Occupant Protection for Autonomous electric Vertical Take-Off and Landing (eVTOL) Vehicles" came to the conclusion that a Ballistic Recovery System should be a necessary piece of equipment but notes that existing systems are not adequate on operations below 400 feet.

To conclude, EASA, NASA, FAA, CAAC and more competent authorities are working on to come up with the right protocols that will enable the certification and safety measures of these powerful and promising new aerial technologies for public purposes (EASA, 2023) {18}. At Chapter 4 it is discussed briefly the regulation situation involving the EVTOL prototype concept.

CHAPTER 4. EVTOL Prototype design process

In this section it is explained, documented and justified all the stages of our EVTOL's prototype design process from a creative perspective, while taking into account all the technology analysis previously done.

4.1. Design technique

The technique we are following to develop this project is called concept design, this one is always carried on by designers, architects and artists at an early stage of every project involving the prototyping of any type of product.

In this case we are focusing on vehicle product design. Our main objective is to sketch a series of different aesthetic designs so we can come up with the right one for the final prototype.

The correct way to do that is to creatively speculate with the shape and forms of our product, understanding its technology, application, and purpose. While keeping on thinking about the materials and the production costs of it.

Designers have to avoid at all costs creating realistic, normal or current designs, that's why they are asked to let loose their creativity. Because they must create concepts that could be at the market 5-10 years on from actuality since we have to be innovative and so evolve the industries. They work in the first stage of any project, take the first steps by visualizing the ideas, modeling them and marking the shape of a project. They have to work thinking always on the posterior stages that will follow their work.

Another thing that is settled as a must is the fact of pursuing sustainability. As we are going through very hard times on our planet, designers have to think on using organic materials, recycled or low polluting matter on their designs.

Work thinking in multifunctionality helps make the process easier, for instance, integrating advanced materials with multiple functions help reduce manufacturing time and its maintenance. It's mandatory to innovate but having in mind its costs, try to reduce the economical one as the time to invest that its production requires…

To synthesize, designers have to creatively create innovative and sustainable designs which will be supervised by industrial designers whom then will prove if it is physically viable so they can give a good check to the production team. This is my job when abording the master thesis.

4.1.1. Methodology and Tools

During the design process we are combining digital and analogic tools. But it’s important to highlight the significance of digitalisation which in the design industry has had a key impact as happened in all others.

The use of digital has been revolutionary, tools like digital modeling and virtual spaces optimized the performance testing of products. Provided the ability to experiment with materials, structures, shapes, stress force simulation and more, at a very fast way. That helped reducing development time, economical cost thereby, accelerating time to market.

In the very first beginning of our design workflow we find the sketching phase, where we use analogic tools aiming to find interesting shapes, structural components ideas, possible materials. In this first stage we use tools like pencil, pen, francese curve rulers and calligraphy pens to get the first ideas.

After we get the first sketches on analogic, we move on to the digital part where we want to come up with the final sketch design by blending the most attractive ideas. This final digital sketch is done on Adobe Photoshop where we can draw to explain the design and use photos (this technique is called photobashing) to give it some texture and show its components and materials.

Now that we have the sketching phase done and a solid fundamental idea, we move up to the modeling phase. We are using a 3D design software named *Blender* to give the 2D final sketch tridimensional shapes and forms so we can study and understand better how the design works and what to improve.

This software is one of the best options when it comes to 3D design software, very popular in the art and design industries. Because aside from modeling, we can add textures, materials and lighting (among many other options) to 3D meshes and render an image or animation to help visualize our ideas.

After we get the 3D mesh done, the next process’s stage is the simulation phase. It is time to bring the EVTOL design to the simulation software called Solidworks, here we can interpret how the real design of the aircraft works at facing forces such as gravity, wind force, centripetal, normal…

This CAD program is commonly used in aerospace engineering to develop real aircraft, vehicles, and products. It allows us to see statistical data visually represented interacting with our 3D mesh, which helps us to improve the design by finding the weak points and issues in our structure.

Once we have the 3D structure of our product finished as we want, we have got to return to Blender. Where we create a 3D scene playing with image composition and lighting to get some image and animated renders which help us show, explain and communicate our ideas in the best way.

Finally, the post production phase, here we edit the render images by adjusting color grading, doing some photobashing and paint over on the Adobe Photoshop and Adobe Lightroom programs. When it comes to the animation renders, we are using Adobe Premiere, a video editing and also audio design software where we turn our animations into an audiovisual narrative.

Also, to develop this master thesis I'm using Trello, a software tool focused on project organization. It has been really helpful for me since I have to develop many different typologies of tasks and have a control of it. As it can be seen in the Gantt's diagram (Fig. 4.1), I segregated the project tasks by temporal stage and typology criteria.

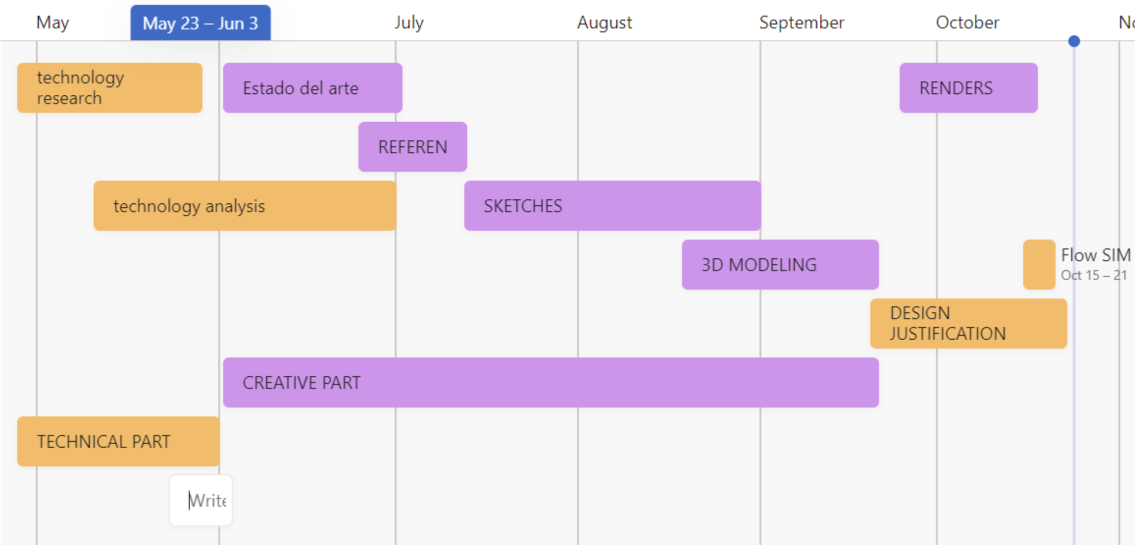


Fig. 4.1 Gantt's diagram with the different project's task organized by timing

As it can be observed, the more time spent (4 monts) has been on creative tasks related as it is where it can be found the value of the master thesis. By the way, it also has been invested hard time (3 months) on technical aspects such as the research and analysis of the technology or the design justification. Because it's important for the creative design to be supported with reliable data.

4.2. State of the art (References)

This is the first stage of our prototype design, the fundamental base of it, that's why it is so important to know exactly the application and purpose of our aircraft which will define the final design.

It's needed to get a good collection of references so we have a solid idea to begin with the project. We must choose with criteria our background of references and segregate it by different themes. One focused on shape, others in color, in texture, and other in current product, in this case EVTOLS.

We have to avoid at all costs not to base our design too much in current EVTOL references because by doing that you are not creating something from scratch, you are just remixing what a person has created after following his thinking process.

So, apart from having the same technolgie’s real prototypes as reference, to come up with a unique and innovative design it's important to have a good selection of references that have nothing to do with the product we are designing. For instance objects such as electrodomestics, toys, tools, is a good way to go.

In addition, when designing an engineer related product we can consider getting as reference nature’s design and engineering facets.

Nature has always been a way of inspiration for humanity as for technological and scientific backgrounds as to spiritual, artistic and philosophical ones.

This practice is called biomimicry (Fig. 4.2) and it has been very commonly used in the design and engineering industries but also at a wide range of subjects.

It consists in designing structures, materials or systems based on biological entities and processes.

Fig. 4.2 Examples of nature inspired technology products. *Source: {19}*

4.2.1. Prototype's purposes

In order to find out how the prototype design should be in terms of structure, type of configuration, materials, and technology to use, it's primordial to know the purpose of it.

Therefore, it has been carried out a market study and also, a research on the main global challenges that humanity is currently facing and will do for the future. So we can find out what EVTOL technology can do against them, the applications and utilities it can bring out as a solution to our urgent problematic necessities.

Supporting on officially validated information, here is the list of the main global challenges that humanity and planet Earth faces in the present and near future according to ONU (2023-2050):

- Overconsumption
- Overpopulation
- Biodiversity loss
- Deforestation & Desertification
- Global warming / climate change
- Environmental disaster
- Habitat destruction
- Malnourishment and hunger
- Pollution (biosphere, water contamination, microplastics, toxic air...)
- Poverty (no/bad resources: food & water contamination)
- Violence
- Inequality

Regarding the last list, here are a serie of EVTOL's possible problem solving applications:

- Mobility (Air taxi, private…)
- Cargo Transport
- Surveillance
- Surveying, mapping, inspection monitoring
- Air Ambulance/Medical Emergency
- Aerial Firefighters Crew
- Agriculture
- Search and rescue missions

In consequence, at the following list are exposed several prototype candidates

<u>EVTOL prototype candidates:</u>

1. Public Aerial bus - (for person transporting - Mobility)

2. AirHealth Assistant

3. Aerial Cargo Transport (mercacargo transportation - Cargo Transport)

4. Private Air Taxi (private personal transport - Mobility)
5. Agriculture Tree - Big Area Sowing Missions
6. Depolluter EVTOL (for rivers, lakes and coasts)
7. AirFirefighter - Big Are fire extinguisher- spray antifire)

The prototype that it has been chosen is the candidate number 7. From the section 4.3 on, it is covered a full explanation of it.

4.2.1.1. Aerial Firefighting

With the intention of knowing how the EVTOL concept can fit into the firefighting application, in this subsection it is approached the current aerial methodologies to discover its lacks.

At present, a lot of resources are applied by all countries around the world where this kind of catastrophic event occurs. But, sometimes the equipment which is being used to face up these fires is not enough,consequenting in dangerous and difficult situations.

In the coming years these fire events will repeat more frequently as climate change increases fastly and out of control. Current equipment and crews are found a little bit obsolete. It took too much effort to solve these situations, consequenting on a huge costs of biosphere mass’s loss, animal and human deaths, money, time... Human units fight against big and hot flames non stop during long hours. This situation exhausts the crew making them inefficient enough to achieve the mission’s targets.

Aerial firefighting current methodologies aside from human crews also include terrestrial and aerial vehicles equipped with the necessary gear, techniques, hardware and software tools. Until nowadays the most common aerial vehicles used have been helicopters and planes with methodologies (Fig. 4.3) and techniques installed on them to face up the fire.

Fig. 4.3 Helicopter landing to fill up water tank. *Source: {20}*

The problem is that these vehicles have a high cost to operate them, that's why normally it is used one or two depending on the fire magnitude. When there is a big fire these ships have to constantly throw the water and leave the place to recharge it from it. losing by that a lot of time and effort to let the fire increase.

In addition crew is needed onboard operating them, the flight of it is manual and not that automated. Pilots have to take huge risks at managing as the advancement of the fire and time fight against them.

Because of their big dimensions (Fig. 4.4), maneuverability is not that good in little or complicated scenarios. Also, They have to repeat a lot of times landing and taking off on difficult spots to recharge the water tank.

Fig. 4.4 Plane maneouvring. *Source: {21}*

That is why it is a hard challenge to keep the required focus and accuracy. Handling this pressure for a long time is not that easy for a human, they get more exhausted and less efficient by the passage of time.

Drones at firefighting

As technology grows, man tries to implement it on the industries. Recently drone technology (Fig. 4.5.) is being implemented onto these crews bringing a lot of benefits by covering all the lacks that obsolete gear and traditional tecniques have.

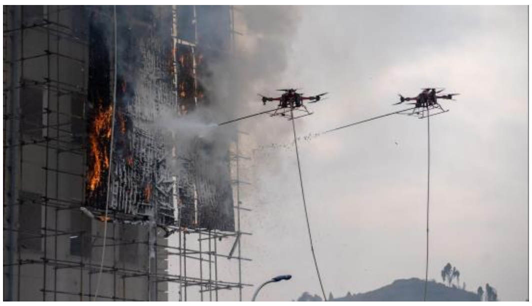


Fig. 4.5 Firefighitng crew upgraded with drone equipment. *Source: {22}*

The main benefits are that they do not emit any type of pollution and are very cheap to operate compared to the current aerial vehicles. It provides a huge evolutive step, is a tool that prevents human damage and makes the mission fight more constant, efficient and optimized.

Thanks to its ease for the logistics, a little sized unmanned aircraft that can be remotely piloted provide a lot of potentiall into the firefighting crew. Being able to carry any type of necessary payload (Fig. 4.6) such as camera (RGB, thermal, x-ray...), LiDAR, sprite machine, water tank, GPS...

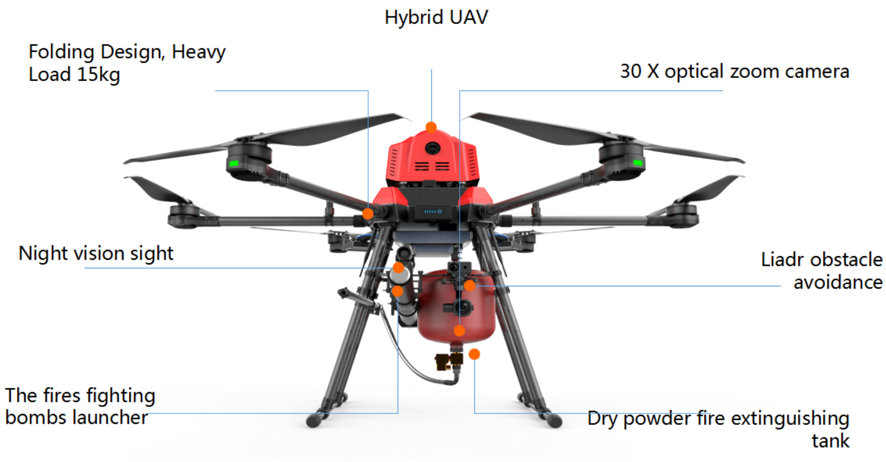


Fig. 4.6. Firefighter drone components. *Source: {23}*

Drones are hybrid and offer multifunctional tasks, since providing visual assessment and carrying search and rescue missions to fight hot flames. Some of the most relevant benefits of implementing drones at firefighting events come from the pros which a machine provides; constancy, efficiency, safety, automated flight…

Search and rescue actions are more efficient, their dimensions are a lot smaller permitting the reach of difficult and tiny places. As they can have thermal or infrared cameras to look for targets on catastrophic events. So situational awareness brought by an aerial perspective is constant throughout the mission.

Visual assessment to the human crews is updated on real time by thermal imagery or even a real time 3d scan that can be provided by the rgb camera or LiDAR sensor. So we get a live fire overwatch that can help the control center make better decisions.

Fires can be face up from an aerial perpective constantly and globally, not just locally as a plane or helicopter offers. Drones can fly formating a swarm to overwatch the fire and fight from any position. In addition, they do not must leave the spot and go fly kilometers away to fill up its tank losing a lot of time. They just have to land for a bit, change batteries and take off.

In addition, a microcontroller can be integrated on them to execute code programs with a desired response such as automated flight, to exchange valuable realtime fire evolution data, using AI to detect objects or monitor the mission... Also, thanks to the help of proximity sensors, IMU and GPS, drones can fly automatedly and safely. They do not require tripulation to operate them so we avoid risking human lifes when carrying challenging manioursor or exhausting activities.

The mentioned before are just a few examples of what implementing drone technology into fire fighting equipment can provide. In the next chapter we will talk furthermore about it and see all of these applied into a real prototype idea.

4.3. Aircraft design

In this section it is justified theoretically and visually the full design process of a conceptual drone prototype designed to fight against fires.

4.3.1. Concept idea

Taking into account all of the mentioned before, what if we go further away and think about combining EVTOL plus drone technology. The prototype consists of that. A human unit managing an EVTOL mothership with a drone squad and AI monitoring installed on it. This is the ultimate aerial aid tool that can help solve this type of problems quicker, easier and safer.

As its design is fully focused on its purpose which is to face up fires in every type of scenario, the mother aircraft's (EVTOL) structural configuration chosen is the Lift + Cruise. It is the perfect one because it combines multirotor and fixed wing flight capacities making it the most polyvalent of all; best autonomy, fast, agile, stable and all directions movement.

Key specifications of the concept: EVTOL+ DRONE SWARM + AI MONITORING

- Sensors: LiDAR (SLAM), thermal rgb camera, spotlights, beacons, loud speaker
- Water and fire extinguisher tools (water tank, hose, fire extinguisher substance)
- AI monitoring provides real time operative documentation on cloud for the human unit to take decisions on it, operate the drone swarm if desired…
- AI tool: data monitoring, mission operator, object detection…
- Drone swarm implemented

What value does it offer?

- Situational awareness:

- Search and rescue: reach difficult places
- Visual assessment: live fire overwatch, rgb and thermal visual data
- Swarm and local actions
- Increase operational safety
- AI real time monitoring

EVTOL mother has the function to carry on water to transfer it to the drones or either throw it itself to the fire.

AI monitoring along with the flight controller have the ability to read all data provided by the sensors and make decisions on real time or either transfer the data's conclusions to human crew.

The drone squad consists of 6 drones Alta X (Fig. 4.7) adapted to fire extinguish capacities. This drone model is the best suitable option for the concept because of its high payload capacity and stabilization as it is very big. However it has a large autonomy, more than 20 minutes, and it can be folded to a simple square for storage so its dimensions decrease a lot.

Fig. 4.7 Alta X folding hability. *Source: {24}*

4.3.2. Sketching

The sketching phase is one of the most important in every product development project, it will decide the shape of it and as it has to provide value, be unique and innovative it's so important to have good references.

It has been stated as fundamental creating the different designs based on the real purpose of the product. Understanding what could be the best shape that adapts perfectly to its utility, application and the environment in which it will perform.

Even though I followed the collection of references that I set up, the main influence in which I based the drawings has been nature aside from aerospace. Mainly in birds, amphibian and aquatic animals. Its shape design is adapted to work at its best in his contextual physical environment. For instance, sharks and whales are perfectly shaped to move fast and agile in the water as birds, eagles and leafs to the sky.This animals are aerodynamically adapted to its environment and are good to reference when looking for the aerodynamic specs for our aircraft structure.

Here is the final “moodboard” (Fig. 4.8) that along with the aeronautical one I came up with. It will work as set of references to create the series of sketches so it helps us achieve unique prototype designs.

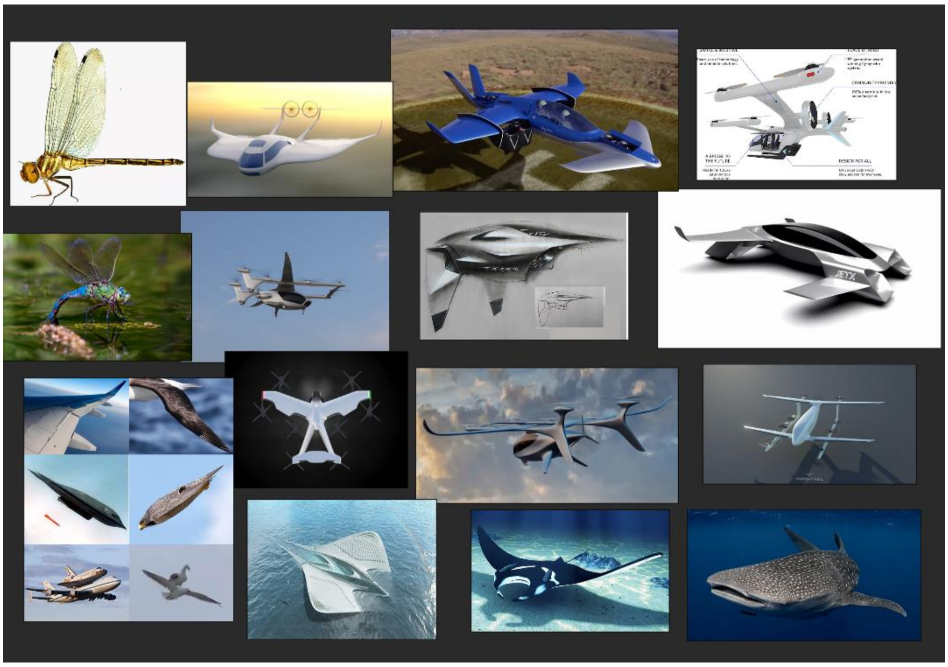


Fig. 4.8 Final set of references (animal and aeronautical) to create the sketches

When sketching all this firsts (Fig. 4.9 and Fig. 4.10) EVTOL concepts, I tried to let loose my creativity and not focus too much on thinking if it's physically viable or not. As this task will be carried out on a further post production stage by the engineers.

Fig. 4.9 Initial series of sketches

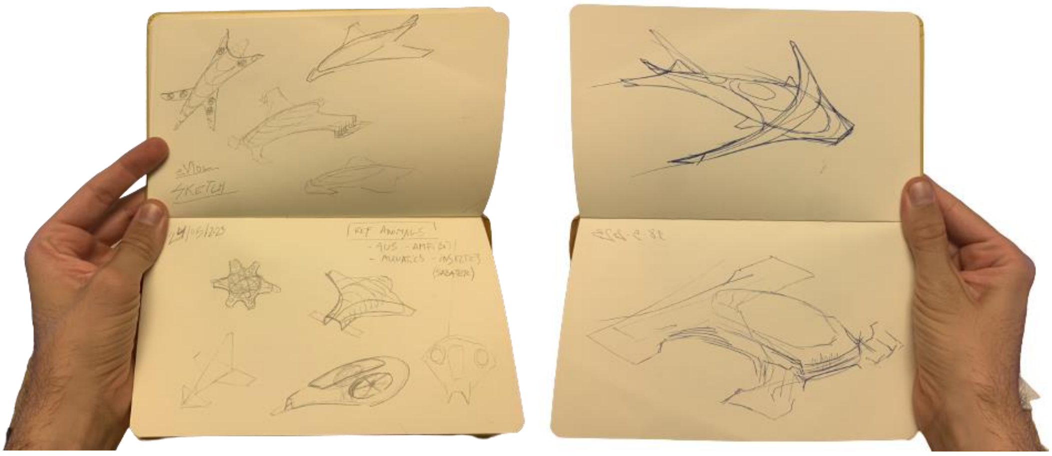


Fig. 4.10 Initial series of sketches

On this first series of sketches I have draw more freely having in mind that in the following series it will be a must to refine them and bring then out to a more physically viable.

Finally, to come up with the definitive one (Fig. 4.11) it has been chosen to mix a pair of sketches that fit the best the the prototype's function and application.

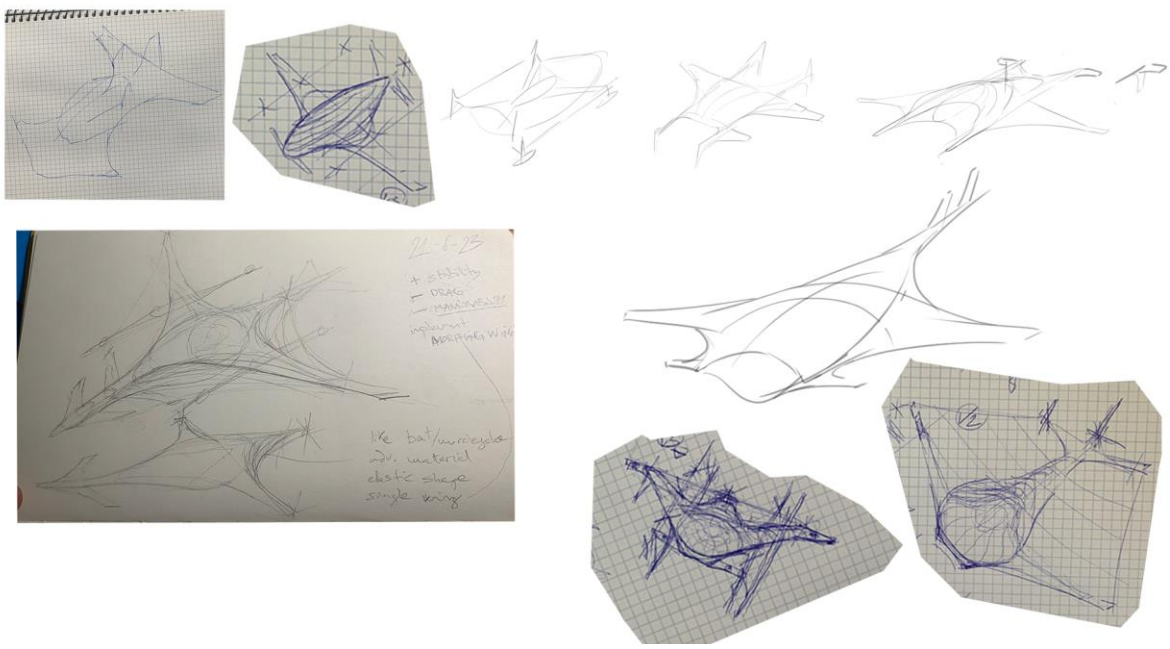


Fig. 4.11 Prototype's final sketchs

4.3.3. Vehicle Modeling

First of all, to design any type of 3D model its fundamental to figure out the blocking volumes of it and start modeling from them.

For this concept it has been realized that the main blocking shapes (Fig. 4.12) are a sphere as the cabine and the frontal part. Connected to it, it is used a cone wich will then be the aircraft tail. Then as for the wings we can start from simple planes.

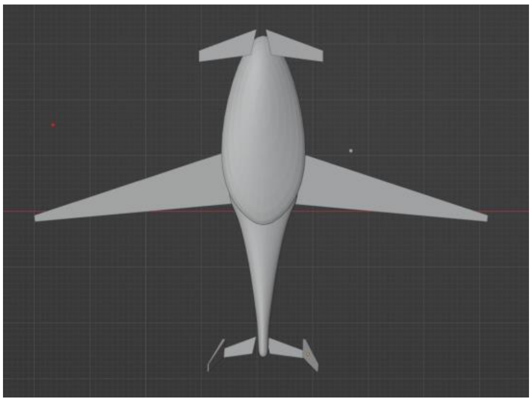


Fig. 4.12 Blocking volums

To model it is combined the technique called vertex by vertex (Fig. 4.13) with the sculpting one (Fig. 4.14) Both are great to define the structure and introduce detail to it. As for the vertex technique it is very useful to do accurate stuff as it can be introduced numeric values.

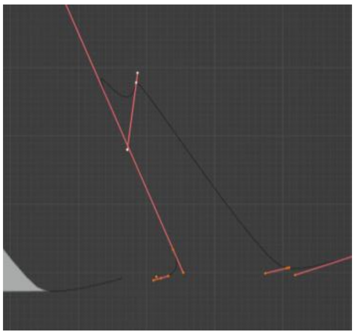


Fig. 4.13 Vertex by vertex technique

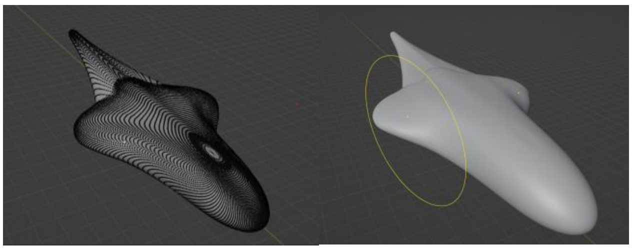


Fig. 4.14 Sculpting technique

I was not satisfied with the final design (Fig. 4.15) I came up with. I spoted some shape and components features that caused a problem fiting the purpose of the ship. This aircraft version wasn't amphibian and terrestrial, it just could land on water because of the floats. Also the water tank wasn't that big enough.

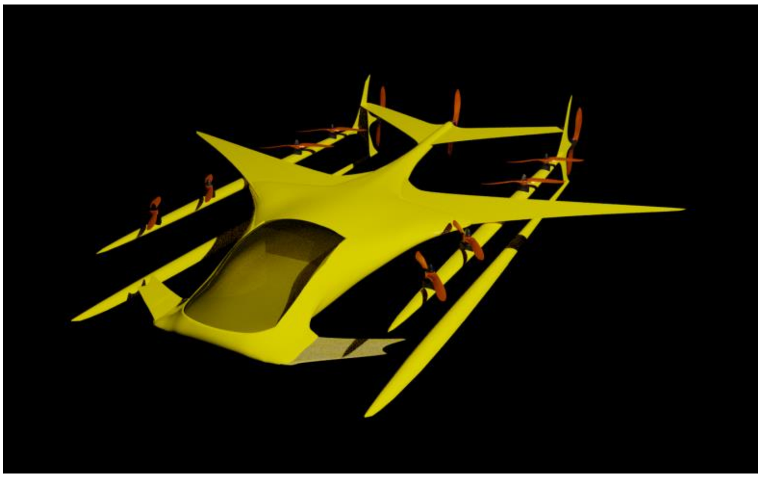


Fig. 4.15 EVTOL's aircraft first concept

So I ended up creating some terrestial landing system (pads) and upgraded the aircraft with a big water float below it. So, in order to understand its volume and sizes, here are a set of the aircraft's final layout renders from different perspectives, frontal (Fig. 4.16), profile (Fig. 4.17) and zenital (Fig. 4.18).

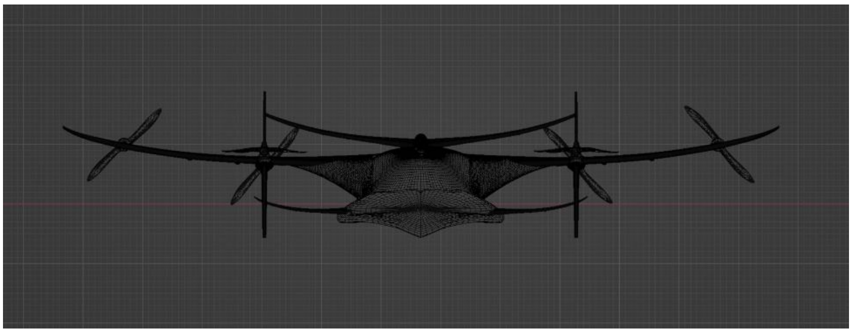


Fig. 4.16 Aircraft's frontal view

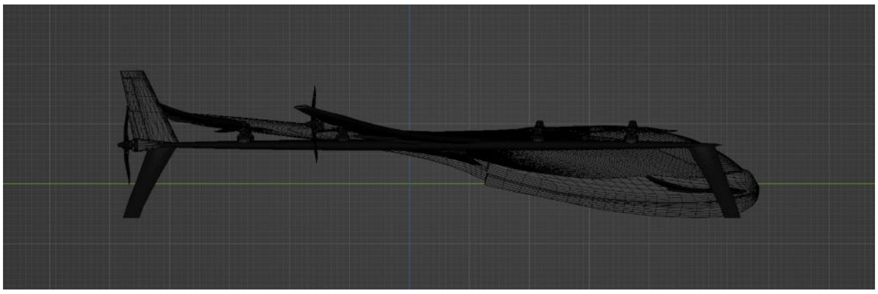


Fig. 4.17 Aircraft's profile view

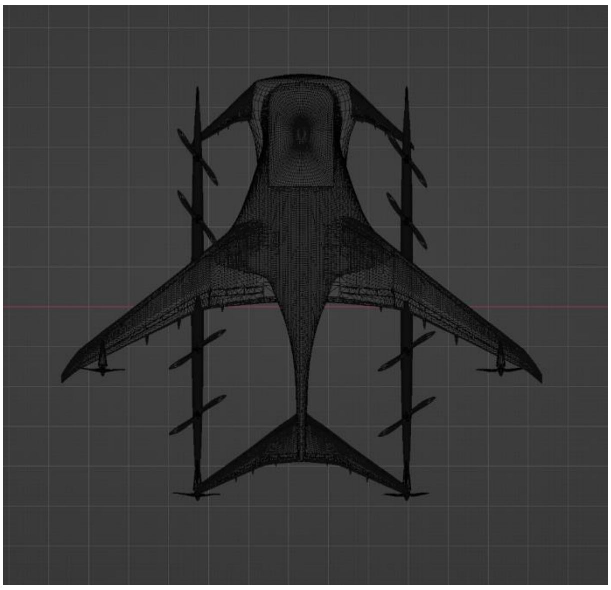


Fig. 4.18 Aircraft’s zenital view

During the modelling process I encountered technical problems on the 3D model’s mesh. As we want it to use on other software, technical skills as decimate, retopology, gravity, subdivision surface, smooth have been used to solve them...

4.4. Prototype Testing

As it has been said before, the main task when designing this first prototype is to focus only on the creative part, to get those good looking and revolutionary aesthetic shapes of the product.

But I wanted to give more of an engineering background behind it and decided to carry the design into a physically viable one. In this section it is explained the importance of aerodynamics and also, it can be seen the results of a simulation about the prototype interacting with real world’s conditions.

4.4.1. Stress Design

As it has been said on the beginning of this section, apart from abording the design from the most creative part of the industry’s product development process, it is intended to work briefly the engineering aspect.

In order to accomplish that, we must import our prototype’s tridimensional model which we modeled on Blender to the software CAD pogramm Solidworks (Fig. 4.19). On this software we can use a tool called flow simulation which help us see how our prototype reacts to the real world physical forces.

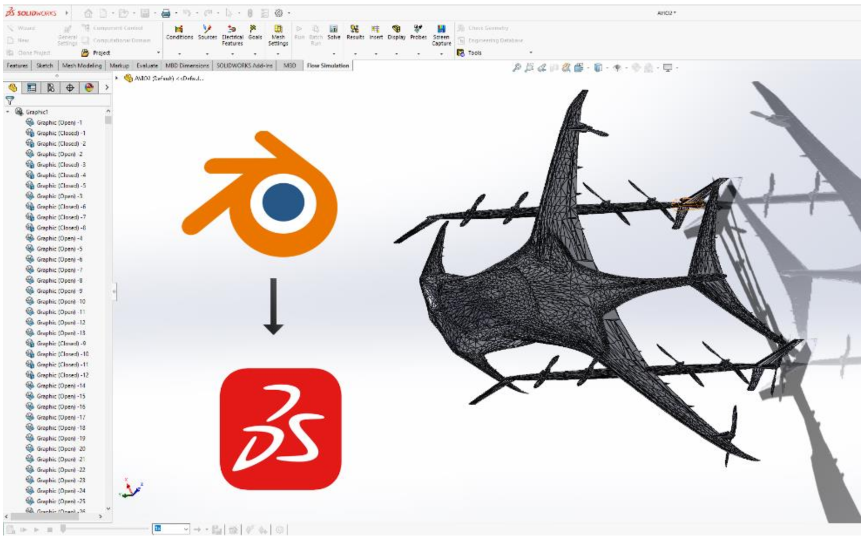


Fig. 4.19 The aircraft 3D model imported from Blender to Solidworks

But first of all let's talk briefly about how aerodynamics work because it will determine if the aircraft is physically viable. Every flying object experiments 4 forces when flying (Fig. 4.20); thrust, lift, weight and drag.

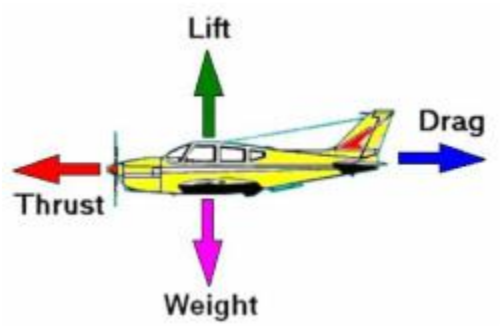


Fig. 4.20 Aerodynamic's forces. *Source: {25}*

A seen on the image on top, the thrust provided by the propulsion method helps the aircraft lift its weight but the air friction resitance produce drag. To create a good aircraft it's a must taking into account the drag force, the less drag we have, the best aerodynamical shape an aircraft has. It wastes less energy so it's more economic, we have more autonomy, velocity, stability...

Following Bernoulli's conservation of energy law, the angle of attack of an airplane's wing will determine a certain value of lift and drag. As seen on the figure below (Fig. 4.21), we can find out how the structure works aerodynamically when the angle is different. From 25 degrees to 90 it is produced a lot of drag and turbulences, at 15 degrees it is achieved the perfect lift momentum so it could correspond to a taking off position. While from 15 to 0 degrees there is the minimum drag and lift so it is the perfect angle for an aircraft to cruise. Therefore, when a wing is below those degress the effect cause on the aircraft is to descend, perfect for landing.

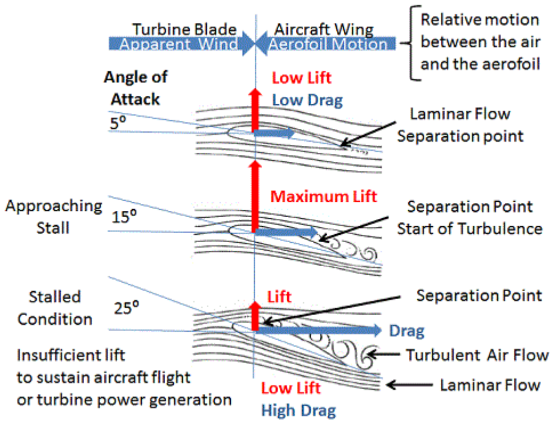


Fig. 4.21 Lift, drag and angle of attack dynamics. *Source: {26}*

Now that it is understood the basic principles of aerodynamics, here is the final prototype flow simulation test (Fig. 4.22).

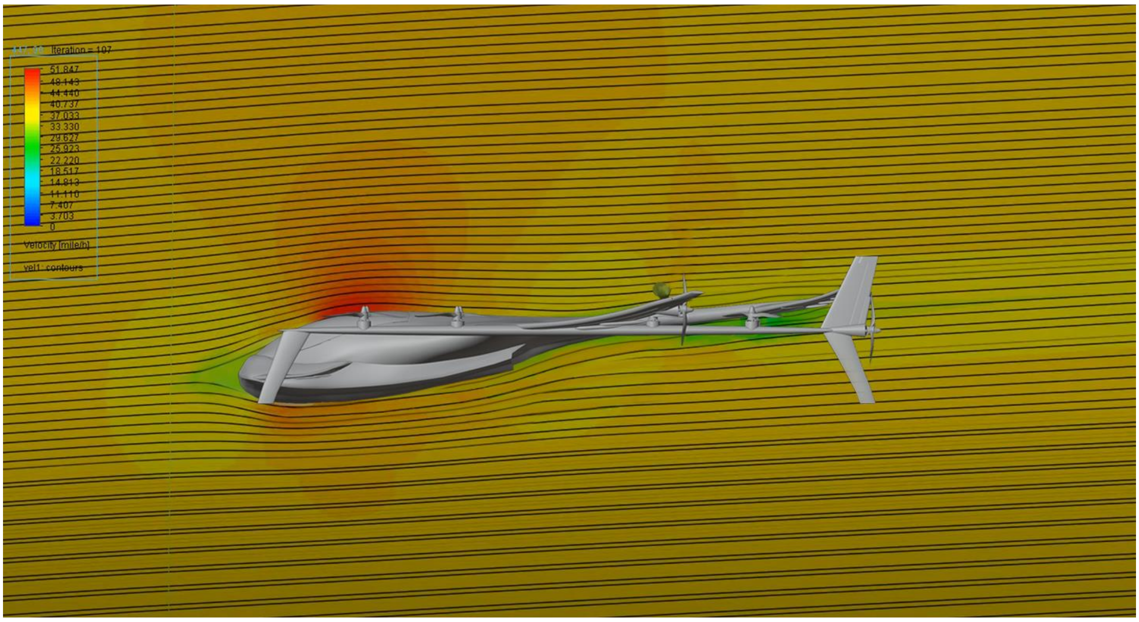


Fig. 4.22 Aircraft's flow simulation result

This simulation has been tested on an angle of 180 degrees to the surface, with a wind velocity of 64 km/h (40mph) and without the influence of the 12 propellers as we are trying to see how the aircraft's shape works.

It can be observed that there is an homogeneous laminar flow around the EVTOL. The part of the aircraft where it appears to be the higher velocity value it's exactly the gravity center of it. It was intended to be there as it's the position of the water tank, the heaviest component. It is noticible that the tear drop kind of shape from the aircraft provides good aerodynamic and stabilization features. The angle of attack that form the whole body of the aircraft works. So there wouldn't be too much upgrades to do when it comes to the aircraft's shape.

CHAPTER 5. EVTOL Prototype

This chapter consists of showing the render results (Fig. 5.1), justifying the component selection and explainig the functioning of the whole concept.

5.1. Renders

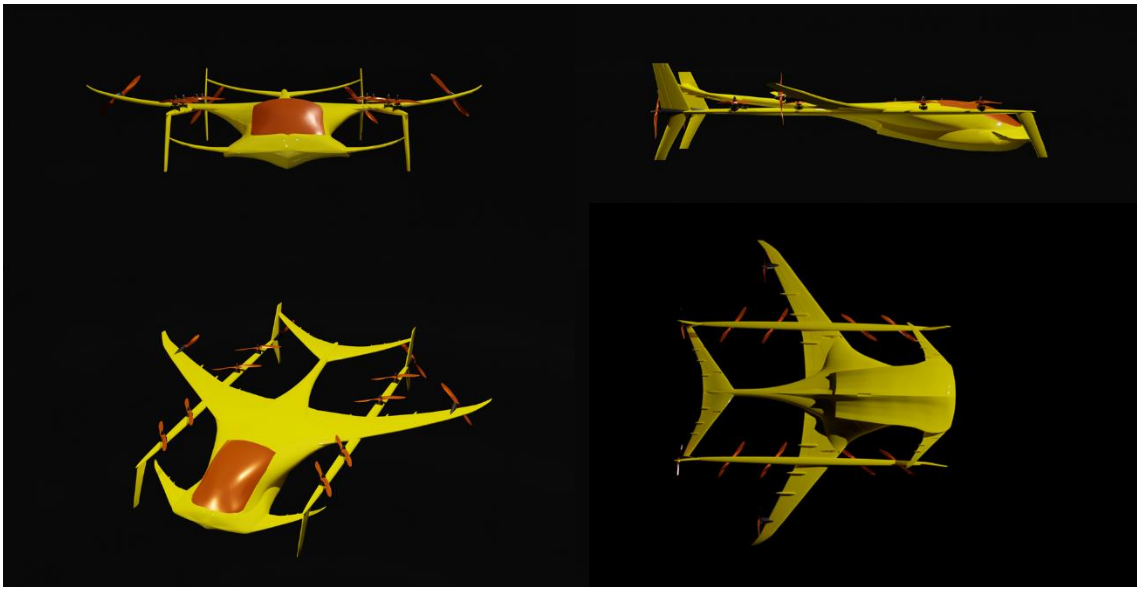


Fig. 5.1 EVTOL's aircraft renders

As this concept aims for versatility, it can be seen that the aircraft's shape reminds of an amphibian animal, which is known by living in terrain and aquatic ecosystems. Also, its structure has so many similarities with a dragon-fly. I referenced on this animal anatomy because it provides him an incredible capacity of stabilization, to fly agile and easily hover even his rare body proportions. In the following figure (Fig. 5.2) are highlighted the main aircraft's features.

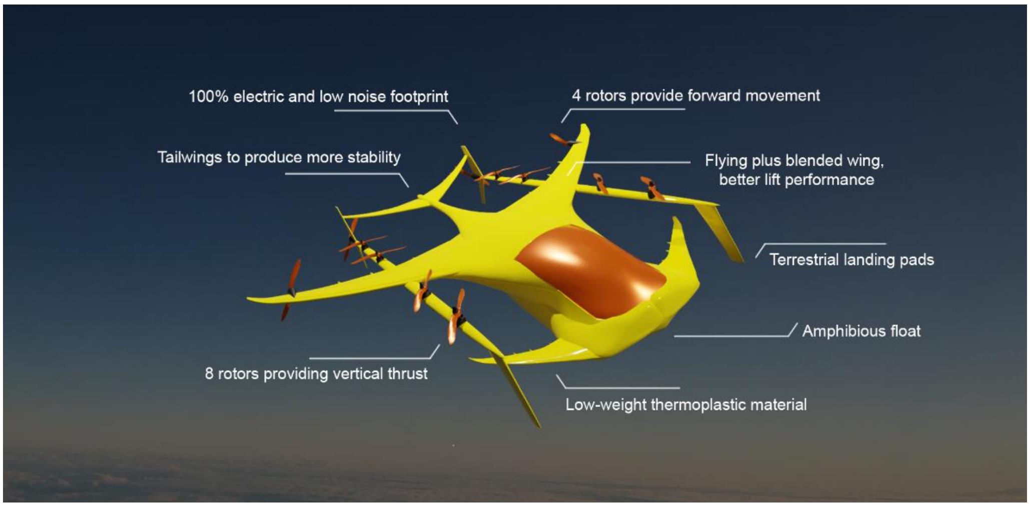


Fig. 5.2 EVTOL's aircraft main features

It has a refined aerodynamic shape to achieve great flight autonomy and wide proportions to make it the most stable possible in any type of scenario. Consists of 8 rotors that provide multirotor flight and 4 rotors vertically oriented to provide forward fixed wing movement. At its bottom we find the float, which provide floating capacities on water. Not only can land on water but also on solid terrain as it has 4 landing pads.

In the tail there is a hole in which inside we can find the hose that thanks to a water bomb it absorbs the water to fill up the tank. The drone squad is installed under both main wings, three in each side. Through them there are pipes that connect the tank with the drones.

Finally, what it would consist of the cockpit if it was a manned aircraft, in this case we find located a big water tank where the fire extinguishing sustances as water and other chemicals are mixed up. Connected to it through the wings there are pipes that havae te function to fill up the drones.

5.2. Fire extinguisher Concept

In this subsection there is explained the main features of the concept as the components selection, software and hardware tools, the different extinguishing fire fighting methodologies that implements...

5.2.1 Components and features

In order to make us an idea about the required components to get this concept prototype to fly, it have been slected the main components (Fig. 5.3). Despite we know the exact dimensions of the aircraft, it hasn’t been done in a super accurate way as we are estimating its weight and capacities approximately.

Specifications Table

Aircraft size: x=12m (wingspan) y=10.6m z=2,4 m

Weight: 1200 kg

Rotors (powr output): 125 kW

Batteries: 6x800V battery pack 2170 lithium-ion battery cells

Maximum Speed: 240 km/h

Autonomy: 110 km

Water Tank Volume: 2000L

Payload: 2000 kg

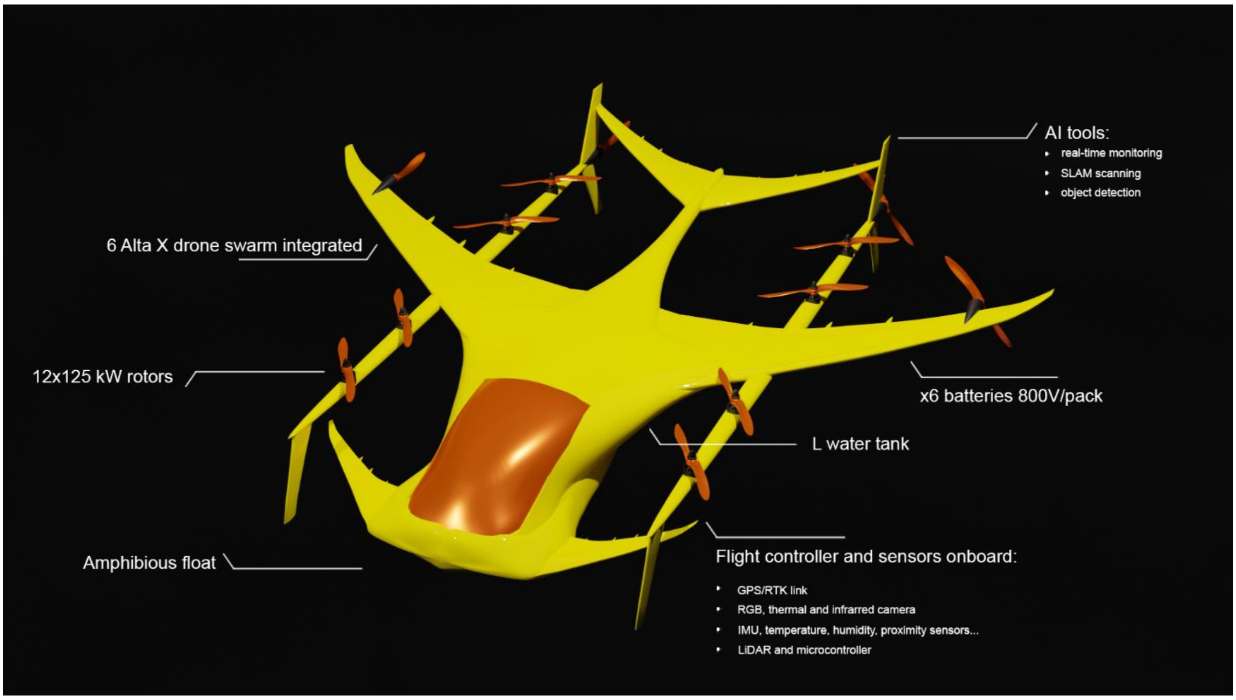


Fig. 5.3 Highlighted components, hardware and software

5.2.2 Fire extinguishing methodologies

The EVTOL mothership is the fundamental element as it's in charge of recolleting water. On the following paragraphs it is explained step by step the EVTOL's methodology when operating in this kind of fire events.

The fire extinguisher process starst with the EVTOL water fill up, then it flies to fire event zone where it deploys the drone swarm. Simultaneously it can overwatch and study the fire evolution with the AI tool so human crews can monitor it and take decisions. Then it must come back to fill up the water tank so it can attack the fire doing the EVTOL rain maniour or either supply the extinguishing sustance to the drone swarm.

This aircraft is intended to cooperate simultaneously with its drone swarm, human crews and terrestrial vehicles on site likefirefighting trucks or ground station where all the fire event is monitored. For instance, the following visual representation (Fig. 5.4) explain it at its best.

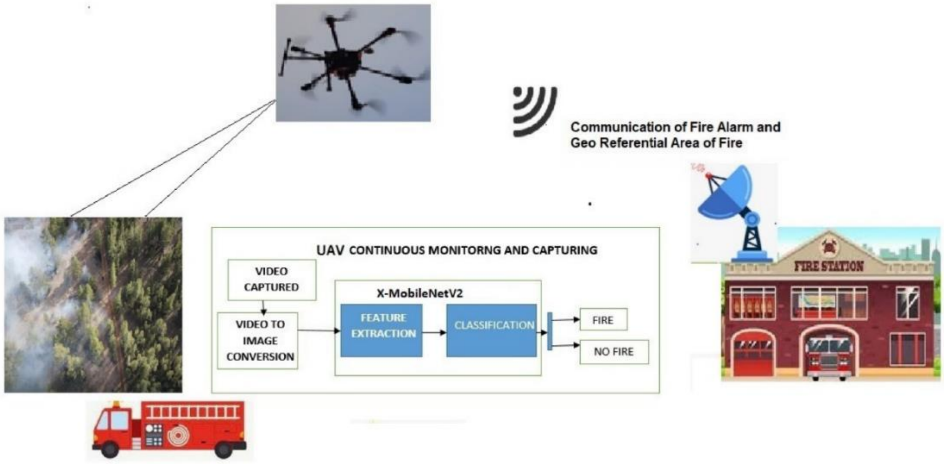


Fig. 5.4 Representation of the firefigthing agents network functioning.
Source: {27}

As we can see drones are constantly monitoring the fire and communicate information on real-time to the human crew thanks to deep learning programs coded onboard the microcontrollador's drone.

To be continued, on the figures below there are represented and explained some of the techniques that this concept idea would implement to fight fires;

1. EVTOL fill up: The mother aircraft has the capacity of landing on water to fill up its 2.000 L tank so then it can supply it to the onboard drones. On the figure (Fig. 5.3) below it's shown how the system works. In the case drones are already deployed, they have to land to connect to EVTOL's pipes.

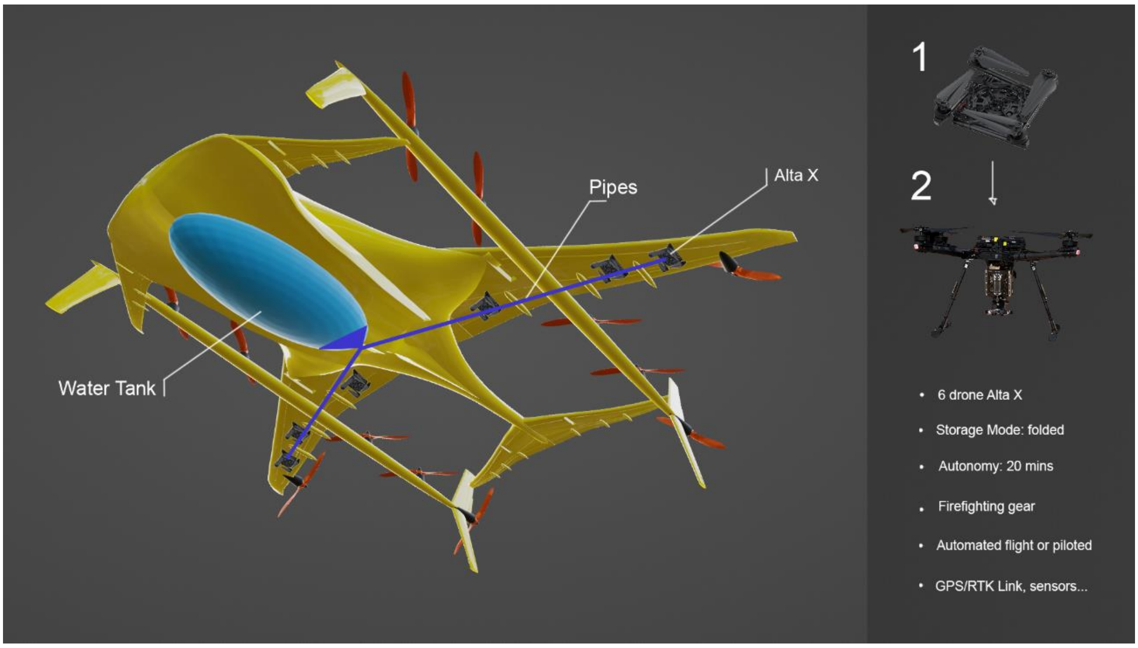


Fig. 5.3 EVTOL and Alta X water suppliment system

2. Drone Local: The 6 Alta X drones can attack the fire individually using their firefighting gear mechanism shown on the figure below (Fig. 5.4)

Fig. 5.4 Alta X equipped with firefighter gear. *Source: {28}*

3. Drone Swarm

- Mesh: The 6 drones holding a water pouring mesh along a huge area to provide fire extinguishing sustance in a uniform manner (Fig. 5.5)

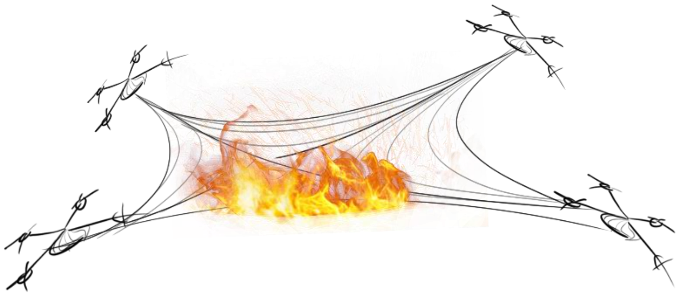


Fig. 5.5 Drone Swarm Mesh Methodology

- Freely: Alta X drones can attack fires on swarm (Fig. 5.6) focusing the same objective but from different perspectives. They move freely and can be remotely or automatedly piloted.

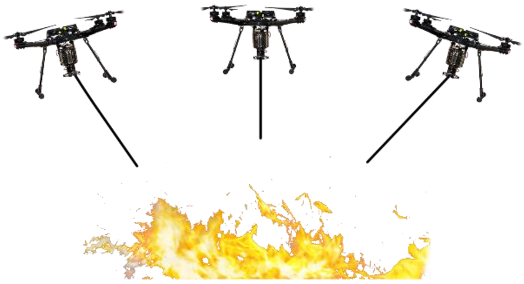


Fig. 5.6 Alta X forming a swarm to fight the fire

4. EVTOL Rain: The mother ship EVTOL has the capacity of throwing 2000L of water on the desired target (Fig. 5.7). It can do it on hover mode or cruising.

Fig. 5.7 EVTOL throwing water plus fire retardant

5. Search and rescue (Fig. 5.8): The EVTOL or the drone squad can reach difficult places thanks to their fiight capacities and small sizes. Thanks to the use of hermal, infrarred or RGB cameras are capable of identifying animals and persons.

Fig. 5.8 Thermal visual data from a drone perspective. *Source: {29}*

In addition the object detection tool (Fig. 5.9) can be trained to detect key factors, obstacles or animal lifes...

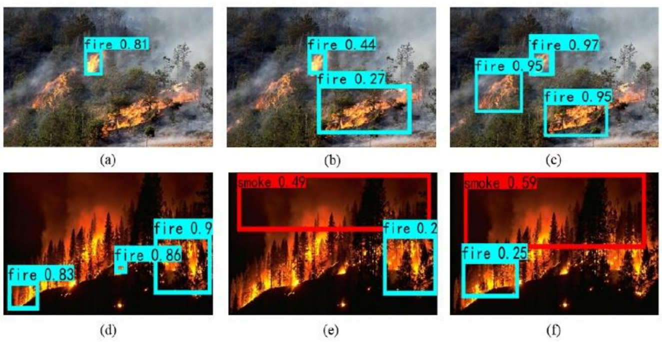


Fig. 5.9 Object detection tool identifying fire evolution. *Source: {30}*

6. Visual assessment: All sensors onboard the mother aircraft and the drones acquire data that is filtered by the flight controller and AI tools. Later that the human crew or either the AI alone can monitor the data, analyse it and take on ground decisions. This technique provide, live fire overwatch, visual data, 3D real time scans.

For instance the LiDAR sensor which has the capacity of scanning the terrain through laser technique (Fig. 5.10). In combination of AI deep learning it can provide a realtime terrain imagery of every new angle the camera onboard sees. And while human crews or drones advance on the terrain, a 3d map is being constantly generated. That is called SLAM technique and it is very helpful when it comes to monitor these type of missions.

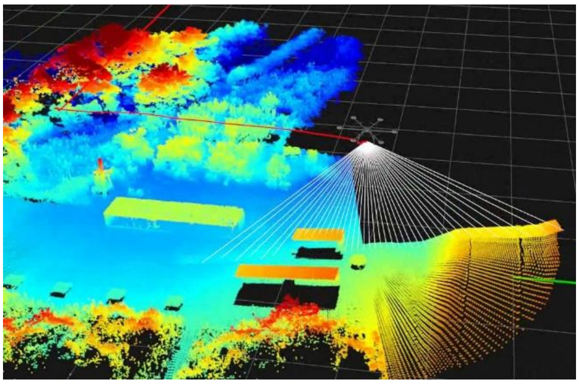


Fig. 5.10 Drone carrying on SLAM technique along AI. *Source: {31}*

Definitely, implementing this EVTOL concept into the firefighting crews would mean and step forward on firefighting current gear. It would make the operatives safer, faster and more efficient thanks to the benefits that EVTOL technology provides. But also thanks to the sensors, the artificial intelligence monitoring, the drone swarm and the automated flight help minimize human risk.

CONCLUSIONS AND FUTURE WORK

After carrying out the whole analysis and investigation around EVTOL technology, it has been understood the full potential of it. Implementing it to the real world at great scale can provide great benefits in a lot of areas. It fits at its best to our current worldwide problematic situations.

It's a polyvalent one because it can accomplish endless applications and utilities, and help solve the problems that our society is currently facing and will do in the near future in the most eco-friendly way.

EVTOL, along with drone technology, have a proper future because they are new tools that add so much value to our world. The biggest companies, stockholders and governments in the world, including governmental institutions such as NASA, are contributing to enable the perfect ecosystem for these technologies to grow up. They already have been investing in it since the last decade as they know how powerful they are and the projection that they have.

As a way to support the investigation and exemplify EVTOL's technology capacities. In this thesis it has been conceptually designed an aircraft prototype which could help face up one of the most frequent problems in our planet, fire catastrophic events.

This concept design helps evolve significantly the current firefighting methodologies which are found obsolete though they ask for too much effort, time and risks. It consists of an EVTOL aircraft that comes along with AI monitoring and a drone swarm integrated on it. This mother EVTOL design is fully focused on its purpose and thought to work on any type of challenging situations and scenarios. It's adapted to have the ability of landing and taking off from the water to fill up its tank. It's versatil and aims for autonomy and agility.

Introducing this conceptual aircraft into the actual fire fighting equipment would be a huge step forward. Human and biosphere damage would be decreased significantly. The process of beating the fire would be far more safe, easy, efficient and its time cost sped up.

Regarding how this technology could improve firefighting methodologies with so much ease thanks to its powerful capacities, imagine how it would be to implement it in other areas that nowadays are obsolete and contribute to polluting our world. Drone and EVTOL technology have so many benefits, applications and utilities. They are here to stay and could be the key to a greener future.

To conclude, I'm satisfied to state that despite encountering obstacles such as the engineering part that I had never worked before. The project's objectives set at the begginning of it have been achieved. The technology‘s research and analysis done have been ideal to contextualize, and come up with an EVTOL prototype that could fit as a solution to the urge of greener aerial systems.

In addition the master’s content that I’ve been learning the last year helped me obtain the required skills and knowledge to approach this kind of project. And not only on the academic aspect but in terms of work also, as the past 4 months I have been working as aeronautical manager, workshop technician and drone pilot at Topshot. This company offers aerial filming services with drones and my daily job is to do flight permissions, check and prepare the material as cameras and drones to take for the filmings, design and print 3D parts for them...

Im very proud of what I learned on my journey during this master as I have been able to complement my previously done course which was oriented on digital arts, desgin and cinema. Now I have more tools and skills to work on.

ACRONYMS

EVTOL	Electrical Vertical Take off and Landing
VTOL	Vertical Take off and Landing
CAD	Computer Aided Design
OSO	Operational Safety Objective
CAAC	Civil Aviation Administration of China
AI	Artificial Intelligence
3D	Three-Dimensional
4D	Four-dimensional
GPS	Global Positioning System
VLOS	Visual Line of Sight
BVLOS	Beyond Visual Line of Sight
RGB	Red Green Blue
Wi-fi	Wireless fidelity
FPV	First Person View
GRC	Grond Risk Class
ARC	Air Risk Class
CNBC	Consumer News and Business Channel
LiDAR	Light Deterction And Ranging
SLAM	Simultaneous Localization and Mapping
SORA	Specific Operations Risk Assessment
SAIL	Specific Assurance Integrity Level
OSO	Operational Safety Objectives
EASA	European Union Aviation Safety Agency
NASA	National Aeronautics and Space Administration
ONU	United Nations Organisation
FAA	Federal Aviation Administration
CAGR	Compound Annual Growth Rate
CAAC	Civil Aviation Administration of China
EUROCAE	European Organisation for Civil Aviation Equipment
UAS	Unmanned Aircraft System
ATS	Air Traffic Service
ATM	Air Traffic Management
USSP	U-Space Service Providers
IMU	Inertial Measurement system
CISP	Common Information Service Providers

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APPENDIX A. FLIGHT PLAN

Flight case (b) SORA (continuation)

Flight case (b) Chasing view BVLOS:

Ground Risk:

- Hit environment obstacles like road elements, animals, trees…
- Hit public (persons)
- Hit the car/fall in the road

GRC level: 3

Intrinsic UAS Ground Risk Class

Max UAS Characteristic dimension	1m / approx. 3ft	3m / approx. 10ft	8m / approx. 25ft	> 8m / approx. 25ft
Typical kinetic energy expected	< 700J / approx. 529 Ft Lb)	< 34KJ / approx. 25000 Ft Lb	< 1084KJ / approx. 800000 Ft Lb	> 1084KJ / approx. 800000 Ft Lb
Operational Scenarios				
VLOS/BVLOS over controlled ground area	1	2	3	4
VLOS in sparsely populated environment	2	3	4	5
BVLOS in sparsely populated environment	3	4	5	6
VLOS in populated environment	4	5	6	8
BVLOS in populated environment	5	6	8	10
VLOS over gathering of people	7			
BVLOS over gathering of people	8			

Our drone dimensions is below 1 m and we flight in BVLOS conditions in a sparsely populated environment rural area.

Mitigations

Mitigation Sequence	Mitigations for ground risk	Robustness		
		Low/None	Medium	High
M1	Strategic mitigations for ground risk	0 : None -1: Low	-2	-4
M2	Effects of ground impact are reduced	0	-1	-2
M3	An emergency Response plan (ERP) is in place, operator validated and effective	1	0	-1

Final GRC level achieved after applying mitigation M1: **1**

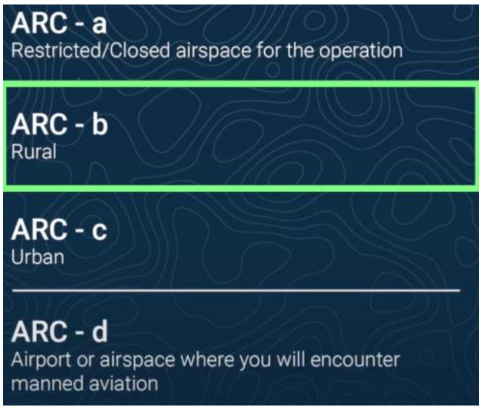
To reduce the GRC and avoid people assemblies we designed before the operation strategic segmented flight zones.

Air Risk:

- Hit obstacles like electric towers/cables,
- Collide with helicopter, drone, animal

The aerial traffic density in the area we operate is very low. It is not needed to apply strict mitigation measures, nevertheless we will be very cautious. Observers and pilot distributed along the sector will be communicating between them and the helicopter any necessary information via radio device at all time to ensure the safety of the airspace.

Therefore we find us in the following situation:



Low TMPR (ARC-b): The probability of encountering another manned aircraft is low, but not negligible, and/or where strategic mitigations address most of the risk, and the resulting residual collision risk is low.

SAIL (Specific Assurance and Integrity Level)

Considering the level risk of GRC and ARC we got a SAIL level 2, very good and low risk.

SAIL Determination

Final GRC	Residual ARC			
	a	b	c	d
≤2	I	II	IV	VI
3	II	II	IV	VI
4	III	III	IV	VI
5	IV	IV	IV	VI
6	V	V	V	VI
7	VI	VI	VI	VI
≥7	Category C operation			

easy
medium
difficult

SAIL level: II Easy

<u>OSO (Operational Safety Objective)</u>

As SAIL level is 2, we found that our mission comply with very safe conditions

OSO

OSO Number	Technical issue with the UAS	SAIL					
		I	II	III	IV	V	VI
OSO 1	Ensure the UAS operator is competent and/or proven	O	L	M	H	H	H
OSO 2	UAS manufactured by competent and/or proven entity	O	O	L	M	H	H
OSO 3	UAS maintained by competent and/or proven entity	L	L	M	M	H	H
OSO 4	UAS developed to authotity recognised design standards	O	O	L	L	M	H
OSO 5	UAS is designed considering system safety and reliability	O	O	L	M	H	H
OSO 6	C3 link performance is appropriate for the operation	O	L	L	M	H	H
OSO 7	Inspection of the UAS (product inspection) to ensure consistency with the ConOps	L	L	M	M	H	H

Justification level

O Optional
L Light
M Medium
H High