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ANALYTICAL HIERARCHY PROCESS APPROACH FOR BASIC COMPONENT AND SYSTEM INTEGRATION IN TACTICAL SURVEILLANCE UNMANNED AERIAL VEHICLES

(*Pendekatan Proses Hierarki Analitik untuk Integrasi Komponen Asas dan Sistem dalam Kenderaan Udara Tanpa Pengendali (UAV) Peninjauan Taktikal*)

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ABSTRACT

The purpose of the article is to analyze Unmanned Aerial Vehicle component weight, its impact on takeoff weight, and system development. Data was gathered through case studies, interviews, document reviews, and field observations at Company XYZ, supplemented by secondary sources. The Analytical Hierarchy Process (AHP) and Quality Function Deployment (QFD) guided component selection. UAV weight was reduced from 150kg to 120kg. The RONCZ1046 aerofoil was chosen for its aerodynamics, structural integrity, and manufacturability. Engine LMN was selected for its power, efficiency, and reliability. Flight tests and maintenance assessments validated UAV integration and performance. This research provides an insight into UAV weight optimization, design consideration and engine selection, supporting future advancements in UAV development.

Keywords: Unmanned Aerial Vehicles (UAVs); Analytical Hierarchy Process (AHP); Quality Function Deployment (QFD); aerofoil selection; engine integration

ABSTRAK

Tujuan artikel ini adalah untuk menganalisis berat komponen UAV, kesannya terhadap berat berlepas, dan pembangunan sistem. Data dikumpulkan melalui kajian kes, temu bual, semakan dokumen, dan pemerhatian lapangan di Syarikat XYZ, serta sumber sekunder. Proses Hierarki Analitik (AHP) dan Penempatan Fungsi Kualiti (QFD) digunakan untuk pemilihan komponen. Berat UAV dikurangkan daripada 150kg kepada 120kg. Aerofoil RONCZ1046 dipilih kerana kelebihan aerodinamik, keutuhan struktur, dan kebolehbuatannya. Enjin LMN dipilih berdasarkan kuasa, kecekapan, dan kebolehpercayaannya. Ujian penerbangan dan penilaian penyelenggaraan mengesahkan integrasi serta prestasi UAV. Kajian ini menyediakan penanda aras bagi pengoptimuman berat, reka bentuk, dan pemilihan enjin UAV, menyokong kemajuan masa depan dalam pembangunan UAV.

Kata kunci: Kenderaan Udara Tanpa Pemandu (UAV); Proses Hierarki Analitik (AHP); Penempatan Fungsi Kualiti (QFD); pemilihan aerofoil; integrasi enjin

1. Introduction

Unmanned Aerial Vehicles (UAVs) are aircraft that operate without a human pilot or direct intervention (Hentati & Fourati 2020). UAVs have gained global popularity and are widely utilized across various sectors beyond the military, including agriculture and the arts. Historically, UAVs were first deployed in 1849 as combat weapons, equipped with bombs for military use. Over time, UAV technology advanced significantly, particularly in military applications such as surveillance. By the late 20th century, UAVs had become a critical asset in defense operations. Their rapid development has enabled last-mile delivery solutions while maintaining environmental sustainability. UAVs offer key advantages, including fast and easy deployment, scalability, economic efficiency, autonomous operation, and exceptional maneuverability. They also vary in design, material composition, size, weight, range, and payload capacity, carrying essential equipment such as communication devices, navigational aids, sensors, and cameras. Categorization of UAVs is often based on factors such as configuration, engine type, weight distribution, and operational domain.

Despite the increasing adoption of UAVs across multiple industries, military tactical surveillance UAVs still face challenges in meeting operational criteria, particularly in tropical climates. The harsh environmental conditions, including high temperatures, strong winds, and high humidity, can impact their aerodynamic performance, structural integrity, and overall effectiveness. A critical gap exists in optimizing UAV design for such environments, particularly in analyzing takeoff weight, aerofoil selection, and propulsion system efficiency. To address these challenges, this study aims to examine the impact of UAV component weight on takeoff performance, investigate the optimal wing, tail, and fuselage configurations, and explore UAV system development using the Analytical Hierarchy Process (AHP) and Quality Function Deployment (QFD). These insights will contribute to improved UAV design and integration, enhancing their performance and reliability in military tactical surveillance missions.

As an outline, the next subtopics will be covered as follows. The literature review explores UAV applications, key components, weight considerations, and design phases. The research methodology details data collection through case studies, interviews, and field observations, utilizing AHP and QFD for selection. The results and discussion focus on weight reduction, aerofoil and engine selection, and design improvements. Finally, the Conclusion summarizes key findings, highlights contributions, and suggests future research directions.

2. Literature Review

Unmanned aerial vehicles (UAVs) are becoming ubiquitous in today's globe. UAVs, which were once only a common military weapon, have since been used for a wide range of other purposes, from helping with search and rescue operations to shooting amazing aerial photos. Given the variety of uses for UAVs nowadays, a more thorough investigation of the fundamental UAVs development is required.

2.1. *Unmanned Aerial Vehicle*

UAVs are essential parts of unmanned aircraft systems (UAS). In addition to the UAVs itself, these systems also include a ground controller and a communication system that connects the two. UAVs are basically airplanes without a human pilot on board, with the ability to operate either remotely with a human operator or autonomously using computers on board. Different levels of autonomy enable UAVs to carry out tasks with differing levels of human assistance (Kale 2021) as required for any logistic function (Ab Rahman *et al.* 2016). For Azar *et al.* (2021), UAVs are becoming essential in many domains for both military and civilian purposes. They are particularly skilled at environmental sensing, traffic monitoring, infrastructure inspection and search and rescue missions. UAVs with cutting edge sensors improve emergency response times, contribute to conservation initiatives and offer thorough evaluations of remote locations. They perform exceptionally well in intelligence, surveillance, target acquisition and reconnaissance (ISTAR) missions in the military, providing situational awareness and real time intelligence without endangering lives.

2.2. *UAVs classification*

According to the study by Al-Zahrani (2023), UAVs are divided into two groups which are civil and military UAVs. Moreover, with respect to the UAVs' aerodynamic techniques, it can be classified into fixed wing UAVs, flapping wing UAVs and rotary wing UAVs. Additionally, for energy source and propulsion system, UAVs can be divided into two groups which are combustion engine-based propulsion system and electrical motors-based propulsion systems while for navigation and control, they can be classified into remotely controlled UAVs or autonomous UAVs.

2.3. *UAVs application in military*

A considerable amount of literature has been published on the application of UAVs in military. The study by Adnan and Khamis (2022) explains UAVs that are now mostly used by the military in the modern world. Furthermore, Adnan and Khamis (2022) has highlighted that in military, UAVs use for satellite communication and military surveillance has resulted in an improvised solution to the previous limitation on limited wide beam coverage. The latest satellites have numerous high-power coverage areas, each of which can extend to a certain area. UAVs equipped with GPS can be used for remote control and training in particular areas. The study claims that gathering intelligence and conducting surveillance are the main uses of military UAVs. In the meanwhile, military units deploy planes like the Global Hawk and the more recent Ultra LEAP—which has flown 18,000 combat hours for vital surveillance missions. In addition, from another study, it can be said that a control unit zone regulates the UAVs system, and a database will keep the data. IoT alone is monitoring and controlling a high-altitude geographical region from a faraway point. Every UAVs has an integrated radar application, making this system even more special. A rhombus or diamond structure is used to build a network specifically for surveillance (Utsav *et al.* 2021). Further research on UAV applications in the military has revealed their potential use as mine detectors. In military detection operations, limited prior knowledge of target areas often results in prolonged work periods, leading to fatigue among personnel. This exhaustion can hinder their ability to accurately identify landmines, increasing the risk of danger. To address this challenge, ongoing research explores the integration of advanced sensors in UAVs for landmine detection, enhancing efficiency and safety. One significant advantage of UAVs in this role is their ability to rapidly and cost-effectively survey large areas, reducing both operational time and risk (Yoo *et al.* 2021).

2.4. *Military UAVs in Tropical Climate Country*

According to the study by Gao *et al.* (2021), in contemporary military operations, unmanned aerial vehicles are essential, yet their performance is greatly influenced by the surrounding environment. UAVs' performance can be greatly impacted by the unexpected weather patterns they encounter in real-world deployments, as opposed to controlled settings. These difficulties are even worse in tropical regions, which frequently face high temperatures, powerful winds, copious amounts of precipitation, and excessive humidity. Airframe integrity, aerodynamics, control systems, and UAV endurance can all be weakened by such circumstances. In addition, bad weather can interfere with airspace monitoring, impair line-of-sight visibility, and interfere with onboard sensors that oversee navigation and collision avoidance. Mission success is seriously jeopardized by these constraints, especially in military missions with tight deadlines where accuracy and dependability are essential.

2.5. *Weight as UAVs important parameter*

UAVs research has benefited greatly from the use of software components, including the uploading of cameras, sensors, actuators, and electric motors. Therefore, when it comes to hardware or mechanical components, the use of lightweight materials and few structural parts is prioritized (Yoo *et al.* 2021). An explanation on why weight is an important parameter in UAVs was given by Kale (2021). Any plane must have more lift and push than weight to take off. The lift is produced by the aircraft's rotor. If you put a lot of loads on the rotor structure, it probably will not be able to steer the aircraft. The push produced by the power plant outweighs the drag control. In a multirotor, this basically happens on each unique engine or propellor structure. The results will continue to retain the flight performance if there is excessive bulk. A lighter structure allows for faster execution and flying time. Stewart *et al.* (2021) added that in surveillance and search missions, Line of Sight communication systems and electro-optical/infrared sensors are usually carried as payloads. UAVs rescue missions can also carry regular payloads such as weapon systems for military operations, first aid supplies, and commercial items for transportation. Hence, each of the payloads used needs to be analyzed as it contributes to the UAVs total weight.

2.6. *Design phase of an aircraft*

El Adawy *et al.* (2023) suggested the three stages of the design process were reportedly conceptual design, preliminary design, and detailed design. To give a clear design route with a credible assessment of likely performance, possible looks, market ability, estimated cost, and a clear picture of whether to move forward to the preliminary design phase or not, the conceptual design phase provides the early design concepts. The potential problems and a potential fix are made clear at the preliminary design stage. The transformation of the final design from the preliminary phase into a physical design that can be constructed and flown is part of the detailed design phase.

2.7. *Components in UAVs system*

UAVs parts include an engine, drive, propeller, emitting antenna, modem antenna, global positioning system antenna, magnetometer, status light emitting diode, Bluetooth transmitter, two digital and power buses, central processing unit, inertial measurement unit, accelerometers, three barometers, three gyroscopes, black box, battery holder, pilot chamber, first person view transmitter, nameplate, and video antenna. The primary parts utilized in the development of UAVs are the frame, brushless direct current motors, propellers, electronic speed controller, LiPo battery, transmitter, receiver, and flight controller, according to Ajay *et al.* (2022).

2.8. *Engine*

According to Çoban and Oktay (2018), UAVs used a variety of engines according to its size. The electric engines are used in light and small models while piston engines are used in heavy and large models of UAVs. These two types of engines are the most preferred and widely used in the development of UAVs. In addition, the use of UAVs engines depends on the country's own classification. In determining the type of engines to be used in a UAVs, the areas that can be considered are power extraction or requirements to operate the UAVs, high altitude effects to allow it operate at high altitude while considering the engine design and performance, potential long term storage requirements to store anything needed in combat and performance life cost tradeoff as the possibility that the desired life span of UAVs can be shorter (Nelson & Dix 2023).

Through the research conducted by Cwojdziński and Adamski (2014), some of the engines used in UAVs are piston engines such as two stroke engines or four strokes engine. While four stroke engines can be classified as rotary engines, Wankel engines, electric diesel hybrid, six stroke engines and disk engines. In addition, there are electric engines and jet engines such as rocket engines, jet engines with compressors and turboprop engines. Weight, size and aerodynamic requirements were some of the factors taken into consideration because engine choice was dependant on the UAV design and operational conditions. Smaller engines were necessary to maintain performance and fuel efficiency in a smaller, lighter UAV. Furthermore, the engine's power output ought to be consistent with the aerodynamic design. A more potent engine with a higher thrust to weight ratio might be prioritized because this kind of UAV is made for efficient missions. Altitude, temperature, endurance, range and performance requirements were among the parameters for the operating conditions. The UAV may require an engine that can function efficiently in a variety of situations and at high altitudes because it was design for surveillance purposes in a tropical nation. To support a long-distance flight and mission, an engine that can provide increase fuel efficiency and dependability over lengthy periods of time may be required.

2.9. *Flight test*

Based on the research and experiment conducted by Kim *et al.* (2023), it is suggested that a multi-degree of freedom flight test framework based on the robot operating system (ROS) for the safe development, validation, and verification of UAVs to meet this design and operational requirements. A test bench with four degrees of freedom is part of the developed flight test system, along with an electronic control unit (ECU) for data collection from sensors and operation software execution, a power supply unit (PSU) for device powering, an operation software toolset developed in ROS for smooth software and hardware integration, and a wind tunnel to simulate the flight environment. Experimental tests on foldable UAVs under development that is powered by rockets were used to confirm the accuracy of the flight test framework. Based on the entire experiment, they were able to verify that the target UAV's flight data and the sensor data from the flight test system were shown via the ROS message bus. Furthermore, it was verified that the controller functions and that the target UAVs received the control command input from the GUI console during the flight test via the flight test system. They concluded that the UAVs can be safely held in their flight test system.

According to Dai *et al.* (2021) to verify the safety of a UAVs autopilot system, continuous outdoor flight tests are required during the whole development stage, but traditional test methods are usually too expensive and inefficient to cover all normal and failure cases. As a result, more efficient real time simulation and test methods for autopilot systems of UAVs are urgently needed for the ever-increasing system complexity as well as high safety requirements in complex environments.

An indoor test bench is designed to evaluate the quadcopter's dynamics and aerodynamics. The quadcopter is fixed to a rigid stick through the center of mass with smooth bearings to reduce friction. Because the quadcopter can rotate freely along a single axis, tests for uniform rotation to determine roll damping coefficient and sweep-frequency testing to identify the system may be carried out. The outdoor flight test scenario where system identification methods are used to measure or obtain the body aerodynamic parameters and overall performance of multi-copter aircraft.

3. Research Methodology

This study mainly focused on the development of the military tactical surveillance UAVs by Company XYZ. Primary data were those that were gathered specifically for the study subject at hand, utilizing methods that were most appropriate for the problem. Every time primary data was gathered, new information was contributed to the body of social knowledge already in existence. This included case study, semi structured interview, field observation, focus group discussion and selection method namely analytical hierarchy process and quality function deployment. Moreover, additional data such as documents, reports and guidelines for UAV can be obtained from official data repository in Company XYZ. This also included document reviews, journal or articles and books. Selection method that was used in this study were AHP and QFD. All the criteria that were needed to fulfil the requirements usage of the methods were determined by experts and professional workers that specialized in UAVs. A list of important parameters was determined in a focus group discussion (as Tukimin *et al.* 2022).

3.1. *AHP*

The method began by structuring the study's problems and objectives into a hierarchical framework, as illustrated in Figure 1. The Analytical Hierarchy Process (AHP) was applied to determine the optimal aerofoil selection, aligning with both design and system requirements. The propulsion system, specifically the engine selection, was identified as the fundamental component for UAV operation. The three-level AHP approach was structured as follows: the primary goal was to select the most suitable aerofoil, evaluated based on aerodynamic performance, structural integrity, payload capacity, environmental considerations, and manufacturability. The alternatives assessed were RONCZ1046, SD7062, and NACA0012. According to Bakhai and Rifat (2023), RONCZ1046 was generally preferred for its low drag performance at moderate angles of attack. This made it ideal for small UAV that needed efficient cruise. Additionally, it was also suitable for customized and high-performance design UAV. Traub (2013) found that SD7062 was perfect for electric UAV and gliders with fixed wing which had a relatively low airspeed. SD7062 was slightly more complex than other aerofoil to manufacture. Meanwhile, Jacobs and Abbot (1933) stated that NACA0012 was useful for control surfaces, aerobatics or any other application that needed equal performance in inverted flight as it possessed a baseline symmetrical airfoil. In addition, RONCZ1046 was efficient for long endurance UAV.

Similarly, for engine selection, the evaluation criteria included performance, efficiency, reliability, and cost, with Engine PQR, Engine LMN, and Engine XYZ considered as alternatives, as shown in Figure 2. Engine PQR was a four-stroke aviation piston engine of 50-100 horsepower that weighed 45 to 60kg. It was mainly used for medium to long range UAV and has a high endurance of more than 15 hours. Engine LMN was a two stroke and four stroke aviation piston engine that weighed 28 to 50kg with a power output of 25 to 80hp of power output. This type of engine was proven in small UAV, target drones and surveillance UAV. This type of engine cost the lowest among the three engines. Engine ABC was a four stroke horizontally opposed piston engine that provided power output of 65 to 100hp and weighed 60 to 65kg. It was reliable and widely used in UAV which made it cost higher than other type of engine.

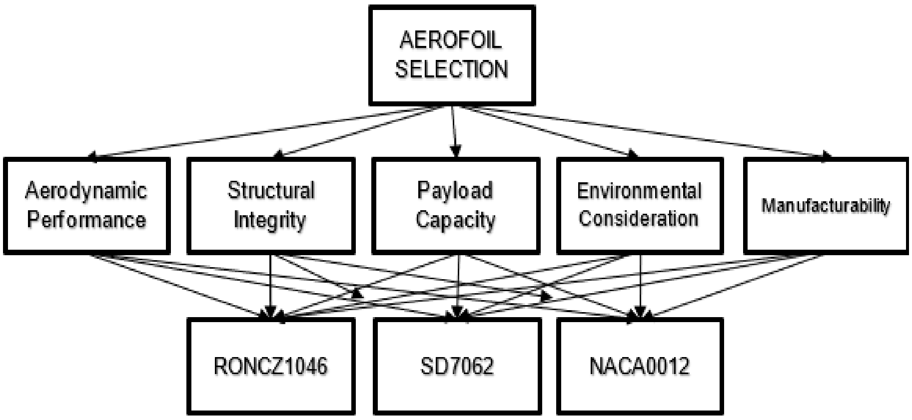


Figure 1: AHP for aerofoil selection

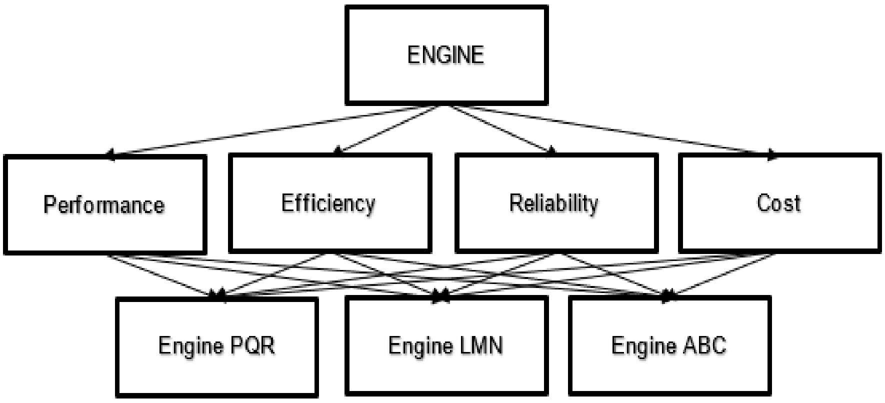


Figure 2: AHP for Engine Selection

3.2. *QFD*

Quality Function Deployment (QFD) is a systematic and structured approach to planning and product development, enabling teams to accurately identify and address customer needs. In this study, HOQ was utilized to prioritize the UAV design and system configuration. Figure 3 illustrates the HOQ framework, which incorporates key customer requirements, including aerodynamic performance, payload capacity, structural integrity, manufacturability, and environmental considerations. System requirements such as performance, efficiency, reliability, and cost were also evaluated. These requirements were then mapped to design alternatives, with RONCZ1046, SD7062, and NACA0012 considered for the aerofoil selection, while Engine PQR, Engine LMN, and Engine ABC were assessed for propulsion system integration. Besides, it provides an overview of the process and stages involved in developing new UAVs. The selection of the optimal design and materials for each UAV component was carefully analyzed and evaluated using a structured methodology.

		Primary Requirement		Aerofoil Selection			Engine Selection			Customer Competitive Assesment		
Row #	Primary Requirement	Functional Requirements / Customer Requirements (Explicit and Implicit)	Importance	RONCZ1046	SD7062	NACA0012	Engine PQR	Engine LMN	Engine ABC	Our Product	UAVs ALR	UAVs PMC
1	Design	Aerodynamic Performance										
2		Payload Capacity										
3		Structural Integrity										
		Enviromental Consideration										
4		Manufacturability										
	System	Performance										
		Efficiency										
		Reliability										
5		Cost										
		Technical Importance Rating										

Figure 3: HOQ for basic component and system integration

4. Results and Discussions

The analysis of development of UAVs covered the topic of weight of selected main components of UAVs and its influence in take-off weight, the wing, tail and fuselage configuration of UAVs by using quality function deployement and the development and basic system of UAVs using analytical hierarchy process. In developing a good UAVs, a proper steps and analysis of each development phase had been made. Every phase was explained in the subtopic below. Briefly, the development undergoes phases as depicted in Figure 4. The analysis and result were explained based on the development flow and also based on the criteria and objectives set in this study.

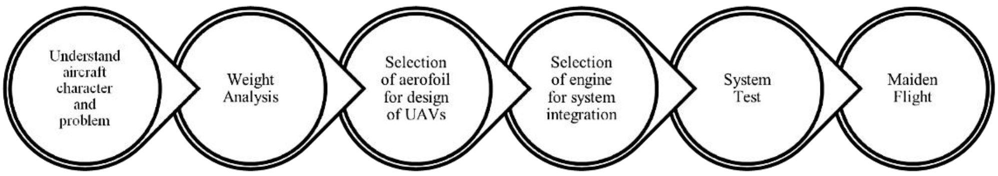


Figure 4: Development flow of UAVs

4.1. *Weight of components of unmanned aerial vehicle*

The payload of an unmanned aerial vehicle (UAV) refers to any equipment it carries during operation. In this development, the payload consists of a surveillance camera, which plays a crucial role in UAV functionality. A 2.6-kilogram surveillance camera was selected as the model for integration into the new UAV, ensuring compatibility with weight constraints and operational efficiency. The structural weight of a UAV is a critical factor in determining its final takeoff weight. To reduce the overall weight, modifications were made to the airframe design, including a narrower fuselage and a shorter wingspan. These adjustments minimized material usage while maintaining structural integrity, leading to a more lightweight and efficient UAV. The structural weight, comprising the fuselage, wings, and tail, was recorded at approximately 42 kg, 19 kg, and 6.5 kg, respectively, totaling 67.5 kg. Future UAV developments should aim for further weight reduction by refining structural design without compromising performance.

Global studies on UAVs indicate that the average total fixed weight is approximately 64.238 kg. In the case of the two UAVs developed by Company XYZ, the weight distribution of components differed by only 1%, highlighting the consistency in design and material selection. This minor variation suggests that further optimizations can be made while maintaining structural stability and functionality.

4.2. *Take-off weight*

The maximum takes off weight of this new developed UAVs is 120kg. This meant that the total weight of UAVs should be less than 120kg. The weight of main components was 15.39kg and the payload was 2.6kg. The fixed weight is 64.24kg which comprised the main components and the payload. Hence, the mass of structure was set approximately 55kg. This was acceptable as the structure of a UAVs has a changeable weight. Therefore, the maximum take-off weight was set to 120kg to allow smooth take off of a UAVs.

4.3. *AHP analysis for aero foil selection*

The process of choosing an aero foil involved analyzing profile data from UAVs that had already been produced and successfully operated by various firms worldwide. According to the investigation, the aero foils from RONCZ1046 and SD7062 had the most potential lift. In terms of lift at low angle of attack, SD7062 performed worse than the other aero foil. Consequently, RONCZ1042 was better suited to transporting additional cargo. In comparison to SD7062, RONCZ1046 had a lower drag to lift ratio. The previously developed UAVs in Company XYZ selected the same aero foil for its horizontal and vertical tails as it does. This was because due to the reason that it will reduce time taken when it came to analyzing alternative types of foil.

The ranking factor used depended on the performance score where the higher the rank was, the higher the performance. Meanwhile, the reciprocal showed that the criteria were less important towards each other. Pairwise comparison of the criteria for UAVs aero foil selection was shown in Table 1. The scale was given by engineers from Company XYZ through focus group discussion. The same criteria such as aerodynamics performance vs aerodynamics performance were marked as 1 as the criteria did not have superiority over each other. For other criteria, it was marked as the row criteria over the column criteria.

Table 1 Pairwise comparison

Criteria	AP	PC	SI	EC	MFG
Aerodynamic performance (AP)	1	5	3	4	7
Payload Capacity (PC)	1/5	1	2	3	5
Structural Integrity (SI)	1/3	1/2	1	2	4
Environmental Consideration (EC)	1/4	1/3	1/2	1	3
Manufacturability (MFG)	1/7	1/5	1/4	1/3	1

Through the scale finalized in Table 1, the weights of the criteria were further calculated as in Table 2. The weight was equivalent to the summation of every single criteria's weight in each column.

Table 2: Weight of the criteria

Criteria	AP	PC	SI	EC	MFG
Sum	1.93	7.03	6.75	10.33	20.00

The score was divided by the total of each column to obtain the normalized pairwise comparison. The result was shown in Table 3. Noted that all the calculations were made beforehand using Microsoft Excel.

Table 3: Normalized pairwise comparison

Criteria	AP	PC	SI	EC	MFG
AP	0.52	0.71	0.44	0.38	0.35
PC	0.10	0.14	0.30	0.29	0.25
SI	0.17	0.07	0.15	0.19	0.20
EC	0.13	0.05	0.07	0.10	0.15
MFG	0.07	0.03	0.04	0.03	0.05

The average of each row was calculated. The result was equivalent to the priority vector in Table 4.

Table 4: Arithmetic average (priority vector)

Criteria	Average
AP	0.48
PC	0.22
SI	0.16
EC	0.10
MFG	0.04

Calculating λmax was necessary to determine the value of CI while calculating λ required the D column vector value and EI values. The calculation for D column vector was made by multiplying the arithmetic average or priority vector with the elements in the first pairwise comparison matrix. The calculation was simplified as the matrix below. Meanwhile the calculation for EI values were obtained by dividing the D column vector with the priority vector.

$$D = \begin{bmatrix} 1 & 5 & 3 & 4 & 7 \\ 1/5 & 1 & 2 & 3 & 5 \\ 1/3 & 1/2 & 1 & 2 & 4 \\ 1/4 & 1/3 & 1/2 & 1 & 3 \\ 1/7 & 1/5 & 1/4 & 1/3 & 1 \end{bmatrix} \times \begin{bmatrix} 0.48 \\ 0.22 \\ 0.16 \\ 0.10 \\ 0.04 \end{bmatrix}$$

$$D = \begin{bmatrix} 2.74 \\ 1.14 \\ 0.79 \\ 0.49 \\ 0.23 \end{bmatrix}$$

The result of the calculation was labeled as D columns vector in Table 5.

Table 5: Calculation results

Criteria	Priority Vector	D columns vector	EI values
AP	0.48	2.74	5.71
PC	0.22	1.14	5.18
SI	0.16	0.79	4.94
EC	0.10	0.49	4.90
MFG	0.04	0.22	5.75

Hence,

λ_{max} = (5.71 + 5.18 + 4.94 + 4.90 + 5.50) / 5
λ_{max} = 26.23 / 5
λ_{max} = 5.25

To calculate the CI,

$\text{CI} = \frac{\lambda max - n}{n-1}$, where *n* is the number of criteria.

$$\text{CI} = \frac{5.25 - 5}{5 - 1}$$

$$\text{CI} = 0.0625$$

To calculate CR,

CR = CI / RI

The value of RI is determined by Table 6.

Table 6 Random index (Saaty 1980)

Matrix Size	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The value of RI is 1.12 since there were five criteria. Hence,

CR = 0.0625 / 1.12
CR = 0.056 ~ 5.60%

The result of CR was 5.60%. The acceptable inconsistency in AHP is below 10%. This happened due to human judgement as this project solely relied on the focus group discussion. Hence, this score was consistent. The priority vector will be used in the QFD.

4.4. *AHP analysis for engine selection*

In determining the engine to be used in the UAVs, another AHP was made based on the steps explained above. This AHP was used to fulfil the objectives of studying the basic system of an unmanned aerial vehicle. The scope narrowed on finding the best engine for the UAVs as it was one of the primary components that affects the operation of the UAVs. In determining the goal of the AHP, the best engine was selected. The criteria that were considered were the performance, efficiency, reliability and cost of the engine. The alternatives selected for the comparison were Engine PQR, Engine LMN and Engine ABC. The pairwise comparison was made to give score for each criterion. The score based on Saaty was displayed in Table 7.

Table 7: Pairwise Comparison for Engine

Criteria	Performance	Efficiency	Reliability	Cost
Performance	1	4	5	7
Efficiency	1/4	1	3	5
Reliability	1/5	1/3	1	4
Cost	1/7	1/5	1/4	1

The arithmetic average or its priority vector were calculated and shown in Table 8.

Table 8: Priority weight of engine

Criteria	Average
Performance	0.58
Efficiency	0.24
Reliability	0.13
Cost	0.05

The calculation made followed the steps explained in AHP for Aero foil Selection. Hence,

$$CR = 0.0800 / 0.90$$
$$CR = 0.0889 \sim 8.89\ \%$$

The result of CR was 8.89 %. The acceptable inconsistency in AHP is below 10% which made this selection process valid.

4.5. *QFD analysis*

To determine the optimal design configuration for the wing, tail, and fuselage of the UAV, input from professionals in UAV development at Company XYZ was gathered through focus group discussions. These discussions helped identify key design requirements aligned with the three-level hierarchy process. The priority weights assigned to the aerofoil and engine played a crucial role in calculating the final score for each alternative, ensuring that the most suitable components were selected based on technical and functional criteria. As shown in Figure 5, the QFD framework was developed using customer requirements identified through the AHP. These requirements included aerodynamic performance, payload capacity, structural integrity, environmental considerations, manufacturability, performance, efficiency, reliability, and cost. The technical requirements were categorized into two main components: aerofoil and engine selection. The aerofoil alternatives considered were RONCZ1046, SD7062, and NACA0012, while Engine PQR, Engine LMN, and Engine ABC were evaluated for propulsion. The highest-scoring alternatives were selected to ensure optimal UAV performance and efficiency.

From the QFD analysis in Figure 5, aerodynamic performance was identified as the most critical design factor, receiving the highest importance rating of 0.48, followed by payload capacity at 0.22. These two factors are essential for optimizing UAV flight efficiency. Additional design considerations included structural integrity (0.16), environmental impact (0.10), and manufacturability (0.04). For system performance, importance ratings were assigned as follows: performance (0.58), efficiency (0.24), reliability (0.13), and cost (0.05), aligning with the priority vector established in the AHP framework. The QFD results also determined the optimal aerofoil selection, with RONCZ1046 scoring 6.45, outperforming NACA0012 (2.95) and SD7062 (2.47). In terms of engine selection, Engine LMN (5.22) was identified as the best option, followed by Engine PQR (2.90) and Engine ABC (1.66). Based on these findings, the UAV design should incorporate RONCZ1046 as the preferred aerofoil for superior aerodynamic efficiency. Additionally, the fuselage configuration should be optimized to accommodate the size, placement, and weight of Engine LMN, ensuring balanced performance and structural integrity.

		Primary Requirement		Aerofoil Selection			Engine Selection			Customer Competitive Assesment		
Row #	Primary Requirement	Functional Requirements / Customer Requirements (Explicit and Implicit)	Importance	RONCZ1046	SD7062	NACA0012	Engine PQR	Engine LMN	Engine ABC	Our Product	UAVs ALR	UAVs PMC
1	Design	Aerodynamic Performance	0.48	●	○	▽				4	3	2
2		Payload Capacity	0.22	○	▽	○				5	3	3
3		Structural Integrity	0.16	○	▽	●				4	4	3
		Enviromental Consideration	0.1	●	○	▽				5	5	5
4		Manufacturability	0.04	○	●	●				4	3	3
	System	Performance	0.58				○	○	▽	5	4	3
		Efficiency	0.24				○	●	▽	3	4	4
		Reliability	0.13				○	●	○	2	3	4
5		Cost	0.05				▽	○	●	4	3	3
		Technical Importance Rating		6.45	2.47	2.95	2.9	5.22	1.66			

Figure 5: Summary of HOQ analysis

4.6. *Analysis of wing, tail and fuselage selection*

Based on the weight fraction of various components relative to the total aircraft weight, the design criteria for the wing, tail, and fuselage were selected, as illustrated in the following figures. The difference in weight distribution between the previous and new UAV models was less than 1%, demonstrating consistency in structural optimization. The contribution percentage of each UAV component served as a reference for determining a safe and efficient structural configuration. As shown in Figure 6, the overall UAV width measured 4.86m, with the main horizontal section spanning 4.50m and a vertical dimension of 1.10m. The outer extensions of the horizontal components were 0.53m, while the central vertical column measured 1.30m. The wing design followed a high aspect ratio configuration, selected based on AHP and QFD analysis for optimal aerodynamic efficiency. Figure 7 illustrates the tail design, featuring a length of 1.53m and a tail height of 0.32m. Additionally, the wing support structure width was recorded at 1.20m, ensuring structural stability and aerodynamic balance.

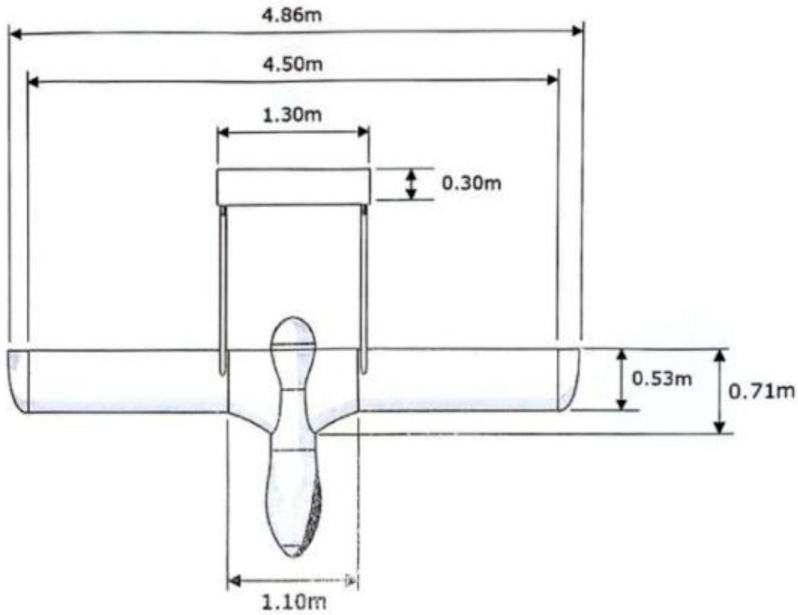


Figure 6: Main wing design

Figure 8 illustrates the overall fuselage design of the UAV. The fuselage dimensions were measured at 4.36 m in width, 3.75m in length, and 1.40 m in height, ensuring a balanced and aerodynamically efficient structure. The figures present the complete design and configuration of the wing, tail, and fuselage. The measurements for each component were determined by professional engineers specializing in UAV design. Detailed calculations were conducted to ensure aerodynamic performance and structural stability. As previously mentioned, the wing design was based on the RONCZ1046 aerofoil, selected for its superior aerodynamic efficiency.

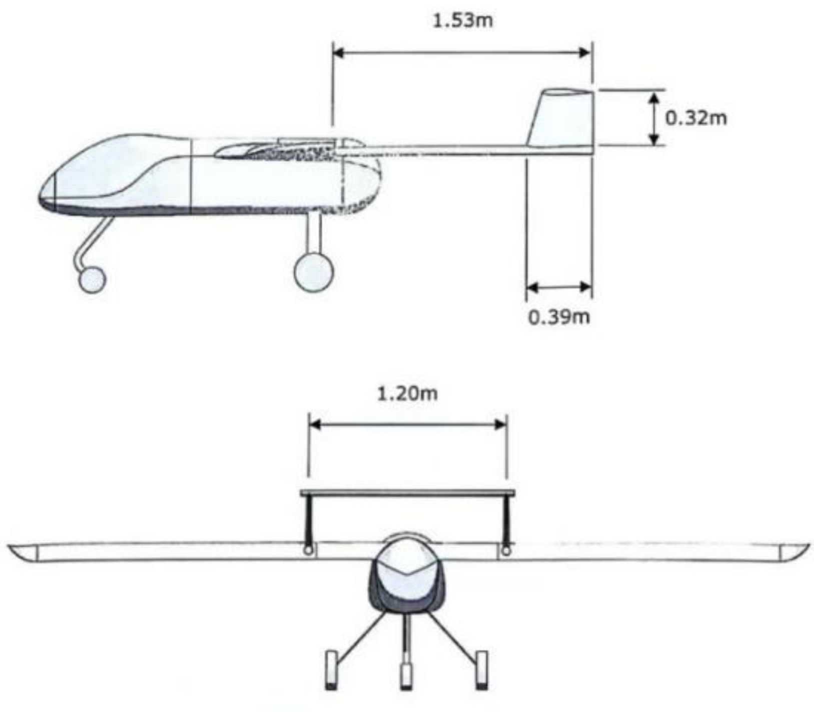
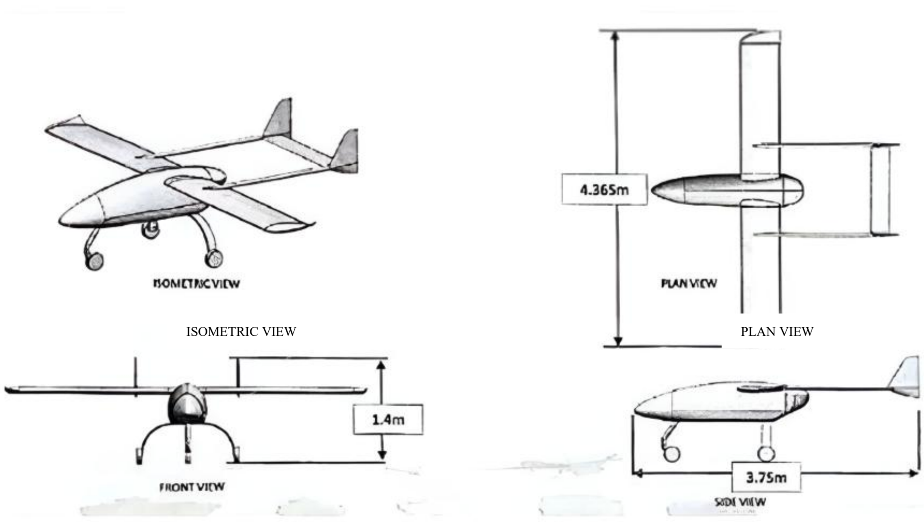


Figure 7: Tail design



ISOMETRIC VIEW

PLAN VIEW

FRONT VIEW

SIDE VIEW

Figure 8: Aerodynamic design

4.7. *Analysis of system test*

The UAV's operation, including takeoff and landing, is designed to be fully autonomous. Before being deemed operational, the UAV underwent three critical flight tests: the operational flight test, the closed-loop flight test with UAV configuration, and the open-loop flight test with radio control (RC) aircraft configuration. For the newly designed UAV, the open-loop flight test was conducted to evaluate its behavior under external pilot control without the assistance of the flight control system. This test assessed static stability and controller input response, allowing for design refinements based on test results. The updated data was then used to optimize the UAV's control system for improved performance.

Prior to flight testing, the UAV underwent evaluations for mechanical integrity, system integration, and composite repairs. During the initial test, the UAV was fully controlled by an external pilot on the ground. Communication between the UAV receiver and the controller was established via a separate radio transmitter. In this phase, the autopilot functions were limited to data logging, emergency safety measures, and stabilization in loiter mode (a programmed input).

The ground range test began with the UAV placed on a trolley, without engine activation. This test focused on detecting frequency interference and verifying the pilot-aircraft command link strength. Following a successful evaluation, a second test was conducted with the entire system and engine running to assess UAV control, behavior, acceleration, and stopping distance. Key performance data were recorded across three test cycles. Some components were identified for potential improvements, including the battery, which lacked sufficient capacity to support the entire system, and the propeller, which required optimization for better takeoff thrust and speed. A small red glider plane was used to simulate air test range assessments and serve as a pilot training tool before the final flight test, ensuring complete familiarity with the UAV’s controls.

Additionally, a weight and balance test were conducted using a 15-liter gasoline tank to ensure UAV stability. This included assessments of static and dynamic stability, with longitudinal, lateral, and directional stability analyzed in both short- and long-period categories. The UAV’s maneuverability was evaluated through its rudder, elevator, and aileron control surfaces, confirming adequate response and balance. A ballast was used to maintain the aircraft's center of gravity (CG) within acceptable limits. The successful completion of all tests validated the UAV’s performance, reliability, and operational readiness.

5. Conclusion

As conclusion, this study successfully achieved its objectives using focus group discussions, QFD, and the AHP. The maximum takeoff weight of the UAV was finalized at 120 kg, while the RONCZ1046 aerofoil was identified as the optimal design choice and served as a benchmark for QFD analysis, ensuring prioritization of customer and technical requirements in wing configuration. To determine the UAV's basic system, AHP and QFD were applied, with Engine LMN selected for its superior performance, efficiency, and reliability. Future research can improve precision and reliability by focusing on fundamental system components and increasing participation in focus group discussions, allowing for more comprehensive UAV design comparisons. Additionally, minimizing data access limitations would facilitate better insights into UAV functionality and system integration. Beyond military applications, this research strengthens national security, scalability, and adaptability, paving the way for UAVs in logistics, surveillance, and disaster management. Moreover, by advancing UAV development and production, this study positions the nation as a leader in UAV technology, ensuring long-term strategic and economic benefits.

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