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A CONCEPTUAL DESIGN OF FLEXIBLE MISSION MALE: AVIONICS SELECTION AND STRUCTURAL DESIGN

By

Akbar Lazuardy Ihsan
11201901001

Presented to the Faculty of Engineering and Life Sciences
In Partial Fulfilment Of the Requirements for the Degree of

SARJANA TEKNIK
In
AVIATION ENGINEERING

FACULTY OF ENGINEERING AND LIFE SCIENCES

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APPROVAL PAGE

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STATEMENT BY THE AUTHOR

I hereby declare that this submission is my own work and to the best of my knowledge, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma at any educational institution, except where due acknowledgement is made in the thesis.

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ABSTRACT

A Conceptual Design of Flexible Mission MALE: Avionics Selection and Structural Design

by

Akbar Lazuardy Ihsan

Dr. Eng. Ressa Octavianty, Advisor

Triwanto Simanjunyak, PhD, Co-Advisor

In this research study, the avionics and structural design of Medium Altitude Long-Endurance (MALE) unmanned aerial vehicle (UAV) was carried out. This UAV is intended to perform multiple purposes, military and civilian, such as intelligence, surveillance, and reconnaissance (ISR), combat, and search and rescue (SAR) operations. The avionics and payload systems were mostly chosen from commercially available parts and classified into basic and specific missions. Those avionics components were largely mounted in the fuselage. In addition, the structural geometric parameters, such as fuselage frame, wing rib, wing spar, stringer, and skin thickness were determined to ensure its ability to sustain the aircraft load +3.8 to -1.5 in compliance with STANAG 4671 .The overall UAV configuration is high aspect ratio wing and X-tail design which was drawn using ONShape software with main material made of Al 2024. The overall length, width, and height of the UAV are 8.34 m in length, 15.94 m in width, and 2.34 m in height, respectively. For the heaviest mission, that is, Combat Mission, the UAV has a maximum take-off mass (MTOM) of 1497.3 kg. For this configuration, the c.g was located at 4.07 m from the aircraft nose. For other mission, the variation of c.g is move +- 2.3 cm from previos configuration.

Keyword: *Aircraft Design, MALE, UAV, Aircraft Structure, Avionics, CAD*

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List of Abbreviations

UAV	**U**nmanned **A**erial **V**ehicle
CG	**C**enter **G**ravity
CAD	**C**omputer **A**ided **D**esign
MALE	**M**edium **A**ltitude **L**ong **E**ndurance
ISR	**I**ntelligence **S**urveillance **R**econnaissance
FAA	**F**ederal **A**viation **A**dministration
ICAO	**I**nternational **C**ivil **A**viation **O**rganization
NATO	**N**orth **A**tlantic **T**reaty **O**rganization
EASA	**E**uropean Union **A**viation **S**afety **A**gency
SAR	**S**earch **A**nd **R**escue
SAR	**S**ynhetic **A**perture **R**adar
SDS	**S**onobuoy **D**ispensing **S**ystem
EO	**E**lectro **O**ptic
SIGINT	**SIG**nal **INT**elligent
MTI	**M**oving **T**arget **I**ndicator
WAMI	**W**ide **A**rea **M**otion **I**magery
COTS	**C**ommercial **O**ff **T**he **S**helf
SAR	**S**earch **A**nd **R**escue
IR	**I**nfra **R**ed
MTOW	**M**aximum **T**ake **O**ff **W**eight
MZFW	**M**aximum **Z**ero **F**uel **W**eight

Dedicated to my parents

CHAPTER 1
INTRODUCTION

1.1 Background

Medium Altitude Long Endurance (MALE) systems have become important in today's military and aerospace industries. They serve mainly for intelligence, surveillance, reconnaissance (ISR), and precision strike operations. MALE systems are versatile and resilient, allowing them to handle a wide range of tasks in addition to their standard operations. This versatility is a considerable benefit, especially when compared to smaller Unmanned Aerial aircraft (UAS), as MALE aircraft can transport a wider and more complicated range of equipment.

A unique aspect of MALE system development is its role in pioneering new, initially larger payload technologies. These technologies usually begin large and require the significant carrying capacity of MALE systems. As technology advances, these payloads become smaller, making them compatible with smaller UAS platforms. As a result, MALE systems usually serve as the first proving ground for these new innovations, paving the way for their eventual widespread usage in unmanned aerial technology.[1] [2]

Indonesia launched a project to create the "Elang Hitam" (Black Eagle), a Medium Altitude Long Endurance (MALE) Unmanned Aerial Vehicle (UAV). This project, directed by PT Dirgantara Indonesia in conjunction with numerous state organizations, including TNI, Ditjen Pothan Kemhan, BPPT, and ITB, aims to develop a UAV capable of flying for 24 hours at altitudes of up to 30,000 feet and equipped for border monitoring and national security. Initially developed for defense, its application shifted to civilian use during the COVID-19 epidemic. However, the initiative faced obstacles, for instance, prohibitions on the development of military UAVs. These restrictions, particularly those relating to acquiring necessary components, resulted from Indonesia's position in international military trade policies. [3]

1.2 Problem Statement

Indonesia, as an archipelago nation with vast borders, faces difficulties in maintaining border security. Using human resources for this purpose is both dangerous and resource-demanding. One effective method is to deploy Medium Altitude Long Endurance (MALE) Unmanned Aerial Vehicles (UAVs), which can improve naval security while requiring fewer resources. However, Indonesia faces difficulties in creating military-grade MALE UAVs, which stopped active development efforts.

Based on Weibel's thesis [4] on UAV classification, We can see why we chose MALE UAVs over smaller UAVs for border surveillance.

- MALE UAVs are designed for longer endurance and can stay airborne for extended periods, typically ranging from several hours to more than a day. This allows them to cover larger distances and provide continuous surveillance over expansive border areas.
- MALE UAVs operate at higher altitudes compared to smaller UAVs. This altitude capability provides a broader view of the border region, allowing for effective surveillance over varied terrain.
- MALE UAVs typically have larger payload capacities compared to smaller UAVs. This enables them to carry advanced sensor payloads such as high-resolution cameras, infrared sensors, radar, and other surveillance equipment.
- Border surveillance often requires monitoring vast and remote areas. The longer endurance, extended range, and higher altitude capabilities of MALE UAVs make them well-suited for efficiently covering large and geographically diverse border regions.

Considering the needs for MALE UAVs, Indonesia should continue to pursue the ability to design and manufacture MALE as independently as possible. A flexible MALE UAVs is worthy of exploration since it may offer effective cost and high utilization. Missions that are considered are Surveillance and Monitoring, SAR, and Defense missions.

1.3 Research Objectives

The research project aims to create a new Medium Altitude Long Endurance (MALE) Unmanned Aerial Vehicle (UAV) offering an innovative alternative to existing MALE UAV designs in Indonesia. This project aims to develop a multi-purpose MALE UAV capable of fulfilling multiple roles and competing effectively in its class. The primary objectives include:

- Design by selection the avionics system to meet the flexible missions requirements.
- Formulate V-n diagram that compiled with mission profiles and STANAG 4671 standards.
- Conceptually design the main structures: fuselage, wing, and the empennage.

1.4 Research Scope and Limitation

The scope and limitations are:

- This research only covers avionics and structure design. While Aerodynamics, Performance, and Stability of UAVs are done by my partner, Mr. Ali.
- The sizing is using intial sizing for this thesis.
- The total load for this aircraft (MTOW) is using the mission with the heaviest mass.
- Testing the structure with FEM is not part of this thesis.
- No optimization of the aircraft structure is done.

1.5 Significance of the Study

The result of this study is as expected:

- Can be used as a reference or starting point for Indonesia or other entities to build MALE UAVs in future development.
- It can be used to estimate what component should be used, the layout, and the weight of future development in MALE UAVs.

CHAPTER 2
LITERATURE REVIEW

2.1 Unmanned Aerial Vehicle

2.1.1 Introduction to Unmanned Aerial Vehicle

Unmanned Aerial Vehicles (UAVs), also known as remote-piloted Aerial Vehicles (RPAVs), form a crucial component of Unmanned Aerial Systems (UAS). These systems include the UAV, a powered vehicle, and supporting elements such as ground control stations, communication links, and other essential equipment. UAVs are distinguished by their ability to operate without human pilots onboard and can be designed for various purposes, including both recoverable and expendable missions.

These versatile vehicles can carry wide range of payloads, ranging from non-lethal surveillance and data-gathering equipment to lethal weaponry for military applications. One of the distinguishing characteristics of UAVs is their operational flexibility; they can be programmed for autonomous flight, relying on pre-set routes and objectives, or operators from the ground or another vehicle can remotely control them. This dual capability allows for a wide range of applications in both civilian and military contexts. [5] [2]

2.1.2 UAVs Terminologies in regulations

To further elaborate on the definitions of Unmanned Aerial Vehicles (UAVs) by the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO), it is necessary to dive into the specifics and effects of these definitions in the broader context of UAV technology and its regulation.

The ICAO, in its Global Air Traffic Management Operational Concept (Doc 9854)[6], provides a comprehensive definition of a UAV. According to the ICAO, a UAV is essentially a pilotless aircraft, as defined in Article 8 of the Convention on International Civil Aviation. This definition highlights that UAVs operate without a pilot-in-command onboard. They can be controlled remotely from various locations the ground, another aircraft, or even space or entirely autonomous based on pre-programmed instructions. This understanding of UAVs, endorsed by the 35th Session of the ICAO Assembly, reflects the organization's commitment to integrating these vehicles into the global aviation framework while acknowledging their unique operational capabilities and requirements.

On the other hand, the FAAs definition, as stated in Public Law 112-95, Section 331(8)[7], focuses more on the concept of an Unmanned Aircraft System (UAS). The FAA describes a UAS as comprising the unmanned aircraft and the associated support equipment necessary for safe and efficient operation. This broader view encompasses the entire ecosystem of UAV operations, including communication systems, navigational aids, and safety mechanisms. Under this definition, an unmanned aircraft is a vital component of a UAS. It is characterized by its ability to operate without direct human intervention from within or on the aircraft. This definition underscores the FAA's approach to UAV regulation, which considers the complexity of safely integrating these systems into the national airspace.

2.1.3 UAV and UAS Terminology

The distinction between Unmanned Aerial Vehicles (UAVs) and Unmanned Aircraft Systems (UAS) is crucial for understanding the broader context of unmanned aerial technology. According to the Federal Aviation Administration (FAA), a UAS encompasses not only the unmanned aircraft itself but also all the associated equipment required to operate the UAV. This definition highlights the complexity and multifaceted nature of unmanned aerial operations, extending beyond the aircraft to the entire system required for its functionality [7].

As a term, UAV refers explicitly to this system's "aircraft" component. The physical vehicle flies and carries out its assigned tasks, such as surveillance, reconnaissance, or payload delivery. The UAV is the core element most people visualise when considering drone technology. However, it is important to understand that the UAV is just one part of a larger ecosystem that is a UAS.

According to Paul Fahlstrom's "Introduction to UAV Systems"[1] Unmanned Aerial Systems are made up of several components. These components are critical to UAV performance and operation. Fahlstrom recognizes and expands on these critical components, with Figure 2.1 offering insight into the complex characteristics of Unmanned Aerial Systems. Here are some examples of UAS systems:

- **Unmanned Aircraft (UAV):** This flying vehicle has various technologies, such as propulsion systems, navigation systems, sensors, and communication equipment. The design and capabilities of the UAV determine its suitability for different tasks and environments.
- **Ground Control Station (GCS):** The GCS is where operators control and monitor the UAV. It can be an advance setup with multiple screens and controls or a simple handheld device, depending on the complexity of the UAV and its mission.
- **Communication Links:** These data links enable control and communication between the UAV and the GCS. They are vital for transmitting commands, receiving telemetry, and sometimes streaming live data such as video feeds.
- **Payloads:** Unmanned Aerial Vehicles (UAVs) primarily carry payloads, which are often the most expensive component of the system. Typical payloads include video cameras (daylight or night), radar sensors, and electronic warfare systems for reconnaissance and surveillance. Laser systems may be added for target designation, significantly increasing costs. UAVs can also carry weapons for various purposes, and armed UAVs may be used for lethal missions. Additionally, UAVs serve as platforms for data and communication relays, extending the coverage and range of radio-frequency systems.

- **Launch and Recovery Systems:** Specialized equipment such as launchers and recovery systems are necessary for some UAVs with significantly larger fixed-wing models. These systems facilitate the safe and efficient deployment and recovery of the UAV.
- **Support Equipment:** This includes all other equipment required for the operation and maintenance of the UAV, such as battery chargers, spare parts, and calibration tools.

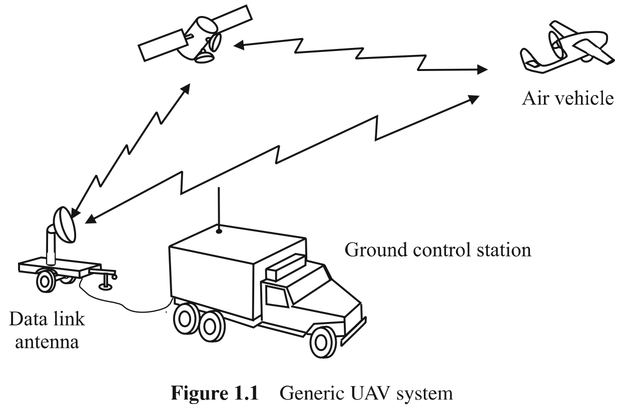

FIGURE 2.1: Visualization of Unmanned Aerial Systems. Image credit: Paul Fahlstrom "Introduction to UAV Systems", 2012

Understanding the difference between UAVs and UASs is critical for various reasons. For starters, it recognizes the complexities of controlling UAVs, which entail far more than simply the flying vehicle. Second, it emphasizes the significance of support systems that ensure the safe and successful use of unmanned aerial vehicles (UAVs), particularly in commercial or regulatory contexts. Finally, it emphasizes the broader effects of UAV technology on policy, legislation, and ethics, as these are influenced by the aircraft and the complete operation system.

2.1.4 UAV classification

According to Weibel's reference in Safety Considerations for Operation of Different Classes of Unmanned Aerial Vehicles in the National Airspace System[4] UAVs can be classified into numerous classes based on their operational capabilities and intended use scenarios. This classification is a foundation for understanding the many types of UAVs and their functions in civilian and military applications. As we can see in Table 2.1, here are some explanation that defined by Weibel:

Class	Representative Aircraft	Mass Range	Operating Area	Operating Altitudes
Micro		Less than 2 lb	Local	Near-surface to 500 ft
Mini		2 to 30 lb	Local	100 to 10,000 ft
Tactical		30 to 1,000 lb	Regional	1,500 to 18,000 ft
MALE		1,000 to 30,000 lb	Regional/ National	18,000 ft to FL 600
HALE			Regional/ National / International	Above FL 600
Heavy*		Over 30,000 lb	National / International	18,0000 ft to FL 450

TABLE 2.1: Summary of Vehicle Classes. Image credit: Weibel Safety considerations for operation of different classes of unmanned aerial vehicles in the national airspace system, 2005

- **Micro:**The Micro class includes UAVs with a mass of less than 2 pounds. These are typically used in local settings for near-surface operations, with operational altitudes ranging from the surface to 500 feet. Due to their lightweight and compact size, Micro UAVs are often employed for indoor missions or in densely populated urban areas where larger UAVs cannot operate safely.
- **Mini:**Mini UAVs have a mass range of 2 to 30 pounds and are also intended for local use. They can operate at higher altitudes than Micro UAVs, typically between 100 to 10,000 feet, which allows them to perform local surveillance, agricultural assessment, and aerial photography tasks.

- **Tactical:**The Tactical class is characterized by a mass range of 30 to 1,000 pounds and is designed for regional operations. These UAVs can reach altitudes of 1,500 to 18,000 feet, making them suitable for more extensive surveillance missions, border security, and environmental monitoring across larger geographic areas.
- **Medium Altitude Long Endurance:**Medium Altitude Long Endurance (MALE) UAVs are larger systems with a mass between 1,000 to 30,000 pounds. They operate on a regional or national level, at altitudes from 18,000 feet up to Flight Level 600 (approximately 60,000 feet). These UAVs are commonly used for prolonged surveillance, communication relay, and intelligence gathering over extensive areas.
- **High Altitude Long Endurance:**High Altitude Long Endurance (HALE) UAVs exceed the MALE class in altitude and endurance, operating above Flight Level 600. Their operational domain is regional, national, or even international, supporting high-altitude tasks such as climate monitoring, high-resolution mapping, and strategic surveillance.
- **Heavy:**The Heavy class comprises UAVs with a mass of over 30,000 pounds. These UAVs are designed for national and international missions, operating at altitudes ranging from 18,000 feet to Flight Level 450 (approximately 45,000 feet). Heavy UAVs are often equivalent to human-crewed aircraft in terms of capabilities. They are used for high-stakes operations such as cargo transport, long-range search and rescue, and other tasks that require significant payload capacities.

2.1.5 Medium Altitude Long Endurance (MALE)

Medium-altitude long-endurance (MALE) unmanned aerial vehicles represent a category of UAVs specifically designed to operate at medium altitude ranges, typically between 20,000 to 60,000 feet. According to Weibel[4], these vehicles are engineered to maintain flight for extended periods and can typically operate from 10 hours to days without refueling or servicing. The operational altitude of MALE UAVs situates them within Class A airspace, which is typically reserved for controlled high-altitude flight, starting from 18,000 feet MSL (Mean Sea Level) up to and including Flight Level 600 (approximately 60,000 feet MSL) as shown in Figures 2.2 and 2.3.

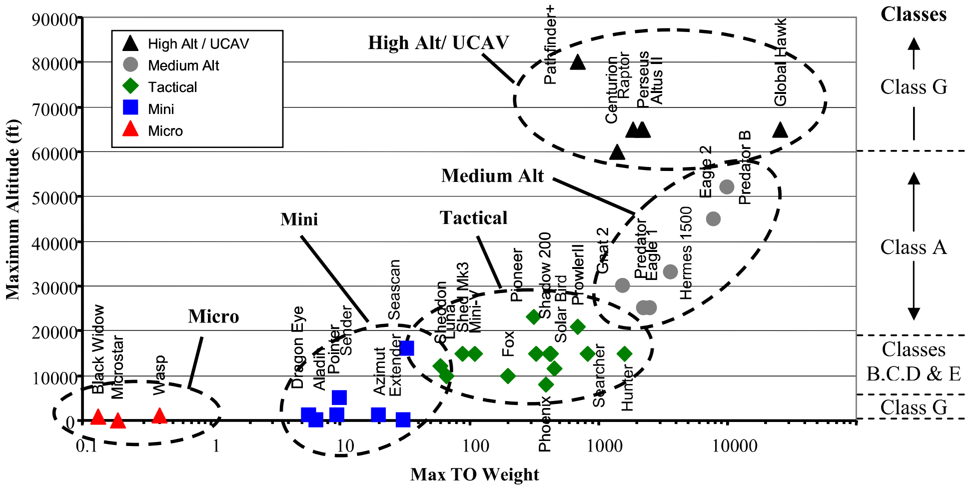

FIGURE 2.2: Maximum Altitudes UAVs. Image credit: Weibel Safety considerations for operation of different classes of unmanned aerial vehicles in the national airspace system, 2005

But, there is another term of "Medium" UAV in UAV categorization. According to Paul Fahlstrom's definition in Introduction to UAV Systems [1], an Unmanned Aerial Vehicle (UAV) is classed as a "Medium" UAV due to its size. The term medium in this context denotes that the aircraft is too large to be transported by a single person while remaining smaller than a standard light aircraft. While offering a clear categorization, Fahlstrom's definition does not promise total rigor in this classification. It is crucial to note that in aerial technology, such definitions frequently include a variety of criteria, including but not limited to the UAV's operational capabilities, payload capacity, and intended application in diverse situations.

In conclusion, Medium-Altitude Long-Endurance (MALE) UAVs play a crucial role in the range of UAV categories. They are unique for their ability to fly at medium altitudes and for long periods. As shown in the image, MALE UAVs are specifically made to function in a distinct area within the UAV system. They operate higher than the usual heights of smaller, tactical UAVs but lower than the very high altitudes where High-Altitude Long-Endurance (HALE) UAVs are found. This positions them as an essential type of UAV, bridging the gap between lower and higher altitude UAV operations.

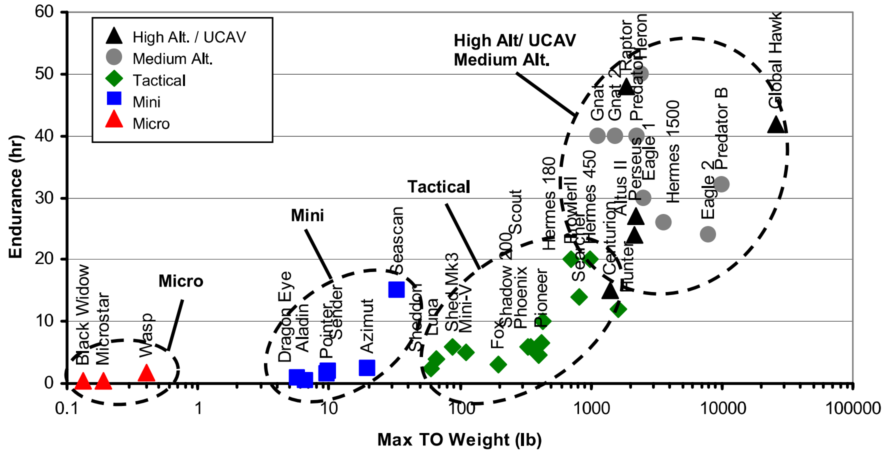

FIGURE 2.3: Maximum Endurance UAVs. Image credit: Weibel Safety considerations for operation of different classes of unmanned aerial vehicles in the national airspace system, 2005

2.2 Design Approach

As we can see in Figure 2.4, first, researching similar aircraft or potential markets sets the foundation for a comprehensive comparative study, gathering crucial data for the initial calculations. This market research not only assesses the economic feasibility but also evaluates the readiness of the technology for integration into the new aircraft design. Then we proceed to the next step. This step involves compiling a "design proposal," a crucial step preceding the design process. This proposal includes considerations regarding the aircraft's potential use, such as reconnaissance, cargo or passenger transport, or its availability for civilian applications like Coast Guard operations or wildfire reconnaissance. At the same time, defining the mission creates crucial limits for the new aircraft, including endurance, range, maximum payload, altitude, and take-off/landing distance.

Once the mission is defined, the process moves to the conceptual design stage. Here, estimations for the aircraft's weight and aerodynamic characteristics are

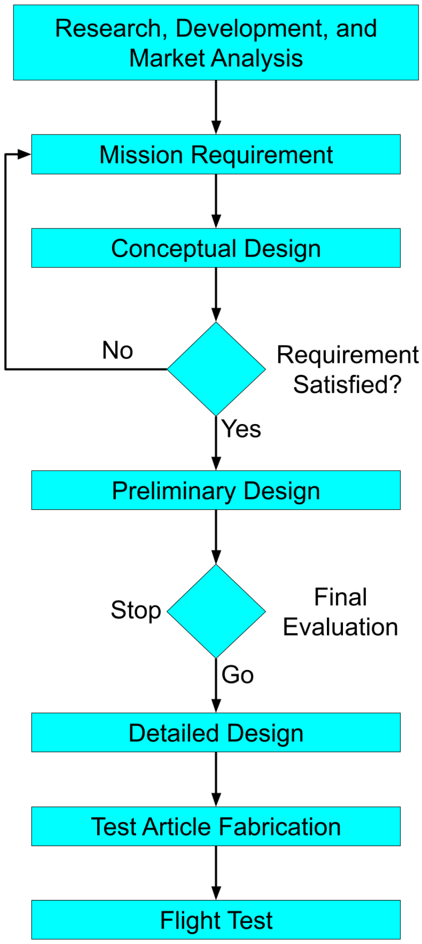

FIGURE 2.4: Design approach of aircraft defined by Corke[8]

aligned with the design proposal. The conceptual design further determines payload capacity, wing and engine positioning, and the placement of weight groups to meet static stability requirements. This stage also influences the size of control surfaces to achieve the desired level of maneuverability. The conceptual design is adapted to the mission specifications stated in the design proposal.

The next step is to perform the preliminary stage, the focus shifts to fine-tuning the design. Calculations are conducted with a concentrated effort on stability, control, structure stresses, and flight mechanics. At this point, additional confirmation may be necessary through building and testing proposed structural components or wind tunnel testing of a scale aircraft model. This step continues with a design assessment to ensure practical and economic feasibility. Once the review is complete, the design is essentially fixed, and revision is not possible without revisiting the preliminary design.

The next stage is to design all the necessary components to build a proper aircraft. This stage relies on structure design, propulsion system, control surfaces, equipment, and subsystems. Testing and integration procedures ensure that all components work together effectively.

In the final phase, flight testing, engineers and test pilots execute a series of maneuvers. The goal is to define the flight envelope and validate that the aircraft performs effectively for its intended mission. This comprehensive approach, from market research to flight testing, ensures a thorough and effective aircraft design process.[8]

The approach used in this thesis focuses on the early design phases of a MALE Unmanned Aerial Vehicle (UAV). It all starts with market research, in which we explore the UAV business to understand consumers wants, see what's currently on the market, and identify the possibilities of a new UAV. Then, based on our findings, we set out to establish what our UAV should do, its mission requirements. These include factors like its flying range, payload capacity, and endurance.

We go to the conceptual design phase once we have an understanding of what the market requires and what our UAV should do. We begin designing our UAV here, deciding on its basic features and technology and considering how to make it efficient.

2.3 Aircraft Structure Component

2.3.1 Fuselage

The fuselages of aircraft are carefully engineered structures consisting of thin sheets of material for the outer skin, which are carefully reinforced by a vast network of longitudinal stringers, strengthened by transverse frames, and strategically integrated with bulkheads to give shape to the fuselage. Longerons, which usually extend across several frame members, further enhance the structural integrity by helping the skin support primary bending loads. Stringers, on the other hand, providing additional support, and for the attachment of the skin. Together, these parts guarantee the structural stability and aerodynamic effectiveness of the fuselage. The aircraft's thin skin acts as its main defense against the outside pressure. However, the stringers provide crucial reinforcement by increasing rigidity and resistance to compression and bending stresses.

By crossing the stringers, the transverse frames help to distribute loads, preserve the shape of the fuselage, and increase the structure's overall strength. In order to maintain the aircraft's safety and performance during flight, this complicated assembly of skin, stringers, and frames must be able to withstand a variety of stresses, such as aerodynamic forces, pressure differentials, and the dynamic loads of takeoff, cruise, and landing [9] [10]. An illustration of fuselage frame is shown in Figure 2.5

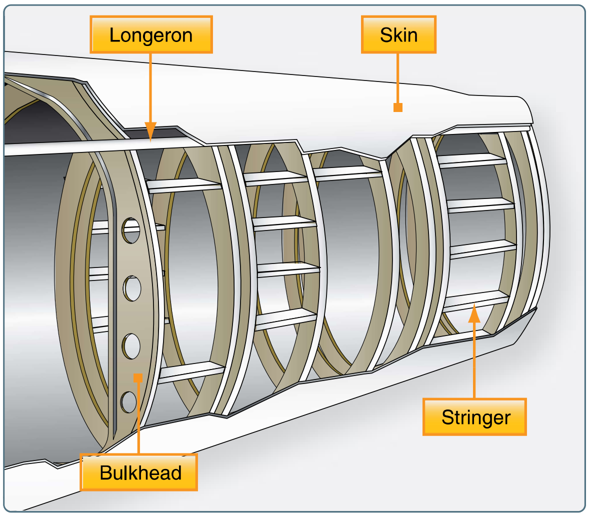

FIGURE 2.5: General Frame Structure. Image Credit: FAA "Aviation Maintenance Technician Handbook-Airframe - Volume 1"

2.3.2 Wing

Aircraft wing sections are highly designed, consisting of thin skins reinforced by an entire assembly of stringers, spars, and ribs. We can see that from Figure 2.6. Together, these elements maintain the wing's structural integrity and aerodynamic performance. The skin, the outer layer, is carefully engineered to be both lightweight and strong, able to withstand the stresses and aerodynamic forces that are applied during flight. As crucial stiffeners that improve the wing's resistance to bending and torsional forces, stringers run longitudinally along the wing.

The main load-bearing components of an aircraft are its spars, which run the length of the wing and support bending loads during flight. The ribs, on the other hand, are spaced periodically and help maintain the airfoil form of the wing as well as distribute aerodynamic forces throughout its surface. The complex interaction of these parts guarantees that the wing is both lightweight and strong enough to endure the stresses of flight, improving the effectiveness and performance of the aircraft. These structural components are essential to the overall structure and operation of the aircraft because of their crucial function in determining the lift, stability, and control characteristics of the wing. [9]

Some types of aircraft designs have fuel tanks built into the wing structure; this arrangement is widespread in high-wing aircraft. This design uses gravity to carry fuel to the engines, located below the fuel tanks and includes a fuel tank in each wing. An illustration of this fuel tank integration into the wing is shown in Figure 2.7. [11]

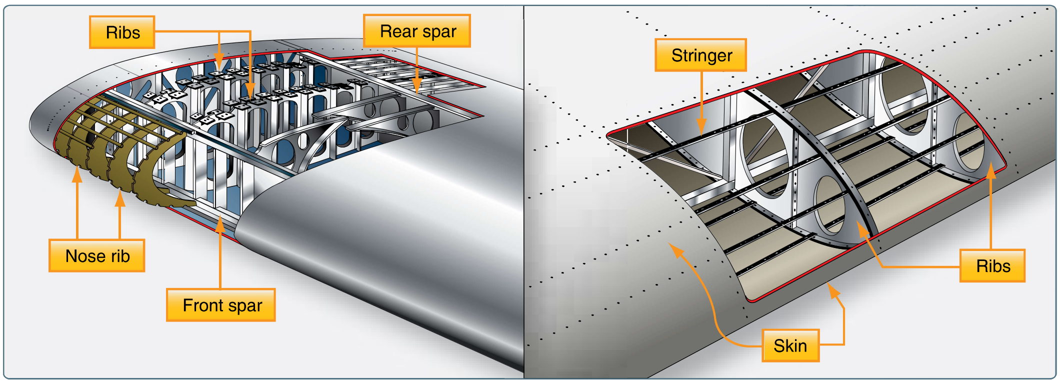

FIGURE 2.6: General Frame Structure. Image Credit: FAA "Aviation Maintenance Technician Handbook-Airframe - Volume 1"

FIGURE 2.7: Fuel Tank Inside of the Wing Structure. Image Credit: FAA "Aviation Maintenance Technician Handbook-Airframe - Volume 2"

2.3.3 Tail

An aircraft's empennage, often known as the tail section, is a crucial part of its design. It includes the tail cone and both stationary and moveable aerodynamic features like stabilizers. These stabilizers' architectural structure, which shows a combination of spars, ribs, stringers, and skin, is modelled after the structure of wings. All of these components work together to play crucial roles in stabilizing and reinforcing the stabilizer as well as transferring stresses caused by bending, twisting, and shear forces experienced during flight. By effectively redistributing any excessive loads to the fuselage, this dynamic stress transfer mechanism reduces the possibility of structural overloads. [10]

2.4 Regulation

Compliance with regulations is crucial in the aircraft design process. It is common for passenger aircraft to follow FAR 23 requirements. In contrast, UAVs adhere to the regulatory framework specified in STANAG 4671, a NATO-endorsed standards agreement. The difference in regulatory frameworks involves separate design considerations for manned passenger aircraft under FAR 23 and unmanned aerial vehicles (UAVs) under STANAG 4671.

FAR Part 23, a section of the United States Code of Federal Regulations, establishes broad standards for avionics and structural design, including small aircraft certification. The avionics standards apply to communication, navigation, and surveillance devices, while the structural criteria maintain the integrity and durability of aircraft components.

STANAG 4671, a NATO standardization agreement, focuses on the interoperability of Unmanned Aerial Vehicle (UAV) systems. Its avionics requirements pertain to communication systems, data exchange protocols, and sensor integration for UAVs, addressing their integration into controlled airspace. Unlike FAR Part 23, STANAG 4671 is specialized and emphasizes data exchange standards rather than detailed structural specifications for conventional manned aircraft.[12] [13]

2.4.1 Regulation on Load Factor

An airplane has a load factor of 1 when motionless on the ground since it is only subject to gravity. If, for example, the airplane accelerates upwards because of a force twice its weight, it experiences a load factor of 2. The pattern corresponds with the magnitude of the applied force. The force applied to an airplane with its weight without acceleration is known as the load factor. [14]

This is defined in STANAG 4671 in the USAR 321 general section as follows: Flight load factors represent the ratio of the aerodynamic force component (acting normal to the assumed longitudinal axis of the UAV) to the weight of the UAV. A positive flight load factor is one in which the aerodynamic force acts upward, with respect to the UAV. [13]

The evaluation of an aircraft's airworthiness involves the application of safety regulations to several aspects of its design. Structural integrity, including safety features for potential crash landings, and compliance with design parameters related to aerodynamics, performance, electrical and hydraulic systems are all included. National and international airworthiness authorities are largely responsible for establishing baseline safety standards. They create official handbooks that include information on design, minimum safety standards, recommended procedures, and operational requirements. [9]

Aircraft design is regulated by STANAG 4671 [13], which defines the structural loads as stated below:

USAR.337 Limit Manoeuvring Load Factors

1. The minimum positive limit manoeuvring load factor n is the minimum of $2.1 + \frac{10900}{(W+4536)}$ (where $W =$ design maximum take-off weight in kg) or 3.8;
2. The negative limit manoeuvring load factor may not be less than 0.4 times the positive load factor;
3. Manoeuvring load factors lower than those specified in this section may be used if the UAV has design features that make it impossible to intentionally exceed these values in flight.

CHAPTER 3
RESEARCH METHODOLOGY

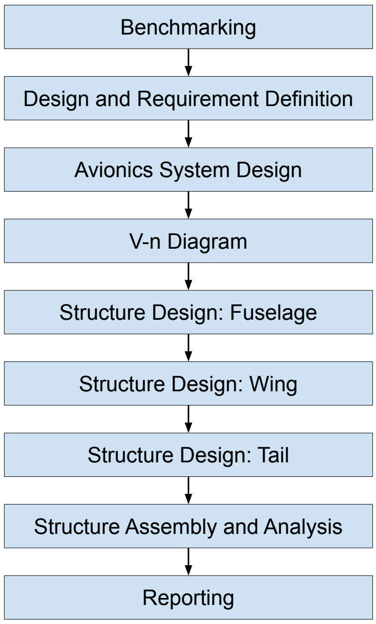

FIGURE 3.1: Flow Chart of Designing MALE UAV

3.1 Benchmarking

The benchmarking process began with an extensive collection and evaluation of available data for the 22 MALE UAVs. This first stage was critical for assessing the rival market and determining important requirements and performance indicators. The analysis focused on a variety of factors, including but not limited to operational capabilities, technological features, and compatibility with STANAG 4671. However, it is important to remember that not all UAVs have all their data publicly available. The results of this benchmarking analysis provided a solid understanding of the current situation with MALE UAV technology and highlighted leading designs and characteristics that match military requirements.

3.2 Design and Requirement Definition

Following the benchmarking analysis, the study continued on to developing a mission profile for the UAV under consideration. This stage involved combining the obtained data to determine which UAV model best met the desired specifications and performance criteria. The mission profile was adjusted to meet the identified demands of the target market or client criteria. It included detailed specifications, performance expectations, and operational capabilities required for the UAV to carry out its intended functions.

3.3 Avionics Component Selection

The next stage of the research method was to choose suitable avionics components for the UAV. This process was influenced by examining the avionics used in the UAVs included in the benchmarking study. The study intended to determine the best avionics components that met the mission profile requirements by comparing them across different models. The availability of off-the-shelf parts was considered, and when public data was unavailable, more investigation on comparable avionics components from competitors was carried out. The compatibility of the selected avionics with the UAV's mission profile was carefully evaluated to verify that the components selected will improve the UAV's operational effectiveness.

3.4 V-n Diagram

After completing the avionics design phase, the research technique created the V-N (velocity-load factor) diagram. The first step is gathering detailed aerodynamic and performance data, which we can acquire from Mr. Ali. The required information includes the following:

- Gross Weight
- Wing Area
- Air Density
- Maximum Lift Coefficient
- Minimum Lift Coefficient
- Cl alpha
- Stall Speed
- Mean Geometric chord
- Cruising speed
- Gust Velocity

Using this information, the study uses formulas developed from Snorri's book [14] to determine the key components required for the V-N diagram design. These factors include:

- Positive Load Factor:
$$n_+ = 2.1 + \frac{24000}{W_0 + 10000} \tag{3.1}$$
- Negative Load Factor:
$$n_- = -0.4n_+ \tag{3.2}$$
- Dive Speed:
$$V_D > 1.40V_C \tag{3.3}$$
- Positive Maneuvering Speed:
$$V_A = V_S\sqrt{n_+} \tag{3.4}$$

- Negative Maneuvering Speed:

$$V_G = \sqrt{\frac{2\,|n_-|\,W}{\rho S C_{L_{\min}}}} \tag{3.5}$$

- Gust Load Factor:

$$n_{\mathrm{g}} = 1 + \frac{K_g \cdot U_{de} \cdot V \cdot C_{L\alpha}}{498(W/S)} \tag{3.6}$$

After identifying these critical velocities and load factors, the research method involves using a specific Excel application provided by Abbott Aerospace [15] to generate the V-N diagram as shown in Figure 3.2. For this diagram, just the Maneuvering Speed, Cruising Speed, Dive Speed, and Stall Speed have been entered into the Abbott Aerospace spreadsheet. This stage helps illustrate the UAV's operational envelope, demonstrating its performance capabilities and structural limitations under different flight situations. Thus, The V-N diagram is an important tool in confirming that the UAV design fits operational and safety requirements.

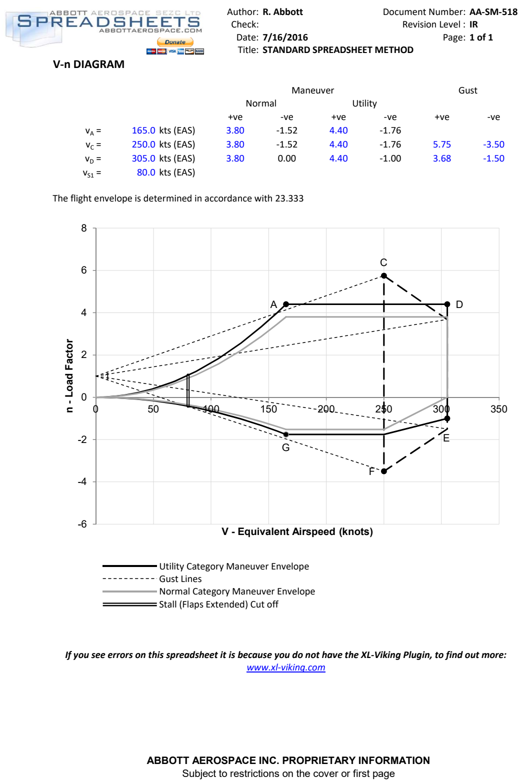

FIGURE 3.2: Example of Excel Programs to Illustrate the V-n Diagram. Source: Abbott Aerospace

3.5 Structure Design: Fuselage

Before beginning the fuselage design process, acquire the shape design from Mr. Ali. This initial phase ensures the design direction is consistent with predefined standards. As a result, avionics must be carefully arranged to avoid potential conflicts between structural component placement and avionics systems. After carefully arranging the avionics, the following step is to size the structural components. This step, known as initial sizing, is critical to figuring out the dimensions and scale of structural parts, giving the foundation for the following design stages.

After finishing the initial sizing, the focus moves to the sketching step, carried out using Onshape. Onshape, a cloud-based 3D CAD system, provides a dynamic platform for designing and developing concepts. This stage is critical because it transforms the theoretical aspects of the design into structural schematics, allowing for a more accurate illustration of the finished product. Finally, once the sketching process is completed successfully, the selection and assignment of materials for the frame begins. This stage is crucial to determining the fuselage's weight, and overall performance. By carefully considering the properties of materials and their compatibility with design objectives, one may ensure that the finished product meets but exceeds, the desired standards.

3.6 Structure Design: Wing

After the completion of the fuselage design, the focus moves to the wings, an essential component that has an important effect on the aircraft's aerodynamic performance and efficiency. The wings' design process begins with the acquisition of the shape design, which is given to Mr. Ali. This first step is crucial because it determines the aerodynamic profile and overall dimensions that will direct the later design processes. After the shape design has been finalized, the following step is to determine the initial wing structural size. This method is crucial to determining the appropriate dimensions and structural arrangement.

Following the initial sizing, the design team moves on to the sketching step, with Onshape acting as the major tool for this activity. This step is crucial in translating the conceptual design into an illustrated schematic, allowing for an in-depth examination and adjustment of the wing's design. After the sketching phase is completed successfully, the final stage in the wing design process is to select and assign materials to the frame. The choice of materials has an important effect on the aircraft's overall performance, affecting factors such as fuel efficiency, range, and payload.

3.7 Structure Design: Tail

After designing the aircraft's fuselage and wings, the design process now focuses on the aircraft's tail. This section is crucial for keeping the aircraft's control and stability while in flight. Getting the shape from Mr. Ali is the first step in the tail design process, and it defines the fundamental requirements for the aerodynamic profile of the tail. The design team moves on to the sketching stage after determining on the sizing parameters.

With the help of Onshape, the team starts working on sketching for the tail design. This stage is crucial for providing the conceptual design a more clear visual representation. The selection and assignment of materials for the construction of the tail frame are the last stage of the tail design process. Making this choice is crucial because the materials used in the design must meet the weight and cost goals while still having the strength and durability required to endure operational loads.

3.8 Structure Assembly

The project moves on to its last and most important phase, assembly, following all necessary components, including as the fuselage, wings, and tail section, have been successfully designed. This stage, which moves from the designs of individual components to an assembly of aircraft structure. The assembly process begins with the assembly of the structural components. This work is done carefully to make sure that every component fits together correctly and follows the design guidelines that were established in the previous stages.

The structural component assembly creates the aircraft's structure, which serves as the base for the construction. Once the structural assembly is completed, the avionics systems must be integrated. These systems are now put inside the structure after being carefully planned and arranged at the beginning of the design phase. An attention to detail is necessary during the crucial step of avionics installation to guarantee that all avionics are not overlap with the structure frames.

After the avionics and structural components are assembled, the project enters the analysis phase, where the overall weight of the aircraft is the primary focus. The evaluation of the aircraft's performance characteristics, such as its fuel efficiency, range, payload capacity, and takeoff and landing capabilities, depends heavily on this examination. Since the entire weight of the aircraft plays a crucial role in these performance indicators, an extensive analysis is carried out to determine the assembled aircraft's mass.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Benchmark Study

Before beginning the design process, an in-depth benchmarking analysis was performed. This study included a thorough examination and comparison of many Medium Altitude Long Endurance (MALE) UAVs from various competitors. This included UAVs that were either operational or in the development stage. We conducted an assessment of 22 UAVs that were recognized as possible rivals in the MALE UAV industry. Following this assessment, the Hermes Starliner and MQ-1 Predator were recognized as the most closely related competitors. The comparison between Hermes Starliner and MQ-1 shown in Table 4.1. These aircraft were chosen as reference models for the design of our conceptual MALE UAV due to their excellent performance characteristics. Furthermore, the Hermes Starliner's compatibility with STANAG 4671, which allows it to operate in NATO member countries' civil airspace without meeting EASA Part 23 regulations, was a key consideration in its selection.

No	1	2
Aircraft Name	General Atomics MQ-1 Predator	Elbit Hermes Starliner
Country of Origin	USA	Israel
Flight Status	Yes	Yes
Compliance to NATO STANAG 4671		Yes
Military/Civilian/Both	Military	Civilian
MTOW (kg)	1,020	1,600
EMTOW (kg)	513	1,150
Payload Mass (kg)	120	450
Fuel Mass (kg)	387	
A/C Dimensions		
Length (m)	8.23	
Height (m)	2.1	
Wing Area (m2)	11.45	
Wing Span (m)	14.8	17
Engine Name	Rotax 914F	Rotax 914 (HFE)
Engine Type (Turboprop/Turbojet/Turbofan)	Piston	Piston
Number of Engines	1	1
Wing Position (High, Mid, Low)	Mid	Mid
Type of Tail	V-Tail Inverted	V tail
Retractable Landin Gear	No	Yes
Range (km)	1250	
Service Ceiling (m)	7,600	9,144

TABLE 4.1: Aircraft Benchmark

4.2 Mission Profile

The aircraft's mission profile depends on the market or customer's needs and preferences. Customer demand variations cause aircraft configuration variances and, as a result, various mission profiles. The mission profile for the proposed aircraft in this study was determined after an in-depth benchmarking assessment. The performance characteristics of the Hermes Starliner and MQ-1 Predator, which became our reference models, helped shape our needs and mission profile. As shown in the Tables 4.2, 4.3 and Figures 4.1, the following mission profile, requirement, and diagram of mission profile is designed primarily for Intelligence, Surveillance, and Reconnaissance (ISR) missions.

Design requirement	
Internal Payload	880 lbs
External Payload	3,300 lbs
Endurance	38.5 hrs
Max Level Speed	264 kts
Cruising Speed	231 kts
Max rate of climb at Sea Level	2,750ft/min
Max operating altitude	56,100 ft
Max range	7.2842 nm
Field performance (take-off and landing)	$\leq$ 5500 ft
Limit load factors (General Aircraft)	+3.8 to -1.52

TABLE 4.2: Design requirements

1.1x Performance from Competitors			
Mission Sequence	Description	Altitude (m)	Distance (km)
1	Engine start, Taxi, and Take Off	Sea Level - 15.24	0.726
2	Climb	25.24 - 4572	100.11
3	Cruise climb ingress	7620	833.4
4	Loiter	7620	-
5	Egress	7620 to 4572	833.4
6	Descent	4572 - Sea Level	100.11
7	Landing, Taxi, Shutdown	Sea Level	0.726

TABLE 4.3: UAV expected performance

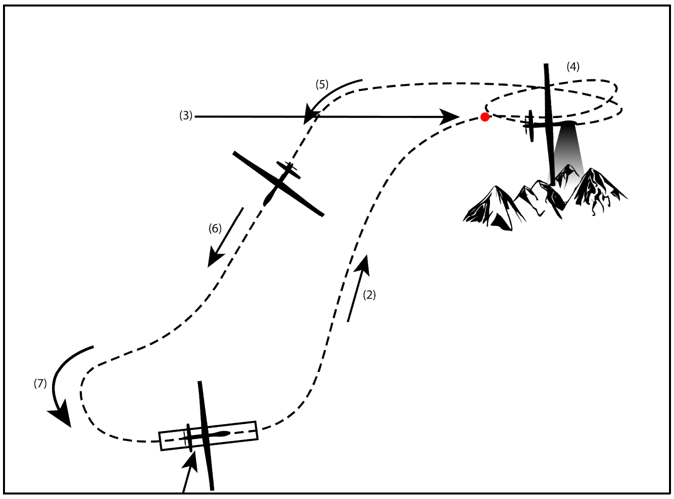

FIGURE 4.1: Mission profile of our MALE UAVs

In addition to our basic interest in ISR operations, we have diversified our scope by including three unique mission types: combat, ISR (Intelligence, Surveillance, and Reconnaissance), and SAR (Search and Rescue). Each mission type has a distinct payload, with particular needs varied according to the nature of the mission. To establish the right payloads, we performed extensive study online. Based on the information gathered, we created several setups for each mission type. The specs for each payload component were carefully listed. We used this data to compute the overall weight of the payload for each mission type. The weights for the various missions are as follows in Table 4.4:

Weight (payload) of various misions	
Combat	456.608 kg
Intelligence, Reconnaisance, and Surveillance	183.408 kg
Search and Rescue	248.725 kg

TABLE 4.4: Payload for every mission

4.3 Avionics Component Selection

4.3.1 Mission Variant

Our conceptual design features a Medium Altitude Long Endurance (MALE) Unmanned Aerial Vehicle (UAV) designed for flexible multi-role missions. This flexibility enables the UAV to be used in a wide range of scenarios, including intelligence, surveillance, and reconnaissance (ISR) missions, combat operations, and Search and Rescue (SAR) missions. The modular avionics system is an important design component. This system's interchangeability ensures that a single aircraft may easily switch between several missions to satisfy the precise needs of each mission. This strategy not only improves the UAV's operating flexibility but also maximizes resource consumption by allowing a single platform to perform many functions. The defined mission profiles for this UAV are as follows:

- **Combat Mission:**The UAV is designed for combat scenarios, with a specific focus on anti-submarine warfare activities. It is equipped with a Sonobuoy Dispensing System (SDS) that uses sonar technology to detect and track submarines. The sonobuoys launched by this technology catch sonar reflections from submarines and send them back to the UAV. The UAV then serves as a communication relay, transmitting the data to ground control units. This information is critical for detecting and predicting submarine movements, which play an important role in maritime security. Furthermore, the UAV has been fitted with an electronic jamming device, which improves its operating capabilities in electronic warfare and anti-submarine missions. This integration of modern technologies establishes the UAV as a critical asset in maritime surveillance and combat scenarios.
- **Intelligence, Surveillance, and Reconnaissance:**The UAV is equipped with modern electro-optical systems, which include a variety of sensors and cameras. It includes Signal Intelligence (SIGINT) capabilities for intercepting and decrypting enemy signals, which lead to important information. Furthermore, the UAV is outfitted with electro-optics (EO), synthetic aperture radar (SAR), and moving target indicator (MTI) technologies. These technologies allow the UAV to sustain long-term surveillance over specific areas

while providing continuous real-time video feeds to ground control. The addition of SAR enables for the creation of radar images in low-visibility conditions, assuring continual operational capability. The UAV's capabilities incorporate both electro-optical (EO) equipment and Wide Area Motion Imagery (WAMI). This mission consists of scanning certain locations to obtain essential information about enemy positions, infrastructure, and movements. The combination of EO and WAMI technologies provides for detailed and broad visual surveillance, which is critical for tactical planning and situational awareness.

- **Search and Rescue:**For the search and rescue mission, the Unmanned Aerial Vehicle (UAV) in this thesis is fitted with Electro-Optical (EO) features and a life raft pod. The UAV's operational protocol includes patrolling specific areas, such as open sea regions, where an aircraft crash has been reported. When the UAV detects survivors, it deploys the life raft near the survivor's location. At the same time, it sends important information about the crash site or the last known location of survivors to the ground control system. This information is critical for coordinating search and rescue operations and coordinating with coast guard units to speed up their reaction to the specified area. This mission profile demonstrates the UAV's capabilities to improve search and rescue operations, particularly in maritime areas.

4.3.2 Shared components each mission

In the context of components for unmanned aerial vehicles (UAVs), it is necessary to look at the formation of shared components that contribute to the aircraft's overall operational. These shared components are critical to the UAV's functionality, remaining consistent and vital all over a wide range of mission types. Regardless of the mission's specific objectives or requirements, these components serve as the basic components for the UAV's smooth and constant operation. The following list in Table 4.5 explain the individual components considered necessary for inclusion in all mission scenarios, highlighting their universal relevance and importance for ensuring optimal UAV performance. Here are the parts list for shared parts:

Parts	Subparts	Parts Name
	Automatic landing-takeoff system	Okis(Airborne Segment)
		Okis(Land Segmentt)
	KA-band sattelite comm sensor	MPT 46WGX(antenna)
		MPT 46WGX(KPSU)
	C-band datalink	C-band datalink
		Auto tracking antenna system
Avionics	Autopilot (FCC)	Vector 600
	Mission control Computer (MCC)	Vector MCC
	Baykar IMU	Bas 201
	Gnss-ins (imu+gps)	CGI-610 Dual-Antenna GNSS-INS
	AIS (Automatic Identification System)	The RadarPluső SA161-MH Receiver
	Power Amplifier	TA1216
	Air Data Recorder	XLDR
	SAR & ISAR	Eagle Eye (Electronic)
Imagery		Eagle Eye (Radar)
	EO/IR/MTI	Wescam MX-15
	Wide Area Motion Imagery	Redkite Block II Pod
	Satcom (dish)	Starlink (Flat) High Performance
Satellite communication	Satcom (power supply)	Starlink Power Supply
	Satcom (Router)	Starlink Router
	Engine	Rotax 914 F (Full System)
Propulsion	Power Distribution System	900W PDU
	Lithium battery	ABli-25
Payload	SIGINT (Signal Intelligence System)	Common SIGINT System 1500

TABLE 4.5: Shared Components

4.3.3 Unique components each mission

The unique equipment configurations of an Unmanned Aerial Vehicle (UAV) tailored for different mission types:

Combat Mission Configuration:

- The UAV is outfitted with a Sonobuoy Dispensing System (Anti Submarine Warfare Systems from General Atomic), which serves a purpose for anti-submarine warfare.
- A Bomb Rack Unit (Bomb Rack Unit from Bayraktar) is included, which allows the UAV to carry and discharge munitions.
- An electronic jammer (Sledgehammer Pod from General Atomic) is used to disrupt enemy communications and radar systems.

Intelligence, Surveillance, and Reconnaissance:

- The UAV has Signal Intelligence (Common SIGINT System 1500) capability to intercept and analyze enemy communications.
- Synthetic Aperture Radar (SAR) (Eagle Eye from General Atomic) and Inverse Synthetic Aperture Radar (ISAR) devices are installed to provide high-resolution imaging, which is especially effective in low-visibility settings.
- A Wide Area Motion Imager (WAMI) (Redkite Block II Pod from Logostech) is integrated for broad-area surveillance and thorough movement analysis.

Search and Rescue:

- The UAV carries a Life Raft (R0101A102 from lifesupportintl), which can be deployed to aid survivors in maritime rescue scenarios.

4.3.4 Components available in the market

In our UAV development, we purposely relied on commercial-off-the-shelf (COTS) parts, widely available in the commercial market and through government contracts. This approach solves the issues caused by proprietary technology, security concerns, and geopolitical factors, which usually limit the availability of specific UAV components.

The decision to use COTS components is caused by the restricted use of certain technology in military-grade UAVs and security and geopolitical constraints. By implementing COTS, we can overcome these limitations and ensure the efficiency of our UAV development.

Furthermore, using COTS parts fits in with our resource optimization plan. Developing proprietary parts can be resource-intensive, so using market-ready alternatives saves resources and increases productivity. Also, using COTS parts ensures that our UAVs may be built and maintained with readily available components. The utilization of COTS components is a practical and effective strategy for dealing the challenging conditions of UAV technology acquisition under government contracts.

Here are some of the available COTS parts as shown in Table 4.6:

Subparts	Part Name	Brand
Automatic landing-takeoff system	Okis(Airborne Segment) Okis(Land Segmentt)	Meteksan
KA-band sattelite comm sensor	MPT 46WGX(antenna) MPT 46WGX(KPSU)	Orbit Orbit
C-band datalink	C-band datalink Auto tracking antenna system	Tualcom Tualcom
Autopilot (FCC)	Vector 600	UAV NAV
Mission control Computer (MCC)	Vector MCC	UAV NAV
Baykar IMU	Bas 201	Baykar
Gnss-ins (imu+gps)	CGI-610 Dual-Antenna GNSS-INS	CHCNAV
AIS (Automatic Identification System)	The RadarPluső SA161-MH Receiver	Shine Micro
Power Amplifier	TA1216	TRIAD system
Air Data Recorder	XLDR	L3Harris
SAR & ISAR	Eagle Eye (Electronic) Eagle Eye (Radar)	General Atomics
EO/IR/MTI	Wescam MX-15	L3Harris
Wide Area Motion Imagery	Redkite Block II Pod	Logos Technologies
Satcom (dish)	Starlink (Flat) High Performance	Starlink
Satcom (power supply)	Starlink Power Supply	Starlink
Satcom (Router)	Starlink Router	Starlink
Engine	Rotax 914 F (Full System)	Rotax
Power Distribution System	900W PDU	Vision Airtronics
Lithium battery	ABli-25	Baykar
Baykar Bomb Rack Unit		Baykar
SIGINT (Signal Intelligence System)	Common SIGINT System 1500	Northrop Grumman
Warfare systems	Anti Submarine Warfare systems pod	General Atomic
Electronic Jammer	Sledgehammer Pod	General Atomic
Life Raft	R0101A102	lifesupportintl

TABLE 4.6: Commercial Off-the-shelf parts

4.4 V-n Diagram

The V-n diagram, also known as the structural envelope, is a graphical representation that relates specific load factors to the airspeeds at which an aircraft is designed to operate. This diagram is typically created by the loads and structures group and serves two purposes. For starters, it defines the aircraft's operational boundaries while also supplying critical structural data. Second, it communicates crucial operating boundaries to pilots, facilitating their comprehension of the aircraft's performance characteristics. The V-n diagram shows key airspeed constraints, such as the maximum velocity with fully deflected control surfaces (VA), as well as the diving speed (VD), which is the maximum airspeed that should not be exceeded under any operational conditions. This diagram plays a vital role in ensuring both the structural integrity of the aircraft and the safety of flight operations.

Before constructing the V-n diagram, it is necessary to gather the specific parameters that will be used in its calculation. These parameters can be obtained from Mr. Ali, who has the required information. The following is a list of the parameters required to build the V-n diagram appropriately as shown in Table 4.7.

Parameters	Numbers
Gross weight	1550 kg
Wing area	14.05 m2
Air density	1.225 kg/m3
Max cl	1.58
Min cl	-0.265
Cl alpha	0.051
Stall speed	10 m/s
Mean geometric chord	0.932856 m
Cruising speed	36 m/s
Gust velocity	50 ft/s

TABLE 4.7: Parameters of UAV

Once we have the necessary information, we can calculate the V-n diagram The results of these computations in Table 4.8 will then be entered into an Excel file provided by Abbott Aerospace Sezc Ltd [15], making it easier to generate the diagram.

V-n diagram calculation result	
Positive load factor	+3.88
Negative load factor	-1.55
Cruising Speed (VC)	70 kts
Dive Speed (VD)	97.97 kts
Maneuvering Speed (VA)	38.33 kts
Negative Maneuvering Speed	334.06 kts
Positive Gust Load Factor	1.27
Negative Gust Load Factor	0.72

TABLE 4.8: $V - n$ Diagram Result

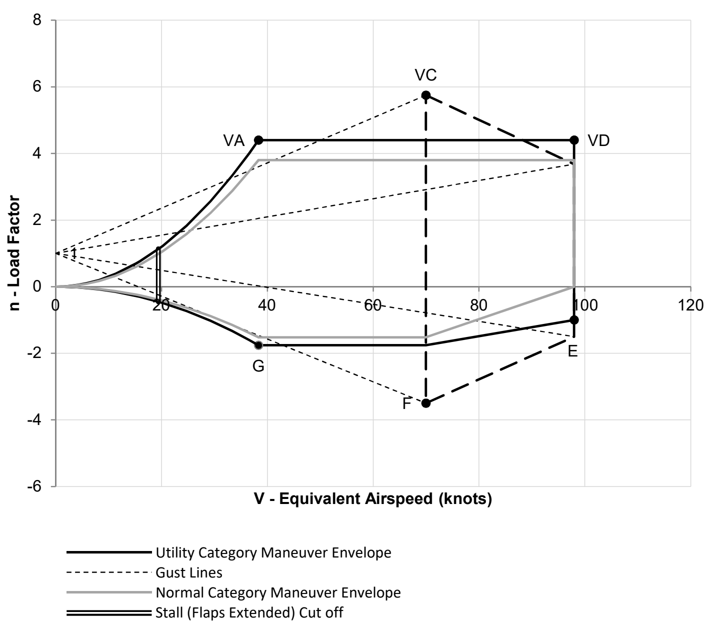

FIGURE 4.2: V-n Diagram

According to the analysis of the stated diagram in Figure 4.2, the aircraft has a positive load factor of roughly 3.88 and a negative load factor of around -1.55. But, Since n+ is greater than normal category maneuver envelope which is 3.80, we can set it to 3.80, which we will do. Given the corresponding adjustment of our positive load factor (n+), the change in our negative load factor (n-) follows automatically. Specifically, when n+ is modified, 0.4n- is automatically transformed to -1.52. Furthermore, the maneuvering speed (VA) is determined to be 38.3 Knots Equivalent Airspeed (KEAS), while the dive speed (VD) is calculated to be 98 KEAS. While VC is a cruising speed. For point G, F, and E is a speed limit on negative speed.f

4.5 Structure Design: Fuselage

Prioritizing avionics arrangement is crucial in the aircraft design process before finishing the fuselage design. This method makes the most effective use of the limited space within the fuselage. By organizing the avionics first, we may avoid potential space conflicts between the avionics equipment and the fuselage construction. If the avionics are handled after the fuselage frame has been developed, it may result in problems like insufficient room or the need for modifications to accommodate this equipment. As a result, this design cycle is crucial to ensure the integrity of both the avionics and fuselage.

Figure 4.3 shows the placement of all antennas in front of the aircraft. This decision is driven by the need to ensure unobstructed signal transmission, as putting the antennas elsewhere may cause signal interference from other components. Additionally, the Electro-Optical/Infrared (EO/IR) is clearly exposed in front of the aircraft. This positioning is not only beneficial to visual clarity, but it also serves another purpose. The EO/IR system operates as a camera, delivering visual feedback to the pilot via the Ground Control System. This front placement allows for a clear field of view, critical for efficient operation and navigation. The remaining components are located close to one another behind the antenna part. This layout is intended to maximize available space, resulting in an efficient and compact configuration within the aircraft's design limitations.

Once all avionic components have been installed, the next phase is to work with Mr. Ali to obtain data to design the aircraft's external shape. This essential step includes an in-depth sharing of specifications and design requirements to ensure alignment with the existing avionics arrangement. Once received, this

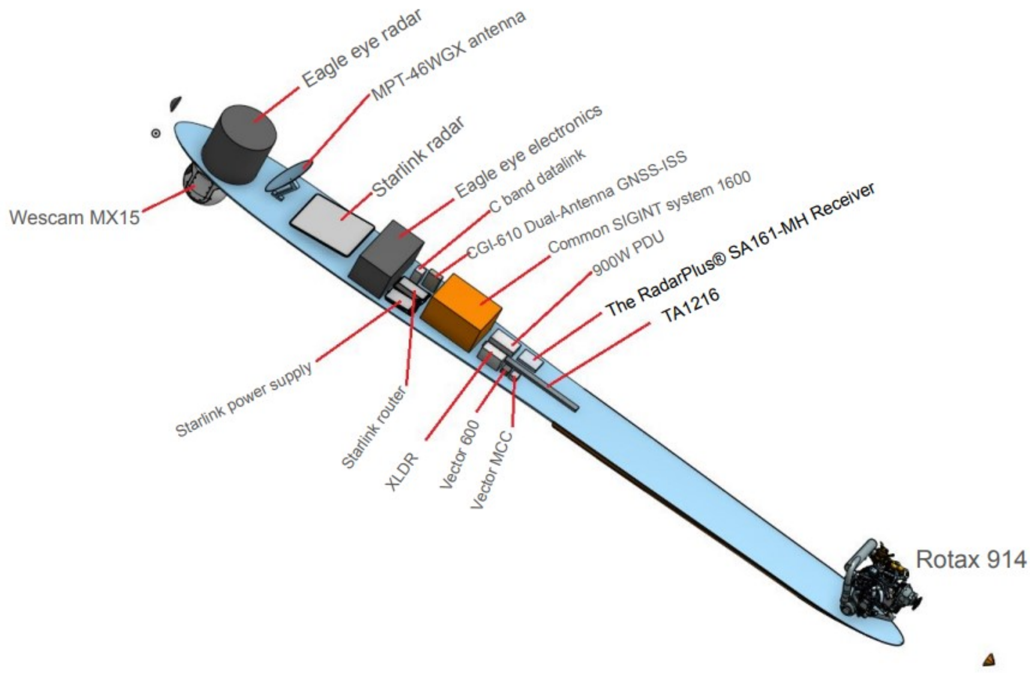

FIGURE 4.3: Avionics Layout Design

information will be transferred into Onshape, a CAD software, for further processing. This import represents the start of the design process, in which conceptual layouts and specifications are turned into detailed construction designs. This will ensures that avionic components fit together with the physical structure, allowing for a smoother design process.

Before beginning the sketching step, perform an initial sizing to determine the dimension of the frame. After receiving these results, the sketching process can begin, with each component methodically created based on the preliminary sizing Table 4.9 details the specific dimensions for our frame, which will be used as a basic reference during the design process.

Specification		
frame	Spacing	60.96 cm
	Depth	0.008 m
Light frame	Width	0.007 m
	Thickness	0.457 mm
	Depth	0.007 m
Heavy Frame (Nose Landing Gear)	Width	0.005 m
	Thickness	0.003 m
	Depth	0.012 m
Heavy Frame (Main Landing Gear)	Width	0.001 m
	Thickness	0.0015 m
	Depth	0.008 m
Heavy Frame (Tail)	Width	0.003 m
	Thickness	0.0005 m
	Thickness	1 mm
Stringer	Height	10 mm
	Flange	5 mm

TABLE 4.9: Specifications of the Frames

Figures 4.4 and 4.5 shows a two-dimensional layout of the frame and stringers. Figures 4.6 and 4.7giving a clear visual sense of their arrangement and design in 3D view.

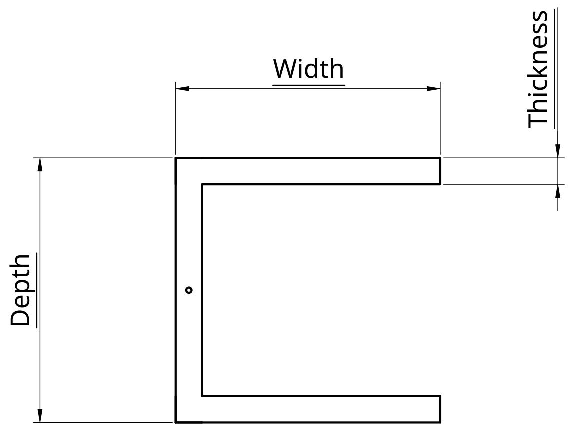

FIGURE 4.4: Frame Layout: 2D

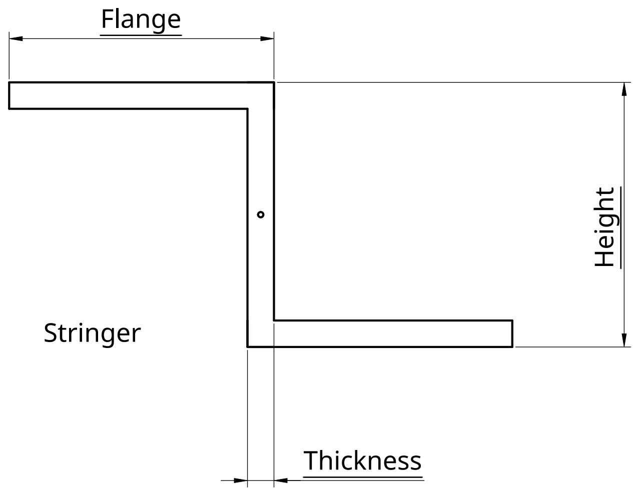

FIGURE 4.5: Stringer Layout: 2D

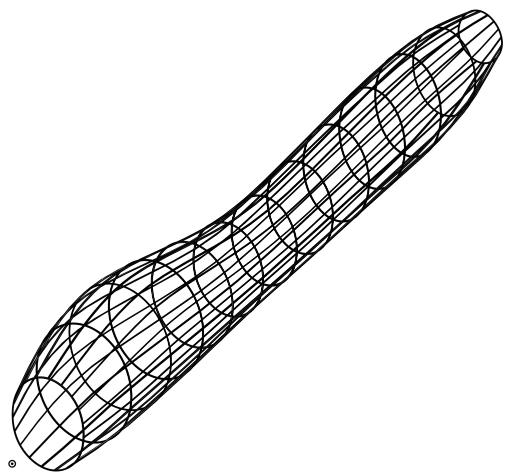

FIGURE 4.6: Fuselage Frame Design

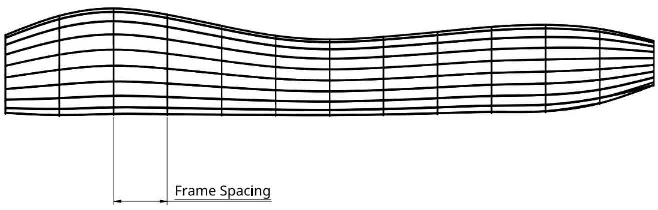

FIGURE 4.7: Frame Spacing

4.6 Structure Design: Wing

The next stage of the aircraft design process focuses on wing design, a critical component that requires careful preparation and execution. The first step is to obtain the wing shape design, which has been assigned to Mr. Ali, as his understanding of aerodynamics is crucial at this stage. After obtaining Mr. Ali's design, the next step is to import it into Onshape, a sophisticated CAD software for design and engineering work.

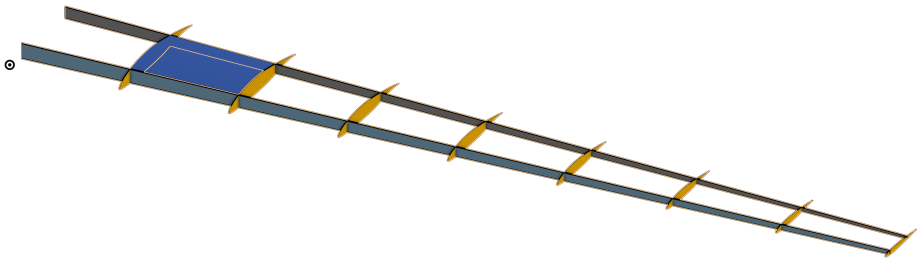

FIGURE 4.8: Wing Structure: Left

After successfully importing the wing shape, the method continues to intial size calculations. This stage is crucial since it defines the wing's structural dimensions, ensuring it meets performance and safety requirements.

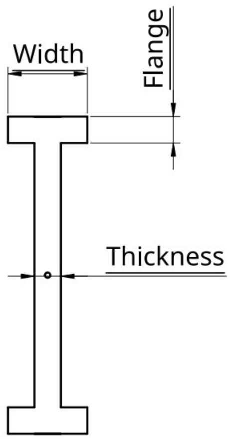

FIGURE 4.9: Spar

Once the intial sizing data has been obtained and verified, the focus will shift to sketching the wing structure in Onshape. This stage involves turning calculations and conceptual designs into structure designs. The fuel tank is positioned internally within the structural frame of the wing architecture by being directly integrated into the design framework. The table below provides a complete summary of all the intial sizes of the wing's construction, including the measurements required for the next stage of development.

For the spar shape, we apply the I-beam shape for the spar because it can withstand a wide range of loads. The usefulness of an I-beam in a structural context, such as an aircraft wing spar, can be explained using basic structural engineering equations. Let's look at one form of stress and the Equations 4.1 for bending moment that explain why the I-beam shape is advantageous:

$$\sigma = \frac{My}{I} \tag{4.1}$$

Where:

- σ= Bending stress
- M = Moment applied to the beam
- y = Distance from the neutral axis to the point where the stress is being calculated
- I = Moment of inertia of the beam's cross-section about the neutral axis

For the same amount of material, an I-beam has a much higher moment of inertia (I) than other shapes (such as a rectangular or circular section). This is because much of the material is spread distant from the neutral axis (in the flanges), increasing I and consequently reducing $\sigma$for the same bending moment (M). This makes I-beams extremely effective in resisting bending pressures[16].

Table 4.10 shows the specific dimensions of our wing structure, which will be used as a basic reference during the design process.

Component	Attribute	Specification
Root	Width	6 mm
	Flange	4 mm
	Thickness	1.8 mm
Tip	Width	4 mm
	Flange	3 mm
	Thickness	1.5 mm
Rib	Thickness	1.2 mm
	Number of Rib along span	16
Fuel Tank Location		15-25 percent half wing span
Fuel Tank Volume (Half)		86465.32 cc

TABLE 4.10: Wing Structure Specification

4.7 Structure Design: Tail

The final step of the aircraft design process focuses on the tail design, which is crucial to providing stability and control. The first step in this phase is collaborating with Mr. Ali to create the tail shape design. After acquiring the tail shape design, the next step is to do sizing calculations for the tail frame. Based on

Teddy's thesis [17], it is suggested that the dimensions of the tail frame structure are roughly half the size of the wing structure. This estimation provides a rough reference for sizing, but further improvements are made based on individual design requirements and constraints. After this step, we convert the data into a sketch. Theoretical sizing and shape designs are converted here into detailed sketches and models.

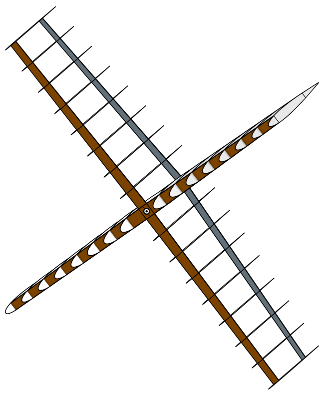

FIGURE 4.10: Tail Frame

Table 4.11 will be useful for reference during the design phase. It includes the primary dimensions and specifications derived from initial sizing estimations. This table serves as both a guide and a checkpoint to ensure that every part of the tail design matches the overall aircraft design objectives and Figure 4.10 give us an illustration of our tail assembly.

Specification		
Root	Width	3 mm
	Flange	2 mm
	Thickness	0.9 mm
Tip	Width	2 mm
	Flange	1.5 mm
	Thickness	0.75 mm
Rib	Thickness	0.6 mm
	Number of Rib along span	16

TABLE 4.11: Tail Frame Specification

4.8 Structure Assembly and Analysis

After finishing each of the individual design phases for the fuselage, wings, and tail, the project proceeds to a final stage: the assembling of these basic sections into a united frame. This phase represents the end of design and engineering work, transforming isolated components into an integrated airplane structure.

The description is supported by a full sketch of the structure's final assembly. Figures 4.11,4.12,4.13,4.14,4.15, and 4.16 illustrates how each of the parts fit together, showing the overall layout of the airplane in top view, left view, and front view. It provides a full perspective of the assembled structure. This drawing is more than just a blueprint for assembly; it is also an important tool for picturing the long-term conclusion to the aircraft design for the next phase of designing and building this UAV.

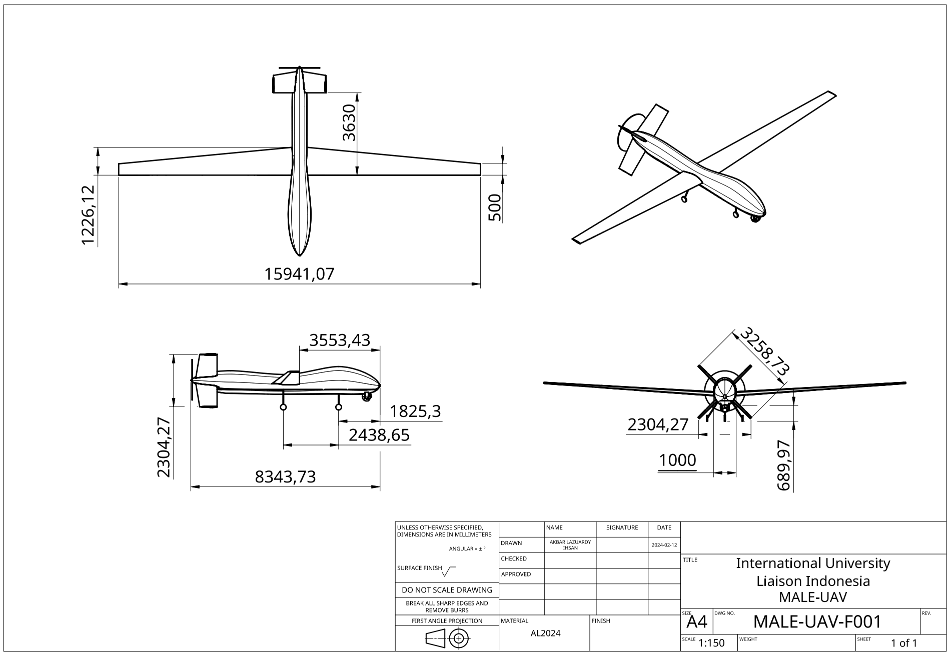

FIGURE 4.11: 3D View Drawing of the frame

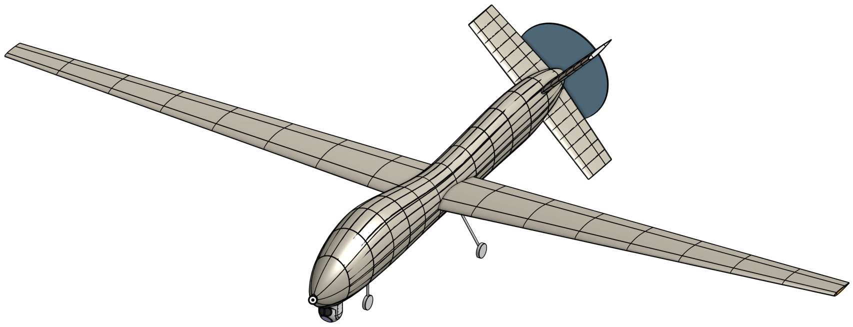

FIGURE 4.12: Full Assembly

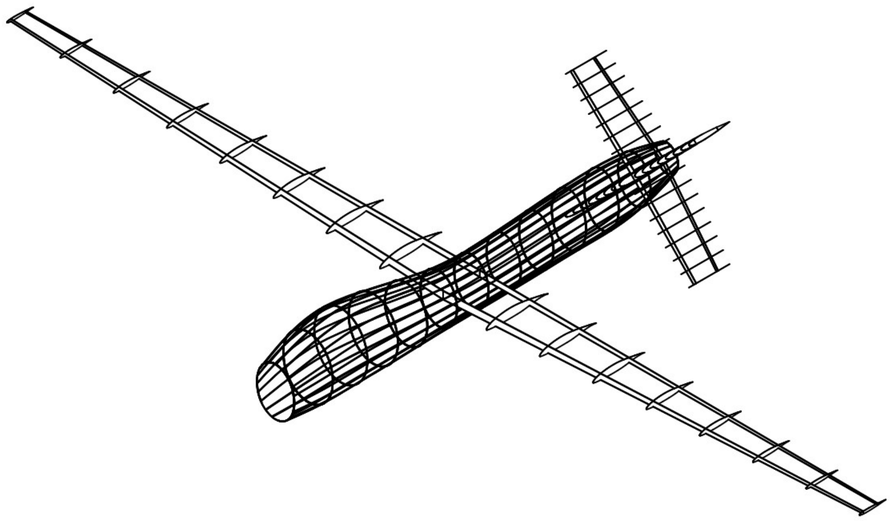

FIGURE 4.13: Structure: ISO View

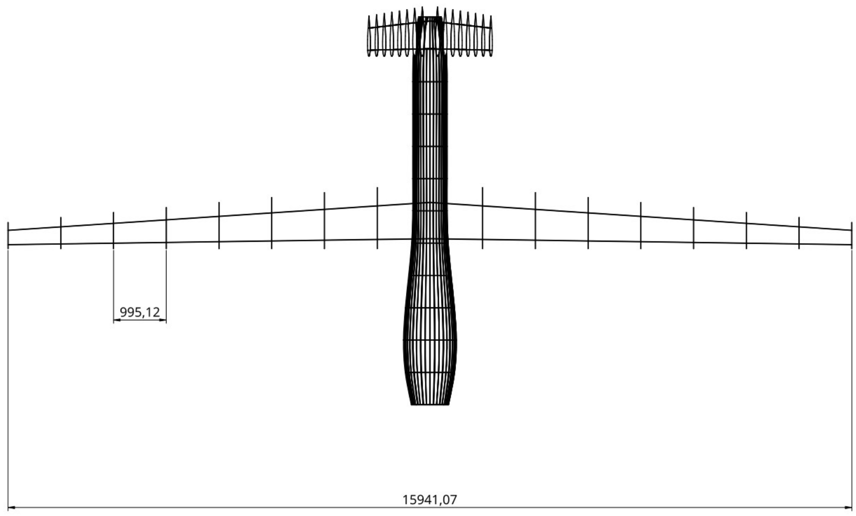

FIGURE 4.14: Structure: Top View

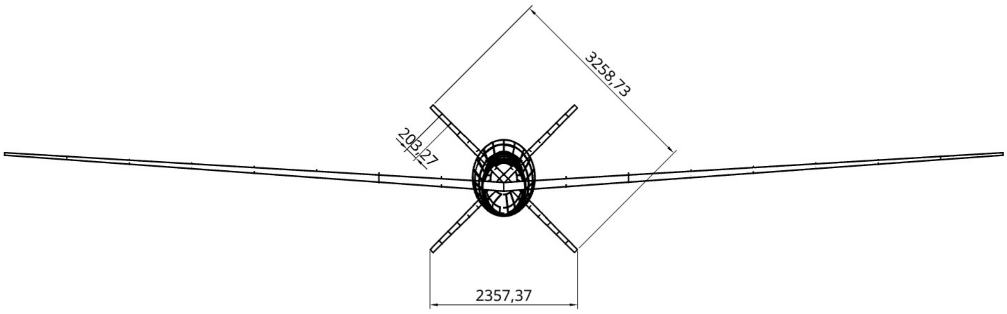

FIGURE 4.15: Structure: Front View

This section contains a complete table in Table 4.12 that summarizes the last stages of the aircraft structure design process. This table is an important reference since it combines the major characteristics of the aircraft's architecture: structural component sizing, construction materials, and overall mass. This table is a crucial instrument for analyzing the aircraft's design, providing a reference point for present assessments and future improvements.

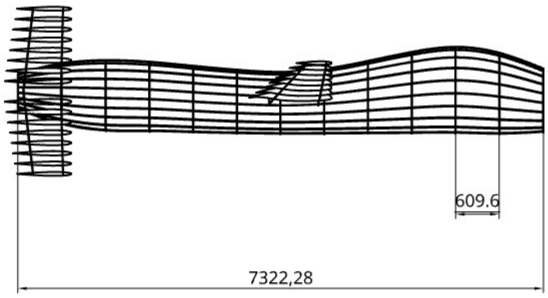

FIGURE 4.16: Structure: Side View

Following successfully constructing the airplane's structural components, the next phase involves utilizing Onshape's capabilities to assign certain materials to different aircraft parts. In this scenario, the airplane's material is AL2024, which was chosen due to its desirable features such as high strength and lightweight, both of which are required for aircraft construction. The reason why we are selecting AL2024 is that the lower strength of aluminum alloy 2024 has greater strength retention at extreme temperatures than 7075 alloys, which is why it has been explored in supersonic high-speed military aircraft applications [18].This stage is crucial because it affects not only the aircraft's structural integrity and performance qualities, but also its total mass and balance. Here is the Table 4.13 specification of AL2024 [19] from MatWeb:

Following the assignment of materials, the next critical step is to input the weight of each airplane component. This detailed weight analysis is crucial for evaluating the aircraft's overall performance, stability, and efficiency. Additionally, the estimated fuel weight of 350 kg is included into the analysis

The final phase of our analysis involved determining the center of gravity (CG) for both the Maximum Take-Off Weight (MTOW) and the Maximum Zero Fuel Weight (MZFW) configurations across all basic and maximum weight mission profiles of the aircraft. This analysis was carried out using Onshape for the detailed weight analysis, with the position of the center of gravity being determined from the aircraft's nose. Figure 4.17, 4.18, 4.19, 4.20, and Table 4.14 contain all the data of CG position.

According to the Table 4.14, the asymmetry along the X-axis in the CG location is due to uneven weight distribution caused by the placement of avionics in both the fuselage and the wings. Despite efforts to fairly distribute the avionics, the different weights of individual components lead to the apparent asymmetry in CG placement.

Table 4.15 and 4.16 contains all of the aircraft's mass data. This contains the total mass of the aircraft. Analyzing this data provides an in-depth understanding of the weight distribution through the aircraft, which is crucial to ensuring optimal balance and flight dynamics. Furthermore, this study helps identify places where weight savings can be made without compromising structural integrity or performance, contributing to the development of lightweight, aircraft design.

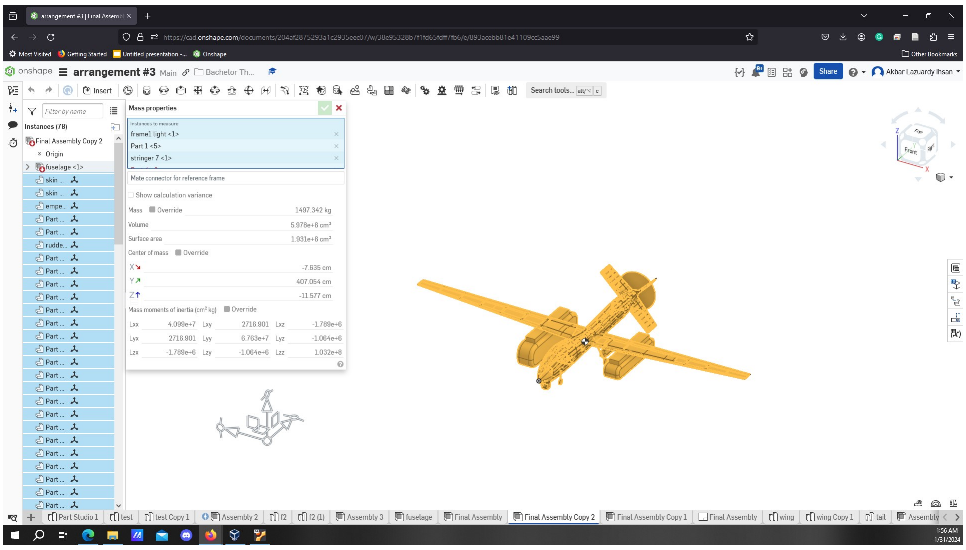

FIGURE 4.17: CG Location (MTOW) Heaviest Mission

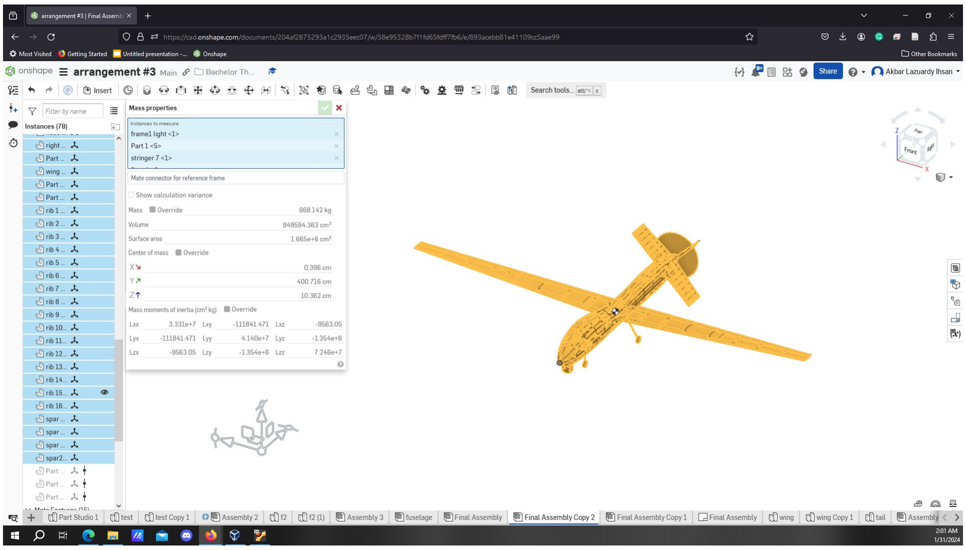

FIGURE 4.18: CG Location (MTOW) Basic Mission

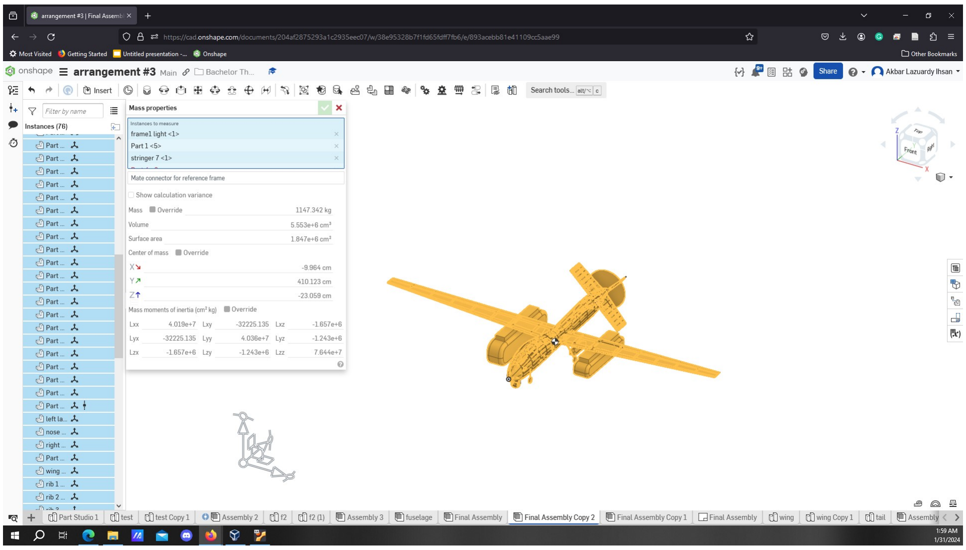

FIGURE 4.19: CG Location (MZFW) Heaviest Mission

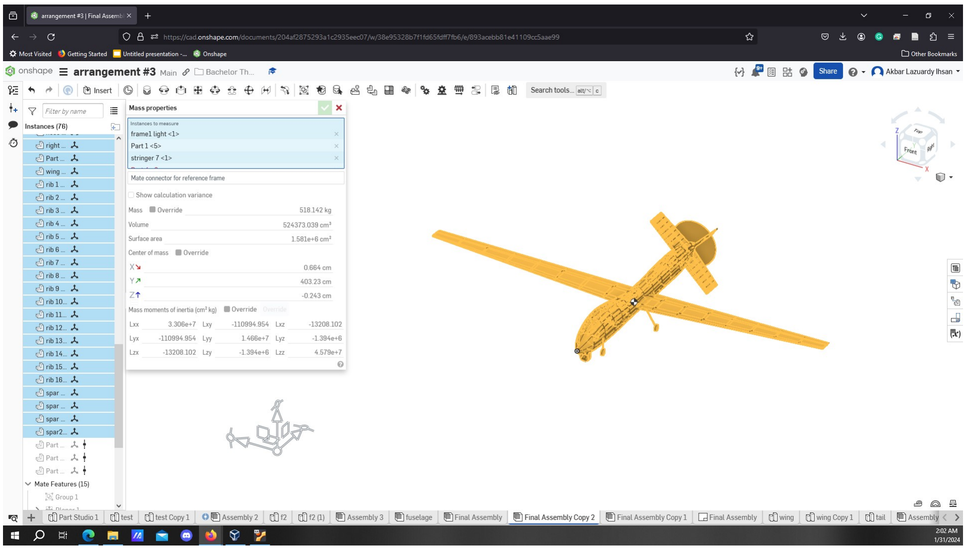

FIGURE 4.20: CG Location (MZFW) Basic Mission

Fuselage		
	Material	AL2024
	Skin Thickness	1 mm
	Frame Spacing	60.96 cm
	Frame Length	7.322 m
Light Frame	Depth	0.008 m
	Width	0.007 m
	Thicknesss	0.457 mm
Heavy Frame (nlg)	Depth	0.007 m
	Width	0.005 m
	Thicknesss	0.003 m
Heavy Frame (mlg)	Depth	0.012 m
	Width	0.01 m
	Thicknesss	0.0015 m
Heavy Frame (Tail)	Depth	0.008 m
	Width	0.003 m
	Thicknesss	0.0005 m
Stringer	Thicknesss	1 mm
	Height	10 mm
	Flange	5 mm
wing		
	Frame Length	15.9m
	Skin Thickness	0.8 mm
Root	Width	6 mm
	Flange	4 mm
	Thickness	1.8 mm
Tip	Width	4 mm
	Flange	3 mm
	Thickness	1.5 mm
Rib	Thickness	1.2 mm
	Number of Rib	16
	Spacing	0.995 m
Tail		
	Width	2.35 m
	Frame Length	3.25 m
	Skin Thickness	0.8 mm
Root	Width	3 mm
	Flange	2 mm
	Thickness	0.9 mm
Tip	Width	2 mm
	Flange	1.5 mm
	Thickness	0.75 mm
Rib	Thickness	0.6 mm
	Number of Rib	16
	Spacing	0.2 m

TABLE 4.12: Sizing Summary

Property		Value	
Young's modulus	E	73000.0	Mpa
Poisson ratio	v	0.3	
Shear modulus	G	27443.6	Mpa
Bulk modulus	K	71568.6	Mpa
Tensile yield stress		324.0	Mpa
Shear yield stress		187.1	Mpa
Density		2780.0	kg/m^3

TABLE 4.13: AL2024 Specification

Location of C.G. from nose (MTOW) heaviest mission	
x	-7.635 cm
y	407.054 cm
z	-11.577 cm
Location of C.G. from nose (MTOW) basic mission	
x	0.396 cm
y	400.716 cm
z	10.362 cm
Location of C.G. from nose (MZFW) heaviest mission	
x	-9.964 cm
y	410.123 cm
z	-23.059 cm
Location of C.G. from nose (MZFW) basic mission	
x	0.664 cm
y	403.23 cm
z	-0.243 cm

TABLE 4.14: CG Position From Nose

Section	Mass (kg)
Fuselage Frame	1.187
Fuselage Stringer	6.699
Wing Spar	14.211
Wing Rib	3.413
Empenage Spar	2.322
Empenage Rib	1.886
Fuselage Skin	65.982
Wing Skin	59.269
Empennage Skin	41.678
Fuselage Only	73.868
Wing Only	76.893
Empennage Only	45.886
Total Frame	196.647
Fuel	350
Total Aircraft Frame	448.542
Total Aircraft (Heaviest Mission)	1497.342
Total Aircraft (Heaviest Mission) MZFW	1147.342
Total Aircraft (Basic/Without Payload)	868.142
Total Aircraft (Basic/Without Payload) MZFW	518.142

TABLE 4.15: Aircraft Component's Masses

Avionics	Name	Mass (Kg)
Automatic landing-takeoff system	Okis(Airborne Segment)	2.5
KA-band sattelite comm sensor	MPT 46WGX(antenna)	14.25
	MPT 46WGX(KPSU)	5
C-band datalink	C-band datalink	0.87
Autopilot (FCC)	Vector 600	0.18
Mission control Computer (MCC)	Vector MCC	0.16
Baykar IMU	Bas 201	0.255
Gnss-ins (imu+gps)	CGI-610 Dual-Antenna GNSS-INS	1.15
AIS (Automatic Identification System)	The RadarPluső SA161-MH Receiver	0.567
Power Amplifier	TA1216	0.65
Air Data Recorder	XLDR	2.27
SAR and ISAR	Eagle Eye (Electronic) Eagle Eye (Radar)	62
EO/IR/MTI	Wescam MX-15	45.5
Wide Area Motion Imagery	Redkite Block II Pod	17
Satcom (dish)	Starlink (Flat) High Performance	5.9
Satcom (power supply)	Starlink Power Supply	1.5
Satcom (Router)	Starlink Router	1
Engine	Rotax 914 F (Full System)	76
Power Distribution System	900W PDU	1.344
Lithium battery	ABli-25	4.3
Propeller	ap420ctf-snr70e	19.6
Baykar Bomb Rack Unit		1
SIGINT (Signal Intelligence System)	Common SIGINT System 1500	38.5554
Warfare systems	Anti Submarine Warfare systems pod	340
Electronic Jammer	Sledgehammer Pod	272.2
Life Raft	R0101A102	16.3293
Sum Weight Combat=		1155.8584
Sum Weight Basic Mission =		202.6584
Sum Weight Search and Rescue=		267.9756

TABLE 4.16: Aircraft Avionic's Masses

CHAPTER 5
SUMMARY, CONCLUSION, RECOMMENDATION

5.1 Summary and Conclusion

5.1.1 Summary

This study building a Medium Altitude Long Endurance (MALE) Unmanned Aerial Vehicle (UAV), focusing on benchmarking, mission profiling, avionics component selection, structure design, and assembly. The procedure started with benchmark research, which evaluated 22 UAVs in the industry and chose the Hermes Starliner and MQ-1 Predator as reference models. This decision was crucial in influencing the UAV's design, especially in terms of performance and compliance with international standards like STANAG 4671.

The UAV's mission profile was developed to meet various applications, including intelligence, surveillance, and reconnaissance (ISR), combat, and search and rescue (SAR) operations. This flexibility was further enhanced by using a modular avionics system, which allows for quick modification to changing mission needs.

Regarding structural design, the project successfully handled the issues of developing and integrating the fuselage, wings, and tail. The design used Onshape software to incorporate the AL2024 material. The outcome of the weight analysis was crucial in obtaining optimal balance and flight dynamics.

The finished product of the V-n diagram provided essential details about the aircraft's operating and structural constraints. In contrast, an in-depth analysis of each structural component confirmed that the aircraft met the appropriate safety and performance criteria.

5.1.2 Conclusion

In this study, a conceptual design of flexible-mission medium-altitude-long-endurance (MALE) UAV was done. Point of conclusion are made as follow:

- From the benchmark study including the Commercial Off-The-Shelf (COTS) research, the avionics system are classified into basic and specific-mission components, such as ISR, combat, and SAR missions.
- The positive and negative load factors for normal manuever in this design are +3.88 and -1.5, respectively. Thus, 1.5 times of those values are used as the limit load factors to determine the size of structural components.
- The maximum take off mass (MTOM) for the heaviest mission is $\approx$ 1497 kg using mainly aluminum-based configuration.
- From the CAD model, two major configuration are constructed, i.e. MALE for basic and SAR missions in which the c.g location is not varied significantly.

5.2 Recommendation

The research on the Medium Altitude Long Endurance (MALE) Unmanned Aerial Vehicle (UAV) provides several key areas for future recommendation:

- Exploring the design with composite material to reduce aircraft weight and increase the endurance.
- Conduct finite element analysis on critical aircraft components to ensure structural integrity under static load specified by limit load factor.
- Further stress analysis under the dynamics load on critical structural components.
- Propose the installation of a pylon as an intermediary component connecting the payload and wing structure.

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Appendices

Appendix A: Mathematical Derivations

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Curriculum Vitae

	Basic Information
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Year	Education
2019 - present	International University Liaison Indonesia (IULI)
2016 - 2019	SMK Penerbangan Banjarbaru
2013 - 2016	Mts Muhammadiyah 3 Al Furqon Banjarmasin
2011 - 2013	SDIT Baitussalam Yogyakarta
2007 - 2011	MDIM Sei Kindaung Banjarmasin
Year	Courses
2018	Safety Management System (Sekolah Tinggi Penerbangan Indonesia)
Year	Seminars & Workshops
2022	Basic Aircraft Maintenance (UNSURYA)
Year	Work Experiences
2017	Mechanic (Intern) at PT. Merpati Maintenance Facility