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PROJECTS

LUMOS - UNMANNED AERIAL VEHICLE FOR HUMANITARIAN AID

Project Report

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Acronyms List

AESA Agencia Estatal de Seguridad Aérea

AOC Air Operator Certificate

AMCW Amplitude modulated continuous wave

AoA Angle of Attack

ATC Air Traffic Control

ATPL Airline Transoprt Pilot Licence

BEMT Blade Element Momentum Theory

BVLOS Beyond Visual Line of Sight

CG Center of Gravity

CPI Consumer Price Index

CPL Commercial Pilot Licence

DAPCA Development and Procurement Cost Analysis

DEM Digital Elevation Model

EASA European Aviation Safety Agency

ENISA European Network and Information Security Agency

ETSI European Telecommunications Standards Institute

EUROCAE European Organisation for Civil Aviation Equipment

eVTOL Electric Vertical Takeoff and Landing

FAA Federal Aviation Administration

FMEA Failure Mode and Effects Analysis

FM Figure of Merit

FMCW Frequency modulated continuous wave

FTA Full-Scale Testing and Analysis

FUNCAS Fundación de las Cajas de Ahorros

FW Fuel Weight

GANP Global Air Navigation Plan

GEO Geosynchronous Equatorial Orbit

GNSS Global Navigation Satellite System

GPS Global Positioning System

HEMS Helicopter Emergency Medical Services

ICAO International Civil Aviation Organization

IRR Internal Rate of Return

ISA International Standard Atmosphere

KPI Key Performance Indicators

LEO Low Earth Orbit

LiDAR Light Detection and Ranging

MCCD Micropolarizer charge-coupled device

MEMS Microelectromechanical system

MFW Maximum Fuel Weight

MGB Main Gearbox

MPL Maximum Payload

MR Main Rotor

MTOW Maximum Take-Off Weight

NACA National Advisory Committee for Aeronautics

NGO Non Governmental Organization

NPV Net Present Value

OCHA Office for the Coordination of Humanitarian Affairs

OPA Optical phased array

OFC Optical frequency comb

OWA Ordered Weighted Average

PRESS Preference Ranking for Evaluating Summary Scores

PR Public Reports

PW Power-to-Weight

QMS Quality Management System

RDTE Research, Development, Testing, and Evaluation

ROI Return On Investment

RPM Revolutions Per Minute

RPAS Remotely Piloted Aircraft Systems

SAR Search And Rescue

SERA Standardized European Rules of the Air

SES Single European Sky

SFC Specific Fuel Consumption

SOP Standard Operating Procedures

SPT Simple Payback Time

TOF Time of flight

TOW Take-Off Weight

TR Tail Rotor

UAS Unmanned Aircraft Systems

UAV Unmanned Aerial Vehicle

UPBT Updated Payback Time

VTOL Vertical Take-Off Landing

WBS Work Breakdown Structure

WFP World Food Programme

WHS World Humanitarian Summit

IDEC International Disaster Emergency Conference

EIA Environmental Impact Assesment

Chapter 1

Introduction

1.1 Aim

Our goal is to develop an innovative solution to assist governments worldwide in responding to natural disasters. We will design a revolutionary UAV with VTOL capabilities, engineered for rapid deployment, long-range missions, and versatile operations in disaster-affected areas. Additionally, we will establish an in-house remote piloting service to ensure seamless and efficient UAV operations, enabling immediate response capabilities in critical situations.

1.2 Scope

1.2.1 Included in the Design and Development

The design and development of the project will include:

- The definition of the overall mission of the aircraft and the performance against it.
- The definition of the equipment (on and off-board) needed and the constraints associated with the implementation of the live UAV operation.
- The definition of the avionic systems (RADAR, GNSS, recovery systems, etc.) that will be equipped in the aircraft.
- The overall aircraft design: structural analysis, 3D blueprints elaboration, and material assessment.
- An aerodynamic analysis, including the main and tail rotors and the airframe.
- The choice of an adequate power plant and its justification based on performance and fuel efficiency, as well as an analysis of the electrical system of the aircraft.
- The definition of the payloads the UAV will be capable of carrying, as well as the operating procedures to ensure efficient and safe loading and unloading.
- The analysis of the weight and balance of the aircraft.
- The study of the potential markets and clients.
- An economic analysis of the feasibility of the project, including a detailed budget.
- An overall breakdown of the solution aimed: the UAV and the piloting service.
- The study of the environmental and safety considerations of the project.

1.2.2 Excluded from the Design and Development

The design and development of the project will not include:

- The production and supply chain analysis and implementation.
- A study of the facilities placement and operational details.
- A deep aerodynamic analysis using CFD.
- A deep structural analysis using FEM.
- A detailed design of the aircraft and its components.

1.3 Requirements

The developed project must meet certain requirements.

1.3.1 UAV Requirements

The UAV must:

- Have a VTOL capability to operate on rough terrains such as mountainous, forested, or earthquake-damaged areas.
- Be able to carry up to 3000 kg of payload (including medical personnel) while maintaining the maximum takeoff weight below 8000 kg.
- Reach a top speed of at least 300 km/h.
- Have an endurance of at least 5 hours with MPL and a minimum range of at least 300 km.
- Be able to withstand extreme conditions such as warlike or extreme weather environments.
- Be capable of transporting and deploying medical and rescue equipment, as well as carrying various types of humanitarian payloads.
- Be equipped to transport injured individuals, functioning as a UAV-ambulance.
- Be designed to minimize fuel consumption, reducing environmental impact and ensuring cost-effectiveness over the lifecycle of the vehicle.

1.3.2 Live Flight Simulator Requirements

The live flight simulator must:

- Be capable of real-time emulation of the vehicle's environment to allow remote piloting as if operating live.
- Accurately replicate the UAV's flight dynamics, environmental conditions, and system responses.

1.4 Justification

When a natural disaster strikes, rapid response is crucial to minimizing human casualties and material damage, as emphasized by the United Nations OCHA [31]. Our solution addresses this need by drastically reducing response times through the development of a UAV with VTOL capabilities, enabling quicker access to affected areas and faster air delivery. UAVs offer significant operational advantages by decoupling pilots from the aircraft, which enhances safety and efficiency. Remote control operations minimize risks and allow continuous service through shift rotations, ensuring uninterrupted response during critical moments.

The potential of this innovative UAV lies in addressing existing gaps in the disaster response market, combining heavy payload capabilities, medical support, and robust operational flexibility. As highlighted in the subsequent market study, no current UAV integrates all these features into a single platform. While existing solutions, such as lightweight medical drones or urban air mobility vehicles, meet individual needs, they fail to address the complex, multifaceted requirements of disaster response missions. Similarly, traditional heavy-lift helicopters, while effective, rely on onboard crews and have significant operational costs.

The proposed UAV represents a paradigm shift. By uniting VTOL functionality with the ability to transport heavy payloads, including injured individuals and medical supplies, it bridges the gap between current UAV limitations and the capabilities of conventional helicopters. Moreover, the absence of onboard crew reduces safety risks and operational costs, enhancing its viability for long-term disaster management strategies.

This justification is supported by insights from the market study, which follows this section. The analysis elaborates on the limitations of existing technologies and highlights the unmet demand for a comprehensive, versatile solution like the one proposed in this project. By addressing these market gaps, this UAV is poised to set a new benchmark in rapid, efficient, and cost-effective disaster response.

Chapter 2

State of the Art

In a project of this characteristics, it is essential to determine the current state of the art, including the latest advancements and innovations in the field, as well as to analyze comparable products currently available in the market.

2.1 Project Overview and Innovation Statement

The project aims to develop an innovative UAV with Vertical Take-Off and Landing (VTOL) capabilities, designed for rapid deployment in disaster-stricken areas. This UAV will be capable of transporting up to 3,000 kg of payload, including medical personnel, and will function as an unmanned ambulance, delivering medical and rescue equipment to areas with challenging terrains.

This solution is absolutely innovative: no existing UAV fully integrates all the requirements of VTOL capability, heavy payload, human transport, and medical and disaster response functionalities. While individual technologies and solutions can meet some of these requirements, there is no model in the current market capable of fulfilling all at the same time. Some combinations of the intended requirements are fully met by existing technologies or models, but this project will bring together all these features for the first time.

2.2 Existing Technologies

2.2.1 UAVs Serving Medical Purposes

Overview: UAVs are being deployed to deliver medical supplies to remote locations, especially in emergencies. Companies like Zipline [32] operate extensively in regions such as Africa and North America, delivering blood, vaccines, and other essential supplies. Swoop Aero [33] focuses on expanding capabilities in remote areas of Australia, providing drones capable of operating in adverse conditions.

Technological Maturity: Emerging. While there are successful implementations in specific regions, scalability challenges remain, and further advancements in drone capabilities and regulations are required.

Comparison to Proposed UAV:

- **Commonalities:** Both focus on medical applications in inaccessible regions and rely on Beyond Visual Line of Sight (BVLOS) communication and remote piloting capabilities.
- **Differences:** Existing medical drones prioritize lightweight payloads and shorter ranges compared to the proposed UAV's heavy payload and long-range capabilities.

2.2.2 Heavy Payload UAVs in Urban Air Mobility (UAM)

Overview: Heavy payload UAVs are being developed under the Urban Air Mobility (UAM) concept to transport passengers or cargo within urban environments. Companies like Joby Aviation [34] and Volocopter [35] are developing prototypes of air taxis to alleviate urban congestion, focusing on safe and sustainable transport solutions.

Technological Maturity: Emerging. Most models are in the testing phase, with significant regulatory hurdles and infrastructure requirements still pending for commercial operations.

Comparison to Proposed UAV:

- **Commonalities:** Both employ VTOL capabilities, focus on passenger safety, and face regulatory challenges associated with UAV operation involving humans on board.
- **Differences:** UAM UAVs prioritize urban environments and short trips, while the proposed UAV is designed for disaster response, requiring robust capabilities for long-distance operations and extreme conditions.

2.2.3 Heavy Payload Helicopters with Air Ambulance Capabilities

Overview: Heavy payload helicopters, such as the Airbus H175, are widely used for air ambulance services, transporting patients, medical equipment, and personnel in emergencies. These are operated by companies like Air Methods [36], as well as governments and governmental agencies like the Hong Kong Government Flying Service [37] for disaster relief and strategic missions.

Technological Maturity: Consolidated. These models have decades of operational experience, a robust regulatory framework, and widespread adoption for critical missions.

Comparison to Proposed UAV:

- **Commonalities:** Both transport heavy payloads, including medical equipment and personnel, with VTOL capabilities and adaptability to various mission requirements.
- **Differences:** Unlike helicopters, the proposed UAV eliminates the need for onboard pilots, potentially reducing operational risks and costs while presenting challenges in reliability and autonomous navigation.

2.3 Reference Model Choice

The most comparable existing technology is **heavy payload helicopters with air ambulance capabilities**. This sector has the highest technological maturity and directly aligns with the proposed UAV's mission to transport medical personnel and equipment. Transitioning to an unmanned system could offer advantages such as reduced crew requirements and enhanced operational flexibility, though it also presents challenges in communication, reliability, and regulatory compliance.

2.4 Technical Analysis of Competitors

Some models with technical features similar to those of the one developed in this project have been selected. They will serve as a reference both technically and commercially during the project's development. These models include the Airbus H175, the Leonardo AW189, the Sikorsky S-92, and the Bell 525. The table below presents the key characteristics of these models in comparison to the one under development in this project.

Characteristic	Airbus H175 [38, 39]	Leonardo AW189 [40, 41, 42]	Sikorsky S-92 [43, 44, 45]	Bell 525 [46, 47, 48]
Air Ambulance	Yes	Yes	Yes	Yes
Cargo	Yes	Yes	Yes	Yes
MTOW (kg)	7,800	8,600	11,861	9,300
Max Payload (kg)	2,700	2,975	4,536	3,710
Max Speed (km/h)	267	294	284	296
Endurance	6 hrs, 9 min	6 hrs, 11 min	5 hrs, 13 min	5 hrs, 54 min
Approx. Cost (M$)	16.2	16.0	27.0	17.0

Table 2.1: Comparison of helicopter models by characteristic.

All these models would fulfill the requirements of the project (or would be close to do so), therefore, serve as a proper reference for further sections.

2.5 Commercial Analysis of Competitors

After having selected the reference models, the commercial tendencies are analyzed:

2.5.1 Model Analysis

- **Leonardo AW189:**
  - **Introduction:** Entered service in 2014.
  - **Market Trend:** Steady growth for medical and heavy payload missions, with big orders placed during the past few months [49].
- **Sikorsky S-92:**
  - **Introduction:** Entered service in 2004.
  - **Orders and Deliveries:** Over 300 units delivered by 2018 [50].
  - **Market Trend:** High demand for strategic air ambulance and heavy transport missions.
- **Airbus H175:**
  - **Introduction:** Entered service in 2015.
  - **Orders and Deliveries:** As of 2020, over 30 units delivered and more than 200 ordered.
  - **Market Trend:** Increasing interest after the COVID crisis, huge number of orders in 2023 and 2024.

[0]Values retrieved from the *Budget* document

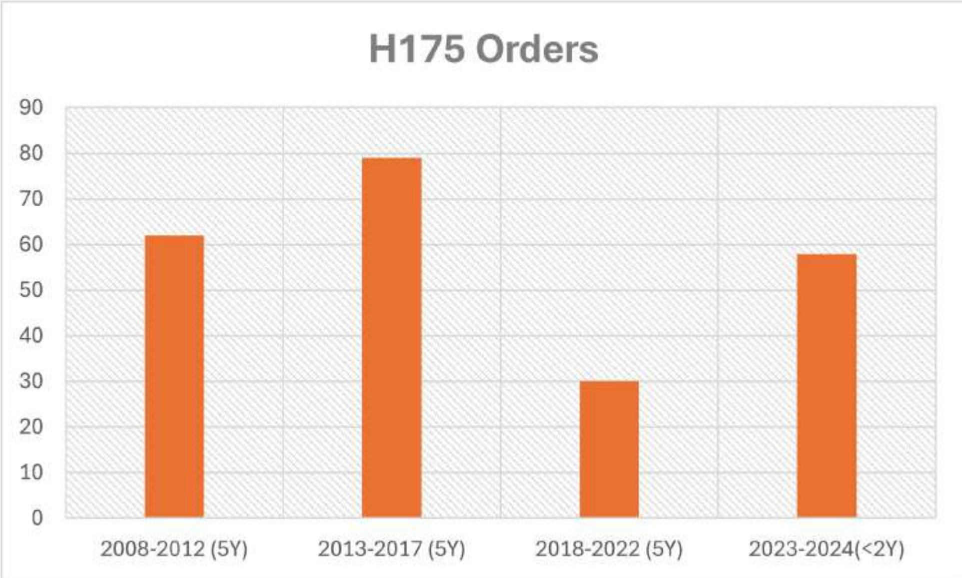


Figure 2.1: H175 or similar model orders by 5 and last 2 year periods [1]

- **Bell 525:**
  - **Introduction:** Pending certification.
  - **Orders and Deliveries:** Pre-orders confirmed.
  - **Market Trend:** Anticipated interest for strategic heavy payload missions, with 97 orders before the certification of the type [51].

2.5.2 General Market Insights

The global air ambulance services market is experiencing significant growth. In 2022, the market was valued at approximately USD 14.6 billion and is projected to expand at a Compound Annual Growth Rate (CAGR) of 10.7% from 2023 to 2030, reaching an estimated USD 33 billion by 2030.

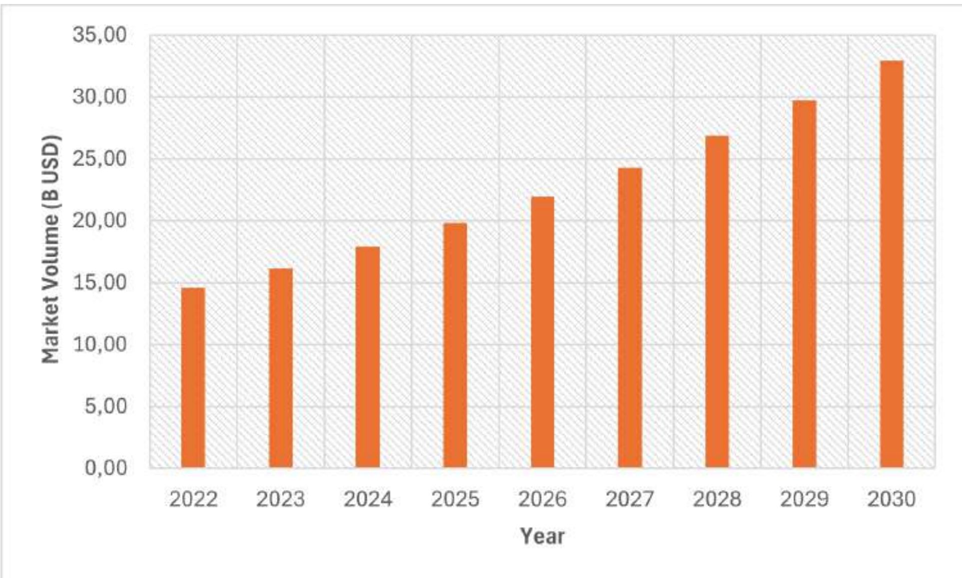


Figure 2.2: Projection of growth of the air ambulance global market [2]

This growth is driven by increasing demand for advanced healthcare services in remote and disaster-stricken regions, coupled with technological advancements in VTOL and emergency service capabilities.

2.5.3 Market Study Key Insights

The market analysis highlights a rising demand for air ambulance services and strategic heavy payload capabilities, underscoring the viability of introducing a UAV with similar functionalities. Replacing helicopters with unmanned systems could reduce operational costs and expand disaster response capabilities while presenting challenges like autonomous navigation reliability and adherence to regulatory standards.

Chapter 3

Technical Solution

3.1 Aircraft Conceptual Design

Once the project's aim, scope, requirements, and market study are established, the design process commences. The initial phase is the conceptual design, where information is gathered to determine the optimal configuration to meet the preliminary requirements and assess feasibility.

The principal UAV configuration parameters are:

- **Propulsion:** Turboshaft engines.
- **Number of engines:** Two engines (twin-engine configuration).
- **Engine location:** Mounted in the fuselage, with power transmission to the rotors.
- **Main rotor:** Five-blade main rotor using NACA 23012 airfoil with linear twist.
- **Tail rotor configuration:** Fenestron design for safety and noise reduction.
- **Tail rotor airfoil:** NACA 0012 for symmetrical performance.
- **Landing gear configuration:** retractable wheels with suspension.
- **Fuselage:** Aerodynamically optimized with low drag coefficient.
- **Stabilizers:** Cambered horizontal stabilizer and vertical stabilizer for aerodynamic stability.
- **Control:** Real-time remote piloting.
- **Navigation:** GNSS and radar systems.
- **Autonomous systems:** Signal attenuation detection, connectivity recovery, and terrain-avoidance systems.
- **Cabin:** Adjusted dimensions for medical personnel comfort and optimal cargo space.
- **Storage organization:** storage organized in cuboid plywood boxes.
- **Cargo security systems:** Cargo restraint systems, ambient control, fire suppression (CO_2), vibration damping, impact protection, and real-time monitoring.
- **Deployment system:** Cargo deployment system, rescue system and elevation boxes structure.

A concise justification of the conceptual design aspects can be found in the following paragraphs. It is important to note that all these factors will be discussed in detail further in the Technical Solution report.

Propulsion

The twin-engine configuration with turboshaft engines, such as the General Electric T700-701D, ensures redundancy and sufficient power output for the UAV's MTOW of 8000 kg, meeting critical mission requirements for safety and performance.

Main Rotor

The five-blade main rotor with NACA 23012 airfoils balances high lift, efficient power consumption, and structural integrity, supporting hover and forward flight performance.

Tail Rotor

A Fenestron tail rotor, equipped with NACA 0012 airfoils, enhances safety, reduces acoustic emissions, and provides efficient anti-torque control under various flight conditions.

Landing Gear

The UAV will feature retractable landing gear with strong suspension to ensure durability and efficiency during operations in challenging environments. The design includes four wheels—two smaller, paired wheels in the front and two larger wheels in the rear—providing stability during takeoff, landing, and ground handling. This configuration enhances shock absorption, and minimizes aerodynamic drag when retracted, making it well-suited for diverse terrains and operational demands.

Fuselage

The aerodynamically optimized cockpit-less fuselage minimizes drag, enhancing forward flight efficiency while accommodating payload and equipment.

Horizontal Stabilizer

A cambered stabilizer improves longitudinal stability and reduces pitch moment variations during transitions between hover and forward flight.

Vertical Stabilizer

The design supports yaw stability and complements the tail rotor's anti-torque function, ensuring overall aerodynamic balance.

Control

The data necessary to recreate the piloting situation in a simulator (imagery, speed, engine indicators, etc.) is processed onboard and sent through a low-latency LEO satellite link using Iridium's constellation. A secondary GEO link will act as a backup.

Navigation

The UAV integrates all the systems necessary to ensure safe navigation, such as radars and geolocation. Voice data to and from ATC will be transmitted through a radio link from the UAV to the TWR and through a satellite link to the pilots.

Autonomous systems

The signal attenuation detection system will act as a warning to pilots before fully losing connection in one or both data transmission modes (LEO and GEO). If the connection is lost, the connectivity recovery system will maneuver the device with the goal of recovering it. The UAV will be equipped with collision avoidance systems to add extra protection and ensure safe operation in rough terrains.

Cabin

The cabin dimensions ensure comfort for medical personnel, thanks to its increased height compared to aircraft of similar characteristics, without significantly compromising the UAV's performance. Additionally, the space has been designed to accommodate the maximum allowable cargo capacity.

Storage organization

Using plywood boxes ensures environmental sustainability, as the material is renewable and biodegradable, while providing a lightweight structure capable of supporting heavy loads. Various cargo packs have been strategically designed in order to provide each mission with the necessary supplies.

Cargo security systems

Cargo restraint systems are essential to securely position the cargo. Ambient control and real-time monitoring provide continuous data on the cargo's condition, while the CO_2 fire suppression system ensures the cargo remains protected in the event of a fire. Impact protection and vibration damping systems minimize the effects of flight conditions on delicate cargo.

Deployment system

An autonomous deployment system is crucial for delivering cargo while the UAV is airborne. The mechanism is designed to release the cargo efficiently, ensuring it can be properly retrieved.

3.2 Power

The Power Section focuses on the essential components that provide and manage energy throughout the helicopter. It covers key areas such as engine selection, power transmission, and the fuel system. This includes determining the appropriate engine type and power output, specifying the main and tail rotor gearboxes for effective power distribution, and designing the fuel system to ensure optimal performance. Each subsection addresses critical tasks to ensure that the helicopter's power system operates efficiently and reliably to meet operational demands.

The design of the propulsion subsystem is focused around 3 main subsections:

- Engine selection
- Power transmission
- Fuel system

A structured approach to the various tasks is essential. First and foremost, selecting an appropriate engine is crucial to ensure the necessary power to meet operational requirements. Following this, the specifications for the gearboxes and the transmission system will be analyzed to ensure efficient delivery of power to the respective rotors. Finally, after completing the performance study, an evaluation of the fuel tanks and the fuel requirements will be conducted to ensure the helicopter can meet the required range specifications.

3.2.1 Engine selection

Selecting the right engine is crucial for ensuring the UAV meets both performance and operational demands. This section details the key factors involved in choosing a high-power turboshaft engine, utilizing a structured decision-making process to identify the optimal solution.

3.2.1.1 Requirements

The engine requirements for this helicopter are primarily driven by the need to support a Maximum Take-Off Weight (MTOW) exceeding 8,000 kg. To meet this demand, the engine selection will focus on high-power turboshafts, often adapted from turboprop aircraft engines due to their proven reliability, efficiency, and power output. These engines must not only provide the necessary thrust for lifting heavy payloads but also ensure optimal performance under various operational conditions, such as high altitudes or hot climates.

A key aspect of the powerplant design is the requirement for a twin-engine configuration. Helicopters operating in high-performance or critical missions, especially those exceeding significant MTOW thresholds, consistently employ dual-engine setups. This design is essential for ensuring redundancy; in the event of a failure in one engine, the second can continue to operate, maintaining sufficient power to avoid mission failure or unsafe conditions. The reliability and safety offered by dual-turbine systems are well-established, which is why most helicopters in this class are equipped with two engines to guarantee uninterrupted performance, even under extreme conditions.

The engine choice must also minimize fuel consumption and economic and weight impacts on the UAV, ensuring optimal performance without compromising payload capacity or increasing operational costs. All these requirements, which become crucial considering a dual-motor configuration, will be further discussed in the following sections.

3.2.1.2 Engine Options

Based on the previously stated requirements, a preliminary study on several engine models has been developed. The model of reference, Airbus H175, is equipped with the Pratt & Whitney PT6C-67E. The chosen models, with similar power and total weight, are shown in the following Table:

ID	Engine Name	Reference Model	Years of Production	Tag Price (million USD)	Usual MTOW (kg)	Power Output (kW)	Specific Fuel Consumption (kg/kWh)	Total Weight (kg)
A	General Electric CT7-8A [52]	Sikorsky S-92	1990s	1.35	19000	1500	0.283	256
B	Pratt & Whitney PT6C-67E [53]	Airbus H175	2010s	1.25	7800	1324.5	0.408	215
C	Safran Makila 1A1 [54]	Airbus H215	2004	1.75	9700	1560	0.227	235
D	General Electric T700-701D [26]	Sikorsky UH-60 Black Hawk	2000s	0.80	10000	1,491	0.283	207
E	Klimov TV3-117VM [55]	Mil Mi-17	1980s	0.90	11100	1641	0.308	270
F	Safran Arriel 2S2 [56]	Sikorsky S-76D	2010s	0.80	7100	783	0.245	200
G	Safran Ardiden 3G [57]	Kamov Ka-62	2010s	1.15	8600	1491	0.236	210
H	General Electric T58-GE-16 [58]	Sikorsky SH-3 Sea King	1960s	1.05	9700	1119	0.339	270

Table 3.1: Engine options summary of characteristics, including Specific Fuel Consumption.

The usual MTOW is obtained from the Maximum Take-Off Weight of different helicopters that use each engine. It is important to note that, while all these helicopter models use a twin-engine configuration to achieve the specified MTOW, Table 3.1 offers the information for a single engine.

It can be observed from Table 3.1 that there are two models that don't reach the $8000kg$ MTOW: the Pratt & Whitney PT6C-67E and the Safran Arriel 2S2. This is not due to the engine's capabilities but because existing models don't have such exigent requirements. Based on the manufacturer's specifications, these engines should be able to withstand the required MTOW of this project with the adequate airframe, gearbox and mounting procedures.

In the following Figure, these 8 engine options are exposed in Power Output vs. Tag Price and Power Output vs. Weight plots, so as to study which of them is, theoretically, the one that extracts the most power for the cheapest price and lowest weight.

Based on the plots from Figure 3.1, it is easy to observe how engine G is the one with the best Power-Weight ratio, engine E dominates the Power-Price ratio and engine C is the one with the best Power-Consumption relation. However, these plots alone do not represent an optimal assessment method and a logical and non-arbitrary method cannot be directly defined.

To decide the adequate engine in a more normalized way, where each criteria is weighted and the decision making process is less arbitrary, the OWA (Ordered Weighted Average) and PRESS decision methods will be applied. The following section highlights the criteria that will be used for the selection process, while the whole procedure for the OWA and PRESS methods can be found in Annex A.1.

3.2.1.3 Assigned Weights

When choosing a helicopter engine it is essential to evaluate each criterion's significance in terms of its contribution to overall performance and efficiency. The chosen variables has been

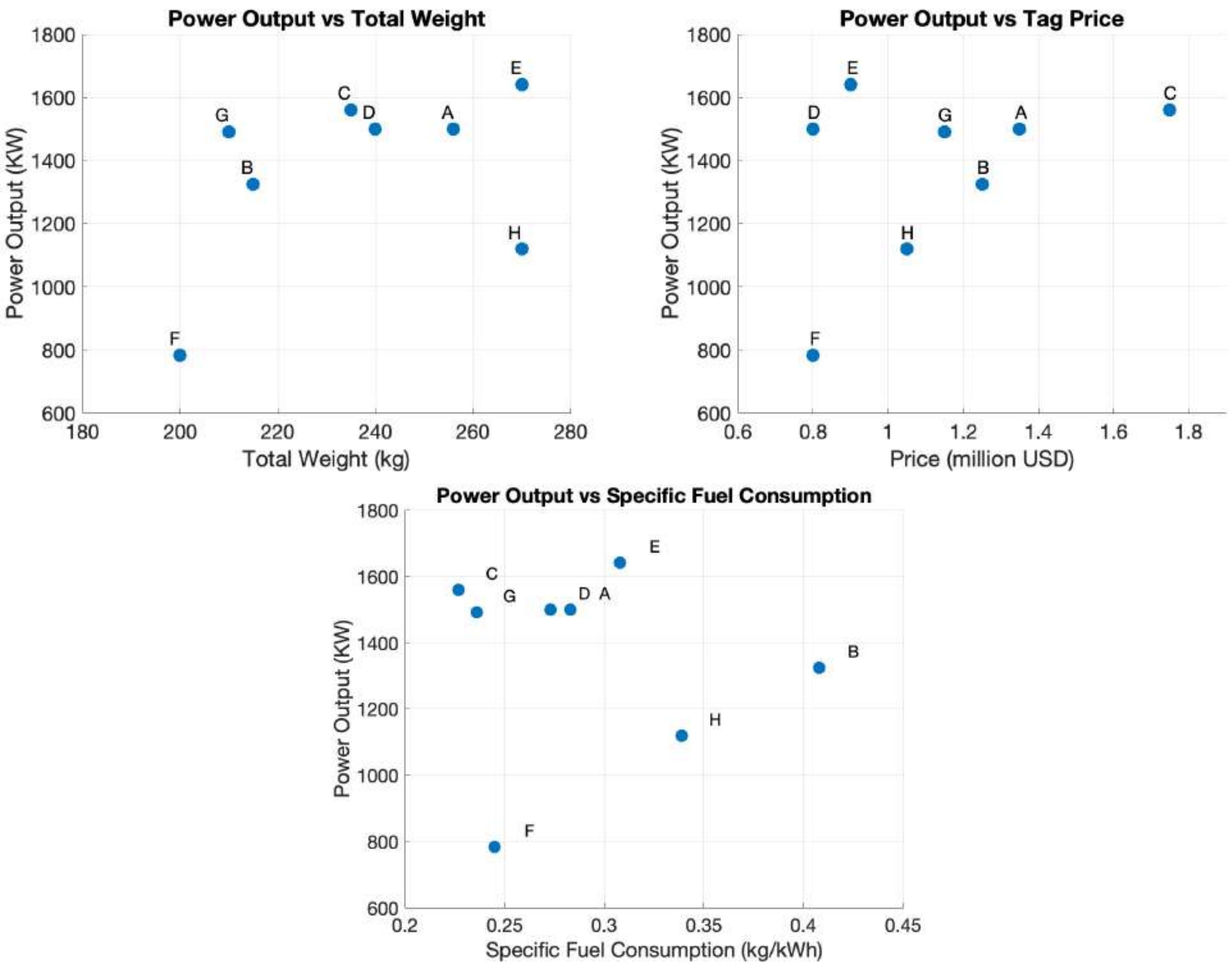


Figure 3.1: Power output compared to weight, price values, and fuel consumption for the engine options.

- Cost: It isn't as important as other characteristics as a result of not contributing too much to the global helicopter cost.
- Power: The power provided is fundamental in order to carry out the required performance.
- SFC: Accounts for fuel consumption during flight, better as less.
- Weight: Secondary becuse the weight is practically insignificant compared to the total one.

In the Annex A.1.2.1 can be found a wider explanation of its importance. Below can be seen the final relative weight assigned to each of them.

Criterion	Cost	Power	SFC	Weight
Relative weighting (%)	**20**	**40**	**30**	**10**

Table 3.2: Assigned weight for each assessment criteria, engine selection.

3.2.1.4 Final choice and configuration

A summary of the results obtained with both methods, OWA and PRESS, is presented in Table 3.3. In this final analysis, each alternative has been assigned a total rank based on both the OWA and its assessment acriteria, and PRESS scores (see appendix A.1). When there is a discrepancy between the two methods, the alternative with the highest combined score has been given the better rank.

OWA vs. PRESS				
Alternatives	**Engine Name**	**OWA**	**PRESS**	**Total Rank**
A	General Electric CT7-8A	0,79	0,15	4
B	Pratt & Whitney PT6C-67E	0,00	0,01	8
C	Safran Makila 1A1	0,59	0,11	5
D	General Electric T700-701D	1,00	1,00	1
E	Klimov TV3-117VM	0,77	0,30	3
F	Safran Arriel 2S2	0,08	0,06	7
G	Safran Ardiden 3G	0,93	0,71	2
H	General Electric T58-GE-16	0,18	0,00	6

Table 3.3: OWA vs. PRESS comparison for engine alternatives with custom colors.

Therefore, it is safe to conclude that **the best engine option is the General Electric T700-701D**, widely known for its use on the Sikorsky UH-60 Black Hawk. The second best option would be the Safran Ardiden 3G, followed by the Klimov TV3-117VM.

Figure 3.2: The selected engine for the UAV will be the General Electric T700. [3]

As outlined in the requirements (Section 3.2.1.1), the selected engine will be configured in a twin-engine setup to provide redundancy and sufficient power. The GE T700-701D technical sheet is shown in Table 3.4, while the overall power-plant characteristics in regular operation are summarized in Table 3.5. It is important to clarify that the values in Table 3.5 represent double those of a single GE T700-701D engine, and will be the ones used for the performance analysis, design and dimensioning of the whole UAV.

Performance Specifications (Sea level/standard day)

Ratings	SHP	(kW)	SFC
Contingency (2.5 min. OEI)	2,000	(1,491)	-
Maximum (10 min.)	1,994	(1,486)	0.465 (78.0)
Intermediate (30 min.)	1,902	(1,418)	0.462 (78.0)
Maximum continuous	1,716	(1,279)	0.462 (78.0)
Length		46 in (117 cm)	
Nominal diameter		15.6 in (39.6 cm)	
Weight		456 lb (207 kg)	

SHP – Shaft Horsepower
OEI – One Engine Inoperative
SFC – Specific Fuel Consumption in lb/SHP-hr (μg/J)
Performance being evaluated

Table 3.4: GE T700-701D performance specifications and dimensions. [26]

Total power-plant characteristics	
Maximum continuous power (kW)	2558
Specific Fuel Consumption (kg/kWh)	0,546
Weight (kg)	414
Length (cm)	117
Price (million USD)	1,6
Output shaft speed (RPM) [59]	20,900

Table 3.5: Summary of the total power-plant characteristics at sea-level and under regular performance conditions.

3.2.2 Power Transmission

Power transmission in helicopters is critical for delivering engine power to the main and tail rotors. The system achieves this by significantly reducing the engine's high rotational speed (RPM) to match the operational requirements of the rotors. For the main rotor, the total reduction ratio is approximately:

$$\tau_{\text{main rotor}} = \frac{\omega_{\text{engine}}}{\omega_{\text{main}}} = \frac{20,900}{270} = 77.4 \tag{3.1}$$

Similarly, the tail rotor gearbox provides a reduction to meet its operational speed, with a ratio:

$$\tau_{\text{tail rotor}} = \frac{\omega_{\text{engine}}}{\omega_{\text{tail}}} = \frac{20,900}{2,000} = 10.5 \tag{3.2}$$

The transmission system, weighing approximately **565 kg**, includes all modules, oil-related components, and shafts. These values are based on the Black Hawk's transmission system, which has a similar twin-engine configuration [12].

Key Elements:

- **Main Rotor Gearbox (MGB):** Reduces engine speed to a lower RPM suitable for the main rotor while ensuring torque distribution for lift and stability.
- **Tail Rotor Gearbox (TGB):** Adapts power for the tail rotor, including speed reduction and a 90-degree power redirection to maintain yaw control.

Detailed descriptions and diagrams of the transmission system, including the shafting system and gearbox designs, can be found in Appendix A.2.

3.2.3 Fuel System

The fuel system in the UAV is designed to ensure safe storage, efficient distribution, and reliable supply of fuel during all phases of operation.

Key Parameters:

- **Fuel Type:** Jet-A1, with an average density of 0.8 kg/L and a freezing point of -47°C.
- **Maximum Fuel Weight (MFW):** Estimated at 2,000 kg, based on benchmarking against similar rotorcraft (e.g., Airbus H-175 and Bell 525) and operational requirements.
- **Fuel Tanks:** Two primary tanks, each with a capacity of 1,250 liters, ensuring center-of-gravity stability during fuel consumption.
- **Additional Capacity:** External tanks can be added for missions requiring extended range or endurance.

Operational Scenarios:

- Typical mission (2.5 hours): Consumes approximately 1,500 kg of fuel.
- Maximum endurance mission (5 hours): Estimated fuel consumption of 1,700 kg.

The system design complies with CS-29 regulations, including crash resistance (CS 29.952) and fuel tank integrity (CS 29.963), to ensure safety and reliability.

For detailed specifications of the fuel tank design, layout, and distribution system, refer to Appendix A.3.

3.3 Aerodynamics

In this section, the aerodynamics of the aircraft and the components of the rotor blades are analyzed.

3.3.1 Main Rotor Blades

To complement the powerplant analysis, it is essential to examine the main rotor blades, which are considered one of the most critical components of the aircraft. The design and subsequent analysis of the blades are vital to ensuring compatibility with the power output of the two selected engines.

A numerical analysis was conducted, calculating the main rotor lift coefficients (C_L), thrust coefficients (C_T), and, most importantly, the power coefficients (C_P). From these results, the total non-dimensional power requirements for hovering and performing axial flight maneuvers were derived.

The parameters used to analyze the main rotor are interdependent and stem from key design inputs. In other words, the total power coefficient depends on variables such as the number of blades, the airfoil used, rotor area, and rotor speed (RPM). These variables are interconnected, forming a complex optimization problem where the goal is to minimize power consumption and maximize the available power from the engines.

Ultimately, the criterion for the design involves using various input variables from helicopters with similar power outputs and maximum takeoff weights (MTOW) to the proposed UAV.

In the following table, the principal blade parameters from major helicopter manufacturers are presented:

Company	Helicopter	Nb (Number of blades)	R (Blade Radius in m)	RPM (Revolutions per minute)
Airbus [60]	H135	4	5.33	395
	H145	5	5.35	386
	H160	5	6	320
	H175	5	7.9	330
	H215	4	7.53	265
	H225	5	7.53	265
	Eurocopter Tiger	4	6.3	286
	NH90	4	8.68	265
Boeing [61]	MH-139	5	6.4	324
	AH-6	5	4.88	430
	AH-64 Apache	4	7.3	294
	H-47 Chinook	3	9.15	225
Bell [62]	505	2	5.33	413
	407	4	5.96	413
	429	4	5.18	375
	412	4	7	324
	525	5	8	209
	AH-1Z Viper	4	7.32	324
	UH-1Y Venom	4	7.32	324

Table 3.6: Major helicopter models from principal manufacturers, highlighted in green, are similar aircraft in terms of MTOW and PW requirements.

3.3.1.1 Airfoil Blades

Detailed aerodynamic data on rotor blade airfoils is often inaccessible to the public, yet it is essential for evaluating performance. Among the critical parameters, the lift-curve slope ($C_{L\alpha}$) plays a pivotal role in numerical simulations and contributes to stall prediction. While $C_{L\alpha}$ tends to remain relatively consistent across various airfoil designs, the stall angle of attack (α_{stall}) can differ significantly depending on the airfoil's geometry. This difference underscores the importance of careful airfoil selection in rotor blade design, as it heavily influences performance under high angles of attack.

Rotor blades experience increased loading when fewer blades are used, resulting in elevated angles of attack and heightened stall risks, particularly during high-speed forward flight. The widely used NACA 5-digit airfoils, notably the 230xx series, exemplify a well-rounded design that balances lift, drag, and stall resistance. These airfoils exhibit a high lift-to-drag ratio, which is crucial for efficient performance in both hover and forward flight modes. Additionally, their favorable stall characteristics help mitigate the occurrence of retreating blade stall. The 230xx series also features a thickness distribution optimized for structural strength without sacrificing aerodynamic efficiency. This careful balance is vital, given the intricate relationship between blade loading, rotor radius, and RPM.

To select the optimal airfoil, the Ordered Weighted Averaging (OWA) decision-making method was applied. Among the selected airfoils—NACA 23012, 23015, and 23018—these were chosen due to their proven balance of lift, drag, and structural characteristics. The final airfoil choice will depend on achieving the best overall performance for both hover and forward flight, ensuring safe and efficient operation under various conditions.

Variables for OWA Method:

The following variables are most untactful for comparing NACA 23012, 23015, and 23018. In the Appendix B.1 can be found a more exhaustive explanation of its variable and their importance.

- $C_{l_{max}}$: A higher coefficient generally correlates with better lift performance. [63]
- α_{stall}: An airfoil with a higher stall angle allows the blade to operate effectively at higher angles of attack, which can improve maneuverability and power efficiency. [64]
- C_{d_0}: Lower C_{d_0} translates to less parasitic drag, crucial for reducing power consumption during cruise and forward flight. [65]
- **Airfoil Thickness:** This variable balances structural integrity with aerodynamic efficiency.

Criterion	$C_{l_{max}}$	C_{d_0}	α_{stall}	**Airfoil thickness**
Relative weighting (%)	**25**	**40**	**30**	**5**

Table 3.7: Assigned weight for each assessment criteria.

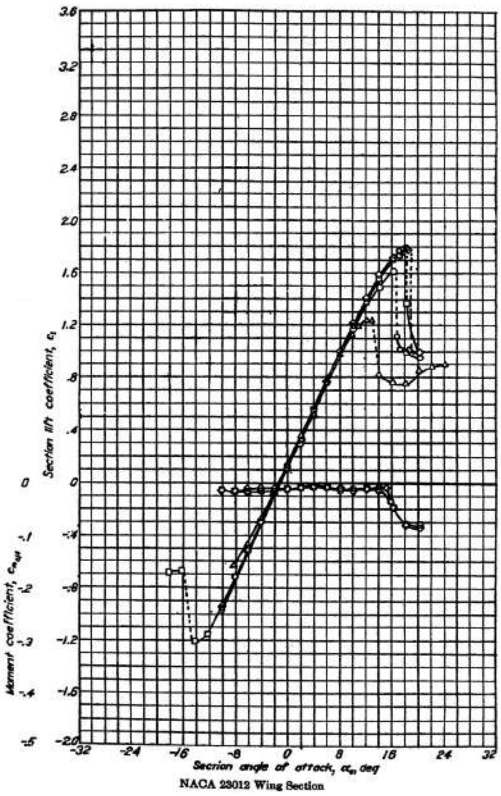
Results:

Therefore, as a result of the relative weighting established, the airfoil that best aligns with the operational capabilities is the **NACA 23012**.

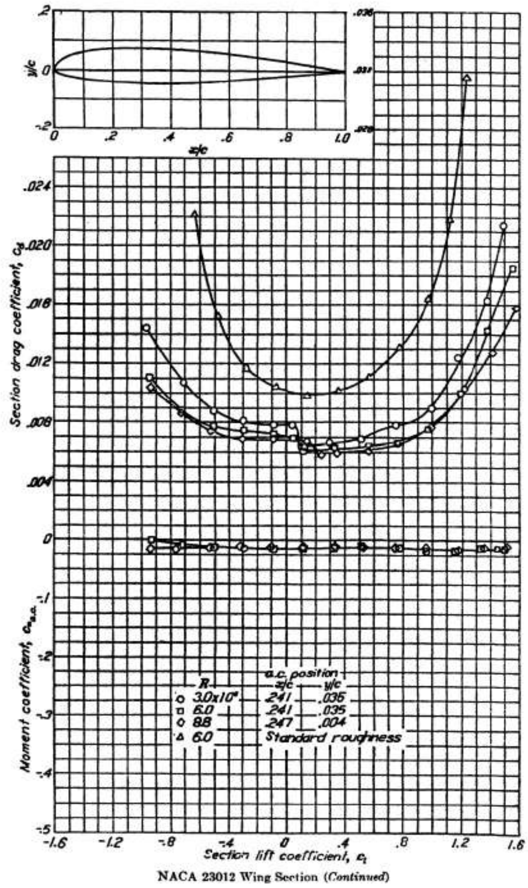
$C_{l_{max}}$	C_{d_0}	α_{stall}	Thickness [°]
1.55	0.009	15.5°	12.00%

Table 3.8: Aerodynamic characteristics of the airfoil.

NACA 23012 experimental curves are provided in figure 3.3. Specifically, figure 3.3a represents the lift coefficient vs. angle of attack at different Reynolds number, while figure 3.3b shows the evolution of the drag coefficient vs. lift coefficient, again, at different Reynolds numbers.



(a) Lift curve of the profile



(b) Polar of the profile

Figure 3.3: Experimental curves on the NACA 23012 profile, extracted from Von Doenhoff and H.Abbot, 1959 [4].

Blade characterization using the BEMT

For the characterization of the blade aerodynamics, to find the necessary coefficients such as the lift distribution along the blades, its thrust distribution, and the power consumption, a comprehensive study is required. Hence the Blade Element Method Theory was conducted. This involves solving for the blade twist or torsion angle distribution, which is assumed to be linear. The twist ensures that the blade operates efficiently by minimizing lift and drag variations between the root and tip. Thus, it is a crucial parameter for determining the optimal blades design given the linear twist constrain.

The following section presents the results of the study conducted using the BEMT.

3.3.1.2 BEMT numerical results

A benchmark analysis was conducted to establish the main rotor parameters, comparing the UAV to similar helicopters in terms of Maximum Takeoff Weight (MTOW) and Power-to-Weight ratio (PW). This approach leverages proven designs to estimate reliable performance metrics, ensuring alignment with real-world operational standards.

The final rotor design parameters, derived from this analysis, are summarized in Table B.3, with the rotor blades adopting a 5-digit NACA 23012 airfoil and linear twist profile. For hover flight, the torsion distribution along the blade is:

$$\theta(r) = 27.7457 - 20r \quad \text{where} \quad r \in [0.0724, 1]\,\text{m}. \tag{3.3}$$

A Blade Element Momentum Theory (BEMT) analysis was conducted to evaluate lift, thrust, and power distributions along the blades, along with required power at various climb speeds. These results are detailed in Appendix B.1.2, including coefficient distributions and required power for axial ascent.

The result of the BEMT analysis also tells us the required power for the main rotor to operate:

$\mathbf{v_z}$ (m/s)	Power (kW)	Power (hp)	Excess Power (kW)	Excess Power (hp)
0	1443.5	1935.7	1114.5	1494.3
5	1670.4	2240.5	887.6	1189.8
10	1932.7	2591.4	625.3	838.4
15	2228.7	2987.7	329.3	441.6
20	2555.5	3425.4	2.5	3.4

Table 3.9: Required power for the main rotor at different axial ascend speed values (v_z) and the corresponding excess power, assuming an available power of 2558 kW.

As shown in the table, the available power for performing an axial ascend of 15 m/s is more than sufficient. For reference, the Airbus H175 has a remarkable climb speed performance[1] of 15.79 m/s.

Ultimately, the top climb speed obtained from the BEMT analysis is 20.03 m/s, the value at which the excess power becomes negative.

3.3.1.3 EASA: Certification Specifications, Acceptable Means of Compliance and Guidance Material for Large Rotorcraft (CS-29)

In the following section, the performance climb and its relation to power requirements within the EASA certification are discussed.

CS 29.65 Climb: all engines operating [66]

The steady rate of climb must be determined:

1. With maximum continuous power;
2. With the landing gear retracted; and
3. At V_Y for standard sea-level conditions and at speeds selected by the applicant for other conditions.

CS 29.66 Climb: One engine Inoperative [66]

For Category A rotorcraft, in critical take-off configurations, the steady rate of climb without ground effect must meet the following:

1. **At 61 m (200 ft) above the take-off surface**:
   - Climb rate must be at least **30 m/min** (100 ft/min) with a critical engine inoperative, landing gear extended, and at a safety speed selected by the applicant.
2. **At 305 m (1,000 ft) above the take-off surface**:
   - Climb rate must be at least **46 m/min** (150 ft/min) with a critical engine inoperative, landing gear retracted, and at a speed chosen by the applicant.

[1] A climb of 3000 meters in 3 minutes and 10 seconds according to Airbus.

3. **At all altitudes and weights for certification**:

   - Climb (or descent) rate must be established with a critical engine inoperative, landing gear retracted, and a speed selected by the applicant.

Requirements 1 and 2 of the EASA CS 29.65 document have been met, tested by means of the BEMT program, which returned positive excess power in both cases.[2]

3.3.2 Tail Rotor Blades

The following section details the tail rotor configuration and parameters specific to the UAV model under consideration, focusing on key design elements such as the number of blades, rotational speeds, and blade dimensions. This analysis provides a technical foundation for understanding the performance characteristics of the chosen configuration.

3.3.2.1 Tail rotor configuration

In selecting the tail rotor configuration for this UAV helicopter, the choice of a Fenestron design offers distinct advantages over the conventional open tail rotor. The enclosed Fenestron system significantly enhances safety by reducing the risk of foreign object damage and accidental contact with ground personnel. This extra layer of security is specially important given that the operations will be pilotless and, therefore, the main source of possible human damages will not be present.

Moreover, this design incorporates a higher number of smaller blades, resulting in a more uniform aerodynamic flow and substantially lower noise emissions, which is crucial for applications requiring reduced acoustic signatures. Furthermore, the Fenestron provides improved anti-torque control efficiency and better stability at high speeds, contributing to more precise handling and increased operational reliability, crucial in challenging operations like the ones undergone by the UAV. These factors collectively make the Fenestron configuration a superior choice for the intended UAV model.

3.3.2.2 Technical parameters

A similar process as the previously used for the main rotor blades will be used to determine the tail rotor blades characteristics. However, given the lesser relevance of the tail rotor in comparison, certain simplifications will be applied to not over-complicate the decision-making process.

As done in the previous section, the principal tail rotor's blade parameters from major helicopter manufacturers are presented in the following Table. It is important to note that this table only features modern helicopters models with a Fenestron, given that this will be the tail rotor configuration used in the designed UAV. This is crucial because Fenestrons usually have a higher RPM and number of blades and a smaller blade radius than open tail rotors and, hence, comparing helicopter models with these two different configurations would not make sense.

Helicopter	Nb (Number of blades)	R (Blade Radius in m)	RPM (Revolutions per minute)
H135 [60]	10	1.2	2630
H145 [60]	10	1.2	2620
H160 [60]	10	1.3	2230
AS365 Dauphin [67]	11	1.5	1900
EC130 [68]	10	1.3	2700

Table 3.10: Helicopters with Fenestron tail rotors, highlighting key tail rotor data.

[2] The corresponding air density according to the ISA and gravity values were used for the different heights on the analysis.

In order to determine the chosen parameters of the tail rotor, a comprehensive **benchmark analysis** will be conducted. A full parametric analysis of all possible rotor configurations would be too complex and is left outside the scope of the project. Analyzing the data from Table 3.10 and taking special consideration to the high-MTOW models, such as the Airbus H160 or the AS365, the final tail rotor design parameters are:

TAIL ROTOR	**Nb (Number of Blades)**	**R (Blade Radius in m)**	**RPM (Revolutions per minute)**	**c (Chord in m)**
UAV	10	1.3	2000	0.2

Table 3.11: Parameters established involving the tail rotor blades.

Next up, the airfoil will be determined. To do so, a simpler form of benchmarking will be implemented, given that applying the OWA method to the tail rotor's profile has been considered as overkill.

A study from Kania et. al. from the Warsaw Institute of Aviation on the "Development of new generation main and tail rotors blade airfoils" reveals how the NACA 0012 (symmetric) and NACA 23012 (slightly cambered) are the most commonly used tail rotor airfoils, even though more modern alternatives can be proposed. Regarding the designed UAV, a more experience-proof alternative like the aforementioned NACA profiles will be used.

The NACA 0012 airfoil is the preferred choice for Fenestron tail rotor configurations due to its symmetrical design, which provides consistent performance regardless of airflow direction. This is crucial for tail rotors, as they often encounter varying angles of attack during different flight maneuvers, including rapid yaw adjustments and crosswind conditions. The symmetrical profile of the NACA 0012 ensures predictable lift characteristics, enhancing stability and control at both positive and negative angles of attack. Additionally, the uniform aerodynamic properties of this airfoil contribute to noise reduction, which is a key advantage of the enclosed Fenestron design. By minimizing pitch sensitivity and providing reliable lift generation, the NACA 0012 effectively supports the primary goals of Fenestron operation: improved safety, efficiency, and low acoustic signatures.

The aerodynamic characteristics of the NACA 0012 airfoil are summarized in the following Table:

$C_{l_{max}}$	C_{d_0}	α_{stall}	Thickness [°]
1.24	0.006	14.75°	12.00%

Table 3.12: NACA 0012 aerodynamic characteristics. Airfoil Tools, 2024. [23].

3.3.2.3 BEMT numerical results

The same code applied for the main rotor will be used in this tail rotor analysis. First, the data from Tables 3.11 and 3.12 is inputted into the BEMT code. Furthermore, a required thrust in order to obtain the lift distribution has to be introduced. To do so, an initial approximation is performed, merely to see if the local lift values ever exceed the $C_{l_{max}}$ value of the chosen airfoil. Assuming a main-tail rotors distance of $d = 8m$ and neglecting the vertical stabilizer force (which will be calculated later on), the necessary thrust offered by the tail rotor is:

$$M_R = \frac{P_R}{\Omega_R} = F_t d \rightarrow F_t = \frac{P_R}{\Omega_R d} \approx 8.55kN \tag{3.4}$$

With these inputs, the yielding thrust and power coefficient distributions along the blades are plotted in the following Figure:

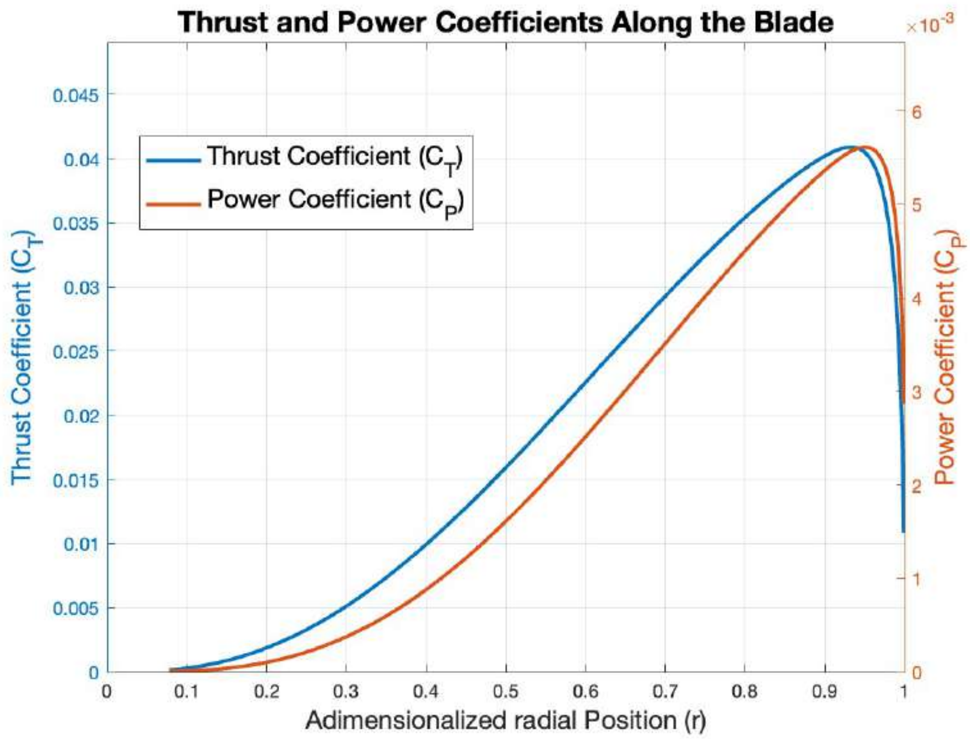


Figure 3.4: Thrust and power coefficient distributions along the blades.

Similar to the results observed for the main rotor, it is observed how the thrust and power coefficients increase as the position gets further away from the root but decreases dramatically just before the tip due to vorticity and tip loss, as seen in Figures B.2 and B.4.

When integrating these distributions along the whole blade, the yielding coefficients are:

$$C_T = 0.0177 \tag{3.5}$$

$$C_P = 0.0021 \tag{3.6}$$

It is important to note that these values are obtained by assuming that the tail rotor experiences a hover flight (completely steady flow around). Taking into account that the most demanding situation power-wise, as seen in the previous section, is axial flight, the assumption that the tail rotor experiences hover is not completely unreasonable. A Fenestron tail rotor would not experience axial movement but rather a slight forward flight, which can be negligible without excessive error.

After adimensionalizing, the yielding power value, at sea-level ISA conditions, is:

$$P = C_P \rho A_t V_{tip}^3 = C_P \rho A (\Omega_t R_t)^3 = 281.47 kW \tag{3.7}$$

This value is a mere approximations for a given flight condition. It is important to take into account that the helicopter's system can regulate the tail rotor's AoA to generate more or less force and to compensate adequately the main rotor's moment, hence changing the required power. However, this value gives an idea of the necessary power to make the tail rotor work.

To check if the required thrust provided by the tail rotor is unrealistic for the tail rotor airfoil and general characteristics chosen, the required lift distribution along the blade is plotted in the following Figure along with the $C_{l_{max}}$ threshold value to see if any blade section exceeds it:

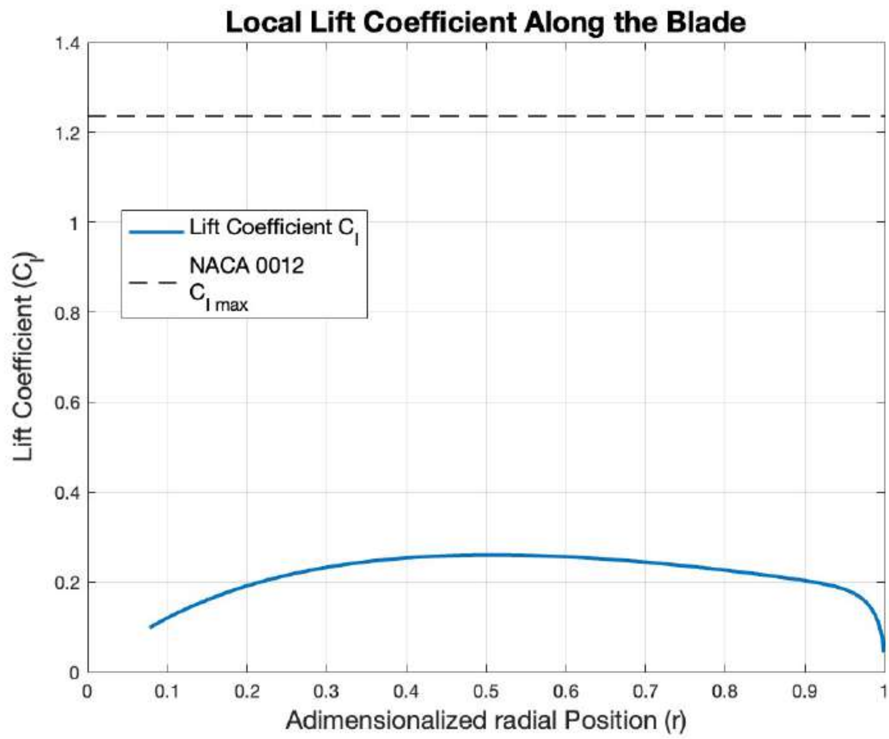


Figure 3.5: Lift coefficient distribution along the blades.

As observed, every position in the blade is very far away from reaching $C_{l_{max}}$ and, hence, inducing a local stall. Therefore, the selected airfoil for the tail rotor is more than capable of sustaining the necessary forces for moment equilibrium.

A more thorough exposition of the main rotor moment compensation will be developed once the vertical stabilizer configuration is introduced later on.

3.3.3 Fuselage Aerodynamics

The aerodynamic properties of the fuselage have been estimated using experimental data obtained from a scale model study [20]. The structure includes the fuselage, mast fairing, landing gear, and a rotating rotor head with blade cuffs, with results focusing on the drag (C_{D_0}) and lift (C_{L_0}) coefficients for the primary forward flight configuration (AoA $= 0°$, AoS $= 0°$).

Aerodynamic Coefficients:

- Drag coefficient: $C_{D_0} = 0.2325$
- Lift coefficient: $C_{L_0} = -0.0125$

Using a reference surface area ($S_{\text{ref}} = 8.15\,\text{m}^2$), the drag and lift forces (f_D and f_L) are calculated as:

- Drag force: $f_D = C_{D_0} \cdot S_{\text{ref}} = 1.85\ m^2$
- Lift force: $f_L = C_{L_0} \cdot S_{\text{ref}} = -0.1018\ m^2$

For detailed information on the experimental setup, configuration-specific results, and additional data, refer to Appendix B.3.

3.3.4 Aerodynamic stability and control surfaces

Aerodynamic stability and control are essential for helicopter safety and performance. This section examines the horizontal and vertical stabilizers' design, their role in managing aerodynamic forces, and the importance of the center of gravity (CG) in maintaining balance and control during forward flight.

3.3.4.1 Horizontal stabilizer

The horizontal stabilizer is a critical component for maintaining longitudinal stability and controlling pitch during forward flight. It counters excessive nose-up or nose-down tendencies, ensuring efficient and balanced helicopter performance, particularly at high speeds.

Key Parameters:

- **Stabilizer Dimensions:**
  - Span: $b = 2.7\,\mathrm{m}$
  - Chord: $c = 0.8\,\mathrm{m}$
- **Selected Airfoil:** NACA 2412, chosen for its high lift characteristics.

Wing span	**Chord**	α_0	$C_{L\alpha}$	$Max\ F_H\ force$
$2.7\ m$	$0.8\ m$	$-2.0520°$	$3.9374\ rad^{-1}$	$10766\ N$

Table 3.13: Dimensions and key characteristics of the designed horizontal stabilizer (at 300 km/h, 15°AoA)

Design Ratio: The equilibrium condition for the pitching moment, derived from the relationship:

$$\frac{d_{MR}}{d_H} = \frac{F_H}{MTOW \cdot g} = 0.14 \tag{3.8}$$

ensures optimal placement of the center of mass.

For detailed force calculations, airfoil selection methodology, and figures, refer to Appendix **??**.

3.3.4.2 Vertical Stabilizer

The vertical stabilizer ensures yaw stability and control in helicopters, counteracting the torque generated by the main rotor. It passively stabilizes the yaw axis during forward flight, reducing tail rotor workload and improving efficiency.

Key Parameters:

- **Stabilizer Dimensions:**
  - Span: $b = 2.5\,\mathrm{m}$
  - Chord: $c = 0.75\,\mathrm{m}$
- **Selected Airfoil:** Symmetrical NACA 0012.

Wing span	**Chord**	α_0	$C_{L\alpha}$	$Max\ F_V\ force$
2.5 m	0.75 m	0°	3.9188 rad^{-1}	1636 N

Table 3.14: Dimensions and key characteristics of the designed vertical stabilizer (at 300 km/h, 3° AoA).

Moment Equilibrium: The relationship between the main rotor torque, tail rotor force, and vertical stabilizer force is expressed as:

$$M_{MR} = d_{TR} \cdot (F_V + F_{TR}) \tag{3.9}$$

This shows that an increase in F_V reduces the tail rotor's required effort, improving overall power efficiency.

For detailed force calculations, airfoil selection methodology, and figures, refer to Appendix B.4.2.

3.3.4.3 Center of Mass Ranges for Helicopter Stability

The center of gravity (CG) is critical for helicopter stability and control during flight. Proper CG positioning ensures safe handling across various phases of operation, particularly during forward flight, where stability challenges are most pronounced due to aerodynamic forces and rotor dynamics.

Forward flight requires maintaining the CG within a defined range to prevent excessive forward or aft cyclic control demands. A forward CG limit between 0.10 and 0.18, derived from structural and dynamic considerations (**EASA CS-29 Amendment 11**), ensures sufficient cyclic authority and prevents instability during critical maneuvers. This range is calculated based on the ratio between the distances from the main rotor to the center of mass and from the center of mass to the horizontal stabilizer (approximately 0.14) in equation 3.8.

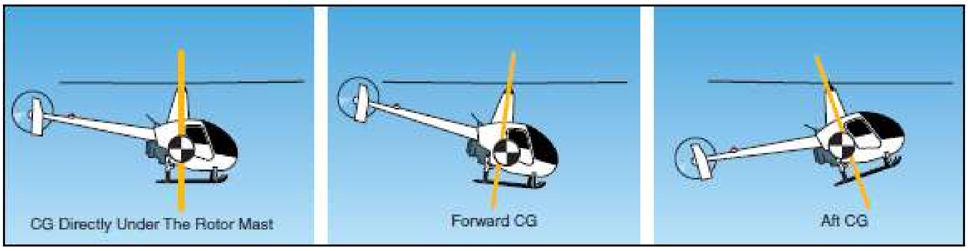


Figure 3.6: The Effect of CG Position on Helicopter Stability [5].

Adhering the EASA CS-29 Amendment 11, ensures safe and efficient helicopter performance in flight operations [69].

For detailed force calculations, refer to Appendix B.4.3.

3.4 Performance

In this section different aspects of the UAV's performance will be analyzed. It is important to note that throughout all of the calculations certain non-idealities are introduced. The values of these factors are approximated using typical values for high-MTOW helicopters. First, the main and tail rotor performances is fixed at $\eta_{MR} = \eta_T = 0.97$. Second, the non-idealities factor has been fixed at $\kappa = 1.15$.

Having defined this, the performance analysis can now be conducted.

3.4.1 Forward flight performance

A Matlab code is implemented to study various cruise speeds (V_∞) in forward flight, determining the optimal cruise speed, range, endurance, and fuel consumption at different altitudes.

3.4.1.1 Power analysis

The power components (profile, climb, induced, and forward power) are computed for different cruise speeds using momentum theory. The available engine power is evaluated by calculating the power at the main and tail rotor shafts, focusing on the P_{tail}/P_{main} ratio. This analysis confirms that the required power for any desired cruise speed is met, ensuring the vehicle's ability to achieve its performance requirements.

The detailed decomposition of shaft power and its components is illustrated in Appendix C.1.1.

3.4.1.2 Optimal cruise speed

The optimal cruise speed minimizes total power required, reducing fuel consumption and maximizing range. Analysis of power requirements reveals the optimal cruise speed as:

$$V_{optimal} = \mathbf{135km/h} \tag{3.10}$$

Operational needs may necessitate a cruise speed above the optimal, but it should remain within the available shaft power limits for safety and reliability. A detailed representation of excess power versus flight speed is provided in Appendix C.1.2.

3.4.1.3 Maximum speed at various flight conditions

The maximum speed at different altitudes is evaluated, accounting for reduced air density and engine power availability. The relationship between altitude and maximum speed shows that the $300km/h$ requirement is only feasible below $2500m$. At higher altitudes, reduced available power imposes restrictions on feasible cruise speeds, with low speeds becoming unviable due to increased induced power.

Further insights and visualizations, including power comparisons at various altitudes, are provided in Appendix C.1.3.

3.4.2 Axial and hover flight performance

The analysis evaluates the power requirements and the operational ceiling under hover conditions, considering the relationship between available and required power as altitude and weight vary.

3.4.2.1 Hover flight power analysis

The hover flight analysis determines the power requirements and operational ceiling for the helicopter under hover conditions. The total shaft power, induced power, and profile power were calculated as functions of altitude. The hover ceiling is defined as the maximum altitude where the required shaft power equals the available power, which decreases with altitude according to Equation C.2.

For a mass of 8000 kg (required MTOW), the hover ceiling is 3066 m. However, as fuel is consumed, the helicopter's mass decreases, increasing the hover ceiling. For instance, consuming 700 kg of fuel raises the hover ceiling to approximately 4290 m. While forward flight allows the UAV to reach higher altitudes during cruise, rescue operations typically require hovering, thus limiting the mission altitude to hover conditions.

Detailed visualizations of power requirements and hover ceiling as a function of mass are provided in Appendix C.2.1.

3.4.2.2 Axial flight power analysis

Axial flight analysis evaluates power requirements during vertical climb at various altitudes. The induced velocity and corresponding shaft power were calculated as functions of climb velocity, with the maximum climb speed determined by the available power.

At sea level, an optimal rate of climb of 13 m/s is identified for rapid ascent to begin operations. However, a more moderate rate of climb may be preferable when carrying personnel to ensure comfort. At higher altitudes, the maximum climb speed decreases due to reduced available power, reaching 0 m/s at 3066 m, the hover ceiling.

Graphs illustrating power variation with climb speed and maximum climb speed versus altitude are presented in Appendix C.2.1.1.

3.4.3 Relevant operations definition

To ensure that the main requirements of the project are met, certain operations must be defined and analyzed. This sections aims to perform this study in detail.

3.4.3.1 Endurance-defining operation

Achieving a flight endurance of 5 hours is a key requirement of this project. While this significantly exceeds the minimum range of 300 km, a dual operational approach ensures both conditions are met. For shorter, fast-response missions, the aircraft can adopt a less optimal flight profile to meet the range requirement. Conversely, endurance-focused missions use a slower, more efficient profile to achieve the 5-hour target.

The endurance-defining operation comprises three phases:

1. **Axial ascent:** A climb to 500 m at a rate of $1.67 m/s$, consuming minimal fuel.
2. **Cruise:** A long cruise at an optimal speed of $140 km/h$ to minimize fuel consumption and extend endurance.
3. **Axial descent:** A descent at $-1.67 m/s$ back to ground level.

Detailed calculations for power consumption, fuel usage, and other parameters are provided in Appendix C.2.2.1. A summary of the operation is presented in Table C.1.

Endurance-defining Operation			
Stage	**Description**	**Duration**	**Fuel Weight Used (kg)**
1-2	Axial ascent	5 minutes	68
2-3	Forward flight	4 hours 50 minutes	1590
3-4	Axial descent	5 minutes	44
TOTAL		**5 hours**	**1702**

Table 3.15: Summary of the endurance-defining operation.

This analysis confirms that the required endurance is achieved using less fuel than the maximum fuel weight (MFW) calculated in Section A.3.1, leaving a margin for reserve, additional hovering, or quicker axial maneuvers. The total cruise distance of $677km$ also satisfies the range requirement.

3.4.3.2 Typical operation

A typical operation represents a standard mission profile, highlighting the UAV's capabilities under normal usage scenarios. This analysis ensures that the operational requirements are met with sufficient margins, showcasing the UAV's efficiency and reliability without nearing its maximum performance limits.

The stages of this typical operation will be:

1. Rapid axial ascent up to a $h_{cruise} = 1500m$.
2. Quick forward flight at a $V_\infty = 280km/h$ up to target, at a distance of 300 km.
3. Axial descent until getting close to the surface.
4. 10 minute hover to find the best landing spot, followed by the landing.
5. Axial ascent up to a $h_{cruise} = 1500m$. The UAV cannot refuel at the rescue spot. When on land, only the resources delivery or the humanitarian rescue is performed.
6. Quick forward flight at a $V_\infty = 280km/h$ back to the base.
7. Axial descent and landing.

For rescue missions involving individuals requiring medical attention, it is assumed the base is equipped with a hospital. If not, the UAV could land at a nearby hospital and return to the base without refueling. It is also assumed that 80% of the available fuel weight is utilized, with a takeoff weight of approximately 7000 kg, including the payload.

Detailed calculations for each stage, including power and fuel consumption, are provided in Appendix C.2.3. A summary of the operation is shown in Table C.2.

Typical Operation			
Stage	**Description**	**Duration**	**Fuel Weight Used (kg)**
1-2	Axial ascent	3 minutes	53
2-3	Forward flight	1 hour 5 minutes	656
3-4	Axial descent	3 minutes	41
4-5	Hover & landing	10 minutes	102
5-6	Axial ascent	3 minutes	47
6-7	Forward flight	1 hour 5 minutes	576
7-8	Axial descent & landing	5 minutes	48
TOTAL		**2 hours 34 minutes**	**1523**

Table 3.16: Summary of the typical operation.

This example demonstrates how a mission covering a distance of 300 km with rapid operations and 80% fuel usage can be executed efficiently. The UAV retains the flexibility to extend the range to 400 km or increase the forward speed to 300 km/h while operating near MTOW.

3.4.4 Operating Conditions

As outlined in the project proposal and aircraft requirements, the UAV must be capable of operating under demanding environmental conditions, such as extreme heat, high altitudes, and severe gusts. These challenges necessitate the use of materials resistant to corrosion in harsh environments, along with an adaptive PID control system to maintain stability in remote and unpredictable areas.

This section focuses specifically on propulsion and aerodynamic requirements to meet these operational demands.The subsequent information was extracted from "Introduction to Flight" by J. D. Anderson [70].

The propulsion system selected for the UAV is designed to provide sufficient power to handle the additional loads imposed by PID-controlled adjustments for stability during strong wind gusts or in high-temperature conditions, where air density is significantly reduced. This ensures the UAV can deliver reliable performance in challenging environments without compromising on efficiency.

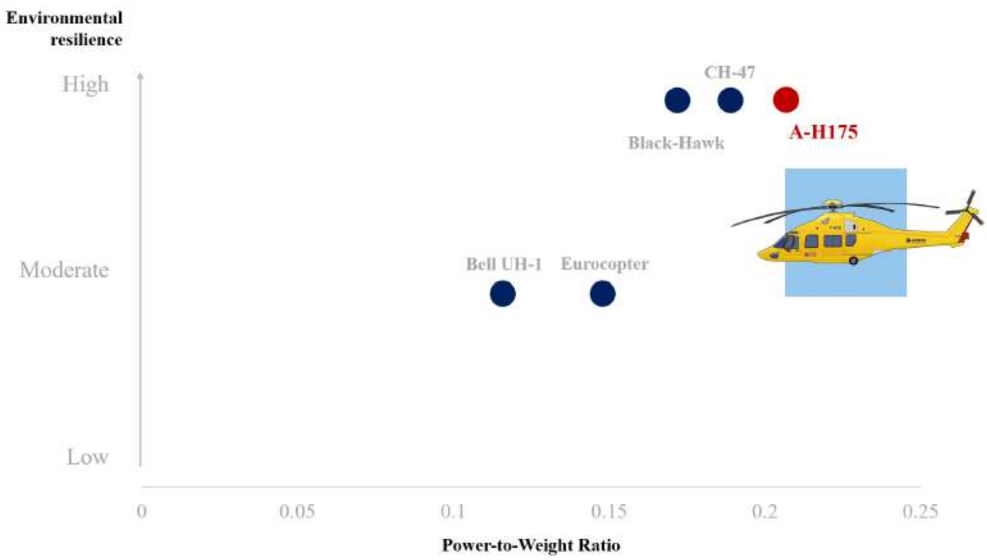


Figure 3.7: Relationship between power-to-weight ratio and environmental resilience for various helicopters. Extracted from [6] and data from Table 3.6.

Figure 3.7 illustrates the relationship between the two key factors for operating in challenging environments: **environmental resilience and power-to-weight ratio.**

- **Environmental Resilience:** This includes the helicopter's design and systems' ability to endure adverse environmental factors such as extreme temperatures, high winds, sand/dust (e.g., desert environments), humidity (e.g., tropical regions), or ice (e.g., arctic conditions). Critical systems like the engine, rotor, and avionics must be optimized to function reliably under these conditions, often requiring features like dust filters, de-icing systems, and corrosion-resistant materials. As this variable is general in nature, the graph only includes a qualitative categorization.
- **Power-to-Weight Ratio:** This defines the helicopter's ability to generate sufficient lift and maneuverability. A high power-to-weight ratio ensures that the helicopter can take off, hover, and climb even in high-altitude or hot environments where air density is low (e.g., the "hot and high" condition). It also allows for carrying payloads in challenging scenarios, such as rescue operations or transporting supplies.

The chart compares several rescue and military helicopters, highlighting their capabilities. Notably, the Airbus H175, which serves as the reference model for the proposed UAV, demonstrates exceptional performance in terms of both power and environmental adaptability. This reinforces the suitability of the Airbus H175 as a baseline for developing a UAV capable of meeting the propulsion and aerodynamic demands discussed in this section.

3.5 Structure & Materials

3.5.1 Materials selection

One of the main aspects in order to be able to withstand extreme conditions and to reach the required level of performance is a great selection of the materials for each and every part of the UAV. With the requirements in hand, an extensive research and posterior decision will be done.

3.5.1.1 Work scope

The conducted research will take into account which are the most widely used materials in the aerospace industry, going from aluminum alloys to composite materials. Once the cutting edge materials are selected, a selection criterion will be applied in order to determine the best option for each component, always taking into account the macroscopic and countable properties of the material and without digging deep into its microstructure.

3.5.1.2 Aerospace materials state-of-the-art

3.5.1.3 Candidates and selection method

3.5.1.4 Fuselage materials

a) **FRAMES**

b) **SIDE PANELS**

c) **LONGERONS**

3.5.1.5 Ultra High Strength Applications (UHS)

3.5.1.6 Blade materials

3.5.2 MB1: Fuselage structure design

The design of the main fuselage structure is a critical aspect of the UAV helicopter project, as it serves as the primary load-bearing component and ensures the integration of various systems. This task, designated as MB1, focuses on developing a structural framework capable of withstanding operational loads while meeting weight and safety requirements.

3.5.2.1 Design requirements

The main fuselage structure must meet specific design requirements to ensure functionality, safety, and compatibility with the overall UAV system. These requirements are categorized as follows:

Structural Requirements

- The fuselage must support operational loads, including payload, rotor forces, and environmental stresses.
- It must withstand extreme conditions, such as high winds, turbulence, impacts and it's associated induced forces.
- The weight of the structure must be minimized to optimize the UAV's performance, aligning with the department's weight constraints.

Interface with Other Systems
The fuselage must integrate seamlessly with various subsystems, requiring:

- Structural attachment points for the rotor system, as detailed in task MB1G.
- Accommodation for avionics and sensors, aligned with MB1F.
- Support for payload and cabin elements, following the design specifications from MB1C and MB2.

3.5.2.2 Structure configuration

The main fuselage structure is interconnected with other tasks within the Design, Materials, and Structures department, particularly:

- **MB1A: Material Selection**, which defines the material properties and constraints for the fuselage components.
- **MB1G: Load Analysis**, which provides essential data on rotor-induced forces and structural responses.
- **MB1C: Secondary Structural Design**, which includes panels and other non-load-bearing components integrated into the fuselage.

The objective of this task is to design the primary structural elements of the fuselage, ensuring it meets performance and safety standards while accommodating the integration of rotors, avionics, and payload systems. The scope includes the design of beams, reinforcements, and critical attachment points for other subsystems.

Simplifying a helicopter structure into frames and longerons is an effective approach for the early stages of design. This method offers several practical advantages, while ensuring the structural integrity of the design remains the primary focus.

First, frames and longerons, as stated in [71], capture the essential elements of the load-bearing structure in a helicopter fuselage. Frames primarily distribute transverse loads, such as those arising from aerodynamic forces and ground reactions, while longerons are optimized for handling axial loads along the length of the fuselage. By focusing on these core components, the design inherently mirrors the primary load paths and structural behavior observed in actual helicopters.

Using frames and longerons also provides a clear and simplified framework for determining the spatial distribution and connectivity of the fuselage's structural elements. This approach ensures that the design aligns with the established payload constraints, which can be seen in table 3.17. Simplification does not undermine the structural integrity but rather facilitates an understanding of how the major structural members interact to maintain stability under operational conditions.

Moreover, this approach is particularly suited to scenarios where the design is developed by analogy with existing aircraft. By focusing on frames and longerons, the design can be adapted and scaled to match the proven configurations of similar structures, reducing uncertainty and leveraging established engineering practices.

Payload dimensions		
Length [m]	**Width** [m]	**Height** [m]
5.4	1.7	2.15

Table 3.17: Payload physical constraints.

Taking all this into account, the following structure has been designed.

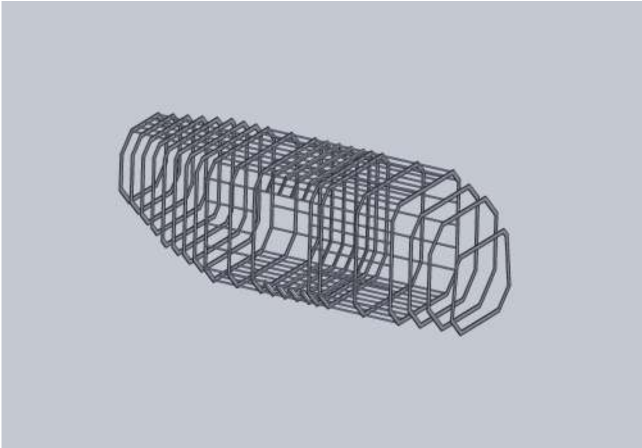


Figure 3.8: Main fuselage design.

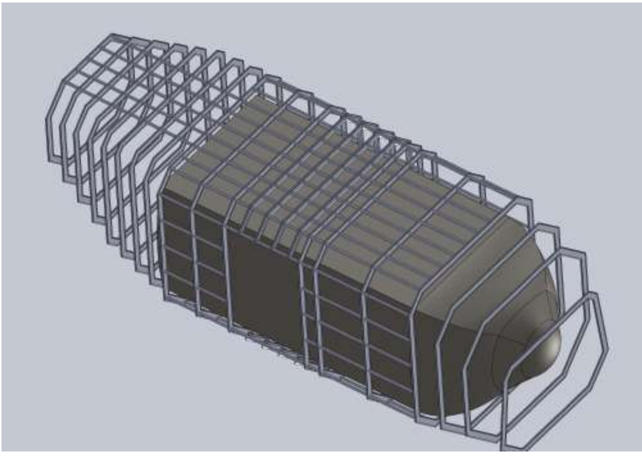


Figure 3.9: Main fuselage design with payload dimensions constraints.

Figure 3.10: Main fuselage design with payload dimensions constraints.

3.6 Payload & Operations

This helicopter, designed for humanitarian aid, has been conceived with the objective of maximizing its operational efficiency in emergency situations, adapting quickly to the specific needs of the mission in which it is deployed. To achieve this, a modular system has been incorporated into its interior, allowing the aircraft to alternate between two predetermined configurations: cargo missions and medical aid missions.

This modular approach not only optimizes the use of available resources but also provides unprecedented flexibility by allowing the helicopter to be rapidly adapted to different types of emergencies as required. The modules that make up the system, one intended for cargo missions and the other for medical missions, have been designed to be interchangeable in a short amount of time, ensuring that the aircraft can perform various functions depending on the circumstances. The modular design is based on a component anchoring and fastening system that ensures the assembly and disassembly process is efficient, without compromising the safety of the operation.

The elements of the cabin have been carefully designed to allow for rapid reconfiguration of the space, optimizing both the available volume and access to the equipment needed for each type of mission. The elements that make up the interior are relatively simple to assemble and disassemble, using mechanisms that promote speed while adhering to safety regulations for both the crew and any personnel that may be transported or assisted. Each module, whether for cargo or medical aid, has been developed with the specific requirements of each mission in mind. For example, the cargo module includes supports for transporting supplies, equipment, and heavy material, while the medical aid module is optimized for victim treatment, with space for emergency beds, medical equipment, and first-aid supplies.

To facilitate the rapid transition between these two modules, standardized connection systems have been used, allowing the helicopter to be reconfigured without the need for specialized tools. This ensures that the mission change can be carried out even under challenging working conditions. The modularity, combined with ease of reconfiguration, not only increases effectiveness in emergency situations but also minimizes the aircraft's downtime, ensuring that resources are available when most needed.

Additionally, the entire process of assembling and disassembling the modules has been designed according to strict safety standards defined by our company, ensuring that the components are robust, easy to handle, and present no risks to the crew or the transported equipment. The fastening, anchoring, and securing systems are designed to withstand the vibrations and impact forces inherent to flight, ensuring that the modules remain securely in place throughout the operation.

3.6.1 Payload storage strategy

This section details the organization of the cargo the UAV will carry. The initial idea is to classify the cargo into different material types and establish packs tailored to specific client needs for various missions.

3.6.1.1 Available load configurations

The following packs have been defined based on disaster scenarios and humanitarian aid missions:

- **Food Pack:** Essential nutrition items such as pre-cooked meals, dried fruits, canned goods, energy bars, water, and purification tablets.
- **Medical Pack:** Basic medical supplies including bandages, antiseptic wipes, splints, medications, and defibrillators.
- **Hygiene Pack:** Personal hygiene items such as soap, hand sanitizer, wipes, and sanitary prod-

ucts.

- **Survival Pack:** Survival tools including thermal blankets, tents, fire-starting kits, and ropes.
- **Shelter Pack:** Temporary shelter items such as tents, tarps, sleeping bags, and ponchos.
- **Search & Rescue Pack:** Tools for search and rescue operations such as beacons, ropes, flashlights, and first aid kits.
- **Communication Pack:** Communication tools including satellite phones, walkie-talkies, and solar chargers.
- **Disaster Response Pack:** Tools for disaster response like generators, solar lamps, and purification systems.
- **Children's Emergency Pack:** Supplies for children including clothing, toys, snacks, and diapers.

3.6.1.1.1 Density study

An estimated density has been assigned to each type of pack, based on content characteristics:

Pack	**Estimated Density (kg/m^3)**
Food Pack [72, 73, 74]	500–800
Medical Pack [75]	200–400
Hygiene Pack [76]	150–300
Survival Pack [77, 78, 79]	100–300
Shelter Pack [80, 81]	50–150
Search & Rescue Pack [82, 83, 84]	300–500
Communication Pack [85, 86]	400–600
Disaster Response Pack [87, 88]	400–750
Children's Emergency Pack [89]	100–250

Table 3.18: Density Estimation of Cargo Packs

3.6.1.2 Container material selection

The boxes used for carrying cargo need to meet several critical characteristics:

- **High Load-Bearing Capacity:** Must support up to 200 kg per box.
- **Lightweight:** Essential for optimizing aircraft performance.
- **Eco-Friendly:** Materials should be recyclable or renewable to minimize environmental impact.
- **Durability:** Must withstand environmental conditions during transport.
- **Impact Resistance:** Prevent damage upon landing.
- **Vibration Dampening:** Protect sensitive cargo.
- **Economic Viability:** Must balance performance with cost-effectiveness.

The following materials were considered:

- Recycled Aluminium [90, 91]

- Natural Fiber Reinforced Plastics (Biocomposites) [92]
- Basalt Fiber [93]
- Plywood [94]

The PRESS method has been applied to select the most suitable material for the cargo boxes, ensuring that the choice is supported by objective criteria and well-grounded analysis. The method is explained in the appendix E.1. According to the results of the PRESS method, with the weights assigned to each factor, the best material option for the boxes is plywood, due to its low density and minimal environmental impact. Other materials, such as recycled aluminum and basalt fiber, also meet many requirements; however, their high density makes them less ideal when the priority is maximizing cargo capacity.

3.6.1.2.1 Advantages and Disadvantages of Plywood

Advantages:

- Plywood's lightweight nature helps optimize the payload, allowing for more cargo to be carried within the aircraft's capacity limits.
- It is an eco-friendly choice, as it is both renewable and biodegradable, aligning with sustainability goals.

Disadvantages:

- **Durability**: Plywood is less durable compared to other materials like aluminum or basalt fiber. However, this is not critical since the boxes are primarily single-use and have limited post-delivery utility.
- **Impact Resistance and Load-Bearing Capacity**: While plywood has limitations in these areas, these shortcomings should not pose significant issues if the operational procedures are followed correctly and all systems function as intended.

3.6.1.3 Arrangement of cargo

Based on the dimensions of the cabin and the available space, the optimal configuration for the box distribution has been determined as follows:

Type 1: 60x60x60 cm Plywood Boxes [95]

- **Specifications:**
  - **Base Thickness:** 1 cm
  - **Side Thickness:** 0.6 cm
  - **Corner Reinforcement:** Steel reinforcements for added durability.
- **Weight per Box:** 10.6 kg
- **Maximum Load Capacity:** 375 kg

Type 2: 80x60x60 cm Plywood Boxes

Figure 3.11: Latch model

- **Specifications:**
  - **Base Thickness:** 1 cm
  - **Side Thickness:** 0.6 cm
  - **Corner Reinforcement:** Steel reinforcements for added durability.
- **Weight per Box:** 13 kg
- **Maximum Load Capacity:** 500 kg

3.6.1.3.1 Cargo distribution layout

The exact layout is illustrated in the accompanying **drawings below**, which show the configuration in detail, ensuring the cabin's capacity is fully utilized without compromising operational performance and surpassing the maximum payload of the aircraft.

(Illustration to be done)

Each box must be clearly labeled to indicate the type of products it contains, facilitating easy identification during loading, unloading, and in case of emergencies. Proper labeling ensures that sensitive or temperature-dependent items can be quickly located and handled accordingly.

The cargo should be arranged with heavier items placed at the bottom and closer to the center of gravity to maintain the UAV's stability during flight. This arrangement minimizes the risk of shifting cargo, which could negatively impact the UAV's flight dynamics and handling.

3.6.1.4 Cargo protection and security systems

Once the study of the cargo is completed, security measures are implemented to ensure that the cargo reaches its destination in good condition.

Ambient Control of the Cabin *(Not done yet)*

Secure Latching and Locking Systems

- **Latches** [96]**:** Prevent accidental opening of cargo compartments during flight.

Real-Time Monitoring

- **Surveillance Cameras:** Install cameras inside the cabin to provide live feeds to operators, allowing them to visually monitor the cargo during flight.
  - **Model:** Hikvision HWT-D320-VF [97].
  - **Placement:** Mounted on the ceiling, positioned at door level for optimal visibility.
- **Infrared Cameras:** Use infrared cameras to monitor temperature-sensitive cargo and detect any potential overheating.
- **Temperature and Humidity Information:** Display real-time data on temperature and humidity to ensure cargo is within safe operating conditions.

CO_2 Fire Suppression System

The CO_2 fire suppression system displaces cabin oxygen to below the level necessary for combustion, extinguishing the fire. CO_2 is stored as a liquid under high pressure in pressurized cylinders, which, when released, rapidly expand from a liquid to a gas, filling the space and lowering the oxygen concentration.

To achieve total flooding, a CO_2 concentration of approximately 35% by volume must be attained within 2 minutes [98]. This reduces the oxygen content in the air to below 15%, effectively extinguishing the fire. Note that at this concentration, human life cannot be supported, making it critical to activate safety protocols prior to deployment.

For a cabin with a total volume of **15 m^3**, the required CO_2 volume can be calculated as:

$$\mathrm{CO_2} = \text{Volume of the cabin} \times 0.35 = 15\,\mathrm{m}^3 \times 0.35 = 5.25\,\mathrm{m}^3$$

This equates to approximately **10–11 kg** of liquid CO_2.

- **Model:** Ansul 426243 [99], capable of carrying up to 35 lbs (15.9 kg) of CO_2. The total weight of the system, including the cylinder and mounting components, is approximately **55 kg**.
- **Placement:** The CO_2 cylinder will be located in the front tip of the cabin to optimize weight distribution and accessibility. Multiple discharge nozzles will be strategically placed along the ceiling and walls to ensure uniform coverage during activation.

Fire Detection Sensors

Heat and smoke detectors are essential for triggering the CO_2 suppression system [100]. These sensors will monitor the cabin for any temperature increases or the presence of smoke.

- **Model:** X-Sense SC01 [101], equipped with photoelectric and electrochemical sensors.
- **Placement:** Two units will be mounted on the ceiling to maximize coverage and sensitivity.

The fire suppression system ensures rapid and effective fire extinguishing while minimizing damage to the cargo and cabin. Its design follows safety guidelines, prioritizing human evacuation and environmental considerations.

Vibration Damping Systems

Vibration damping systems are critical to protecting sensitive cargo from the adverse effects of mechanical vibrations during flight. By minimizing the transmission of vibrations, these systems enhance the safety and integrity of items stored in the UAV. The selected vibration isolation model is designed to provide stability and durability under varying operational conditions.

- **Model:** STAG MP-2 [102]
- **Location:** Inside the boxes, positioned at the base.

Impact Protection Systems

Impact protection systems are designed to safeguard cargo against sudden shocks or impacts that may occur during handling, transport, or landing. These systems enhance the structural integrity of the storage units and the cabin, reducing the risk of damage to sensitive equipment and supplies.

- **Impact Absorbing Materials:** Apply impact-absorbing materials to the interior of the cabin, particularly near the cargo area, to minimize damage from sudden jolts or impacts.
- **Reinforced Structures:** Reinforce the corners of the boxes with steel reinforcements to increase their strength and prevent structural failure upon impact.

3.6.1.4.1 Arrangement of Cargo Protection Systems

(Altready explained in 3.6.1.4 so probably no need for this section)

3.6.1.4.2 Reliability and Integrity Assessment

Ensuring the reliability and integrity of the implemented security systems is critical to the safe and efficient operation of the UAV. This assessment involves identifying potential failure modes, evaluating their effects on mission performance, and implementing strategies to mitigate risks. Using the **Failure Mode and Effect Analysis (FMEA)** methodology [103], each component is analyzed to ensure it meets the necessary safety, durability, and operational standards under varying conditions.

The key safety elements and their respective failure modes studied are:

CO_2 Fire Suppression System

- **Failure Mode:** CO_2 system does not discharge properly.
  - **Effect:** Inability to extinguish fire, leading to loss of cargo and damage to the UAV.
  - **Causes:** Malfunctioning release valve, insufficient CO_2 supply, or blockage in the nozzle.
  - **Mitigation:** Regular maintenance and inspection of release valves, sensors, and CO_2 pressure levels. Consider using multiple cylinders for redundancy.
- **Failure Mode:** CO_2 cylinder leaks.
  - **Effect:** Reduction in CO_2 available for fire suppression.
  - **Causes:** Faulty cylinder, corrosion, or improper sealing.
  - **Mitigation:** Periodic cylinder inspection and replacement. Consider having two cylinders for redundancy.
- **Failure Mode:** Accidental activation of CO_2 system while passengers are present.
  - **Effect:** Displacement of oxygen in the cabin, potentially leading to asphyxiation and loss of life among passengers.
  - **Causes:** Faulty activation sensor, human error, or software malfunction triggering the system unnecessarily.
  - **Mitigation:**

    * Install safety interlocks to prevent activation when passengers are detected.
    * Conduct thorough pre-flight checks of activation systems.
    * Integrate manual override controls to cancel activation in non-critical scenarios.
    * Use visual and audible warnings prior to system discharge to allow evacuation.

Fire Detection Sensors

- **Failure Mode:** Heat and smoke detectors fail to trigger.
  - **Effect:** Delayed response to a fire.
  - **Causes:** Faulty sensors, blocked detectors, or calibration issues.
  - **Mitigation:** Regular sensor testing, cleaning, and ensuring correct placement of cargo.

Vibration Damping Systems

- **Failure Mode:** Vibration isolation pads wear out.
  - **Effect:** Excessive vibrations transmitted to sensitive cargo, leading to potential damage to delicate products.
  - **Causes:** Material degradation.
  - **Mitigation:** Use high-quality pads, perform regular inspections for wear and tear, and replace them periodically.
- **Failure Mode:** Incorrect installation.
  - **Effect:** Reduced effectiveness in dampening vibrations.
  - **Causes:** Human error during installation.
  - **Mitigation:** Proper training for installation personnel and well-defined carrying protocols.

Latching System

- **Failure Mode:** Latch mechanism fails.
  - **Effect:** Cargo may shift or fall during flight.
  - **Causes:** Mechanical failure, corrosion, or poor manufacturing.
  - **Mitigation:** Regular inspection and maintenance of the latching mechanisms. Use corrosion-resistant materials such as stainless steel.

Surveillance and Monitoring Systems

- **Failure Mode:** Surveillance cameras fail to provide a live feed.
  - **Effect:** Operators are unable to monitor the cargo effectively.
  - **Causes:** Power failure, signal disruption, or camera malfunction.
  - **Mitigation:** Implement redundant power sources and signal relays. Conduct routine camera maintenance and periodic system checks.

3.6.1.5 Operational Cargo Accessibility Validation

This involves testing the cargo systems to ensure efficient accessibility under various operational scenarios while maintaining system reliability and safety. *(Not done yet)*

3.6.2 Cargo deployment mechanism

In this section, a mechanism will be developed to correctly deploy the cabin's cargo from the air without the need to land. For this purpose, a study has been conducted to identify the best current methods for carrying out this operation by comparing different current mechanism:

1. Deployment with Crane or Winch
A crane or winch system is used to lower the cargo from the helicopter to the ground in a controlled manner. The package is attached to a cable that unwinds slowly until it reaches the destination.

- **Advantages:** Ideal for areas where the helicopter cannot land, such as mountainous regions, rough terrain, or rescue operations at sea.
- **Disadvantages:** It can be slower and requires great skill to keep the helicopter stable during the descent.

2. Air Drop
In this case, the helicopter flies at low altitude and drops the cargo, which is usually equipped with parachutes or cushioning devices. This system is widely used by military and humanitarian organizations in emergencies.

- **Advantages:** Fast and efficient, it can cover large areas quickly without landing.
- **Disadvantages:** There is a risk of damaging the cargo if the parachute or cushioning system fails, and a clear drop area is required.

3. Deployment via Fast Rope
Instead of using a crane or dropping the package, a thick rope is hung from the helicopter, allowing personnel to slide down to the ground. While more common for troops, this method can be adapted for small loads in specialized containers.

- **Advantages:** Allows rapid deployment without landing, useful in areas where the helicopter cannot remain stationary for long.
- **Disadvantages:** Not ideal for heavy or delicate loads.

4. Deployment with Hover Stabilization
The helicopter hovers at a low altitude, allowing personnel or specialized machinery to move the cargo from the helicopter to the ground manually or with lifting systems.

- **Advantages:** Full control over the cargo, minimizing the risk of damage from falls.
- **Disadvantages:** Requires more time, fuel consumption, and pilot skill.

5. Autonomous Delivery with Drones or UAVs (Helicopter Complement)
Helicopters may operate alongside drones or unmanned aerial vehicles (UAVs) for deliveries in more complex or inaccessible locations.

- **Advantages:** High precision and safety. UAVs can navigate tight or hazardous spaces where it would be risky or difficult for a helicopter.
- **Disadvantages:** Developing technology with limited capacity for heavy loads.

6. Deployment with Brief Landing
The helicopter performs a short landing (only seconds or minutes) to offload cargo and takes off quickly.

- **Advantages:** Ideal for delicate cargo that requires precise handling.
- **Disadvantages:** Requires suitable terrain and safe conditions for landing.

Although these methods do not allow for full process automation—or, if they do, are overly complex for the intended task—alternative options are presented below. These solutions enable proper usage both during flight and after landing.

7. Hook and Cable System with Remote Release
This is one of the most common methods. The helicopter carries the cargo suspended in a net or container attached to a hook with a long cable. The release of the cargo is controlled remotely from the helicopter cabin using a remote mechanism. This system is widely used in:

- **Humanitarian Aid:** To drop supplies or provisions in inaccessible areas.
- **Military Operations:** When precise cargo release is required.
- **Advantages:** Can release cargo in areas where landing is unsafe and precise control from the cabin.

8. Cargo Parachutes
A less common but useful method for areas where landing is not possible is using a parachute system for the cargo. The helicopter releases the cargo with a parachute, allowing it to land gently at the designated location.

- **Advantages:** Reduces impact upon landing and useful in situations where precision is less critical, but safety is paramount.

9. Capsule or Container Systems with Propulsion
This system consists of autonomous containers or capsules equipped with small propulsion systems or flight control devices. These are released from the helicopter and adjusted for a smooth and controlled landing.

- **Advantages:** Ensures gentle and precise landings and useful for delivering to specific or difficult-to-access locations.

10. Automated Ramps or Motorized Rollers
This system is used in cargo helicopters carrying packages in a cargo compartment. The automated ramps or motorized rollers inside the helicopter are activated to move packages toward the cargo door and eject them without human intervention, for example:

- The roller system of the CH-47 Chinook.

- Automated unloading systems in civilian helicopters such as the Sikorsky S-92.

11. Gravity-Assisted Discharge Doors
Some cargo helicopters, like transport airplanes, use specialized compartments with doors that, once opened, allow packages to slide out via gravity.

For the task we aim to carry out, one of the most efficient methods that allows us to achieve the objective in an optimal way is the integration of **motorized rollers**. These rollers will guide the cargo toward the doors so that it can either be dropped from a specific height or placed on the surface below. Additionally, **parachutes** will be used to slow the descent of the packages, ensuring a safe landing.

For the design of motorized rollers, we must adhere to the current layout of the helicopter cabin. The main idea is to integrate rollers on the cabin floor along with a system that ensures proper separation of the boxes to guarantee the correct deployment of all packages.

Given the current load distribution, it is ideal to work with rollers capable of supporting significant weight. Based on market research, we will use rollers with a diameter of 100 mm and a shaft diameter of 20 mm.

Since this is a helicopter cabin, the roller distribution must be studied in relation to the location of the doors. Additionally, an electric motor system will be employed to move the rollers.

3.6.2.1 Safe landing system

The main current methods for safely deploying packages from a helicopter are as follows:

1. Deployment via Parachutes
Packages are released with a small parachute that automatically deploys upon exiting the helicopter.

- **Advantages:** The parachute slows the fall, reduces impact, and ensures a more stable trajectory, which is useful for fragile packages or when precision is required.
- **Disadvantages:** The system requires clear airspace to ensure the parachute does not get tangled. It can also be affected by wind.

2. Descent Cable System
A retractable cable lowers the package to a height close to the ground before releasing it.

- **Advantages:** Allows for controlled and safe descent without the need for the helicopter to come to a complete stop. This system is ideal when the terrain does not permit a close landing.
- **Disadvantages:** Requires a mechanism to control the descent and release the package at the correct height. It becomes more complicated in strong wind conditions.

3. Deployment Capsule with Airbags
The package is placed inside a capsule equipped with an airbag system. Upon release, the airbag inflates automatically before reaching the ground to cushion the impact.

- **Advantages:** Protects the package from impact upon landing and enables drops from greater heights.
- **Disadvantages:** The airbag system requires a sensor or timer to ensure inflation occurs at the right moment. Its accuracy may be affected if the terrain is sloped or uneven.

4. Guided Deployment Using Wings or Directional Parachutes
Similar to a parachute but with maneuverability. A directional parachute or a set of lightweight wings allows for steering the package towards its destination.

- **Advantages:** Greater precision in landing and useful in moderate wind conditions. It can avoid hazardous areas along the descent path.

- **Disadvantages:** The autonomous control system requires guidance algorithms and possibly GPS sensors to ensure the package reaches the desired delivery point.

5. Deployment with Cargo Drones
A drone attached to the helicopter picks up the package and autonomously transports it to the destination.

- **Advantages:** Allows for controlled delivery, avoids obstacles, and ensures precision landing. Ideal for hard-to-reach areas.

- **Disadvantages:** This system is more complex as the drone must integrate with the helicopter and have sufficient autonomy for the mission.

6. Free-Fall Controlled Drop Modules or Shock Absorbers
Packages are placed in containers with internal shock absorbers that allow for free-fall deployment from the helicopter. Upon ground impact, the shock absorbers reduce the impact force.

- **Advantages:** Reduces the cost of external components like parachutes or drones.

- **Disadvantages:** Requires precise calibration of the shock absorbers according to the package weight and deployment height. It is more suitable for flat terrain or obstacle-free areas.

Based on the examples provided, the most suitable and cost-effective option is deployment via **parachutes**. This method is compatible with the internal cargo configuration and simplifies integration with the existing structure. Additionally, it is the most economical option.

3.6.2.2 Cargo Loading and Unloading Protocol

Effective cargo loading and unloading protocols are essential for the safe and efficient operation of the UAV. These protocols ensure that supplies are handled with care, minimizing the risk of damage and ensuring that the cargo is securely transported. Well-defined procedures also allow personnel to work efficiently, especially in time-sensitive scenarios.

(Still not fully developed)

3.6.2.2.1 Pre-Loading Preparations

3.6.2.2.2 Loading Procedure

3.6.2.2.3 Unloading Procedure

3.6.2.2.4 Post-Unloading checks

3.6.3 Medical Supplies

3.6.3.1 Medical Supplies list

Helicopter Emergency Medical Services (HEMS) play a crucial role in the healthcare emergency response system, especially in hard-to-reach areas or time-sensitive scenarios where immediate medical intervention can be the difference between life and death. Given the demanding operational environment, HEMS must be equipped with Advanced Life Support (ALS) medical devices that comply with both international and national regulations to ensure safety, functionality, and operational efficiency.

The operation of medical helicopters in Europe is primarily governed by Regulation (EU) 965/2012 [104], which establishes the technical and administrative requirements for commercial air operations, including HEMS missions. Within this framework, Subpart SPA.HEMS addresses the conditions and minimum equipment required on board helicopters to ensure advanced medical care. According to SPA.HEMS.110, all medical equipment installed in the helicopter must be approved under Regulation (EU) 748/2012 [105], which governs the certification of aircraft and aeronautical components. This ensures that all devices installed meet safety and functionality standards for operation in an aviation environment. These regulations do not specify exactly which medical equipment shall be included in the helicopter, but those used must be approved and certified. The principle applied here is that no equipment (medical or otherwise, installed or not) shall affect the airworthiness or safe operation of the aircraft, even in the case of failures or malfunctions.

At the national level, countries like Spain complement these European regulations with domestic rules such as Royal Decree 836/2012 [106], which sets out the technical specifications and minimum equipment required for medical transport vehicles, including helicopters. This implies that the medical equipment on board must be equivalent to what is expected in land ambulances for advanced life support but adapted for the unique challenges of the aerial environment.

Key Technical Specifications for Onboard Medical Equipment:

- **Vibration Compatibility:** Medical devices must resist constant helicopter vibrations. Monitoring units, ventilators, and electronic devices must pass vibration tests to ensure their functionality during flight.
- **Reduced Weight and Dimensions:** Limited space and weight constraints require compact, lightweight devices that maintain performance while adhering to the helicopter's operational limits.
- **Restraint Systems:** Equipment must be securely fastened to prevent displacement during sudden maneuvers or adverse conditions, with restraint systems certified to withstand flight-phase G-forces.
- **Electromagnetic Compatibility (EMC):** Devices must resist interference from the helicopter and other onboard electronics to maintain performance and safety.

Essential Medical Equipment for HEMS:

1. Advanced Life Support Equipment (ALS)
These are critical devices to maintain the patient's life during transport or until they reach a medical facility.

- Defibrillator Monitor
- Mechanical Ventilator
- Infusion Pump
- Manual Resuscitator (Ambu Bag) with Masks

2. Monitoring Equipment
These devices are essential for evaluating and tracking the patient's vital signs during flight.

- Multiparameter Monitor
- Portable Pulse Oximeter
- Digital Thermometer

3. Airway and Breathing Equipment
These devices are critical to ensuring a safe and effective airway in emergency situations.

- Laryngoscope with Blades of Various Sizes
- Endotracheal Tube (ETT)
- Laryngeal Mask Airways (LMA)
- Nasopharyngeal and Oropharyngeal Airways
- Portable Oxygen with Regulator
- Portable Nebulizer

4. Venous Access and Medication Administration Equipment

- Intravenous Catheters
- Intraosseous Access Kit
- Disposable Syringes and Needles
- Intravenous Solutions and Fluids
- Emergency Medications

5. Trauma and Orthopedic Support Materials

- Cervical Collars
- Rigid Rescue Board
- Inflatable and Rigid Splints
- Bandages and Gauze

- Tourniquets

6. Cardiac Support Equipment

- External Pacemaker
- Suction Device

7. Patient Transport Equipment

- Rescue Stretcher (Scoop Stretcher)
- Folding or Spinal Stretcher
- Patient Restraint System

8. Personal Protective Equipment (PPE)

- Disposable Gloves
- Masks and Face Shields
- Protective Glasses
- Gowns and Protective Suits

9. Communication Equipment

- Radios and Communication Systems
- Tablet or Electronic Device

10. Additional Materials

- Thermal Fluid Bag
- Emergency Childbirth Kit
- Burn Kit
- Thermal Blanket (Emergency Blanket)
- Disposable Electrodes

11. Specialized Equipment
Depending on the type of mission and the medical personnel on board, some helicopters may carry additional equipment:

- Minor Emergency Surgery Kit
- Extracorporeal Membrane Oxygenation (ECMO) Devices

12. Helicopter Emergency Systems

- Emergency Suction System
- Mobile Lighting

13. Basic Supplies

- Alcohol, Antiseptics, and Disinfectants
- Adhesive Tape and Sutures
- Trauma Shears

14. Biological Resources
This section includes critical blood products necessary for trauma care and critical situations.

- Blood Bags
- Plasma Products
- Platelets
- Crossmatched Blood Products

This list covers the essential equipment and supplies necessary to ensure a medical helicopter is prepared to address various emergencies, from severe trauma to cardiac or respiratory crises. The primary goal is to stabilize the patient and provide appropriate care during transportation to the nearest hospital. See appendix E.2 for a more detailed list with the functions and commercial models of each supply.

3.6.3.2 Restocking of Medical Supplies Procedure

The restocking of medical supplies is a vital process to ensure the effectiveness of operations. These helicopters are designed to respond to critical situations, so they must be fully equipped with functional medical devices ready for use. The unpredictable and urgent nature of HEMS missions makes it essential to have strict replenishment protocols after each intervention to ensure that the necessary equipment is always available and operational. The replenishment of medical supplies is not only an operational measure but also a legal requirement aimed at ensuring the quality of medical care on board and avoiding deficiencies that could endanger patients. Equipment such as cardiac monitors, defibrillators, ventilators, oxygen systems, and emergency supplies must be checked and replenished after each mission to ensure they are ready for use in the next emergency.

Annex IV of BOE 216/2008 [106] is one of the key documents that regulate this process. It states that before each flight, the pilot in command must ensure that all equipment, including medical devices, is operational and in good condition. This implies the need for protocols to verify and replenish medical supplies after each intervention. Additionally, the annex reinforces the responsibility of maintaining the aircraft in optimal operating conditions, which includes the maintenance of medical equipment on board.

Annex 6 of the ICAO (International Civil Aviation Organization), in its Chapter 6 [107], also establishes the importance of having a continuous maintenance program that includes medical equipment in aircraft dedicated to emergency services. This chapter emphasizes that medical devices must be regularly checked to ensure they are functioning properly during operations. Specifically, Annex 6 states that emergency equipment, including medical devices, must be ready for use at any time, which requires an effective and efficient replenishment process.

Regulation (EU) 965/2012 [104], which regulates air operations in the European Union, complements these regulations. This regulation establishes that HEMS helicopters must be equipped with certified and operational medical supplies. The SPA.HEMS subpart of this regulation requires that medical equipment be kept in good condition and that its replenishment is immediate after each mission. This regulation ensures that operators establish and follow specific procedures to verify the functionality of medical equipment before each flight, which is fundamental to the safety and effectiveness of operations.

From these regulations, it can be concluded that having a replenishment and maintenance procedure that guarantees the proper execution of emergency medical activities is fundamental and mandatory for operation. This procedure must be thoughtfully developed and implemented by the operators of these helicopters, placing this responsibility on us. Although we have no constraints or guidelines for its design, so as long as it is efficient and safe, we are free to establish this protocol as we wish.

3.6.3.2.1 Medical Equipment Restocking Protocol for HEMS Helicopters

A. Objective
The purpose of this protocol is to ensure that HEMS (Helicopter Emergency Medical Services) helicopters are properly equipped with all necessary medical devices in optimal condition after the completion of each mission. This will guarantee the aircraft's immediate readiness for its next use, prioritizing patient safety and the effectiveness of operations.

B. Scope
This protocol applies to all HEMS helicopters and their medical and technical personnel responsible for the verification, maintenance, and replenishment of medical equipment. Strict compliance with these guidelines is mandatory and essential for the continuity of emergency operations with the highest safety standards.

C. Replenishment Procedure

C.1. Start of the Process
The replenishment process for medical equipment must begin immediately after the helicopter returns to base following a mission. The assigned technical personnel must inspect and replenish the medical equipment, ensuring that all necessary materials are available for future operations.

C.2. Use of the Checklist
To guarantee the correct verification and replenishment of medical equipment, a structured checklist will be used, including all items that must be present, operational, and in good condition (see checklist in section 6). The checklist used to carry out this protocol has been designed to make this procedure as optimal as possible by grouping all the items in groups of related elements that will be nearby located in the cabin. The following steps detail the procedure for using the checklist:

1. **Assignment of Responsibilities:** The assigned personnel (medical and technical) are responsible for conducting the inspection using the checklist. Each member must be trained in handling medical equipment and the replenishment process.

2. **Sequential Review:** The checklist is designed in a sequential manner, allowing each item to be reviewed step by step. The personnel responsible must follow the predefined order of the list without skipping any items. This ensures that all essential components are systematically checked.

3. **Verification of Operational Status:** For each item on the checklist, the personnel must:

    - Check its physical condition and functionality.
    - Register whether the equipment is operational, non-operational, or needs replenishment.

    - Record observations if the equipment presents faults or requires maintenance.

4. **Replenishment or Replacement:** If any equipment needs to be replenished or replaced, it must be indicated on the checklist, and the responsible personnel must carry out the necessary corrective actions. The replenishment process must be completed within a maximum of three hours after the helicopter arrives back at base.

5. **Final Confirmation:** Once all checklist items have been reviewed and marked, the individual in charge of the inspection must sign the checklist, certifying that the process has been completed in accordance with the protocol. If non-operational equipment is found, it must be immediately reported to the superior authority so corrective actions can be taken.

C.3. Restrictions for Takeoff
The helicopter cannot take off for a new mission until the checklist is fully completed and signed, certifying that all medical equipment is in optimal condition. However, in cases of extreme emergency, the pilot in command may authorize takeoff under the following conditions:

- The helicopter is the only available HEMS.
- The missing or non-operational items are not essential for the current mission.

In such cases, the status of the missing equipment must be properly recorded, justifying the aircraft's departure without a fully completed checklist.

D. Recordkeeping and Documentation
All verification and replenishment procedures must be documented. Completed checklists must include signatures from both technical and medical personnel, as well as the pilot in command, to confirm that the aircraft is operational. These documents must be archived for future reference and internal audits.

E. Responsibilities
It is the responsibility of the HEMS operator to ensure full compliance with this protocol and within the established timeframes. Failure to follow these procedures will be subject to investigation and may result in corrective actions. Operational safety and regulatory compliance are priorities that must be adhered to at all times.

The checklist that must be printed and obligatorily used before each mission can be found in appendix E.3.

3.6.4 Cabin Interior

3.6.4.1 Seats design

The design of the passenger compartment seats has to ensure both functionality and adaptability for the diverse operational needs of a humanitarian helicopter. The seats are engineered to occupy the minimum possible space, maximizing the cabin's usable area for passengers and medical equipment. Despite their compact design, the seats adhere to ergonomic standards to provide adequate comfort and support for occupants during extended missions or turbulent flight conditions.

To facilitate rapid reconfiguration of the cabin, the seats are designed to be easily mountable and detachable. This is achieved through a simple mechanism located at the rear of the seats, consisting of secure hooks that attach to a fixed support mounted on the wall. This system not only simplifies the installation and removal process but also ensures the stability and safety of the seats during flight.

The ease of detachment is particularly advantageous for missions requiring swift transitions between passenger transport, medical evacuation, and cargo operations, making the design highly versatile and efficient.

The seat assembly is composed of three primary structural components: the backrest, the seat base, and a set of articulating links. The articulating links function as mechanical joints, connecting the backrest to the seat base and enabling controlled angular movement. This design allows the seat to fold and unfold efficiently, facilitating storage and rapid reconfiguration for operational flexibility. The assembly is secured using M30-diameter pins, which serve as pivotal axes for rotation. This rotational capability afforded by these pins allows for precise alignment and smooth articulation between the seat elements, maintaining structural stability throughout the adjustment range.

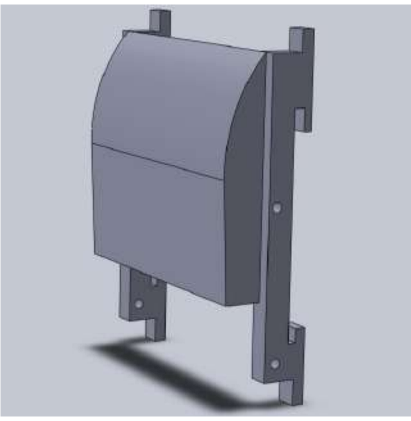


Figure 3.12: Backrest View

Figure 3.13: Seat Base View

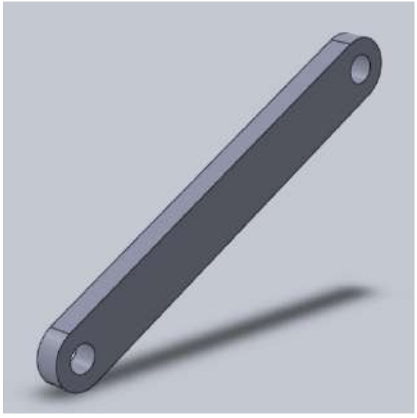


Figure 3.14: Links View

As can be observed in Figure 3.16, the rear section of the seat features the hooks previously mentioned, designed to slot into a retainer securely anchored to the fuselage. This mechanism ensures that the seat is firmly fixed in place during flight, providing both stability and safety.

On the other hand, regarding the safety belt, it has been decided to use the certified Sparco SFI/ NO FIA [108] belt (see Figure 3.17), a six-point harness designed to ensure proper assurance of the passenger to the seat during the flight.

Figure 3.15: Mounted Seat Front View

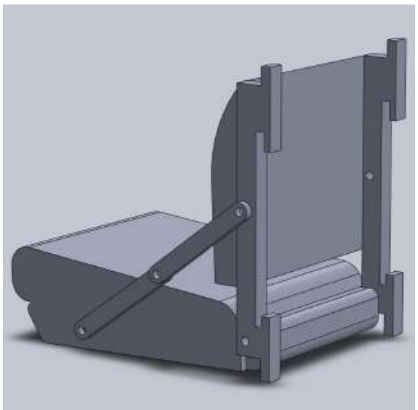


Figure 3.16: Mounted Seat Back View

Figure 3.17: Security Seatbelt View

Regarding the seating arrangement within the cabin, one seat will be positioned immediately adjacent to the stretcher, and this seat must be occupied at all times by the onboard medical professional.

Additionally, a minimum of two and up to a maximum of four seats will be installed based on the available space within the cabin, ensuring that they do not interfere with the medical professional's operational area. Consequently, the aircraft will be capable of transporting a maximum of five passengers (four in seats and one on the stretcher), in addition to one medical professional onboard. Should the need arise, a second medical professional may occupy one of the seats designated for passengers. This arrangement ensures flexibility in personnel allocation while maintaining operational efficiency and prioritizing patient care.

The configuration of seats and their placement must adhere strictly to safety and ergonomic standards, ensuring that all crew members and passengers are safely secured. Moreover, the seats allocated to medical personnel and passengers must allow for clear and unobstructed access to critical medical equipment and emergency exit routes. This configuration is designed to optimize the use of available space while maintaining the necessary operational standards for both medical care and flight safety.

3.6.4.2 Cabin Layout For Medical Operations

Medical equipment on board the helicopter must be positioned in accordance with Regulation (EU) 965/2012 [104], specifically CAT.OP.MPA.160 and CAT.OP.MPA.225, to ensure the safety of the crew, passengers, and equipment during all flight phases.

Firstly, as per CAT.OP.MPA.160, the operator must establish procedures to make sure that medical equipment, along with other cargo, is properly secured. It is essential that devices are placed in designated compartments to prevent movement, ensuring they do not obstruct aisles or emergency exits. Additionally, the equipment must be securely fastened to prevent injuries to occupants or damage to the equipment during maneuvers or turbulence.

Furthermore, regarding crew and passenger safety, CAT.OP.MPA.225 states that during takeoff and landing, as well as any phase of the flight deemed necessary by the commander, both crew members (medical personnel) and passengers (patients) must be properly secured with seatbelts or harnesses. This guarantees that in the event of abrupt movements of the helicopter, there is no risk of injury due to unsecured equipment. On the other hand medical supplies must be located in a way that warrants the correct execution of the potential clinical operations that can occur during the mission. This implies that all devices must be within reach of stretcher where the patient will lay and every utensil easily accessible to avoid time expenses in emergency situations. Taking all exposed into account the cabin layout has been designed based on the top view of the cabin.

In this representation, the primary elements to be installed inside the helicopter cabin during the operation of the medical assistance module are strategically arranged. The area designated for medical operations (highlighted in pink) must remain entirely free of obstructions to ensure the prevention of any incidents during critical procedures.

Additionally, a dedicated storage area (highlighted in green) is allocated for stowing passengers' personal belongings or minor payload that may be required during the mission. The seating arrangement has been planned to maintain unobstructed access to the exits in the event of an emergency.

As outlined in the previous section, should the mission require it, the two seats closest to the lateral doors can be removed. This adjustment creates additional space that can be utilized to enhance medical operations, improving accessibility and maneuverability within the cabin.

3.6.5 Cabin ambientation

(In this section, the distribution of the different cabin elements will be established to ensure the ambiance is suitable when it is crewed.)

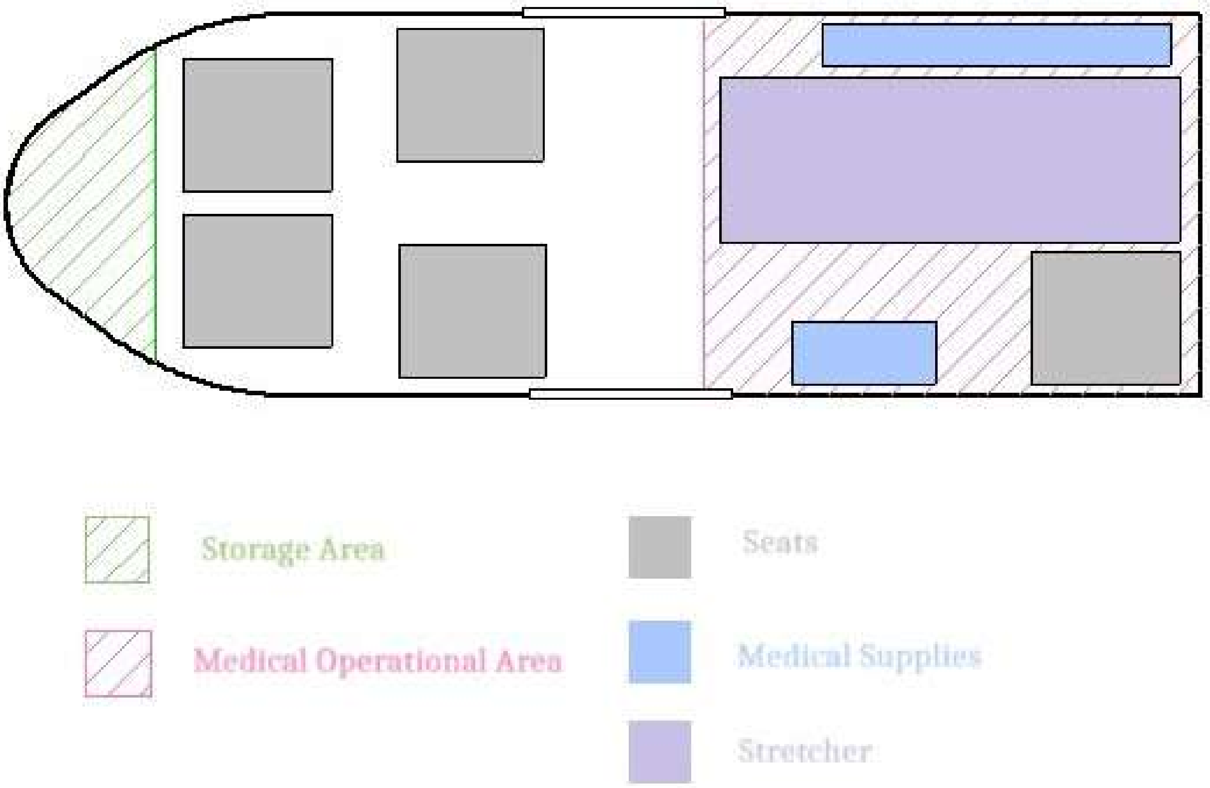


Figure 3.18: Cabin Layout Top View

3.6.6 Doors

(The design of the doors, as well as their structure, will be added soon.)

3.6.7 Operations

(Following sections are going to be used to ensure that previous sections are done properly to ensure the correct function)

3.6.7.1 Cargo procedures

3.6.7.2 Medical aid procedures

3.7 Avionics & Systems

3.7.1 Communications system

The UAV requires a communication system that can establish the following connections:

- Pilot - ATC: to transmit the navigation information required by the ATC and needed by the UAV.
- Pilot - UAV: to transmit the navigation information to the pilot and send back the desired control response.

The pilot - ATC connection is possible by the following 2 different channels [27]:

On the one hand it is possible to directly connect the ATC to the pilot. That implies that the facility must have direct visual connection with the ATC facility for radio transmission, or that the ATC facility must be physically connected to the control facility. The first option is a several limitation for the range of the UAV, because it will always have to be in contact with the same ATC. The second option is difficult because nowadays there is no such infrastructure.

On the other hand it is also possible to connect the UAV to the ATC with a conventional radio and then use pilot - UAV communication channel. In other words, we can connect the pilot and the ATC using the UAV as a switch. The main disadvantages of this option are that the communication will experience a delay due to the increase of steps in the process and that the pilot - UAV channel will be more charged. This are disadvantages that we can accept and therefore we will use choose this second channel for the pilot - ATC communication.

The pilot - UAV communication is only possible using radio waves. In the next section the general requirements for this communication will be studied.

3.7.1.1 General Requirements of the system

Table 3.19 shows the average data transmission requirements for a large UAV. By adding up the maximum requirements for control, navigation aids, voice relay, data relay, airborne weather radar and video transmission, it is found that a 10 kbps uplink and a 310 kbps downlink connection is needed.

There is no specific requirement for the latency, but it should be as short as possible.

3.7.1.2 Pilot - UAV satellite connection system

In general, the curvature of the Earth and natural occlusion difficult communication with terrestrial wireless networks. By comparison, satellite communication networks have an intrinsic capacity to provide service to wider areas in remote locations [109]. The characteristics of the satellite communication system will hardly depend on the choice of the satellite orbit, i.e Low Earth Orbiting (LEO) or Geosynchronous Equatorial Orbit (GEO) [110].

The most relevant characteristics for our application: latency and elevation angle are thoroughly analyzed for both possibilities in sections F.1 and F.2.

3.7.1.3 Definition of the system

After analyzing both GEO and LEO in sections F.1 and F.2, it is found that the latency of both cases is very similar.

PHASE OF FLIGHT AND OPERATING MODE (MANUAL OR AUTOMATIC)	COMMAND AND CONTROL				ATC RELAY			SENSE AND AVOID		
	CONTROL		NAVAIDS		VOICE RELAY	DATA RELAY		TARGET TRACKS	AIRBORNE WEATHER RADAR	VIDEO
	UPLINK (UL)	DOWNLINK (DL)	UL	DL	UL and DL	UL	DL	DL	DL	DL
MAXIMUM FOR ANY PHASE OF FLIGHT	4600	7600	670	1100	4800	50	60	9100	28 000	270 000
AVERAGE FOR MANUAL OPERATION	1700	3200	670	870	4800	24	31	9100	8700	270 000
AVERAGE FOR AUTOMATIC OPERATION	440	650	140	190	4800	24	31	9100	8700	270 000
OVERALL AVERAGE	690	1200	250	330	4800	24	31	9100	8700	270 000

Table 3.19: Estimated peak and average non-payload throughput requirements (bps) for a typical large UA over a 4 h flight. Table from [27] with information from [28] and [29].

Figure 3.19: IMS-350™ Integrated Mission System and Satcom for UAV. [7]

However, the behavior of the elevation angle is far different for both options. In the first one, the elevation angle changes from 90° near the equator to 0° before arriving to the north pole, and it is constant along time, as can be seen in section F.1. In the second option, the value of the minimum elevation angle moves between 8° (when the UAV is at the equator) to more than 20° (when the UAV is close to the north pole)), and is not constant in time: it can take any value between this minimum elevation angle and 90°.

Furthermore, due to the proximity of the satellite to the UAV, the power needed to communicate through this orbit is lower for the LEO [111].

Therefore, the option considered to be better suited for our project is the Iridium LEO constellation. The system chosen is the IMS-350™ (see figure 3.19) with the Certus 350 High Gain Antenna, that can provide up to 352 kbps uplink and up to 704 kbps downlink [112], specifications that fulfill the requirements defined in section 3.7.1.1.

3.7.1.4 Limitations of the system. Maps of minimum flying altitude

One way to quantify the limitations in the performance of the UAV due to a low elevation angle of the satellites at which it is connected is to draw a map of the minimum flying altitude above the ground. We have defined this minimum altitude as the lowest altitude at which the line of sight between the aircraft and the satellite is free of obstacles when the satellite is seen from the UAV position at a given elevation. As studied in section **??**, if the line of sight between the UAV and the satellite is obstructed, the signal loss is very significant (-6dB), and connectivity losses are possible.

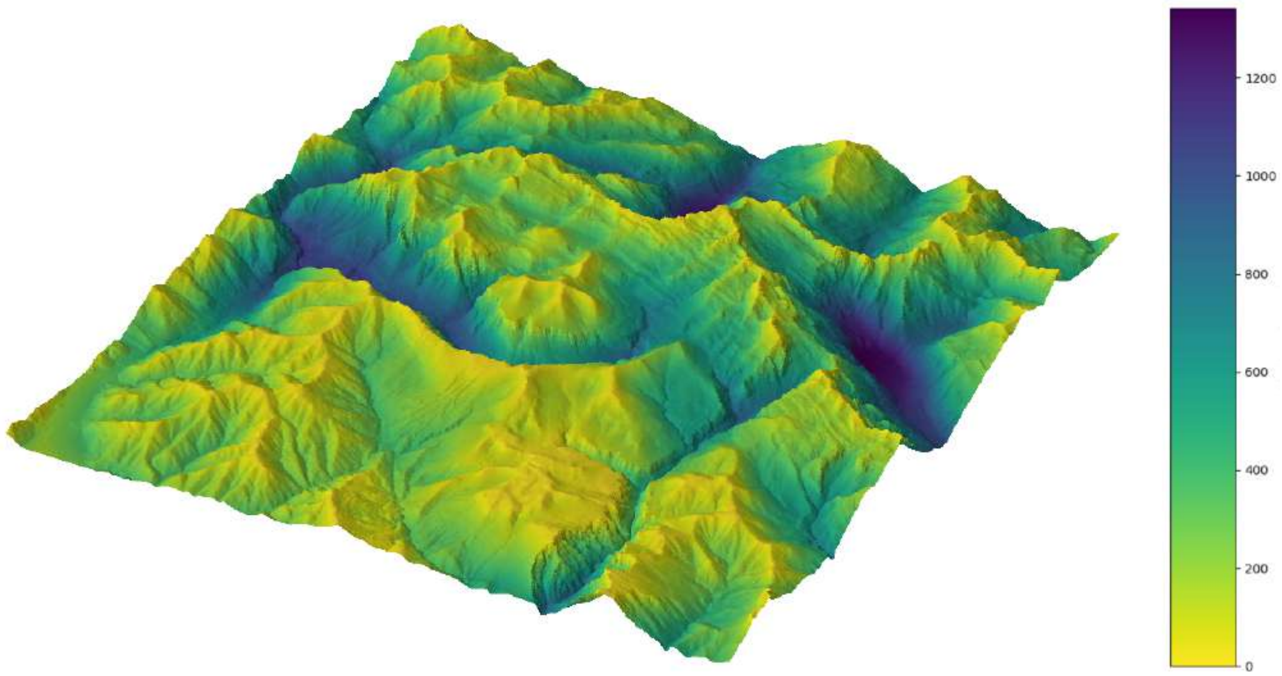


Figure 3.20: 3D surface of the altitude in Ordesa and Monte Perdido National Park in the worst-case scenario. The colors represent the minimum flying altitude in meters. See section F.3.

In section F.3 a software capable of finding the minimum flying altitude for a given region on the surface of the Earth is developed. Ordesa and Monte Perdido National Park, a challenging scenario due to its very steep mountains, is used as a real case scenario to demonstrate how the software works.

Figure 3.20 shows the minimum flying altitude for the worst-case scenario. In other words, it is the minimum altitude at which there is clear sky above the minimum elevation angle. It is a very conservative map, but it can be calculated very quickly, providing a first estimate of zones with easy access (summits and ridges) and more inaccessible ones (valleys).

Figure 3.21 shows the percentage of area at which the UAV can land without loosing connection as a function of time during a 2h interval. This 2h interval is relevant because the minimum flying altitude map is expected to be periodical with a 2h period as explained in section F.3.2.2. Therefore, the results of this figure can be extrapolated for any time interval. They show that the landing area moves between 75% and 100%, with windows in which more than 95% of the available landing area is reached.

Another example of the usage of this software can be seen in this video: `https://youtu.be/5O46whovyXk`. It shows the minimum flying altitude in a 10 minutes time evolution in Ordesa and Monte Perdido National Park. Therefore, it can be seen that using the software developed in section F.3, the mission's trajectory can be planned and optimized to ensure satellite coverage.

The main conclusions of the study in section F.3 indicate that the changing elevation of the Iridium satellites make the landing options in the worst-case scenario very limiting, but allows to cover almost all the area during some specific periods. Therefore, the best performance of the system will be achieved if the UAV flies at the minimum flying altitude of the worst-case scenario and waits until there is a favorable window to land.

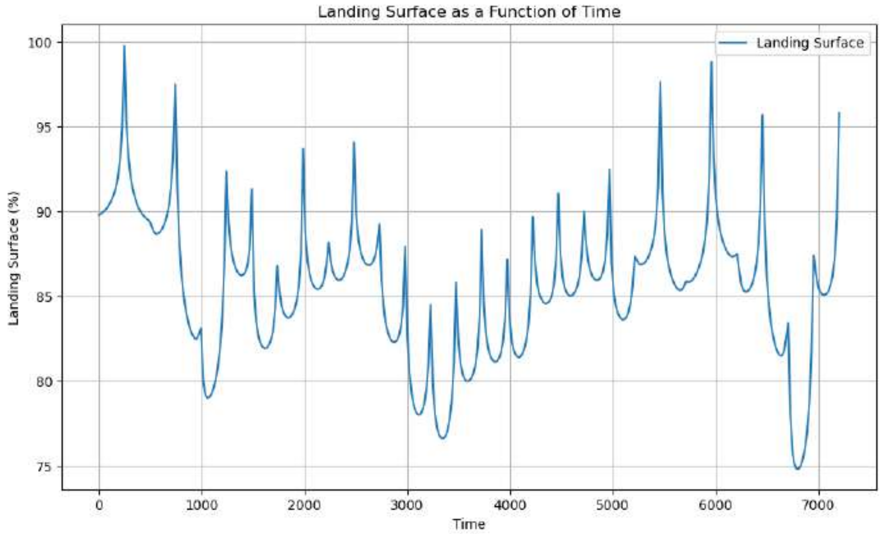


Figure 3.21: Landing surface percentage evolution for a 2h interval in Ordesa and Monte Perdido National Park.

3.7.2 Interference

The performance of the communications system can be significantly affected by interference. 2 types of interference phenomenon will be studied in detail:

- The interference between the Pilot-UAV channel and the UAV-ATC channel.
- The interference between the Pilot-UAV channel with itself.

3.7.2.0.1 Pilot-UAV and UAV-ATC channel interference.

The solution provided to connect the Pilot and the ATC implies using the UAV as a voice relay. Since both Pilot-UAV and UAV-ATC are radio channels, if they work at the same bandwidth there will be interference from one to the other. For example, if the UAV receives a voice signal from the ATC and with a certain delay it transmits the signal at the same frequency to the pilot, the transmitted message will overlap with the received message. One possible solution to this problem is to use different bandwidth for the Pilot - UAV channel, and another option is to transform the analog voice signal into a digital signal and transmit it a at a higher frequency. In our case, we will choose this second option.

3.7.2.0.2 Pilot-UAV self-interference.

When energy reaches the receiver of a telecommunications system by more of one path we talk about *multipaths*. This phenomenon usually arises due to the reflection of the electromagnetic wave in a surface. A multipath propagation is undesirable because signals from different paths arrive with a relative phase that makes them interfere.

For example, if there is an airplane flying at an altitude of $3km$ that tries to communicate with a satellite above it, there are two possible paths for the signal: the straight line and the reflection on the Earth surface. A simple calculation shows that the time delay of the reflected ray is $20\mu s$. This effects can cause intersymbol interference, but not a significant garbling [113]. Therefore, the effect can be solved by setting a bit length larger than this delay.

3.7.3 Weather conditions effect

Radio communications are based on the propagation of electromagnetic waves. The speed and losses of this propagation depend on the medium of transmission. The case of the air is a good approximation for a vacuum transmission, but, when transmission is done through other substances special considerations have to be taken into account. For example, the possibility of a successful transmission through clear sky is not the same that for a heavy rain condition.

In the study *Experimental Evaluation of Iridium Performance under Varying Weather Conditions and Elevation Angles* [114] this considerations are studied in a real scenario. The results found indicate that communications in heavy weather conditions are very difficult. For instance, the success rate for communication in thunderstorm is 4 times lower than for mainly clear conditions.

It has to be highlighted that the antenna used for the experiment [115] is far less powerful than the one chosen for the project . Nonetheless, this real case test indicates that once the communications system is assembled, it must be carefully checked on thunderstorm conditions.

To bypass this connectivity problem, a bad weather conditions mode will be implemented. This mode will be manually activated by the pilot if bad conditions are foreseen and it will be automatically activated when the system detects information loss. The functions of the mode are described below:

- The system selects the most relevant information of the aircraft. The choice of the relevant information can be done automatically, or it can be also done by the pilot and real-time updated.
- The system sends this important information to the pilot with redundancy to minimise the effect of information loss.
- The system sends the information from the pilot to the aircraft with redundancy. In this case, there is no need to select the information because as it can be seen comparing the results of section 3.7.1.1 and section 3.7.1.3, the communication system can transmit much more information in the uplink direction than the necessary.

3.7.4 Global Navigation Satellite System

A precise information about the global position of the aircraft is necessary to predict if there will be an obstacle in the trajectory: mountains, other aircrafts, buildings... Therefore, a system that provides this information is very usefull for an aircraft, and it is specially needed in a a large UAV. Due to its reliability, global coverage and precision, the Global Navigation Satellite System (GNSS) is the primary system used to get this information [116]. There are four GNSS systems available: GPS, GLONASS, BeiDou and Galileo.

The IMS-350 chosen for the communication to the airplane (section 3.7.1.3) supports a GPS interface [112]. Therefore, choosing an accessory antenna of the IMS-350 to provide GPS information assures compatibility between the equipments and efficiency of the whole system. The option chosen is the Iridium/GPS Low Gain Antenna [112].

3.7.5 Terrain mapping systems

3.7.5.1 Overview of the system

RADAR systems for object detection are commonly found in aircraft, since it is used for coordination of air traffic and collision between aircraft mid-air avoidance. This system is used because it provides a superior performance in long distance detecting range and reliability in front of bad weather conditions. That is the reason why our UAV surely will have a RADAR system. However, our UAV has two very different operation regimes, which are the route between the place where the UAV is stationed until the place where it is needed and the landing. The terrain mapping system presented here is aimed at that second operating regime, where the velocity of the aircraft and the height above the ground are reduced in comparison with the first regime. Therefore, the RADAR system might not provide the level of accuracy that is needed in order to land safely.

Our UAV will be provided with several cameras to enable the pilot to evaluate the environment in which the UAV will be flying on. However it has to be considered that if the pilot makes decisions based only in what he or she is able to see through these cameras, some safety issues might arise. As the UAV will have to navigate across areas which are most probably going to have an irregular surface, we need to have a terrain mapping system in order to gain awareness of the UAV environment in places where it can be difficult to visually assess the situation. These systems can be used to assess the distance to the ground the UAV is flying. Moreover, these systems can also be used in order to search for places where potential victims may be.

All things considered, we propose a mixed system that consists of two basic parts. First, we will incorporate cameras in order to provide an image of the scene the UAV is viewing. This cameras will be the RGB type in order to obtain texture-based and color-based information.They have been selected as these cameras provide good and efficient results for the majority of the conditions in which the UAV will fly. However, they have limitations when it comes to bad weather conditions and other factors that might reduce visibility. To address these limitations, which can cause important safety issues, a LiDAR system will be incorporated and will form the second part of the mixed system. In the following sections, both systems will be described, as well as their interaction. This system will also be used in the landing assistance system, mainly the RGB cameras part. Owing to this reason, their functioning will be explained more in detail in the corresponding section.

For comparison, we can see in figure 3.22 how would the pilot see the information received from the LiDAR device.

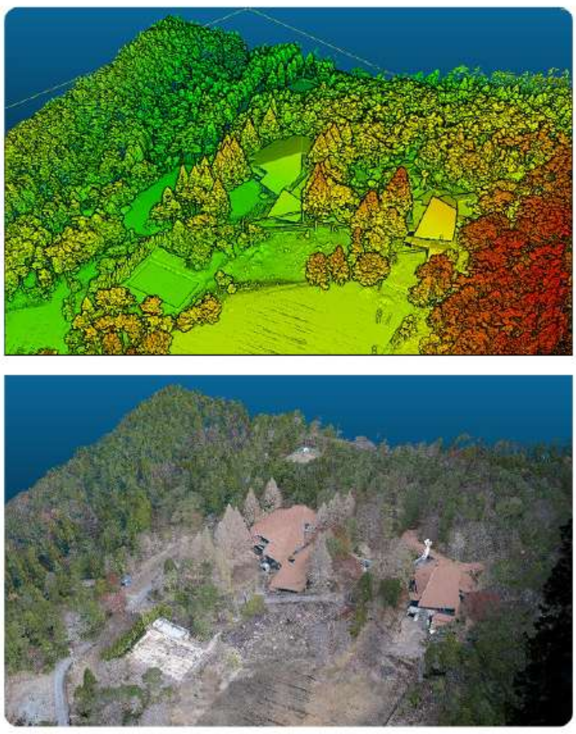


Figure 3.22: LiDAR data. Extracted from [8]

3.7.5.2 LiDAR

The LiDAR system works under the concept that the distance between the device and any point in the terrain can be calculated following simple steps. First, the system emits light, then waits until this beam reaches the ground and bounces back, and finally the device is able to collect this signal and calculate the time difference between the emission and the recovery. All the characteristics that are associated with the transmitted light will be labeled TX, whereas the ones associated with the received signal (that is, the transmitted signal after it bounces back) will be labeled RX.

The power received by can be calculated as:

$$P_{RX} = P_{in} \cdot \eta_{TX} \cdot \eta_{TX} \cdot \frac{\rho A_{RX}}{4\pi R^2} \tag{3.11}$$

where η_{TX} and η_{TX} represent the efficiency of both devices (transmitter and receiver), ρ is the reflectivity of the object, A_{RX} is the area of the receiver and R the distance to the object.

It is worth bearing in mind that the higher the area of the receiver is, the more distance it can measure. It should also be mentioned that P_{in} is limited for eye safety reasons to 5mW.

There are three main configurations in which this calculation can be done. The first one is pulsed TOF (time of flight). It calculates the distance to the target by multiplying the time between the transmitted and received signal and the speed of light, dividing it by two. The second one is AMCW (amplitude-modulated continuous wave). Instead of calculating the elapsed time between signals, it calculates the phase difference between both. The last configuration is FMCW (frequency-modulated continuous wave). This configuration obtains information from the beat signal, which is a signal that derives from the interaction of the transmitted and received signals (interaction pattern).

By applying this last method, some advantages over the other configurations (mainly the first one presented) are acquired. They include higher depth resolution, a lower peak power on the transmitted beam and decoupling from other LiDAR systems nearby among others.

Besides, using the FMCW method we can also obtain information on the velocity of the object we are detecting. This feature is of our interest, since it means that not only the LiDAR system can give the pilot information on the layout of the terrain, but will be also able to detect whether there is any object moving in the vicinity of the UAV, such as objects that may be at risk of colliding with the UAV or it can even give a hint on where the people that need help are.

Aside from the different configurations in which LiDAR can work, we can identify two groups of LiDAR that are of our interest. They are the solid state LiDAR and the nanophotonics-based LiDAR. We will review some of them and finally decide using the OWA method which is the best for our UAV.

It is worth mentioning that LiDAR traditionally has been used for terrain recognition and 3D mapping, but the data obtained had to be thoroughly processed before an image could be obtained. However, the research and testing of systems which can process LiDAR data in real time has led us to believe that the implementation of this system is optimal, since the pilot will be able to access this data while the UAV is flying. More information on the problems of processing LiDAR real-time and the algorithms that makes it possible can be found in [117], [118] and [119].

3.7.5.2.1 Solid state LiDAR

Three different solid state LiDAR devices will be reviewed: flash-based and scanning-based (MEMS-based and OPA-based) LiDAR. Following, a brief description of each device will be provided, as well as an overview of the different advantges and disadvantages each device offers.

Flash-based LiDAR

First, optical pulses are provided by the laser (532nm). These pulses are mainly reflected in the mirror that is placed immediately afterwards and then are directed to the target. A small portion of these pulses are absorbed at the PD in order to activate a system which activates the Pockels cell after some time, τ. Then, the pulses that bounce back from the target return and are detected by the MCCD. The information is obtained from the polarization state of the returning signal.

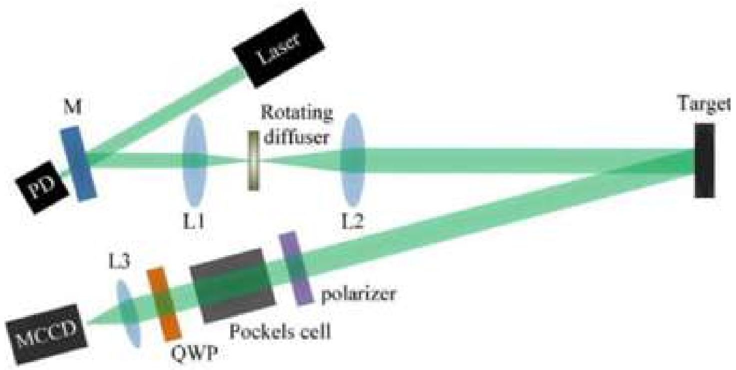


Figure 3.23: Flash-based LiDAR outline. Extracted from [9]

Some of the main advantages are listed below:

- It can capture the entire scene in a single shot, which means that the pilot will be able to evaluate the situation fast.
- Long-term reliability, which ensures proper functioning of the system throughout its operating life.
- High data acquisition rate, that means that it is capable of providing more precise images.

Some of the main disadvantages are listed below:

- Its resolution limited by the physical size of PD arrays.
- Requires optical pulse with high power. As we have mentioned before, the power of the emitter is limited for eye safety issues.
- It needs a detector with high sensitivity.

(MEMS)- based LiDAR

Microelectromechanical system LiDAR devices (MEMS) are often used in small UAVs, so they are lightweight. They also have a sensing distance that can exceed 200m. They can have two configurations, 1D and 2D, which means that the laser scans in one direction or both for the vertical and horizontal direction.

Some of the main advantages are listed below:

- Compact and lightweight. It will not add significant weight to the aircraft.
- High signal-to-noise ratio (compared with flash type LiDAR), which means that it will be less affected by perturbations.

- Lower cost than the other options

Some of the main disadvantages are listed below:

- Needs mechanical moving parts, which can degrade in the long-term
- Low angular resolution

(OPA)-based LiDAR Optical phased array (OPA) based LiDAR has an integrated photonics platform integrated on a chip that includes all the devices it needs to make the measurements, such as the laser and the optical filters. Its main advantage over the MEMS device is that it doesn't require moving parts, so it has a greater reliability. Its configuration makes it easier to be integrated with electronic circuits or other devices. It also permits the FMCW configuration mode, which is not possible in the previous devices shown. Some of these devices (the ones that don't have a phase shifter) have been proven to be able to have a sensing distance of 185m.

Some of the main advantages are listed below:

- Compact platform (can be miniaturized to the chip scale). It will not affect the performance of the UAV.
- Low manufacturing cost
- High signal-to-noise ratio (compared with flash type LiDAR), which means that it will be less affected by perturbations.

3.7.5.2.2 Nanophotonics-Based LiDAR

More recently, nanophotonics-based LiDAR devices have been developed. These devices work with structures which are smaller than the wavelength used (sub wavelength dimensions). This enables them to reach an extreme resolution, of the order of magnitude of nm. There are several of these devices that could be presented, but for our UAV, the ones that are of most interest are the following:

Optical switches: It is based on the flash type of sensors, but with multiple emitters, and the emission is switched between them (hence the name). This new configuration makes it possible to reduce the power of the laser, which is a great advantage with respect to its solid-state counterpart since, as mentioned before, the high power needed was a problem. That also makes the sensing range increase.

Frequency comb (OFC): These kind of LiDAR devices have proven a high precision in measuring the velocity at which objects move. A frequency comb is a set of equally distanced frequencies of known value [120]. When they form a beat signal with the frequencies that bounce back from the object, the unknown frequencies are much more precisely measured.

More information about these devices can be found in [121] and [9].

3.7.5.2.3 Comparison and choice

To use the OWA decision method, we first need to establish which are the best candidates for each type of LiDAR. In figures 3.24, 3.26, 3.25 and 3.27, we can find in each row a different device using the working principles that we have presented before (flash-based, MEMS, OPA, optical switches and frequency comb). We can directly discard the ones that have a range inferior to 60m, because they would be of no use to our UAV.

Sensing approach	Wavelength	Sensing distance	Pixel array	Remarks	Reference/Year
TOF	532 nm	16 m (5.2 mm range precision)	1024 × 1024 for micro-polarizer CCD (MCCD)	A Pockels cell is used to modulate light polarization state with time. Measured light intensity can be used to calculate the polarization state and hence the range.	[19] / 2016
TOF	532 nm	17 m (<4 mm precision)	1024 × 1024 (CCD, with pixel size: 7.4 µm)	A polarization modulator is used with a low bandwidth detector. Distance can be derived from intensity information.	[37] / 2017
TOF	905 nm	N.A.	2 × 192	Single-photon avalanche diode (SPAD)-based sensor array, fabricated in a 0.35 µm CMOS process. Ambient light rejection implemented for improved measurement quality.	[38] / 2018
TOF	637 nm	50 m (8.8 cm accuracy)	252 × 144	SPAD-based sensor array, fabricated on 180 nm CMOS technology platform.	[18] / 2019
TOF	671 nm	Up to 50 m (0.17 m accuracy)	256 × 256/64 × 64	SPAD-based sensor array, fabricated on 90 nm 1P4M/40 nm 1P8M process.	[39] / 2019
TOF	905 nm	2–20 m (with precision up to 7 cm)	32 × 32	SPAD-based sensor array, fabricated on 180 nm CMOS technology platform.	[40] / 2021
TOF	780 nm	100 m (0.07 m accuracy)	256 × 128	SPAD-based sensor array, fabricated on 45 nm CMOS technology platform.	[41] / 2021

Figure 3.24: Flash-based LiDAR devices. Extracted from [9]

Sensing approach	Wavelength	Sensing distance	Measured velocity (v)	TX & RX structure	Reference/Year
FMCW	Around 1550 nm	0.5–2 m (edge coupler without scanning, 20 mm resolution), 0.2–0.5 m (OPA with 2D scanning)	75–300 mm s^{-1} (edge coupler)	Edge coupler (light collimated with 20× objective), 1D OPA	[23] / 2017
FMCW	C+L band (tunable laser)	185 m (1D scanning without phase shifter) and 6–12 m (2D scanning with phase shifter)	N.A. (demonstrate velocity sensing for a spinning target)	1D OPA (512 elements)	[24] / 2019
FMCW	1550 nm	10–40 cm (1D scanning without phase shifter, 3.3 cm resolution)	N.A.	1D OPA (128 elements)	[73] / 2019
TOF	Around 1300 nm	10 m (2D scanning, with precision of <8 cm)	N.A.	TX: 1D OPA (32 elements)	[14] / 2020
TOF	940 nm	12 m maximum measurable range in indoor environment	N.A.	TX: 1D OPA with phase shifter and liquid crystal	[25] / 2021

Figure 3.25: OPA LiDAR devices. Extracted from [9]

Sensing approach	Mirror aperture	Wavelength	Sensing distance	Scanning dimension	Scanning angle	Scanning speed	Reference/Year
TOF	N.A.	N.A.	Target: >200 m (20 cm resolution)	1D	$\pm 15^\circ$	N.A. (LiDAR with 20 frame per second)	[21] / 2019
N.A. (mirror only)	2 mm × 4 mm	Visible wavelength (red)	N.A.	1D	$>\pm 45^\circ$	1.5 kHz	[43] / 2020
TOF	5 mm (diameter)	Visible wavelength	2 m	2D	$\pm 8^\circ$	N.A. (fast axis: few kHz)	[22] / 2016
N.A. (mirror only)	N.A.	Visible wavelength (red)	N.A.	2D	45.3°, 42.6° for two axes	710 Hz (7.5 Vac), 997 Hz (5 Vac)	[44] / 2016
N.A. (mirror only)	2 mm (diameter)	Visible wavelength (red)	N.A.	2D	41.9°, 40.3° for two axes	0.95 kHz, 1.46 kHz for two axes	[45] / 2017
N.A. (mirror only)	12 mm (diameter)	Visible wavelength (green)	N.A.	2D (micromirror + rotor)	26°	1.24 kHz for microscanning mirror	[46] / 2017
TOF	2 mm (diameter)	905 nm	80–250 cm (7.2 cm resolution)	2D	$\pm 2.8^\circ$	N.A. (LiDAR with 41 Hz measurement rate)	[20] / 2018
TOF	0.7 mm × 0.7 mm	905 nm	N.A. (3.6 cm range resolution)	2D	17° ($\pm$ 8.5°)	2.2 kHz	[47] / 2018
N.A. (mirror only)	2 mm × 2.5 mm	Visible wavelength (red)	N.A. (2D scan pattern at distance of 7 m)	2D	15° × 12°	0.7 kHz (rotational scanning resonant mode)	[48] / 2019
TOF	1.2 mm × 1.4 mm	905 nm	35 cm (1.5 cm depth accuracy at 30 cm)	2D	9° × 8°	N.A. (LiDAR frame rate: 6.25 fps)	[10] / 2021

Figure 3.26: MEMS LiDAR devices. Extracted from [9]

Nanophotonics device	Sensing approach	Wavelength	Sensing distance	Measured velocity (v)	Reference/Year
Microdisk resonator (for OFC generation)	TOF	1520 to 1580 nm	26 m (without scanning, with $\pm$0.466 m uncertainty)	N.A.	[30] / 2018
Microring resonator (for OFC generation)	TOF	1530 to 1620 nm	Up to 2 mm (spatial resolution of 2 μm, without scanning, object with moving speed of 150 m s^{-1})	N.A.	[1] / 2018
Optical switches (for sequential illumination) and PDs	FMCW	N.A. (C or L-band based on laser source)	Up to 60 m (single channel), 9.5 m (eight channels for spatial scanning), 28 cm resolution limited by modulation bandwidth	5 km h^{-1} (target walking at 30 m)	[29] / 2018
Racetrack resonator and bus waveguide with an inverse-designed reflector	TOF	Around 1550 nm	Up to 30 m (without scanning)	N.A.	[81] / 2020
Microring resonator (for OFC generation)	FMCW	1500 to 1630 nm OFC span (1530-1560 nm used for LiDAR sensing)	10 m (without scanning, with <1 cm measurement imprecision), 4–7 m (with 1D scanning mirror and spectrally dispersed comb lines)	$\pm$10 m s^{-1}	[2] / 2020
Optical switches (for sequential illumination)	TOF	1550 nm	4.8–7.5 m (beam steering by switching light to a 2D fiber array, range error: 2 cm)	N.A.	[82] / 2020
Metasurface-based SLM (for beam steering)	TOF	1560 nm	Up to 10 m (single-point measurement, with 4 cm accuracy), 2.4–4.7 m (with 2D beam steering)	N.A.	[33] / 2021
Optical switches (for sequential illumination) and PD array	FMCW	1550 nm	17 m (1.8 mm precision, target with 85% reflectance); 75 m (3.1 mm precision, target with 30% reflectance)	$\pm$10 mm s^{-1}	[32] / 2021
Optical switches (for sequential illumination)	TOF	1544–1562 nm	1.08 and 11.22 m (multiple wavelengths with 1D beam steering by thermal switching)	N.A.	[83] / 2021
Optical switches (for sequential illumination)	FMCW	1550 nm	0.8, 5, and 10 m (with 2D scanning, 1.7 cm distance resolution)	N.A.	[84] / 2022

Figure 3.27: Nanophotonics LiDAR devices. Extracted from [9]

That leaves five possible devices which can be seen in the following table.

	Distance measured (m)	Resolution (m)	Maturity (years)	Sensing aproach
Flash	100	0.07	3	TOF
MEMS	200	0.2	5	TOF
OPA	185	-	5	FMCW
Optical swich (1)	60	0.28	6	FMCW
Optical swich (2)	75	0.0031	3	FMCW

Then, we need to establish which features are interesting for our UAV and their relative weight depending on their importance. We can find it in the following table.

- Distance measured : It is very important that we have a wide range of distance in which we can measure, because the longer the range is, the more information the pilot will have and therefore he or she will be able to make better decisions.
- Resolution : We need as much resolution as possible to be able to detect possible hazardous spots to land. However, it is not a main concern, since the LiDAR resolution is good enough for our purposes.
- Maturity : As we are in the aerospace sector, we want the systems to be mature enough to guarantee their performance and not to find unexpected problems.
- Sensing approach : We have initially remarked that there are some sensing approaches that would be better than others since they have features that interest us (FMCW). Owing to this, sensing approach has been qualified as: TOF = 1, AMCW = 3; FMCW = 5.

Feature	Importance
Distance measured	70
Resolution	30
Maturity	50
Sensing aproach	60

The first problem we encounter is that we don't have resolution data for the OPA model. Owing to this, we have applied the method assuming that the OPA has the worst resolution among the different models and it has been repeated without considering the resolution criterion. The results are the following:

Device	OWA result
Flash	0.365
MEMS	0,632
OPA	0,794
Optical swich (1)	0,627
Optical swich (2)	0,571

Table 3.20: OWA considering OPA has the worst resolution (0.3m)

Device	OWA result
Flash	0,289
MEMS	0,659
OPA	0,893
Optical swich (1)	0,689
Optical swich (2)	0,500

Table 3.21: OWA without considering the resolution criterion

We can see that in both cases, the one that gets more OWA grade is the OPA-based device, with a great distance from the runner-up, so this is the one we will use.

3.7.5.3 RGB camera and LiDAR coupling

In order to provide the best result possible, the two devices are coupled. The aim is that each device compensates for the disadvantages of the other, an therefore provide a robust result.

LiDAR systems are active, as they provide the laser that they use to calculate the distances, which means that they are not as influenced on external factors such as bad weather conditions. On the other hand, RGB cameras use the external light, so they don't work well in situations in which it is diminished. The LiDAR system has also a more accurate spatial coordinates estimation than RGB cameras. However, RGB cameras can extract information from the picture itself (color, texture), whereas LiDAR can not, and are also able to identify objects in these images.

More information on the algorithm necessary to fuse this two sensors can be found in [122].

3.7.6 Landing assistance systems

Landing is the most critical part of the UAV operation, and therefore it can't be left to the pilot's judgement only. That's what motivates the incorporation of a landing assistance system, which will enable an easier and safer landing.

Two main parts can be distinguished in every landing assistance system. the first one is the responsible of pointing the exact spot where the UAV must land (the designation of this spot will be left at the pilot's judgement). They are the laser guided systems. Secondly, there are the obstacle avoidance systems, which ensure that the landing is possible without any accidents. The implementation of both systems will be explained in the next sections.

3.7.6.1 Landing spot recognition

In this section it will be described the procedure which will be followed in order to establish the landing spot. There are several options ([123]):

- Based on the images received, the pilot pinpoints the exact location of the landing
- The pilot chooses the landing spot based on GPS information
- Based on the images captured by the RGB camera, there is an algorithm that recognizes a certain spot as possible to land

In our UAV, the three of the options mentioned come together. Firstly, the pilot has to introduce an approximate location of the landing spot, based mainly on the information about the location of the people that have to be rescued. When the UAV is in this zone, it will use the LiDAR+RGB system to look for the people that need help. Next, the algorithm used for terrain identification and object classification (the latter will be explained in the following section) will present the pilot landing spot possibilities. Finally, the pilot will asses the situation and make the final decision.

When this landing site is found, the UAV will begin the landing operation. In [124] and [125], it can be found some algorithm possibilities that the UAV can use in order to land precisely on the designated spot. An interesting algorithm for the UAV is found in [126], as its algorithm has proven in real life tests to be reliable even with wind disturbances. However, some aspects of this last algorithm should be more carefully considered and modified (because it uses a ground station for control), but it is out of the scope of the project. In figure 3.28 it can be seen schematically how a basic algorithm could look like.

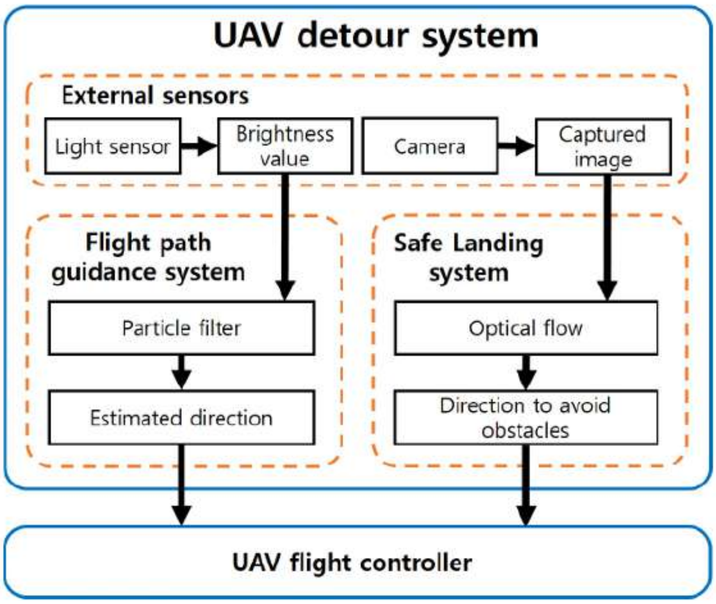


Figure 3.28: Proposed basic landing algorithm. Extracted from [10]

3.7.6.2 Obstacle avoidance systems

The state of the art in this field is huge. However, as we used a LiDAR+RGB camera system for terrain mapping systems, we will also use this system to provide the obstacle avoidance.

One of the main challenges that RGB cameras present when given the task of identifying the objects that may appear beyond them is 3D reconstruction. In our case, it is not a problem, since LiDAR is the system responsible of this aspect. The main function of the camera is to identify objects in the image itself in order to be able to classify the different objects, which are taken into account to perform the landing. The LiDAR system excels at 3D reconstruction (we notice that there are no range limitations that may affect the LiDAR system during this operation), and therefore the RGB camera would use superpose this information to the one that collects and be able to identify the objects that appear in the image.

This data identification process is commonly done using the dense correspondence technique [**?**]. The parameters that this method uses are the color that represents gradients and local curvature, among others, and an estimation of the distance to the object. Then, the compatibility criteria decides which model adjusts better to the data given and provides an answer. That said, nowadays, these more traditional techniques are being surpassed by Deep Learning techniques, which provide much faster results (more information about these techniques in [122]). In our case, we consider that this latter techniques are better suited, since we are interested in the speed at which the alerts would be sent.

Nevertheless, their use would require more involvement from the pilot's side, as he/she would have to verify the data given by the algorithm.

Finally, as it has been pointed out, this object recognition system is not only used for landing, but can also be used as an alert system when the camera detects some objects that could be previously labeled as dangerous.

3.7.6.3 On autonomy

In several of the UAVs that have these kind of landing assistance systems, the autonomous performance of the operation was the main objective. However, it is out of the scope of this project. What we can say is that even though we can not assure that our system permits a totally autonomous landing, it is able to perform the operation with minimal pilot supervision, which means that it can be performed despite some communication issues that may appear.

The fact that this landing is performed semi-autonomously also provides robustness in the system, because it has a double-check, that means, the on-board computer performs the calculations and the pilot double-checks in case there is some sort of malfunction. That provides a safer procedure than if it had to be performed mainly by the pilot.

3.7.7 Pilot interface

In this section it will be established how the UAV will be controlled. There are mainly two parts, the operations that will be performed by the pilot and the operations that will be performed by typical control systems.

As the operations performed by the UAV will be out of the pilot's direct sight, our project proposes an interface that will basically be the same that can be found in any helicopter flight simulator, but instead of simulating the data, it will be transmitted from the various sensors the UAV will include.

3.7.7.1 Necessary data

First we need to establish the different data that the pilot needs to see in the interface. Based on the analysis in the Communications section, it is concluded that the total data transmission rate required from the UAV to the ground via a LEO satellite link is approximately 300 kbps.

This estimate encompasses all data transmitted from the aircraft to the ground, which will be processed to provide a fully realistic piloting experience in the simulator. The data to be transmitted includes:

1. **Flight Control Data**:
   - **Rotor RPM**: Monitoring the main and tail rotor speeds.
   - **Blade Pitch Angles**: Collective mode (all of the blades with the same value), cyclic (specific value for each blade to roll and pitch), and anti-torque pedal inputs (to control the tail rotor and therefore the yaw).
   - **Control Surfaces Positions**: For horizontal stabilizers.
2. **Navigation Data**:
   - **Attitude (Pitch, Roll, Yaw)**: For real-time visualization of the UAV's orientation.
   - **Position and Velocity (GPS Coordinates)**: Accurate GPS data for tracking and ground speed.
   - **Altitude (AGL and MSL)**: Altitude data relative to ground level and mean sea level.

- **Heading**: Current aircraft heading to guide navigation.

3. **Airframe State Data**:
   - **Velocity (3D)**: Linear velocity in the x, y, and z axes (airspeed).
   - **Acceleration (3D)**: Including vertical acceleration (G-forces).
   - **Angular Rates**: Rates of change for pitch, roll, and yaw.

4. **Engine and Powerplant Data**:
   - **Engine RPM**: Real-time engine speeds and temperature.
   - **Fuel Level**: Continuous updates to ensure a realistic fuel consumption experience.
   - **Power Consumption**: For electrical components.

5. **Sensor Data**:
   - **Inertial Measurement Unit (IMU) Data**: Accelerometers, gyroscopes, and magnetometers.
   - **Wind Speed and Direction**: For environmental feedback to the simulator.
   - **Weather and Atmospheric Data**: Temperature, humidity, pressure, etc.

6. **Camera and Visual Feedback**:
   - **Forward-looking and Surround View Cameras**: To give the pilot a realistic visual experience.
   - **LiDAR and RGB camera**: For better terrain recognition

7. **Communication and Status Information**:
   - **Telemetry Data**: System health and status messages.
   - **Communications Status**: Signal quality, latency, and link integrity.
   - **Mission Information**: Waypoints, target locations, and dynamic mission updates.

8. **Environmental Awareness Data**:
   - **Radar Data**: For obstacle detection system and HTCAS (Helicopter Traffic Collision Avoidance System).

9. **Voice Communication for ATC**:
   - **ATC Voice Transmission**: To ensure that the remote pilot can interact with ATC in the same manner as traditional piloted aircraft, providing instructions, clearances, or addressing emergencies.

3.7.7.2 Control system

In a traditional helicopter, all sensor data, pilot inputs, and environmental feedback are collected and processed by an onboard flight control computer. This onboard system interprets this data to generate control outputs and alerts for the pilot, and visual indicators (like artificial horizon, speed, or engine status) are displayed on cockpit screens. The processed data is used to command actuators, such as adjusting the rotor blade angles, controlling thrust, and stabilizing the aircraft.

The advantages of onboard processing include:

1. **Real-time decision-making**: The system quickly interprets and acts on incoming data, which is critical for maintaining stability and responding to emergencies.

2. **Low data transmission load**: Since only critical data is transmitted externally (for example, for monitoring by ground control or ATC), the transmission requirements remain lower.

The case of our UAV is slightly different than a traditional helicopter and therefore the onboard processing of sensor data needs adaptation since the pilot operates from a ground-based simulator. This scenario presents two major alternatives:

Onboard Data Processing Approach: Collect and process all available data onboard using a lightweight flight computer. The processed information is then transmitted via a LEO satellite link to the simulator on the ground. Images, video, and voice communications would still need to be transmitted raw due to their nature. This approach mimics the traditional flight control setup in terms of onboard processing, with the difference being that the pilot receives visual and control signals remotely.

Ground-Based Data Processing Approach: Transmit all sensor data raw from the UAV to the ground via the LEO satellite link. The flight control computer and processing would reside entirely on the ground. This configuration means that the ground system would receive direct and unprocessed sensor data, which would then convert into meaningful information in real-time.

In terms of safety, the onboard processing approach offers localized decision-making capabilities even if there are delays or disruptions in satellite communication. In an emergency, real-time data analysis onboard allows the UAV to make critical adjustments autonomously, such as activating the connectivity recovery procedures. The onboard flight computer acts as a failsafe, mitigating the risks associated with latency or data loss. The ground-based approach presents greater safety risks in case of communication failures or latency issues. If raw data transmission fails or is delayed, the ground simulator would lack crucial, timely information, and the UAV could become unstable or unresponsive to pilot commands.

Onboard processing is more data-efficient, as only critical or processed data needs to be transmitted,reducing the load on the satellite link. Raw video and voice would still require a substantial bandwidth, but transmitting all collected data raw would impose a much higher burden on communication channels. Transmitting raw data, while it might provide the simulator with the highest level of detail, could overwhelm the satellite link due to the sheer volume. A satellite-based communication system with limited bandwidth would struggle with continuous high-volume transmission of raw sensor data, increasing costs and reducing the efficiency of real-time responses.

Based on these considerations, it is safer and more efficient to adopt the onboard data processing approach. This approach aligns closely with traditional flight control principles and mitigates the risks of communication delays or data loss. The onboard system can autonomously handle minor corrective actions, while the simulator on the ground can rely on processed data streams to build the piloting experience. Moreover, since one of the main limitations that our UAV has in terms of communication is the data that can be transmitted to the ground station, it has been considered that the more data that can be proccesed onboard the better. That, not only will reduce the load of transmission, but it gives a greater degree of autonomy on the UAV. For all of these reasons, our UAV will include a complex control system, with pilot supervision insetad of the alternative of proccessing the data on the ground.

3.7.7.3 Adaptation of the flight simulator

A helicopter flight simulator is a highly sophisticated system designed to emulate the real-world dynamics and behavior of a helicopter. It typically has the following elements:

- **Control Interface**: Replicates the physical cockpit controls of a helicopter, including the cyclic, collective, anti-torque pedals, and additional instruments like throttle and trim settings.
- **Visual Systems**: Provides a realistic, 3D, representation of the external environment. This can include terrain, weather conditions, other aircraft, and obstacles.
- **Motion Platform**: To create the physical sensations associated with helicopter movements, enhancing realism.
- **Flight Model**: Simulators run advanced algorithms and models that mimic helicopter aerodynamics, control responses, and environmental interactions. These models are based on both theoretical data and real-world flight tests and in this case will be based upon a H175 simulator.
- **Data Inputs**: In traditional training scenarios, simulators work with preset or simulated inputs to represent different conditions and responses.

In our case, the UAV will include all these features, with some diferences. First, all the simulated data will be replaced by the data that the UAV collects (as it has been listed in previous sections). Secondly, the visual systems will incorporate the data collected by the RGB camera + LiDAR system, and the alert system that recognizes potential threats to the aircraft.

3.7.7.4 Transition to real-time data from the UAV

Some considerations need to be taken into account in order to correctly adapt the simulator from working with preset data to real-time data. These include:

1. **Real-Time Data Processing Integration**: The simulator will need a system to interpret and process incoming data streams (such as IMU readings, GPS positions, engine status, and control surface positions) in real-time. This involves enhancing its input systems to connect directly with the satellite communication link.
2. **Latency Compensation and Data Interpolation**: Since satellite links inherently have some latency, the simulator's software must employ **data prediction algorithms** to fill in gaps and ensure smooth control responses. Techniques like Kalman filtering or spline interpolation can be used to handle minor lags, as explained by Sasiadek and Hartana [127].
3. **Safety Mechanisms**: Developed in the corresponding recovery procedures section, directed to prevent connection failures and to handle them autonomously if sudden.

3.7.8 Pilot licence

In order to establish which licence would the pilot need in order to be able to fly our UAV, a study will be made of the different licences that are required for both helicopter and UAV piloting. Once the possibilities are established, the needs that our UAV has in legal terms.

In the first place, we need to bear in mind that regulations concerning aircraft may vary from country to country, so the information provided here may only apply for European countries and the United States.

Europe: In order to be able to fly an 8000 Kg UAV in Europe, according to European Aviation Safety Agency (EASA) ([128]) a pilot must have the following licences :

- Air Operator Certificate (AOC)
- Pilot licence

Additionally, the aircraft must have a type certificate and a certificate of airworthiness.

United States: In the case of the United States, the Federal Aviation Administration (FAA) establishes that any person that wants to pilot a UAV which has the size of an helicopter needs:

- Remote pilot certificate (more information on how to get this certification in [129])
- Commercial Pilot Licence (CPL) or an Airline Transoprt Pilot Licence (ATPL)

Aside, the UAV must have a certificate of registration (in the following reference more information can be found: [130]).

Therefore, it can be concluded that those pilots that have a commercial plane flying licence with a UAV certification should be able to fly this UAV in most countries. It should be studied if a pilot that has an helicopter licence needs to have a commercial pilot licence or not.

3.7.9 Connectivity recovery Procedures

As the control system of the UAV from the ground station is totally dependant on the satellite connection, some fail-safe measures must be established in case this connection is altered in any way. This possible scenarios cover from a degraded signal to a total loss of signal. In this section more details on the behavior of the UAV in these scenarios will be provided.

3.7.9.1 GEO Backup System

To enhance reliability in communication, an additional GEO (Geostationary Earth Orbit) system will serve as a backup to the primary LEO link. The GEO system will automatically activate in cases of LEO connectivity failures or upon pilot decision during progressive losses. This redundancy ensures continuous operation and mitigates risks associated with communication disruptions.

3.7.9.1.1 Advantages and Disadvantages of the System

Advantages of a GEO System Backup

- **Enhanced Security:** The backup GEO system ensures that a loss of the LEO link does not compromise operations, providing an additional layer of reliability.
- **Greater Coverage:** GEO satellites, positioned at higher altitudes, offer larger coverage areas and are less prone to handover issues, especially over equatorial and remote regions.
- **Improved Robustness:** The dual-system design increases the resilience of the UAV communication framework, particularly in extreme weather or warlike environments.
- **Versatility:** A hybrid approach enables optimized operations, allowing for adaptability depending on mission-critical conditions.

- **Autonomy in Critical Scenarios:** Adding a GEO link as a failsafe allows the UAV to continue essential operations, even under degraded conditions.

Disadvantages of a GEO System Backup

- **Heavier Equipment:** GEO connectivity necessitates additional antennas and supporting hardware, increasing UAV weight and potentially reducing payload capacity.
- **Higher Latency:** Communication delays are inherent in GEO links due to their greater orbital distance, which affects real-time piloting and the realism of the simulator interface.
- **Complexity in Switching Systems:** Integrating two communication systems introduces operational and software complexities, requiring robust management to avoid conflicts or inefficiencies.
- **Increased Costs:** Adding GEO capability involves higher costs for equipment, installation, and operational support, potentially impacting the project budget.

3.7.9.2 GEO Service and Device Selected

Based on the requirements for global coverage, reliability, and compatibility with UAV operations, the **Inmarsat Global Xpress (GX)** system has been selected as the GEO backup service [131]. This system provides seamless worldwide connectivity through a geostationary satellite constellation and ensures robust performance under challenging operational conditions.

- **Global Coverage:** GX ensures consistent connectivity across the globe, including remote and challenging environments, making it suitable for disaster response UAV operations.
- **High Data Rates:** The system supports data rates up to 50 Mbps, significantly exceeding the 300 kbps requirement for UAV operations.
- **Reasonable Latency:** With a latency of approximately 700 ms, GX facilitates near-real-time communication (in degraded mode in comparison with the LEO system), essential for remote piloting and simulator interfaces.
- **Compact Terminals:** Inmarsat offers lightweight and compact terminals, designed for UAV applications, ensuring minimal impact on payload capacity. The **Cobham AVIATOR 200S** is selected as the one the aircraft will use [132].

The Inmarsat GX system balances the need for high-performance communication with the operational demands of the UAV, providing a reliable and efficient solution for backup connectivity.

3.7.9.3 Progressive connectivity loss prediction

The obstruction of the line of sight between the UAV and the satellite due to a mountain affects the propagation of the signal and can cause the loss of connectivity. Since the UAV is designed to fly in very difficult terrains (including mountain ranges) the characteristics of the loss in this case have to be carefully studied.

If we consider that a mountain acts as a very sharp object, the knife-edge theory can be used to model this phenomenon. The knife-edge theory models the propagation of an electromagnetic wave beyond a very sharp object and it states that a well defined obstruction of a an electromagnetic wave behaves like a secondary source. Therefore, the loss of signal is progressive.

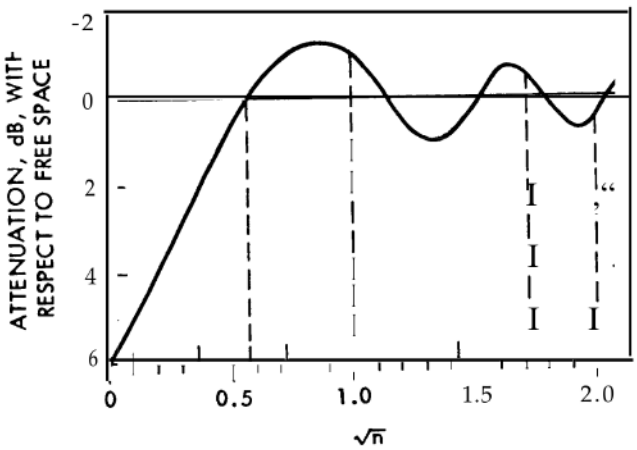


Figure 3.29: Attenuation due to knife-edge diffraction with relation to free space, as a function of $h_c/F_1 = \sqrt{n}$ [11]

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Figure 3.29 shows the progressive attenuation of the signal as a function of h_c/F_1. h_c is the path clearance, the distance between the point of the knife-edge and the right line connecting the transmitter and the receiver. F_1 is the first Fresnel zone, a parameter that depends on the distance between the transmitter, the receiver and the knife-edge, and wavelength. It can be clearly seen that as the knife edge approaches the line of sight between transmitter and receiver, the signal amplitude diminishes.

Figure 3.29 shows another interesting effect: the amplitude of the signal oscillates before the diminishing. This sequence of constructive and destructive interference can be used to predict an imminent connection loss [133] and to act to move to a zone with better satellite coverage before it is too late.

3.7.9.4 Operational Scenarios

3.7.9.4.1 Scenario A: Sudden Loss of LEO Connection

- **Detection:** The system detects a total LEO link failure.
- **Automatic Transition:** The GEO backup link is engaged immediately without pilot intervention.
- **Notification:** Pilots are notified of the switch to degraded mode, indicating higher latency in communication.
- **Continued Operation:** The UAV maintains full operational capability under degraded GEO mode, ensuring mission continuity.

3.7.9.4.2 Scenario B: Progressive Loss of LEO Connection

- **Detection:** The system monitors signal strength and identifies progressive degradation in the LEO link.
- **Alert and Recommendation:** Pilots are alerted about the weakening signal, with a recommendation to switch to GEO mode.
- **Pilot Decision:**
  - If pilots opt to switch, the system transitions smoothly to GEO degraded mode.
  - If they decline and the LEO connection is lost, the system defaults to Scenario A, activating GEO backup automatically.

In either case, the system provides clear status updates, confirming the operational mode and associated conditions (e.g., degraded latency).

In both scenarios, once the LEO connection stabilizes and is confirmed robust, the system transitions back to the primary LEO link automatically. The GEO backup reverts to standby mode, ready for reactivation if needed.

3.7.9.4.3 Scenario C: Dual (GEO and LEO) Failure

- **Detection:** The system detects a loss of both LEO and GEO connections.
- **Automatic Maneuver:** The automatic recovery maneuver is initiated to restore connectivity. This maneuver is designed to optimize the UAV's position or orientation to re-establish communication with one or both networks.
- **Notification:** The pilots are informed of the dual failure and the activation of the recovery maneuver, along with real-time updates on its progress.

In order to recover the satellite connection, the UAV will initate a climb until it is able to establish connection either with the GEO or LEO networks, and when it does so, it will alert the pilot and ask if it should continue with the maneuver or not.

To sum up the different scenarios, the logic sequence that the UAV will follow is shown in figure 3.30. At the end of each branch, the sequence starts again, so it is constantly checking the signal connection status.

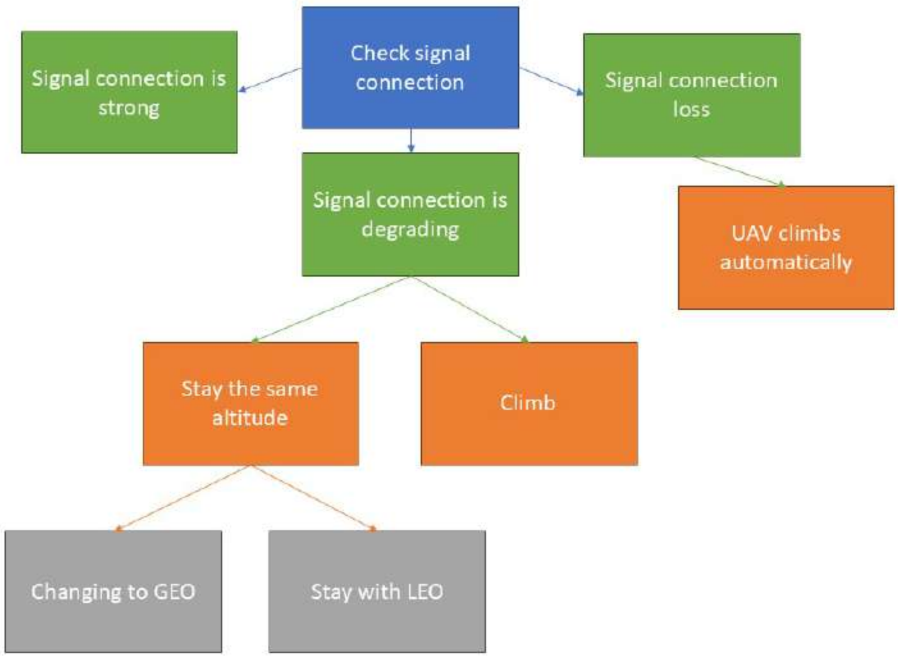

Figure 3.30: Logic sequence followed by the UAV

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3.7.10 Electrical system dimensionalisation

We are still working on this

3.7.11 Avionics testing

In order to certify that all the avionics systems work some testing procedures should be applied. First of all, the individual components should be tested and its good functioning verified. Then, the combination of the different systems working together has to be tested in different scenarios. The specific tests that have to be carried out are listed below:

- **Weather testing:** In order to ensure that all the systems will work even in the most extreme weather conditions that our UAV will find, especially the communication and terrain mapping systems, should be tested and verified that they can still perform correctly.
- **Communication testing:** Testing of the different systems that communicate the UAV with the ground station and the ATC. They should also be tested the basic flying systems such as the GNSS, GPS and RADAR.
- **Connectivity recovery procedures:** The connectivity recovery procedures should be tested, by flying the UAV in places where the connectivity could be a problem and verify that the alert system for connectivity loss are activated. Also, the minimum altitude flying map's accuracy should verified.
- **Signal testing:** It should be verified that the data is transmitted fast enough in all kind of adverse environments for it to be considered real-time data.
- **Landing assistance and terrain mapping systems testing:** Verification that the 3D reconstruction image provided by the LiDAR and the following object recognition algorithm accurately represent the terrain ahead.

Chapter 4

Environmental Viability

4.1 Introduction

An Environmental Feasibility Study is an essential step in evaluating the potential environmental impacts of a proposed project before it is implemented. This study is necessary to identify and mitigate negative environmental consequences, ensure compliance with legal frameworks, and promote sustainable practices.

In the case of the helicopter project, designed for rapid disaster response operations, including medical services and cargo transport, it is crucial to assess environmental aspects such as energy consumption, emissions, noise pollution, material usage, and effects on wildlife. The goal is to ensure that the system can be deployed effectively while minimizing its impact on the environment, adhering to regulatory requirements, and contributing to sustainable development goals.

4.2 Executive Summary

This Environmental Feasibility Study examines the ecological and operational sustainability of a helicopter system engineered for humanitarian aid, medical logistics, and cargo transport in disaster-affected areas. The project prioritizes efficiency through Vertical Take-Off and Landing (VTOL) capabilities, offering operational flexibility in infrastructure-limited regions.

Key environmental concerns include greenhouse gas emissions from fuel combustion, noise pollution affecting urban and rural areas, and potential ecosystem disturbances. These issues are addressed through detailed impact assessments and mitigation strategies. The study recommends employing advanced navigation systems, noise-dampening technologies, and regular monitoring of environmental indicators. A comprehensive Environmental Management Plan ensures adherence to regulations and long-term sustainability throughout the system's lifecycle.

4.3 Legal Framework

The legal framework establishes the regulatory boundaries within which the project must operate to ensure compliance with aviation and environmental standards. These guidelines inform the project's design, implementation, and operations while safeguarding ecological integrity and public interest.

The helicopter system is subject to international, regional, and national laws governing aviation and environmental sustainability. Compliance with these standards ensures responsible operations in diverse contexts. The primary regulatory frameworks include:

- **European Union Aviation Safety Agency (EASA):** Regulations governing emissions, noise, and safety for unmanned and manned aerial systems operating within European airspace.
- **International Civil Aviation Organization (ICAO):** Global benchmarks for environmental standards, including emissions and noise control, applicable in international operations.
- **National Environmental Regulations:** Local laws addressing air quality, biodiversity protection, and waste management, particularly in ecologically sensitive areas.
- **Environmental Impact Assessment (EIA) Guidelines:** Mandatory evaluations to identify and mitigate potential environmental risks prior to project deployment.

Adherence to these frameworks ensures regulatory compliance, operational integrity, and ecological responsibility.

4.4 Background

Natural disasters frequently overwhelm existing infrastructure and highlight the need for rapid and innovative logistical solutions. Traditional transport systems often fail to meet the speed and accessibility requirements of such emergencies. This project introduces an advanced aerial platform designed to address these gaps while minimizing its environmental footprint.

Previous studies on aerial systems for disaster relief have revealed common challenges, such as high fuel consumption, elevated noise levels, and the complexity of meeting regulatory standards. These findings have informed the design of this project, emphasizing the importance of sustainable practices, noise reduction, and operational efficiency.

4.5 Objective

The primary objective of this project is to enhance disaster response capabilities and humanitarian logistics using an environmentally conscious helicopter system. Specific goals include:

- Reducing response times to disaster zones and areas lacking infrastructure.
- Minimizing environmental impact through advanced design and operational protocols.
- Demonstrating adaptability to diverse terrains, including urban, rural, and remote locations.

The project seeks to establish a benchmark for integrating sustainability into disaster management while meeting operational demands.

4.6 General Description

The helicopter features advanced VTOL capabilities, enabling operations in regions with limited or no infrastructure. This functionality is crucial for disaster-stricken zones where conventional runways are unavailable. Its design prioritizes energy efficiency and low emissions, achieved through lightweight materials and aerodynamic optimization.

Operational uses include the delivery of medical supplies, patient evacuation, and cargo transport. Noise-reduction technologies, such as Fenestron tail rotors, are integrated to minimize disturbances during takeoff, flight, and landing. These features make the helicopter suitable for urban environments and ecologically sensitive areas, ensuring its flexibility across a range of missions.

4.7 Description of the Area of Influence

The area of influence for the project includes urban centers, rural regions, and protected ecosystems. Each presents unique environmental challenges and operational requirements.

- **Urban Zones:** Operations focus on delivering medical supplies and essential goods while managing noise impacts and ensuring air quality compliance.
- **Rural and Remote Areas:** The helicopter supports disaster relief by transporting personnel, supplies, and equipment to regions with limited accessibility.
- **Ecologically Sensitive Regions:** Flight paths are carefully planned to avoid critical habitats, minimize ecosystem disturbances, and align with conservation priorities.

Long-term monitoring will assess cumulative impacts across these zones to inform adaptive management strategies.

4.8 Identification of Environmental Effects on the EIA

An Environmental Impact Assessment is necessary to identify and quantify the potential environmental impacts of the UAV project. Key environmental factors that must be considered include:

- **Energy Consumption and Emissions:** The UAV's energy consumption and greenhouse gas emissions will be analyzed to assess its carbon footprint. This includes the type of fuel used, the energy efficiency of the propulsion system, and the potential for using alternative energy sources, such as biofuels.
- **Noise Pollution:** Noise generated by the UAV during takeoff, flight, and landing is a significant environmental concern, particularly in urban and residential areas. Noise levels will be modeled and monitored to ensure compliance with local regulations and minimize disturbance to local communities.
- **Impact on Wildlife:** UAV flight paths may intersect with sensitive wildlife habitats. It is crucial to assess the potential impact on local fauna and ecosystems, particularly in areas of ecological importance, such as national parks and nature reserves.
- **Material Use and Waste Generation:** The UAV's construction materials, battery use, and waste management protocols will be evaluated to ensure that sustainable practices are followed throughout its lifecycle.

Each of these factors will be examined in detail, and appropriate mitigation measures will be identified to reduce the environmental impact.

4.9 Prediction and Evaluation of Environmental Impacts

The prediction and evaluation of environmental impacts involve a thorough analysis of how the helicopter system interacts with the natural and human environment at every stage of its lifecycle. These impacts are analyzed quantitatively and qualitatively using a combination of modeling tools, field data, and stakeholder consultations. By focusing on measurable parameters such as emissions, noise levels, and ecosystem disturbances, this evaluation ensures that all potential consequences are identified and addressed.

The analysis is divided into three main impact categories:

Greenhouse Gas Emissions

The combustion of aviation fuel during operations is a primary contributor to greenhouse gas emissions. Emission modeling tools, such as ISO 14064-compliant software, are used to estimate:

- **Operational Emissions:** Carbon dioxide (CO), nitrogen oxides (NO), and particulate matter emitted during takeoff, cruising, and landing phases are calculated for different payload capacities and flight durations.
- **Manufacturing Emissions:** The carbon footprint associated with the production of composite materials, metal components, and energy-intensive manufacturing processes.
- **Lifecycle Emissions:** Evaluations include the emissions from resource extraction, transportation of materials, maintenance operations, and eventual decommissioning of components.

These assessments identify hotspots where emissions are most significant, enabling targeted mitigation strategies.

Noise Pollution

Acoustic disturbances are a major concern, especially in urban and ecologically sensitive areas. Using advanced tools such as CadnaA or SoundPLAN, noise levels are modeled for:

- **Takeoff and Landing:** These phases generate peak noise levels due to rapid thrust adjustments. Decibel readings are simulated to evaluate their compliance with local and international noise standards.
- **In-Flight Operations:** Noise propagation is analyzed across various altitudes and flight speeds to determine the reach and intensity of the acoustic footprint.
- **Emergency Deployments:** High-speed emergency missions, which may involve rapid altitude changes, are assessed for their acoustic impact on residential and wildlife zones.

Noise impact maps are generated to visualize zones of potential disruption and develop strategies for noise abatement.

Ecosystem and Biodiversity Impacts

The system's operations may intersect with natural ecosystems, requiring a detailed assessment of potential disruptions:

- **Wildlife Interactions:** Autonomous systems and navigation technology are evaluated for their ability to avoid migratory bird routes and nocturnal wildlife activity.
- **Habitat Disturbance:** Low-altitude operations near sensitive habitats are analyzed for physical disruptions, such as vibrations, noise, or increased human activity.
- **Cumulative Impacts:** Long-term operations are assessed for gradual ecosystem changes, such as behavioral shifts in wildlife or vegetation stress near flight corridors.

Collaboration with environmental experts ensures that mitigation measures are informed by scientific evidence and local ecological knowledge.

Quantitative Metrics

Quantitative methods are used to assign numerical values to the severity and extent of each impact. For instance:

- Green house gas emissions are measured in metric tons of CO equivalent.
- Noise levels are reported in decibels (dB) and compared against regulatory thresholds.
- Habitat disruptions are quantified in terms of affected area (hectares) and species vulnerability.

This data-driven approach provides a clear framework for evaluating trade-offs and prioritizing mitigation efforts.

4.10 Prevention of Environmental Impacts

The prevention of environmental impacts is a core component of sustainable project development. Effective prevention strategies focus on minimizing risks at their source and implementing best practices throughout the lifecycle of the helicopter system. These measures are categorized into emissions reduction, noise mitigation, and ecological preservation.

Emissions Reduction Strategies

Reducing the carbon footprint of the helicopter system requires improvements in fuel efficiency and operational protocols:

- **Optimized Aerodynamics:** Advanced aerodynamic designs minimize drag, reducing fuel consumption during all flight phases.
- **Efficient Flight Operations:** Implementing protocols such as reduced idling times, optimized cruising speeds, and efficient flight paths lowers overall emissions.
- **Fuel Innovations:** While the helicopter is not hybrid, exploring biofuels or synthetic fuels could significantly lower its carbon intensity without requiring major design modifications.

Emphasis is placed on optimizing operational efficiency to achieve emissions reductions without compromising mission effectiveness.

Noise Mitigation Techniques

Acoustic impact is managed through design enhancements and operational adjustments:

- **Fenestron Tail Rotors:** These components significantly lower sound intensity during takeoff, landing, and hovering phases.
- **Flight Path Design:** Avoiding densely populated areas and wildlife habitats reduces noise disturbances. Routes are dynamically updated based on real-time environmental data.
- **Operational Scheduling:** Restricting flights during night hours in urban and rural regions ensures minimal disruption to communities and nocturnal wildlife.

Noise control strategies are validated through real-world testing and community feedback.

Ecosystem and Wildlife Preservation

Preventative measures are tailored to protect biodiversity and minimize ecosystem disruptions:

- **Avoidance of Sensitive Areas:** Flight plans are adjusted to bypass critical habitats, nesting sites, and migratory routes.
- **Seasonal Operations:** Activities are scheduled to avoid sensitive periods, such as breeding or migration seasons.
- **Autonomous Navigation:** Collision-avoidance systems prevent interactions with birds and other wildlife during flights.

These strategies align with regional conservation goals and international biodiversity standards.

4.11 Environmental Management Plan

The Environmental Management Plan establishes a structured framework to monitor, mitigate, and manage environmental impacts throughout the helicopter system's lifecycle. It is a dynamic document that adapts to new data, technologies, and regulatory requirements.

Monitoring Programs

Continuous monitoring ensures that the project complies with environmental standards and identifies emerging risks:

- **Emission Audits:** Regular assessments of CO and NO levels during operations provide actionable insights for improving efficiency.
- **Acoustic Surveys:** Noise monitoring stations near urban, rural, and wildlife-sensitive areas collect data to verify compliance with decibel limits.
- **Ecosystem Monitoring:** Satellite imagery, on-site surveys, and ecological sensors track changes in biodiversity and habitat conditions.

Data from these programs informs periodic updates to the Environmental Management Plan.

Corrective Measures

Proactive responses to unexpected environmental impacts are an integral part of the Environmental Management Plan:

- **Incident Response Protocols:** Standard operating procedures (SOPs) address issues such as fuel spills, noise violations, or wildlife disturbances.
- **Remediation Actions:** Habitat restoration, noise abatement measures, or compensatory conservation initiatives are implemented to offset negative impacts.

These measures ensure swift resolution of environmental issues while maintaining operational continuity.

Sustainability Initiatives

Long-term sustainability is achieved through ongoing efforts to integrate green technologies and practices:

- **Technology Integration:** Advances in materials science and propulsion systems are incorporated to enhance efficiency and reduce impacts.
- **Community Engagement:** Collaborations with local stakeholders promote awareness, trust, and alignment with regional environmental priorities.
- **Lifecycle Management:** Sustainable practices are embedded across the lifecycle, including manufacturing, operation, maintenance, and decommissioning phases.

The Environmental Management Plan includes specific timelines and responsibilities for each initiative, ensuring accountability and transparency.

Periodic Review and Updates

The plan is reviewed annually to incorporate new findings, address stakeholder concerns, and adapt to changing environmental regulations. Regular updates ensure that the plan remains relevant and effective over the project's lifespan.

4.12 Description of Compliance with Legal Framework

The project fully adheres to all relevant legal requirements, including:

- **EASA Standards:** Compliance with emissions, noise, and safety regulations for European airspace.
- **ICAO Guidelines:** Alignment with global environmental benchmarks for aviation.
- **National and Regional Laws:** Fulfillment of specific requirements related to air quality, biodiversity protection, and waste management.

A compliance register will be maintained to track adherence to these legal requirements throughout the UAV's operational lifecycle. The mentioned regulations are exposed in section 7

Chapter 5

Economic Aspects

5.1 Marketing and Communications

This section explores the marketing and communications framework for the VTOL helicopter, encompassing the development of its brand identity and the strategic approaches to effectively position it in the market. The discussion covers key aspects such as the brand's principles and values, as well as strategies for marketing and communication to ensure alignment with the needs of stakeholders in disaster response scenarios.

5.1.1 Brand development

Brand development is a crucial aspect of positioning the VTOL helicopter as a reliable and innovative solution for disaster response and medical emergencies. By establishing a strong identity, the brand aims to work with governments and NGOs, the primary stakeholders, who require efficient, robust, and sustainable tools for addressing natural disasters. This section outlines the principles, values, and attributes that define the brand, ensuring it reflects the humanitarian and technological excellence required to inspire trust and commitment in mission-critical operations.

5.1.1.1 Brand identity

Brand identity defines how a brand communicates its values and personality, combining visuals and messaging to create a memorable, consistent image that builds trust.

5.1.1.1.1 Brand name

LUMOS

The name Lumos was selected for its simplicity, symbolic strength, and emotional resonance. Derived from the Latin word for "light," Lumos represents hope and guidance.

- **Symbolism of Light:** Light universally symbolizes hope, perfectly aligning with the helicopter's mission to provide aid in disasters and emergencies.
- **Simplicity and Memorability:** The name is short, easy to remember, and has a modern, distinctive sound, making it appealing on a global scale.
- **Global Versatility:** Its Latin origin gives it an international character, ensuring it is easily understood across languages and cultures.

5.1.1.1.2 Slogan

"Hope Doesn't Wait—Neither Do We."

"Hope Doesn't Wait—Neither Do We" captures the urgency and commitment of Lumos to deliver aid when every second counts.

- **Urgency and Action:** The slogan reflects the life-saving immediacy required in disaster response, aligning with the mission of Lumos to act rapidly in critical situations.
- **Emotional Resonance:** By focusing on "hope," it establishes a strong connection with stakeholders, evoking trust in moments of crisis.
- **Memorability:** The rhythmic and concise structure of the slogan makes it easy to recall.

5.1.1.1.3 Logo

This Lumos logo reflects the brand's focus on precision, reliability, and modernity.

Figure 5.1: Enterprise's logo

- **Simplicity and Elegance:** The logo uses a minimalist design with clean lines and geometric shapes, representing a modern and aesthetic. This simplicity ensures it is timeless and easily recognizable, crucial for building a strong brand identity.
- **Professional Tone:** The dark color palette of deep blue and light accents provides a sense of authority, reliability, and professionalism. It is suitable for appealing to serious sectors like governments, military, and NGOs, which value functionality and trust.
- **Versatility:** The logo's clean and simple design ensures it is versatile for various applications, whether on digital platforms, printed materials, or promotional items.
- **Symbol of Strength and Precision:** The geometric circle around the rotor adds balance to the design and symbolizes unity and focus. The helicopter's forward motion represents the brand's drive toward progress.

5.1.1.2 Brand core

5.1.1.2.1 Mission and Vision

Mission: To deliver advanced VTOL technology that empowers stakeholders to respond effectively to natural disasters and medical emergencies. Our mission is to provide reliable, sustainable, and innovative aerial solutions that save lives and ensure the swift delivery of critical aid in the most challenging environments.

Vision: To become the global leader in VTOL technology for disaster response and medical emergencies, renowned for innovation, sustainability, and humanitarian impact. Our vision is to establish lasting partnerships with key stakeholders, creating a safer and more resilient world through advanced aerial solutions.

5.1.1.2.2 Principles

The brand's principles embody its core values, guiding its mission to innovate, support communities, and drive positive impact.

- **Innovation:** Commitment to pioneering advanced VTOL technologies for emergency and disaster response.
- **Reliability:** Delivering consistent, robust performance in the most critical situations to build stakeholder trust.
- **Empathy:** Placing human needs at the core, focusing on saving lives and supporting affected communities.
- **Humanitarian Focus:** Driven by the mission to alleviate suffering and support recovery in disaster areas.
- **Sustainability:** Minimizing environmental impact through eco-friendly design and responsible operations.
- **Accessibility:** Providing cost-effective solutions to the needs of the stakeholders.
- **Transparency:** Maintaining clear communication and accountability in all operations and collaborations.
- **Visionary Thinking:** Constantly pushing the boundaries to redefine what's possible in disaster response technology.

5.1.1.2.3 Value proposition

The value proposition highlights how the helicopter addresses the unique needs of key stakeholders.

- **NGOs:** Rapid deployment of aid and personnel to remote areas, maximizing humanitarian impact in emergencies.
- **Governments:** Advanced solutions for disaster preparedness, efficient emergency response, and public safety.
- **Military:** Reliable and adaptable platforms for logistics, reconnaissance, and critical mission support.
- **Air Ambulance Operators:** Solutions for patient transportation and rescue missions.

5.1.2 Marketing Strategy

The proposed campaigns for the UAV project are structured to address specific market demands, align with the operational priorities of prospective clients, and meet the stringent requirements for credibility and visibility inherent to dual-purpose systems integrating humanitarian aid and cargo delivery. Drawing on established practices from industry leaders such as Airbus and Boeing, these strategies are designed to leverage technical precision and operational effectiveness, ensuring their alignment with the expectations of governmental and corporate stakeholders.

Value Marketing Strategy:
This campaign emphasizes the importance of delivering quantifiable metrics to substantiate the UAV system's return on investment. Governments and multinational corporations require data-driven validation of how the UAV enhances emergency response capabilities and optimizes logistical efficiency. For example, Boeing highlights these advantages in its disaster response initiatives by showcasing performance data and cost analyses. Airbus employs similar tactics by publishing case studies that focus on real-world operational savings and time efficiencies.
To replicate these approaches, the UAV project will deploy targeted case studies, operational impact reports, and ROI-focused presentations that illustrate its capacity to save lives and streamline cargo operations in critical environments.

Thought Leadership Campaign:
Positioning the UAV project as an authoritative solution requires engagement with recognized experts and strategic participation in industry forums. Airbus frequently presents its advancements in disaster relief and logistics at international summits such as the World Humanitarian Forum. Boeing enhances its standing through technical white papers and collaborations with global agencies.
The UAV project will adopt a similar approach by hosting panels at key industry events (such as WHS or IDEC), publishing research on dual-purpose UAV applications, and partnering with respected organizations to establish its credibility in the humanitarian and logistics sectors.

Content Marketing Strategy:
For a multi-functional platform, educational outreach is critical to demonstrate its integration potential and technical capabilities. Airbus effectively educates its audience by producing video content and detailed blogs that explore the practical deployment of their systems. Boeing complements this by publishing interactive content that walks clients through system capabilities.
The UAV project will focus on creating high-quality technical content, including video demonstrations, system integration guides, and blogs optimized for technical audiences. These resources will provide clarity on the UAV's adaptability for both medical aid and cargo missions, building trust and authority within the logistics and emergency response communities.

Demonstration and Service Testing Campaign:
Live demonstrations remain the most effective method to exhibit a system's operational viability. Airbus regularly conducts simulations to display its aircraft's performance in disaster scenarios, while Boeing invites stakeholders to participate in real-world trials of their technologies.
The UAV project will incorporate a robust demonstration program, showcasing its dual-purpose functionality at trade shows and private events. Pilot programs will allow potential clients to experience its performance firsthand, evaluating its capabilities under simulated mission conditions, such as medical aid delivery to remote areas or time-critical cargo operations.

Partnerships and Public Relations Campaign:
Building alliances with established organizations in healthcare, logistics, and emergency management significantly enhances the perceived reliability of any system. Airbus's collaborations with the Red Cross and Boeing's partnerships with logistics providers serve as benchmarks for this approach.

The UAV project will establish partnerships with NGOs, logistics companies, and disaster management agencies to expand its network and gain endorsements. Participation in sector-specific conferences and publishing success stories in prominent industry journals will further reinforce the system's reputation.

Some of the key partnerships for the project include collaboration with the Red Cross, a globally recognized humanitarian organization, which would enhance credibility through joint initiatives and real-world disaster trials. A partnership with the World Food Programme (WFP) would showcase the UAV's potential in large-scale logistics, particularly in emergency food distribution and crisis zones. Additionally, participating in events like the Global Disaster Relief Summit would provide valuable exposure and opportunities to engage with industry leaders, while publishing success stories in respected journals would further solidify the UAV project's position as a critical solution in humanitarian aid and logistics.

Influencer Marketing and Project Ambassadors Strategy:
Industry endorsements from qualified professionals such as medical experts and logistics leaders significantly impact the adoption of new technologies. Airbus frequently collaborates with disaster responders, while Boeing utilizes testimonials from logistics experts to validate its systems' efficacy. The UAV project will engage key opinion leaders and experienced professionals as ambassadors to highlight its real-world impact. These endorsements will be distributed through targeted social media campaigns and technical forums, demonstrating the system's effectiveness to decision-makers in both government and private sectors.

By adopting proven strategies from aerospace leaders like Airbus and Boeing, the UAV project can effectively position itself as a dual-purpose solution for humanitarian and cargo missions. These campaigns combine technical rigor with operational relevance, addressing the critical requirements of a high-stakes market and ensuring credibility, visibility, and adoption by large corporations and government entities.

5.1.3 Communications Plan

The Communications Plan outlines a structured approach to effectively share information, engage stakeholders, and promote collaboration for the UAV project. It ensures transparency, alignment with objectives, and timely feedback while enhancing visibility and trust among all involved parties.

5.1.3.1 Objectives of the Communication Plan

The goal of this communication plan is to establish a structured framework to effectively share information with stakeholders of the UAV project. The specific objectives include:

- Ensuring stakeholders remain informed about the project's progress, milestones, and key updates.
- Facilitating timely feedback and addressing concerns from stakeholders.
- Strengthening trust and collaboration with key entities.
- Promoting transparency and alignment with regulatory requirements.
- Enhancing the visibility of the project and its value among prospective clients and investors.

5.1.3.2 Stakeholder Categorization

The stakeholders are categorized based on their roles and interests:

- **Primary Stakeholders:** Investors (e.g., emergency response agencies, defense and homeland security departments, aerospace and drone companies), regulators (e.g., ICAO, ATC authorities), and key operators (e.g., helicopter pilot unions, medical organizations).
- **Secondary Stakeholders:** Governments, NGOs, military forces, insurance companies, technology providers, and satcom providers.
- **Internal Stakeholders:** Project team members and customers.

5.1.3.3 Communication Strategies

The communication plan ensures stakeholder alignment through updates, tailored channels, demonstrations, and feedback, enhancing collaboration and project success.

5.1.3.3.1 Regular Presentations and Updates

To provide stakeholders with structured and periodic updates on the project's progress.

- **Format:** Conduct virtual meetings or in-person presentations depending on stakeholder preferences.
- **Content:** Include updates on:
  - Project milestones and progress.
  - Financial and operational updates for investors.
  - Risk assessments and mitigation strategies.
  - Compliance with regulatory requirements.
- **Deliverables:** Share summary reports and key insights with stakeholders after each presentation.

5.1.3.3.2 Tailored Communication Channels

To ensure communication is accessible and relevant for each stakeholder group.

- **Email Briefings:**
  - Weekly updates for internal stakeholders.
  - Monthly updates for investors and regulators.
- **Secure Portal:** Establish a dedicated platform where stakeholders can:
  - Access real-time project dashboards.
  - View shared documents, such as compliance reports and technical updates.
  - Submit questions or feedback.
- **Workshops:** Organize collaborative sessions with regulatory agencies and technology partners to align on compliance and integration requirements.

5.1.3.3.3 Stakeholder-Specific Engagement

Address the unique needs of individual stakeholder groups.

- **Investors:** Conduct exclusive presentations showing financial ROI, operational milestones, and progress.
- **Regulators:** Host monthly workshops to discuss regulatory compliance, technical parameters, and potential integration challenges.
- **Technology Providers:** Schedule technical briefings to coordinate equipment integration and resolve compatibility issues.
- **Potential Clients (Governments, NGOs, etc.):** Provide tailored demonstrations and case studies highlighting the UAV's dual-purpose capabilities.

5.1.3.3.4 Demonstrations and Pilot Programs

Allow stakeholders to evaluate the UAV's functionality in real-world scenarios.

- Conduct live demonstrations at industry conferences, focusing on disaster relief, medical aid delivery, and logistics scenarios.
- Develop pilot programs where select stakeholders can test the UAV system under controlled real-world conditions.
- Gather feedback from these trials to refine the system and align it with stakeholder expectations.

This section aligns with the Demonstration and Service Testing Campaign and Thought Leadership Campaign from 5.1.2, offering stakeholders a hands-on opportunity to evaluate the UAV's capabilities. The feedback gathered from these live demonstrations will be critical in refining the product and building trust within the industry.

5.1.3.3.5 Public Relations and Media Campaigns

Enhance the visibility of the UAV project and its value proposition.

- Publish articles and success stories in industry-specific journals (e.g., aviation, logistics, and emergency response).
- Maintain an active presence at global events like the World Humanitarian Summit to showcase the project's applications.
- Collaborate with trusted organizations like the Red Cross or Doctors Without Borders to validate the project's impact.

The Partnerships and Public Relations Campaign and Content Marketing Strategy from 5.1.2 are essential here, as they focus on enhancing the visibility of the UAV project. By collaborating with trusted organizations like the Red Cross and showcasing success stories, these efforts validate the project's impact and broaden its reach.

5.1.3.4 Feedback Collection and Resolution

To ensure stakeholders' concerns, suggestions, and expectations are effectively addressed. By gathering structured feedback through surveys, meetings, and direct queries, the project team can promptly implement improvements, ensuring alignment with stakeholder needs and fostering trust.

- Distribute surveys after meetings and demonstrations to gather stakeholder feedback.
- Designate communication managers to categorize feedback and ensure timely resolution.

5.1.3.5 General communications plan among stakeholders

- **Weekly:** Email updates for internal teams.
- **Bi-Monthly:** Presentations for primary stakeholders.
- **Monthly:** Compliance updates for regulators.
- **Quarterly:** Progress reviews for secondary stakeholders.

Stakeholder Group	Frequency	Communication Format	Key Topics
Team Members	Weekly	Internal meetings, email updates	Progress, challenges, and task assignments
Investors	Bi-monthly	Virtual meetings, detailed reports	Financial updates, milestones, ROI
Regulators (EASA, ICAO, etc.)	Monthly	Workshops, compliance updates	Regulatory alignment, operational parameters
Governments and NGOs	Quarterly	Presentations, email briefings	Potential applications, partnership proposals
Medical and Pilot Organizations	Bi-monthly	Meetings, feedback sessions	Operational needs, personnel integration
Technology Providers and Satcom	Bi-monthly	Technical briefings, integration sessions	System updates, collaborative developments
Competitors (via PR)	As Needed	Public reports, media statements	Differentiation and market positioning

Table 5.1: Stakeholder Communication Plan

This communication flow plan ensures that all stakeholders are engaged, informed, and aligned with the UAV project's objectives. By leveraging tailored strategies, regular updates, and direct engagement, the project builds trust and fosters collaboration, ensuring a successful outcome. In fact, during the design process of this project, this plan has been followed for the communications between team members, turning out to be a useful and efficient structure that has allowed the work to be carried out in an organized manner as established.

5.2 Economic Feasibility Study

Economic viability is a critical factor in aerospace projects, particularly in the development of a project of this magnitude. While technical performance and operational capabilities define the potential success of such systems, their feasibility ultimately depends on whether they can be developed, produced, and operated within realistic financial constraints.

This study focuses on assessing the financial feasibility of the humanitarian aid project by calculating key economic metrics such as the Net Present Value (NPV), Break-even Points, Internal Rate of Return (IRR), Updated Payback Time (UPBT), and Simple Payback Time (SPT). These metrics provide a comprehensive understanding of the project's financial performance, offering insights into its profitability, risk factors, and timeline for investment recovery.

By leveraging the Development and Procurement Cost Analysis (DAPCA) method used in the *Budget* document and contextualizing the data within the five-year production timeline, the analysis evaluates core financial aspects such as production costs, revenues, initial investment requirements, and recurring expenses. The study also identifies critical sensitivities to external factors, which are essential for informed decision-making and ensuring mid- to long-term sustainability.

This analysis aims to provide a structured framework for evaluating the financial dynamics of the project, ensuring that economic considerations align with the technological and operational objectives.

The key variables and assumptions that form the foundation of our financial analysis are going to be outlined first. This includes detailed cost estimates from the budget document and from outside of it, the planned production and sales schedule, and the economic rates applied, such as the discount rate and inflation rates for both costs and sales prices. Defining these parameters is essential for ensuring the accuracy and reliability of our financial projections.

5.2.1 Production Schedule

For simplicity reasons, it will be assumed that all units produced in a given year are sold within the same year.The distribution of produced/sold units over the years has been decided to be as follows:

Year	**1**	**2**	**3**	**4**	**5**
Number of units	10	15	15	15	15

Table 5.2: UAV units produced/sold each year

The production and sales plan has been adjusted to ensure steady growth and efficient resource use. In the first year, 10 units will be produced and sold. This initial phase allows time to establish the production process, test the system, and address any issues that may arise. Starting with a smaller volume ensures quality control and lays the foundation for scaling up.

From the second to the fifth year, production increases to 15 units annually. This ramp-up aligns with improved efficiency as workers and machinery gain experience in manufacturing the UAVs. Maintaining this consistent output from the second year onward helps balance demand with production capacity, ensuring reliability and optimal use of resources.

This plan minimizes risks in the early stages while supporting sustainable growth and meeting market expectations over the project timeline.

5.2.2 Initial Investment

To calculate the initial investment required for the project, it is necessary to estimate the Research, Development, Testing, and Evaluation (RDTE). These encompass engineering, tooling, and testing expenses, which must be fully covered prior to the production of the first unit.

Area	**Cost**
Engineering	€ 115,319,554
Tooling	€ 72,096,046
Testing	€ 22,218,522
Total (rounded)	€ 210,000,000

Table 5.3: Initial Investment Calculation [1]

[1]Values retrieved from the *Budget* document

5.2.3 Variable Costs

In this section, costs depending on the quantity of aircraft produced or that are not constant through the period of time evaluated are discussed.

5.2.3.1 Costs Associated with Production

The rest of the costs coming from the DAPCA analysis—Manufacturing, Quality, Support, Materials, Engines, Interiors, and Avionics—are variable in nature, directly influenced by the number of units produced annually. These costs are incurred during the production phase of each aircraft, meaning their magnitude scales with production output.

Area	Cost/aircraft
Manufacturing	€ 2,257,133
Quality	€ 132,333
Support	€ 444,890
Materials	€ 331,612
Engines	€ 1,536,000
Interiors	€ 19,200
Avionics	€ 409,136
Total	€ 5,117,040

Table 5.4: Production-Associated Costs per Aircraft

5.2.3.2 Marketing Costs

The marketing costs for the project are estimated at a total of €6,000,000, distributed progressively over the five-year production period. In the first year, €2,000,000 is allocated to support the initial launch, covering expenses such as promotional campaigns, participation in key aerospace trade shows and congresses, the development of marketing materials, and customer engagement initiatives to secure early contracts. Another €2,000,000 is planned for the second year to maintain visibility through continued event participation, targeted advertising, and client outreach efforts.

As the project gains recognition, marketing costs gradually decrease, with €1,000,000 allocated for the third year, focusing on maintaining customer relationships and attending select trade events. For the fourth and fifth years, €500,000 is budgeted annually, primarily for ongoing brand presence through digital advertising, smaller promotional events, and maintaining relationships with key stakeholders. This strategic distribution ensures that resources are concentrated where they are most impactful, supporting a strong market entry while allowing for sustained engagement and brand positioning in later stages.

5.2.3.3 Logistics Costs

The logistical costs for the humanitarian aid UAV project are estimated at €550,000 per helicopter, representing 5% of the unit year-zero selling price of 11 million euros. This allocation aligns with industry norms, where logistical expenses typically range between 3% and 7% of a product's price [134, 135], reflecting the complexity of aerospace operations.

This budget is designed to cover key logistical needs, including specialized transportation for UAVs, secure storage, insurance for risk management, and compliance with international customs and regulatory requirements. As highlighted by The Logistics World [136], logistics costs can account for up to 50% of total operating costs in some sectors, underscoring their critical role in ensuring efficiency and reliability.

This estimation ensures sufficient resources to manage logistical challenges effectively, enabling timely and secure delivery of UAVs to clients while maintaining high operational standards.

5.2.4 Fixed Costs

This section accounts for costs that don't depend on the specific year or the number of units produced in a year. Instead, they remain constant across each year (they are only adjusted because of inflation).

5.2.4.1 Warranty and Maintenance Costs

Allocating 2% of the initial investment annually, or €4,200,000 approximately, for warranty-related maintenance is a prudent and efficient decision. This budget is designed to cover minor repairs, component replacements, and adjustments required during the warranty period, ensuring customer satisfaction without overextending resources. [137]

In the aerospace industry, maintenance costs represent a smaller fraction of total operating expenses, and 2% aligns with these standards while providing a margin for unanticipated claims. Additionally, subcontracting maintenance could optimize these costs further. This allocation balances financial prudence with operational readiness, ensuring warranty obligations are met while supporting the project's mid- to long-term sustainability and reliability.

5.2.5 Economic Factors

In this section, economic key parameters that influence the feasibility of the project are exposed and quantified.

5.2.5.1 Discount Rate

A discount rate of 7% has been selected for this analysis, taking into account the additional risks associated with the innovative nature of this passenger-carrying UAV project. While Eurocontrol's recommendations for aeronautical projects [138, 139] suggest a lower rate of 3%, this project introduces greater uncertainty due to its novel technology and approach, necessitating a higher rate to account for these risks.

5.2.5.2 Inflation

The annual inflation rate, based on the projections detailed in the report by Fundación de las Cajas de Ahorros (FUNCAS) [140] concerning the Consumer Price Index (CPI) for Spain, is estimated to be 2.3%. According to the report's analysis and forecast, the inflation rate for the period extending to December 2025 is expected to stabilize around this value.

A higher inflation rate of 3% annually will be applied to the selling price of the units produced, as well as to the costs. This adjustment accounts for sector-specific dynamics in aerospace manufacturing and operations. This annual inflation rate is justified by several interconnected factors inherent to the aerospace sector.

Manufacturing costs in this industry typically rise at a rate slightly above the general CPI due to the increasing prices of raw materials, advanced components, and specialized labor. Essential materials such as composites, titanium, and cutting-edge avionics are heavily influenced by global market fluctuations, often exceeding broader economic inflation trends.

Operational expenses also contribute significantly to cost escalations. These include the rising prices of fuel, the integration of new technologies, and the need to comply with stricter regulatory standards. Maintaining airworthiness and ensuring operational safety over the helicopter's lifecycle necessitate substantial financial investment, further amplifying the inflationary pressure.

5.2.6 Pricing and Profit Margin

Upon analyzing the gross profit margins of leading helicopter manufacturers, it is observed that Airbus maintains a margin of approximately 15% [141, 142], while both Leonardo and Sikorsky report margins around 36% [143, 144].

For the humanitarian aid UAV under development, a year-zero unit sale price of €11,000,000 has been established. Taking into account the effects of inflation, if all costs, both variable and fixed, are added to the initial investment and the result is divided by the number of units intended to be produced, the average cost per aircraft will be approximately €9,700,000. The average selling price throughout the production will be approximately €12,000,000. This places the project at a margin of around 24%, which is a reasonable number compared to the reference cases of Airbus on one hand and Leonardo or Sikorsky on the other.

When comparing the sale price of our newly designed UAV with other helicopters in the market:

- **Airbus H175**: around €16,210,000 [145]
- **Airbus H145**: around €9,050,000 [146]
- **Sikorsky S-76D**: around €14,300,000 [147]

It is concluded that the UAV offers a competitive value proposition, balancing an attractive price with a solid profit margin.

5.2.7 Results Interpretation

Year	**0**	**1**	**2**	**3**	**4**	**5**
Initial Investment	€ 210,000,000	-	-	-	-	-
Amortization	€ 0.00	€ 42,000,000	€ 42,000,000	€ 42,000,000	€ 42,000,000	€ 42,000,000
Units sold	0.00	10.00	15.00	15.00	15.00	15.00
Price per unit [2]	€ 11,000,000	€ 11,330,000	€ 11,670,000	€ 12,020,000	€ 12,381,000	€ 12,753,000
Revenue	€ 0.00	€ 113,300,000	€ 175,050,000	€ 180,300,000	€ 185,715,000	€ 191,295,000.00
Fixed Costs	€ 0.00	€ 4,326,000	€ 4,455,780	€ 4,589,453	€ 4,727,137	€ 4,868,951
Variable Costs	€ 0.00	€ 60,430,516	€ € 92.304.248	€ 93.980.648	€ 96.237.313	€ 99.124.432
Cash Flow	-	€ 48.543.483	€ 78.289.972	€ 81.729.899	€ 84.750.550	€ 87.301.617
Present Value	-	€ 45.367.742	€ 68.381.494	€ 66.715.943	€ 64.655.789	€ 62.244.846

Table 5.5: Economic Feasibility Summary

Break-even Point: 9 units for first to third years and then 8 units

In the first year, with a production plan of 10 helicopters and a break-even point of 9 units, the margin is extremely tight, leaving little room for error. This makes the first year particularly risky, as any shortfall in sales or unexpected cost increases could lead to losses. Ensuring sales of at least 9 helicopters is critical, and securing pre-sales contracts or binding agreements will be essential to mitigate this risk. Rigorous cost control measures should also be implemented to safeguard the project's financial position during this phase.

In years 2 and 3, production increases to 15 helicopters annually, while the break-even point remains at 9 units. This creates a more comfortable margin of 6 helicopters, reducing financial vulnerability and enhancing the project's stability. The focus should shift to maintaining consistent demand for

[2]Prices are rounded up to the next thousand €.

the full production volume of 15 units, which will be key to fully leveraging this increased capacity. Strengthening market presence and nurturing relationships with buyers will be critical to sustaining sales, which is also mentioned in section 5.2.3.2. At the same time, ongoing cost monitoring and optimization will help maximize profitability during this period.

By Years 4 and 5, the project reaches its most favorable financial phase, with production still at 15 helicopters annually but the break-even point dropping to 8 units. The resulting margin of 7 helicopters offers a substantial buffer against potential market fluctuations. This strong position allows for a focus on maximizing profitability and reinvesting returns into strategic initiatives, such as product development, market presence consolidation (section 5.2.3.2, or further operational improvements. Protecting these gains through proactive risk management will be essential to ensuring continued success.

Simple Payback Time (SPT): 2 years and 9 months

The Simple Payback Time, calculated without discounting future cash flows, is approximately 2 years and 10 months. This indicates a rapid recovery of the initial investment, showcasing the project's strong cash flow generation from early stages.

Updated Payback Time (UPBT): 3 years and 5 months

When accounting for discounted cash flows based on the discount rate determined in section 5.2.5.1, the Updated Payback Time extends to approximately 3 years and 5 months. This reflects the impact of the time value of money but still highlights a competitive recovery period, underscoring the project's financial feasibility.

Net Present Value (NPV): € 97.365.813

With a Net Present Value of €93.37 million at the end of the fifth year, the project demonstrates exceptional profitability and significant value creation. This result emphasizes its capacity to deliver strong returns beyond the recovery of initial costs.

Internal Rate of Return (IRR): 21.58%

The Internal Rate of Return stands at 21.58%, indicating a highly efficient investment with returns significantly exceeding standard benchmarks. This further reinforces the project's appeal as a financially sound and lucrative opportunity.

5.2.8 Conclusion

As a conclusion, the project demonstrates clear financial viability with metrics that collectively highlight its strong potential for profitability and investment appeal. The payback periods confirm a swift recovery of the initial investment, providing early financial security. This is complemented by a robust net present value, reflecting the ability to generate substantial long-term returns well above costs.

The internal rate of return further underscores the project's attractiveness, exceeding typical benchmarks and showcasing its efficiency as an investment. Together, these indicators reveal a well-balanced financial structure, with the ability to mitigate risks in the short term while delivering consistent profitability over time. The project stands out as a compelling and sustainable venture with excellent prospects for value creation.

Chapter 6

Project Management

This section outlines critical elements of project management that are integral to the successful delivery of the project. We address safety management, risk mitigation, quality control, and project scheduling as individual but interconnected areas, each contributing to the overall efficiency and success of the initiative.

Safety management focuses on implementing rigorous protocols and measures to safeguard personnel, assets, and the operational environment throughout the project lifecycle. Risk mitigation involves identifying potential hazards, assessing their impact, and establishing strategies to minimize or eliminate them. Quality control ensures that project outputs meet predefined specifications, standards, and regulatory requirements, ensuring consistency and reliability. Finally, project scheduling provides a structured timeline, identifying critical milestones and resource allocation strategies to ensure timely and efficient execution.

These topics are addressed separately to provide clarity and depth, while recognizing their interdependencies. This approach enables the development of a cohesive project management framework, ensuring that each aspect is carefully planned and monitored to achieve the desired outcomes.

6.1 Safety considerations

Safety considerations are paramount in any high-risk operation, especially when it comes to a humanitarian helicopter that combines cargo transport and emergency medical services (HEMS). In such complex and high-stakes missions, the safety of the aircraft, the crew, the patients, and the cargo is the primary concern. Operational safety ensures that the helicopter can perform its missions in the most hazardous environments with the least risk of accidents or failures. This includes everything from protecting the crew and passengers to safeguarding critical supplies and ensuring the continued airworthiness of the helicopter in adverse conditions.

Given the nature of this humanitarian project, safety considerations must be applied across multiple facets of the helicopter's operation. A combination of technological, procedural, and human factors must be taken into account to create a safe and efficient environment for the aircraft to operate. The effectiveness of the mission is dependent on reducing the risk of accidents, preventing incidents before they occur, and ensuring that the aircraft is well-equipped to deal with emergencies.

6.1.1 General considerations

Aircraft Design and Structural Integrity:
The design of the helicopter plays a crucial role in ensuring its safety. The structure must be capable of withstanding external forces, such as turbulence, rough landings, and potential collisions. An essential

consideration is to ensure that the design allows for the protection of the crew, passengers, and cargo during both routine and emergency operations. Moreover, the structure must integrate safety features that protect against fires, the spread of toxic fumes, and the rapid depressurization of critical systems.

Control and monitoring of the aircraft and mission:
Avionics systems are critical for ensuring the operational safety of the helicopter, particularly in complex missions such as humanitarian aid, cargo transport, and HEMS. These systems include flight control, navigation, and communication technologies that enhance situational awareness and ensure safe operation. Flight control systems help stabilize the aircraft, while weather radar and collision avoidance systems reduce risks from adverse weather and nearby obstacles. Reliable communication systems, including satellite links, ensure continuous contact with ground support and emergency teams, enabling effective coordination in remote or disaster-stricken areas.

Mission Complexity and Operational Environment:
Humanitarian helicopter missions often take place in complex, rapidly changing, and sometimes hostile environments. These include natural disaster zones, conflict areas, or regions with inadequate infrastructure. In these conditions, the safety protocols must account for environmental factors such as unpredictable weather, limited visibility, rough terrain, and the lack of reliable communication channels. The helicopter must be equipped with systems that ensure safe operations, even when external factors pose significant challenges.

Performance Limitations:
Performance limitations are essential to ensure the safe and efficient operation of the helicopter during humanitarian missions. These limitations include avoiding excessive structural loads that could compromise the aircraft's integrity, preventing entry into a stall condition, and ensuring the aircraft operates within its maximum performance range. Operating beyond these limits can lead to catastrophic failures such as engine overloads, loss of control, or insufficient range to complete the mission. Additionally, the helicopter's design must ensure that it remains stable and controllable at all altitudes and speeds, with adequate margins for emergency maneuvers and recovery from critical flight conditions.

Human Factors and Crew Safety:
The well-being and performance of the flight crew (medical assistant and remote pilots) are fundamental to ensuring the safety of the mission. Fatigue, stress, and the mental health of the crew are critical factors that directly impact decision-making abilities, response times, and overall mission effectiveness. As such, establishing protocols to manage fatigue and ensuring regular psychological evaluations are key. Crew members must be adequately trained not only to respond to emergencies but also to handle the demanding and often unpredictable nature of humanitarian missions.

Health and Safety for Passengers and Cargo:
The helicopter must also ensure the safety of any passengers, including patients requiring medical evacuation or other personnel involved in the mission. Medical systems on board must be designed to stabilize patients during transport, which includes securing patients in place and providing life-saving equipment. Likewise, cargo must be securely stored and prevented from shifting during flight, which could jeopardize the stability of the aircraft or the safety of its occupants.

6.1.2 Principal Safety Mechanisms

Passive Safety Systems:
Passive safety systems are designed to protect the helicopter, crew, and passengers during an accident or emergency. These systems aim to minimize injuries and damage through the aircraft's design and its onboard safety features. For example, the use of crash-resistant seats, structural reinforcement

to absorb impact forces, and fire-resistant materials in key areas of the helicopter's construction are essential. Passive safety also includes systems that reduce the chances of a catastrophic failure, such as fuel shut-off valves in the event of an emergency landing or the use of automatic fire suppression systems that engage when smoke or heat is detected.

The implementation of passive safety mechanisms is a proactive measure to ensure that even in the event of an emergency, the likelihood of fatal injuries or major aircraft damage is minimized. These mechanisms are essential because they provide a basic layer of protection without requiring action from the crew.

Preventive Maintenance and Monitoring:
Preventive maintenance and constant monitoring of the helicopter's systems are critical to ensuring that all operational components are functioning correctly. Maintenance protocols should be established to inspect and test key systems regularly, such as engines, avionics, hydraulics, and landing gear. This helps identify any potential issues before they lead to failure, reducing the likelihood of accidents caused by mechanical malfunctions. Additionally, continuous monitoring during flight is essential to detect irregularities in engine performance, fuel consumption, temperature, or vibration that could indicate a developing fault.

Preventive maintenance must include a detailed checklist to verify all aircraft components before and after each flight. The use of advanced diagnostic tools, such as vibration sensors, real-time data analytics, and automated alerts, enhances the ability to monitor and correct issues before they become critical. This process significantly reduces risks during operations, especially in complex and unpredictable environments.

Active Safety Measures:
Active safety measures focus on preventing accidents through pilot intervention, flight control systems, and real-time communication. These include systems like weather radar, collision avoidance technology, and emergency warning systems that alert the crew to potential hazards. Additionally, flight control systems that automate certain responses, such as autorotation in the event of engine failure, enhance the helicopter's safety by providing backup systems that can be relied upon in case of crew incapacity or system failure.

Active safety mechanisms are necessary to ensure that the crew is supported during the mission, particularly in high-risk environments. These technologies provide the crew with situational awareness and enable them to take quick action to avoid or mitigate accidents.

Training and Simulation:
Comprehensive training for the crew, including emergency response drills, ensures that they are prepared for a wide range of scenarios. Simulations of emergency situations, such as forced landings, system failures, or medical emergencies, are essential to ensuring that the crew knows how to respond quickly and effectively. This includes training in both technical skills and decision-making under stress, which is crucial in high-stakes humanitarian missions where the time for decision-making may be limited.

Regular training and the use of simulators are key to reducing human error during operations. They help the crew remain calm and efficient during high-pressure situations, improving safety outcomes and ensuring that all team members understand their roles during an emergency.

Compliance with Regulatory Standards:
Adhering to regulatory standards is essential when implementing safety mechanisms in the helicopter to ensure both legal compliance and operational reliability. These regulations, established by organizations such as EASA, ICAO, and national authorities (before commented), provide a framework that guarantees the helicopter meets international safety benchmarks. Compliance ensures that all

systems, from avionics to structural components, adhere to proven design and performance criteria, reducing risks associated with untested or non-standard solutions.

Regulatory standards also play a critical role in harmonizing operational procedures, ensuring that the helicopter can integrate seamlessly into existing airspace systems while maintaining compatibility with global aviation protocols. For example, requirements for collision avoidance systems or communication standards ensure the aircraft can operate safely in congested or complex airspace. Furthermore, adherence to these regulations demonstrates a commitment to safety, bolstering confidence among stakeholders, including operators, clients, and oversight agencies.

Implementing mechanisms in accordance with these standards not only ensures the aircraft's airworthiness and minimizes liabilities by adhering to established best practices, but also is mandatory to achieve in order to mitigates risks during inspections or certifications and ensures smooth operations, even in highly regulated environments.

Redundant Subsystems for Emergencies:
Redundant subsystems are vital for ensuring helicopter safety during emergencies or failures of critical components. These systems provide backup functionality for essential operations, such as avionics, power, hydraulics, and navigation, allowing the helicopter to maintain stability and control even if primary systems fail.

By implementing redundancy, the aircraft ensures continuous operation in scenarios like engine or control failures, giving the crew time to manage issues and safely complete the mission. This is particularly critical for humanitarian and emergency medical missions, where operational reliability directly impacts lives. Redundancy significantly reduces risks, enhances safety, and ensures mission success under adverse conditions.

Risk Prevention and Protocol Implementation:
These measures are designed not only to minimize the likelihood of accidents but also to provide clear guidance on how to respond effectively in emergency situations. Preventive strategies aim to identify potential hazards in advance, addressing them through proactive measures such as regular maintenance, crew training, and operational planning.

Protocols serve as structured guidelines that standardize responses to various scenarios, ensuring that the crew can act decisively and efficiently under pressure. Whether dealing with an unexpected mechanical failure, adverse weather conditions, or medical emergencies, having well-defined protocols reduces confusion and improves outcomes. They also foster consistency in safety practices, aligning the actions of all team members with the best practices and regulatory requirements.

By combining risk prevention strategies with detailed protocols, operators can reduce uncertainties, enhance operational resilience, and ensure that the helicopter is prepared for both routine missions and high-stakes emergencies. This dual focus on prevention and preparedness strengthens overall safety, safeguarding lives and mission-critical assets.

6.1.3 Summary

The safety of a humanitarian helicopter involved in cargo and HEMS missions is a multifaceted concern that involves various layers of protection. These layers range from the design of the aircraft and its safety systems to the mental and physical health of the crew. The implementation of effective passive safety systems, preventive maintenance protocols, and active safety measures is essential to minimize risks during operations. Equally important are training programs and human factor management, ensuring that the crew can effectively handle the stresses of these high-risk missions.

When properly addressed, these safety considerations contribute significantly to the successful execution of humanitarian missions, safeguarding both the lives of the crew and the patients or cargo they transport. Through a comprehensive approach, including proactive safety measures, robust preventive protocols, and crew readiness, the project ensures a safe, efficient, and reliable operation, even in the most challenging and unpredictable environments.

This analysis highlights the fundamental safety measures and protocols that need to be established and maintained to guarantee the protection of the helicopter, crew, passengers, and cargo during humanitarian missions. This encompasses aspects from the different technical departments of the project, addressing structural, avionics, performance, and passenger compartment-related issues. However, those more technical and specific aspects and related to regulatory compliance in certain areas have been treated in greater depth in the respective sections for each department, following the statements and mechanisms commented above.

6.2 Risk Assessment and Mitigation Strategies

Developing an innovative UAV capable of disaster response and medical evacuation presents both opportunities and risks. The less innovative aspects of the project, such as aerodynamics, structural design, and basic systems, will draw inspiration from existing technologies. This approach minimizes risks by leveraging established designs and methodologies. However, integrating advanced features such as remote piloting, human transportation capabilities, and versatile mission profiles presents significant challenges. These complexities may impact certification processes, technological reliability, and market acceptance. While these innovations offer distinct advantages, they also necessitate careful risk assessment and mitigation strategies.

6.2.1 Regulatory Burden for UAVs Carrying Passengers

Risk: Certifying UAVs designed to transport passengers poses substantial regulatory challenges. Currently, frameworks primarily address drones for logistics and surveillance. Organizations like the European Union Aviation Safety Agency (EASA) are developing standards for Urban Air Mobility (UAM) and passenger-carrying drones, but these are still evolving. Achieving type certification requires rigorous testing to ensure compliance with safety, performance, and operational standards.

- Passenger UAVs undergo stricter scrutiny due to the higher stakes involved.
- Regulatory uncertainties can delay market entry as authorities adapt to emerging technologies.
- Urban UAM systems, precursors to UAV passenger operations, have faced delays due to air traffic integration and public safety concerns. [148]

The absence of established certification pathways for passenger-carrying UAVs may lead to increased costs, extended timelines, and potential market hesitancy.

Mitigation Strategy: Time is a favorable factor, as the regulatory environment for passenger-carrying UAVs is expected to mature by the time the project reaches implementation. Regulatory bodies such as EASA and FAA are progressing towards frameworks for Urban Air Mobility (UAM), which will provide a more predictable and consolidated landscape. During this period, rigorous testing and validation of the UAV's safety and operational reliability can align with these evolving standards. Collaboration with UAM companies, can provide shared insights, while lobbying efforts within institutions may advocate for more favorable regulatory conditions.

6.2.2 Satellite Communication for Remote Piloting

Risk: Utilizing satellite communication for remote piloting, particularly through Iridium's Low Earth Orbit (LEO) satellite constellation, offers global coverage and reduced reliance on ground infrastructure. However, this approach presents risks:

- **Coverage Limitations:** While Iridium provides near-global coverage, maintaining real-time communication in remote or extreme environments may encounter blind spots or latency issues. [149]
- **Dependence on a Single Provider:** Relying solely on one LEO constellation makes the system vulnerable to disruptions or service outages.
- **Unproven Technology at Scale:** Combining heavy payload UAVs with satellite piloting on a global scale is relatively untested, posing challenges in meeting reliability and performance standards.
- **Client Confidence:** Convincing governments and agencies to adopt a satellite-dependent system will require extensive demonstrations to build trust in its reliability and security.

Mitigation Strategy: Mitigating risks associated with satellite communication involves actively monitoring the emergence of new Low Earth Orbit (LEO) constellations, such as Starlink and OneWeb, which may offer redundancy and enhanced global coverage. Continuous evaluation of satellite communication developments is crucial to integrate robust and future-proof systems. LEO connectivity is on the rise, which could gradually increase confidence in satellite-based systems. Additionally, participating in satellite communication congresses and industry gatherings can provide updates on advancements and foster collaborations with industry leaders, enhancing trust and reliability in satellite-operated systems.

6.2.3 Customer Profile and Geopolitical Risks

Risk: Trade wars and protectionist policies pose significant risks to the project's success. Escalating tariffs and trade restrictions could impact both the supply chain and market access:

- **Material Costs:** The UAV relies on advanced materials and components, some of which may need to be imported from non-European countries. Tariffs on these imports could increase production costs, reducing profitability.
- **Market Access:** Selling the UAV to non-European governments and companies could be hindered by protectionist measures that prioritize domestically produced technologies.
- **International Relations:** The current geopolitical climate could discourage some governments from purchasing European UAVs, particularly in regions with strained relations with the EU.

Mitigation Strategy: While the geopolitical risks associated with trade wars and protectionism are largely beyond direct control, preemptive steps can mitigate their impact. Advocacy against protectionist measures in key international trade institutions is essential to promote fair trade practices. Should tariffs or restrictions be implemented, reassessing supplier options and prioritizing domestic or regional providers may mitigate the impact. Exploring local alternatives could not only reduce reliance on international suppliers but also lower logistical complexities, ensuring greater flexibility in sourcing and market access. [150]

6.2.4 Versatility as a Double-Edged Sword

Risk: The UAV's versatility, designed to operate across missions from disaster response to medical evacuation and heavy payload transport, introduces market challenges:

- **Lack of Specialization:** Specialized competitors may outperform the UAV in niche markets. For example, a company focused solely on air ambulance services may offer more tailored solutions for medical emergencies.

- **Market Confusion:** Potential customers may struggle to understand or fully appreciate the value of a multipurpose platform, particularly if their needs align with a single application.
- **Operational Complexity:** A versatile design may require compromises in performance or cost-effectiveness compared to specialized alternatives, potentially reducing competitiveness.

Mitigation Strategy: To address versatility challenges, the UAV design can be adapted to meet specific customer needs. For exclusive air ambulance operators, a dedicated configuration focusing solely on medical operations can maximize appeal and competitiveness. For customers such as governments, which often require multipurpose solutions, a versatile platform capable of fulfilling diverse roles such as rescue missions, payload transport, and personnel deployment is more suitable. Tailoring the value proposition to emphasize versatility for those who need it and specialization for those who prioritize it ensures broader market acceptance. Research highlights that aligning value propositions with distinct customer profiles significantly enhances market appeal, satisfaction, and competitive advantage [151].

6.3 Quality

Quality management serves as a fundamental pillar of this VTOL project, ensuring the highest standards of safety, reliability, and performance are consistently achieved. Given the aircraft's mission to operate in critical scenarios such as medical emergencies and disaster response, quality is embedded throughout every phase—from design to operation.

The primary objective is to uphold rigorous international standards while delivering a product to the specific demands of its application. This includes minimizing operational risks, enhancing reliability, and ensuring compliance with all relevant aerospace regulations.

6.3.1 Compliance with AS9100 Standard

The VTOL project adheres to the AS9100 standard as the foundation of its quality management system (QMS), ensuring the highest level of quality in every phase of design, production, and operation. This compliance aligns the project with the rigorous demands of the aerospace industry, addressing the safety, reliability, and operational performance critical for medical emergencies and disaster response missions [152].

Key elements of AS9100 compliance include:

Risk Management:

- A comprehensive risk management process is integrated into the project, identifying and addressing potential failures in critical systems such as:
  - **Propulsion systems:** Risk assessments for engine redundancy and failure scenarios.
  - **Flight control systems:** Mitigation strategies for software or hardware failures.
  - **Payload handling:** Ensuring safe and reliable operation under various loading conditions.
- Risk controls include Failure Mode and Effects Analysis (FMEA) and regular design reviews.

Design and development
The design process incorporates AS9100 guidelines to ensure traceability and control:

- **Design validation:** Simulated and real-world testing to confirm the aircraft meets mission requirements.

- **Configuration management:** Rigorous control of design changes to maintain system integrity.
- **Documented requirements:** Every design specification is linked to its verification method, ensuring traceability and compliance.

Supply Chain Control

The project relies on a robust supplier management system.

- All materials and parts are subjected to traceability protocols to ensure compliance with design and safety standards.
- Supplier performance is monitored through regular audits and inspections.

Operational Planning and Control
The production process follows strict planning protocols.

- Assembly procedures are documented and verified to prevent deviations.
- Special processes, such as composite fabrication and rotor balancing, are validated according to AS9100 requirements.

Product Safety

Safety is a core focus, addressed by:

- Proactive identification of potential hazards in flight operations.
- Implementation of redundancies in control and communication systems, such as backup links using GEO satellites in addition to the primary LEO network.
- Comprehensive pre-flight checklists and automated monitoring systems.

Performance Monitoring and Evaluation To ensure the success of the VTOL project and adherence to the highest quality standards, a set of KPIs has been determined to monitor performance throughout design, production, and operational phases. Below are the most relevant KPIs for this project:

- **Prototype Success Rate:** Percentage of prototypes that meet all performance criteria during the first round of testing (target: $\geq 90\%$).
- **Production Defect Rate:** Percentage of components or systems found defective during assembly (target: $\leq 2\%$).
- **Rework Costs:** Proportion of the production budget spent on correcting defects (target: $\leq 3\%$).
- **Supplier On-Time Delivery Rate:** Percentage of suppliers delivering materials or components within the agreed schedule (target: $\geq 95\%$).
- **Test Repeat Rate:** Percentage of tests that require repetition due to failures or incomplete data (target: $\leq 5\%$). **Net Promoter Score (NPS):** Customer feedback score, indicating satisfaction and likelihood of recommending the product (target: $\geq 8/10$). **Warranty Claim Rate:** Proportion of units requiring repairs under warranty (target: $\leq 1\%$).

Audits and Continuous Improvement

- Regular internal and external audits are conducted to ensure adherence to AS9100 and identify areas for improvement.
- Corrective actions are implemented for any nonconformities detected.

6.4 Planning and scheduling

The planning and scheduling process is pivotal to ensuring the efficient execution of project tasks within the defined timeline and resource constraints.

6.4.1 Organisation

The project's organizational structure was carefully devised to ensure efficiency and clarity in task allocation and communication among team members. As illustrated in Figure 6.1, the project team is divided into five key areas: Aerodynamics, Power Plant and Performance, Structural Design and Materials, Project Management and Marketing, Payload and Operations, and Avionics, Simulation and Telecommunications. Each division focuses on specialized tasks aligned with the project's objectives.

The figure employs a color-coded system and symbols for better understanding:

- **Crown icons**: Represent team coordinator overseeing overall project alignment.
- **Yellow circles**: Denote individuals responsible for economic research.
- **Blue circles**: Indicate technical managers leading specific domains.

This section provides further details on the roles and responsibilities within each area, as well as the contributions of the highlighted team members to the project's success.

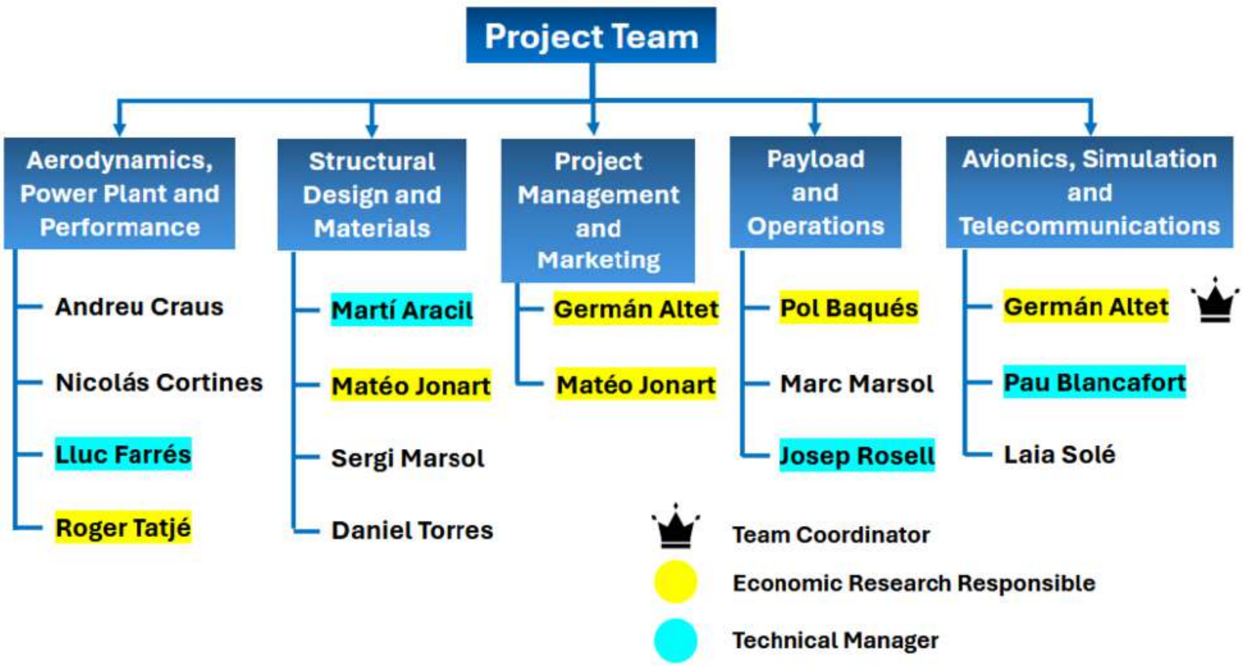


Figure 6.1: Project internal organization structure

6.4.1.1 Task Breakdown

Aerodynamics, Power Plant, and Performance: Conducting aerodynamic analysis of rotors and airframe, selecting the power plant based on performance and fuel efficiency, and evaluating the aircraft's electrical system. Weight and balance analysis is also included.

Structural Design and Materials: Creating the aircraft's overall structural design, performing structural analysis, developing 3D blueprints, and selecting materials based on performance and durability.

Project Management: Performing tasks related to project management and coordinating the non-technical tasks.

Payload and Operations Analysis: Defining the UAV's payload capacities and establishing operational procedures to ensure safe and efficient loading and unloading.

Avionics, Simulation, and Telecommunications: Defining the onboard and offboard equipment required, including system constraints for live UAV operations. Determining systems like radars and other technologies to be integrated into the aircraft.

6.4.1.2 Roles and Responsibilities

Project Coordinator: Germán Altet. Responsible for communication with the client and ensuring the proper functioning of the internal work structure.

Secretary: Rotational. One group member assumes the role every week, tasked with taking notes and preparing the meeting minutes.

Financial Responsibilities: There will be no dedicated team for financial aspects. However, one member from each team (highlighted in Figure 6.1) will take responsibility for the economic matters related to their area of work as well as projects management and marketing whose tasks will be coordinated by the Project Management group members. At the end of the project, when the overall financial feasibility is assessed, these members will collaborate to produce the required deliverables, thereby reducing the technical workload during that period.

Technical Managers: There will be a technical manager in each of the subgroups, responsible for coordination with other groups and the project coordinator. The technical managers are:

- Lluc Farrés
- Martí Aracil
- Josep Rosell
- Pau Blancafort

6.4.2 Initial Planning

The initial plan for the VTOL development project was structured around a comprehensive timeline to ensure efficient resource allocation and the delivery of the product within the desired timeframe.

6.4.2.1 Work Breakdown Structure (WBS)

The planning process was organized using a (WBS) to clearly define the project's scope and tasks, facilitating efficient management and coordination. It is divided into key subsystems and components, each further broken down into specific tasks:

1. UAV
   - 1.1 Power Plant
     - 1.1.1 Engine Selection (**PW1**)
     - 1.1.2 Power Transmission (**PW2**)
     - 1.1.3 Fuel System (**PW3**)
   - 1.2 Aerodynamic Surfaces
     - 1.2.1 Main Rotor Blades (**AD1**)
     - 1.2.2 Tail Rotor Blades (**AD2**)
     - 1.2.3 Fuselage Aerodynamics (**AD3**)
     - 1.2.4 Aerodynamic Stability and Control Surfaces (**AD4**)
   - 1.3 Performance Analysis
     - 1.3.1 Forward Flight Performance (**PF1**)
     - 1.3.2 Axial and Hover Flight Performance (**PF2**)
     - 1.3.3 Operating Conditions (**PF3**)
   - 1.4 Main Body
     - 1.4.1 Fuselage (**MB1**)
       - 1.4.1.1 Structure
       - 1.4.1.2 Systems Accommodation Parts
       - 1.4.1.3 Rotor System Integration
     - 1.4.2 Cabin (**MB2**)
       - 1.4.2.1 Cargo
       - 1.4.2.2 Medical Aid
       - 1.4.2.3 Passenger Compartment
     - 1.4.3 Cabin Ambientation
     - 1.4.4 Doors
   - 1.5 Landing Gear
     - 1.5.1 Wheel (**LG1**)
     - 1.5.2 Shock Absorber (**LG2**)
     - 1.5.3 Mounting System (**LG3**)
   - 1.6 Empennage
     - 1.6.1 Horizontal Stabilizer (**EP1**)
     - 1.6.2 Rudder (**EP2**)
     - 1.6.3 Tail Boom (**EP3**)
     - 1.6.4 Tail Rotor Accommodation (**EP4**)
   - 1.7 Avionics
     - 1.7.1 Control (**AV1**)
       - 1.7.1.1 Pilot Interface
       - 1.7.1.2 Landing Assistance System
       - 1.7.1.3 Connectivity Recovery Procedures
     - 1.7.2 Navigation (**AV2**)
       - 1.7.2.1 GNSS
       - 1.7.2.2 Terrain Mapping Systems
     - 1.7.3 Communications System (**AV3**)
     - 1.7.4 Electrical System Dimensionalisation (**AV4**)
   - 1.8 Operations
     - 1.8.1 Cargo Procedures (**OP1**)
     - 1.8.2 Medical Aid Procedures (**OP2**)
   - 1.9 Testing Procedures
     - 1.9.1 Power Plant Testing Procedures (**TS1**)
     - 1.9.2 Structural Testing Procedures (**TS2**)
     - 1.9.3 Payload Testing Procedures (**TS3**)
     - 1.9.4 Avionics Testing Procedures (**TS4**)
   - 1.10 Marketing and Communications
     - 1.10.1 Brand Development (**MC1**)
     - 1.10.2 Marketing Strategy (**MC2**)
     - 1.10.3 Communications Plan (**MC3**)
   - 1.11 Market Analysis
     - 1.11.1 Current Market Overview (**MA1**)
     - 1.11.2 Target Market and Customer Analysis (**MA2**)
     - 1.11.3 Economic Feasibility Study (**MA3**)
   - 1.12 Project Management
     - 1.12.1 Meeting Minutes (**PM1**)
     - 1.12.2 Budget (**PM2**)
     - 1.12.3 Requirements (**PM3**)
     - 1.12.4 Regulations (**PM4**)
     - 1.12.5 Schedule (**PM5**)

6.4.2.2 Gantt chart

The following Gantt chart represents the initial schedule, highlighting not only the sequence of activities but also the critical path identified in Figure 6.2 with a red dashed line, which identifies the tasks that directly influence the project's timeline. This chart provides a clear view of the project's workflow and dependencies, serving as a vital tool for managing progress and addressing potential risks.

The project spans a total duration of approximately **10 weeks**, as shown in Figure 6.2. Different components and activities of the project are executed in overlapping timelines to ensure efficient progression. Below is a summary of the main subtasks and their respective durations:

- The tasks related to the UAV aerodynamics, power plant and performance are scheduled over a period of approximately **6 weeks**. This timeline ensures that foundational components are ready early for further integration with other subsystems.
- Development of the main body spans around **6 weeks**, with its tasks scheduled in parallel with several other subtasks to optimize overall project timing.
- Avionics-related tasks extend for approximately **8 weeks**, while partially overlapping with other technical developments is also within the critical path.
- Operations and testing procedures, aimed at validating the system's functionality, are completed within approximately **4 weeks**, scheduled toward the later stages of the timeline.
- Marketing, communications, and project management tasks are starting at the first third of the project duration and expanding until the end, running across the entire project timeline, with a duration of nearly **7 weeks**.

6.4.2.3 Appendix Reference to Project Charter Details

The appendix H provides comprehensive documentation originating from the project charter, detailing the tasks and their respective work packages as outlined in the Work Breakdown Structure (WBS). This section includes:

- **Identification of tasks and work packages:** A systematic breakdown of tasks categorized by unique identifiers and descriptions to ensure clarity and traceability.
- **Interdependencies among tasks:** A summary of the relationships and sequence of tasks, highlighting dependencies to facilitate project scheduling and resource allocation.
- **Human resources and effort allocation:** An estimation of the personnel required, including their roles, expertise, and the level of effort (in hours) necessary to accomplish each task.
- **Human resources and effort allocation:** An estimation of the personnel required, including their roles, expertise, and the level of effort (in hours) necessary to accomplish each task.

- **Budget breakdown:** Initial cost estimations for the preliminary study, covering human resources, software and hardware tools, and a contingency margin to account for potential risks and adjustments.

This appendix serves as a reference to guide the development and management of the project, ensuring alignment with the objectives and efficient use of resources. For detailed tables, figures, and additional descriptions, refer to the corresponding subsections in the appendix.

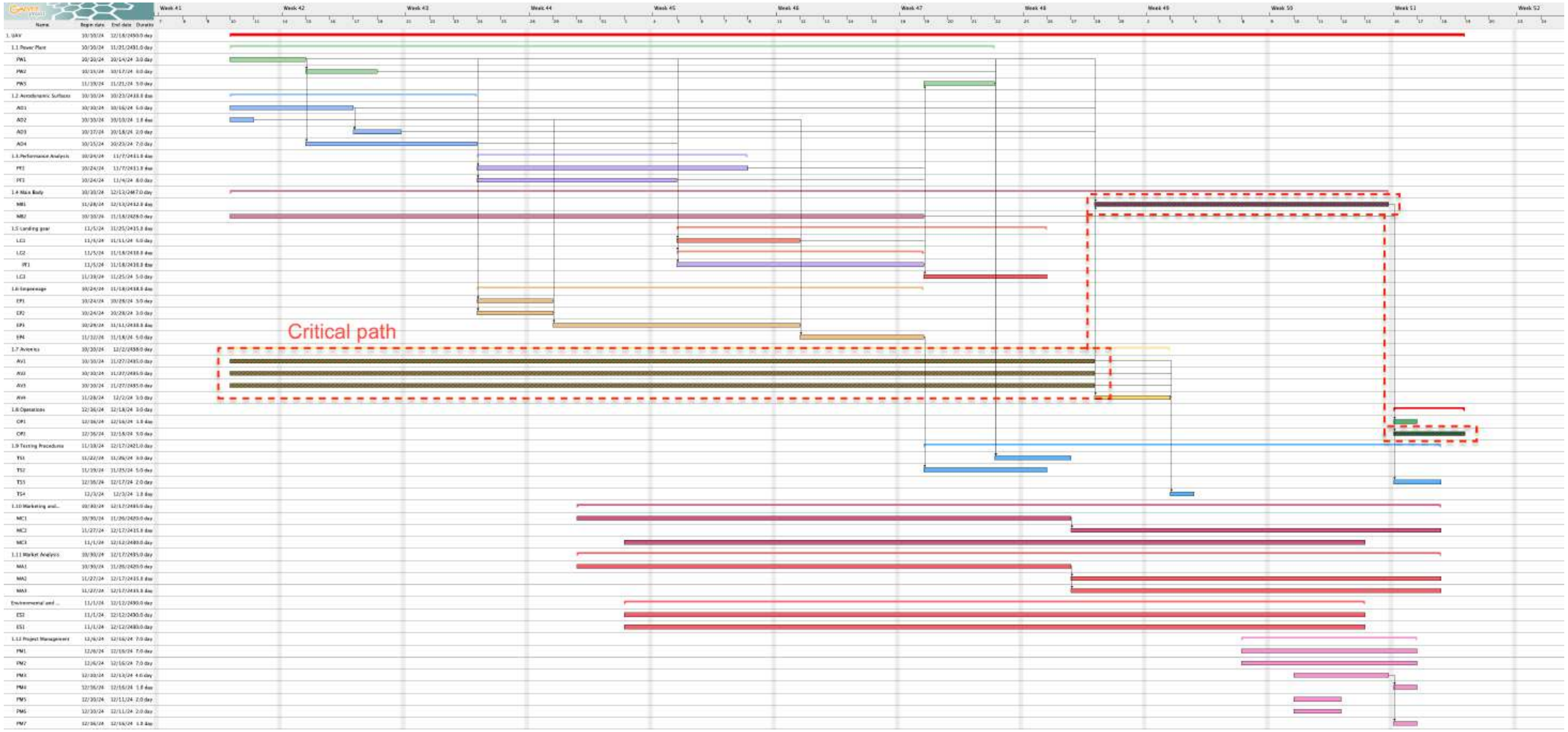


Figure 6.2: Gantt chart and critical path

6.4.3 Modifications & Considerations

Chapter 7

Regulation

7.1 Main organizations

It is essential to thoroughly research and comply with existing UAV regulations, as they are established by international and national aviation authorities to ensure safety and operational integrity. Adhering to these regulations is crucial because without compliance, our UAV will not receive the necessary authorization to operate. These rules govern critical aspects such as flight safety, airworthiness, and communication systems, and failure to meet them can result in the denial of flight permits. Therefore, aligning our project with these regulations is vital for its successful integration into the airspace and its acceptance by regulatory bodies.

In Europe, some of the the main organizations with the most relevant regulations are:

- **European Union Aviation Safety Agency (EASA):** Oversees safety and regulatory frameworks for all civil aviation across the EU, including UAVs.
- **International Civil Aviation Organization (ICAO):** Establishes global standards and recommended practices for aviation safety, including unmanned systems.
- **Agencia Estatal de Seguridad Aérea (AESA - Spain):** Spain's national aviation authority responsible for enforcing EASA regulations and managing UAV operations within Spanish airspace.
- **European Telecommunications Standards Institute (ETSI):** Ensures compliance with communications standards critical for UAV command and control systems.
- **Single European Sky (SES) Authorities:** Regulates air traffic management to ensure integration of UAVs into the broader European airspace.
- **European Organisation for Civil Aviation Equipment (EUROCAE):** Provides guidance on performance specifications and standards for UAV technologies.
- **European Union Agency for Cybersecurity (ENISA):** Governs cybersecurity standards for UAV systems to prevent data breaches and hacking risks.

Among those institutions, we have chosen to focus on AESA, EASA, and ICAO as the primary regulatory bodies for the legal framework of our UAV project due to their comprehensive and complementary roles in aviation safety and regulation. EASA provides a unified regulatory framework across Europe, ensuring that our project meets the necessary safety and operational standards for UAVs within European airspace. AESA, as the national authority in Spain, does a similar job in national scale, while ICAO's global standards provide an internationally recognized foundation for our UAV's compliance. By adhering to these three key bodies, we ensure our project meets both European and international standards, facilitating smooth integration into the airspace and ensuring regulatory approval and operational safety on a global scale.

7.2 Main regulations

The most important regulations referring to our project for each organization are:

7.2.1 Agencia Estatal de Seguridad Aérea (AESA - Spain)

Real Decreto 1036/2017 [153]

Scope: Governs the use of UAVs in Spanish airspace, detailing operational and safety requirements for diverse UAV applications, including cargo and humanitarian missions. It aligns with EASA's broader regulations while adding Spain-specific considerations.

Main Provisions:

- **Operational Categories:** UAVs are classified based on their use case and weight, ranging from low-risk recreational drones to high-risk professional operations such as BVLOS (Beyond Visual Line of Sight) in urban or controlled airspace. Limits are placed on flight altitudes and distances (e.g., flights within visual line of sight are capped at 120 meters altitude).
- **Authorization Requirements:** Operators performing BVLOS missions or operating in high-density areas must apply for special authorization, including detailed mission plans and risk mitigation strategies.
- **Geofencing and Safety Systems:** UAVs flying near restricted zones (e.g., airports, military bases) must have geofencing capabilities to prevent unauthorized access. Collision-avoidance systems are required for UAVs operating near manned aircraft corridors.
- **Training and Certification:** UAV pilots are required to undergo certified training programs and pass practical examinations for operations in the "specific" and "certified" categories.

Ley 21/2003 de Seguridad Aérea [154]

Scope: Provides the overarching legal framework for aviation safety in Spain, applying to all aircraft, including UAVs, to ensure the safety of operations and the public.

Main Provisions:

- **Registration and Oversight:** All UAVs exceeding a specific weight or intended for commercial use must be registered with EASA. Operators must maintain flight logs and operational data for auditing purposes.
- **Airworthiness Compliance:** UAVs must meet technical requirements for reliability, particularly for critical missions like medical aid. Equipment inspections are mandated at regular intervals.
- **Enforcement Mechanisms:** Violations of safety regulations result in significant penalties, including fines or suspension of operational licenses.
- **Alignment with EU Regulations:** AESA enforces EASA regulations at the national level while incorporating local adaptations where necessary.

7.2.2 European Union Aviation Safety Agency (EASA - EU)

Regulation (EU) 2018/1139 [155]

Scope: Establishes EASA's authority to regulate civil aviation in the EU, including the operation of UAVs for both recreational and commercial purposes.

Main Provisions:

- **Safety Oversight:** EASA sets safety objectives for UAV operations and oversees compliance through national aviation authorities (e.g., AESA in Spain).
- **Centralized Certification:** High-risk UAVs in the "certified" category (e.g., those carrying cargo or passengers) must be EASA-certified, ensuring harmonized standards across member states.
- **Stakeholder Collaboration:** Encourages cooperation between manufacturers, operators, and regulators to continuously update safety standards.

EASA UAV Operational Manual Guidelines [156]

Scope: Requires operators to submit a comprehensive operational manual as part of their authorization process.

Main Provisions:

- **Risk Assessment:** Operators must include specific risk assessments for each mission, highlighting how potential hazards (e.g., loss of GPS signal) are mitigated.
- **Operational Details:** Manuals must document standard operating procedures (SOPs), emergency protocols, and maintenance schedules.
- **Approval and Updates:** EASA reviews and approves the manual before operations commence. Any significant changes must be resubmitted for approval.

Commission Implementing Regulation (EU) 2019/947 [157]

Scope: Defines operational requirements for UAVs under three categories: open, specific, and certified.

Main Provisions:

- **Open Category:** Covers low-risk operations (e.g., visual line of sight with a maximum weight of 25 kg). Requires basic compliance with rules like no-fly zones and line-of-sight operation.
- **Specific Category:** UAV operators must submit a Specific Operations Risk Assessment (SORA) for approval. This involves identifying risks, assessing severity, and outlining mitigation measures.
- **Certified Category:** Includes the most demanding requirements, such as type certification, certified remote pilots, and stringent maintenance protocols. Equivalent to manned aviation standards.

Commission Delegated Regulation (EU) 2019/945 [158]

Scope: Specifies design, manufacturing, and marketing requirements for UAVs in the EU.

Main Provisions:

- **UAS Categorization:** Establishes three categories of UAS operations—Open, Specific, and Certified—based on risk levels and operational complexity.
- **CE Marking and Product Standards:** Requires UAS and their components to carry CE marking, ensuring compliance with EU safety, health, and environmental standards.
- **Electronic Identification and Geo-awareness:** Mandates features like remote identification and geo-awareness to enhance operational safety and ensure regulatory compliance.
- **Manufacturer and Importer Obligations:** Specifies responsibilities for ensuring product compliance, providing documentation, and enabling traceability through unique serial numbers.

Part-SERA (Standardised European Rules of the Air) [159]

Scope: Establishes the air traffic rules for unmanned aerial vehicles (UAVs), integrating their operation with manned aircraft under a set of harmonized rules for European airspace.

Main Provisions:

- **Visual flight rules (VFR) and instrument flight rules (IFR):** Regulates how UAVs must operate in European airspace to avoid collisions with manned aircraft.
- **Airspace restrictions:** Defines flight restrictions for UAVs in specific areas, such as high-density air traffic zones or air traffic control (ATC) areas.
- **Separation requirements:** Specifies the minimum distance UAVs must maintain from other aircraft to ensure safety.

EASA Easy Access Rules for Unmanned Aircraft Systems (UAS) [160]

Scope: Consolidates and provides easy access to all European Union Aviation Safety Agency (EASA) regulations related to unmanned aircraft systems, offering a user-friendly guide to implementing UAV-related rules across Europe.

Main Provisions:

- **Operational categories:** UAVs are divided into different operational categories (open, specific, and certified), each with its own safety requirements.
- **UAV certification:** Establishes the need for type certification and remote pilot training for operating UAVs in the certified category, ensuring safety for higher-risk missions (e.g., cargo, medical).
- **Notification and oversight requirements:** Operators must notify local authorities of specific UAV operations and comply with oversight and auditing requirements.

7.2.3 International Civil Aviation Organization (ICAO - Global)

Annex 6, Part I [161]

Scope: Establishes operational requirements for commercial air transport, including UAVs used for cargo or medical aid.

Main Provisions:

- **Flight Safety:** UAV operators must establish pre-flight checklists, operational risk assessments, and emergency response plans.
- **Performance Monitoring:** Real-time monitoring of UAV performance (e.g., engine health, navigation) is mandatory during missions.
- **Safety Management Systems (SMS):** Operators must implement SMS programs to identify and manage operational risks.

Annex 8 [162]

Scope: Specifies airworthiness requirements for UAVs.

Main Provisions:

- **Structural Integrity:** UAVs must undergo rigorous design and structural testing to ensure reliability during operations.
- **Redundancy and Fail-Safe Systems:** Critical systems (e.g., propulsion, navigation) must have redundancies to prevent failure in high-risk scenarios.

Doc 10019 – Manual on Remotely Piloted Aircraft Systems (RPAS) [163]

Scope: Provides a detailed framework for UAV integration into controlled airspace.

Main Provisions:

- **Communication Systems:** UAVs must be equipped with reliable command and control links, compatible with air traffic systems.
- **Airspace Coordination:** Operators must ensure seamless interaction with manned aircraft, particularly in controlled airspace.

Annex 19 (Safety Management Systems) [164]

Scope: Defines the requirements for implementing Safety Management Systems (SMS) in the operation of both manned and unmanned aircraft, to manage and mitigate operational risks.

Main Provisions:

- **Operational safety requirements:** Requires operators to implement safety management systems to assess and mitigate risks during UAV operations.
- **Risk assessment:** Operators must identify, assess, and mitigate risks associated with their operations using risk management tools, safety procedures, and internal audits.
- **Emergency response plans:** UAV operators must develop and maintain emergency response plans that cover potential failure scenarios, loss of communication, and other operational risks.

Global Air Navigation Plan (GANP) [165]

Scope: Establishes guidelines and strategies for the integration of UAVs into the global air navigation system, ensuring a smooth and safe transition for UAV traffic within manned air traffic systems.

Main Provisions:

- **UAV traffic management:** Provides principles for managing UAV traffic in integration with manned aircraft to ensure safety and efficiency in global airspace.
- **Communication and control technologies:** Focuses on the implementation of advanced communication and control technologies to ensure UAVs can safely operate within controlled airspace and in harmony with other aircraft.
- **Global planning and coordination:** Encourages international cooperation in the regulation and standardization of UAV operations in global airspace, promoting the harmonization of policies at the worldwide level.

The certification of this UAV, including cargo transport and emergency medical services, faces substantial regulatory challenges under the current frameworks established by the aviation authorities mentioned. These regulations were primarily developed for manned aircraft and impose rigorous standards that do not easily accommodate the unique operational characteristics of unmanned systems. However, there are realistic indicators that these barriers may ease in the near future, enabling projects like this to achieve legal certification.

One of the primary challenges lies in meeting airworthiness requirements. UAVs are subject to frameworks like EASA Part 21 [105], which ensure the structural, mechanical, and electronic reliability of aircraft. These standards often assume the presence of onboard pilots and traditional cockpit systems, which are entirely absent in UAVs. The command and control (C2) systems for UAVs must not only match the reliability of human pilots but also ensure continuous communication links, especially in remote areas where these missions are most needed. Demonstrating this level of reliability is particularly difficult given the technological maturity required and the critical scrutiny placed on unmanned operations entering congested civilian airspace.

Additionally, regulations such as those outlined in ICAO Annex 6 impose strict operational standards, including requirements for Detect and Avoid systems to prevent collisions. UAVs must seamlessly integrate into existing air traffic management systems, ensuring they can safely operate alongside manned aircraft without disrupting flight operations. Current technology has made progress in this area, but the complexity of ensuring reliable interaction with ATC systems presents a significant regulatory barrier.

For a UAV helicopter serving HEMS missions, specific compliance challenges arise. Regulations mandate that onboard medical equipment be accessible and operable during flight, typically assuming the presence of medical personnel. The absence of a crew complicates adherence to these standards, raising questions about how UAVs can ensure patient safety or respond to emergencies en route. Furthermore, standards like EASA CAT.POL.H.225 (from [104]) require secure handling and protection for transported patients or critical medical supplies, adding further complications to unmanned operations.

Despite these hurdles, there are compelling reasons to believe that these regulatory challenges may ease in the near future. The rapid development of UAV technology and its increasing adoption in civilian sectors are driving regulatory reforms. For example, EASA and ICAO have already introduced specific frameworks for drones and unmanned systems, such as the EASA "U-Space" [166] regulation and ICAO's proposed amendments for integrating UAVs into controlled airspace. These frameworks aim to address the unique needs of UAVs, paving the way for their broader acceptance in diverse applications.

Additionally, the proven utility of UAVs in humanitarian aid, particularly during natural disasters and emergencies, is shifting public and regulatory perceptions. UAVs have demonstrated their ability to deliver medical supplies, food, and equipment to inaccessible regions faster and more efficiently than traditional methods. As the societal benefits of UAVs become clearer, regulatory bodies are likely to adopt a more accommodating stance, especially for missions with high humanitarian impact.

The ongoing advancements in artificial intelligence and machine learning also bolster the case for UAVs. These technologies enable more reliable autonomous operations, from navigation to collision avoidance, making UAVs safer and more predictable. As these capabilities mature, they will reduce the perceived risks associated with unmanned systems, encouraging regulators to revise existing standards to reflect technological progress.

Finally, political and economic pressures to modernize aviation systems are creating momentum for regulatory change. Governments and industry leaders recognize the potential of UAVs to revolutionize logistics and emergency response, aligning with sustainability and innovation goals. These forces are likely to drive updates to regulatory frameworks, allowing projects like the humanitarian UAV helicopter to gain certification and operate within legal parameters.

In conclusion, while significant regulatory challenges currently restrict the certification of UAV helicopters for humanitarian missions, there is a clear trajectory toward a more favorable environment. Technological advancements, shifting perceptions, and evolving regulatory frameworks are aligning to support the integration of UAVs into critical operations. As these trends continue, the legal and operational feasibility of such projects will improve, enabling them to deliver on their transformative potential in the coming years.

Chapter 8

Conclusions & Lessons Learnt

Bibliography

[1] AeroBoek. Airbus h175 order book, 2023. URL https://www.aeroboek.nl/ab-038.htm.

[2] Grand View Research. Air ambulance services market size, share & trends analysis report, 2023. URL https://www.grandviewresearch.com/industry-analysis/air-ambulance-services-market.

[3] Hunini. T700-ihi-401c2 engine left side view at jmsdf maizuru air station july 16, 2016. Wikimedia Commons, July 2016. URL https://commons.wikimedia.org/w/index.php?curid=50843308. Own work, CC BY-SA 4.0.

[4] Ira H. Abbott and Albert E. von Doenhoff. Theory of Wing Sections, Including a Summary of Airfoil Data. Dover Publications, Inc., New York, 1959. Unabridged and corrected republication of the work originally published by McGraw-Hill Book Company, Inc., 1949.

[5] Steam Community. Helicopter center of gravity visual guide, n.d. URL https://steamcommunity.com/sharedfiles/filedetails/?id=440071256. Accessed: 21-Oct-2024.

[6] Author(s) Name(s). Power-to-weight ratio, Year. URL URL. Accessed: Date of Access.

[7] SKYTRAC. Ims-350: Broadband uav satcom, 2021. URL https://www.skytrac.ca/products/broadband-uav-satcom/ims350/.

[8] YellowScan. Lidar vs. radar: A comprehensive comparison, 2020. URL https://www.yellowscan.com/knowledge/lidar-vs-radar/.

[9] Nanxi Li, Chong Pei Ho, Jin Xue, Leh Woon Lim, Guanyu Chen, Yuan Hsing Fu, and Lennon Yao Ting Lee. A progress review on solid-state lidar and nanophotonics-based lidar sensors. Laser & Photonics Reviews, 16(11):n/a, 2022. doi: 10.1002/lpor.202100511.

[10] Joon Yeop Lee, Albert Y. Chung, Hooyeop Shim, Changhwan Joe, Seongjoon Park, and Hwangnam Kim. Uav flight and landing guidance system for emergency situations. Sensors, 19(20): 4468, 2019. doi: 10.3390/s19204468.

[11] Martin P. M. Hall. Effects of the troposphere on radio communication. 1979. URL https://api.semanticscholar.org/CorpusID:128642580.

[12] Joseph H. Mancini. An overview of advancements in helicopter transmission design. Technical Report NASA-TM-83741, NASA, 1983. URL https://ntrs.nasa.gov/api/citations/19830011853/downloads/19830011853.pdf. AVRADCOM/NASA Advanced Transmission Development Investigation.

[13] bzig. Helicopter gear reduction, 2024. URL https://youtu.be/iG0WC2ewM4I. Accessed: 2024-11-06.

[14] Miguel A. Barcala Montejano and Ángel A. Rodríguez Sevillano. Power transmission system in helicopters, 2010. Course document on helicopter power transmission.

[15] Daniel Yago. Disseny d'aeronaus - ch. 1 - introduction, 2024. URL mailto:daniel.yago@upc.edu. Course notes for 2024-2025 Q1.

[16] Robertson Fuel Systems. Crash-resistant fuel tank (crft), n.d. URL https://robertsonfuelsystems.com/commercial/crash-resistant-fuel-tank-crft/. Accessed: 2024-12-05.

[17] Robertson Fuel Systems. Crash-resistant fuel tank (crft), 2024. URL https://robertsonfuelsystems.com/commercial/crash-resistant-fuel-tank-crft/. Accessed: 2024-11-27.

[18] Airbus Helicopters. H125 crash-resistant fuel system (crfs) presentation, 2018. URL https://www.pilotopolicial.com.br/wp-content/uploads/2018/05/H125-CRFS-Presentation-v1.5-Draft.pdf. Accessed: 2024-11-27.

[19] Kim Christensen and Ben Welsh. Danger spins from the sky: The robinson r44, the world's best-selling civilian helicopter, has a long history of deadly crashes. Los Angeles Times, 2018. URL https://www.latimes.com/projects/la-me-robinson-helicopters/. Accessed: 2024-11-27.

[20] Roman Reß, Moritz Grawunder, and Christian Breitsamter. Aerodynamic analysis of a helicopter fuselage with rotating rotor head. In 5th European Conference for Aeronautics and Space Sciences (EUCASS), Munich, Germany, 2013. EUCASS Association. Published by the EUCASS association with permission.

[21] Bloques AutoCAD. Transportes aéreos, 2024. URL https://www.bloquesautocad.com/descargas/vehiculos/aereos/transportes_aereos_06.htm#google_vignette. Accessed: December 6, 2024.

[22] Airfoil Tools. Airfoil plotter (naca2412-il), n.d. URL http://airfoiltools.com/plotter/index?airfoil=naca2412-il. Accessed:21-10-2014.

[23] AirfoilTools. Naca 0012 airfoil details, 2024. URL http://airfoiltools.com/airfoil/details?airfoil=n0012-il. Accessed: 21-Oct-2024.

[24] International Civil Aviation Organization. Manual for ICAO Aeronautical Mobile Satellite (Route) Service Part 2 - IRIDIUM. International Civil Aviation Organization.

[25] OpenAI. Schematic illustration of a helicopter flying low in a mountain valley. DALL-E image generated in ChatGPT, 2024. URL https://chat.openai.com/.

[26] GE Aerospace. T700-701d engine datasheet, 2024. URL https://www.geaerospace.com/sites/default/files/datasheet-T700-701D.pdf. Accessed: 2024-10-14.

[27] Stephen B. Heppe. Problem of UAV Communications, page 30. Springer Science+Business Media Dordrecht, 2015. doi: 10.1007/978-90-481-9707-1_30.

[28] RTCA SC-203. Guidelines for uas command and control (c2). Technical report, May 2009. RTCA SC-203 CC008.

[29] ITU-R. International telecommunication union - recommendations. Technical report, 2009.

[30] Copernicus. Copernicus Digital Elevation Model Product Handbook, April 2024. URL https://spacedata.copernicus.eu/documents/20123/121239/GEO1988-CopernicusDEM-SPE-002_ProductHandbook_I4.0.pdf. Accessed: 2024-11-06.

[31] Humanitarian Dispatches. 5 essentials for the first 72 hours of disaster response, 2019. URL https://medium.com/humanitarian-dispatches/5-essentials-for-the-first-72-hours-of-disaster-response-51746452bc88. Accessed: 2024-11-26.

[32] Zipline. Transforming healthcare logistics with autonomous delivery drones, 2023. URL https://www.flyzipline.com/.

[33] Swoop Aero. Swoop aero: Advancing global healthcare through drone logistics, 2023. URL https://swoop.aero/.

[34] Joby Aviation. Joby aviation: Pioneering electric vtol, 2023. URL https://www.jobyaviation.com/.

[35] Volocopter. Volocopter: Next-gen air mobility, 2023. URL https://www.volocopter.com/en/.

[36] Avion Revue Internacional. Airbus helicopters firma su mayor contrato de soporte hcare para un cliente civil, 2021. URL https://www.avionrevue.com/helicopteros/airbus-helicopters-firma-su-mayor-contrato-de-soporte-hcare-para-un-cliente-civil/.

[37] Government Flying Service. Aircraft of the government flying service: Photo gallery, 2023. URL https://www.gfs.gov.hk/en/multimedia-centre/photo-gallery/aircraft/index.html.

[38] H175 technical information, . URL https://www.airbus.com/en/products-services/helicopters/civil-helicopters/h175/h175-technical-information?utm_source=chatgpt.com.

[39] Airbus h175 price range, . URL https://www.businessairnews.com/hb_aircraftpage.html?recnum=EC175#:~:text=Totals%20and%20company%20lists%20below,site%20filter%20for%20other%20regions.&text=Typical%20price%3A%20%2415%2C301%2C000%20to%20%2418%2C743%2C000,H175%20%2418%2C743%2C000%20new.

[40] Aw189 heavy twin helicopter overview, . URL https://www.bristowgroup.com/fleet/heavy-twins/leonardo-aw189.

[41] Aw189 product details, . URL https://helicopters.leonardo.com/en/products/aw189-1.

[42] Leonardo aw189 price range, . URL https://www.businessairnews.com/hb_aircraftpage.html?recnum=AW189#:~:text=Typical%20price%3A%20%244%2C860%2C000%20to%20%2416%2C000%2C000,AW189%20%2416%2C000%2C000%20new.

[43] Sikorsky s-92 multi-mission helicopter brochure, . URL https://lockheedmartin.com/content/dam/lockheed-martin/rms/documents/s-92/9244_S-92%20MM_Brochure_2024_1.pdf.

[44] Sikorsky s-92 history and specifications, . URL https://sikorskyarchives.com/home/sikorsky-product-history/helicopter-innovation-era/sikorsky-s-92/.

[45] Sikorsky s-92 price range, . URL https://www.paramountbusinessjets.com/private-jet-charter/aircraft/sikorsky-s-92#:~:text=Sikorsky%20S%2D92%20Private%20Charter%20Flights%20and%20Prices&text=The%20average%20purchase%20price%20of,S%2D92%20is%2025%2C000%2C000%20USD.

[46] Bell 525 relentless overview, . URL https://experience.bellflight.com/bell-525-kiosk/p/6.

[47] Bell 525 relentless features and specifications, . URL https://www.tamaviacaoexecutiva.com.br/venda-de-aeronaves/helicopteros/bell-525-relentless?locale=en.

[48] Bell 525 price range, . URL https://www.businessairnews.com/hb_aircraftpage.html?recnum=B525.

[49] Bristow Group. Bristow upgrades fleet with new aw189 helicopters to meet growing demand, 2022. URL https://www.bristowgroup.com/news-media/press-releases/detail/552/bristow-upgrades-fleet-with-new-aw189-helicopters-to-meet.

[50] Lockheed Martin. Sikorsky delivers production number 300 s-92® helicopter to era group inc., 2018. URL https://news.lockheedmartin.com/2018-02-28-Sikorsky-Delivers-Production-Number-300-S-92-R-Helicopter-to-Era-Group-Inc.

[51] AeroBoek. Bell order book, 2023. URL https://www.aeroboek.nl/ab-025.htm.

[52] GE Aerospace. Ct7 turboprop engine, 2024. URL https://www.geaerospace.com/commercial/aircraft-engines/ct7. Accessed: 15-Oct-2024.

[53] Pratt & Whitney. Pt6c helicopter engine, 2024. URL https://www.prattwhitney.com/en/products/helicopter-engines/pt6c. Accessed: 15-Oct-2024.

[54] Safran Group. Makila, le moteur d'hélicoptère le plus performant et fiable de sa catégorie, 2024. URL https://www.safran-group.com/fr/produits-services/makila-moteur-dhelicoptere-plus-performant-fiable-sa-categorie-0. Accessed: 15-Oct-2024.

[55] Lijalem Gebrehiwet, Yared Nigussei, and Tesfu Teklehaymanot. A review-differentiating tv2 and tv3 series turbo shaft engines. International Journal of Research Publication and Reviews, 3(8): 1822–1838, 2022. doi: 10.55248/gengpi.2022.3.8.51. URL https://www.ijrpr.com.

[56] Safran Group. Arriel 2c / 2c2, the engine of the airbus dauphin helicopter, 2024. URL https://www.safran-group.com/products-services/arriel-2c-2c2-engine-airbus-dauphin-helicopter. Accessed: 15-Oct-2024.

[57] Safran Group. Ardiden 3g obtains easa type certification, 2017. URL https://www.safran-group.com/pressroom/ardiden-3g-obtains-easa-type-certification-2017-06-19. Accessed: 15-Oct-2024.

[58] National Air and Space Museum. General electric t58-ge-8f turboshaft engine, 2024. URL https://airandspace.si.edu/collection-objects/general-electric-t58-ge-8f-turboshaft-engine/nasm_A19920060000. Accessed: 15-Oct-2024.

[59] This Day in Aviation. General electric t700-ge-700, n.d. URL https://www.thisdayinaviation.com/tag/general-electric-t700-ge-700/. Accessed: 2024-11-04.

[60] Airbus. Products & services - helicopters, 2024. URL https://www.airbus.com/en/products-services/helicopters. Accessed: 26-Oct-2024.

[61] The Boeing Company. Boeing defense - rotorcraft, 2024. URL https://www.boeing.com/defense/rotorcraft. Accessed: 23-10-2024.

[62] Bell Textron Inc. Bell flight - home page, 2024. URL https://www.bellflight.com/. Accessed: 23-10-2024.

[63] John D. Anderson Jr. Introduction to Flight. McGraw-Hill Education, 2021.

[64] John D. Anderson Jr. Fundamentals of Aerodynamics. McGraw-Hill Education, 2017.

[65] Daniel P. Raymer. Aircraft Design: A Conceptual Approach. American Institute of Aeronautics and Astronautics, 2018.

[66] Certification Specifications, Acceptable Means of Compliance and Guidance Material for Large Rotorcraft (CS-29). EASA, 2023. Amendment 11, ED Decision 2023/001/R, European Union Aviation Safety Agency, accessed from http://easa.europa.eu/.

[67] Aviation Broker. Dauphin as365 n3 technical data, 2024. URL https://www.aviation-broker.com/fileadmin/user_upload/flugzeuge/helikopter/dauphin_AS365N/TD_AS365_N3.pdf. Accessed: 26-Oct-2024.

[68] Aviators Database. Ec130 b4 technical data, 2024. URL https://www.aviatorsdatabase.com/wp-content/uploads/2013/07/EC130-B41.pdf. Accessed: 26-Oct-2024.

[69] European Union Aviation Safety Agency. Certification Specifications, Acceptable Means of Compliance and Guidance Material for Large Rotorcraft (CS-29). European Union Aviation Safety Agency, Cologne, Germany, 2024. URL https://www.easa.europa.eu/document-library/certification-specifications/cs-29.

[70] J. D. Anderson. Introduction to Flight. McGraw-Hill Education, New York, 7th edition, 2016.

[71] Dominik B. Schwinn, Peter Weiand, Matthias Schmid, and Michel Buchwald. Structural sizing of a rotorcraft fuselage using an integrated design approach. In ICAS 2018 Proceedings. German Aerospace Center (DLR), 2018. URL mailto:dominik.schwinn@dlr.de.

[72] FAO. Density database, n.d. URL https://www.fao.org/fileadmin/templates/food_composition/documents/upload/Density_databse_v1_final.pdf. Accessed: 2024-11-28.

[73] Engineering Toolbox. Density of materials, n.d.. URL https://www.engineeringtoolbox.com/density-materials-d_1652.html. Accessed: 2024-11-28.

[74] AquaCalc. Food volume to weight calculator, n.d. URL https://www.aqua-calc.com/calculate/food-volume-to-weight. Accessed: 2024-11-28.

[75] Medical Wholesale. Bandages and gauze, n.d. URL https://store.medicalwholesale.com/products/Bandages-Gauze.asp. Accessed: 2024-11-28.

[76] Engineering Toolbox. Density of materials, n.d.. URL https://www.engineeringtoolbox.com/density-materials-d_1652.html. Accessed: 2024-11-28.

[77] Outdoor Life. Best emergency blankets, n.d. URL https://www.outdoorlife.com/gear/best-emergency-blankets/. Accessed: 2024-11-28.

[78] Outdoor Gear Lab. Best camping tent, n.d.. URL https://www.outdoorgearlab.com/topics/camping-and-hiking/best-camping-tent. Accessed: 2024-11-28.

[79] Gear Junkie. Best fire starter, n.d.. URL https://gearjunkie.com/outdoor/best-fire-starter. Accessed: 2024-11-28.

[80] Engineering Toolbox. Density of materials, n.d.. URL https://www.engineeringtoolbox.com/density-materials-d_1652.html. Accessed: 2024-11-28.

[81] Outdoor Gear Lab. Best sleeping bag, n.d.. URL https://www.outdoorgearlab.com/topics/camping-and-hiking/best-sleeping-bag. Accessed: 2024-11-28.

[82] Hildebranski. Search and rescue gear list, n.d. URL https://hildebranski.com/search-and-rescue-gear-list/. Accessed: 2024-11-28.

[83] Treeline Review. Best personal locator beacons, n.d. URL https://www.treelinereview.com/gearreviews/best-personal-locator-beacons. Accessed: 2024-11-28.

[84] Outdoor Gear Lab. Best first aid kit, n.d.. URL https://www.outdoorgearlab.com/topics/camping-and-hiking/best-first-aid-kit. Accessed: 2024-11-28.

[85] Satellite Phone Store. Satellite phones, n.d. URL https://satellitephonestore.com/?srsltid=AfmBOopIWedfNrU-ex6PIH8U3YE7JM9hSOE4TVkbACUC7tXgctIADFCe. Accessed: 2024-11-28.

[86] Gear Junkie. Best walkie-talkies, n.d.. URL https://gearjunkie.com/technology/best-walkie-talkies. Accessed: 2024-11-28.

[87] Gardeners World. Best solar lights, n.d. URL https://www.gardenersworld.com/reviews/best-solar-lights/. Accessed: 2024-11-28.

[88] Tymbia. Portable generator sets, n.d. URL https://www.tymbia.com/gb/252-portable-generator-sets. Accessed: 2024-11-28.

[89] Engineering Toolbox. Density of materials, n.d.. URL https://www.engineeringtoolbox.com/density-materials-d_1652.html. Accessed: 2024-11-28.

[90] ThyssenKrupp. Density of aluminium, n.d. URL https://www.thyssenkrupp-materials.co.uk/density-of-aluminium.html. Accessed: 2024-11-28.

[91] ABD Die Casting. Pure aluminum vs recycled aluminum, n.d. URL https://www.abdiecasting.com/die-casting/pure-aluminum-vs-recycled-aluminum/. Accessed: 2024-11-28.

[92] MDPI. Density of biocomposites, n.d. URL https://www.mdpi.com/2073-4360/13/6/851. Accessed: 2024-11-28.

[93] Wikipedia. Basalt fiber, n.d.. URL https://en.wikipedia.org/wiki/Basalt_fiber. Accessed: 2024-11-28.

[94] Wikipedia. Plywood, n.d.. URL https://en.wikipedia.org/wiki/Plywood. Accessed: 2024-11-28.

[95] Rajapack. Caja de madera contrachapada 78x58x58cm, n.d. URL https://www.rajapack.es/cajas-carton-contenedores-cajas-postales/cajas-contenedores-para-exportacion-productos-pesados/caja-madera-contrachapada-78x58x58c
skuCB866.html?HubAttribute=LengthInternal+x+WidthInternal+x+HeigthInternal+in+cm&_gl=1*1onhd25*_up*MQ..*_gs*MQ..&gclid=CjwKCAiAjKu6BhAMEiwAx4UsAhVeSq8jUzzsTx_OpeeDxeKaU6EF83J6y7WelQbpwlo_OtJnITsgmRoCONEQAvD_BwE. Accessed: 2024-11-28.

[96] GrabCAD Community. Latch lock 3d model, n.d. URL https://grabcad.com/library/latch-lock-6. Accessed: 2024-11-28.

[97] Hikvision. Hwt-d320-vf surveillance camera, n.d. URL https://www.hikvision.com/es/products/Turbo-HD-Products/Turbo-HD-Cameras/hiwatch-series/hwt-d320-vf-spain/. Accessed: 2024-11-28.

[98] UK Maritime and Coastguard Agency. Co2 fire suppression guidance, 2019. URL https://assets.publishing.service.gov.uk/media/5d8cd2f7ed915d556efe16d4/MGN_354.pdf. Accessed: 2024-11-28.

[99] Johnson Controls. Co2-based fire suppression systems, n.d. URL https://docs.johnsoncontrols.com/specialhazards/api/khub/documents/CqAv0VrnAu2nKTaFC651Ug/content. Accessed: 2024-11-28.

[100] Pefipresa. Types of fire detectors and how they work, n.d. URL https://www.pefipresa.com/en/blog-fp/types-of-fire-detectors-how-they-work/. Accessed: 2024-11-28.

[101] Business Insider. The best smoke detectors for home safety, n.d. URL https://www.businessinsider.com/guides/home/best-smoke-detector. Accessed: 2024-11-28.

[102] Leroy Merlin. Placa antivibrante stag mp-2, n.d. URL https://www.leroymerlin.es/productos/calefaccion-y-climatizacion/aire-acondicionado/accesorios-de-climatizacion/soportes-y-amortiguadores-para-aire-acondicionado/placa-antivibrante-stag-mp-2-13925695.html. Accessed: 2024-11-28.

[103] SoftExpert. What is fmea? understanding the concept, n.d. URL https://blog.softexpert.com/es/fmea-que-es/. Accessed: 2024-11-28.

[104] BOE. Reglamento (ue) 965/2012. https://www.boe.es/doue/2012/296/L00001-00148.pdf, 2012. Accessed: 2024-10-05.

[105] BOE. Reglamento (ue) 748/2012. https://www.boe.es/doue/2012/224/L00001-00085.pdf, 2012. Accessed: 2024-10-05.

[106] BOE. Reglamento (ce) nº 216/2008. https://www.boe.es/buscar/doc.php?id=DOUE-L-2008-80511, 2008. Accessed: 2024-10-05.

[107] UDI. Anexo 6 de la oaci. https://web.udi.edu.co/files/img/ANEXO.6.pdf, 2024. Accessed: 2024-10-05.

[108] Puravida Sportwear. Arnés sparco de seguridad sfi / no fia. https://www.puravidasportwear.com/arnes-sparco-sfi-no-fia-b18d/?otcountry=ES&sku=04806SFINR&srsltid=AfmBOopI6q5FLYvK02dKV_HL_pLajaaW3fNckZ2-7tlv9WCzQysJOIEMVEI, 2024. Accessed: 2024-11-28.

[109] L. D. Earley. Communication in challenging environments: Application of leo/meo satellite constellation to emerging aviation networks. 2021 Integrated Communications Navigation and Surveillance Conference (ICNS), 2021. doi: 10.1109/icns52807.2021.9441549.

[110] Nozhan Hosseini, Hosseinali Jamal, David W. Matolak, Jamal Haque, and Thomas Magesacher. Uav command and control, navigation and surveillance: A review of potential 5g and satellite systems. IEEE Aerospace Conference, 2019. doi: 10.1109/AERO.2019.8741719.

[111] Iridium Communications Inc. Iridium certus® 700, n.d. URL https://www.iridium.com/services/iridium-certus-700/. Retrieved November.

[112] SKYTRAC. Skytrac ims-350: Broadband uav satcom brochure, 2021. URL https://www.unmannedsystemstechnology.com/wp-content/uploads/2021/03/SKYTRAC-IMS-350-US-EN-r02.pdf.

[113] Warren L. Flock. Propagation effects on mobile-satellite systems. In Propagation Effects on Satellite Systems, chapter 6. NASA Jet Propulsion Laboratory, 1987. URL https://descanso.jpl.nasa.gov/propagation/1108/1108Chapter6.pdf.

[114] Alexander Ilyin, Alexey Matinyan, Alexey Rolich, and Leonid Voskov. Experimental evaluation of iridium performance under varying weather conditions and elevation angles. In 2024 International Seminar on Electron Devices Design and Production (SED), pages 1–5, 2024. doi: 10.1109/SED63331.2024.10741060.

[115] Hirschmann. Itas iridium transceiver antenna system. Communication Solutions from Hirschmann. URL https://telematik-markt.de/sites/default/files/firm/products/itas__datasheet_1_0_en.pdf.

[116] Federal Aviation Administration. Satellite Navigation - GPS, 2024. URL https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss. Accessed: 2024-11-23.

[117] Xiaoye Liu. Airborne lidar for dem generation: some critical issues. Progress in Physical Geography, 32(1):31–49, 2008. doi: 10.1177/0309133308089496.

[118] Dmitriy Korchev, Shinko Cheng, Yuri Owechko, and Kyungnam Kim. On real-time lidar data segmentation and classification. International Conference on Image Processing, Computer Vision, and Pattern Recognition (IPCV'13), 2013.

[119] Yecheng Lyu, Lin Bai, and Xinming Huang. Chipnet: Real-time lidar processing for drivable region segmentation on an fpga. IEEE Transactions on Circuits and Systems I: Regular Papers, 2018. doi: 10.1109/TCSI.2018.2881162.

[120] RP Photonics. Frequency combs, n.d. URL https://www.rp-photonics.com/frequency_combs.html.

[121] Inki Kim, Renato Juliano Martins, Jaehyuck Jang, Trevon Badloe, Samira Khadir, Ho-Youl Jung, Hyeongdo Kim, Jongun Kim, Patrice Genevet, and Junsuk Rho. Nanophotonics for light detection and ranging technology. Nature Nanotechnology, 16(5):508–524, 2021. doi: 10.1038/s41565-021-00895-3.

[122] Pan Wei, Lucas Cagle, Tasmia Reza, John Ball, and James Gafford. Lidar and camera detection fusion in a real-time industrial multi-sensor collision avoidance system. Electronics, 7(6):84, 2018. doi: 10.3390/electronics7060084.

[123] Bo Jiang, Zhonghui Chen, Jintao Tan, Ruokun Qu, Chenglong Li, and Yandong Li. A real-time semantic segmentation method based on stdc-ct for recognizing uav emergency landing zones. Sensors, 23(14):6514, 2023. doi: 10.3390/s23146514.

[124] Jamie Wubben, Francisco Jose Fabra Collado, Carlos Miguel Calafate, Tomasz Krzeszowski, Johann Marcelo Márquez Barja, Juan-Carlos Cano, and Pietro Manzoni. Accurate landing of unmanned aerial vehicles using ground pattern recognition. Electronics, 8(12):1532, 2019. doi: 10.3390/electronics8121532.

[125] Miguel Moreira, F̆00E1bio Azevedo, Andr̆00E9 Ferreira, D̆00E1rio Pedro, Jŏ00E3o Matos-Carvalho, ̆00C1lvaro Ramos, Rui Loureiro, and Lŭ00EDs Campos. Precision landing for low-maintenance remote operations with uavs. Drones, 5(4):103, 2021. doi: 10.3390/drones5040103.

[126] Zijian Ge, Jingjing Jiang, Ewan Pugh, Ben Marshall, Yunda Yan, and Liang Sun. Vision-based uav landing with guaranteed reliability in adverse environment. Electronics, 12(4):967, 2023. doi: 10.3390/electronics12040967.

[127] J.Z. Sasiadek and P. Hartana. Sensor data fusion using kalman filter. 2:WED5/19–WED5/25 vol.2, 2000. doi: 10.1109/IFIC.2000.859866.

[128] European Union. Commission implementing regulation (eu) 2019/947 of 24 may 2019 on the rules and procedures for the operation of unmanned aircraft, 2019. URL https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R0947.

[129] Federal Aviation Administration. Become a drone pilot, n.d.. URL https://www.faa.gov/uas/commercial_operators/become_a_drone_pilot.

[130] Federal Aviation Administration. Register your drone, n.d.. URL https://www.faa.gov/uas/getting_started/register_drone.

[131] Boeing. Inmarsat-5 global xpress secure global mobile broadband. Retrieved from https://www.boeing.com/content/dam/boeing/boeingdotcom/space/commercial-satellite-services/docs/Inmarsat-5_Global_Xpress_Secure_Global_Mobile_Broadband.pdf.

[132] Cobham SATCOM. Aviator 200s user manual. Retrieved from https://fcc.report/FCC-ID/ROJ-AVIATOR200S/5579005.pdf.

[133] Altair Engineering. Propagation models - knife-edge diffraction, 2021. URL https://2021.help.altair.com/2021/winprop/topics/winprop/user_guide/proman/propagation_models/proman_prop_model_knife_edge.htm. Accessed: 2024-11-25.

[134] Kuehne+Nagel. Thrust through trust: Logistics for the aerospace supply chain transformation, 2022. URL https://home.kuehne-nagel.com/.

[135] McKinsey & Company. Addressing continued turbulence: The commercial aerospace supply chain, 2024. URL https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/addressing-continued-turbulence-the-commercial-aerospace-supply-chain#/.

[136] The Logistics World. Costos logísticos: ¿qué indicadores hay que monitorear?, 2024. URL https://thelogisticsworld.com/logistica-y-distribucion/costos-logisticos-que-indicadores-hay-que-monitorear/.

[137] Mach Helicopters. ¿cuánto vale un helicóptero?, 2024. URL https://machhelicopters.com/cuanto-vale-un-helicoptero/.

[138] EUROCONTROL Business Cases Team. EUROCONTROL Standard Inputs for Economic Analyses. EUROCONTROL Headquarters, Brussels, Belgium, 10.0 edition, May 2024. ISBN 978-2-87497-129-7. URL https://ansperformance.eu/economics/cba/standard-inputs/.

[139] ansperformance. EUROCONTROL Standard Inputs for Economic Analyses - 46 Discount rate, 2023. URL https://ansperformance.eu/economics/cba/standard-inputs/chapters/discount_rate.html.

[140] FUNCAS. Ipc abril 2024: Previsiones hasta diciembre 2025. https://www.funcas.es/textointegro/ipc-abril-2024-previsiones-hasta-diciembre-2025/, 2024. Accessed: 2024-11-30.

[141] Investing. Ratios financieros de Airbus Group (AIR) - Investing.com, 11 2024. URL https://es.investing.com/equities/eads-ratios.

[142] Airbus Helicopters UK Limited. Airbus helicopters uk limited annual report and financial statements, December 2023. URL https://www.airbus.com. This document includes strategic, financial, and operational information for the year ending 31 December 2023.

[143] Investing. SKK Holdings Ltd (SKK) Margen beneficio bruto, 2024. URL https://mx.investing.com/pro/NASDAQCM:SKK/explorer/gp_margin.

[144] Investing. Ratios financieros de Leonardo (LDO) - Investing.com, 11 2024. URL https://es.investing.com/equities/finmeccanica-ratios.

[145] bjt. Airbus Helicopters H175, 11 2016. URL https://www.bjtonline.com/aircraft/airbus-helicopters-h175.

[146] bjt. Airbus Helicopters H145, 11 2016. URL https://www.bjtonline.com/aircraft/airbus-helicopters-h145.

[147] bjt. Sikorsky S-76D, 11 2016. URL https://www.bjtonline.com/aircraft/sikorsky-s-76d.

[148] European Union Aviation Safety Agency (EASA). Urban air mobility (uam) landscape, 2023. URL https://www.easa.europa.eu/en/domains/drones-air-mobility/drones-air-mobility-landscape/urban-air-mobility-uam.

[149] Iridium Communications. Iridium global network, 2023. URL https://www.iridium.com/network/.

[150] European Commission. Trade policy report 2023, 2023. URL https://ec.europa.eu/newsroom/trade/redirection/document/100023.

[151] Paulo Cesar Leite and Patricia Fonseca. Value propositions and customer alignment: Building competitive advantage, 2016. URL https://repositorio.ucp.pt/bitstream/10400.14/21613/4/201464217.pdf.

[152] SAE International. AS9100D Quality Management Systems - Requirements for Aviation, Space, and Defense Organizations, 2016. Available at: https://assem-tech.com/wp-content/uploads/2019/03/AS9100D.pdf [Accessed: 26-Nov-2024].

[153] Agencia Española de Seguridad Aérea. Real decreto 1036/2017. https://www.boe.es/buscar/doc.php?id=BOE-A-2017-1572, 2017. Accessed: 2024-11-19.

[154] Agencia Española de Seguridad Aérea. Ley 21/2003 de seguridad aérea. https://www.boe.es/buscar/act.php?id=BOE-A-2003-13616, 2003. Accessed: 2024-11-19.

[155] European Union. Regulation (eu) 2018/1139 of the european parliament and of the council of 4 july 2018 on common rules in the field of civil aviation and establishing a european union aviation safety agency. https://eur-lex.europa.eu/legal-content/ES/TXT/PDF/?uri=CELEX:32018R1139, 2018. Accessed: 2024-11-19.

[156] European Union Aviation Safety Agency. Guidelines on operations in the open and specific category, 2022. Accessed: 2024-11-19.

[157] European Union Aviation Safety Agency (EASA). Easy access rules for unmanned aircraft systems regulations (eu). https://www.easa.europa.eu/en/document-library/easy-access-rules/easy-access-rules-unmanned-aircraft-systems-regulations-eu, 2020. Accessed: 2024-11-19.

[158] European Union Aviation Safety Agency. Commission delegated regulation (eu) 2019/945. https://eur-lex.europa.eu/legal-content/ES/TXT/PDF/?uri=CELEX:32019R0945, 2019. Accessed: 2024-11-19.

[159] European Union Aviation Safety Agency. Standardised european rules of the air (sera). https://www.easa.europa.eu/en/regulations/standardised-european-rules-air-sera, 2021. Accessed: 2024-11-19.

[160] European Union. Regulation (eu) 2019/947 of the european parliament and of the council of 24 july 2019 on the rules and procedures for the operation of unmanned aircraft systems. https://eur-lex.europa.eu/legal-content/ES/TXT/PDF/?uri=CELEX:32019R0947, 2019. Accessed: 2024-11-19.

[161] International Civil Aviation Organization. Annex 6: Operation of aircraft, part i, international commercial air transport. https://ffac.ch/wp-content/uploads/2020/09/ICAO-Annex-6-Operation-of-Aircraft-Part-I-International-commercial-air-transport.pdf, 2020. Accessed: 2024-11-19.

[162] International Civil Aviation Organization (ICAO). Annex 8: Airworthiness of aircraft. https://ffac.ch/wp-content/uploads/2020/09/ICAO-Annex-8-Airworthiness-of-Aircraft.pdf, 2020. Accessed: 2024-11-19.

[163] Skybrary. Safety management and safety culture. https://skybrary.aero/sites/default/files/bookshelf/4053.pdf, 2020. Accessed: 2024-11-19.

[164] Civil Aviation Authority (CAA). An19: Guidelines for the operation of unmanned aircraft systems (uas). https://caainternational.com/wp-content/uploads/2018/05/AN19_2ed-publication.pdf, 2018. Accessed: 2024-11-19.

[165] International Civil Aviation Organization. Global air navigation plan (ganp). https://www4.icao.int/ganpportal/, 2024. Accessed: 2024-11-19.

[166] European Union Aviation Safety Agency (EASA). What is u-space? file:///C:/Users/polba/Downloads/what_is_u-space.pdf, 2024. Accessed: 2024-11-25.

[167] Murat Ciniviz Nurullah Gültekin. Specific fuel consumption (sfc) explanation for helicopter engine selection. International Journal of Hydrogen Energy, 2023.

[168] John D. Anderson. Introduction to Flight. McGraw-Hill Education, 2007.

[169] L. Bruhn. Aircraft Design Projects for Engineering Students. Elsevier, 1990.

[170] J. GORDON LEISHMAN. Principles of Helicopter Aerodynamics. University of Maryland, 2000.

[171] Raymond W. Prouty. Helicopter Performance, Stability, and Control. Krieger Publishing Company, 1995.

[172] J. Gordon Leishman. Principles of Helicopter Aerodynamics. Cambridge University Press, Cambridge, UK, 2nd edition, 2006. ISBN 978-0-521-85860-1.

[173] Repsol. Jet a-1 aviation fuel, 2024. URL https://www.repsol.com/en/products-and-services/aviation/jet-a-1/index.cshtml. Accessed: 2024-11-26.

[174] TotalEnergies. Jet a-1 aviation fuel, 2024. URL https://aviation.totalenergies.com/en/fuels-and-services-aviation/aviation-fuels/jet-a1#:~:text=JET%20A%2D1%20is%20a,melting%20point%20of%20%2D47.0%C2%BAC. Accessed: 2024-11-26.

[175] Airbus. H175 technical information, 2024. URL https://www.airbus.com/en/products-services/helicopters/civil-helicopters/h175/h175-technical-information. Accessed: 21-Oct-2024.

[176] Airbus. H135 technical information, 2024. URL https://www.airbus.com/en/products-services/helicopters/civil-helicopters/h135/h135-technical-information. Accessed: 2024-11-26.

[177] Flight-Study. Helicopter fuel systems, 2024. URL https://flight-study.com/helicopter-fuel-systems/. Accessed: 2024-11-27.

[178] WILLIAM G. BOUSMAN. Airfoil design and rotorcraft performance, 2003.

[179] Paul Eglin. Aerodynamic design of the nh90 helicopter stabilizer. In 23rd European Rotorcraft Forum, Dresden, September 1997. EUROCOPTER. URL https://dspace-erf.nlr.nl/server/api/core/bitstreams/1121db0d-cdc4-43e1-aa20-4d6d8514f3c4/content#:~:text=An%20horizontal%20stabilizer%20can%20be%20characterized%20with%20two%20parameters%3A&text=Its%20efficiency%20that%20can%20be,of%20the%20angle%20of%20attack.

[180] Federal Aviation Administration (FAA). Weight and Balance Handbook (8083-01A). Federal Aviation Administration (FAA), 2007. URL https://paragonair.com/public/docs/FAA-Handbooks/8083-01A_%282007%29_WnB/. Accessed: October 23, 2024.

[181] Airfoil Tools. Naca 23012 airfoil polar data. URL http://airfoiltools.com/polar/details?polar=xf-naca23012-il-500000. Accessed: 2024-11-17.

[182] Federal Aviation Administration (FAA). Helicopter Flying Handbook, 2012. URL https://www.faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/helicopter_flying_handbook/hfh_ch07.pdf. Accessed: 2024-11-19.

[183] The exergy efficiency of turboprop propulsion systems. Science Direct, 2023. URL https://www.sciencedirect.com/science/article/abs/pii/S0360544223009878#:~:text=The%20exergy%20efficiency%20of%20turboprop,and%2099%25%20for%20gas%20turbine. Accessed: 2024-11-25.

[184] Ground Control. Leo satellites and uav/drone operations, 2021. URL https://www.groundcontrol.com/blog/leo-satellites-uav-drone-operations/.

[185] Ph. D. Margaret M. McMahon. Measuring latency in iridium satellite constellation data services. Technical report, 2005. URL https://apps.dtic.mil/sti/tr/pdf/ADA464192.pdf.

[186] Copernicus digital elevation model, n.d. URL https://spacedata.copernicus.eu/collections/copernicus-digital-elevation-model. Retrieved November 6, 2024.

[187] European Space Agency. Copernicus global digital elevation model, 2024. URL https://doi.org/10.5069/G9028PQB. Distributed by OpenTopography. Accessed: 2024-11-03.

[188] Rasterio documentation, n.d. URL https://rasterio.readthedocs.io/en/stable/. Retrieved November 6, 2024.

Appendix A

Power

A.1 Engine selection

This section will discuss further how the engine has been selected using 2 decisions methods (OWA and PRESS).

A.1.1 Common scale

The various engines from Table 3.1 will undergo normalization to enable the comparison of different criteria, each of which may have distinct value scales and parameter types. The best-performing engine for each criterion will be assigned a score of 5, while the least-performing engine will receive a score of 1. The remaining engines will have their scores linearly interpolated based on their performance relative to the best and worst values. It is important to note that the normalization process is not equal for each variable: intuitively, a low price is better that a high price but low power is worst than high power. Hence, price, fuel consumption and weight are normalized using method 1 and power using method 2:

$$\text{Method 1:} \rightarrow \ x_{i_{normalized}} = 5 - 4 \cdot \frac{x_i - min(x)}{max(x) - min(x)} \tag{A.1}$$

$$\text{Method 2:} \rightarrow \ x_{i_{normalized}} = 1 + 4 \cdot \frac{x_i - min(x)}{max(x) - min(x)} \tag{A.2}$$

Consequently, the following results are obtained:

N°	Engine Name	Price	Power	Fuel Consump.	Weight
A	General Electric CT7-8A	2.68	4.34	4.52	1.80
B	Pratt & Whitney PT6C-67E	3.11	3.52	1.00	4.14
C	Safran Makila 1A1	1.00	4.62	4.41	3.00
D	General Electric T700-701D	5.00	4.34	4.80	2.71
E	Klimov TV3-117VM	4.58	5.00	3.82	1.00
F	Safran Arriel 2S2	5.00	1.00	4.75	5.00
G	Safran Ardiden 3G	3.53	4.30	5.00	4.43
H	General Electric T58-GE-16	3.95	2.57	2.94	1.00

Table A.1: Normalized Evaluation of Helicopter Engines

A.1.2 OWA Method

The Ordered Weighed Average method is a decision-making tool that ranks criteria based on their values rather than fixed weights. It allows for flexibility in decision-making by applying weights to the ordered criteria, enabling a balance between different performance aspects. This method is useful for considering both optimistic and pessimistic scenarios when comparing options, providing a comprehensive evaluation.

A.1.2.1 Variables used

SFC:
Specific Fuel Consumption measure how efficiently an engine converts fuel into power. Specifically, it is the amount of fuel consumed per unit of power generated, usually given in units like $kg/(kW \cdot h)$ or $lb/(hp \cdot h)$. Plays a significant role in determining the aircraft's efficiency, especially at cruising altitudes. Helicopters engines usually operate at medium and high regimes during most of their flight, where fuel SFC remains practically constant. Lower values means more efficient fuel usage, leading to cost savings, extended flight time, or greater ability to carry additional payload. Since fuel presents one of the major operational costs in aviation, having an engine with a low SFC is essential to make the helicopter economically viable for sustained operations [167].

Power:
The power of the engine refers to the amount of energy it can produce, and it plays a critical role in the overall performance of the helicopter. Although the weight of each engine contributes to the total mass, it is relatively small compared to the helicopter's overall weight. Therefore, the engine's power output becomes the most relevant factor for ensuring the helicopter has sufficient thrust and can perform efficiently under various operational demands. Particularly during take-off, landing and in hover conditions, which are the critical aspects of helicopter operation.

A higher power output enables the helicopter to handle greater payloads, achieve better flight performance, and operate in more challenging environments. Thus, selecting an engine with adequate power is essential for meeting performance objectives and mission requirements [168].

Cost:
The price of the engine refers to the cost associated with acquiring and implementing the engine within the helicopter's design. This criterion is crucial as it directly impacts the overall budget of the project. Choosing an engine with a higher price may offer superior performance or durability, but it must be carefully balanced with the financial constraints of the project. Ensuring cost-effectiveness is essential to maintaining a viable and sustainable design, particularly if the helicopter is intended for commercial or budget-sensitive operations [169].

Weight:
Weight is an important factor in engine selection as it directly influences the helicopter's overall efficiency, stability, and operational capabilities. The engine's weight contributes to the helicopter's total mass, which affects performance characteristics such as payload capacity, range, and fuel consumption. An engine with a lighter weight allows more useful payload to be carried, which can be critical for mission-specific requirements, such as transporting passengers, cargo, or specialized equipment. Additionally, the weight distribution affects the helicopter's center of gravity, which is essential for stability during flight, particularly in hover, take-off, and landing phases. However, in larger helicopters, the impact of engine weight is somewhat less significant compared to smaller ones, as the overall mass of the helicopter reduces the relative influence of the engine's weight [170].

Among the criteria, power is assigned the highest weight at 40%. Power is a critical determinant of the helicopter's capability to fulfill its operational roles, particularly during demanding conditions like hovering, take-off, and challenging environments. A sufficient power output ensures that the helicopter can handle its intended missions effectively, and without adequate power, all other aspects of performance are compromised. SFC is assigned a weight of 30% as it is crucial for ensuring efficiency which impacts operational cost and range. The cost of the engine is assigned a percentage of 20% as it directly influences the project's economic feasibility. Balancing cost with performance is key to maintaining a sustainable and practical helicopter design, ensuring that the selected engine provides the required power and efficiency without exceeding financial constraints. Finally, weight is assigned 10%, as its impact, while still notable, is comparatively less significant in larger helicopters. The weight of the engine affects payload and efficiency, but larger helicopters are better equipped to handle the effects of engine weight due to their higher overall capacity [171].

A.1.3 Results

The following table show the results obtained where the final OWA value are computed following the next expression:

$$\text{OWA} = \frac{\sum_{i=1}^{n} p_i \cdot g_i}{p_{max} \cdot \sum_{i=1}^{n} g_i} \tag{A.3}$$

Criteria		Price	Power	SFC	Weight	Sum(g×p)	OWA	NORMALIZED
Weight	g	2.00	4.00	3.00	1.00	10.00		
A	p	2.68	4.34	4.52	1.80			
	g×p	5.37	17.37	13.56	1.80	38.10	0.76	0,62
B	p	3.11	3.52	1.00	4.14			
	g×p	6.21	14.10	3.00	4.14	27.45	0.55	0,00
C	p	1.00	4.62	4.41	3.00			
	g×p	2.00	18.49	13.23	3.00	36.71	0.73	0,54
D	p	5.00	4.34	4.80	2.71			
	g×p	10.00	17.37	14.41	2.71	44.49	0.89	1,00
E	p	4.58	5.00	3.82	1.00			
	g×p	9.16	20.00	11.45	1.00	41.61	0.83	0,83
F	p	5.00	1.00	4.75	5.00			
	g×p	10.00	4.00	14.24	5.00	33.24	0.66	0,34
G	p	3.53	4.30	5.00	4.43			
	g×p	7.05	17.20	15.00	4.43	43.68	0.87	0,95
H	p	3.95	2.57	2.94	1.00			
	g×p	7.89	10.27	8.83	1.00	27.99	0.56	0,03

Table A.2: OWA table results for the engine selection

The OWA table results provide an overview of the performance of different engines, considering various criteria as previously commented. These weights indicates that power and SFC are the most influential factors in the decision-making process.

Upon evaluating each engine based on their respective scores for each criterion, engine D emerges as the best overall performer, achieving the highest aggregated weighted score of 0.86. Its strong performance, particularly in Power and SFC, aligns well with the given weight distribution, making it the most suitable engine among the evaluated options.

Engines A and G also perform well, but neither surpasses Engine D in the overall evaluation. Engine G, in particular, shows strong performance in terms of SFC and power. However, its high cost has a significant impact on the overall score, preventing it from becoming the top choice.

The normalized values provides a relative comparison of each engine's performance against the best reference, which in this case is Engine D with a normalized score of 1.00. Engines like B and F, with low normalized scores, indicate insufficient performance in key areas.

To validate the decision, the PRESS method will also be explored and analyzed. This approach aims to provide two crucial insights. First, it will help confirm the selection between Engines D, G, or potentially A. Second, it will assist in making a definitive decision about which engine is ultimately the best choice.

A.1.4 PRESS Method

To gain further analysis on which engine option to choose, the PRESS method will be developed. This method, similarly to OWA, is a decision-making technique that will help create a ranking of the options based on their performance across different criteria. However, it finds the best option by comparing it to the rest based on all criteria rather than finding the alternative with the best weighted as OWA method does. To give more consistency to the study, the different criteria and their respective weights using in this method will be the same as those summarized in Table 3.2.

To apply the PRESS method, the first step is to have the performance of each engine across each criteria normalized, which is something that has already been done for the OWA method and is summarized in Table E.1. To continue, the valuation matrix must be completed. To do so, the score of each engine at every criteria is taken and divided by the maximum score of all engines in said criteria, multiplying it then by its weight. The next equation explains this process:

$$x_{i_{val.matrix}} = \frac{x_{i_{normalized}}}{max(x_{criteria})} \cdot g_{criteria} \tag{A.4}$$

The resulting variation matrix is shown in the following Table:

VALUATION MATRIX				
Alternatives	**Valuation (Qij)**			
A	1,07	3,47	2,71	0,36
B	1,24	2,82	0,60	0,83
C	0,40	3,70	2,65	0,60
D	2,00	3,47	2,88	0,54
E	1,83	4,00	2,29	0,20
F	2,00	0,80	2,85	1,00
G	1,41	3,44	3,00	0,89
H	1,58	2,05	1,77	0,20

Table A.3: Valuation matrix for the alternatives with updated values, engine selection.

Already from Table A.3 it is visible how engines D, G and A, the three that stood out in the OWA method, get some of the best valuations. However, this matrix does not lead to any direct conclusion. This is why the domination matrix is developed next. This matrix helps understand how each engine performs against each other engine option. A value of 0 in a domination matrix cell implies that engine i is inferior to engine j in each studied criteria, while higher values imply a superiority in some or all categories. The specific formula to compare engine i in relation to another engine j is:

$$T_{ij} = \sum_{k=1}^{n} [Q_{ik} - Q_{jk}] \quad \text{when } Q_{ik} > Q_{jk} \tag{A.5}$$

where n is the number of criteria, T_{ij} is the dominance matrix score and Q_{ik} and Q_{jk} are engine's i and j's scores in criteria k. The results are summarized in the following Table:

DOMINATION MATRIX									
Alternatives	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Total (Di)**
A	0,00	2,77	0,67	0,00	0,58	2,67	0,00	2,53	9,23
B	0,64	0,00	1,07	0,29	0,63	2,02	0,00	1,40	6,04
C	0,46	2,92	0,00	0,28	0,75	2,90	0,26	2,92	10,50
D	1,28	3,69	1,84	0,00	1,10	2,71	0,59	3,30	14,51
E	1,28	3,46	1,73	0,53	0,00	3,20	0,98	2,72	13,91
F	1,70	3,18	2,20	0,46	1,53	0,00	0,70	2,30	12,07
G	1,15	3,25	1,65	0,46	1,40	2,79	0,00	3,31	14,00
H	0,51	1,50	1,18	0,00	0,00	1,25	0,17	0,00	4,61
Total (di)	7,02	20,77	10,35	2,01	5,99	17,55	2,70	18,48	

Table A.4: Domination matrix for the alternatives with updated values, engine selection.

Table A.4 illustrates even further how certain engines dominate in every criteria over others. It is important to note that, while the Total (di) row below displays how the engine of column i is dominated by others, the Total (Di) column on the right displays the opposite, how that engine i dominates the other alternatives. Thereupon, a low value on the Total (di) row and high value on the Total (Di) column would be ideal. To illustrate this, the importance index (I) is calculated as follows:

$$I_i = \frac{D_i}{d_i} \quad \text{with } i \text{ representing each alternative} \tag{A.6}$$

The results of the importance index, along with its own normalization (0 to 1 values), are presented in the following Table:

IMPORTANCE INDEX		
Alternatives	**Index**	**Normalized Index**
A	1,31	0,15
B	0,29	0,01
C	1,01	0,11
D	7,22	1,00
E	2,32	0,30
F	0,69	0,06
G	5,19	0,71
H	0,25	0,00

Table A.5: Importance Index for the alternatives with custom colors, engine selection.

As observed in Table A.5, the three best performing engines based on the PRESS method are engines D, G and E, in that order, while engines B and H are, by far, the less suitable.

A.2 Transmission System Details

Power transmission in helicopters is a critical system responsible for delivering engine-generated power to both the main and tail rotors. The high rotational speed (RPM) produced by the engine must be significantly reduced before reaching these rotors, as the required operational RPM for the main rotor is much lower to maintain controlled lift and stability. Similarly, the tail rotor, responsible for counteracting torque and providing yaw control, also requires reduced RPM, though not as substantially as the main rotor. This reduction is achieved through a complex series of gearboxes and shafts, ensuring that each rotor operates within its optimal speed range for safe and efficient helicopter performance. Figure A.1 shows a general schematic representation of the transmission in a twin-engine helicopter.

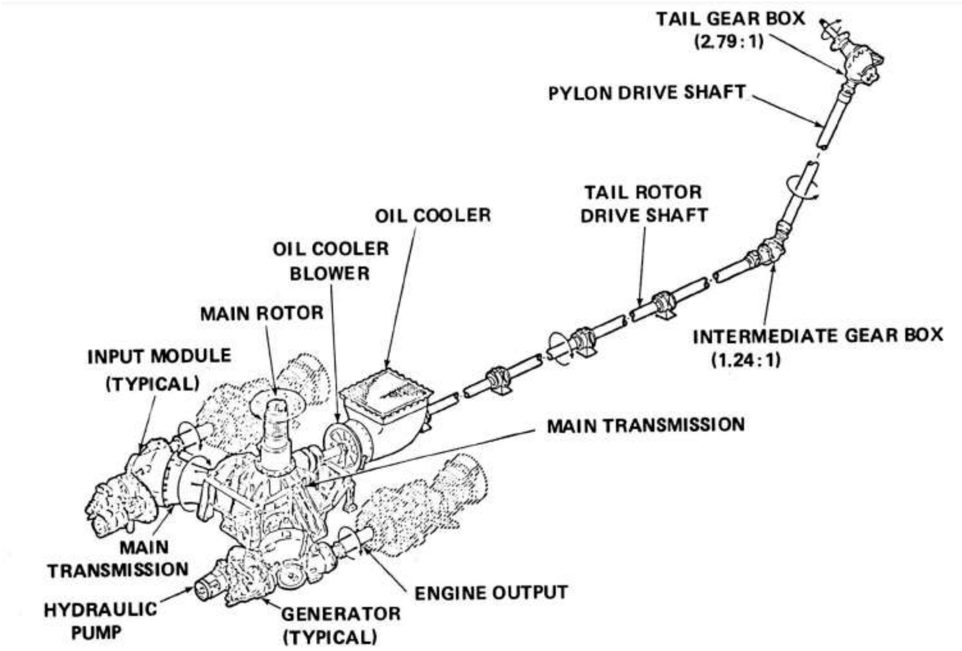


Figure A.1: General transmission scheme in a twin-engine helicopter [12].

The whole transmission system (including all modules, oil, oil cooler and blower, oil lines, and related hardware) is estimated to weigh **565 kg**. This approximation has been based on the weight of the Black Hawk's transmission [12], which has the same twin GE T700 engine configuration as our UAV.

The main parts of the transmission system and their required RPM ratios are described in the following sections.

A.2.1 Main rotor gearbox

As stated, the main gearbox (MGB) is central to the helicopter's power transmission system, converting the high-speed output from the engine into a lower rotational speed suitable for the main rotor. This gearbox incorporates a reduction system, often utilizing a combination of bevel and planetary gears, to achieve the necessary decrease in RPM without excessive weight or space requirements. The planetary gear arrangement, in particular, provides a compact and efficient means to handle the high power loads typical in helicopter operations, distributing torque evenly and supporting the durability of the gearbox [172]. Additionally, for this project's UAV, the MGB must also ensure stable power delivery under varying flight and load conditions.

Figure A.2: Detailed render of the main rotor gearbox. [13]

Speed Reduction:

As shown in Table 3.5, the selected engines rotate at 20,900 RPM, while the required main rotor speed has been found to be 270 RPM (Section **??**, Table B.3). Therefore, the total transmission ratio between the engine and the rotor blades must be:

$$\tau_{\text{main rotor}} = \frac{\omega_{engine}}{\omega_{main}} = \frac{20,900}{270} = 77.4 \tag{A.7}$$

A.2.2 Tail rotor gearbox

The tail rotor gearbox is a critical component in a helicopter's transmission system, responsible for adapting and directing the power transmitted from the engine to the tail rotor. Typically located at the end of the tail boom, it performs several essential functions.

Power Redirection:

The gearbox changes the direction of the power transmission by 90 degrees, allowing the tail rotor to rotate in a plane perpendicular to the tail boom. This redirection is vital for generating the thrust needed to counteract the torque produced by the main rotor, maintaining yaw stability.

Speed Reduction:

The tail rotor gearbox decreases the rotational speed to match the specific requirements of the tail rotor. This step prevents the tail rotor from spinning excessively fast, which could impair its performance and durability.

The total transmission ratio between the engine (main gear) and the tail rotor gear is:

$$\tau_{\text{tail rotor}} = \frac{\omega_{engine}}{\omega_{tail}} = \frac{20,900}{2,000} = 209 : 20 = 10.5 \tag{A.8}$$

A.2.3 Transmission shafting system

The power from the engine/s is transmitted through a shaft/s, to the main gearbox and hence the main rotor and to the tail rotor through one or two gearboxes. The following information has been extracted from Introduction to Rotor crafts, Daniel Yago 2024 [15].

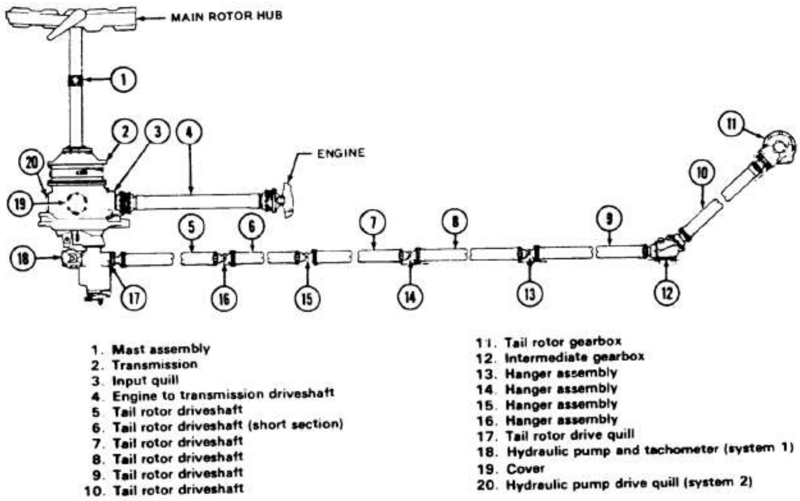


Figure A.3: Power Transmission Shaft diagram [14]

In the **Airbus H175** (reference model), the shaft system (excluding gearboxes) includes several critical components:

- **Main Rotor Transmission System and Mast**: The main transmission gearbox reduces the high engine speed by approximately 80 times to achieve an optimal main rotor speed (around 300 rpm), providing the necessary torque for lift and maneuvering. The main rotor mast, directly driven by this gearbox, transmits torque to the rotor blades and is built to withstand substantial aerodynamic forces, ensuring stability. The system also includes a clutch, which allows the engine to start independently of the main rotor and only engages at sufficient engine speed, with common types being centrifugal and belt clutches [14].

- **Tail Rotor Transmission System, Driveshaft, and Freewheel Unit**: The tail rotor transmission consists of a segmented driveshaft connected by flexible couplings, transmitting power from the main gearbox to the tail rotor through the intermediate gearbox (IGB) and tail rotor gearbox (TGB). This setup adjusts the tail rotor speed to approximately six times that of the main rotor, providing essential anti-torque for helicopter stability. The freewheel unit, a one-way sprag clutch, allows the rotor to keep spinning if engine rpm falls below rotor speed, enabling autorotation for safe descent during engine failure [14].

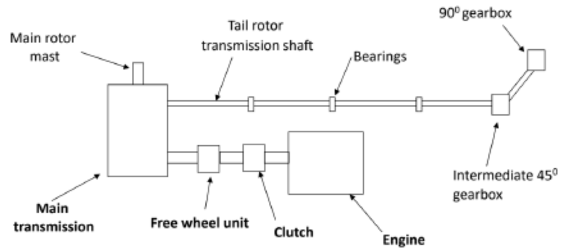


Figure A.4: Transmission system sketch [15]

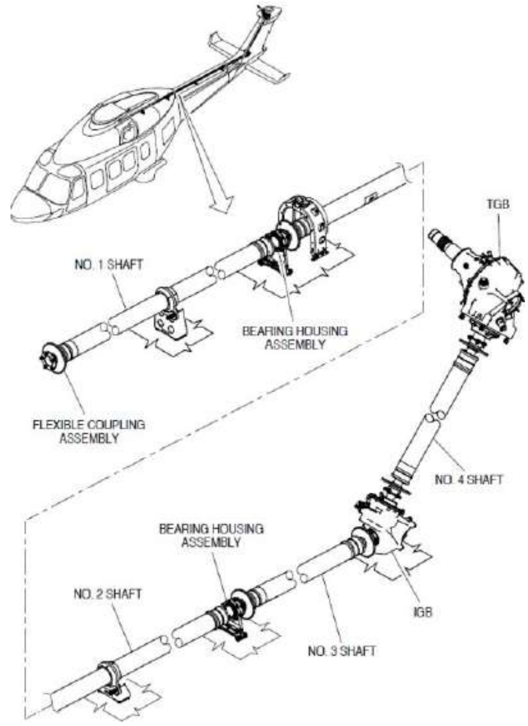


Figure A.5: Transmission shaft diagram [15]

A.3 Fuel system

In the following section, the primary parameters, capacity values, and systems related to fuel are discussed.

A.3.1 Design and specifications of the fuel tank

Before analyzing the designed fuel tanks, the propellant used is first studied and thoroughly examined, with the main information extracted from Repsol Aviation Fuel Jet A-1 [173] and TotalEnergies Jet A-1 [174]. Once the foundational aspects are established, the UAV's fuel capacity, along with key parameters, will be presented and discussed in detail.

Aviation fuel

Initially, the UAV proposed will use Jet-A1 fuel, a widely utilized aviation-grade kerosene. This fuel type is specifically formulated to meet the high-performance demands of aeronautical operations, offering a consistent energy output and reliable combustion characteristics.

One of its key properties is its relatively low freezing point of -47°C, making it suitable for operations in diverse and extreme atmospheric conditions. Jet-A1 has a moderate octane rating compared to automotive fuels, as aviation kerosene prioritizes controlled combustion over high compression ratios. This ensures stable engine performance at varying altitudes and temperatures, which is critical for safety and efficiency in UAV operations. Moreover, Jet-A1 is less volatile than gasoline, reducing the risk of vapor lock in fuel systems during high-altitude operations.

From an economic perspective, the cost per gallon or liter of Jet-A1 is a significant parameter, as fuel expenses represent a substantial portion of operational costs. As of recent data, the price of Jet-A1 typically ranges between 2.50 or 4.00 per gallon, depending on market fluctuations, regional availability, and geopolitical factors. This cost must be factored into the UAV's mission planning, endurance optimization, and overall economic feasibility.

Aircraft fuel capacity

The objective of this analysis is to estimate the Maximum Fuel Weight (MFW) of the proposed UAV by benchmarking it against similar rotorcraft with comparable characteristics, such as the Airbus H-175 or Bell 525, in terms of flight endurance, Maximum Takeoff Weight (MTOW), or maximum velocity.

Jet-A1 fuel has an average density ranging from 0.775 to 0.840 kg/L at 15°C, depending on its specific batch and formulation. For calculation purposes, a commonly used average value is 0.8 kg/L.

- **Airbus H-175 [175]:** MFW 2,600 kg
- **Airbus H-135 [176]:** MFW 1,400 kg
- **Bell 525 [62]:** MFW 1,900 kg
- **Bell 429 [62]:** MFW 1,000 kg

Based on the capabilities of the UAV, it will be more comparable to the Airbus H-175 or Bell 525. Consequently, the rotorcraft is estimated to have a MFW of 2,000 kg. This value will need to be validated and contrasted against the performance study of the aircraft to ensure its adequacy.

Following Section PF3, where relevant operational definitions are provided, the estimated MFW can be compared with mission and endurance requirements.

A typical mission (see Section 3.4.3.2) consists of seven stages, with a total flight time of two and a half hours. During this time, the UAV must efficiently conduct humanitarian air rescue operations, land at a hospital, and subsequently return to either its base or an aerodrome, depending on the specific scenario. This process is estimated to consume approximately 1,500 kg of Jet-A1 fuel. However, in operations requiring maximum endurance—approximately five hours—the fuel consumption is estimated to rise to 1,700 kg (see Section 3.4.3.1).

Thus, the proposed fuel capacity of **MFW 2,000 kg** adequately covers both scenarios with security factors of 0.75 and 0.85, ensuring operational reliability and flexibility.

Fuel tank design

The fuel tank is a critical aircraft component, ensuring the safe storage, management, and supply of fuel during all phases of flight. It plays a vital role in maintaining operational reliability and minimizing risks, such as in-flight fires or fuel system failures.

The design must comply with Section CS-29 regulations for rotorcraft, addressing key aspects such as fuel system independence, crash resistance, and flame propagation prevention. This analysis is based on *EASA Certification Specifications, Acceptable Means of Compliance, and Guidance Material for Large Rotorcraft (CS-29)* [69].

Therefore, this section focuses on the fuel tank design, number of fuel tanks, and its positioning on the aircraft, considering the following key chapters: CS 29.952 (Fuel System Crash Resistance), and CS 29.963 (Fuel Tanks).

- **Crash Resistance (CS 29.952)**: Ensures fuel systems can withstand impact loads without rupturing.
- **Fuel Tank Design and Integrity (CS 29.963)**: Addresses construction, material strength, and leakage prevention.

Firstly, concerning the location of the fuel tank, the fuel tanks are usually mounted to the airframe as close as possible to the CG. This way, as fuel is burned off, there is a negligible effect on the CG.

Figure A.6: Fuel tank at aircraft fuselage example. Extracted from [16].

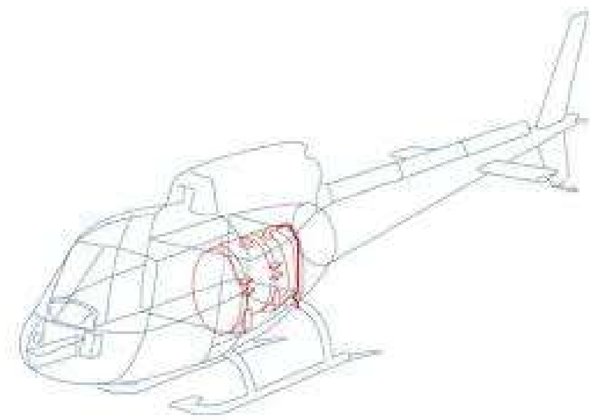


Figure A.7: Fuel tank sketch. Extracted from [17].

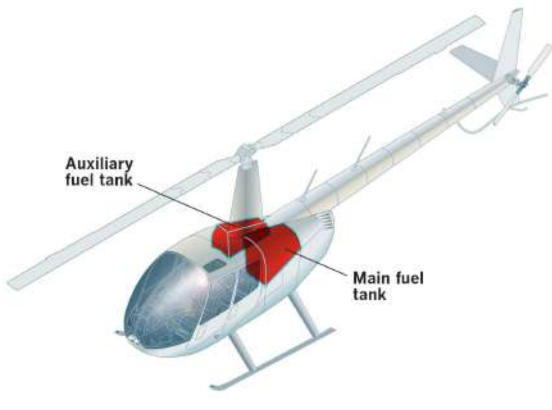


Figure A.8: Fuel tank plus auxiliary fuel tank position. Extracted from [18]

Secondly, in relation to the fuel capacity of 2,000 kg, which corresponds to 2,500 liters of Jet A1, the UAV will have two principal tanks, each capable of holding 1,250 liters of fuel.

Furthermore, if an special mission requires an overseas flight or extended flight endurance additional external fuel tanks could be added as in military expeditions.

Figure A.9: External fuel systems. Extracted from [19]

Lastly, following the CS29 section, the fuel system must ensure crash resistance to minimize fire hazards during survivable impacts. This includes compliance with drop test requirements, inertial load factors, and self-sealing breakaway couplings to prevent fuel leaks. Attachments must be frangible or deformable to avoid structural damage, while fuel tanks must be impact- and tear-resistant. Additionally, fuel systems must be separated from ignition sources and occupied areas for maximum safety.

A.3.2 Description of the layout of fuel distribution system and pumps

Once the main aspects of the fuel tank and fuel characteristics are discussed, it is possible to explain the distribution of the fuel system and pumps.

The general arrangement of the fuel tanks, along with the basic pump configuration, is illustrated in the following image.

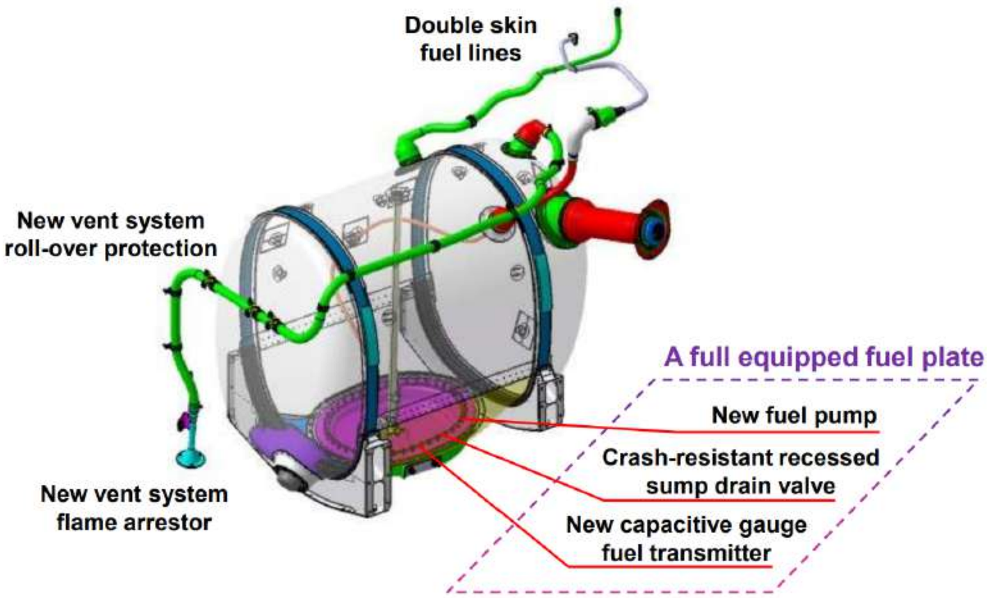


Figure A.10: Fuel tank and distribution system sketch. Extracted from [18]

Furthermore, since the fuel must reach the turboprop engine located near the main rotor, pumps are essential for efficient delivery. Most non-gravity feed fuel systems include both an electric pump and a mechanical engine-driven pump, and so will do the UAV. The **electric pump** serves to maintain positive fuel pressure to the engine-driven pump and acts as a backup in case of **mechanical pump** failure. Moreover, to ensure clean and efficient combustion, a fuel filter is included in the system to remove moisture and sediment before the fuel reaches the engine [177].

Nevertheless, this systems are typically controlled by a switch in the cockpit, allowing the pilot to activate it when needed. Additionally, regulating the precise amount of fuel injected into the engine—commonly controlled via the throttle and displayed on the command screen (particularly in piston engines)—should be automated. By integrating a CPU, the system can precisely manage the volume of fuel and oxygen, optimizing performance and ensuring reliability [177].

Appendix B

Aerodynamics

B.1 Main rotor blades

This section encompasses all that related for the selection as well as the study of the main rotor blades.

B.1.1 Airfoil blades selection. OWA method

Next, will be showed some characteristics applied to this decision method.

B.1.1.1 Variables used

The weights assigned to each criterion reflect their relative importance to overall airfoil performance, as outlined below:

- **Parasitic Drag Coefficient (C_{d_0}) - 40%:**
  This criterion has the highest weighting because minimizing drag is crucial for efficient flight, especially during cruise and forward flight. Parasitic drag directly impacts on fuel consumption and power efficiency. For applications where long-duration or fuel efficiency is critical, reducing drag provides significant performance gains, making C_{d_0} the most important criterion in the overall evaluation.

- **Stall Angle (α_{stall}) - 30%:**
  The stall angle determines the maximum angle of attack at which the airfoil can operate before stalling. As said before, higher stall angle improves the airfoil's maneuverability and efficiency at high angles of attack, which is especially beneficial during takeoff, landing, or high-demand maneuvers. Its relatively high weight reflects its importance for ensuring safety and versatility during flight.

- **Maximum Lift Coefficient ($C_{l_{\max}}$) - 25%:**
  While the maximum lift coefficient is essential for determining the airfoil's lift capacity, it is assigned a slightly lower weight compared to drag and stall angle. This reflects the fact that many airfoil applications prioritize minimizing drag and enhancing safety over achieving maximum lift. However, $C_{l_{\max}}$ remains a significant factor, as it determines the airfoil's ability to maintain flight at low speeds, particularly during takeoff and landing.

- **Airfoil Thickness - 5%:**
  Airfoil thickness is given the lowest weight in this analysis, as it has a more indirect influence on aerodynamic performance compared to lift, drag, and stall angle. While airfoil thickness affects structural integrity and can influence aerodynamic efficiency, its impact is less critical than the

other variables considered in this comparison, justifying the lower assigned weight.

This distribution of weights emphasizes the importance of minimizing drag and ensuring high maneuverability, with lift performance and structural considerations playing supporting but secondary roles.

B.1.1.2 OWA method results

The aerodynamic data from the 5-digit airfoils is:

Nº	NACA	$C_{l_{max}}$	C_{d_0}	α_{stall} [°]	% Thickness
A	23012	1.55	0.009	15.50	12.00%
B	23015	1.75	0.011	14.50	15.00%
C	23018	1.85	0.013	13.50	18.00%

Table B.1: Aerodynamic airfoil comparison extracted from Von Doenhoff and H.Abbot, 1959[4].

Criteria	Weight	A		B		C	
	g	p	gxp	p	gxp	p	gxp
$C_{l_{max}}$	25.00	3.00	75.00	1.67	41.67	1.00	25.00
C_{d_0}	40.00	1.00	40.00	2.00	80.00	3.00	120.00
α_{stall}	30.00	3.00	90.00	2.00	60.00	1.00	30.00
% Thickness	5.00	1.00	5.00	2.00	10.00	3.00	15.00
Sum (gxp)	100.00		210.00		191.67		190.00
OWA			**0.700**		**0.639**		**0.633**

Table B.2: Airfoil OWA method; A is NACA 23012, B NACA 23015 and C, NACA 23018.

B.1.2 BEMT numerical results

To determine the primary parameters of the rotor blades, a comprehensive **benchmark analysis** was conducted, comparing the proposed UAV with similar helicopters in terms of Maximum Takeoff Weight (MTOW) and Power-to-Weight ratio (PW), while taking into account the considerations previously discussed.

Given the scope and timeline of this project, conducting a full parametric analysis of all possible rotor configurations would be computationally expensive and resource-intensive. By focusing on existing designs with proven performance in comparable scenarios, it is possible to derive reliable estimates for key design parameters. Furthermore, benchmarking ensures that our UAV design aligns with real-world performance standards, particularly for operational parameters like endurance, power efficiency, and flight dynamics.

Thus, the final main **rotor design parameters** are:

MAIN ROTOR	**Nb (Number of Blades)**	**R (Blade Radius in m)**	**RPM (Revolutions per minute)**	**c (Chord in m)**
UAV	5	6.5	270	0.6

Table B.3: Parameters established involving the main rotor blades

These parameters have been extracted from previous benchmark analysis and taking into account typical blade chord values.

Using **5-digit NACA airfoil 23012** with **linear twist**, after convergence on the method we obtain the following torsion for a unit length blade on hover flight:

$$\theta(r\,[\mathrm{m}])\,[\mathrm{deg}] = \theta_0 + \theta_{tw}\,r = 27.7457 - 20\,r \quad \text{where} \quad r \in [0.0724, 1]\,\mathrm{m}$$

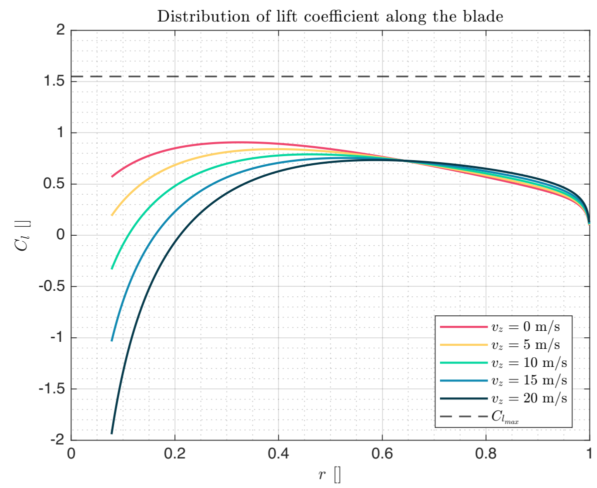


Figure B.1: Lift coefficient distributions along the blades for different rates of climb

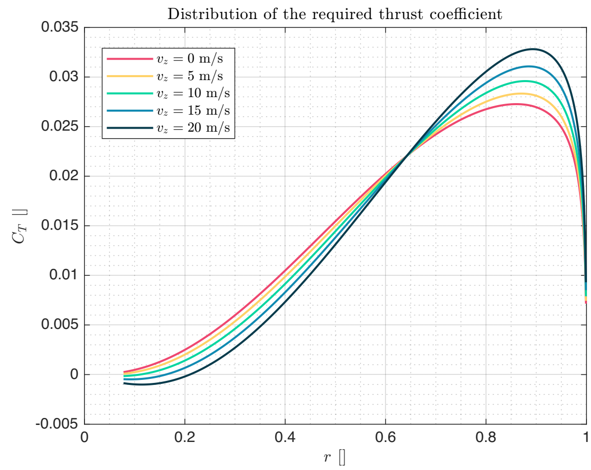


Figure B.2: Thrust coefficient distributions along the blades for different rates of climb

Figure B.3: Lift and thrust coefficient distributions along the blades for different rates of climb

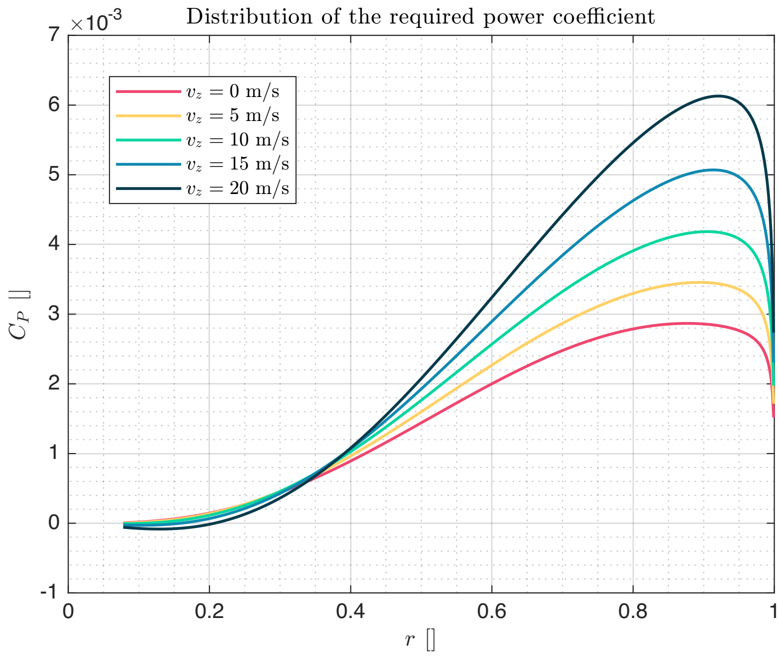


Figure B.4: Power coefficient distributions along the blades for different rates of climb

The result of the BEMT analysis also tells us the required power for the main rotor to operate:

v_z (m/s)	Power (kW)	Power (hp)	Excess Power (kW)	Excess Power (hp)
0	1443.5	1935.7	1114.5	1494.3
5	1670.4	2240.5	887.6	1189.8
10	1932.7	2591.4	625.3	838.4
15	2228.7	2987.7	329.3	441.6
20	2555.5	3425.4	2.5	3.4

Table B.4: Required power for the main rotor at different axial ascend speed values (v_z) and the corresponding excess power, assuming an available power of 2558 kW.

As shown in the table, the available power for performing an axial ascend of 15 m/s is more than sufficient. For reference, the Airbus H175 has a remarkable climb speed performance[1] of 15.79 m/s.

Ultimately, the top climb speed obtained from the BEMT analysis is 20.03 m/s, the value at which the excess power becomes negative.

B.2 Horizontal stabilizer airfoil selection

In helicopter design, both symmetric and asymmetric airfoils are considered depending on performance requirements. The NACA 0012 is a common symmetric choice due to its predictable behavior at both positive and negative angles of attack, making it ideal for general stability. However, for enhanced performance, asymmetric airfoils are more effective. In this study, the NACA 2412, NACA 4415, NACA 5414, and NACA 6412 are evaluated for their superior performance at low angles of attack, as they generate negative lift more efficiently. This is crucial for maintaining longitudinal stability during forward flight without introducing excessive drag. These asymmetric profiles are favored for their ability to provide greater efficiency in force generation with minimal angle adjustments. [178]

In the selection of an aerodynamic profile for the horizontal stabilizer of a helicopter, one of the most crucial performance metrics is the zero-lift angle of attack (α_0). The reason this parameter is so important is that the horizontal stabilizer primarily operates at low or near-zero angles of attack during forward flight. The goal is to generate the necessary stabilizing force (typically a downward force for an inverted profile) without requiring large angles of attack. A profile with an α_0 close to zero enables the stabilizer to start producing stabilizing force with minimal angular deflection, resulting in more efficient performance and better control of the helicopter's longitudinal stability. Hence, focusing on α_0 allows us to select a profile that is effective in low-angle operations, ensuring smoother flight and less drag.

[1] A climb of 3000 meters in 3 minutes and 10 seconds according to Airbus.

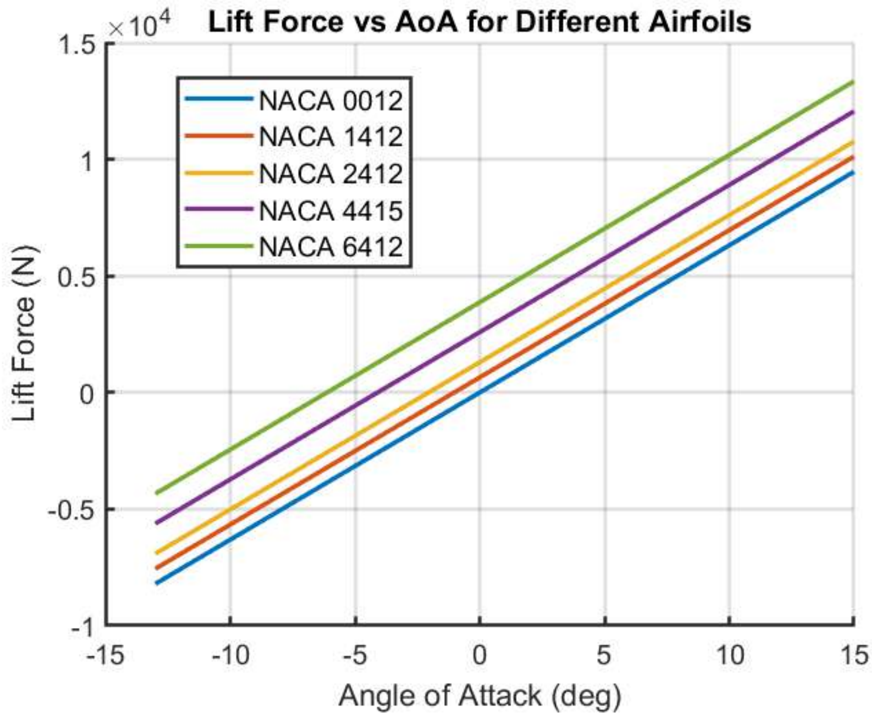


Figure B.5: Lift force vs AoA dor different airfoils

The graph above demonstrates the Lift Force vs Angle of Attack (AoA) for several NACA airfoils. All the curves show nearly parallel trends, which indicates that the slope of lift force (or lift coefficient) is similar across these airfoils. This observation shifts the focus to α_0, where the curves cross the zero-lift line. The position of this zero-lift crossing will determine how early the airfoil begins to produce stabilizing forces.

Furthermore, the chosen range of maximum angles of attack in the graph remains well below the stall angle, meaning that the airfoils are still generating lift efficiently without experiencing flow separation or stall. This is important, as the airfoil needs to maintain performance at these higher angles without the risk of entering stall, which could otherwise drastically reduce the stabilizer's effectiveness.

In optimizing the performance of a helicopter's horizontal stabilizer, the key objective is to maximize aerodynamic efficiency while generating the stabilizing forces needed to counteract the helicopter's pitching moments, especially during forward flight. To achieve this, an asymmetric airfoil becomes the preferred choice. Unlike symmetric airfoils, which require larger angles of attack to generate the same amount of lift, asymmetric airfoils such as the NACA 2412 or NACA 4415 can generate substantial lift (or downward force when inverted) at lower angles of attack.

This characteristic is crucial because, in forward flight, the stabilizer needs to maintain control and stability without requiring significant angular adjustments, which could otherwise increase drag and reduce the helicopter's overall performance. The NACA 2412 profile, with its moderate camber, provides a good balance by generating sufficient corrective stabilizing forces at lower angles of attack. The stabilizer's role is not to generate large amounts of force but rather to provide small corrective forces to maintain longitudinal balance. The **NACA 2412** improves performance and efficiency without needing large control inputs or significant deflections. By focusing on this asymmetric airfoil, we can optimize the stabilizer to operate efficiently at low angles, ensuring better stability control with minimal drag penalties, avoiding the need to generate excessive forces.

B.3 Fuselage aerodynamics

he fuselage aerodynamic coefficients have been estimated based to an scale model. The structure consists of the fuselage with a mast fairing, landing gear, and a rotating rotor head that includes blade cuffs. The tail boom is truncated just before the horizontal stabilizer. The engine intake and outlet are sealed with covers that conform to the model's geometry. The following experimental study has been extracted from Aerodynamic Analysis of a Helicopter Fuselage with Rotating Rotor Head, Roman Reß, Moritz Grawunder, and Christian Breitsamter, 2013 [20]

Figure B.6: Baseline configuration. Extracted from [20].

Results are given of the force measurements carried out with different fuselage configurations. The results are presented in form of aerodynamic coefficients C_D, and C_L calculated from the experimental data using the following equations:

Drag coefficient:

$$C_D = \frac{D}{q_\infty \cdot S_{\text{ref}}}$$

Lift coefficient:

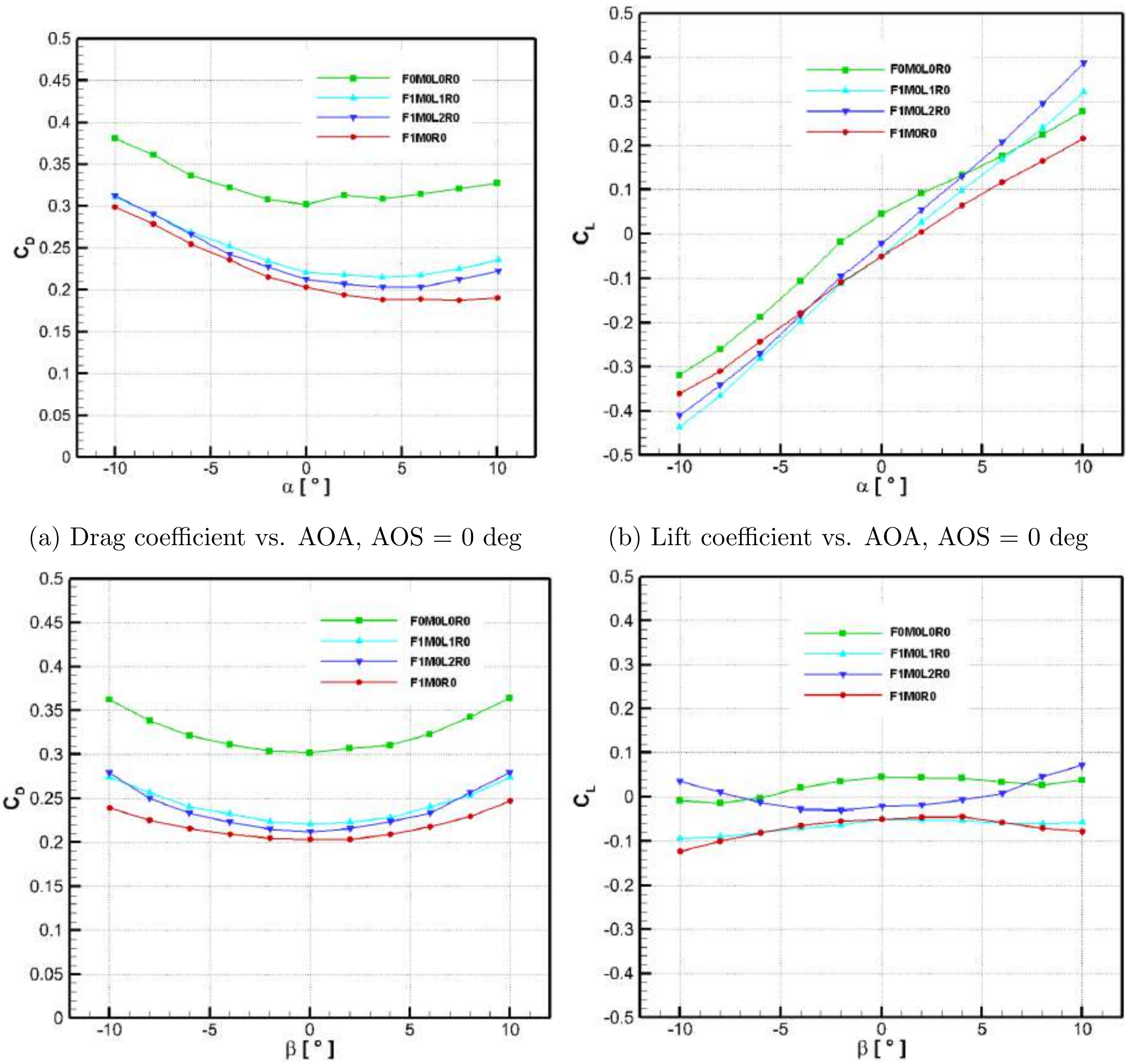
$$C_L = \frac{L}{q_\infty \cdot S_{\text{ref}}}$$

To establish the experimental model, various configurations have been considered, each assigned a unique identification code.

For example:

- **F0M0L0R0:** fuselage F0 + mast fairing M0 + landing gear L0 + rotor head R0.

Each number represents different fixed configurations of the landing gear and model components. The mean values of the aerodynamic coefficients across all configurations will be calculated to determine the primary aerodynamic loads on the fuselage.



(a) Drag coefficient vs. AOA, AOS = 0 deg

(b) Lift coefficient vs. AOA, AOS = 0 deg

(c) Drag coefficient vs. AOS, AOA = 0 deg

(d) Lift coefficient vs. AOS, AOA = 0 deg

Figure B.7: Lift and Drag fuselage coefficients based on experimental data. Extracted from [20].

In summary, considering an angle of attack (AoA) of 0° and an angle of sideslip (AoS) of 0° as the primary forward flight configuration, the parameters C_{D_0} and C_{L_0} are obtained.

Thus, for the drag force coefficient:

$$C_{D_0} \approx \frac{\sum_{i=1}^{n} C_{d_i}}{n} \approx 0.2325 \tag{B.1}$$

And for the lift force coefficient:

$$C_{L_0} \approx \frac{\sum_{i=1}^{n} C_{l_i}}{n} \approx -0.0125 \tag{B.2}$$

Thus, f_D is defined as $C_{D_0} \cdot S_{ref}$, and f_L is $C_{L_0} \cdot S_{ref}$. Considering forward flight, where the front aircraft width is approximately 2.14 m, and the height is 4 m, the reference surface calculated yields, $S_{ref} \approx 8.15\,\mathrm{m}^2$.

- $f_D \approx C_{D_0} \cdot S_{ref} \approx 1.85\ m^2$
- $f_L \approx C_{L_0} \cdot S_{ref} \approx -0.1018\ m^2$

B.4 Aerodynamic stability and control surfaces

B.4.1 Horizontal stabilizer

The horizontal stabilizer in a helicopter is crucial for maintaining longitudinal stability and controlling pitch, particularly during forward flight. As the helicopter transitions from hover to forward flight, the stabilizer helps prevent excessive nose-up or nose-down tendencies caused by the shift in rotor thrust and center of pressure. This stabilizing force ensures that the helicopter remains balanced and efficient at high speeds, reducing the need for constant pilot input.

The forces on the horizontal stabilizer are influenced by flight speed and rotor dynamics, with the stabilizer often required to generate either upward or downward corrective forces. A cambered airfoil is ideal for this role, as it produces lift or downward force even at small angles of attack. This makes the stabilizer more effective in maintaining stability without creating excessive drag, allowing the helicopter to perform smoothly across different flight regimes while minimizing control inputs and enhancing overall aerodynamic efficiency.

Figure B.8 presents a diagram illustrating the basic forces acting on a helicopter during forward flight. To simplify the analysis, and considering that typical AoA values range between $-10°$ and $10°$, the forward component of the thrust is neglected. Consequently, it is assumed that $T\cos(\alpha) \approx T$, where T is the total thrust.

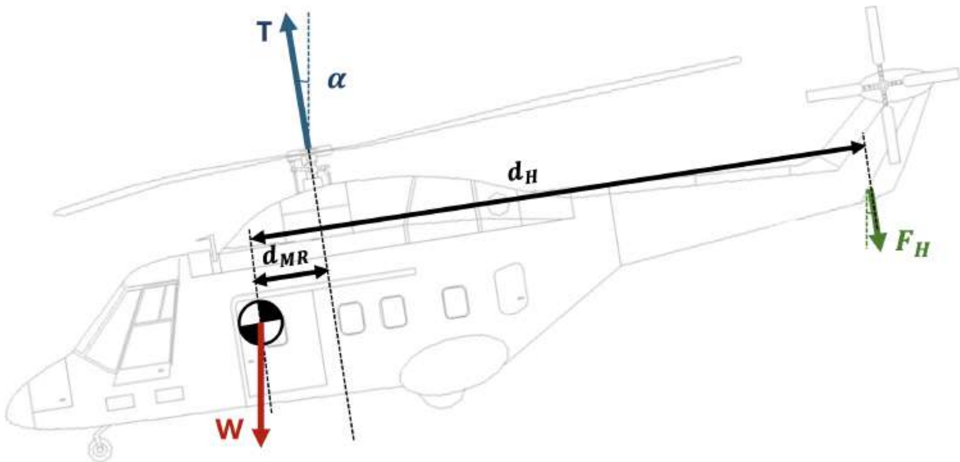


Figure B.8: Helicopter dynamics in forward flight. Background image from AutoCad Blocks [21]

The horizontal stabilizer plays a crucial role in reducing the pitching moment, as depicted in Figure B.8. The condition for equilibrium is determined by the following relationship:

$$\sum \vec{M} = 0 \tag{B.3}$$

$$T \cdot d_{MR} = F_H \cdot d_H \tag{B.4}$$

In force equilibrium, $T = W = m \cdot g = MTOW \cdot g$, leading to:

$$MTOW \cdot g \cdot d_{MR} = F_H \cdot d_H \tag{B.5}$$

To calculate the downward force generated by the horizontal stabilizer, F_H, a brief analysis is carried out.

First, the dimensions are derived from the design of the NH90 helicopter, a model with characteristics similar to the UAV, as reported by Eglin (1997) [179].

$$\text{Span: } b = 2.70\, m \tag{B.6}$$
$$\text{Chord: } c = 0.80\, m \tag{B.7}$$

Next, a brief study will be conducted to determine the airfoil that generates the highest lift with these dimensions.

Airfoil choice

To select the final airfoil for the helicopter's horizontal stabilizer, it is essential to study their lift characteristics and other relevant properties. An study has been conducted on several airfoils until reaching the best decision as explained in Appendix

The corresponding diagram for this airfoil is shown in the following image.

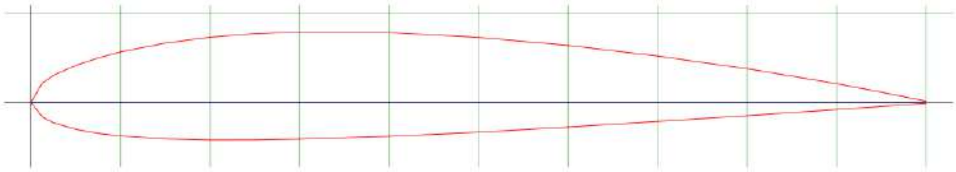


Figure B.9: Airfoil NACA 2412 diagram [22].

The following table provides a summary of the dimensions and characteristics of the selected horizontal stabilizer airfoil. The maximum force value is based on a maximum speed of 300 km/h for an angle of attack of 15°.

Wing span	**Chord**	α_0	$C_{L\alpha}$	$Max\ F_H\ force$
2.7 m	0.8 m	$-2.0520°$	3.9374 rad^{-1}	10766 N

Table B.5: Dimensions and key characteristics of the designed horizontal stabilizer

Substituting the maximum horizontal stabilizer force, F_H, into the pitching moment equilibrium (Equation B.5) gives the ratio of the distances between the horizontal stabilizer and the main rotor.

$$\frac{d_{MR}}{d_H} = \frac{F_H}{MTOW \cdot g} = \frac{10766}{8000 \cdot 9.81} \approx 0.14 \tag{B.8}$$

This ratio is essential for the design of the empennage and the accurate determination of the optimal center of mass position.

B.4.2 Vertical stabilizer

The vertical stabilizer in a helicopter is a critical component for maintaining yaw stability and control. It works by generating aerodynamic forces that counteract the torque produced by the main rotor, which tends to make the fuselage rotate in the opposite direction. Positioned at the tail of the helicopter, it helps stabilize yaw movements by creating a small but constant corrective force during forward flight, reducing the workload on the tail rotor. Unlike in some fixed-wing aircraft, the position of the vertical stabilizer in helicopters is generally fixed, meaning it doesn't move dynamically like a rudder. Instead, it passively stabilizes the yaw axis, particularly during cruise flight, while the active control of yaw is handled by the tail rotor, which adjusts its thrust to fine-tune the yawing moment.

To further understand how the vertical stabilizer acts, the following Figure shows a complete diagram of the moments at play:

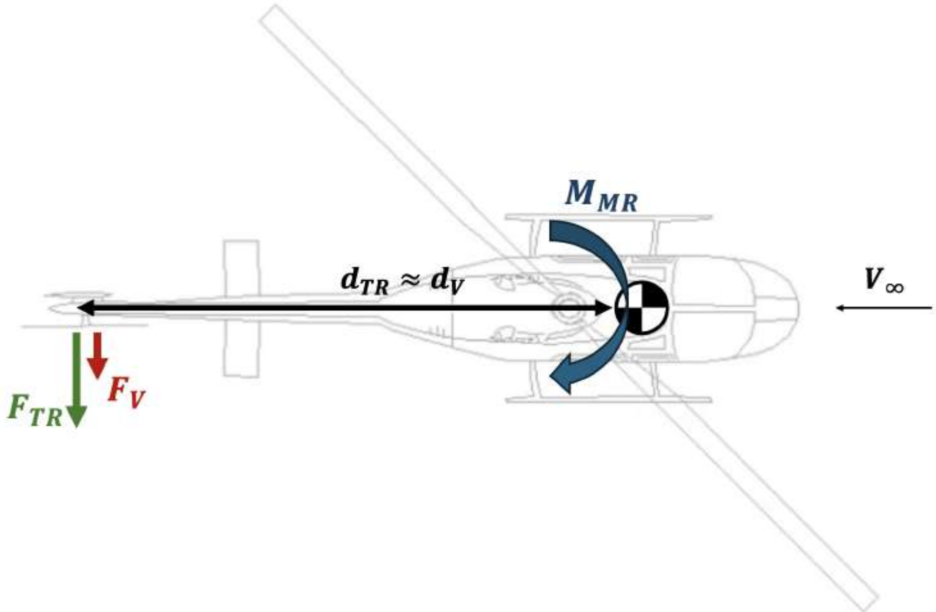


Figure B.10: Helicopter yaw moments. Background image from AutoCad Blocks [21].

From Figure B.10, the following moments balance is established:

$$\sum \vec{M} = 0 \tag{B.9}$$

$$M_{MR} = d_{TR} \cdot (F_V + F_{TR}) \tag{B.10}$$

This expression suggests that as the aerodynamic lift generated by the vertical stabilizer, F_V, increases, less effort—and consequently less power from the engines—is required by the tail rotor.

Changes and Explanations:

In order to calculate the value of F_V, the airfoil, dimensions and angle of incidence of the vertical stabilizer has to be established. First of all, the approximate dimensions of the empennage (which will be specifically determined in the Design section) have been taken from helicopter of similar MTOW and utility, for example the Airbus H175 [175]. This analysis has yielded a stabilizer dimension (supposed rectangular for calculistic simplicity) with the following geometric parameters:

$$\text{Span: } b = 2.50\,m$$

$$\text{Chord: } c = 0.75\,m$$

To compute the angle of incidence and select the airfoil type, a benchmarking process will be conducted, drawing on data from similar helicopters and various aerodynamic studies. A study by Dr. Leishman in Principles of Helicopter Aerodynamics [172] demonstrates that the vertical stabilizer typically uses a symmetric airfoil profile to provide consistent forces in both yaw directions. Additionally, an angular deviation from the longitudinal axis, typically around $\alpha \approx 3°$, is introduced to generate a lateral force (F_V) during forward flight, as symmetric airfoils produce no lift at $\alpha = 0°$. This deviation value will be used in force calculations.

To evaluate the most critical F_V value, the UAV's top speed, $v = 300km/h$, and a symmetrical NACA 0012 profile will be used. Moreover, the lift slope of the whole stabilizer ($C_{L\alpha}$) is computed using the same code as in the previous section. The corresponding diagram for the chosen airfoil along with the summary table are shown in the following Figures:

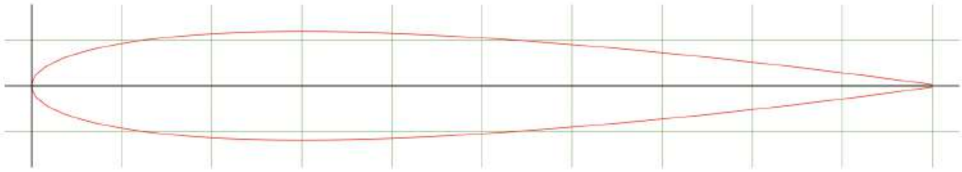


Figure B.11: Airfoil NACA 0012 diagram [23]

Wing span	**Chord**	α_0	$C_{L\alpha}$	$Max\ F_V\ force$
2.5 m	0.75 m	0°	3.9188 rad^{-1}	1636 N

Table B.6: Dimensions and key characteristics of the designed vertical stabilizer

B.4.3 center of mass ranges for helicopter stability

The center of gravity (CG) in a helicopter is essential for maintaining stability and effective control during flight. Its correct positioning allows pilots to handle the aircraft safely across various scenarios such as takeoffs, landings, and maneuvers in windy conditions. A helicopter's longitudinal attitude is highly dependent on cyclic control authority, and if the CG deviates beyond defined limits, it can lead to instability, compromised maneuverability, or difficulties in recovering from critical situations.

When the CG is too far forward, it causes the helicopter to tilt forward, pulling the rotor disk in that direction. To counteract this, the pilot needs to apply rearward cyclic control. However, excessive forward CG can reduce cyclic authority, impairing the pilot's ability to perform a proper flare for landing, leading to longer landing distances.

On the other hand, if the CG exceeds the aft limit, the helicopter assumes a tail-low attitude, which may demand more forward cyclic input than what is available, especially during hovering. Insufficient forward cyclic power increases the risk of a tail strike and can make it difficult to lower the nose in windy conditions or high-speed flight.

Helicopters have specific weight limits, but reaching the maximum isn't always safe in every situation. Factors like high-density altitudes can decrease the safe operating weight by affecting essential flight maneuvers. Additionally, shifts in the center of gravity can occur due to factors like fuel consumption, which may impact the aircraft's control. Therefore, it's important to consider the aircraft's weight and balance during all stages of flight to maintain safe operations [180].

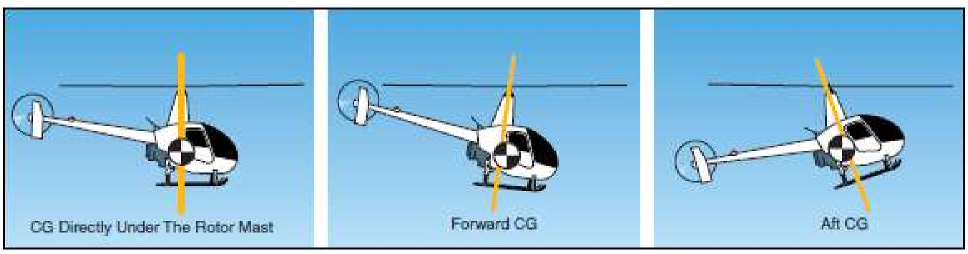


Figure B.12: The Effect of CG Position on Helicopter Stability [5].

In this section, the analysis will focus on the center of gravity (CG) range during forward flight, as this phase is where stability and control challenges are most critical for a helicopter. Forward flight is the most commonly utilized mode of operation, where the influence of CG positioning is particularly significant due to the effects of aerodynamic forces and rotor dynamics. By examining the CG range in this context, the goal is to establish guidelines that ensure safe and efficient helicopter performance.

The **EASA CS-29 Amendment 11** establishes guidelines for defining the forward limit of the center of gravity (CG) in helicopters to ensure safe and stable flight operations. According to **CS 27.27**, the forward CG limit must be determined based on the helicopter's structural capacity and compliance with all applicable flight requirements. Given the calculated ratio of approximately 0.14 from equation B.8, which reflects the relationship between the distances from the main rotor to the center of mass and from the center of mass to the horizontal stabilizer, a reasonable forward CG limit would be set between 0.10 and 0.18. This range is essential to maintain sufficient cyclic control authority and prevent scenarios where the helicopter's stability or control could be compromised. By keeping the CG within this defined forward range, the helicopter can operate safely without risking loss of control or compromising flight safety [69].

Appendix C

Performance

C.1 Forward flight performance

In order to conduct a thorough study on the forward flight performance, a Matlab code is implemented where different cruise speeds (V_∞) are studied. In this analysis, the optimal cruise speed will be determined along with the various cruise speeds at different altitudes, the range and endurance at forward flight and the fuel consumption rates at different forward flight phases.

C.1.1 Power analysis

To perform a power analysis, the different power components (profile, climb, induced and forward power) are computed for different cruise speeds, along with the total power, using the momentum theory.

For reference, the available engine power has to be computed in order to see if the cruising is possible at every speed. To do so, at each speed the calculations are performed to compute the power at the main and tail rotor shafts to establish a P_{tail}/P_{main} ratio that will yield an available power value.

The main rotor shaft power, with all its components, is graphed in Figure C.1, also giving the reference of the shaft power available. It is important to note that the shaft power is decomposed into climbing, induced, profile and forward powers, whose tendencies are also shown next:

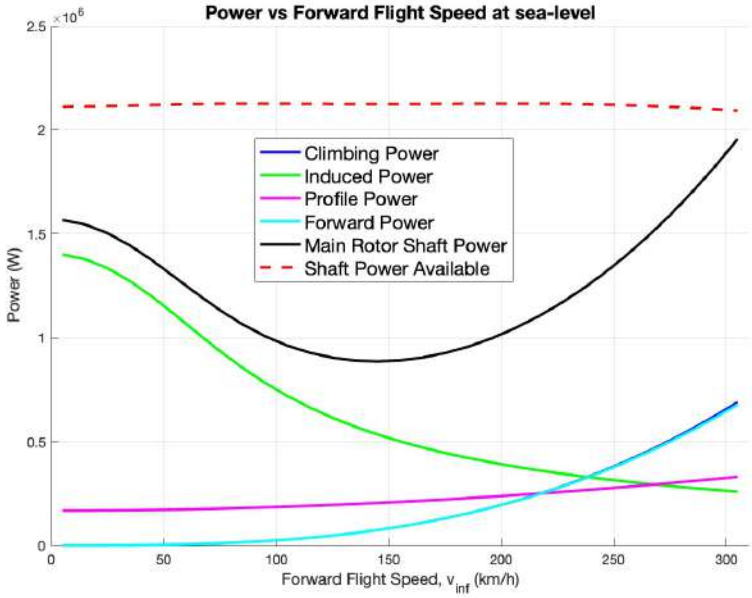


Figure C.1: Power decomposition as a function of cruise speed at ISA sea-level conditions.

Figure C.1 proves how the shaft provides enough power for any cruise speed desired. Therefore, the requirement of reaching a speed of $300km/h$ is successfully met under these conditions.

C.1.2 Cruise speed for optimal performance

To optimize the cruise speed of a helicopter, it is essential to balance power efficiency, operational requirements, and mission constraints. The optimal cruise speed typically corresponds to the point where the total power required (shaft power) is minimized, as this minimizes fuel consumption and maximizes range efficiency. This speed is influenced by aerodynamic forces, including induced power, profile power, and parasitic drag.

To identify this speed, Figure C.1 is analyzed, pinpointing the speed where the total power curve reaches its lowest value. The following figure shows the excess power available at each flight speed, still at ISA sea-level conditions:

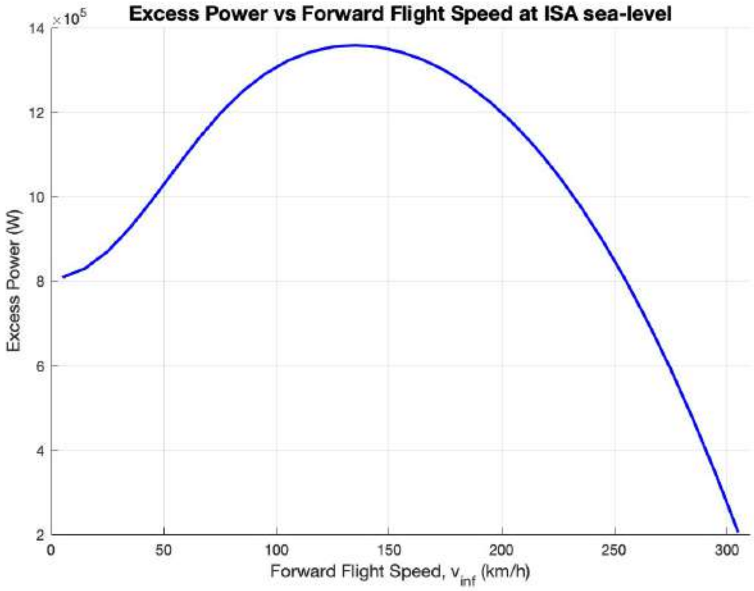


Figure C.2: Excess power at each flight speed.

Figure C.2 yields an optimal cruise speed, the one that minimizes the required power and hence the fuel consumption and range. This value stands at:

$$V_{optimal} = \mathbf{135km/h} \tag{C.1}$$

In practice, the cruise speed may also account for operational needs, such as reducing travel time, even if it slightly increases power consumption. Additionally, environmental conditions, payload, and available engine power must be considered, especially at high altitudes or with heavy loads. To ensure reliability, the cruise speed should stay below the maximum shaft power available, leaving sufficient margin for unexpected maneuvers or environmental variations.

C.1.3 Maximum speed at various flight conditions.

This maximum speed should be studied at different flight heights. When the altitude increases, the air becomes less dense, therefore, generating less lift and less drag. Although a smaller drag force should induce higher maximum speeds, a bigger AoA has to be introduced to generate more lift and maintain stable flight.

Therefore, using the main rotor blade's data (NACA 23012 [181]), the resulting drag coefficient can be extracted for each AoA. Then, the maximum speed can be extracted as the value of V_∞ where the available and the required powers yield exact values.

Another necessary consideration is the fact that the available power that an engine gives is not constant. Specifically, it approximately reduces proportionally to the density ratio:

$$\frac{P}{P_0} = \left(\frac{\rho}{\rho_0}\right)^n \tag{C.2}$$

where n usually stands around $n = 0.6$ for turboshafts [182].

Taking ISA conditions and conducting this study for different altitudes, the maximum speed is determined for different heights, with the following Figure summarizing the results:

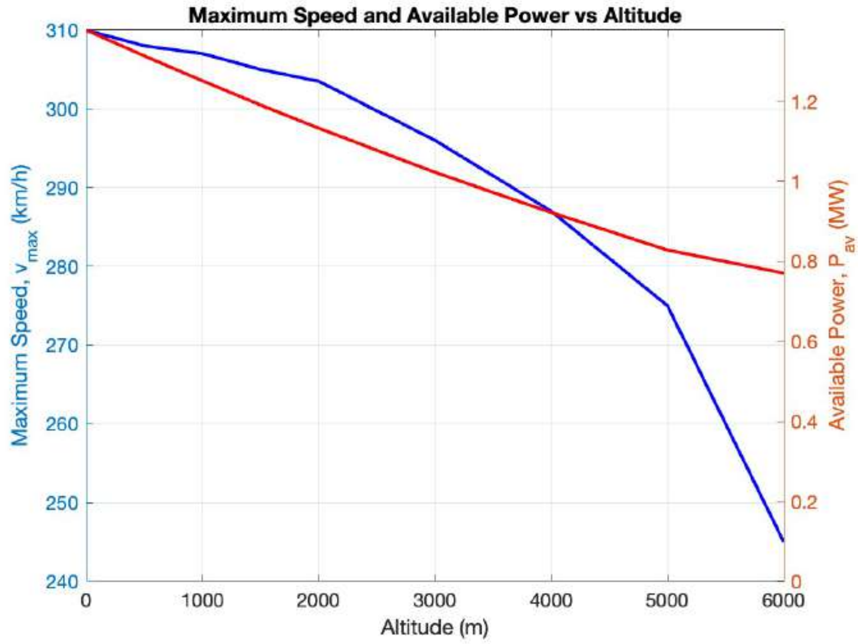


Figure C.3: Maximum speed at different altitudes.

From Figure C.3 it is inferred that the $300km/h$ speed requirement will only be meet at heights below $2500m$. Moreover, despite the air density reducing the drag, the reduction of available power proves to be more influential and this is why the maximum speed is inversely proportional to the height. It can be surprising how, at a height of $6000m$, the available power has reduced by nearly a 45% in contrast to sea-level.

However, another interesting fact that this analysis has revealed is the range of speeds where forward flight is theoretically possible at different heights.

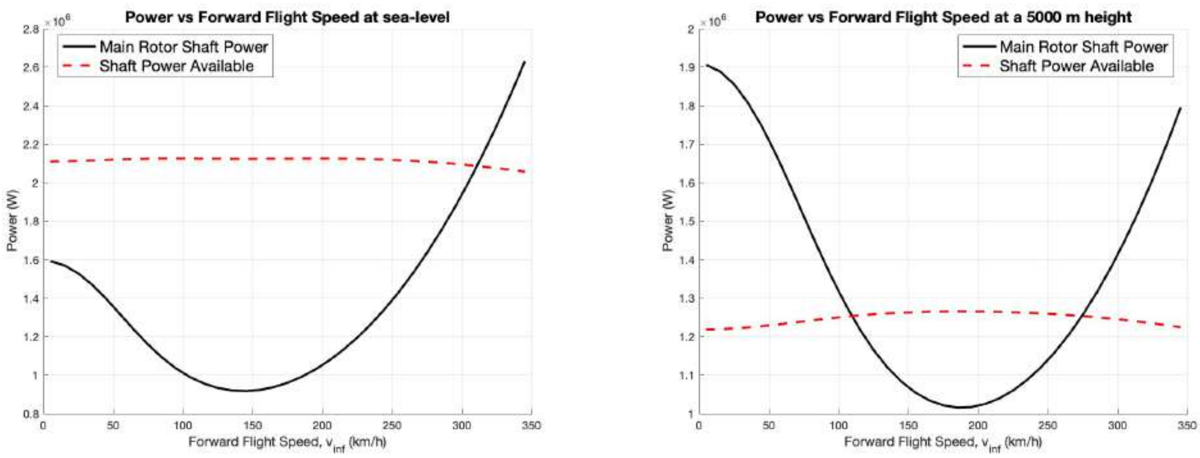


Figure C.4: Required vs. available power at sea-level (left) and 5000 m (right)

Figure C.4 illustrates that at sea level, all cruise speeds up to the maximum speed are feasible. However, at higher altitudes (e.g., 5000 m in the depiction), low speeds demand more power than is available due to the increased induced power, resulting in a restricted range of acceptable speeds. This indicates that while forward flight is achievable at high altitudes, it becomes potentially hazardous due to minimal or even negative excess power at certain low speeds, combined with a reduction in maximum speed.

C.2 Axial and hover flight performance

Hover flight represents a critical operational mode for rescue and emergency missions, where the helicopter must sustain stable flight without forward motion. The analysis evaluates the power requirements and the operational ceiling under hover conditions, considering the relationship between available and required power as altitude and weight vary.

C.2.1 Hover flight power analysis

The hover flight analysis focuses on determining the power requirements and operational ceiling for the helicopter in hover conditions. The total shaft power, induced power, and profile power were calculated as functions of altitude. The hover ceiling, defined as the maximum altitude where the required shaft power equals the available power, was also determined. It is important to remark that the available power decreases with altitude as stated in Equation C.2.

Figure C.5 illustrates the variation of power with altitude in hover flight, showing the breakdown of total power into its components and the operational ceiling. Additionally, Figure C.6 depicts the relationship between hover ceiling and helicopter mass.

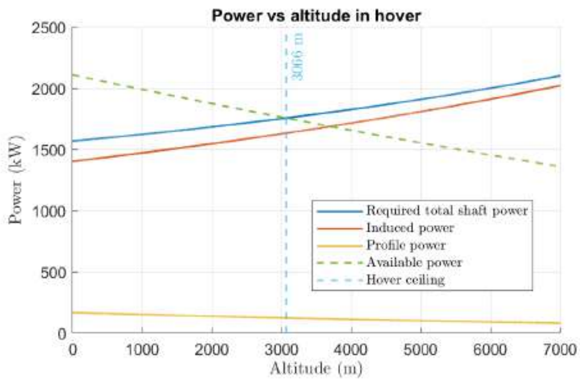


Figure C.5: Power vs. altitude in hover flight.

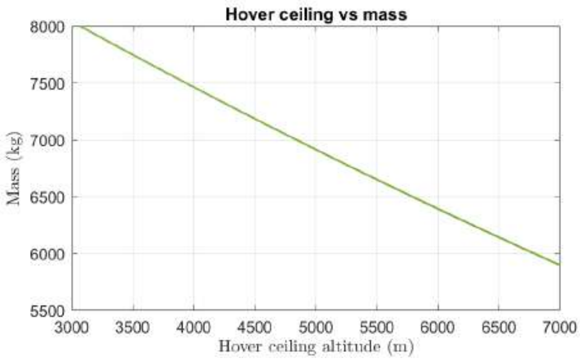


Figure C.6: Hover ceiling altitude as a function of helicopter mass.

From this analysis, it can be concluded that, with a mass of 8000 kg (required MTOW), the maximum altitude at which the UAV will be able to hover is 3066 m.

However, as seen in Figure C.6, this hover flight ceiling can be increased to more than 6500 m as the mass of the helicopter decreases due to fuel consumption. It is also important to note that during forward flight in cruise, the UAV will be able to reach higher altitudes thanks to the incident flow speed, as seen in Figure C.4.

Nevertheless, since the rescue operations will always require the UAV to hover, the first approach would be to set the mission altitude limit under 3066 m. It is safe to assume, however, that the weight of the aircraft will be significantly lower when reaching the emergency destination. More specifically, as will be later explained in Table C.2, in a typical mission more than 700 kg of fuel will have been consumed at the time of arrival to destination. According to Figure C.6, this means that the **mission altitude limit** could be theoretically set up to **4290 m**.

This fact doesn't exclude that, during the cruise phase, a higher more-optimal altitude can be reached to avoid obstacles or increase performance.

C.2.1.1 Axial flight power analysis

The axial flight analysis examines the power requirements during vertical climb at various altitudes. The induced velocity and corresponding shaft power were calculated as functions of climb velocity. The maximum climb speed was identified as the velocity at which the required shaft power equals the available power. Figure C.7 shows the variation of power with climb speed at sea level, while Figure C.8 presents the maximum climb speed as a function of altitude.

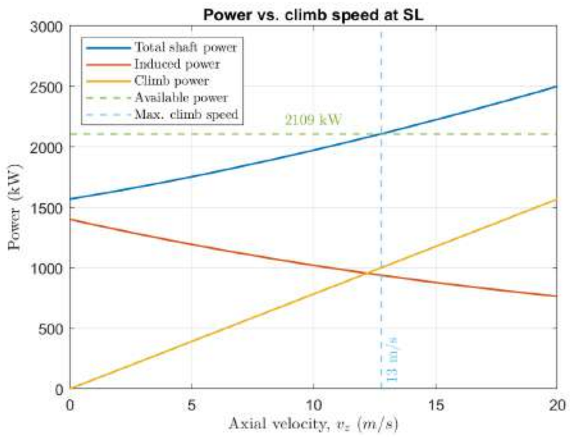


Figure C.7: Power vs. climb speed at sea level.

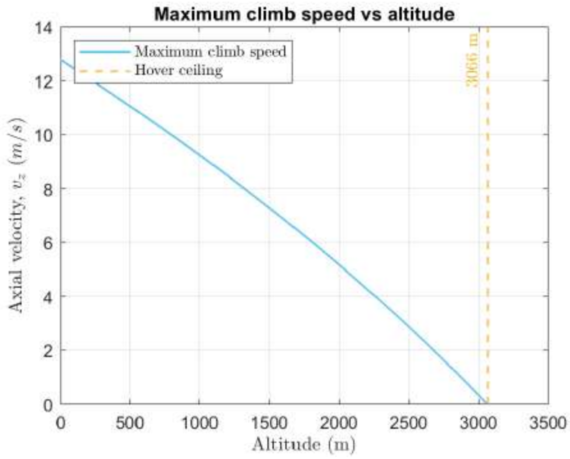


Figure C.8: Maximum climb speed vs. altitude.

Since the purpose of axial climb will be to increase altitude as quick as possible to depart from the base and begin operations, **an optimal rate of climb of up to 13 m/s** at Sea Level has been established. It is important to note that, due to the sudden decrease in pressure, it might be preferable to use a more moderate rate of climb to ensure comfort when the UAV is carrying personnel.

As seen in Figure C.8, the maximum climb speed will decrease slightly as available power is reduced with altitude, eventually reaching 0 m/s at 3066 m (hover ceiling).

C.2.2 Relevant operations definition

To ensure that the main requirements of the project are met, certain operations must be defined and analyzed. This sections aims to perform this study in detail.

C.2.2.1 Endurance-defining operation

One of the most critical requirements is achieving a flight endurance of 5 hours. While this requirement significantly surpasses the minimum range of 300 km, a dual operational approach can address both conditions. For shorter, fast-response missions, the aircraft can prioritize a less optimal flight profile to meet the 300 km range requirement. Conversely, for endurance-focused missions, a slower, more efficient flight profile can be adopted to achieve the 5-hour endurance target. This operational flexibility ensures the aircraft meets both mission profiles effectively.

This won't be a representative operation, one that is far from the typical mission that the UAV will perform, but that will prove the ability of the helicopter to fly for 5 hours and, therefore, meet the endurance requirement. This flight will be defined in three basic stages: first, an axial ascent into a safe cruising altitude of $500m$ that will last 5 minutes. Then, a long cruise at the optimal cruise speed for this altitude, which stands at $V_{\infty} = 140km/h$ as for the analysis developed in Section **??**, is completed. This cruise lasts 4 hours and 50 minutes and is obviously performed at the least power-requiring speed to minimize fuel consumption. Last, another axial descent lasting 5 minutes takes the helicopter into a safe landing.

For the first phase ($1 \rightarrow 2$), a lineal approximation will be made, assuming that the weight of the helicopter does not vary significantly. Therefore, based on the results of Section **??**, a slow axial flight of about $V_z = 1.67 m/s$ can be assumed to consume $1490kW$ of power constantly. Knowing this, the required fuel for this stage can be calculated:

$$FW_{1\rightarrow 2} = c_t \cdot t_{1\rightarrow 2} \cdot P_{req_{1\rightarrow 2}} = \mathbf{67.8kg} \tag{C.3}$$

with c_f being the SFC.

Moving on, the cruising phase ($2 \rightarrow 3$) has to be computed using Breguet's endurance equation to account for the lost of weight during this phase, which in this case will be considerable. The equation states the following:

$$E = \frac{\eta_p}{c_f g V_\infty} \cdot \frac{L}{D} \cdot \ln\left(\frac{W_2}{W_3}\right) \tag{C.4}$$

For the engine's efficiency (η_p), a typical value for these calculations in heavy helicopters [183], $\eta_p = 0.9$, will be used. Moreover, the initial weight W_2 is computed assuming that this operation began with MTOW, therefore $W_2 = MTOW - FW_{1\rightarrow 2} = 7932.2kg$. Finally, the aerodynamic efficiency is taken as $\frac{L}{D} = \frac{C_L}{C_D} \approx 5$, a typical value for high-MTOW helicopters that aligns with the aerodynamic analysis.

Imposing an endurance (E) of 4 hours and 50 minutes ($17400s$), the final weight of this stage $W_3 = 6342.05kg$ is defined. Therefore, the fuel needed for this flight phase is:

$$FW_{2\rightarrow 3} = W_2 - W_3 = \mathbf{1590.15kg} \tag{C.5}$$

Lastly, the last stage of this endurance-defining operation is the descent. For an axial speed of $V_z = -1.67m/s$ (500 m in 5 minutes), and again assuming a constant use of power, which in this case stands at $961kW$, the fuel consumed is:

$$FW_{3\rightarrow 3} = c_t \cdot t_{3\rightarrow 4} \cdot P_{req_{3\rightarrow 4}} = \mathbf{43.73kg} \tag{C.6}$$

After this analysis, the following table summarizes the calculations:

Endurance-defining Operation			
Stage	**Description**	**Duration**	**Fuel Weight used (kg)**
1-2	Axial ascent	5 minutes	68
2-3	Forward flight	4 hours and 50 minutes	1590
3-4	Axial descent	5 minutes	44
TOTAL		**5 hours**	**1702**

Table C.1: Summary of the endurance-defining operation.

As observed in Table C.1, the required endurance of 5 hours is met while using less fuel than the MFW calculated in Section A.3.1, still leaving a considerable margin for reserve, extra hovering phases or quicker axial ascent/descent. Moreover, the range requirement is of course also met, with a total cruising distance of $677km$.

C.2.3 Typical operation

The typical operation is also useful to define because it shows what a usual mission, in relation to how this UAV will be used, looks like. When relating it to all of the previous analyses, it will be confirmed that this type of operations can be carried out with relative ease, not getting close to the UAV's capabilities.

The stages of this typical operation will be:

1. Rapid axial ascent up to a $h_{cruise} = 1500m$.
2. Quick forward flight at a $V_\infty = 280km/h$ up to target, at a distance of 300 km.
3. Axial descent until getting close to the surface.
4. 10 minute hover to find the best landing spot, followed by the landing.
5. Axial ascent up to a $h_{cruise} = 1500m$. The UAV cannot refuel at the rescue spot. When on land, only the resources delivery or the humanitarian rescue is performed.
6. Quick forward flight at a $V_\infty = 280km/h$ back to the base.
7. Axial descent and landing.

It is supposed that, in the case of this operation involving the rescue of individuals requiring medical attention, a hospital is placed in the base itself. Otherwise, the UAV could of course land in a nearby hospital and then , without refueling, fly back to base. Moreover, it is supposed that 80% of the available FW is used, with the TOW being approximately 7000 kg when accounting for payload.

To conduct this study, let's analyze the different stages individually.

Stage 1 → 2: Axial ascent. Given the rescue nature of this mission, the ascent up to h_{cruise} must be quick. Assuming a rapid axial speed of $V_z = 8m/s$, the required time for this stage is: $t_{1\to2} = h_{cruise}/V_z = 187.5s$. Moreover, the amount of fuel needed is computed assuming a constant power output, as per Section **??**, of $Preq_{1\to2} = 1850kW$. This yields:

$$FW_{1\to2} = c_t \cdot t_{1\to2} \cdot P_{req_{1\to2}} = \mathbf{52.61kg} \tag{C.7}$$

Stage 2 → 3: Quick forward flight. With an initial weight of $W_2 = TOW - FW_{1\to2} = 6947.39$, 300 km are traveled at a constant speed of 280 km/h, hence investing 1 hour and 5 minutes. By applying Breguet's endurance formula, Equation (C.4), using the same engine and aerodynamic efficiencies, the final weight after this forward flight phase is $W_3 = 6291.21kg$. Therefore, the amount of fuel used results in:

$$FW_{2\to3} = W_2 - W_3 = \mathbf{656.18kg} \tag{C.8}$$

Stage 3 → 4: Axial descent. Again recalculating the initial weight analogously, this stage focuses on a quick axial descent at a $V_z = -8m/s$. Therefore, this operation will take approximately the same time as the first one, $t_{3\to4} = 187.5s$. The power required will be considered constant, at $Preq_{3\to4} = 1450kW$. This yields:

$$FW_{3\to4} = c_t \cdot t_{3\to4} \cdot P_{req_{3\to4}} = \mathbf{41.23kg} \tag{C.9}$$

Stage 4 → 5: Extended hover. To find the best landing spot in a challenging environment, an approximately 10-minute hover flight will most likely be necessary. After computing $W_4 = 6249.98kg$, it is determined that this flight, at sea-level, consumes a constant $Preq_{4\to5} = 1120kW$. Therefore:

$$FW_{4\to5} = c_t \cdot t_{4\to5} \cdot P_{req_{4\to5}} = \mathbf{101.92kg} \tag{C.10}$$

Stage $5 \to 6$**: Axial ascent.** This stage is analog to $1 \to 2$ but the fuel computation will be slightly different because the UAV's weight has decreased. At the beginning of this phase, the weight is $W_5 = 6148.06kg$. Applying the same vertical speed, the power required in this case drops to $Preq_{5\to6} = 1650kW$. This yields:

$$FW_{5\to6} = c_t \cdot t_{5\to6} \cdot P_{req_{5\to6}} = \mathbf{46.92kg} \tag{C.11}$$

Stage $6 \to 7$**: Quick forward flight.** Again, this stage is analog to $2 \to 3$ with the initial weight modified ($W_6 = 6101.13kg$). Assuming the same cruising speed (rapid operation will probably still be necessary if an injured individual or critical cargo is onboard), the application of Equation (C.4) yields a value of $W_7 = 5525kg$,:

$$FW_{6\to7} = W_6 - W_7 = \mathbf{576.13kg} \tag{C.12}$$

Stage $7 \to 8$**: Axial descent and landing.** For the final descent, the same quick axial descent speed is assumed, adding a 2-minute hover to factor in a precise and safe landing. All in all, the average power used in this stage is averaged to be $Preq_{7\to8} = 1280kW$. Hence:

$$FW_{7\to8} = c_t \cdot t_{7\to8} \cdot P_{req_{7\to8}} = \mathbf{48.05kg} \tag{C.13}$$

A summary of the typical operation shown in the following Table:

Typical Operation			
Stage	**Description**	**Duration**	**Fuel Weight used (kg)**
1-2	Axial ascent	3 minutes	53
2-3	Forward flight	1 hour and 5 minutes	656
3-4	Axial descent	3 minutes	41
4-5	Hover & Landing	10 minutes	102
5-6	Axial ascent	3 minutes	47
6-7	Forward flight	1 hour and 5 minutes	576
7-8	Axial descent & Landing	5 minutes	48
TOTAL		**2 hours 34 minutes**	**1523**

Table C.2: Summary of the typical operation.

Even though the described mission is just an example of what a normal operation would look like, it shows how using just 80% of the fuel weight and nearly MPL, a quick operation at nearly 300 km of distance is more than possible.

The capabilities of the helicopter can still be pushed more towards its limit, by increasing the distance of the operation towards a maximum of 400 km and the forward speed to 300 km/h while taking off at MTOW.

Appendix D

Materials, design & structure

D.1 Materials selection OWA methods

D.1.1 Fuselage material selections

D.1.2 Blade material selection

Appendix E

Payload & Operations

E.1 Selection of the box material

The materials listed in Section 3.6.1.2 will be normalized to allow fair comparison across criteria with different scales and units. The evaluation parameters include weight, cost, eco-friendliness, durability, impact resistance, and load-bearing capacity. Each material will be scored on a scale from 1 to 5, with the best-performing material receiving a score of 5 and the least-performing a score of 1. Intermediate values will be linearly interpolated based on their relative performance.

Normalization methods vary according to the parameter's desirability. For example, lighter weight and lower cost are preferred, while higher durability, impact resistance, and load-bearing capacity are advantageous. Eco-friendliness is assessed based on its overall sustainability impact, with higher scores for renewable or recyclable materials. Each parameter is normalized using the appropriate method to reflect its specific contribution to material suitability.

The following table shows the results obtained for each material and criteria:

N°	Material	Weight	Cost	Eco-Friend.	Durability	Impact Resist.	Loa
A	Recicled Aluminium	2.68	4.34	4.52	1.80	1.80	
B	Hemp Fiber Reinforced Plastic	3.11	3.52	1.00	4.14	1.80	
C	Basalt Fiber	1.00	4.62	4.41	3.00	1.80	
D	Plywood	5.00	4.34	4.80	2.71	1.80	

Table E.1: Normalized Evaluation of Container Materials

N°	Material	Weight	Cost	Eco-Friend.	Durability	Impact Resist.	Load Cap.
A	Recicled Aluminium	2.68	4.34	4.52	1.80	1.80	1.80
B	Hemp Fiber Reinforced Plastic	3.11	3.52	1.00	4.14	1.80	1.80
C	Basalt Fiber	1.00	4.62	4.41	3.00	1.80	1.80
D	Plywood	5.00	4.34	4.80	2.71	1.80	1.80

Table E.2: Normalized Evaluation of Container Materials

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E.2 Extended Medical Supplies List

1. Advanced Life Support Equipment (ALS)
These are critical devices to maintain the patient's life during transport or until they reach a medical facility.

- Defibrillator Monitor:
  - Capable of performing ECG (electrocardiograms).
  - Continuous cardiac rhythm monitoring.
  - Manual and automatic defibrillation function (AED).
  - Capnography and pulse oximetry.
- Mechanical Ventilator:
  - Volume and pressure control for respiratory assistance in patients with respiratory failure.
  - Invasive and non-invasive ventilation modes.
- Infusion Pump:
  - For controlled administration of intravenous (IV) medications, fluids, or solutions in emergencies.
- Manual Resuscitator (Ambu Bag) with Masks:
  - Self-inflating bag for manual ventilation of patients with apnea or respiratory failure.

2. Monitoring Equipment
These devices are essential for evaluating and tracking the patient's vital signs during flight.

- Multiparameter Monitor:
  - Non-invasive blood pressure monitoring (NIBP).
  - Oxygen saturation (SpO2).
  - Capnography (CO_2 in exhaled air).
  - Invasive blood pressure for critically ill patients.
- Portable Pulse Oximeter:
  - Continuously measures oxygen saturation in the blood.
- Digital Thermometer:
  - Used to monitor the patient's body temperature.

3. Airway and Breathing Equipment
These devices are critical to ensuring a safe and effective airway in emergency situations.

- Laryngoscope with Blades of Various Sizes:
  - Used for endotracheal intubation in patients requiring advanced airway control.
- Endotracheal Tube (ETT):

  - Available in various sizes for different patients (adult and pediatric).
- Laryngeal Mask Airways (LMA):
  - Alternative to secure the airway in emergencies where intubation is difficult.
- Nasopharyngeal and Oropharyngeal Airways:
  - To maintain open airways in semi-conscious patients.
- Portable Oxygen with Regulator:
  - Oxygen source for respiratory support during flight.
- Portable Nebulizer:
  - For administering inhaled medication to patients with asthma or respiratory issues.

4. Venous Access and Medication Administration Equipment

- Intravenous Catheters:
  - Various gauges for peripheral venous access in patients.
- Intraosseous Access Kit:
  - For administration of medications and fluids in critically ill patients where venous access is difficult (usually pediatric).
- Disposable Syringes and Needles:
  - Various sizes for medication administration.
- Intravenous Solutions and Fluids:
  - Saline solution, Ringer's lactate, and other IV fluids.
- Emergency Medications:
  - Includes adrenaline, atropine, lidocaine, amiodarone, vasoactive drugs, and muscle relaxants.

5. Trauma and Orthopedic Support Materials

- Cervical Collars:
  - For cervical immobilization in patients with suspected spinal trauma.
- Rigid Rescue Board:
  - For mobilizing and immobilizing polytraumatized patients.
- Inflatable and Rigid Splints:
  - To immobilize limb fractures.
- Bandages and Gauze:
  - Material to control hemorrhages and dress wounds.

- Tourniquets:
  - To control severe extremity hemorrhages.

6. Cardiac Support Equipment

- External Pacemaker:
  - For temporary cardiac pacing in patients with severe bradycardia.
- Suction Device:
  - For clearing the airway of secretions, blood, or vomit in obstructed patients.

7. Patient Transport Equipment

- Rescue Stretcher (Scoop Stretcher):
  - Lightweight stretcher to transport the patient from the accident scene to the helicopter.
- Folding or Spinal Stretcher:
  - Used for transporting the patient within the helicopter.
- Patient Restraint System:
  - Safety harness to secure the patient during flight.

8. Personal Protective Equipment (PPE)

- Disposable Gloves:
  - For protection against infections.
- Masks and Face Shields:
  - To protect medical personnel and patients.
- Protective Glasses:
  - Eye protection in environments with the risk of body fluids.
- Gowns and Protective Suits:
  - For handling patients with infectious diseases.

9. Communication Equipment

- Radios and Communication Systems:
  - To coordinate with hospitals, other emergency units, and air traffic control.
- Tablet or Electronic Device:
  - For access to medical protocols, patient records, and real-time data tracking.

10. Additional Materials

- Thermal Fluid Bag:
  - To maintain the appropriate temperature of IV fluids in cold climates.
- Emergency Childbirth Kit:
  - To assist with childbirth during the flight.
- Burn Kit:
  - Sterile gauze and specialized dressings for severe burns.
- Thermal Blanket (Emergency Blanket):
  - To prevent hypothermia in trauma or cold weather situations.
- Disposable Electrodes:
  - For ECG monitoring and defibrillation.

11. Specialized Equipment
Depending on the type of mission and the medical personnel on board, some helicopters may carry additional equipment:

- Minor Emergency Surgery Kit:
  - Basic surgical materials for emergency procedures.
- Extracorporeal Membrane Oxygenation (ECMO) Devices:
  - Used in extremely critical situations, though rare in helicopters due to limited space.

12. Helicopter Emergency Systems

- Emergency Suction System:
  - To evacuate fluids in cases of massive aspiration.
- Mobile Lighting:
  - Portable light for medical evaluation in low-visibility environments.

13. Basic Supplies

- Alcohol, Antiseptics, and Disinfectants:
  - For wound cleaning and equipment disinfection.
- Adhesive Tape and Sutures:
  - For temporary wound closure.
- Trauma Shears:
  - To cut clothing and quickly access wounds.

14. Biological Resources

This section includes critical blood products necessary for trauma care and critical situations.

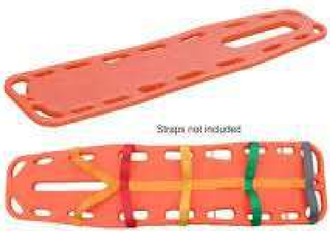
- Blood Bags:
  - Prepared blood products for transfusions, including red blood cells (RBCs), which are essential for patients with significant blood loss.
- Plasma Products:
  - Fresh frozen plasma (FFP) is crucial for patients requiring clotting factors in situations such as trauma or severe coagulopathy.
- Platelets:
  - Administered to patients with thrombocytopenia or to support those undergoing procedures that may increase bleeding risk.
- Crossmatched Blood Products:
  - Pre-arranged blood components for specific patients in critical situations to avoid transfusion reactions.

Equipment / Model	Photo	Equipment / Model	Photo
Defibrillator Monitor LIFEPAK 15 V4+		External Pacemaker Pace modelo 101	
Mechanical Ventilator Hamilton-T1		Suction Device DeVilbiss Suction Unit	
Infusion Pump Alaris Asena CC plus		Rescue Stretcher (Scoop Stretcher) Ferno Scoop Stretcher	
Manual Resuscitator (Ambu Bag) Ambu Mark IV		Patient Restraint System Ferno Patient Restraint Harness	
Multiparameter Monitor Philips IntelliVue MX800		Disposable Gloves Microflex Disposable Gloves	

Portable Pulse Oximeter Masimo Radical-7		Masks and Face Shields 3M Aura Respirator	
Digital Thermometer Welch Allyn Pro 400		Protective Glasses Uvex Stealth Safety Glasses	
Laryngoscope McGRATH Series 5		Gowns and Protective Suits DuPont Tyvek Coveralls	
Endotracheal Tube (ETT) Shiley Endotracheal Tube		Radios and Communication Systems Motorola XPR 7550e	
Laryngeal Mask Airways (LMA) LMA Supreme airway		Tablet or Electronic Device Apple iPad Pro	

Nasopharyngeal Airway Berman Airway		Thermal Fluid Bag Medline Thermal IV Bag	
Portable Oxygen with Regulator OxyGo Portable Oxygen System		Emergency Childbirth Kit Kito Emergency Childbirth Kit	
Portable Nebulizer PARI Vios		Burn Kit Burn Dressing Kit	
Intravenous Catheters BD Insyte Autoguard		Thermal Blanket CuraPlex Mylar Emergency Blanket	
Intraosseous Access Kit EZ-IO Intraosseous Device		Disposable Electrodes Covidien PreGel Electrodes	

Disposable Syringes and Needles BD Luer Lock Syringe		Minor Emergency Surgery Kit Medesy Surgery Kit	
Intravenous Solutions and Fluids Lactated Ringer's Solution		Extracorporeal Membrane Oxygenation (ECMO) Maquet Cardiohelp ECMO	
Emergency Medications Epinephrine Auto-Injector		Emergency Suction System Laerdal Suction Unit	
Blood Bags For each blood type		Mobile Lighting LEDL200	
Plasma Products For each blood type		Alcohol Alkofarma 70º Antiseptic alcohol	

Cervical Collars SAM Splint		Antiseptics Betadine Antiseptic Solution	
Rigid Rescue Board Spine Board		Equip Disinfectants Bacillol 30 Foam	
Inflatable and Rigid Splints VACULIFE Inflatable Splint		Adhesive Tape and Sutures 3M Micropore Tape	
Bandages and Gauze Kerlix Gauze		Trauma Shears Fiskars Trauma Shears	
Tourniquets CAT Tourniquet Gen 7			

E.3 Checklist for restocking procedures

6. HEMS MEDICAL SUPPLIES CHECKLIST

1- Advanced Life Support Equipment (ALS)
Defibrillator Monitor......... ....CHECK POWER
Mechanical Ventilator..................................CHECK POWER
Infusion Pump..CHECK POWER
Manual Resuscitator..........................CHECK FOR DAMAGE

2- Monitoring Equipment
Multiparameter Monitor...................................CHECK POWER
Portable Pulse Oximeter...............................CHECK POWER
Digital Thermometer......................................CHECK POWER

3- Airway and Breathing Equipment
Laryngoscope with Blades...................CHECK FOR DAMAGE
Endotracheal Tube (ETT)........................CHECK FOR DAMAGE
Laryngeal Mask Airways (LMA).............CHECK FOR DAMAGE
Nasopharyngeal Airways.....................CHECK FOR DAMAGE
Portable Oxygen with Regulator...................CHECK POWER
Portable Nebulizer.......................................CHECK POWER

4- Patient Transport Equipment
Rescue Stretcher (Scoop Stretcher).......CHECK FOR DAMAGE
Patient Restraint System.....................CHECK FOR DAMAGE

1- Advanced Life Support Equipment (ALS)
Defibrillator Monitor......... ....CHECK POWER
Mechanical Ventilator..................................CHECK POWER
Infusion Pump..CHECK POWER
Manual Resuscitator..........................CHECK FOR DAMAGE

6- Cardiac Support Equipment
External Pacemaker....................................CHECK POWER
Suction Device..CHECK POWER

7- Venous Access and Medication Administration Equipment
Intravenous Catheters........................CHECK FOR DAMAGE
Intraosseous Access Kit.....................CHECK FOR DAMAGE
Disposable Syringes and Needles.........CHECK FOR DAMAGE
Intravenous Solutions and Fluids....................CHECK EXPIRY
Emergency Medications..............................CHECK EXPIRY

8- Personal Protective Equipment (PPE)
Disposable Gloves.....................................CHECK EXPIRY
Masks and Face Shields..............................CHECK EXPIRY
Protective Glasses...........................CHECK FOR DAMAGE
Gowns and Protective Suits.................CHECK FOR DAMAGE

9- Communication Equipment
Radios and Communication Systems............CHECK POWER
Tablet or Electronic Device..........................CHECK POWER

12- Helicopter Emergency Systems
Emergency Suction System.........................CHECK POWER
Mobile Lighting...CHECK POWER

10-Additional Material
Thermal Fluid Bag......................................CHECK EXPIRY
Emergency Childbirth Kit......................CHECK FOR DAMAGE
Burn Kit..CHECK EXPIRY
Thermal Blanket (Emergency Blanket)...CHECK FOR DAMAGE
Disposable Electrodes.................................CHECK EXPIRY

11-Specialized Equipment
Minor Emergency Surgery Kit..............CHECK FOR DAMAGE
ECMO Devices...CHECK POWER

13-Basic Supplies
Alcohol, Antiseptics, and Disinfectants............CHECK EXPIRY
Adhesive Tape and Sutures.................CHECK FOR DAMAGE
Trauma Shears................................CHECK FOR DAMAGE

14- Biological Resources
Blood Bags...CHECK EXPIRY
Plasma Products.......................................CHECK EXPIRY
Platelets..CHECK EXPIRY
Crossmatched Blood Products......................CHECK EXPIRY

Every item shall be onboard, in good conditions and function properly. For correct maintenance preserve each item following manufacturers recommendations.

-CHECK FOR DAMAGE: Verify object has no imperfections and is safely stored.

-CHECK POWER: Turn on the device, check its power alimentation and verify it operates properly.

NOTE: Don't turn on all devices at same time in order to avoid excessive power consumption.

-CHECK EXPIRY: Verify that the item is in good condition and has not passed its expiration date.

Appendix F

Avionics & Systems

F.1 Study of the Geostationary satellites

The wide area covered and the fact that it does not move relative to the Earth make a geostationary satellite an excellent option for satellite communication. We will follow a simple calculation to find their elevation and latency.

The potential energy of a satellite due to the gravitational field of the Earth is:

$$V = -G\frac{Mm}{r}$$

And the kinetic energy of a satellite is:

$$T = \frac{1}{2}mv^2 = \frac{1}{2}m((\omega r)^2 + \dot{r}^2)$$

So, we have that the Lagrangian is:

$$\mathcal{L} = T - V$$

and the Euler-Lagrange equations for the r coordinate give:

$$m\ddot{r} - G\frac{Mm}{r^2} + m\omega^2 r = 0$$

If we impose $\dot{r} = 0$ and isolate r, it is possible to find the radius of the orbit for a geostationary satellite.

$$r = \left(\frac{GM}{\frac{2\pi}{24\cdot 3600}}\right)^{\frac{1}{3}} \approx 4.22 \cdot 10^7 m$$

Now, as an example of working operation, let's assume there is need for communication to a UAV that is at a latitude of 42º North (Pyrenees). The angle at which the UAV sees the satellite above the horizon is the elevation angle. In this case:

$$\tan(\lambda) = \frac{R\sin(42^\circ)}{r - R\cos(42^\circ)} \approx 0.114$$

$$\beta = 48^\circ - \lambda \approx 42^\circ$$

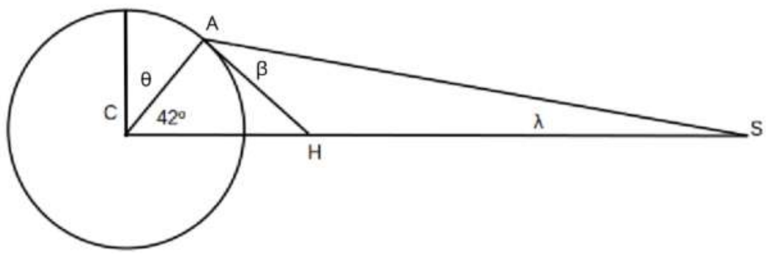


Figure F.1: Diagram of the center of the Earth (C), the UAV (A), the Satellite (S). $|\vec{CA}| = R = 6.37 \cdot 10^6 m$ is the Earth's radius, $|\vec{CS}| = r$ is the satellite orbit's radius and β is the elevation angle.

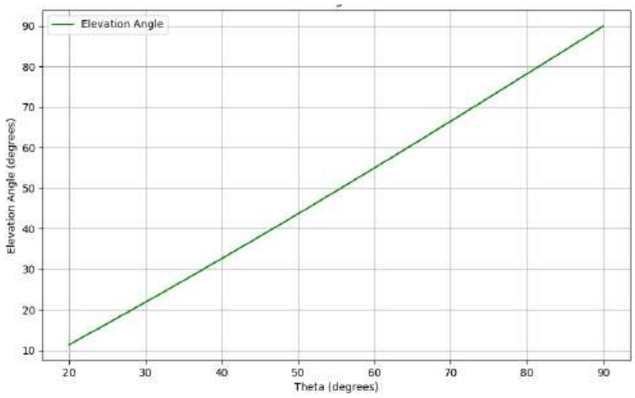


Figure F.2: Elevation of the geostationary satellite as a function of angle θ.

Therefore the UAV will see the satellite $\beta = 42°$ above the ground. The general case for an arbitrary θ can be seen in figure F.2. The aircraft can only operate if it can see clear sky for an elevation larger than angle β when looking to the South (if the UAV is located in the north hemisphere), limitation that can turn the UAV useless in a mountain operation.

An other problem related to the geostationary orbit is the high latency. Just as a theoretical ceiling, light will have to travel the $|\vec{AC}|$ 4 times (UAV-satellite-ground base-satellite-UAV).

$$|\vec{AC}| = (r - R\cos(42°))/\cos\lambda = 3.81 \cdot 10^7 m$$

$$t = 4|\vec{AC}|/c = 0.51s$$

The minimum latency for a latitude of 42° is 0.51s, and since $R \ll r$, this will be the approximate value for all the possible values of θ.

F.2 Study of the LEO satellites. The Iridium Constellation

Low Earth Orbit (LEO) satellites can improve the intrinsic high latency problem of the geostationary satellites, and some times they also have larger elevation angles.

The Iridium constellation is a LEO constellation that has been operating for some decades and at least until 2021 the only globally accessible satellite IoT network [184]. This constellation is formed by 66 satellites located in 6 distinct planes in a near-polar orbit at $h = 7.8 \cdot 10^5 m$ over the Earth's surface. Therefore, in each plane there are 11 satellites turning one after the other. The angular distance between 2 consecutive satellites is then $\Delta\theta 360°/11 = 32.72°$. Furthermore, satellites in neighbouring planes rotate in the same direction, but their trajectories are alternated in such way that there is minimum superposition of the area covered by each one. The angle between co-rotating planes is $\Delta\phi_1 = 31.6°$, and the angle between the Plane 6 and the counter-rotating part of Plane 1 is $\Delta\phi_1 = 22°$. We note that since the Earth is turning around its north pole - south pole axe, the orientation of the planes relative to the position of the planet continuously changes.

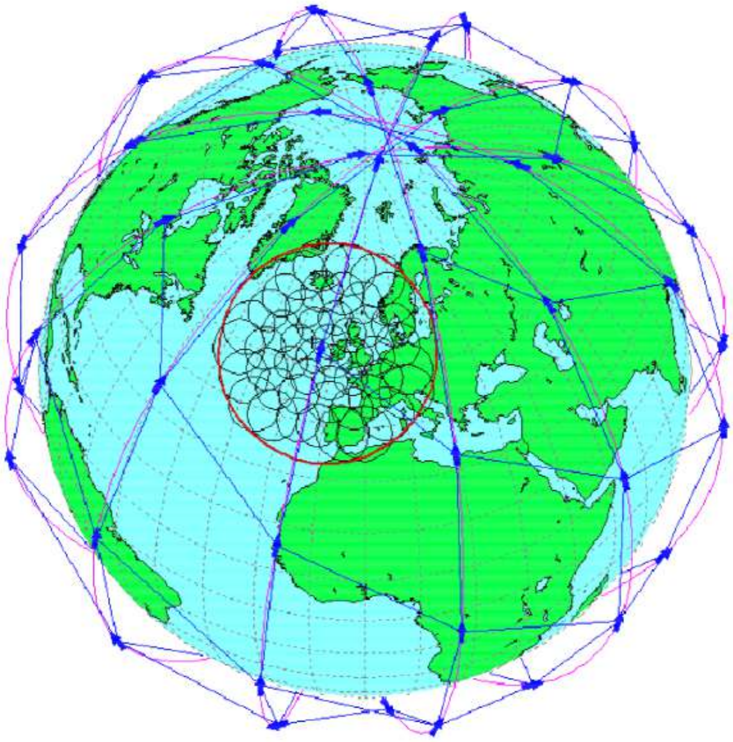


Figure F.3: Orbits of Iridium 66-Satellite Constellation. [24]

To evaluate the suitability of this orbit, we will calculate the minimum elevation at which a point A on the surface of the Earth will see a satellite. The coordinates of point A are:

$$\vec{A} = R \begin{pmatrix} \cos(\phi)\sin(\theta) \\ \sin(\phi)\sin(\theta) \\ \cos(\theta) \end{pmatrix}$$

To find this angle, we need first to find the maximum distance to the closer satellite. If θ is large enough, the closer satellite will be located in one of the neighbouring planes. Then, there are 2 possible cases to be studied depending on the situation of A.

F.2.1 Case 1: A is between two co-rotating planes.

In this case, we can assume that satellites in the 2 planes move as if they where a block and considere all the possibilities just by referencing the position of one of the satellites from point A. If we connect the positions of all the satellites of the planes with segments forming triangles, we see that the satellites closer to A are the ones that form the triangle covering the area where A is located. Then, without loss of generality, it is possible to reduce the problem to finding the distance to the closer of 3 satellites that form a triangle: P, Q (located in the West of plane), and S (located in the East plane). We can give the position of the satellites relative to A using θ_{rel}, ϕ_{rel} as:

- Satellite S is at ϕ_{rel} radians East and θ_{rel} radians South of point A.
- Satellite P is at $\Delta\phi$ radians West and $\Delta\theta/2$ radians South of point S.

- Satellite Q is at $\Delta\phi$ radians West and $\Delta\theta/2$ radians North of point S.

Then, the position of the satellites is:

$$\vec{P} = (R+h)\begin{pmatrix}\cos(\phi+\phi_{\text{rel}}-\Delta\phi)\sin(\theta+\theta_{\text{rel}}+\Delta\theta/2)\\ \sin(\phi+\phi_{\text{rel}}-\Delta\phi)\sin(\theta+\theta_{\text{rel}}+\Delta\theta/2)\\ \cos(\theta+\theta_{\text{rel}}+\Delta\theta/2)\end{pmatrix}$$
$$\vec{Q} = (R+h)\begin{pmatrix}\cos(\phi+\phi_{\text{rel}}-\Delta\phi)\sin(\theta+\theta_{\text{rel}}-\Delta\theta/2)\\ \sin(\phi+\phi_{\text{rel}}-\Delta\phi)\sin(\theta+\theta_{\text{rel}}-\Delta\theta/2)\\ \cos(\theta+\theta_{\text{rel}}-\Delta\theta/2)\end{pmatrix}$$
$$\vec{S} = (R+h)\begin{pmatrix}\cos(\phi+\phi_{\text{rel}})\sin(\theta+\theta_{\text{rel}})\\ \sin(\phi+\phi_{\text{rel}})\sin(\theta+\theta_{\text{rel}})\\ \cos(\theta+\theta_{\text{rel}})\end{pmatrix}$$

It is possible to study all the possibilities by looking at all the values of ϕ_{rel} and θ_{rel} such that A cordinates are inside the triangle formed by points P, Q and R.

$$\phi_{\text{rel}} \in (0, \Delta\phi)$$
$$\theta_{\text{rel}} \in (-\frac{\phi_{\text{rel}}-\Delta\phi}{\Delta\phi}\Delta\theta/2), \frac{\phi_{\text{rel}}-\Delta\phi}{\Delta\phi}\Delta\theta/2))$$

Finally, d_1, the distance to the closer satellite in the worst-case scenario, can be numerically found. The results for $\theta = 48°$ North and $\phi = 2°$ East can be seen in figure F.4.

F.2.2 Case 2: A is between two counter-rotating planes.

In this second case, it is no longer possible to consider that all the satellites move as a block, because there are some satellites going North and other satellites going South. For each of the planes, we can assume that the closer satellite to A will be either the nearest satellite with a larger longitude or the nearest satellite with a smaller longitude. Therefore, we can reduce the problem to finding the distance to the closer of 4 satellites P, Q (located in the West plane) S and T (located in the East plane). We can give the position of the satellites relative to A using ϕ_{rel}, θ_{rel1}, θ_{rel2} as:

- Satellite S is at ϕ_{rel} radians East and θ_{rel1} radians South of point A.
- Satellite T is at $\Delta\theta$ radians North of point S.
- Satellite P is at $\Delta\phi$ radians West of point S and θ_{rel2} radians South of point A.
- Satellite Q is at $\Delta\theta$ radians North of point P.

Then, the position of the satellites is:

$$\vec{P} = (R+h)\begin{pmatrix}\cos(\phi+\phi_{\text{rel}}-\Delta\phi)\sin(\theta+\theta_{\text{rel2}})\\ \sin(\phi+\phi_{\text{rel}}-\Delta\phi)\sin(\theta+\theta_{\text{rel2}})\\ \cos(\theta+\theta_{\text{rel2}})\end{pmatrix}$$

$$\vec{Q} = (R+h)\begin{pmatrix}\cos(\phi+\phi_{\text{rel}}-\Delta\phi)\sin(\theta+\theta_{\text{rel2}}-\Delta\theta)\\ \sin(\phi+\phi_{\text{rel}}-\Delta\phi)\sin(\theta+\theta_{\text{rel2}}-\Delta\theta)\\ \cos(\theta+\theta_{\text{rel2}}-\Delta\theta)\end{pmatrix}$$

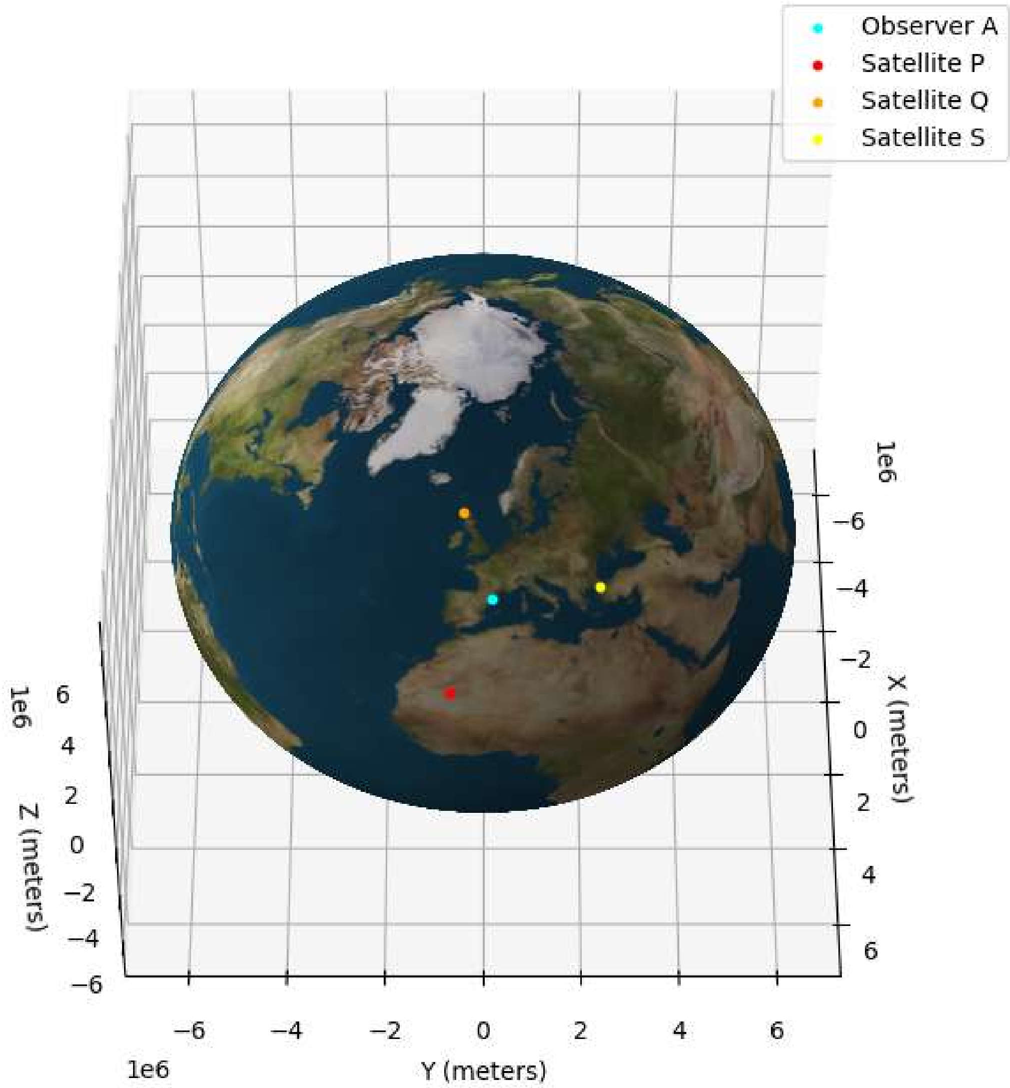


Figure F.4: Worst-case scenario for the configuration with 3 satellites.

$$\vec{S} = (R+h)\begin{pmatrix}\cos(\phi+\phi_{\text{rel}})\sin(\theta+\theta_{\text{rel1}})\\ \sin(\phi+\phi_{\text{rel}})\sin(\theta+\theta_{\text{rel1}})\\ \cos(\theta+\theta_{\text{rel1}})\end{pmatrix}$$

$$\vec{T} = (R+h)\begin{pmatrix}\cos(\phi+\phi_{\text{rel}})\sin(\theta+\theta_{\text{rel1}}-\Delta\theta)\\ \sin(\phi+\phi_{\text{rel}})\sin(\theta+\theta_{\text{rel1}}-\Delta\theta)\\ \cos(\theta+\theta_{\text{rel1}}-\Delta\theta)\end{pmatrix}$$

It follows from figure F.3 that there is an additional constrain: the position of satellites in the West plane is not independent of the position of satellites in the East plane because they are the counter-rotating part of a plane co-rotating with the East plane. In other words, since the satellites rotate with the same speed, the sum of angles θ_{rel1} and θ_{rel2}, relatives to point A, must remain constant for all the trajectory.

It is possible to find this constant θ_{120} by checking for which angles of θ the sum $\theta_{rel1}+\theta_{rel2}$ equals 0. This is the same question as to look for which longitude satellites from the East plane and satellites from the West plane will coincide. From figure F.3 we can see that this will happen for $\theta_n = \frac{\Delta\theta}{4}+\frac{\Delta\theta}{4}\cdot n$ for $n \in 1, 2...11$. Then, for points that are not at an angle θ_n, the constant θ_{120} will be 2 times the difference of latitudes until the closer crossing latitude, because while one of the satellites will have moved from θ_n to θ, the other satellite will have moved the same longitude difference in the opposite sense.

$$\theta_{\text{rel120}} = \Delta\theta - 2\left(\left(\theta+\frac{\Delta\theta}{4}\right) \bmod \frac{\Delta\theta}{2}\right)$$

In the same way than for the 3 case satellite, d_2, the distance to the closer satellite in the worst-case scenario, can be numerically found. The results for $\theta = 48°$ North and $\phi = 2°$ East can be seen in figure F.5.

F.2.3 Minimum elevation angle

Figure F.6 relates the distance to the satellite with the elevation angle.

Using the law of cosines:

$$(R+h)^2 = R^2 + d^2 - 2Rd\cos\left(\frac{\pi}{2}+\beta\right)$$

$$\beta = \arccos\left(\frac{(R+h)^2 - R^2 - d^2}{2Rd}\right) - \frac{\pi}{2}$$

Where β is the elevation angle. Figure F.7 shows the minimum elevation angle as a function of θ.

We find that the latency for the Iridium Constellation is of the same order of magnitude of a geostationary satellite [185].

F.3 Map of satellite coverage

One way to quantify the limitations in the performance of the UAV due to a low elevation angle of the satellites at which it is connected is to draw a map of the minimum flying altitude above the ground. We have defined this minimum altitude as the lowest altitude at which the line of sight between the aircraft and the satellite is free of obstacles when the satellite is seen from the UAV position at a given

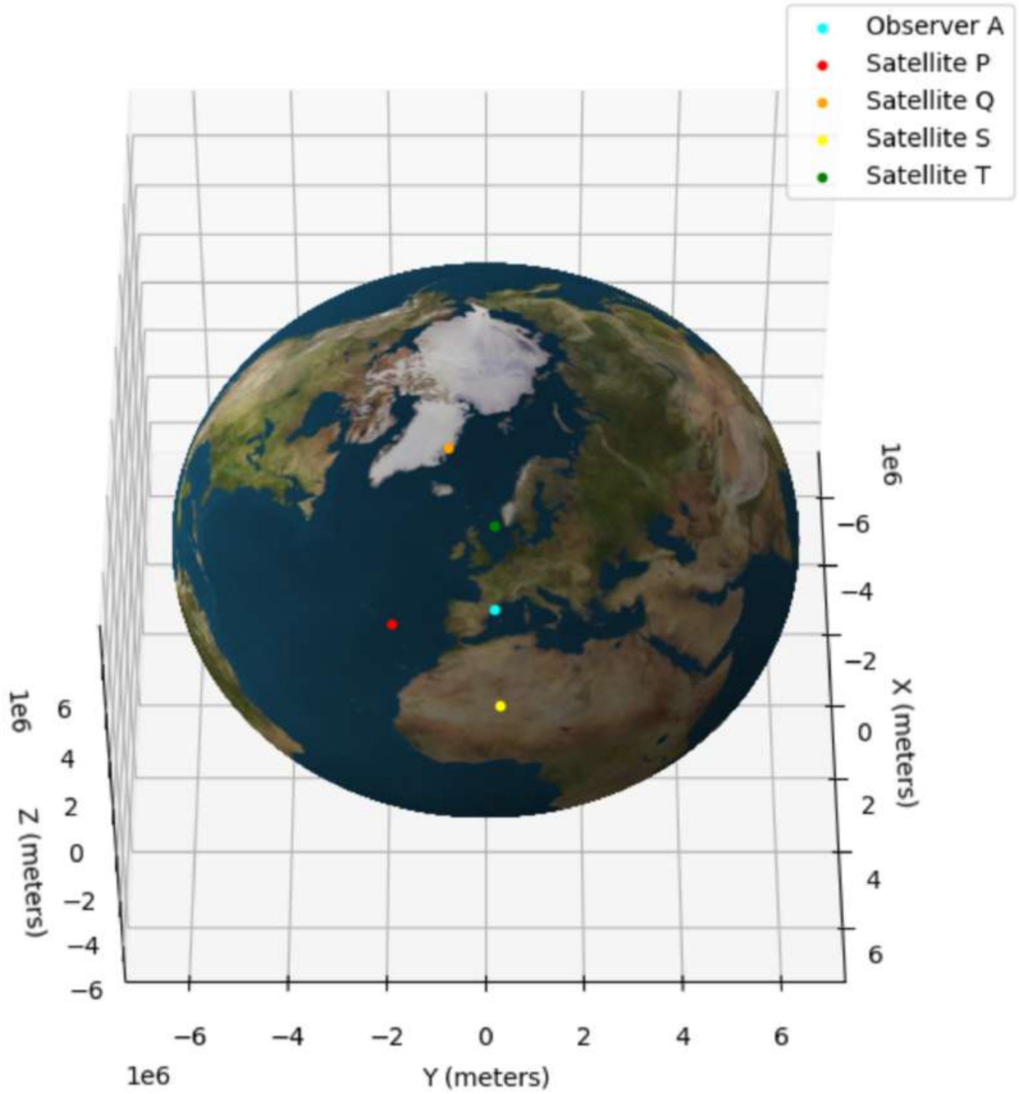


Figure F.5: Worst-case scenario for the configuration with 4 satellites.

elevation. This can be schematically seen in figure F.8. As studied in section **??**, if the line of sight between the UAV and the satellite is obstructed, the signal loss is significant, and connectivity losses are possible.

F.3.1 General description of the Software

To draw a minimum flying altitude map of a certain region, a terrain altitude over sea level map of the region is needed. Copernicus Earth observation program provides this information through Digital Elevation Models (DEM) [186]. For its accessibility and accuracy the GLO-30 (30m precision) models will be used [187].

This models can be processed using *Python*'s library *rasterio* [188] and transformed into a matrix H. Each element h_{ij} in this matrix is the altitude over sea level corresponding to the terrain located at a certain latitude and longitude determined by i,j. Nearest neighbor elements are physically separated by a distance d_{nni} and d_{nnj} given by the Digital Elevation Model (DEM) model. For the GLO-30 models the latitude spacing between nearest neighbor elements is 30.9m and the longitude spacing depends on latitude as shown in table F.1.

Then, for each position (i,j) in the matrix, the physical distance to any other element (k,l) of the

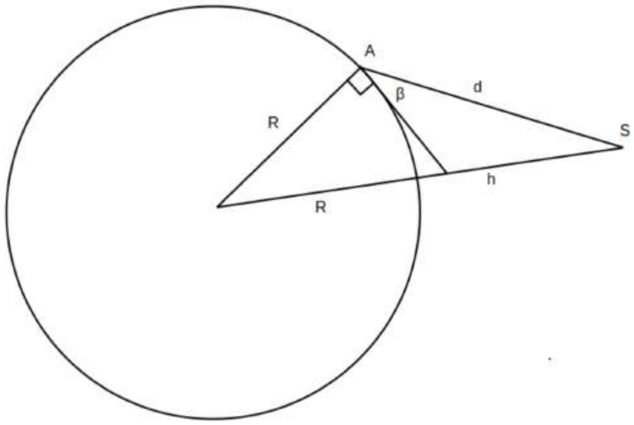


Figure F.6: Diagram of point A on the surface of the Earth and the closer satellite S.

Latitude	Longitude spacing	Approx. Resolution
0° - 50°	1.0”	30.9m – 19.9m
50° - 60°	1.5”	29.9m – 23.3m
60° - 70°	2.0”	31.0m – 21.2m
70° - 75°	3.0”	31.8m – 16.2m
75° - 80°	5.0”	26.9m – 13.5m
80° - 85°	10.0”	27.0m – 0.5m

Table F.1: GLO-30 Spacing for Different Latitude and Longitude Ranges. [30]

matrix is calculated. We know that the minimum flying altitude at position (i,j) m_{ij} plus the distance from (i,j) to (k,l) times the tangent of the elevation angle of the satellite β must be higher than the increase of altitude between points (i,j) and (k,l).

$$m_{ij} + \sqrt{(i-k)^2 d_{nni}^2 + (j-l)^2 d_{nnj}^2}\,\tan\beta \geq h_{kl} - h_{ij}$$

Rearranging the terms, it is found that the minimum flying altitude that element in (k,l) imposes to the element in (i,j) is:

$$m_{ij_{kl}} = h_{kl} - h_{ij} - \sqrt{(i-k)^2 d_{nni}^2 + (j-l)^2 d_{nnj}^2}\,\tan\beta$$

By computing this minimum flying altitude for all the points k,l and taking the maximum of those altitudes, the minimum flying altitude of point i,j is found.

$$m_{ij} = \max_{k,l}(m_{ij_{kl}})$$

If we repeat this algorithm for all the elements (i,j) in the region we get a matrix M containing the minimum flying altitude for all the analyzed zone.

This algorithm is intuitive but it is unpractical because the number of calculations needed to perform it increases with the square of the number of points investigated N. If for each two points (i,j) and (k,l) there is need for n calculations, to find the minimum flying altitude of point (i,j) we will need to perform nN operations. And to find the minimum flying altitude at all the points we will need to perform nN^2. And this n calculations include multiplications, additions, squares and square roots.

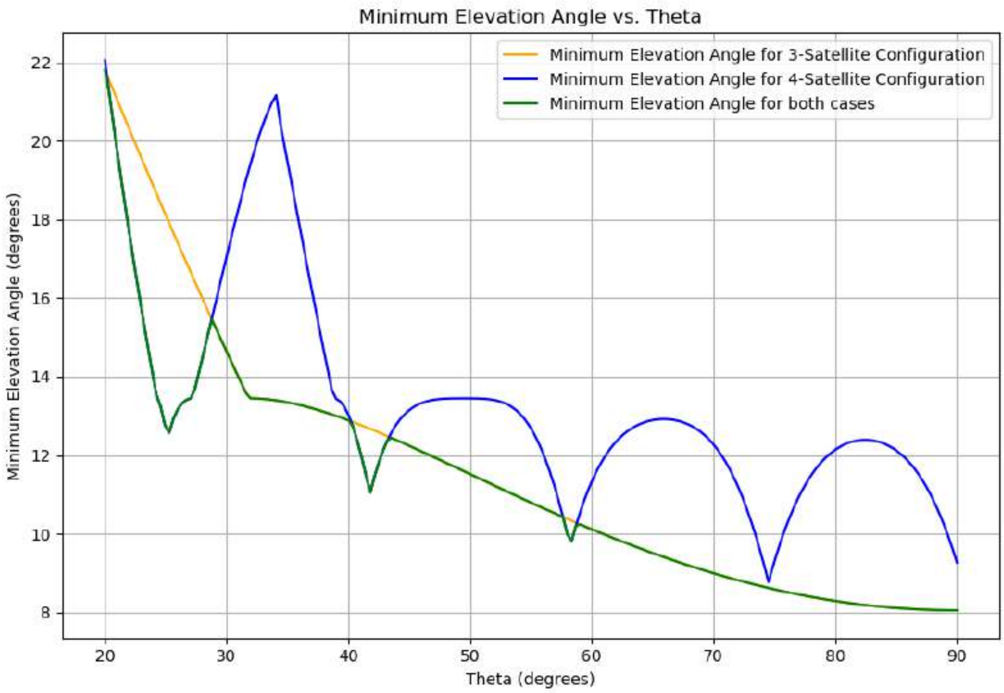


Figure F.7: Minimum elevation angle for different values of θ.

That is the reason why the code we have implemented is slightly different: it performs the same calculation but it scales as N and not N^2 and the number of operations n consist only in subtracting one matrix to another.

F.3.2 Real case scenario: Ordesa and Monte Perdido National Park

In the following sections a real-case scenario is developed: Ordesa and Monte Perdido National Park (Pyrenees) is studied as an example. Figure F.9 shows the altitude corresponding to Ordesa and Monte Perdido National Park provided by Copernicus through its GLO-30. This study is performed in 3 levels of detail in order of increasing accuracy and computational time. First, a worst-case scenario is treated in section F.3.2.1. Then, a particular favorable window is studied in section F.3.2.2. Finally, the general case with time evolution is treated in section F.3.2.3

F.3.2.1 Worst-case scenario

To make a first estimate of the minimum flying altitude we set the elevation angle β to the minimum elevation angle for the latitude of the region (see figure F.7). The resulting minimum flying altitude map can be seen in Figure F.10. Figure 3.20 shows the same information in a more visual way: The 3 dimensional surface has the shape of the altitude over sea level but the colors corresponding to the minimum flying altitude.

Figures F.10, and 3.20 show that the limitations of the minimum elevation angle affect mainly the flight at the bottom of the valleys while the summits are accessible for landing because they have 0 minimum flying altitude. If we analyze the places with a minimum flying altitude below 3m we find that they represent the 0.6%. This means that in the worst-case scenario, the airplane will only be able to land on the 0.6% of the surface.

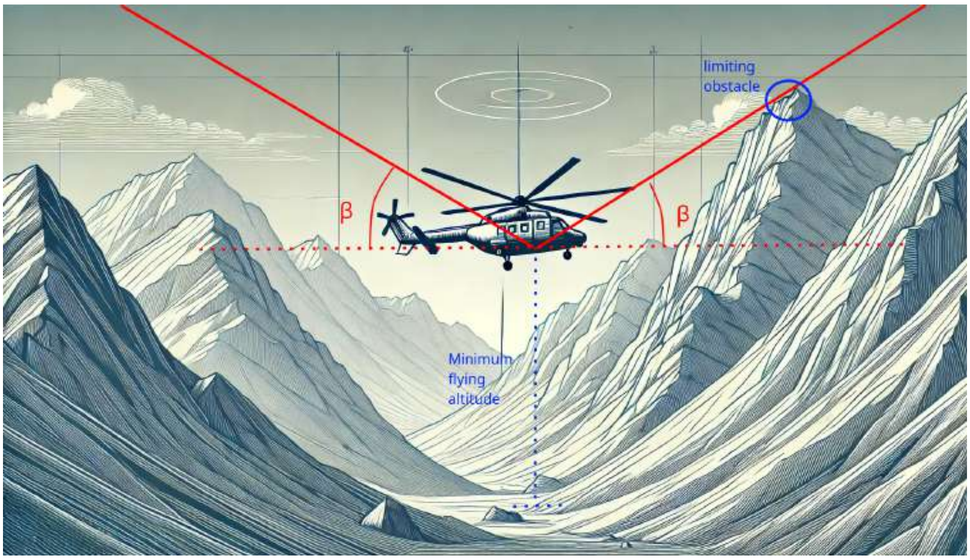


Figure F.8: Diagram of the minimum flying altitude. Elaborated upon [25].

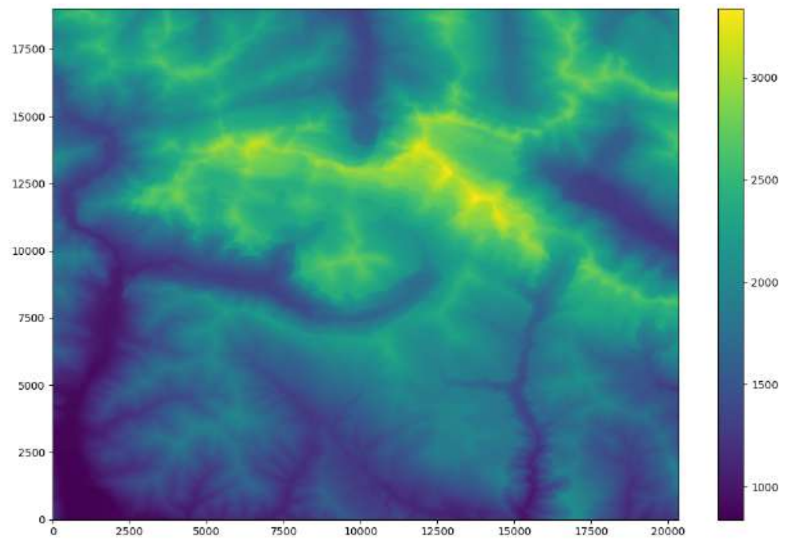


Figure F.9: Colormap of the altitude above sea level in Ordesa and Monte Perdido National Park. All the distances are given in meters.

F.3.2.2 Window conditions

The 0.6% of landing surface for the worst-case scenario studied in section F.3.2.1 is not very competitive. For this reason, in this section we will study a more favorable case. First of all, we will consider that we are in the most common satellite configuration, case 1 in section F.2.1.

The satellites of the Iridium constellation circle the Earth once every 100 minutes and in each plane there are 11 satellites [24]. Therefore, the time that passes between one satellite is at a longitude and the next one is at the same longitude is :

$$t = \frac{100 \cdot 60s}{11} = 545s$$

But the next satellite doesn't follow the same trajectory above the ground because the Earth turns too. The longitude movement from one satellite to the following one is:

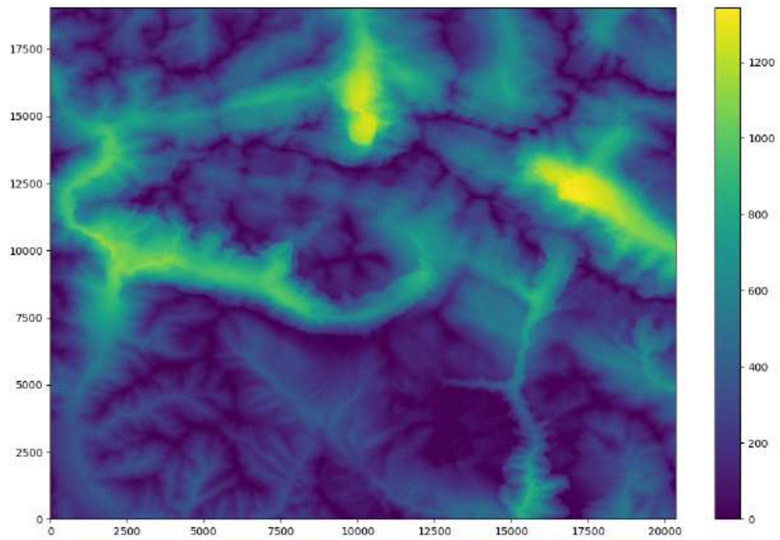


Figure F.10: Colormap of the minimum flying altitude in Ordesa and Monte Perdido National Park for the worst-case scenario. All the distances are given in meters.

$$\Delta\phi = t \cdot \omega_{Earth} = 0.0396 rad = 2.27^{\circ}$$

And the time it takes to cover all the longitude between co-rotating planes is:

$$t = 32^{\circ}/2.27 \circ \cdot 545 s = 7682 s \approx 2h$$

Figure F.12 shows the elevation angle as a function of ϕrel and θ_{rel} for Ordesa and Monte Perdido National Park latitude. It can be clearly seen that the effect of each one of the satellites is limited only to its nearest region. That is the reason why if the UAV is inside one of the subregions, it can be considered only the effect of one of the satellites, as seen in figure F.13.

So, we can assume that once in 2h there will be a favorable window, in which the satellite in figure F.13 will be very close to the UAV. In fact, once every 2h there will be more than one favorable window because, as it has been shown, the longitude movement from one satellite to the following one is 0.0396 rad.

During one of this windows, the UAV will have to move from the worst-case scenario minimum flying altitude to the desired landing altitude or do the opposite process. We estimate this time to be of about 2 minutes, with 2 minutes of safety margin. Having this considerations in mind, it is possible to recalculate the elevation angle for this case. The latitude movement of the satellite during the window time is:

$$\Delta\theta = \frac{2\pi}{100 min} \cdot 4 min = 0.2513 rad$$

Figure F.13 shows that for a $\theta_{rel} = 0.2513 rad/2$, the corresponding elevation angle is 39°. Figure F.14 shows the map of minimum flying altitude for this elevation angle in Ordesa and Monte Perdido National Park. In this case, the landing surface represents the 68.3% of the map, a much larger area than the one found for the worst-case scenario studied in section F.3.2.1.

If we take a shorter window time, the maximum latitude difference between the UAV and the satellite during the window will be smaller and thus the elevation angle will be larger. For example, during

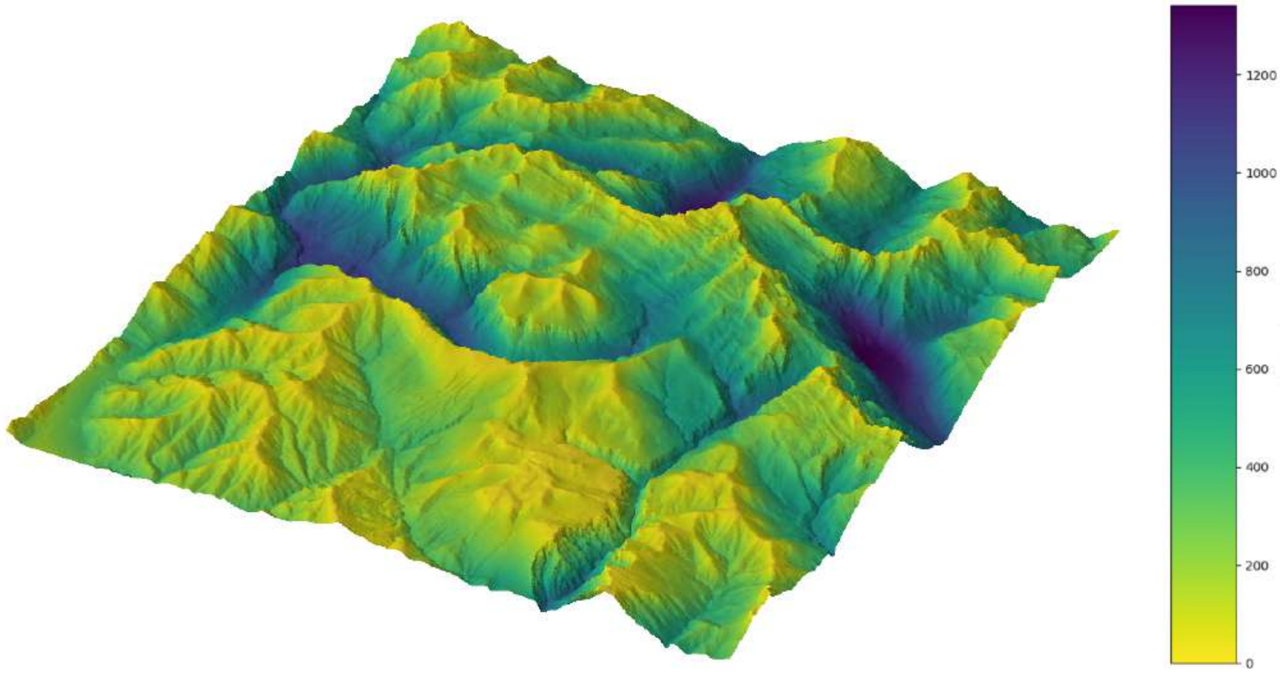


Figure F.11: 3D surface of the altitude in Ordesa and Monte Perdido National Park for the worst-case scenario. The colors represent the minimum flying altitude in meters.

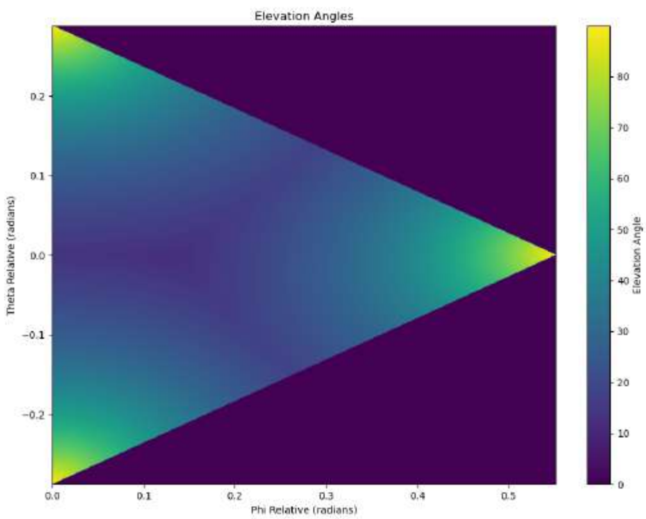


Figure F.12: Elevation angle as a function of ϕ_{rel}
and θ_{rel} for the 3-Satellite case and 43 degrees of latitude.

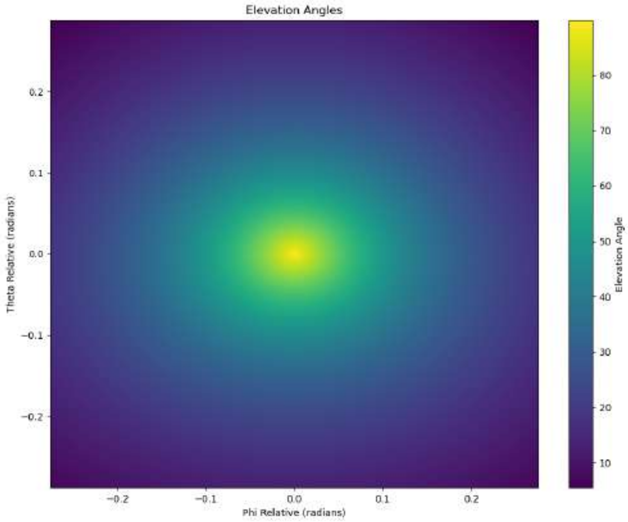


Figure F.13: Elevation angle as a function of ϕ_{rel} and θ_{rel} for the 1-Satellite case and 43 degrees of latitude.

the central 2 minutes of the 4 minutes initial window, the latitude movement of the satellite is:

$$\Delta\theta = \frac{2\pi}{100min} \cdot 2min = 0.126rad$$

Then, the corresponding elevation angle for $\theta_{rel} = 0.126rad/2$ seen in figure F.13 is 60°. If we recalculate the minimum flying altitude for Ordesa and Monte Perdido National Park, we find that the landing surface represents the 96.8%. We can also make this calculation for a 6 minutes window. The result found is that in this case it is possible to land at 27.1% of the area. The landing area for different window sizes is resumed in table F.2.

	Worst-case scenario	6 minutes window	4 minutes window	2 minutes window
Covered area (%)	0.6	27.1	68.3	96.8

Table F.2: Landing area in Ordesa and Monte Perdido National Park for different window conditions.

F.3.2.3 General case with time evolution

The results from the previous F.3.2.1 and F.3.2.2 sections can be further improved if we introduce to the system the direction of the satellites. That is to say: it is not necessary for the UAV to see the sky above the elevation angle for all the directions, it is just necessary to have clear sky in the direction of the satellite. The counterpart of this approach is that due to the movement of the satellites, the results found are only valid for a given instant of time. Therefore it is necessary to repeat this calculation for several instants of time to have an idea of the time evolution of the minimum flying altitude.

To implement this idea, for a given position of the UAV, the elevation angle and direction for all the satellites in the Iridium constellation are calculated. Then, for each satellite the procedure described in section F.3.1 is repeated but only considering the cells in the direction of the satellite. Finally, the minimum flying altitude is the minimum of the minimum flying altitudes for each satellite.

Figure F.15 shows the percentage of area at which the UAV can land without loosing connection as a function of time during a 2h interval. This 2h interval is relevant because the minimum flying altitude map is expected to be periodical with a 2h period as explained in section F.3.2.2. Therefore,

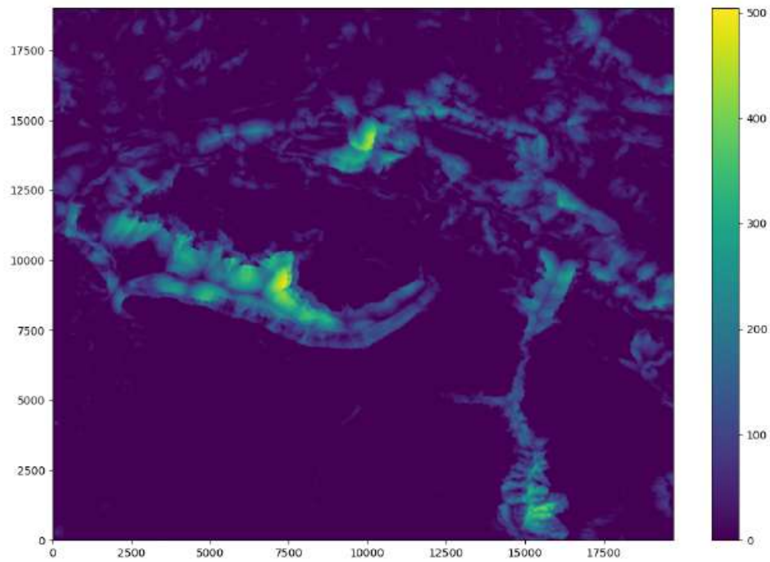


Figure F.14: Colormap of the minimum flying altitude in Ordesa and Monte Perdido National Park. All the distances are given in meters.

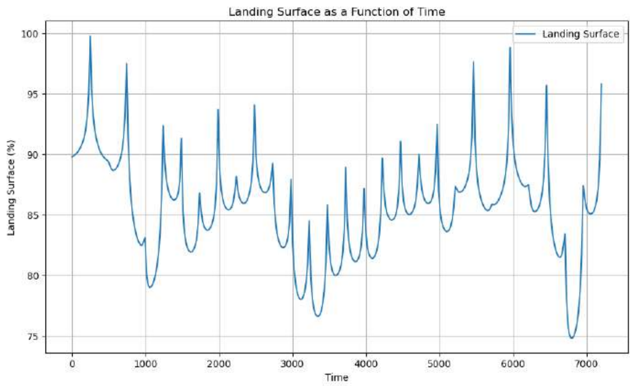


Figure F.15: Landing surface percentage evolution for a 2h interval in Ordesa and Monte Perdido National Park.

the results of this figure can be extrapolated for any time interval. They show that the landing area moves between 75% and 100%, with windows in which more than 95% of the available landing area is reached.

Another example of the usage of this software can be seen in this video: https://youtu.be/5O46whovyXk. It shows the minimum flying altitude in a 10 minutes time evolution in Ordesa and Monte Perdido National Park.

F.3.3 Conclusions

The changing elevation of the Iridium satellites make the landing options in the worst-case scenario very limiting, but allows to cover almost all the area during some concrete periods. Therefore, the best performance of the system will be achieved if the UAV flies at the minimum flying altitude of the worst-case scenario and waits until there is a favorable window to land. Using the information provided by the software developed in section F.3.2.3 and the GLO-30 DEM, the mission's trajectory can be planned and optimized to ensure satellite coverage.

Appendix G

Developed software

Due to the extension of the code developed to solve some of the aspects of the project, it has been decided that a Github repository is the best option for presenting it. It can be found here: https://github.com/paublancafortguardiola/Unmanned-Aerial-Vehicle-for-Humanitarian-Aid/tree/main

Appendix H

Project Management

H.1 Planning and scheduling

H.1.1 Tasks identification from work breakdown structure WBS

Work Packages	ID	Task
1.1.1 Engine Selection	PW1A	Determine the type and configurations of engines.
	PW1B	Determine the engine's size and power output.
1.1.2 Power Transmission	PW2A	Determine the specifications for the main rotor gearbox.
	PW2B	Determine the specifications for the tail rotor gearbox.
	PW2C	Description of the transmission shafting system.
1.1.3 Fuel System	PW3A	Design and specifications of the fuel tank.
	PW3B	Description of the layout of fuel distribution system and pumps.
1.2.1 Main Rotor Blades	AD1A	Design and analysis of the main rotor blades.
	AD1B	Determine tip speed of main rotor blades.
	AD1C	Study and design of twist for optimizing lift distribution of main rotor blades.
1.2.2 Tail Rotor Blades	AD2A	Design and analysis of the tail rotor blades.
1.2.3 Fuselage Aerodynamics	AD3A	Determine drag reduction techniques on the fuselage.
	AD3B	Study the fuselage shaping for stability in crosswinds and forward flight.
1.2.4 Aerodynamic Stability and Control Surfaces	AD4A	Design of the main control surfaces.
	AD4B	Determine the aircraft's center of mass ranges.
	AD4C	Validate dynamic stability under various flight conditions.
1.3.1 Forward Flight Performance	PF1A	Conduct power analysis.
	PF1B	Determine cruise speed for optimal performance.
	PF1C	Establish maximum speed under various flight conditions.
	PF1D	Calculate the range and endurance for forward flight.

Work Packages	ID	Task
	PF1E	Analyze forward fuel consumption rates across different flight phases.
1.3.2 Axial and Hover Flight Performance	PF2A	Conduct power analysis.
	PF2B	Determine optimal climb speed for ascent performance.
	PF2C	Define ceiling altitude.
	PF2D	Analyze autorotation for safe descent.
	PF2E	Evaluate fuel consumption in axial and hover flight.
	PF2F	Analyze flight endurance.
1.3.3 Operating Conditions	PF3A	Analyze performance at high altitudes.
	PF3B	Analyze performance under extreme temperature conditions.
	PF3C	Analyze performance in icing conditions.
	PF3D	Study the tolerance to wind gusts and turbulence.
	PF3E	Design emergency landing protocols.
	PF3F	Analyze design point calculation.
	PF3G	Analyze standard mission calculation.
1.4.1.1 Structure	MB1A	Choose the appropriate materials for each part.
	MB1B	Design the main structural components such as beams.
	MB1C	Design the side panels which give the structure a body.
1.4.1.2 Systems Accommodation Parts	MB1D	Development of the fuel deposit and its accommodation to the main body.
	MB1E	Study and design of the power unit accommodation to the body.
	MB1F	Accommodation of the avionics, sensors and any electronic component.
1.4.1.3 Rotor System Integration	MB1G	Analysis of the physical loads caused on the structure by the rotor.
	MB1H	Development of the rotor integration system.
1.4.2.1.1 Storage	MB2A	Dimension the cabin and organize storage locations within the cabin for efficient access.
	MB2B	Validate the accessibility and security of the compartments.
	MB2C	Plan the layout for distributing equipment within the cabin.
1.4.2.1.2 Distribution	MB2C	Plan the layout for distributing equipment within the cabin.
1.4.2.1.3 Launching Mechanism	MB2D	Design the launching systems for air and land delivery.
	MB2E	Coordinate the integration of existing launching systems into the cabin.
	MB2F	Design the recovery systems on the payload for air delivery.
1.4.2.2.1 Medical Supplies	MB2G	Identify the list of necessary medical supplies.
	MB2H	Define restocking protocols for the medical supplies.

Work Packages	ID	Task
1.4.2.2.2 Cabin Distribution	MB2I	Plan the layout to ensure medical equipment is accessible and safe.
1.4.2.2.3 Security systems	MB2J	Identify necessary security measures for onboard equipment and personnel.
	MB2K	Ensure the proper placement of security systems within the cabin.
1.4.2.4 Passenger Compartment	MB2L	Selection of an adequate seat design.
	MB2M	Distribution of the seats.
	MB2N	Mechanism to remove and place seats.
1.4.2.5 Cabin ambientation	MB2O	Design cabin ambient settings for different operational conditions, including noise, lighting, and temperature control.
1.4.2.5 Doors	MB2P	Design the lateral doors of the helicopter.
1.5.1 Wheel	LG1A	Analyze the wheel parameters required to withstand the operation conditions.
	LG1B	Choose the most appropriate wheel according to the requirements.
1.5.2 Shock Absorber	LG2A	Analyze the forces involved during landing.
	LG2B	Design a shock absorber capable of withstanding the forces involved on landing.
	LG2C	Verify the shock absorber design through FEM simulation.
1.5.3 Mounting System	LG3A	Design the link part between the wheel, the shock absorber and the fuselage.
	LG3B	Verify the structural integrity of the part under work loads through FEM simulation.
1.6.1 Horizontal Stabilizer	EP1A	Design the structure of the horizontal stabilizer.
1.6.2 Rudder	EP2A	Design the structure for the rudder.
1.6.3 Tail Boom	EP3A	Analyze the force loads that the tail boom will withstand.
	EP3B	Choose the most appropriate material for each part.
	EP3C	Design the main structure of the tail boom, such as the internal beams.
	EP3D	Design the side panels of the tail boom.
	EP3E	Design the accommodation parts for the tail rotor drive shaft.
1.6.4 Tail Rotor Accommodation	EP4A	Analyze the loads that the tail rotor will transmit to the tail boom.
1.7.1.1 Pilot Interface	AV1A	Determine the pilot interface.
	AV1B	Determine the license needed.
1.7.1.2 Landing Assistance	AV1C	Determine a landing assistance system.
1.7.1.3 Connectivity recovery procedures	AV1D	Determine connectivity recovery procedures.
1.7.2.1 GNSS	AV2A	Determine the GNSS and other localization and orientation systems used.
1.7.2.2 Terrain Mapping Systems	AV2B	Determine the terrain recognition systems.
	AV3A	Determine the satellite communications system.
	AV3B	Determine the radio communication system.
	AV3C	Study the electromagnetic interference.

Work Packages	ID	Task
	AV3D	Study the extreme weather effects over communication systems.
1.7.4.3 Electricity Supply System	AV4A	Determine the electricity needs for the electrical systems of the plane.
	AV4B	Determine the battery.
1.8.1 Cargo Procedures	OP1A	Establish cargo loading and delivery protocols.
	OP1B	Establish recovery safety protocols.
1.8.2 Medical Aid Procedures	OP2A	Establish protocols for restocking and quick access.
	OP2B	Create detailed procedures for emergency situations (e.g., patient evacuation, onboard medical emergencies, system failures).
1.9.1 Power Plant Testing Procedures	TS1A	Establish the procedures for correct power plant testing.
1.9.2 Structural testing procedures	TS2A	Establish the procedures for correct structural testing.
1.9.3 Payload Testing Procedures	TS3A	Develop test procedures for all medical and cabin-related systems.
	TS3B	Execute operational tests for equipment functionality and accessibility.
	TS3C	Document test results and implement any necessary changes.
1.9.4 Avionics Testing Procedures	TS4A	Determine the procedures for correct testing the control, communications and navigation system.
1.10.1 Brand Development	MC1A	Develop brand values, vision and mission.
	MC1B	Design logo and color schemes
1.10.2 Marketing Strategy	MC2A	Plan marketing initiatives.
1.10.3 Communications Plan	MC3A	Plan communication flow with the stakeholders.
1.11.1 Current Market Overview	MA1A	Make a report about the state of the art and similar products present in the market.
1.11.2 Target Market	MA2A	Analyze customer needs and behaviors.
1.11.3 Economic Feasibility Study	MA3A	Assess the cost-effectiveness, financial viability, and potential economic benefits of the project.
1.12.1 Meeting Minutes	PM1A	Prepare the agenda for each team meeting.
	PM1B	Document key decisions and agreements made during the meetings.
	PM1C	Ensure follow-up on action items agreed during the meetings.
1.12.2 Budget	PM2A	Estimate the costs for each project phase and deduce the estimated project budget.
	PM2B	Review and approve the initial project budget.
1.12.3 Requirements	PM3A	Validate and prioritize requirements with stakeholders.
	PM3B	Validate that deliverables meet the defined requirements.
1.12.4 Regulations	PM4A	Identify applicable regulations.
	PM4B	Technical standards.
	PM4C	Risk assessment.
1.12.5 Schedule	PM5A	Create the overall project schedule.
	PM5B	Monitor project progress against the schedule.

Work Packages	ID	Task
1.12.6 Risks	PM6A	Identify potential risks for the project.
	PM6B	Develop mitigation plans for high-priority risks.
1.12.7 Quality	PM7A	Review the product's quality standards.
1.12.8 Final Report	PM8A	Compose the final report document.
	PM8B	Ensure the final report is validated by stakeholders.
	PM8C	Archive the final report for future project reference.
1.13.1 Environmental Feasibility Study	ES1A	Evaluate the potential environmental impacts of the project.
1.13.2 Safety Assessment	ES2A	Evaluate the potential safety risks of the project.

Table H.1: Task identification

H.1.2 Brief task description

Next, a brief task description of the previous tasks will be stated.

PW1A: Identify and evaluate the appropriate engine types and configurations that meet the helicopter's performance needs, including factors like fuel efficiency, reliability, and operational altitude.

PW1B: Determine the engine's size and power output based on lift, payload and flight requirements.

PW2A: Define the specifications for the main rotor gearbox, ensuring it can efficiently transmit power from the engine to the rotor blades while handling the stresses it is subjected to.

PW2B: Define the specifications for the tail rotor gearbox to ensure proper yaw control and stability.

PW2C: Description of the transmission shafting system to transmit power between the engine and both rotors while ensuring durability, weight optimization, and minimal power loss.

PW3A: Calculate the fuel tank requirements (volume and placement) and provide the technical specifications, ensuring they meet thehelicopter's endurance and range requirements for the mission.

PW3B: Determine the layout of fuel lines, distribution and pump system to provide a consistent and balanced fuel supply from the tank to the engine.

AD1A: Analyze and choose an adequate profile for the main rotor blades, focusing on aerodynamics, structural integrity, and weight to maximize lift, efficiency, and overall flight performance.

AD1B: Determine the optimal rotor tip speed to achieve a balance between aerodynamic efficiency and noise reduction.

AD1C: Study and incorporate blade twist in the design to optimize lift distribution along the length of the blade.

AD2A: Analyze and choose an adequate profile for the tail rotor blades, ensuring they provide sufficient thrust for yaw control.

AD3A: Determine and locate the adequate drag reduction elements on the airframe, justifying its need for aerodynamic optimization.

AD3B: Study the fuselage to improve stability during crosswinds and forward flight.

AD4A: Design the helicopter's main control surfaces (shape and size) to ensure stable and responsive flight control across all operating conditions.

AD4B: Determine the aircraft's center of mass ranges to ensure stable flight across all operating conditions.

AD4C: Validate the helicopter's dynamic stability through various tests and calculations.

PF1A: Conduct a power analysis to understand the engine's performance in forward flight and ensure sufficient power is available at all flight phases.

PF1B: Determine the helicopter's optimal cruise speed to balance performance and efficiency.

PF1C: Establish the helicopter's maximum speed under various flight conditions.

PF1D: Calculate the helicopter's range in forward flight, considering fuel capacity, engine efficiency, and aerodynamic drag to optimize endurance.

PF1E: Analyze fuel consumption across different flight phases.

PF1F: Analyze flight endurance in forward flight.

PF2A: Perform a power analysis for axial and hover flight to ensure the engine provides sufficient lift and control.

PF2B: Determine the optimal climb speed for ascent performance.

PF2C: Define the ceiling altitude in different operating conditions.

PF2D: Analyze the autorotation characteristics for safe descent during engine failure, ensuring controlled, power-off landings.

PF2E: Evaluate fuel consumption in axial and hover flight, including in ground effect scenarios, to optimize fuel usage during vertical operations.

PF2F: Analyze flight endurance in axial and hover flight.

PF3A: Analyze the helicopter's performance at high altitudes and ensure that it reaches operational requirements.

PF3B: Assess performance under extreme temperature conditions and ensure that it reaches operational requirements.

PF3C: Evaluate the helicopter's ability to operate in icing conditions and ensure that it reaches operational requirements.

PF3D: Study the helicopter's tolerance to wind gusts and turbulence and ensure that it reaches operational requirements.

PF3E: Design emergency landing protocols for extreme situations and ensure that they reach operational requirements.

PF3F: Analyze design point calculation and ensure that it meets performance and operational requirements.

PF3G: Analyze standard mission calculation to verify it meets operational efficiency and performance benchmarks.

MB1A: Determination of the required properties according to the operation regime and corresponding material technical research in order to fulfill the requirements.

MB1B: Establishment of a safety factor criteria and dimensioning of the main structural components (beams, reinforcements, etc.) according to it.

MB1C: Design of the other parts (not fundamental load-wise) of the fuselage. This can include cabin panels or possible windows.

MB1D: Fuel deposit design following the concept in terms and performance and posterior accommodation and placement of it into the frame.

MB1E: Study the possible solutions in order to accommodate the selected engine into the current fuselage system and design of the final approach.

MB1F: Integration of the avionics and electronic components into the fuselage. Correct placement and implementation of the on-board sensors into the body.

MB1G: Make a structural analysis of the effect of the rotor on the rest of the structure (when rotor spinning & when rotor standing still).

MB1H: Decide, design and if possible numerically or physically test the system to connect the structure with the rotor.

MB2A: Study the cabin measurements and design storage solutions and compartments to optimize space while maintaining the functionality and safety of the stored items.

MB2B: Conducting tests to ensure that personnel can easily access the supplies in various operational scenarios, and validating the integrity of the security systems.

MB2C: Study the space and find the optimal way of placing the equipment within the cabin, maximizing usability while taking into account the center of gravity and balance of the UAV.

MB2D: Designing and creating mechanisms that allow the deployment of the payload by air or upon landing.

MB2E: Ensuring compatibility of the mechanism with the other existing systems in the aircraft.

MB2F: Developing systems that can ensure a safe landing for the payloads delivered, minimizing the damage and securing its reception.

MB2G: Study the current systems of medical vehicles to compile a list of the necessary medical supplies, ensuring that the UAV is fully equipped for its task.

MB2H: Creating guidelines for efficient processes of restocking of all the medical supplies needed.

MB2I: Plan the layout of the cabin distribution to ensure that it facilitates quick and efficient medical response and a safe procedure of the mission.

MB2J: Design security systems to protect onboard equipment and personnel from collisions, malfunctions, hijacking, theft and other possible disaster scenarios.

MB2K: Ubicate the security systems in a way that does not interfere with operations and other systems within the cabin.

MB2L: Design the seats for passengers guaranteeing that they meet safety, ergonomic and health requirements for the personnel onboard.

MB2M: Establish the correct distribution of the seats so that they don't interfere when working and they take up as little space as possible.

MB2N: Elaborate the correct mechanism to remove and place seats to adequate the cabin for certain operations.

MB2O: Take care of internal ambient and design a cabin that can protect passengers against temperatures, noise and light insufficiency at different operational conditions.

MB2P: Determinante the best door option for medical aid and create a lateral door that can offer a correct usage for this type of requirements.

LG1A: Look for the wheel size and materials so it can withstand the aircraft's loads even during a hard landing.

LG1B: Design the 3D model using any software (for example SolidWorks).

LG2A: Realize a quantitative study of the forces involved during a hard landing, not a normal one, by means of any software or any other method.

LG2B: The design of the shock absorber should include either its blueprints and relevant information related to shock absorbers, or a reference of a commercial one that fits its requirements.

LG2C: Test whether the designed shock absorber meets its requirements using FEM analysis, for example using SolidWorks.

LG3A: Design the 3D model (for example using SolidWorks).

LG3B: Test its integrity when subject to a hard landing workload using any simulation software or FEM analysis (for example using SolidWorks).

EP1B: Attending the normal flight conditions, determine the nominal aerodynamic forces it should provide.

EP1A: Provide the 3D model and its blueprints based on the aerodynamic profile.

EP2A: Provide the 3D model and its blueprints.

EP3A: Attending to normal flight conditions, determine the nominal forces it should withstand.

EP3B: Research and choose the best material for each part, considering not only force constraints but also weight and cost.

EP3C: Provide the 3D model and its blueprints.

EP3D: Provide the 3D model and its blueprints.

EP3E: Provide the 3D model and its blueprints.

EP4A: Study, in normal flight conditions, the tail rotor net force and moment contribution.

EP4B: Provide the 3D model and its blueprints.

AV1A: Study the real-time piloting necessities of the UAV, determination of the interface based on a helicopter simulation with real-time data.

AV1B: Investigate the required license and availability of pilots that have it.

AV1C: Determine the landing assistance system and its operation conditions.

AV1D: Determine the connectivity recovery procedures connectivity loss assessment.

AV2A: Determine the GNSS and other localization and orientation systems used.

AV2B: Assessment of the different sensors needed for the terrain mapping in order to perform the flight safely and determination of the ones needed. Determination of a RADAR system.

AV3A: Study of the requirements of the transmission (latency, bandwidth and data throughput) between the UAV and the control room and determine a suitable satellite communication system along with its operational limitations.

AV3B: Determine the radio system to communicate with the ATC.

AV3C: Study the possible electromagnetic interference between the communication system and other electromagnetic emitting systems, such as radar or the radio communication.

AV3D: Study the effect an extreme weather condition can have over the satellite communications system.

AV4A: Determine the power needs for the electrical systems of the aircraft.

AV4B: Determine the necessities and solutions in terms of energy storage: batteries.

OP1A: Determine the necessary protocols for cargo loading and delivery.

OP1B: Establish the recovery safety protocols to ensure the security of the mission.

OP2A: Determine the protocols for restocking medical supplies and ensure quick access to them.

OP2B: Create detailed protocols for different emergency situations such as patient evacuation, system failures or onboard medical emergencies.

TS1A: Describe the testing procedures to ensure a correct operation of all power plant elements, including the engine, transmission and main rotor.

TS2A: Describe the testing procedures to ensure a correct structural operation.

TS3A: Elaborate the testing procedures needed for different cabin systems such as medical machinery or passengers safety measures.

TS3B: Execute operational tests to check the quick accessibility and functionality of different medical supplies that ensure the correct function in extreme conditions.

TS3C: Elaborate a document that validates different tests and provide any necessary change.

TS4A: Determine the testing procedures needed to ensure the robustness of the control, navigation and communications systems.

MC1A: Define the core principles that guide the brand's identity and purpose.

MC1B: Create the visual elements of the brand, such as the logo, color palette, and typography, to ensure a consistent and recognizable image.

MC2A: Outline specific marketing campaigns and strategies.

MC3A: Develop a structured plan for how information will be shared with key stakeholders. This will include regular presentations to provide progress updates and address any concerns or feedback from them.

MA1A: Determine the current state of the art, detailing the latest advancements and innovations in the field, as well as providing an analysis of comparable products currently available in the market. Overview of key competitors, trends, and technologies shaping the industry.

MA2A: Evaluate the needs and behaviors of potential customers within the target market to better understand demand and preferences.

MA3A: Study the financial viability and assess the potential economic benefits the project may generate, considering both short-term and long-term financial implications.

PM1A: Prepare the meeting agenda, outlining key discussions points and decisions to be made.

PM1B: Document key decisions, action items and agreements made during the meetings to provide a clear record for future reference.

PM1C: Ensure follow-up on action items by tracking their progress and confirming that tasks assigned in meetings are completed on time.

PM2A: Develop detailed cost estimates for each project phase, including labor, materials, and resources. Consolidate these estimates to establish the overall project budget.

PM2B: Consolidate and approve the overall project budget after reviewing cost estimates with the stakeholders.

PM3A: Confirm and prioritize the documented requirements with the stakeholders.

PM3B: Confirm that project deliverables fulfill all specified and approved requirements.

PM4A: Validate the project adheres to relevant regulatory standards set by the main European regulators.

PM4B: Verify that all technical standards and guidelines are followed.

PM4C: Conduct regulatory risk assessment to identify potential compliance issues and mitigate legal risks.

PM5A: Create a detailed overall project schedule, including major milestones, deliverables and timelines for all phases of the project to ensure timely completion.

PM5B: Monitor the project and make adjustments to the schedule as needed, ensuring all changes are properly documented.

PM6A: Identify potential risks that could negatively impact the project's success, documenting them in a risk register.

PM6B: Develop mitigation plans for the highest-priority risks, outlining actions to reduce or eliminate their impact.

PM7A: Regularly review and update product quality. The updates will need to be reported, documented and validated by stakeholders.

PM8A: Compose the final project report, detailing the project's outcomes, achievements and overall performance.

PM8B: Ensure the final report is validated by stakeholders, obtaining their approval to confirm that the project has met its objectives and requirements.

PM8C: Archive the final report and all associated documentation for future reference or project planning.

ES1A: Assess the potential environmental impacts of the project by examining factors such as resource consumption, waste production, emissions, and effects on local ecosystems.

ES2A: Evaluate the potential safety risks of the project.

H.1.3 Interdependency relationship among tasks

The following table shows the interdependence among the most importants tasks.

Code of task	Task identification	Preceding task(s)
PW1	Engine Selection	-
PW2	Power Transmission	PW1
PW3	Fuel System	PW1, PF
AD1	Main Rotor Blades	-
AD2	Tail Rotor Blades	-
AD3	Fuselage Aerodynamics	AD1
AD4	Aerodynamic Stability and Control Surfaces	PW1
PF1	Forward Flight Performance	PW1, AD
PF2	Axial and Hover Flight Performance	-
PF3	Extreme Conditions Analysis	PW1, AD
MB1	Fuselage	MB2, PW1, AV1, AV2, AV3, AD1, AD3
MB2	Cabin	PF3
LG1	Wheels	PF3
LG2	Shock Absorber	PF3
LG3	Mounting System	LG2, LG3
EP1	Horizontal Stabilizer	AD4
EP2	Rudder	AD4
EP3	Tail Boom	AD2, EP1, EP2
EP4	Tail Rotor Accommodation	AD2, EP3
AV1	Control	-
AV2	Navigation	-
AV3	Communications System	MB2, AV1, AV2, AV3
AV4	Electrical System Dimensionalization	MB2, AV1, AV2, AV3
OP1	Cargo Procedures	MB2

Code of task	Task identification	Preceding task(s)
OP2	Medical Aid Procedures	MB2
TS1	Power Plant Testing Procedures	PW
TS2	Structural Testing Procedures	MB, EP, LG
TS3	Payload Testing Procedures	OP, AV
TS4	Avionics Testing Procedures	AV
MC1	Brand Development	-
MC2	Marketing Strategy	MC1
MC3	Communications Plan	MC1
MA1	Current Market Overview	-
MA2	Target Market and Customer Analysis	MA1
MA3	Economic Feasibility Study	MA1
PM1	Meeting Minutes	-
PM2	Budget	-
PM3	Requirements	PM1
PM4	Regulations	PM3
PM5	Schedule	PM3
PM6	Risks	-
PM7	Quality	PM3
PM8	Final Report	PM3
ES1	Environmental Study	-
ES2	Safety Study	-

Table H.2: Interdependencies

H.1.4 Human resources and level of effort (hours) to develop each task

The table below shows the level of effort for each task.

Code of task	Resources (n° of members)	Level of effort [h/member]
PW1A	2	3
PW1B	2	3
PW2A	3	3
PW2B	3	3
PW2C	3	3
PW3A	3	3
PW3B	3	3
AD1A	4	5
AD1B	4	2
AD1C	4	4
AD2A	4	3
AD2B	4	5
AD3A	4	5
AD3B	4	5
AD4A	4	5
AD4B	4	5
AD4C	4	5
PF1A	3	5
PF1B	3	5
PF1C	2	4

Code of task	Resources (n° of members)	Level of effort [h/member]
PF1D	2	4
PF1E	2	2
PF2A	3	5
PF2B	3	5
PF2C	3	3
PF2D	3	3
PF2E	2	3
PF2F	2	3
PF3A	2	3
PF3B	2	3
PF3C	2	3
PF3D	2	3
PF3E	2	4
PF3F	2	3
PFFG	2	3
MB1A	2	2.5
MB1B	4	11.5
MB1C	4	5
MB1D	1	3
MB1E	2	3
MB1F	1	3
MB1G	2	5
MB1H	2	3
MB2A	2	2
MB2B	2	2
MB2C	2	3
MB2D	3	5
MB2E	2	3
MB2F	3	5
MB2G	1	2
MB2H	1	3
MB2I	1	3
MB2J	1	3
MB2K	2	5
MB2L	2	3
MB2M	2	3
MB2N	1	2
MB2O	2	3
MB2P	3	5
MB2Q	3	5
LG1A	1	5
LG1B	2	5
LG2A	1	2.5
LG2B	4	12.5
LG2C	1	5
LG3A	3	5
LG3B	1	5
EP1A	2	5
EP2A	2	5

Code of task	Resources (n° of members)	Level of effort [h/member]
EP3A	2	5
EP3B	2	2.5
EP3C	4	5
EP3D	2	2.5
EP3E	2	5
EP4A	1	5
EP4B	3	5
AV1A	2	10
AV1B	1	5
AV1C	2	5
AV1D	3	10
AV2A	1	5
AV2B	1	5
AV3A	2	10
AV3B	1	5
AV3C	1	5
AV3D	1	5
AV4A	3	5
AV4B	3	2
OP1A	1	1
OP1B	1	1
OP2A	1	2
OP2B	2	4
TS2A	3	3
TS3A	1	1
TS3B	1	1
TS3C	1	1
TS4A	1	1
MC1A	1	3
MC1B	2	2
MC2A	2	2
MA1A	4	2
MA2A	4	3
MA3A	3	3
MA3B	2	3
PM1A	1	5
PM1B	2	5
PM1C	2	5
PM2A	4	7
PM2B	4	7
PM3A	1	4
PM3B	1	4
PM4A	3	3
PM4B	3	3
PM4C	3	3
PM5A	2	2
PM5B	2	2
PM6A	2	2.5
PM6B	2	2.5

Code of task	Resources (n° of members)	Level of effort [h/member]
PM7A	2	2.5
PM7B	14	3
PM8A	1	2
PM8B	1	2
ES1	3	1
ES2	3	1

Table H.3: Human resources and level of effor

H.1.5 Budget (initial estimation for the basic engineering project)

H.1.5.1 Human Resources

To develop this project, the work and collaboration of engineers from various sectors will be required. In addition, it has been decided to include a senior engineer in each department to coordinate and supervise the junior engineers, ensuring the proper development of the project. Below is a list of the specialists hired for each department, along with their respective salaries.

H.1.5.1.1 Aerodynamics, Power Plant and Performance Department

Aerospace Engineer: Aerospace engineers are essential to optimize the UAV's shape to enhance flight efficiency, reduce air resistance, and ensure stability in various operational conditions. They will also design the power plant and select the propulsion system, ensuring the UAV has adequate power to maximize energy efficiency while achieving the required speed, range, and payload capacity.

- Number of junior engineers hired and salary: **3 / 11.64 € per hour**
- Number of senior engineers hired and salary: **1 / 41.82 € per hour**

H.1.5.1.2 Structural Design and Materials Department

Structural Engineer: Structural engineers analyze and design the main structure of the UAV to withstand loads and vibrations during flight. Their work ensures the UAV is lightweight yet strong enough to handle mechanical stresses, enhancing durability and performance.

- Number of junior engineers hired and salary: **3 / 10.65 € per hour**
- Number of senior engineers hired and salary: **1 / 35.73 € per hour**

H.1.5.1.3 Payload and Operations Department

Mechanical Engineer: Working in the payload department, mechanical engineers design the mechanisms that support and deploy the UAV's payload, ensuring robustness and operational efficiency during missions.

- Number of junior engineers hired and salary: **1 / 10.82 € per hour**

Structural Engineer: This department's structural engineers design the cabin's interior to optimize it for cargo and medical aid missions.

- Number of junior engineers hired and salary: **1 / 10.65 € per hour**

Systems Engineer: Systems engineers in the operations department will integrate all UAV subsystems, ensuring that everything, from propulsion to payload and communication systems, works together efficiently.

- Number of senior engineers hired and salary: **1 / 46.88 € per hour**

H.1.5.1.4 Avionics, Simulation, and Telecommunications Department

Software Engineer: Software engineers program the UAV's control systems and autonomy, developing the software that manages sensors, navigation, and real-time data processing. They are essential for enabling the UAV to fly autonomously and complete its missions efficiently.

- Number of junior engineers hired and salary: **1 / 10.65 € per hour**

Electrical Engineer: Electrical engineers develop and integrate the power and electronic systems of the UAV, including the motors, sensors, and flight control systems. They ensure efficient and stable energy distribution across the UAV, powering all critical components.

- Number of junior engineers hired and salary: **1 / 10.77 € per hour**

Telecommunications Engineer: Telecommunications engineers design the communication and remote control systems. They ensure that the UAV maintains a stable and secure connection with ground operators, whether for autonomous missions or manual remote control.

- Number of senior engineers hired and salary: **1 / 30.83 € per hour**

Taking into account that each engineer will work around 90 hours (as stated in the guide of the subject), the brute cost for human resources will be **23,851.8 €** In addition, considering that 24.1% of the wages must be paid to Social Security, this adds **5,748.28 €** to the total cost for human resources.

The final human resources cost is calculated as follows:

$$\text{Final Human Resources Cost} = \text{Wages} + \text{Social Security} = 23,851.8 + 5,748.28 = \mathbf{29{,}600.08}\ \text{€}$$

H.1.5.2 Software Tools

List of the software tools that will be necessary for the project and their price:

SolidWorks

- Required licenses: 5
- Purpose: For materials, structure, and exterior design by structural engineers (4 licenses) and the interior/payloads team (1 license).
- Cost per license: 2,800 €

- Total cost: 14,000 €

MATLAB Simulink

- Required licenses: 14
- Purpose: To perform various calculations and system simulations.
- Cost per license: 900 €
- Total cost: 12,600 €

PSIM

- Required licenses: 2
- Purpose: Standard tool for electrical engineers in the payloads team for electrical system design and simulations.
- Cost per license: 3,700 €
- Total cost: 7,400 €

ROS

- Required licenses: 1
- Purpose: For robotics and automation in the payloads team, ROS is used to develop and integrate the control and automation systems of the UAV.
- Cost: Free (open-source)
- Total cost: 0 €

PX4 AUTOPILOT

- Required licenses: 1
- Purpose: PX4 is essential for UAV flight control, used to implement and test the UAV's autonomous and semi-autonomous capabilities, including flight control algorithms and navigation systems.
- Cost: Free (open-source)
- Total cost: 0 €

Total Software Cost: 34,000 € It is important to note that these are yearly prices for licenses. However, the project is expected to be up to 4 months long. In order to better quantify the cost for this project (considering the licenses could be used in other projects during the rest of the year), we will apply a correction.

Total Software Cost With Amortization: $34,000 \cdot \frac{4}{12} = 11,333.33$ €

H.1.5.3 Hardware Tools

List of the hardware tools that will be necessary for the project and their price:

14 Intel Core i7 Laptops

- Cost per unit per year: 1,200 €
- Total cost for 14 laptops: 16,800€

Home working will be implemented, so no facilities will be considered in this budget.

Following the same logic as for software, the life of the computers will be estimated within four year

Amortization over 4 years: Total Hardware Cost With Amortization: $16,800 \cdot \frac{4}{12 \cdot 4} = 1,400$ €

Cost With Amortization (Software + Hardware): $11,333.33 + 1,400 = 12,733.33$ €

H.1.5.4 Contingency margin

For this project, considering the complexity of developing a novel solution, a 20% contingency margin has been selected in order to ensure that the budget accounts for potential delays, design adjustments, or additional testing requirements. The choice has been according to the guidelines provided by AACE.

H.1.5.5 General budget

The following outlines all the cost sources previously discussed, which together define the budget for the preliminary study of the project. The table below provides a summary of this information.

Activity	Cost (€)
Human resources	29,600.08
Software tools	12,733.33
Contingency margin	8,466.68
Total	**50,800.09**

Table H.4: General budget

That corresponds to the total amount of money required to carry out the preliminary study. However, in order to generate benefits for the business and have some kind of ROI, it has been decided to apply a profit margin of 15% that adds 7.620,01 € to the final price:

PVP = Total cost + Profit margin = 50.800,09 + 7.620,01 = 58.420,10 €. Since this is a first approach, the PVP will be rounded to **58.500 €**.