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A CONCEPTUAL DESIGN OF A COMPACT AND LOW-COST DEFENSE MULTICOPTER UAV

By

Fulki Shah Jahan
11201901013

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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Triwanto Simanjuntak, PhD	___________
Thesis Advisor	Date
Dr. Eng. Ressa Octavianty	___________
Thesis Co-Advisor	Date
Dipl.-Ing. Sentot Wahjoe Georitno, M.Si.	___________
Dean of Faculty of Engineering and Life Sciences	Date

EXAMINERS APPROVAL PAGE

Dr. Eng. Odi Akhyarsi	____________________
Examiner 1	Date

Ananta Wijaya, S.T., M. Sc. Tech.	____________________
Examiner 2	Date

STATEMENT BY THE AUTHOR

I hereby declare that this submission, A Conceptual Design of a Compact and Low-cost Defense Multicopter UAV, 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.

Fulki Shah Jahan	
Student	Date

ABSTRACT

A Conceptual Design of a Compact and Low-Cost Defense Multicopter UAV

by

Fulki Shah Jahan

Triwanto Simanjuntak, PhD, Advisor

Dr. Eng. Ressa Octavianty, Co-Advisor

This research study explored the conceptual design of a low-cost and compact defense Unmanned Aerial Vehicle as an additional tactical equipment. The UAV concept, which utilized off-the-shelf components, was designed to provide situational awareness and purpose-built to carry out payload dropping and defense kamikaze loitering munition operations. The topic was investigated due to the possible demand for affordable and versatile tactical UAVs in modern military operations, emphasizing the need for innovative solutions to enhance defense operational capabilities. The research study addressed the challenge of developing an operational efficient UAV for military defense applications with components available in the open market. The primary problem revolved around balancing compatibility of the off-the-shelf components with the operational performance to create a UAV that meets military requirements. The study employed a comprehensive methodology, incorporating benchmarking, defining design requirements and objectives, conceptual sizing, component selection, CAD modeling, performance analysis and cost analysis, to inform the design process. The performance calculation was conducted using an open-source online multicopter performance calculator. The result produced a virtually agile and affordable "off-the-shelf" tactical defense UAV, suitable for ISR and loitering munitions operations.

Keyword: *Multicopter, Conceptual Design, Defense UAV, Loitering Munition*

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List of Abbreviations

UAV	**U**nmanned **A**erial **V**ehicle
COG	**C**enter **O**f **G**ravity
CAD	**C**omputer **A**ided **D**esign
RPM	**R**otation **P**er **M**inute
ESC	**E**lectronic **S**peed **C**ontrol
ISR	**I**ntelligence **S**urveillance **R**econnaissance
FFF	**F**used **F**ilament **F**abrication
RPV	**R**emotely **P**iloted **V**ehicle
UAS	**U**nmanned **A**ircraft **S**ystem
MALE	**M**edium **A**ltitude **L**ong **E**ndurance
HALE	**H**igh **A**ltitude **L**ong **E**ndurance
VTOL	**V**ertical **T**akeoff and **L**anding
JUAV	**J**oint **UAV**
CoE	**C**enter of **E**xcellence
DoD	**D**epartment of **D**efense
VTX	**V**ideo **T**ransmitter
FC	**F**light **C**ontroller
LiPo	**Li**thium **Po**lymer
LiIon	**Li**thium **Ion**
ABS	**A**crylonitrile **B**utadiene **S**tyrene
SAAS	**S**oftware **as a S**ervice
iOS	**i**Phone **O**perating **S**ystem
GPS	**G**lobal **P**ositioning **S**ystem
OTS	**O**ff **T**he **S**helf
TNI	**T**entara **N**asional **I**ndonesia
AiO	**A**ll **i**n **O**ne
FCU	**F**light **C**ontrol **U**nits

PWM	**P**ulse **W**idth **M**odulation
PC	**P**oly **C**arbonate
RT	**R**adio **T**ransmitter
BEC	**B**attery **E**liminating **C**ircuit
HD	**H**igh **D**efinition
OSD	**O**n **S**creen **D**isplay
CMOS	**C**omplementary **M**etal **O**xide **S**miconductor
FPV	**F**irst **P**erson **V**iew

Dedicated to my parents

CHAPTER 1
INTRODUCTION

1.1 Background

The twentieth century saw a massive growth in the urban population, increasing urban areas which have exerted a much greater influence in military operations. Urban densification is considered a necessity to aid fast-growing cities that go through a combination of demographic change, economic pressure, and large transport infrastructure projects [1]. The increase in the growth of cities has contributed to problems of combat in built-up areas. Urban areas are traditionally avoided for military combat operations since they prove to be costly, slow and often inconclusive. However, they are sometimes unavoidable [2] due to strategic achievements or the political and/or economic value they provide to the outcome. Urban areas will become the primary battlegrounds in future conflicts, making engagement in these settings inevitable. Any future war against peer or near-peer enemy has an increasing chance to contain some measure of urban combat.

Urban areas are referred to as unique terrain [3] that possesses very strong conduct of lethal defense. Unlike natural environments such as wooded areas of the forest, rugged terrains of mountains, and open sandy dunes of the desert, the man-made physical terrain in urban areas consists complexity of dense construction, where the density is represented by the wealth and power of the country in the form of economic institutions, industrial bases, transportation complexity and political and cultural centers. Due to the densely populated terrain, military combat in urban areas can be the most destructive. Close quarter battles that take place in urban combats constitute the limitations to military weapons used. Ruthless behavior of non-state forces who do not believe in the rules of engagement are also a big contribution to the destruction.

A Soldier's Recommended Load 68.9 lbs / 31.25 kg includes:	
7.8 lbs / 3.5 kg uniform	16 lbs / 7.3 kg armour plates
4.2 lbs / 1.9 kg combat helmet	0.5 lbs / 0.23 kg compass
6.4 lbs / 2.9 kg M4 assault Rifle	1 lbs / 0.45 kg first aid kit
4.6 lbs / 2.1 kg 2 canteens of water	2 lbs / 0.9 kg 2 M67 Fragment Grenades

TABLE 1.1: A Soldier's Recommended Load According to the 1990 US Army Field Manual

Military Infantry troops deployed into combat zones usually carry a significant number of loads. Generally, the military gear they carry can add up to a weight of 68 pounds (31 kg) or more, which mainly consists of their apparels, armor, weapons, ammunition, food, essentials and a first aid kit as shown in Table [1.1], according to the 1990 US Army Field Manual [4]. As much as 120 pounds (54 kg) could be added when in an active combat operation. The amount of weight a soldier carries can also vary depending on the environment [5] they are assigned in. The amount of gear varies on the specific requirements of a mission or their role within the unit. However, regardless of their role, a soldier is expected to carry a significant amount of equipment as an essential.

1.2 Problem Statement

Military operations conducted in urban areas present distinct challenges, elaborated below distinguishes two key factors often described:

- Complex Environment: The densely built and intricate urban man-made landscapes compromise various structures and narrow streets, maneuvering within such settings becomes complicated due to limited visibility, potential civilian presence, and the need to navigate through buildings, making the operations more challenging.

- Civilian Considerations: Unlike conventional battlegrounds, urban areas may host significant civilian populations that are unfortunately caught in between the warfare. Operations conducted to eliminate enemies in the presence of civilians have certain conditions that restrict the use of high combat power. Therefore, the Rules of Engagement (ROE) are applied. This balances the military objectives with minimizing or eliminating civilian casualties, since managing the impact of conflict on civilians becomes a critical factor during military operations in urban settings.

Situational awareness in these circumstances becomes limited where precision is critical, especially with enemies hiding behind cover or away from the line of sight. The use of heavy artillery and air support are severely limited due to avoiding civilian casualties. These defense operations require the operators to carry a significant amount of military gear that are carried while walking, marching, running or even act as fighting essentials.

1.3 Research Objectives

The objectives of this research are:

- Conceptually design a low cost and compact defense UAV capable of conducting ISR and loitering munition operations.
- Analyze the performance of the UAV concept.

1.4 Research Scope and Limitation

The scope and limitation of this research are:

- The design requirements are formulated through the iteration of existing concept comparison.
- The UAV airframe components for the UAV uses Fused Filament Fabrication as the design's material.

- The performance analysis for the variety of operational scenarios are not accounted for and focuses on the general scope of each operations.
- The performance calculation is calculated with the help of an open-source online multi-copter performance calculator.
- There will be no physical testing of the UAV.
- The components are selected on the basis of off-the-shelf method.

1.5 Significance of the Study

The results of this research is expected to:

- Develop future research for UAVs that are cost-effective and compact for military defense operations.

CHAPTER 2
LITERATURE REVIEW

2.1 Urban Environment

Urban or metropolitan areas are defined as very developed regions [6] that are generally further referred to as towns, cities, and suburbs. The presence of human structures like houses, commercial buildings, roads, bridges, railways, etc, make up the existence of an urban civilization. Throughout the world, it is common that a dominant pattern of migration from rural areas, opposite to urban areas consisting of low population density and large amounts of undeveloped land often called the countryside, to urban areas is noticeable within countries, due to greater economic opportunities offered since the advancement of technology. However, most of the world's population still lives in rural areas.

2.2 Unmanned Aerial Vehicle

As defined in the name, an Unmanned ariel vehicle (UAV) is an aircraft that needs no flight crew onboard, they either act as an automated 'Drone' or a remotely piloted vehicle (RPV). In the above statements, three terms are mentioned that similarly describe the same vehicle. Various other terms can be used to describe them, the most common, 'Drones,' 'RPVs' and 'UAVs' as a word can be used interchangeably, they provide the same definition, since they are aerial vehicles that can fly with a human remotely controlling them, or advanced cases sometimes, function without direct human intervention. Of the three, RPV is the least common term used. Above them all, exists a definition used to describe the whole ecosystem itself. Referred to as UAS or Unmanned Aircraft Systems, it includes not only the UAV or the drone as a vehicle but also the pilot on the ground controlling the flight and the systems included that connect the pilots to the vehicle. The ‘UAV’ and ‘Drone’ are components of the UAS since it only refers to the vehicle by itself [7]. Since this paper focuses solely on the vehicle, the term UAV shall be used.

2.2.1 Early Concept

The rapid pace of the ever-growing modern technology has allowed UAVs to come a long way since their inception. With the complicated nature of this technology, it is often to forget the roots and building blocks that brought the UAV industry to where it stands today. The origins of UAVs can be traced back to when they were balloons and kites. Typically, balloons and kites are not the first to be mentioned in this discussion. Surprisingly, these ancestors to the UAV are flying inventions that date back centuries before the first ever UAV was even made. Moreover, to exactly pinpoint where the first UAV was made is difficult, since the technology has evolved, with its popularity surging relatively recently [8]. In Annonay, France, Joseph-Michel and Jacques-Étienne Montgolfier are the ones who hosted the first public demonstration of an unmanned aircraft, a hot-air balloon. From a technical perspective, they were the first flying object crafted [9], not to require a human pilot.

Pilotless airborne vehicles were first developed during the mid-1800s when the First World War broke out. The early concept of an Unmanned Aerial vehicle took form as aerial target practice drones, developed by Great Britain and the USA, with ‘The Aerial Target’ being the first recognized radio-controlled aircraft, which was built by the British Royal Navy in 1917. The Aerial Target was an experimental radio-controlled de Havilland monoplane, used in the trial flight of March the 21st, 1917, and marked the first UAV to fly under remote control. The remote-control components were designed by Dr. Archibald Low and came with a twin-opposed engine designed by Granville Bradshaw which produced about 35 hp. The American version of a remote-controlled aircraft, the Kettering Bug, an aerial torpedo first flew in October 1918.

FIGURE 2.1: The first public demonstration of the Hot Air Balloon at Annonay, Ardèche, France by the Montgolfier brothers

Despite showing promising results in flight tests, neither was operated in combat during the war. The first UAV to appear in operations was the 'Queen Bee', the result of a full-size retooling of the de Havilland DH82B biplane, operated in 1935. The biplane had a radio and servomechanism-controlled controls in the back seat and could be conventionally piloted from the front seat, but it mostly flew unmanned for artillery gunners in training [10]. While early UAV applications were dominated by military and reconnaissance mission benefits, the 20th century saw the evolution of the UAV as remote-controlled or autonomous aircraft begin to take shape.

2.2.2 Configuration Types

UAVs come in a wide range of sizes, capabilities, and models [11], each designed to fulfill specific purposes. These aircraft offer a range of options to supply different needs and requirements. The diverse selection of UAV configurations ensures the appropriate model for the intended application [12]. With such variety, UAVs have revolutionized industries ranging from filmmaking and agriculture to defense and emergency services. According to the Drone Industry Insight's 'UAV Configuration Types' [13] illustrated in Figure [2.4], UAVs are initially divided

FIGURE 2.2: The Aerial Target

into two distinct categories. Configurations under the 'Heavier than air' category are further discussed.

1. Fixed Wing

   A fixed-wing UAV is characterized by a single rigid wing that resembles and functions similarly to an airplane. They generate lift, capable of harnessing air, instead of relying on vertical lift rotors, which allows them to stay afloat in the air, which means they are suitable for an endurance flight and fly at high speeds. Consequently, this type of UAV only requires energy to propel itself forward and not to maintain its position in the air.

   - Small UAV: Penguin B, Penguin
   - MALE: MQ-9 Reaper, General Atomics
   - HALE: MQ-4C Triton, Northrop Grumman

2. Hybrid VTOL

   Hybrid VTOL (Vertical Takeoff and Landing) UAV types combine the advantages of both fixed-wing and rotor-based designs. These UAVs feature rotors integrated into their fixed wings, enabling them to hover, take off, and land vertically. They combine the endurance of a conventional fixed-wing UAV with the vertical takeoff capability of rotary-wing UAVs, eliminating

FIGURE 2.3: Prime Minister Winston Churchill and Captain David Margesson, Secretary of State for War, watching the launch of the Queen Bee from its ramp

the need for large takeoff and landing spaces. While this category of hybrid UAVs is currently limited in availability, as technology progresses, it has the potential to gain popularity in the upcoming years.

- VTOL Fixed Wing: JOUAV CW-15, JOUAV
- Tilt Wing: Aero 2, Dufour Aerospace
- Tilt Engine: Eagle Eye, Bell Helicopter
- Tilt Platform: Wingtra One Gen II, Wingtra

3. Multi-Rotor

   Multi-rotor UAVs are named so due to their possession of multiple motors. They are further classified according to the number of motors. Among these, quad-copters are the most widely favored multi-rotor UAVs. These UAVs are particularly attractive as they are relatively simple to operate and are available at affordable price. Additionally, they offer enhanced maneuverability and framing control.

   - Tricopter: Scorpion, BSS Holland
   - Quadcopter: Mavic 3, DJI

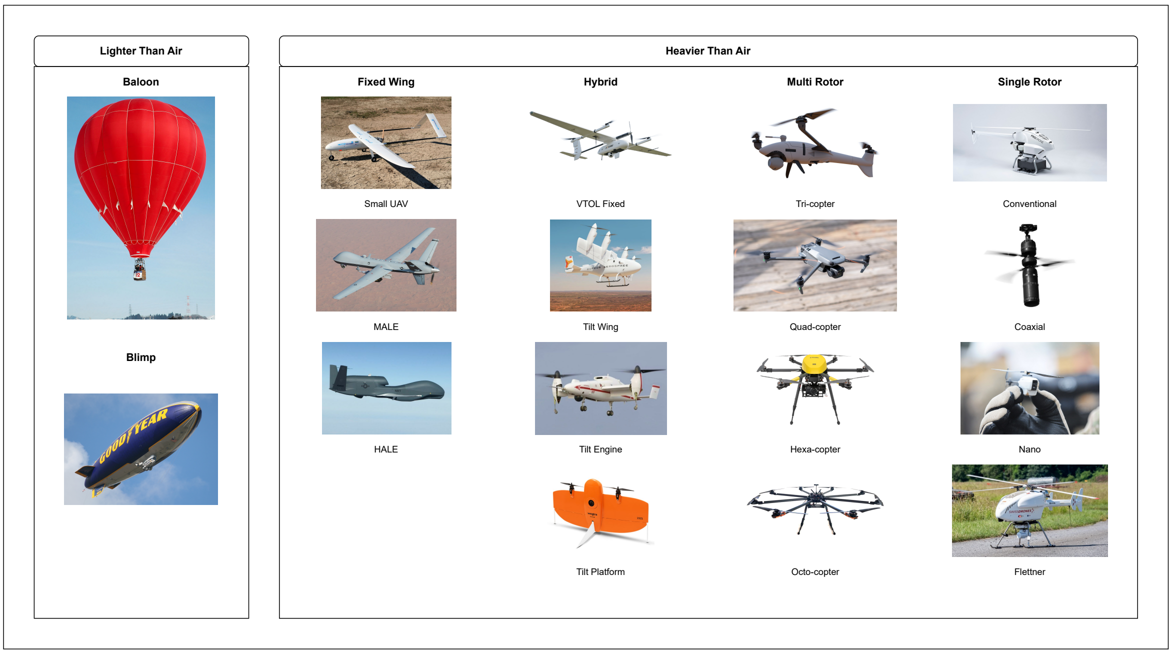


FIGURE 2.4: Droneii UAV Configuration Types

- Hexacopter: Trimble ZX5, Trimble
- Octacopter: Botlink Octacopter, Botlink

4. Single-Rotor

   Single-rotor UAV variants are known for their robustness and resilience. These UAVs bear a striking resemblance to real helicopters in their structure and design, consisting of a single large rotor functioning as a spinning wing that provides the main thrust, along with an additional tail rotor responsible for managing direction and stability. Single-rotor UAVs typically use gas engines rather than batteries, which greatly increases their flight time.

   - Conventional: Pro Drone PDH-GS 120
   - Coaxial: Ascent Aerosystems Spirit
   - Nano: FLIR Black Hornet 4
   - Flettner: Swiss Drones SDO 50 V2

2.2.3 Military Classifications of UAVs

UAVs are available at wide ranges of capabilities along with their size in recent years. Their notable advantages in conventional war methods have gained them attention in the utilization of UAVs in military operations. These vehicles have played a progressively significant role in numerous conflicts, initially serving surveillance and intelligence purposes and later evolving to include armed variations, transforming into weapons systems. UAVs have gained prominence in modern warfare, showcasing their effectiveness in a variety of combat operations. They now hold a significant position in counter-terrorism and counterinsurgency efforts, with expectations of their importance growing in future military engagements. The affordability of UAVs makes them easily replaceable and suitable for executing highly hazardous or politically sensitive missions. These remotely operated defense technologies come equipped with an array of sensors and weaponry, providing real-time intelligence on enemy movements and locations. This capability enhances precision in targeting, improves situational awareness, and increases the safety of military personnel by avoiding human operators' exposure to the inherent risks of combat. This technological advancement has revolutionized the contemporary battlefield, offering military forces a valuable tool for achieving strategic objectives with greater efficiency and reduced risk. Various models are designed to fulfill specific purposes.

Because military UAVs exhibit significant operational distinctions from their civilian counterparts [11], they form a distinct category separate from civil UAVs. The JUAV CoE has established its own classifications based on operational characteristics and other attributes of UAVs. These classifications encompass tactical, operational, and strategic UAVs, each operating under different commands with distinct scopes. Strategic UAVs are employed for extensive surveillance missions in hostile territories. An example is the Global Hawk, capable of cruising at 20,000 meters above sea level for 40 hours, covering a distance of 3,000 nautical miles. Operational UAVs, exemplified by systems like the Predator and Reaper, operate at altitudes of 7,500 and 15,000 meters, respectively. These UAVs are deployed at the theater level of combat and serve both reconnaissance and offensive purposes. In contrast, tactical UAVs [14] are characterized by low altitude and limited range, typically 20 miles or less. An example is the Dragon Eye system. Unlike strategic and operational UAVs, which can be either remotely piloted or pre-programmed for autonomous flight, tactical UAVs are fully controlled by operators. They are frequently utilized by police forces in developed nations for tasks such as crowd control and border surveillance.

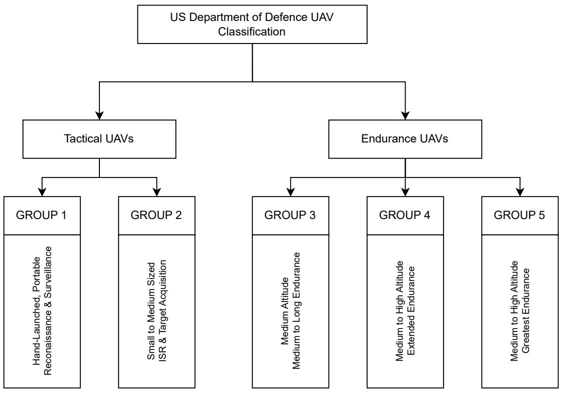


FIGURE 2.5: United States Department of Defense UAV Classification

According to the US Department of Defense, Numerous classifications are employed for military UAVs [15], with capabilities ranging widely based on UAV size, performance, and function. UAVs come in various sizes and speeds, from those with a wingspan of less than one foot hovering at treetop level to those with a wingspan exceeding 130 feet operating above 60,000 feet. These informal classifications differ significantly depending on the perspective used, such as tactical use, performance, size, airworthiness, levels of autonomy, and more. The identification of individual groups of UAVs is based on attributes like airspeed, weight, and operating altitude, and is briefly outlined in Table [2.1] and Figure [2.5].

2.3 Quadcopters

Multirotor drones have become widely popular as platforms for research and applications within the domain of Unmanned Aerial Vehicles. A quadcopter, a subtype of multirotor UAV [16], comprises four arms or booms, each equipped

<table>
<tr><th>UAV Groups</th><th>MTOW (kg)</th><th>Normal Operating Altitude (ft)</th><th>Speed (kts)</th><th>Representative UAVs</th></tr>
<tr><td>Group 1</td><td>0 -9.5</td><td>< 1200 AGL</td><td>100</td><td>Raven (RQ-11), WASP</td></tr>
<tr><td>Group 2</td><td>9.5 - 24.9</td><td>< 3500 AGL</td><td rowspan="2">< 250</td><td>ScanEagle</td></tr>
<tr><td>Group 3</td><td>< 598.7</td><td rowspan="2">< FL 180</td><td>Shadow (RQ-7B), Tier II / STUAS</td></tr>
<tr><td>Group 4</td><td rowspan="2">> 598.7</td><td rowspan="2">Any Speed</td><td>Fire Scout (MQ-8B, RQ-8B), Predator (MQ-1A/B), Sky Warrior ERMP (MQ-1C)</td></tr>
<tr><td>Group 5</td><td>> FL 180</td><td>Reaper (MQ-9A), Global Hawk (RQ-4), BAMS (RQ-4N)</td></tr>
</table>

TABLE 2.1: United States Department of Defense UAS Group Descriptions

with a rotor known for its remarkable maneuverability and capacity for intricate movements. Multirotor UAVs, including quadcopters, are unmanned aerial vehicles relying on multiple rotors to generate lift for flight. The operational principle involves two rotors rotating clockwise and another two-rotating counterclockwise. By adjusting rotor speeds, the quadcopter can generate thrust and execute various turning maneuvers. A distinctive feature of quadcopters is their Vertical Take-Off and Landing (VTOL) capability, making them well-suited for scenarios with limited launch space. Their ability to hover in place offers an advantage over fixed-wing UAVs and aircraft, particularly in tasks like small-scale surveillance and reconnaissance. Additionally, quadcopters generally boast simpler construction, affordability, and ease of flight compared to other UAV types. They are available in various sizes, from mini quadcopters, measuring only about an inch square, to professional systems with diameters ranging from 300 to 900 mm. The trade-off between volume (increasing weight) and the power required for lift sets an upper limit on frame size. Striking the right balance between battery weight, size, and flight endurance becomes crucial. The typical flight time of a battery-powered quadcopter UAV is approximately 30 minutes. However, recent designs have extended this duration by incorporating battery cells into the structure of larger quadcopters, enhancing their flight endurance. This targeted innovation aims to push the boundaries of what multirotor drones can achieve and broaden their potential applications, particularly in military defense.

2.3.1 Flight Dynamics

The motion of a quadcopter UAV can be categorized into three types [17][18], determined by the relative movement of its four propellers. These three types are pitch, roll, and yaw.

1. Pitch involves the forward or backward tilting of the UAV. When the UAV pitches forward, it moves in a forward direction, and when it pitches backward, it moves in the opposite direction. Pitch control allows the UAV to change its horizontal orientation and move along the longitudinal axis.

2. Roll refers to the sideways tilting motion of the UAV. When the UAV rolls to one side, it moves in that direction. By adjusting the roll input, the UAV can perform lateral movements along the lateral axis.

3. Yaw is the rotational motion around the vertical axis of the UAV. It allows the UAV to turn or change its heading. By controlling the yaw input, the UAV can rotate clockwise or counterclockwise.

2.3.2 Forces and Moments

When a quadcopter is in flight, it experiences various forces that determine its movement [17][18]. The resultant force, which is a combination of these forces, dictates the quadcopter's overall motion. The major forces acting on a quadcopter include;

1. **Weight**: The weight of the quadcopter is the force exerted on it due to its mass. This force always acts in the direction of gravity. The heavier the quadcopter, the more power is required to lift and maneuver it.

2. **Lift**: Lift is the upward force that counteracts the quadcopter's weight. It is generated by pressure differences across the quadcopter, primarily in the vertical direction. The speed, size, and shape of the propeller blades play a crucial role in determining the amount of lift force. Lift is necessary to elevate the quadcopter against the force of gravity. To create this force, all four propellers run at high speeds, generating the necessary lift to keep the quadcopter airborne.

3. **Thrust**: Thrust is the force that propels the quadcopter in the direction of its motion. In the context of quadcopter dynamics, this force is typically perpendicular to the plane of the rotors. During hovering, thrust is purely vertical, but if the thrust is inclined, the quadcopter will tilt forward or backward. Thrust is crucial for achieving controlled motion in the desired direction at a consistent speed. To achieve the desired motion, two propellers are often operated at a higher speed to generate the necessary thrust.

4. **Drag**: Drag is the force that opposes the quadcopter's motion and acts in the opposite direction to its velocity. It is caused by air resistance, which is influenced by factors such as pressure differences and the viscosity of the air. The aerodynamic shape of the quadcopter is carefully designed to minimize drag and optimize its efficiency in overcoming air resistance.

2.3.3 Components

The components of a UAV can vary depending on the specific model and purpose of the UAV. However, below are the main components commonly found in most non-autonomous quadcopters:

1. **Frame**: The frame acts as the structural skeleton that binds all the elements together, furnishing stability and resilience to the UAV.

2. **Motors**: The motors generate rotational motion, which is then conveyed to the propellers, creating upward or forward thrust. In quadcopters, it's customary to have two motors rotating clockwise and two rotating counterclockwise to counterbalance the rotational forces produced by the propellers. This equilibrium is crucial due to Newton's Third Law, asserting that every action has an equal and opposite reaction. Maintaining an even number of opposing motors ensures stability by balancing the rotational forces. Contemporary UAVs often employ brushless motors, recognized for their enhanced efficiency and performance in comparison to brushed motors.

3. **Propellers**: Propellers have a vital function in directing and propelling the UAV. When each propeller turns, it pushes air downward, causing a variance

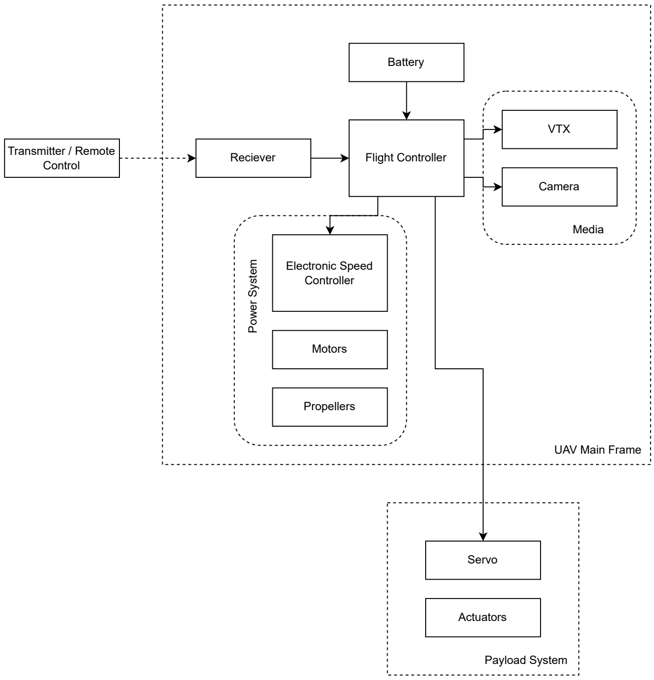


FIGURE 2.6: Non-Autonomous Quadcopter UAV Component Architecture - [19]

in air pressure. This pressure discrepancy results in a lower-pressure area above the propeller and a higher-pressure area below it. As a result, the UAV encounters an upward force, enabling it to rise and remain in flight.

4. **Electronic Speed Controller**: Each motor is connected to an Electronic Speed Controller (ESC) responsible for governing the motor's speed and rotation. The ESCs receive signals from the flight controller, enabling them to finely adjust the power supplied to the motors. This exacting control empowers the UAV to navigate with precision and responsiveness, as the ESCs modulate the motor power in accordance with the input received from the flight controller.

5. **Flight Controller**: The flight controller acts as the core intelligence of the UAV, essentially serving as its "brain." It comprises a compact electronic circuit board containing sensors, microprocessors, and firmware. Utilizing information from various sensors such as accelerometers, gyroscopes, and

magnetometers, the flight controller evaluates the UAV's orientation, stability, and position. Moreover, it interprets input commands from either the pilot or an autonomous system, making essential adjustments to the motor speeds accordingly. The pivotal function of the flight controller guarantees accurate control and coordination of the UAV's movements.

6. **Battery**: Quadcopters depend on rechargeable batteries, typically lithium polymer (LiPo) batteries, as their primary power source. These batteries supply the essential electrical energy to power the motors, flight controller, Electronic Speed Controllers (ESCs), and other electronic components within the UAV.

7. **Radio Transmitter**: To operate the UAV manually, a remote control or transmitter is employed. This device allows the pilot to send commands and control inputs to the UAV, including adjustments to throttle, pitch, roll, and yaw. The transmitter establishes wireless communication with a receiver situated on the UAV, facilitating the transmission of control signals.

8. **Camera**: The camera has a vital role in capturing aerial photos and images, representing a significant application of UAVs. In the market, there is a diverse array of camera types and qualities, providing various options for selection.

2.4 Payload

The equipment allowing the UAV to accomplish its missions. UAV payloads can generally be categorized into the following four sub-elements: sensors, communication relay, weapons, and cargo. In this paper, the context of the payload would be weapons.

2.4.1 Hand-Held Grenades

"Grenade" is a term derived from the Latin word, granatus, defining an object that is "filled with grains." The "grains" mentioned refers to the explosive mixtures and compounds contained within metal canisters which is set off by the various nature of ignition methods. Some sources also relate the term with ‘granada,’ a Spanish word for pomegranate, resembling the weapon with the common fruit. Grenades are acknowledged as compact hand bombs designed for inflicting damage at short ranges [20]. The basic concept involves igniting combustible material to generate an explosion—a rapid expansion of gases creating significant outward pressure. During World War I, hand grenades were also referred to as "hand bombs." The prevailing strategy behind their use in military forces was that grenades could effectively eliminate enemies positioned underground or behind cover. In the trench warfare of World War I, soldiers could employ grenades to neutralize machine gunners without exposing themselves to the enemy. Additionally, grenades could compel the enemy to move into the open [21], making them susceptible targets for rifle and machine gun fire. With the development of mechanical ignition systems that enhanced practicality and safety, grenades became an indispensable component in modern warfare.

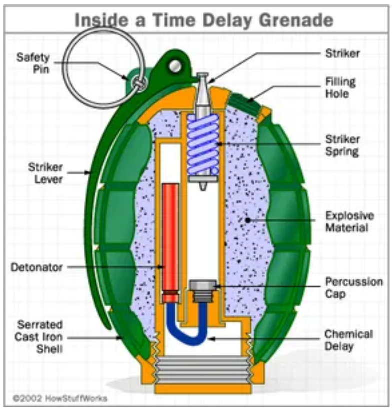


FIGURE 2.7: Anatomy of a Time-delay Fragmentation Hand Grenade

The firing mechanism of a fragmentation grenade is activated by a spring-loaded striker housed within the grenade. Typically, the striker is secured by the striker lever located on the grenade’s top, and this lever is held in position by the safety pin. When a soldier holds the grenade, the striker lever is pressed against the body. To initiate the firing process, the safety pin is withdrawn, and the soldier then throws the grenade. Below [22] is what happens once the grenade is released:

1. Once the pin is removed, the lever loses its restraint, allowing the spring-loaded striker to descend freely. The spring propels the striker downward, striking the percussion cap, and the impact generates a small spark.

2. This spark initiates the ignition of a slow-burning substance in the fuze. In approximately four seconds, the delay material burns completely through.

3. The end of the delay element is linked to the detonator, a container filled with more combustible material. The burning material at the delay's end ignites the content in the detonator, triggering an explosion within the grenade.

4. This explosion ignites the explosive material surrounding the grenade's sides, leading to a significantly larger explosion that ruptures the grenade.

5. Fragments of metal from the outer casing are propelled outward at high velocity, embedding into anything or anyone within range. Such a grenade might also contain additional serrated wire or metal pellets to enhance fragmentation damage.

2.5 3D Printing Technology

Fused Filament Fabrication (FFF) [23], also known as 3D printing, is a manufacturing process that involves constructing objects layer by layer by depositing melted material. The materials commonly used in this process are the same thermoplastics found in traditional manufacturing, such as ABS and Nylon. FFF has played a pivotal role in the proliferation of desktop 3D printers [24] and stands as the most widely adopted 3D printing technology. This popularity is attributed to its low initial investment requirements, a wide range of applications, and the minimal specialized knowledge needed for effective utilization. In the FDM/FFF (Filament Deposition Modeling/Fused Filament Fabrication) type of printers, parts are built using strands of plastic feedstock known as filaments.

The plastic is melted and extruded to progressively construct the 3D model. Various types of 3D printer filaments are available, known for their strength and durability. In essence, 3D printing, specifically through Fused Filament Fabrication, revolutionizes manufacturing by enabling the creation of objects layer by layer using melted thermoplastics, offering versatility, accessibility, and ease of use for a wide range of applications.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Research Outline

To fulfill the conceptual design, the research outline is done through a systematic approach. Each phase is gone through in order, describing the results with certain level of details as it progresses. The concluding factor of each phase will cater a starting point for the next phase. Below is the order that aided the author to conduct an efficient method of conceptual designing:

1. Benchmarking: The UAV market is always expanding as the technology advances significantly. A wide range of UAVs are available and are now increasingly common in both professional and civilian environments. Different types of UAVs are used for various purposes. Benchmarking is a tool that allows us to narrow the UAV categories and classification scope and find the correct references from products similar to our design approach.

2. Defining Design Requirements and Objectives: Clarifying the operational objectives of the UAV will highlight the requirements based on the information collected describing the existing constrains and their importance to the contribution of the design.ion Requirements

3. Conceptual Sizing: Conceptual sizing identifies the essential problems that are extracted from the design objectives and requirements and are translated into the initial sizing stage of the functioning solutions.

4. Component Selection: The functioning solutions from the previous phase are further aided with the addition of technical components to produce the feasible layout and architecture of the conceptual design.

5. CAD Modeling: This phase will consist of a 3D modeling process that compliments the two previous phases of Initial sizing and component selection. The completed product will produce an importance to overall weight estimation of the UAV which will later be used in the next phase.

6. Performance Analysis: Final step to the conceptual designing would be assessing all the supporting data and specifications from the previous phases and using it to analyze the performance. This final step will virtually determine whether the design can be concluded.

7. Cost Estimation: Cost estimation is a critical step in low-cost design. The conceptual product is assessed through cost factors which mainly consist of the total component budget.

3.2 Web Based Tools and Softwares

The research utilize several web-based tools available as open source to conduct estimations and analysis of the UAV design. The website provides significant resources that has aided this research study. The aforementioned tools and their use are listed below:

3.2.1 eCalc xcopterCalc - Performance Calculation

To conduct performance calculations, An open-source web-based performance calculator programmed to calculate various UAV configurations called eCalc [25] is used. Since the configuration type of the UAV is a quad-copter, eCalc's xcopterCalc for multicopters would be the reasonable calculator.

3.2.2 Onshape - Computer Aided Design

Onshape [26] is a web-based computer-aided design (CAD) software system, delivered via a software as a service (SAAS) model. The online software uses cloud computing for running computer-intensive processing and rendering performed on Internet-based servers. The user does not require to maintain the software

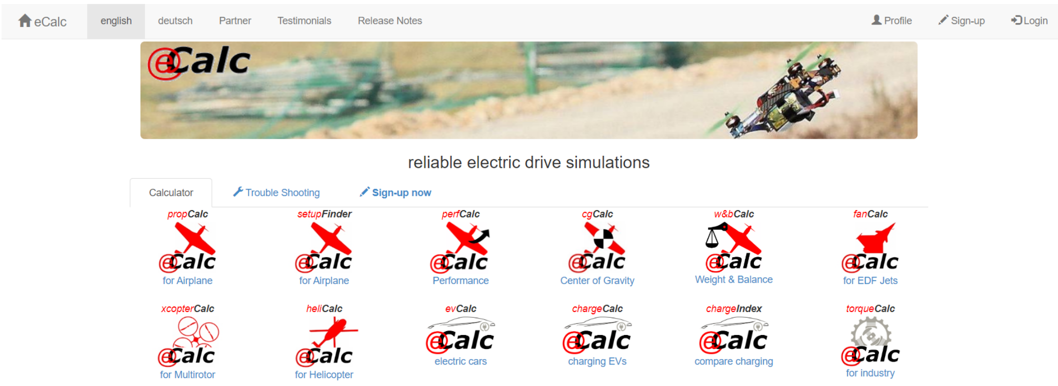


FIGURE 3.1: eCalc Performance Calculator

since Onshape releases upgrades directly to the web interface, since it is a product of the SAAS system. Users are able to take advantage of the product via web browser or even mobile apps, both in IOS and Android.

3.3 Benchmarking

Conducting a benchmark study during the conceptual design phase allows identifying and understanding best practices in similar products or systems. This knowledge helps in incorporating successful design elements from existing solutions, leading to improved functionality and efficiency. By benchmarking against existing products or solutions, one can compare the performance of the conceptual design with industry standards. This helps in setting realistic performance goals and ensuring that the proposed design meets or exceeds current benchmarks. It helps in justifying design choices, selecting appropriate technologies, and prioritizing features based on their impact on overall performance and user satisfaction. Understanding how similar designs have performed in real-world applications helps in identifying potential risks and challenges. This proactive approach addresses issues early in the conceptual stage, reducing the likelihood of costly and time-consuming revisions later in the development process. The SpearUAV's Viper40 [27] and Defendtex's Drone40 [28] are the only known two concepts with specifications to be released into public that are design for similar operational objectives. Both operate as loitering munition UAVs that also provides additional surveillance. There are updates about Defendtex's Drone40 while SpearUAV's Viper40 is still a prototype. The following are descriptions and features of the two UAV concepts.

PRODUCT	SPECIFICATION	w PAYLOAD	w/o PAYLOAD	UNITS
	Overall Weight	300	110	g
	Payload Weight	190	190	g
	Max Speed	72	72	km/s
	Endurance	30	60	min
	Max Range	20,000	20,000	m
	Length	180	120	mm
	Diameter	40	40	mm

TABLE 3.1: Defendtex Drone40 Specification

The Drone 40 is described as an autonomous, loitering munition UAV deployed from standard 40mm grenade launchers or when needed, hand launched. It features a GPS based autopilot system with a portable ground control station communication. The Drone40 is equipped with modular payload bay that offers quick in field changes ranging from ISR payloads to kinetic effects. In a non-kinetic operation, the UAV is recoverable and reusable. The targeting and control of the Drone40 is achieved through the integration with existing deployed smart devices and readily available communication technology. The Drone40's explosive payload is made in-house. Table [3.1] shows the specifications of the Drone40.

PRODUCT	SPECIFICATION	w PAYLOAD	w/o PAYLOAD	UNITS
	Overall Weight	450	250	g
	Payload Weight	200	200	g
	Max Speed	65	65	km/s
	Endurance	25	35	min
	Max Range	1000	5000	m
	Length	N/A	N/A	mm
	Diameter	40	40	mm

TABLE 3.2: SpearUAV Viper40 Specification

The Viper40 is designed as a compact quick-launch UAV made for unpredictable terrains of challenging conditions and bustling urban locals that is conveniently stowed in a combat vest to ensure immediate accessibility during intense combat situations. It seamlessly integrates with existing military hardware, specifically compatible with existing grenade launchers like the M320. Once launched, the UAV provides an aerial viewpoint for a clear line-of-sight targeting and diversions capabilities. The UAV also carries a 40mm integrated explosive payload to carry out loitering munition operations. Table [3.2] shows the specifications of the Viper40.

3.4 Defining Design Requirements and Objectives

A Low Cost and Compact UAV used in strategic tactical defense operations in an urban environment should be able to carry out reconnaissance operations as well as lethal defense operations. After learning the specifications of the competitor's data from the benchmarking section, the user needs, mission requirements and objectives for this research's UAV conceptual designed is declared. However, limitations to expectations of the conceptual outcome are imposed to the design. This is largely to to the component and payload availability and characteristics, which will be explained later in this research paper.

3.4.1 User Needs

The main possible user needs are formulated based on the features present in the competitor's UAV.

3.4.2 Mission Requirements - ISR Operations

Evaluating competitor's specifications, the ISR mission requirements for this research is established as follows:

Compact	To occupy minimal space in a personnel's carry-on.
	Lightweight enough to reduce personnel's weight load.
	Do not require take-off or landing zones.
	Capable of interchanging payload between operations.
Low Cost per Unit	Avoiding shipping costs, able to be assembled and manufactured on-site.
	Capable of recovering UAV in certain operations.
Fixed on-board Camera	Includes a camera mount, for a camera to guide the UAV operator visually.
Payload Releasing	Suitable mechanism for payload releasing during dropping or kamikaze operation.
Off-the-Shelf Components	Consider market available payload.
	Avoid in-house built components, consider components available in the market.
	Components specifications and configurations allowed to be altered according to user's desire

TABLE 3.3: User Needs

3.4.3 Mission Requirements - Loitering Munition Operations

Evaluating competitor's specifications, the loitering munition mission requirements for this research is established as follows:

3.5 Conceptual Sizing

Through identifying the design objectives and requirements we can continue abstracting and reformulating a problem description, within the scope of the requirements and its goals. The view to the problem broadens and relieves any unnecessary details and help to determine the core requirements of the design. This helps us to narrow our design perspectives, focusing on innovations directly related to the requirements of the design. For the conceptual sizing we will be focusing on determining the structural design configuration of the UAV. Through

ISR Operations			
No	Design Requirements	Objectives	
		Target	Goal
1	Capable for ISR Operations	Yes	Yes
2	Overall Weight (g)	400	250
3	Payload combatibility	On-board Camera	Others
4	Endurance (min)	30	60
5	Range (m)	5000	10000
6	Dash Speed (km/h)	65	75

TABLE 3.4: ISR Operations Design Requirements

Loitering Munition Operations			
No	Design Requirements	Objectives	
		Target	Goal
1	Capable for payload dropping	Yes	Yes
2	Capable for defense kamikaze	Yes	Yes
3	Overall Weight (g)	800	650
4	Payload compatibility	Fragmentation hand grenade	Others
5	Endurance (min)	15	30
6	Range (m)	1000	5000
7	Dash Speed (km/h)	65	75

TABLE 3.5: Loitering Munition Operations Design Requirements

the benchmarking process, we know that most of the existing prototypes or products use a quadcopter configuration for their design. As we know from our literature review about multi-copters and quadcopters, they are agile vehicles and a suitable configuration candidate for military operations in urban environments. Our base configuration for our UAV design would be a quadcopter, which would mean that there will be 4 ‘arm’ structures to be considered on the UAV. To initiate the conceptual sizing phase, we start from formulating an airframe configuration.

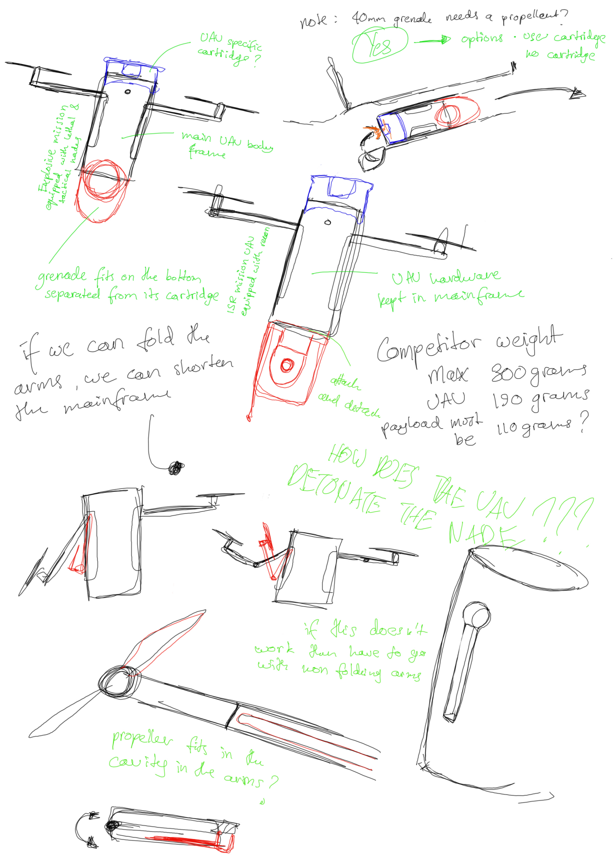


FIGURE 3.2: Early Concept

3.5.1 UAV Classification

Based on the US Department of Defense UAS Group Descriptions in Table [2.1], military UAV classification group is divided into 5. The UAV concept in this research study belongs to group 1, which will fall in the weight category below 9.5kg, fly under 1200 ft AGL and have an estimated speed of upto 100 km/h. However, to be more specific, the grouping is broken down into further 3 main classifications according to the JUAV CoE. The UAV concept in this research falls into the category of 'Tactical UAVs'.

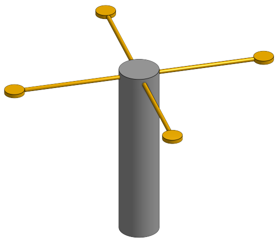
3.5.2 Airframe Configuration

Assessing the requirements from the above requirements and objectives, we start to formulate our concept from the main airframe shape. Multi-copter UAVs comes in various configurations. With each configuration, we can narrow down similarities based on their operational objectives. We can determine the shape of the airframe first hand by referring to similar UAV prototypes or in operations of the same nature. Based on the benchmark study, all the purpose-built tactical defense UAV are of a cylindrical shape. The drone40, and the Spear Viper40, are of a cylindrical shape, mainly because they are designed to be launched out of a launcher when needed. The benchmark study reveals that both the manufactures designed their UAVs with a 40 mm diameter configuration. This is because the UAV could be launched from existing 40 mm grenade launchers, not needing a stand-alone launcher for the UAV. This research suggests a payload criteria later in the study, that will restrict the design to follow a 40 mm diameter size. Hence, the UAV airframe is predicted to be larger than the competitors. Whilst UAV frames available in the market come in a cuboid configuration, to fit the components efficiently in the frame. A cylinder will have less the volume than a cuboid of the same diameter and length. However, these two functions are necessary to be incorporated into the design. Hence for the outer shell of the airframe, a cylinder is considered, and a cuboid frame will be installed inside the cylindrical shell to house the needed components.

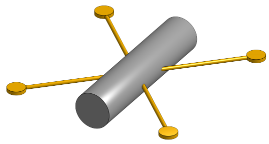
3.5.3 Airframe Orientation

The airframe orientation concerns the airframe or fuselage orientation of the UAV, either horizontal or vertical. From the benchmark study, we can observe that Defendtex's Drone40 has a vertical airframe orientation whilst SpearUAVs Viper40 has adapted a the conventional horizontal airframe approach. In a vertical airframe, the weight can be evenly concentrated in the center since, in theory, the components are stacked on top of each other in that orientation. A horizontal airframe would be possible if we could place the battery and the payload right at the center of the airframe. Since, our components are made up of market available components, we will be unable to make modifications to the electronics.

This would mean that there are no available loopholes to be exploited to adjust the component position. In addition, the electronics would take up the majority internal space available at a set dimension. To keep it in a small diameter, the arms are placed on the top center of the UAV, similar to the drone40. This orientation will also provide good stability to the UAV.



(A) Vertical Airframe Orientation



(B) Horizontal Airframe Orientation

FIGURE 3.3: Airframe Orientation

3.5.4 Payload Criteria

From the benchmark study, it is acknowledged that both Defendtex and SpearUAV uses integrated explosives for loitering munition operations. Meaning, they can blend the payload system into the UAV design, allowing the UAV to be more streamline and attain the initial features. In this paper's case, the research does not include the consideration to design an explosive device from scratch that can be integrated into the UAV, since the approach would be too complex. Therefore, an existing payload reference is considered. Fragmentation hand grenades are light explosive weapons frequently used during combat. Due to the research's place of origin, Hand grenades known to be used by Indonesian military forces are listed in Table [3.6][29].

Most fragmentation hand grenades weigh around 400 to 600 grams alone .For this research, the Pindad GT5-pea2 [30]Defensive Grenade will be a reference for the payload weight calculation and acts as a general medium for Loitering Munitions operations where payload is considered, whether during Payload Dropping or Defense Kamikaze. The specifications are included in Table [3.7]. PT Pindad, previously known as Perindustrian Tentara Nasional Indonesia Angkatan Darat (translated as Indonesian Army Industries), is a government-owned company in

Fragmentation Hand Grenades							
Model	Image	Dimension LxB (mm)	Origin	Version	Fuse delay	Type	Mass (g)
US Military M26		99 x 57	United States	M26	4 - 5 sec	Defensive, striker delay	454
Soviet F-1		130 x 55	Soviet Union	F-1	3.6 - 4 sec	Defensive, Striker delay	600
US Military M67		90 x 64	United States	M67	4.5 - 5 sec	Defensive, Striker delay	400
PT. Pindad GT5-PEA		108 x 50	Indonesia	GT5-PEA	4 - 6 sec	Defensive, Striker delay	430

TABLE 3.6: Indonesian Military Force Fragmentation Hand Grenade Known Equipment List

Indonesia that focuses on manufacturing military and commercial goods. Pindad specializes in supplying weaponry and munitions (known as alat utama sistem persenjataan, Alutsista) to the Indonesian National Armed Forces and various uniformed agencies. Its primary goal is to enhance the defense and security capabilities of the Republic of Indonesia.

FIGURE 3.4: Pindad GT5-pea2 Defensive Grenade

Specifications		
Ammunition	Overall Length	108 mm
	Weight	430 g
	Diameter	50 mm
Components	Body	Grey Cast Iron
	Detonator	No. 8 M1
	Charges	TNT Powder
Characteristics	Delay Time	4 - 6 seconds
	Safety System	Double, clip and pin
	Extraction Force of safety pin	5 - 15 kg
	Safety Range	Radius 30 m (min)
	Fragments	1000 pcs

TABLE 3.7: Pt. Pindad GT5-pea2 Hand Grenade Specification Table

3.5.5 Payload Releasing Mechanism

There are an abundant of object releasing mechanisms available as reference. These mechanisms consist of different moving parts that functions as one system. Moreover, the core to the mechanism would consist an actuator that will initiate the desired movements. The range for release mechanism will depend on the freedom of the actuator. But we must keep in mind that components chosen for the design should be available to the open market or off-the-shelf, which also applies for the payload. For this conceptual design, the gt5-pea2 hand grenade of Pindad is considered. To avoid any mechanical failure during active operations, the number of moving parts should be limited. The main function of the mechanism should comply with payload releasing and payload dropping operations. The only similarities would be, in both operations, they should be able to hold the grenade in place and armed during take-off and loitering.

3.6 Component Selection Criteria

Component selection in the field of aeronautical engineering plays a critical factor [31]. The overall primary system performance of the UAV greatly depends on the weight of the aircraft. Therefore, the selection of the UAV components must

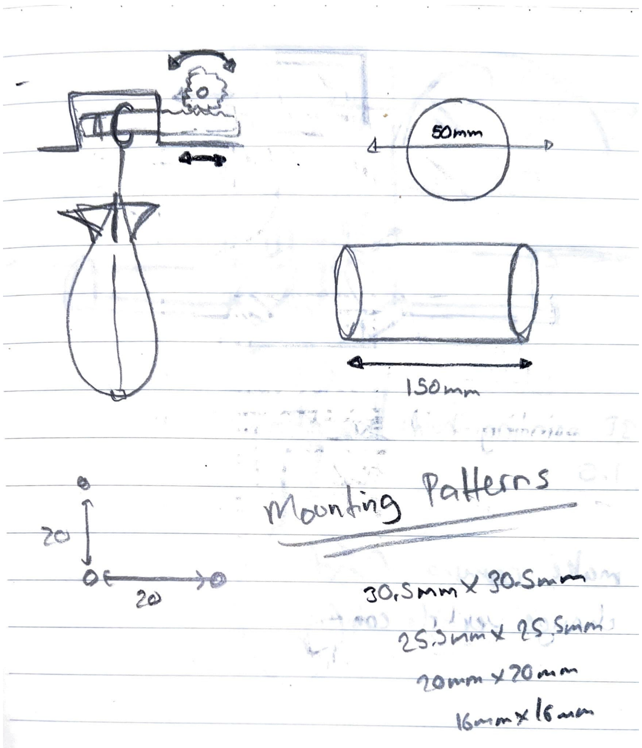


FIGURE 3.5: Payload Releasing Concept

be considered from the perspective of weight. Apart from the weight factor, the component criteria are also regulated by the total cost cap it accumulates to. We must keep in mind that Low Cost is one of our objectives to be fulfilled. Components selection is fulfilled through the method of components off-the-shelf. The term "off-the-shelf" (OTS) refers to products that are readily available for purchase as pre-made items, rather than being custom-built or specially designed. The "off-the-shelf method" typically refers to an approach or strategy that involves using commercially available, pre-manufactured components or solutions to meet a specific need or requirement, instead of creating a custom solution from scratch. The key advantages of the off-the-shelf method include time and cost savings, as well as the convenience of leveraging existing solutions. However, it may also have limitations, as the available components may not perfectly align with the specific requirements of the UAV Concept. To select the appropriate components, we must know the estimated thrust required.

3.6.1 Theoretical Calculation

The estimations conducted in this paper to design a UAV concept are based on theoretical calculations [32], using related conditions. Equation [3.1] is obtained from the data collected from existing products that are designed for similar operations objectives with this paper. The comprehensive relationship between the payload weight and overall weight of existing products are shown in Table [3.8].

$$W_{Pl} = 0.539 W_O \tag{3.1}$$

Company	Defendtex	SPEAR
Product	Drone40	Viper40
Overall Weight	300	450
Payload Weight	190	200
W_0	0.63	0.44
Avg	0.539	

TABLE 3.8: Relationship Between Payload Weight and Overall Weight of Selected Quadcopters

We know that we are using Pindad's GT5-pea2 defensive grenade as the payload reference, which weighs 430 g. Additional 40 grams are added into the overall payload weight estimation that includes the structures, actuators and payload releasing mechanism. Estimated Payload system weight will be at 470 g in total. The overall weight of the UAV can be calculated as $\frac{470}{0.539} = 872$ g. Therefore, from the above estimated overall weight, we can achieve the minimum thrust required by a single propeller of the UAV. For a quad-copter at a normal level, a single propeller should produce $\frac{872}{4} = 218$ g of minimal thrust. Thrust-to-Weight ratio at a maximum level is assumed to be 1.75, while the normal level ratio is equal to 1. With the following significant inputs, primary components of the UAV can be estimated. Thrust of a single propeller at a maximum level will require thrust of:

$$\frac{1.75x872}{4} = 382g \tag{3.2}$$

Components including the propeller, motor, battery and ESC are the primary components can utilize the data. Furthermore, the individual component criteria are explained below.

3.6.2 Motor

The UAV in this conceptual design uses brushless motors to provide the necessary thrust power. The selection of the proper motors is very important, since it varies with the nature of the mission. A quadcopter configuration is chosen for this design, that would mean we would require 4 motors in total. The essential characteristics of a drone motor are the Amperage, KV rating, the torque, and the recommended propeller dimensions. The KV rating is inversely proportional to the torque. A higher KV rating setting would produce faster motor RPM but less torque. A high KV rating motor can fly fast but would carry less load for a given voltage. Our primary loitering munition operation objective is the ability to fly with a hand-grenade. The payload weight, in our case, the Pindad gt5-pea, is almost the same as the UAV itself, which would mean that we would need a high torque. A high torque producing motor would have a low KV rating, which is what we need. The motor diameter should also be limited, since the design adapts folding arms, the UAV should retain its compactness. The estimated minimum thrust at a maximum level requirement, according to the calculation in Equation [3.2] above is 382 grams. Therefore, the selected motor must have thrust more than 382g.

3.6.3 Electronic Speed Controller

ESCs controls the speed and rotational direction of the motors and the propellers. The ESC's amperage must be higher than the total current drawn by all motors and other supplementary components. It is important to consider every component's consumption. The higher the UAV flies, the more the motor consumes power. But since our UAV is designed to fly at low altitudes, consumption based on altitude will not be regulated. ESCs are available individually connected to each motor, meaning one ESC per motor. However, for small sized UAVs, an all-in-one ESC is more suitable since it gives the same function but is more compact.

3.6.4 Flight Controller

Flight controllers being the computers of the UAVs, do not have compatibility issues with other parts of the UAV. The only things to be considered are preferred flight control software the user is used to and the microcomputer specifications. Some manufactures have designed FCs that can be stacked with the ESC board. This type of "All-in-one" stack are more compact.

3.6.5 Propeller

Critical factors in selecting propellers to be considered are the propeller length and pitch. The pitch defines the traveling distance per single revolution of the propeller, the higher the pitch the farther it cuts through the air and create more pressure difference. High propeller pitches produce high top speed but less acceleration, subsequently more turbulence and give out less torque. Lower pitch propellers delivers maximum rpm even at lower speeds but produce less top speed.]On the other hand, larger propeller diameters that attain more contact with the air, contribute to higher substantial lift, even at a lower rpm. This relates directly to flight efficiency, since the small increase or decrease in diameter can change the flight efficiency of the UAV. However, larger blades force the motors to consume more power and have a low rate of change in RPM. Synchronizing the propeller diameter and pitch depends on the operational objectives of the UAV. For payload focus heavy UAVs, a lower pitch is suitable since it results in more torque to reduce exhaustion of the motor when carrying the payload. This would decrease the burden on the motors and draw less current from the battery which will reward an increased flight time. The larger the propeller, the more efficient the flight will be, but we must remember that our UAV must be within the ‘Compact’ rule. Therefore, to stay in the compact range, folding propellers are preferred. Larger blades with low pitch are paired with motors that have low KV ratings.

3.6.6 Radio Transmitter and Receiver

A compatible radio transmitter is interfaced with the flight controller on the UAV. The radio controller or transmitter must have at least four channels to control a quadcopter efficiently.

3.6.7 LiPo Battery

Lithium Polymer Batteries have high energy density and provides a higher voltage of 3.7 V per cell. Battery capacity is denoted by its mAh, the higher the capacity, the more power it supplies, meaning more potential flight time. But it also means that, the size and weight will increase along with the given capacity. Motors will also often have their compatibility with the battery in terms of the number of cells. For example, a battery specification of 2200 mAh 3S 30C will have a capacity of roughly 2200 mAh, a voltage output of 3 x 3.7 V or 11.1 V and a current production of 30 x 2200 mA or 66A. The battery must be selected on the basis of the combined current consumption of the motors.

3.6.8 Camera

The camera provides the birds-eye view to the operator. The selection of the camera is not at all strict, providing a wide range of selections. The only considerations taken are the weight and dimensions of the camera. The mounting provided in the UAV is 30 x 30 mm, the camera should fit within those dimensions and has to be as lightweight as possible. The camera should also provide clear imaging to provide better mission effectiveness.

3.6.9 VTX

The VTX or video transmitter is a component of the UAV that tirelessly transmits the live feed from the camera to the desired display. When selecting the VTX, consider compact size, channel support, and accurate transmitting frequency. Additionally, long range and high output power provides optimal performance for the operator.

3.6.10 FPV Compatibility

Flying the UAV in FPV mode or First Person View [33] has it's benefits over flying traditionally. FPVs give an immersive experience that binds the UAV with the pilot for a futuristic viewing. FPVs allow for more precise flying and better accuracy as the low-latency transmission makes for quicker reactions and better situational awareness of the surroundings. Certain VTX provide low latency image transmission from the onboard camera to the desired display. FPV setup will although, need additional FPV googles.

3.7 CAD Modelling

After selecting the necessary components, the CAD model can be produced. Creating a CAD model helps to engage in an iterative design processes. We can easily modify, refine, and experiment with different design configurations without the need for physical prototypes at each stage. This iterative approach accelerates the development timeline and enhances the overall quality of the final design. The UAV is required to be as compact as possible while retaining structural strength.

3.7.1 Component Placement

The efficient placement of components is necessary to minimize useless empty spaces, allowing the design to be as smaller as possible. Cable management of the electronics should be taken into notice and little spacing margin should be provided.

3.7.2 Weight Estimation

3D printing is the chosen method of manufacturing because of its availability and economic benefits. Polycarbonate filament [34] is selected for the UAV component material. It should be made aware that this material should have a minimum thickness of 1.75 mm. CAD modeling largely contributes to the research with its ability to input material properties for each component of the UAV. This

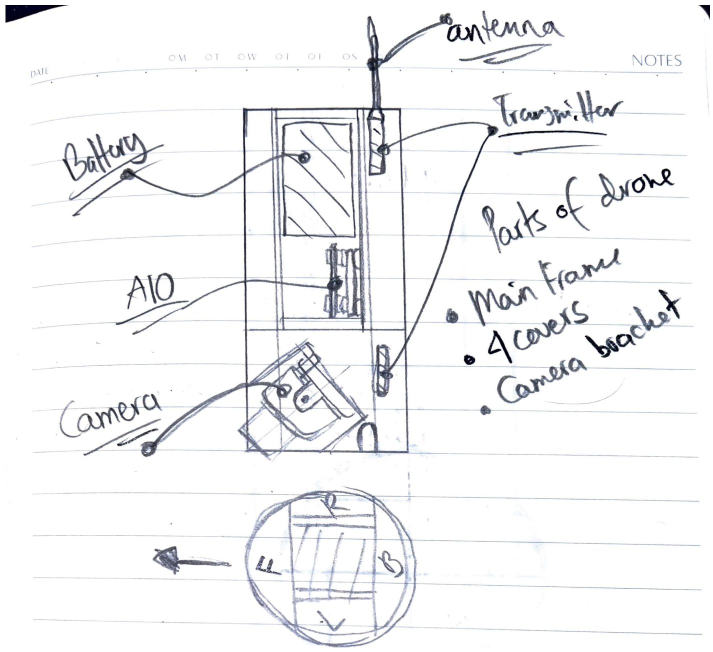


FIGURE 3.6: Component Architecture Concept

feature enabled the incorporation of real-world material specifications into the CAD model, producing weight estimations with respect to its part size.

3.8 Performance Calculation

After achieving component specification and complete weight estimation from the previous phases, performance calculation can be initiated. The sequence provided by eCalc dictates what parameters are included for the calculator input. Figure [3.7] shows the input section that is divided into five sections; General, Battery Cell, Controller, Motor and Propeller. After the data input is completed by the user, the results are shown in the form of Quick check gauges, Results and graphs informing Range estimator and Motor characteristics during full throttle.

3.8.1 Data Input - General

The inputs for the general sections contains general specifications and configuration of the UAV. Environmental conditions are also included in the calculator.

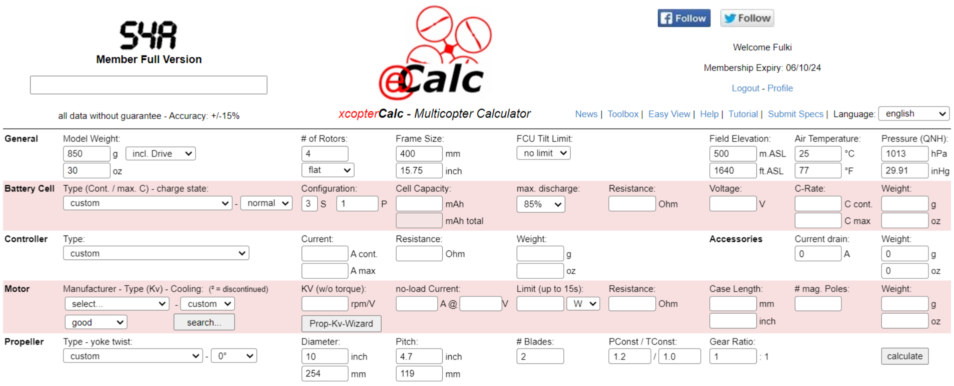


FIGURE 3.7: eCalc xcopter Multicopter Performance Calculator

Since this research author's campus is situated in Jakarta, Indonesia, the environmental conditions of Jakarta are used for reference. Below are the required parameters to be considered.

1. **Model weight**: The model weight is categorized into three types; weight including the drive (overall weight), weight without battery and weight without drive. According to the calculator, the drive consist of the Battery, the ESC, the Motors, and +10% for the props. By the time we reach the performance analysis phase, all electric components and UAV structures are found. Hence we can directly input the overall weight of the UAV

2. **Number of rotors**: The total number of motors arranged respective of their configuration. A flat rotor will consist of one motor per arm.

3. **Frame size**: The size of the frame is defined by the distance between the two opposite motors, or double the arm length from center to motor.

4. **FCU tilt limit**: Most FCU (Flight Control Units) or flight modes limit the maximum tilt of the UAV for better control. However, we do not limit in this design.

5. **Environmental conditions**: The environmental conditions in Jakarta is used for reference. A field elevation of 100m above seal level, air temperature of 30 deg C, and pressure of 1012 hPa.

3.8.2 Data Input - Battery Cell

The battery cell parameters are given for certain battery types, but the given parameters are avoided for the calculations. To have a precise result of the analysis, the parameters of the battery cell is typed in manually. The UAV uses a LiPo battery to power the flight.

1. **Type and charge state**: The battery type is the given battery parameters according to the calculator's battery capacity. We will be using a custom type to input the parameters manually. The charge state dictates the battery percentage. During fast paced operations, batteries are assumed to be precharged to 100%.

2. **Configuration**: As far as LiPo batteris are concerned, the battery configuration is the number of cells present in the battery.

3. **Cell capacity**: Battery capacity defined as battery mAh.

4. **Max discharge**: Max discharge rate is the maximum percentage of the battery's total capacity to be used for the flight. To maximize performance results, the discharge rate is assumed at its maximum potential.

5. **C-rate**: The C-rate of the battery follows manufacturer's specifications.

6. **Weight**: The weight of the battery is defined weight per cell. For example, if the battery configuration contains 4 cells, the manufacturer's weight specification is divided by 4.

3.8.3 Data Input - Controller

The controller in this calculator is the electronic speed controller. The ESC's amperage must be higher than the total current drawn by all the motors and other components if any. The calculator assumes input parameters are of individual ESC to each motor. Adjustments are to be made if an all-in-one ESC is considered.

1. **Type**: The controller type is the amperage of one ESC. The parameter to be included in this option should only be of one ESC. For example, if the ESC amperage is 55A x4, the parameter input should be 55A.

2. **Weight**: The calculator assumes that the an individual ESC is connected to each motor, meaning the weight input in the calculator is weight per ESC. If the user intends to use an all-in-one ESC, the weight input should be the manufacture's weight divided by the number of motors.

3. **Accessories**: Additional accessories is defined in this section and the corresponding current consumption if supplied by flight battery

3.8.4 Data Input - Motor

The calculator provides a search bar to find the motor selected for the UAV. Various motor specifications are available in-built. Manual input of parameters are not needed if the motor is available in the list of motors.

1. **Manufacture**: Choose the manufacture of motor

2. **Type**: Choose motor type given in the list

3.8.5 Data Input - Propeller

The bigger the prop diameter, the more efficient the copter hovers, but has a trade-off with control response.

1. **Diameter**: The diameter is the overall disk size of the propeller.

2. **Pitch**: Pitch inputs and diameter inputs are typed in according to manufacture data if applied. propeller with pitch to diameter ratio greater than 0.667 tends to stall with increasing load. A stalling propeller blade might lead to loss of control.

3. **Number of blades**: Number of blades on a single propeller.

3.8.6 Data Input - Custom Components

As long as the component's technical data is available, custom data can be used. Choose «custom» in the drop down list of the respected section and enter the required data fields.

3.8.7 Result - Quick Check Gauges and Results

Results displayed in Figure [3.8] the quick check gauges are shown as an addition for quick overview of the setup. The following section shows a more detailed result.

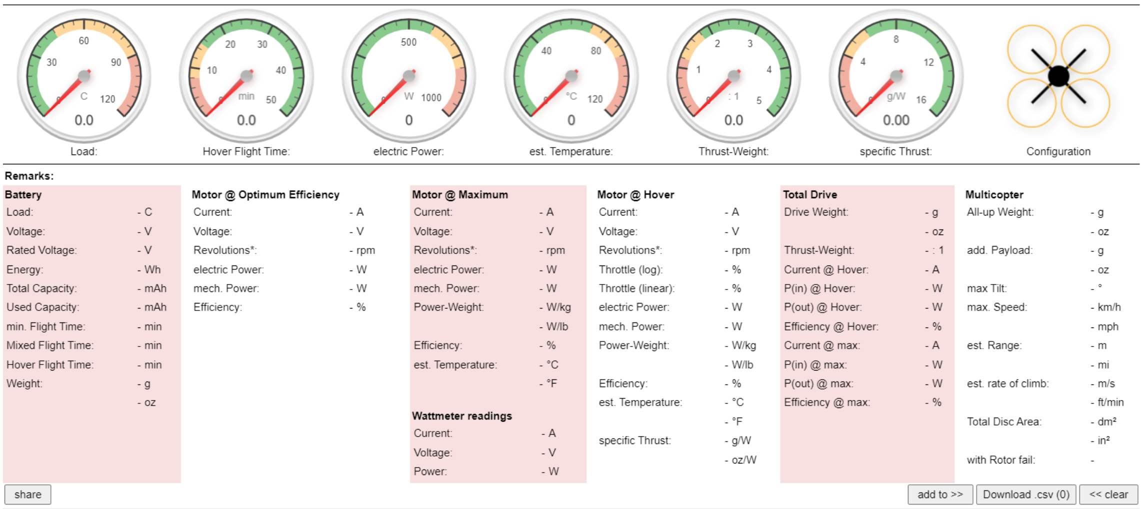


FIGURE 3.8: eCalc xcopter Quick Check Gauge and Results

1. **Load**: The discharge rate of the battery, the following indicators displayed:
   - green; The range for continuous C-rate
   - yellow; The range for peak C-rate
   - red; Over limit
2. **Hover Flight Time**: The range for flight time during hover only
3. **Est Temperature**: Predicted maximum temperature of the UAV
   - green; Normal range
   - yellow; Critical range
   - red; Over the limit, risk of overheat
4. **Electrical Power / Current**: The maximum values in relation to the specified motor limit (max 15sec) either in Wattage or amps.

- green; Normal range
- yellow; Critical range up to limit
- red; Over the limit, risk of permanent damage

5. **Thrust-to-Weight ratio**: Indicator for flight performance. The higher the value, the more agile the copter gets. It also shows max throttle for hover
    - green; 1.8 and above needs 60% throttle for hover
    - yellow; 1.2 to 1.8 results in 60% to 80% throttle for hover
    - red; hovering is not possible at this range
6. **Specific Thrust**: Specific thrust of the propeller indicates the overall hover efficiency.
    - green; 6g/W and above is considered as good efficiency
    - yellow; 4 to 6g/W is considered as poor efficiency
    - red; below 4g/W is ineffective

3.8.8 Result - Battery Remarks

- **Load**: Actual discharge rate in relations to battery capacity.
- **Voltage**: Battery Voltage under expected max current
- **Rated Voltage**: According to manufacture
- **Energy**: Of battery
- **Total Capacity**: Of battery
- **Used Capacity**: Used capacity of flight according to max discharge percentage of the battery. Base for any flight time calculation
- **min. Flight Time**: Expected minimal flight time based on maximum throttle (based on max discharge rate of battery) and independence from weight.

- **mixed Flight Time**: Expected flight time based on overall weight when flying based on max discharge rate of battery. Base is the geometric mean value of current difference from hover to max
- **Hover Flight Time**: Expected Flight Time based on overall weight when hovering only (based on max discharge rate of battery)
- **Weight**: Total weight of the battery pack.

3.8.9 Result - Motor (individual) at Optimal Efficiency and Maximum

- **Current (Opt Efficiency)**: Current for maximum motor efficiency .
- **Current (Maximum)**: Maximum amp load.
- **Voltage**: Voltage at the motor.
- **Revolutions**: Maximum revolutions.
- **Electric Power**: Electric input power
- **mech. Power**: Mechanical output power or shaft power.
- **Power-to-Weight**: The Power Weight Ratio for the maximum current case.
- **Efficiency**: Efficiency at maximum Amp Draw.
- **Est Temperature**: Estimated Temperature of the Motor Case, subject to the motor cooling. Temperatures over 80°C and higher might damage the motor. Temperature over 100°C are very critical.

3.8.10 Result - Motor (individual) at Hover

- **Current**: Estimated current at hovering, the hover current should be close to the optimal current or slightly below.
- **Voltage**: Motor voltage at hovering.

- **Revolutions**: Propeller revolutions at hover.
- **Throttle (log)**: Some ESC aims for a (pseudo) power or thrust linearity. This Throttle position for hovering represents the stick position to hover in manual mode assuming a logarithmic PWM (Puls Width Modulation) transformation by a power or thrust linear ESC. **Remark**: As this logarithmic curve may differ between brands this is a empirical value.
- **Throttle (linear)**: Conventional ESCs aim for (pseudo) RPM linearity. The Throttle position for hovering represents the stick position to hover in manual mode with a linear PWM (Puls Width Modulation) by RPM linear ESCs. That means 60% Throttle represent the PWM controls the FET 60% on / 40% off resulting in a linear voltage/rpm at the motor. **Remark**: Do not mistake this value with the PVM Time in micro seconds shown on some flight control logs.
- **el. Power**: Electric input power.
- **mech. Power**: Mechanical output power or shaft power.
- **Power-Weight**: Power to Weight Ratio at hover. 150W/kg is a rule of thumb, very efficient setups bring that down to approximately 80W/kg.
- **Efficiency**: Motor efficiency at hovering.
- **est. Temperature**: Predicted motor temperature, subject to the motor cooling.
- **Specific Thrust**: Grams of Thrust produced with one Watt of electric Input Power at the propeller.

3.8.11 Result - Total Drive

- **Drive Weight**: Weight of all drive components (with 10% margin for propeller weight compensation and others)
- **Thrust-Weight**: Thrust to weight ratio, result below 1.2 will almost be impossible to fly.

- **Current at Hover**: The sum of all motors when hovering
- **el. Power at Hover**: Electrical input power of the battery when at hovering.
- **mech. Power at Hover**: Mechanical output power or shaft power when hovering.
- **Efficiency at Hover**: The total efficiency at hovering
- **Current at max**: Sum of all motors at full thrust
- **el. Power at max**: Electrical input power of battery at full thrust.
- **mech. Power at max**: Mechanical input power or shaft power at full thrust.
- **Efficiency at max**: Total efficiency achieved at full thrust.

3.8.12 Result - Multicopter

- **All-up Weight**: Overall calculated flying weight (Basic Weight + Drive Weight). The calculated values are based on this All-up weight.
- **add. Payload**: Maximum additional payload possible to hover if 80% Throttle is applied to guarantee maneuverability.
- **max. Tilt**: Theoretically maximum possible Tilt of the copter to maintain level flight (neglecting down force due tilt).
- **max. Speed**: Theoretically maximum attainable forward speed in flight at maxi tilt and max throttle (neglecting copter aerodynamic drag and down force due tilt), with restricted tilt that may result in a climb.
- **est. Range**: Represents the max Range considering standard drag. Real values may differ depending on the actual drag.
- **est. rate of climb**: Estimated maximum achievable rate of climb (neglecting copter aerodynamic drag).
- **Total Disc Area**: The total disc area is the area covered by the diameter of the rotors from the top of the copter. The higher the disc area the more efficient the copter is.

3.8.13 Graph - Range Estimator and Motor Characteristics

The Range Estimator, shown in Figure [3.9], provides a relative indication of the anticipated range under still air conditions during horizontal flight of a helicopter, without accounting for translational lift. Typically, the projected range (depicted in green) falls between two curves: the "No Drag Range" (theoretical maximum range without drag) and the "Std Drag Range" (range calculated with an assumed average drag coefficient of Cd=1.3). The range may extend further, especially when operating within the optimal range of translational lift. It's important to note that, due to the rudimentary nature of this assumption, the range might be lower than the Standard Drag Range at higher speeds. The extremity of the range graph corresponds to the maximum speed achievable in level flight.

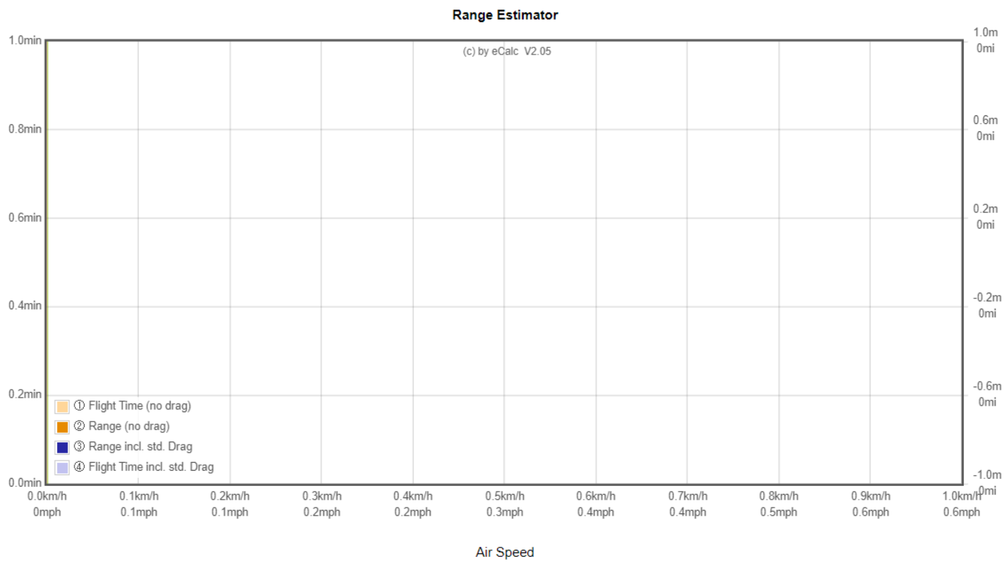


FIGURE 3.9: Range Estimator

The Motor Characteristics chart in Figure [3.10] illustrates the comprehensive thrust values as current increases during the dyno test, highlighting the maximum values. If the estimated motor case temperature surpasses 80°C, it will be represented in red, indicating the potential for permanent damage due to elevated temperatures.

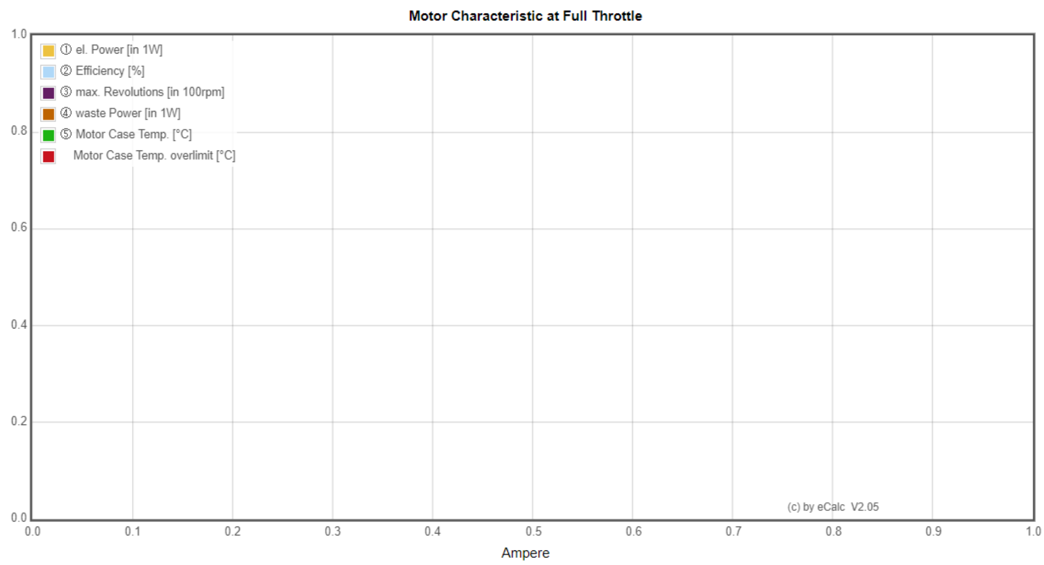


FIGURE 3.10: Motor Characteristics

3.9 Performance Analysis

To prove the accomplishments of the mission objectives established in the research paper, the performance analysis of the above calculated results is conducted. In this section, the requirements concerned that needs to be proved directly by the performance analysis are the endurance, range and dash speed of each operations. Each of the mentioned requirements represents a branch that influences the validity of other parameters such as the weight, capability of conducting the intended functions and payload compatibility. The performance analysis is divided into two types, adjusting with the two different operational objectives. First step to the analysis is identifying the highlighted results that will translate into a conclusion. The calculator greets the user with a simple reading through the quick check gauges and later on feeding the detailed results.

1. **General endurance**: Indicated on some of these gauges generally briefs the user about what results one is to expect. The 'Hover Flight Time' gauge shows the endurance of the UAV if only hovering is taken into account. During ISR operations, staying in a hovering flight may be possible. The hover throttle percentage is mentioned in the 'Motor @ Hover' section. There are two variations to the result, but the highest value is considered as a

safety margin. The throttle percentage dictates the thrust lever position maximum to hover the UAV. In the event where the operator needs a stationary lookout, the UAV can be deployed and hover in place to provide the operator surveillance radius of that area. However, ISR operations usually involve the UAV to fly in low speeds with brief stops to better asses the situation, stabilizing the UAV to view a clear graphical image of the live feed. In the battery section we are able to see more results on the possible endurance readings, 'Minimal Flight Time' and 'Mixed Flight Time'. The two readings involves phases that includes max throttle, which we will assume is assumed to be almost irrelevant for ISR missions. The 'Minimal Flight Time' dictates the minimal values when the UAV is set on full throttle. This situation may apply for defense kamikaze operations, where the operator uses it for instant attack. The operator spots and locate the target prior to launching the UAV, and the UAV is launched at full throttle towards the target wasting no time. Whereas, in detect and attack situations, the UAV is sent to hover briefly and then proceed to the target, which explains the 'mixed Flight Time' of the battery section. However, The endurance of the UAV is better predicted and understood based on the average speed it will fly in.

2. **Endurance relative to speed**: As mentioned above, ISR operations involves the UAV to fly at low speeds. This data is given in the range estimator graph supplied by the calculator. The given readings are presented with standard drag consideration and no drag. The larger value (with drag) is considered to simulate real world situations. To achieve the endurance relative to speed, the speed value is selected that will correspond to the endurance value.

3. **Maximum range relative to speed**: Similar to the endurance, range values for the UAV depends on the speed it is flying in. The selected speed value corresponds with the designated range maximum range values of that given speed. Estimated range values based of the best values of the calculator are also given in the Multicopter section of the result.

4. **Maximum dash speed**: Finally, the UAV requirements values could be complete with the maximum dash speed the UAV can fly. This value is given in the multicopter section of the results as well.

5. **Estimated temperature**: There are other important parameters given as well. The temperature indicator informs the user whether the UAV is safe to operate. During ISR or payload dropping operations, where the UAV recovery is considered, the UAV must be able to fly back to its origin. Even in loitering munitions operations, if the UAV would suddenly have a rise in temperature and overheat, it could stall the ESC and eventually the UAV midway.

6. **Agility**: The thrust-to-weight ratio given in the quick check gauges indirectly describes the agility of the UAV. Scoring above the mean thrust-to-weight value would mean that the UAV will have better acceleration and therefore more agile.

7. **Additional payload**: The additional payload result in the muticopter section is the value that can be carried at an 80% hover rate.

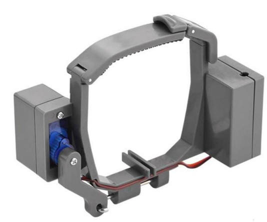
8. **Estimated rate of climb**: The values for this parameter dictates the maximum take-off speed the UAV is capable of.

9. **Weight safety margin**: The all-up-weight of the calculator may be different than the weight inserted by the user. But this is acceptable and is treated as weight additions that may be needed in the actual application.

3.10 Cost Estimation

Cost estimation is a critical step in low-cost design. It facilitates accurate budget planning, ensuring that the design process aligns with available resources. It also aids in resource allocation, helping to identify and utilize materials and equipment efficiently, thereby minimizing waste. The process supports decision-making by allowing the evaluation of different design alternatives based on their estimated costs. Moreover, it plays a key role in assessing project feasibility, determining whether the project is financially viable and executable within available resources. Furthermore, it supports continuous improvement throughout the design process by identifying areas for optimization and cost-saving opportunities. Overall, cost estimation is integral to the success of low-cost design projects. In the process of conducting cost estimation, we evaluate both the electronic and airframe components' cost cap. However, due to the classified nature of the UAV references in these operations, pinpointing an exact target for achievement is challenging. Consequently, the cost estimation for the UAV concept will be compared with that of the DJI Mavic Pro3 in Figure [3.11a], currently utilized for similar purposes. The underlying concept of this paper involves designing a purpose-built alternative to the DJI Mavic Pro3, specifically tailored for deployment in modern battlefields. Notably, the UAV in question is equipped with an additional payload dropping component in Figure [3.11][35], enhancing its functionality and adaptability for payload dropping applications. However, employing dozens of DJI Mavics for military use could add huge expenses. The DJI Mavic alone costs $ 2199 [36], while the addition of the payload dropping attachment adds $ 199. In total, the rough estimate would tally upto $ 2398 per UAV. To deem it as a low cost defense UAV, the conceptual design should cost significantly lower.

(A) DJI Mavic Pro 3



(B) DJI Mavic Pro Payload Drop Release

FIGURE 3.11: DJI Mavic Pro 3 Payload Dropping

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Mission Profile

Defining a mission profile will act as a blueprint for the UAV's operations. It is a detailed plan outlining the specific tasks, maneuvers, and conditions the UAV will encounter during its missions derived from the user needs and mission requirements. There are two defined operation types; ISR and Loitering Munitions. However, the Loitering Munitions Operation is further divided into two objectives; payload dropping and defense kamikaze. In ISR operations in Figure [4.1], the UAV is utilized as a reconnaissance tool to provide situational awareness to the user. The nature of this operation is to collect any possible field intelligence, and return back to the user to be stored or reused later.

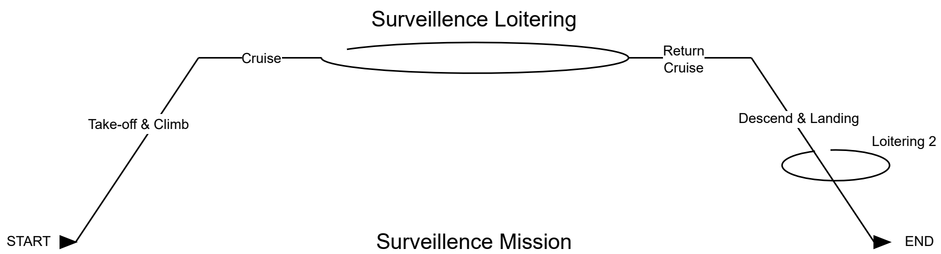


FIGURE 4.1: General ISR Operations Mission Profile

If the user intends to retrieve or reuse the UAV in a loitering munition operation, payload dropping in Figure [4.2] is advised. The UAV in payload dropping operations are design to fly, payload drop and return to the user once the task is completed. This type of operation is usually suitable in the event where the target is in an open area, clear of any overhead obstructions.

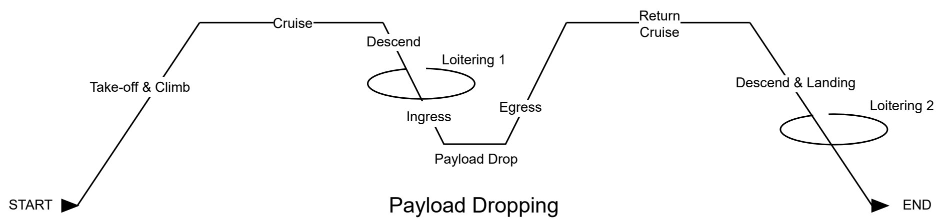


FIGURE 4.2: Payload Dropping Operations Mission Profile

Kamikaze Defense operations in Figure [4.3], as the name suggests, utilizes instant exploding of the grenade upon releasing the release mechanism, in the effective proximity of the target. Most hand grenades come with a time-delay fuse that sets a time interval in the fuse of the hand-grenade. However, some cases proved the time-delay fuse in the hand grenade can be removed and set in a way that the grenade explodes upon igniting. This method of instant ignition of the grenade is more effective when used in a Kamikaze Defense Operation.

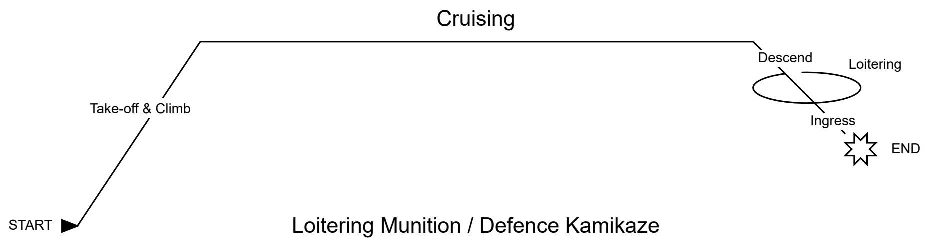


FIGURE 4.3: Defense Kamikaze Mission Profile

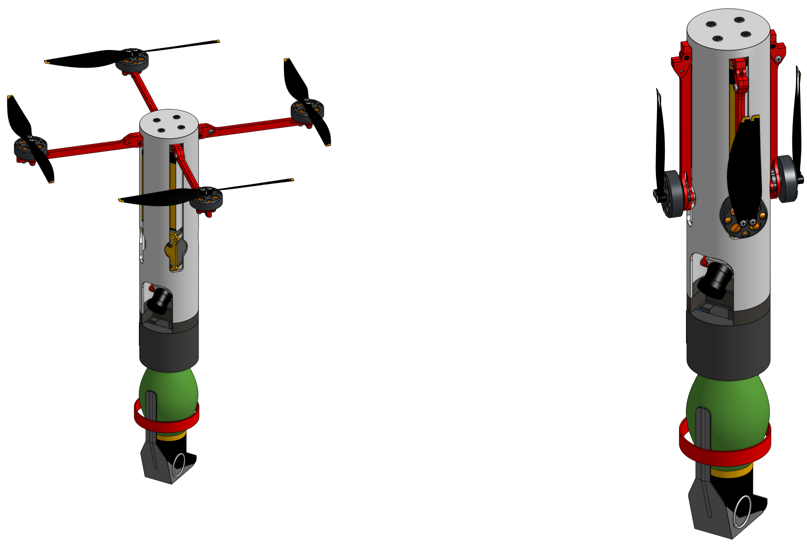
4.2 Structures

The shell, frame and arms make up the substructure components of the overall UAV structure during ISR operation or when without carrying payload. The CAD works below illustrates the UAV when armed and folded. The UAV is held together using different types of screws. An additional payload system structure is added for loitering munition operations with the Pindad GT5-pea2 in Figure [3.4] hand grenade strapped onto the body of the payload releasing mechanism.

(A) CAD of ISR Armed

(B) CAD of ISR Folded

FIGURE 4.4: UAV CAD Illustration During ISR Operations



(A) CAD of Loitering Munition Armed

(B) CAD of Loitering Munition Folded

FIGURE 4.5: UAV CAD Illustration During Loitering Munition Operations

4.2.1 Structures - Dimensions

Top View dimensions of the UAV: Refer Figure [4.6]

- Motor-to-motor length: 243.3 mm
- Center to outer diameter length: 200.35 mm
- Outer diameter: 400.7 mm
- Directional width: 329.45 mm

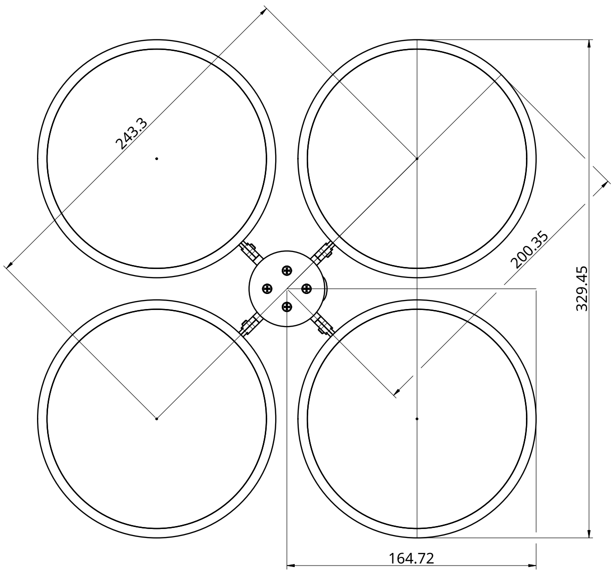


FIGURE 4.6: Top View Dimensions

ISR Ops in-flight dimensions of the UAV: Refer Figure [4.7]

- Bottom to propeller height: 199.25 mm
- Width: 329.45 mm

ISR Ops folded dimensions of the UAV: Refer Figure [4.8]

- Height: 191 mm
- Shell width: 50 mm

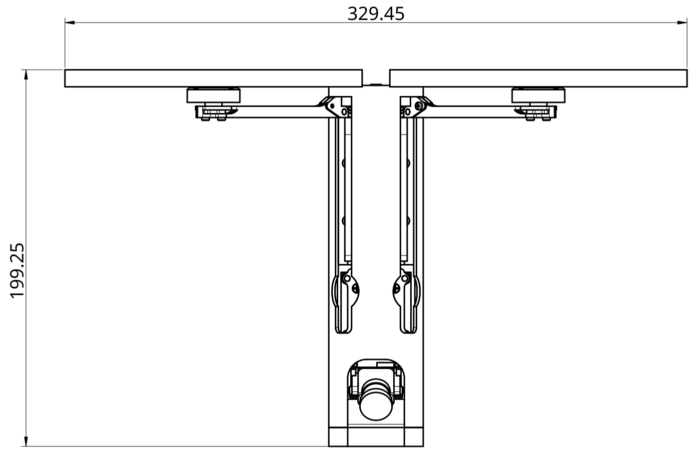


FIGURE 4.7: ISR Ops In-flight Dimensions

- Outer diameter: 91.11 mm
- Directional width: 74.23 mm

Loitering Munition Ops folded dimensions of the UAV: Refer Figure[4.9]

- Overall Height: 340.5 mm

4.2.2 Airframe

The airframe houses the electronic components of the UAV. The airframe is further made up of the frame in Figure [4.10b] and the shell in Figure [4.10a]. The shell provides a closure for the internal components. The frame is further broken down into the arm support, camera brackets and frame. The frame referred is designed to accommodate the later explained electronic components selected. With the overall weight achieved, the UAV would need a certain high capacity battery to support a satisfactory flight time. The bulge in the frame is to give room to the said battery. Mounting holes are also subjected to the intended mounting configuration and size of the components. There are two types of mounting configuration present in the frame, 20 x 20 mm and 30.5 x 30.5 mm configurations.

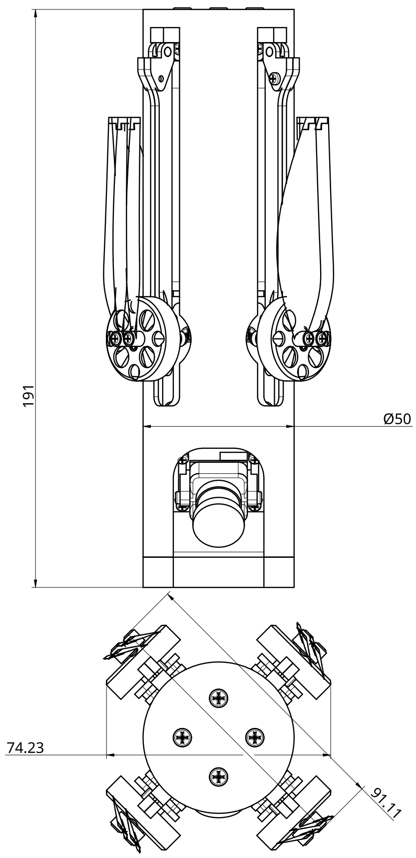


FIGURE 4.8: ISR Ops Folded Dimensions

The arm illustrated in Figure [4.11] will house the motor. The arm is split into two parts and are screwed together onto the arm support. The arm folds into the shell of the UAV, limited by the frame inside. The opening provided for the arm

4.2.3 Airframe - Dimensions

Airframe frame dimensions: Refer Figure [4.12]

- Camera mounting space: 30 x 30 mm
- Frame thickness: 2 mm
- Frame height x width: 30 x 30 mm
- Allowed electronic components space: 123.79 mm

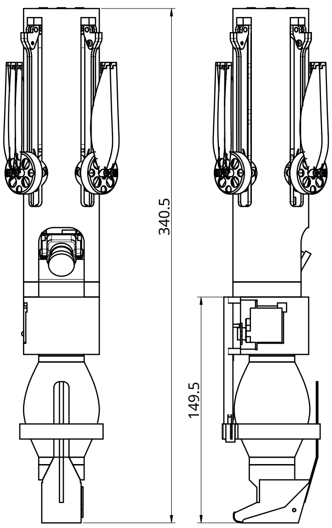


FIGURE 4.9: Loitering Munition Ops Folded Dimensions

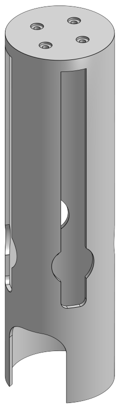
- Frame inner height (shortest): 26 mm
- Frame inner height (largest): 33 mm
- Frame battery bulge length: 80 mm
- Frame battery bulge width: 8 mm
- Frame top opening: 20 x 22 mm

Airframe Shell dimensions: Refer Figure [4.13b]

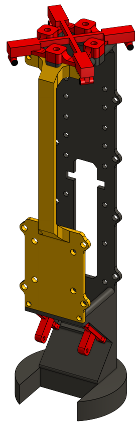
- Shell Diameter: 50 mm
- Shell height: 181 mm
- Shell thickness: 2 mm

Airframe Arm dimensions: Refer Figure [4.13a]

- Arm Length: 110 mm
- Arm height out: 6 mm



(A) Shell



(B) Frame

FIGURE 4.10: Airframe Components of the UAV

FIGURE 4.11: Arm

- Arm height in: 11 mm
- Arm thickness out: 4 mm
- Arm thickness in: 6 mm
- Movement axle diameter: 3 mm
- Motor casing in: 17 mm
- Motor casing out: 19 mm

4.2.4 Payload System

The payload system consists of the whole payload releasing mechanism and the payload itself. The release mechanism chosen for the UAV design uses simple steps and less moving parts, it uses a 'latch' like release mechanism. Components

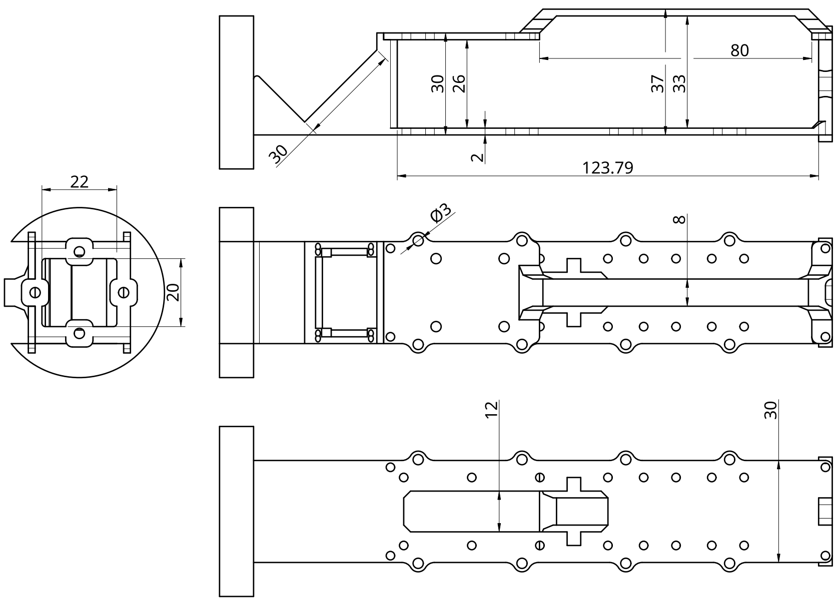
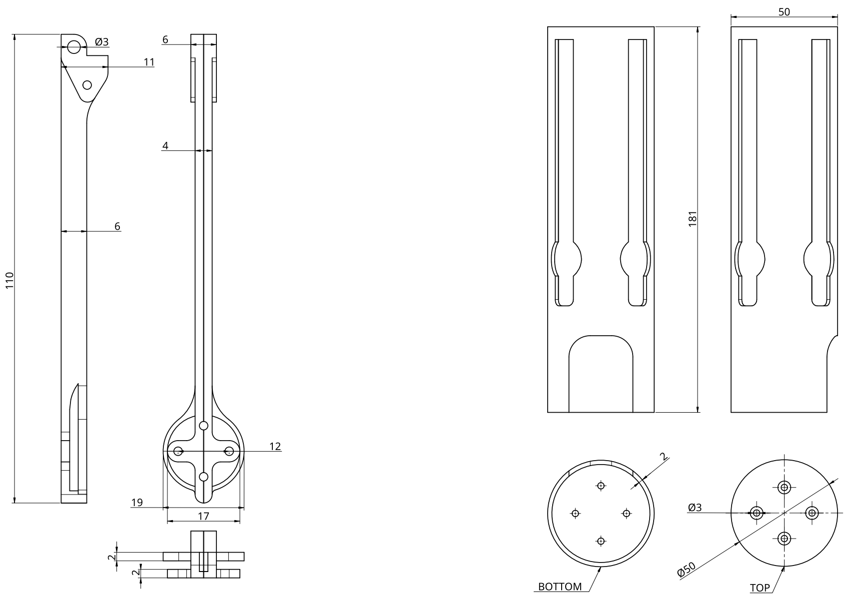


FIGURE 4.12: Frame Dimensions

for the payload system consists of the body, a servo, a hook, a rod, a strap and the Pindad gt5-pea hand grenade. This vertical payload releasing strap mechanism is used for both of the loitering munitions operations, with the hand grenade placed upside down. Since the servo is required to connect with the flight controller or the onboard computer, quick installing of the additional payload system cannot be made during combat. For this design, the user is advised to prepare the loitering munition configuration prior to operating the UAV. The payload system body is stuck onto the airframe of the UAV using a strong sticky adhesive. The only difference for the loitering munition operations is that the grenade or payload should stay put on the UAV even after releasing of the release mechanism. This is achieved by sticking the lower end of the grenade to the flat surface of the payload system structure.

The phases of the release mechanism are illustrated in Figure [4.15], and explained below:

1. When the servo is activated, the hook rotates with the servo and moves in an upward motion.



(A) Arm Dimensions

(B) Shell Dimensions

FIGURE 4.13: Arm and Shell Dimensions

2. this upward motion lifts the aluminum rod [1a].
3. the rod acts as a latch to the strap and this releases the strap [1b].
4. force from the grenade's lever is strong enough to push the strap out of the way, striker ignites the fuse and the grenade explodes.

4.3 Materials

Materials for all of the airframe structure, payload system body and hook are 3D printed. The structure uses Polycarbonate (PC), a filament that produces models that are high in strength, tough, heat resistant and high optical clarity. The axial direction of the filament has a tensile strength of 66 MPa. PC costs 70 to 200 USD per kg and is available at a diameter of 1.75 mm. A silicon rubber strap with a diameter smaller than the UAV is used to hold the grenade in place while keeping it armed. This is possible due to the elastic properties of the silicone rubber material. The hook is made from aluminum metal for its strength to hold

FIGURE 4.14: CAD Illustration of Payload System

the strap in place. Table [4.1] provides a complete list for materials used in the conceptual design.

Structure	Substructure	Material
Airframe	Shell	PC/ABS
	Frame	PC/ABS
	Arm Support	PC/ABS
	Arm	PC/ABS
	Cam Bracket	PC/ABS
Payload System	Body	PC/ABS
	Strap	Silicone Rubber
	Rod	Aluminum
	Hook	PC/ABS

TABLE 4.1: UAV Materials List

4.4 Electronic Components

Figure [4.16] illustrates the configuration plan for the UAV concept's components. The placement of the UAVs within the frame is optimized, and intentional spaces and gaps have been incorporated to facilitate effective cable management.

Overall weight will play a significance in the performance of the UAV. The more heavier the UAV, the more restrictions it will impose on achieving mission

(A) Phase 1 and 2   (B) Phase 3 and 4

FIGURE 4.15: Payload Release Mechanism Illustration

requirements and objective targets. The following UAV conceptual design considers weight as a restriction also implies that the operator wont have to carry significant additional load. The UAV is intended to act as an additional tool to provide situational awareness and a lethal weapon in dire situations, so to carry supplementary gear that significantly add weight could cause discomfort to the operator. However, weight is not the only contributing factor. Apart from designing the UAV as light as possible, we should also design it as compact as possible. Dimensions of the electronic components will directly dictate the shape and dimensions of the UAV concept. The dimensions of components like the ESC, FC, VTX, RT and the camera are not necessarily parallel with the specifications. The bigger the component does not always mean they offer a better specification for the mentioned electronics. This is possible because even the compact versions offer enough contributions to the objectives made for the performance of the UAV. This does not go the same for the propeller, motor and the battery. The components below are the ones selected for the UAV concept.

4.4.1 Selected Drive Components

The drive components play a major role to the performance of the UAV. According to eCalc xcopter multi-copter performance calculator, the drive components are the ESC, battery, motor and the propellers.

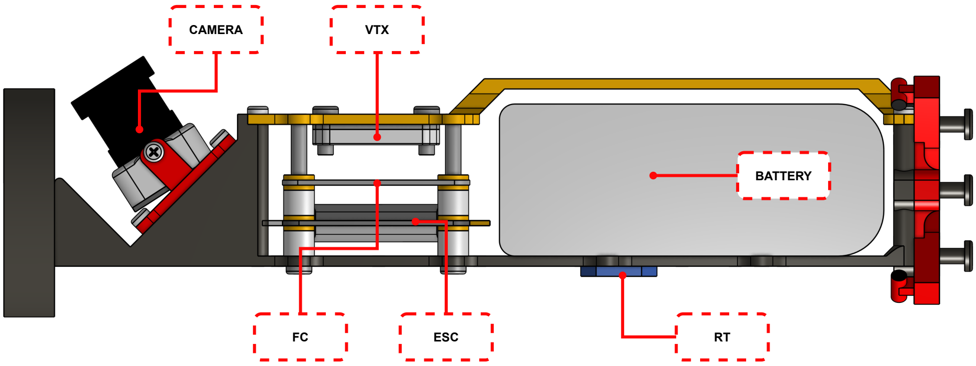


FIGURE 4.16: Electronic Component Configuration

1. **ESC and FC**: The ESC selected for the UAV is a 4-in-1 type. A 4-in-1 ESC eliminates the need to have individual ESCs for each motor, meaning they are much more compact and lighter. T-Motor's F55A PRO II is considered, having a current rating of 55A. This ESC from T-Motor is paired with the F7 FC, they are stacked on top of each other. An AIO stack will be very advantageous to the design, the overall height of the stack is approximately 16 mm, including the spacers, which fits perfectly in the frame and has extra space above it. The detailed specifications are given in Table [4.17]

2. **Motor**: There is a wide range of motors to choose from. But the selection could be narrowed down by the motor diameter. One aspect of the user needs states that the UAV should be launcher compatible. Low KV rated motors mostly are of large diameters, since UAVs that are designed for carrying heavy payloads like agricultural or photography needs are large in size, which naturally needs more torque. Larger diameters will contribute to larger outer diameter of the UAV, thus will cause the launcher to be bigger which wont could cause the overall equipment to not be compact

FIGURE 4.17: T-Motor F7 + F55A PRO II HD Stack - [37]

Specification		Unit
	L 45	mm
Dimensions	B 41	mm
	H 7.3	mm
Weight (Incl Heatsink)	17.5	g
Continuous Current	55 x 4	A
Burst Current	75 x 4	A
BEC Output	10 at 2A	V
BLHeli	32	bit

TABLE 4.2: T-Motor F55A PRO II ESC Specifications

enough. This research's UAV concept is small in size but is heavy for the size since it carries a payload that weighs 430 grams with pre-made market-available components. The most suitable motor that has the highest torque with minimal motor diameter is T-Motor's F2004 (1700KV). The motor has an optimal take-off weight of 400g per motor. The efficiency of the motor naturally dictates through diameter and pitch of the propeller. Other motors that still fit the dimension criteria are tested in the eCalc and provide no better performance than the current selection with a similar configuration. The specifications of the motor is given in Table [4.4].

3. **Propeller**: It was difficult to find folding propellers with small diameters. Due to the nature of the UAV, a suitable propeller would be of large enough diameter with a small pitch. DJI as a manufacture produces videography UAVs that comes in a compact size, one of them being the Mavic lineup, are

Specification		Unit
Dimensions	L 37	mm
	B 37	mm
Weight	7.4	g
Memory	16	M
Input Voltage (3-6s)	12V - 25 - 2V	-
BEC (Receiver)	5/2A	V
BEC (VTX)	10/2A	V
Mounting Holes	30.5x30.5	mm
MCU	STM32F722RET6	-
Gyro	BM1270	-
Filmware Target	TMOTORF7	-

TABLE 4.3: T-Motor F7 FC Specifications

Image	Specification		Unit
	Dimensions	D 24	mm
		H 17.25	mm
	Weight (Incl Cable)	16.4	g
	Shaft Diameter	3	mm
	Idle Current (10V)	0.38	A
	Max Power (60s)	503	W
	Internal Resistance	221	mOhm
	Configuration	12N14P	-
	Rated Voltage (LiPo)	6S	-
	Peak Current (60s)	21.2	A

TABLE 4.4: T-Motor F2004 1700KV Specification - [38]

compact by design and uses folding arms and propellers. DJI's propellers manufactured for Mini Pro4/Mini Pro 3 in Figure [4.18] is chosen for the UAV. The propellers are 6 inch in diameter, which is not too big for the UAV with a pitch of 3 inch. They also produce less noise according to the manufacture, which could make the UAV more stealthy. Larger DJI propellers causes easy overheat, the more larger the propeller the more pitch it has.

4. **Battery**: Initially the battery chosen to power the UAV was Flywoo's Explorer 900 mAh battery. This battery was found due to the satisfactory dimensions. The CAD model was built around the then chosen electronic

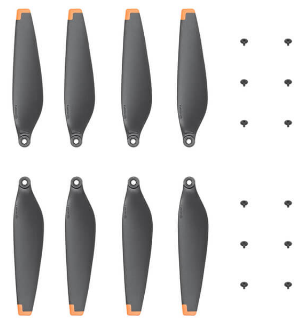


FIGURE 4.18: DJI Mini 4 Pro/Mini 3 Pro Propellers - [39]

Specification		Unit
Dimensions	D 6	inch
	Pitch 3	inch
Weight	0.9	g

TABLE 4.5: DJI Mini 4 Pro/Mini 3 Pro Propellers Specification

components, illustrated in Figure [1]. The 900 mAh battery was then compared with Thunder Power's 1300 mAh, Tattu's 1550 mAh, Lumenier N20's 1600 mAh and Lumenier's 1800 mAh. The dimensions got bigger with the increase of battery capacity. Due to the already set initial dimensions of the frame, installing the 1300,1550, 1600 or 1800 battery would require the frame to be elongated. The Table [1] explains each length adjustments corresponding to the batteries, not including a 2 to 5 mm margin to avoid cramping of components. The goal of the UAV is to design it as compact as possible. Aside from compact carry-on reasons, it would be an advantage if the UAV could enter closed spaces via openings like windows or doorway for example in an urban setting. Before determining the preferred battery considered in the design, each of the batteries were compared through the performance outcome from the calculator inputs in Table [2] and Table [3], with then weight and configuration of the UAV. The Lumenier 1800 mAh battery would require extreme elongation to the airframe of the UAV, about an addition of 42 mm. The Tattu 1550 mAh battery offers similar performances in the required fields. Henceforth, the Luminier 1800 is excluded from the consideration. The Tattu 1550 mAh battery, compared to Luminier N20's 1600 mAh, has better performance despite Luimier N2O's greater capacity. Due to that, the 1600 battery is also eliminated from the selection consideration. The Luminier N20 is also longer in length than the Tattu. The final draw goes down to the battery selection between the 900, 1300 and 1550 mAh batteries. The 900 mAh maintains its compact nature with decent performance in terms of hover time with and without payload. The 1300 and 1550 gave out better performance than the 900 but needed airframe adjustments. Eventually, Tattu's 1550 mAh battery was chosen for giving out the best performance. The specifications of the battery is given in Table [4.6].

Image	Specification		Unit
		L 76	mm
	Dimensions	B 38	mm
		H 30	mm
	Weight	167	g
	Maximum Capacity	1550	mAh
	C - Rating	130C	-
	Max Burst	240C	-
	Configuration	4S1P	-
	Voltage	14.8	V
	Discharge Plug	XT60	-
	Charge Plug	JST-XHR-5P	-

TABLE 4.6: Tattu R-Line Version 4.0 1550mAh 4S 130C LiPo Battery - XT60 Specification - [40]

4.4.2 Selected Non-Drive Components

The non-drive components are the rest of the components with specifications that do not directly serve an importance to the UAV.

1. **Camera**: The RunCam Night Eagle 3 stands out as an extremely responsive camera designed for night flights. This micro-sized camera, measuring

19x19mm, incorporates an OSD feature to showcase a pilot ID, power-on duration, and external battery voltage. Renowned for its exceptional night vision capabilities among analog FPV cameras, the Eagle 3 delivers vivid high-resolution images. Its Starlight CMOS sensor enables outstanding performance in low-light conditions. A night-vision camera is chosen for this UAV, specifications of the camera is given in Table [4.7].

FIGURE 4.19: RunCam Eagle 3 Night Vision Camera - [41]

Specification		Unit
	L 19	mm
Dimensions	B 19	mm
	H 25	mm
Weight	8.5	g

TABLE 4.7: RunCam Eagle 3 Night Vision Camera Specification

2. **VTX**: The above camera is paired with the VTX from T-Motors. The specifications of the VTX is given in Table [4.8].

Specification		Unit
Dimensions	D 20	mm
	W 20	mm
Weight	7.58	g

TABLE 4.8: T-Motor FT800 VTX Specification

FIGURE 4.20: T-Motor FT800 VTX - [42]

3. **Actuator**: The Hitec HS-55 represents a cost-effective, high-quality analog servo with a 9g form factor. This lightweight servo is well-suited for a wide range of planes that require 9g servos. Known for its reliability, the servo features a durable resin gear train, and its casing is among the most slender options in the market.

FIGURE 4.21: Hitec HS-55 - [43]

4.5 Weight Estimation

The weight estimations for the UAV external structures are achieved from the OnShape's results based on density of the different materials chosen. The weight estimations for electronic components are referred from their respective manufacture's given specifications. Weight estimations are divided into three sections; Empty Weight, Electronic Components Weight and Payload System Weight, to define a detailed weight category.

4.5.1 Empty Weight

Empty weight consists of structures that are produced in the CAD modeling software. This will include the weight of the airframe with Polycarbonate filament material, without the internal electronic components.

No	Components	Mass (g)
1	Shell	54
2	Arm Support	4
3	Frame	38
4	Arm x4	12
5	Cam Bracket x2	1
	Total	109

TABLE 4.9: Airframe Components Weight Estimation

The total empty weight accumulates to 109 grams.

4.5.2 Electronics Weight

Electronics weight consists of the weight referred from the specifications of each respected components from the manufacture's data. This weight only covers the electronics selected for the UAV concept.

No	Component	Mass (g)
1	Camera	8.5
2	FC	7.4
3	ESC	17.5
4	Battery	167
5	Motor x 4	65.6
6	Prop x 4	3.6
7	VTX	7.58
8	RT	1.2
	Total	278.4

TABLE 4.10: Electronics Weight Estimation

Total electronics weight accumulates to 278 grams. The result of Total Empty Weight and Electronics Weight adds up as Total weight of the UAV during ISR operations. For Total Weight during ISR operation, Empty Weight + Electronic Components Weight is; 109 + 278.4 = 387.4.

4.5.3 Payload System Weight

Payload system weight consists of structures of the payload releasing mechanism and the payload itself.

No	Components	Mass (g)
1	Body	23
2	Strap	2
3	Servo	9
4	Metal Rod	0.6
5	Hook	0.6
6	GT5-pea2	430
	Total	465.2

TABLE 4.11: Payload System Weight Estimation

Total Payload System Weight accumulates to 465 grams including the payload. Initially the overall weight was estimated at 872 g. Empty Weight + Electronic Components Weight + Payload System Weight makes up the now actual overall weight, which will be 109 + 278.4 + 465.2 = 853 grams. Since the actual overall weight is lower than the estimated overall weight, there are no change of electronic components needed to be adjusted.

4.6 Performance Analysis

The performance analysis of the UAV are divided into two configurations. Although three separate operations are defined for the UAVs objectives, the two from loitering Munitions operations will consists of the same amount of components and the same configuration.

4.6.1 ISR Operations Input

The following inputs in Table [4.14] and Table [4.17] in the calculator shown in Figure [4.22] are made for ISR Operations. Below briefed are some highlighted inputs.

1. **General**: The overall weight for ISR Operations adds up to 387 grams as known from the weight estimations above. Environmental conditions of Jakarta, Indonesia is used for reference.

2. **Controller**: The weight of the ESC is 17.5g and adjusted is to $\frac{17.5}{4} = 4.375g$. The camera is used for accessories values.

3. **Battery Cell**: To accomplish optimal values, the battery is assumed to be at its full potential. The charge state is set to full, with max discharge 100%. Since the components for this UAV is modular and the nature of the operations, the components or the UAV itself is assumed to be used for a short time span. The battery weight, 167 g is adjusted to $\frac{167}{4} = 41.75g$.

General		
Parameter	Input	Unit
Model Weight	387	g
	(Incl Drive)	-
Frame Size	243	mm
Field Elevation	100	m
Air Temperature	30	^oC
Pressure (QNH)	1012	hPa

TABLE 4.12: General Inputs

Controller		
Parameter	Input	Unit
Type	55A	-
Current cont	55	A
Current max	55	A
Weight	4.375	g
Accessories	Camera	-
Current drain	0.09	A
Weight	9	g

TABLE 4.13: ESC Inputs

TABLE 4.14: ISR Operation Input

Battery Cell		
Parameter	Input	Unit
Type	1550 mAh	-
Charge state	Full	-
Configuration	4S1P	-
Cell Capacity	1550	mAh
Max discharge	100%	-
Resistance	0.0081	ohm
Voltage	3.7	V
C-rate cont	130	-
C-rate max	240	-
Weight	41.75	g

TABLE 4.15: Battery Cell Inputs

Motor		
Parameter	Input	Unit
Manufacture	T-Motors	-
Type (Kv)	F2004-1700	-
Propeller		
Parameter	Input	Unit
Type	DJI	-
Diameter	6	inch
Pitch	3	inch

TABLE 4.16: Motor and Propeller Inputs

TABLE 4.17: ISR Operation Input (2)

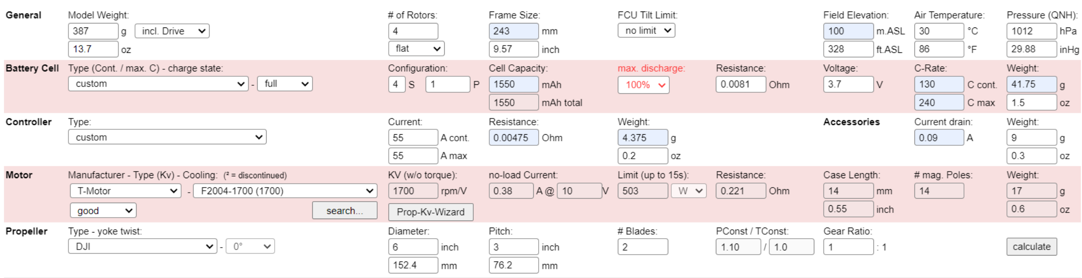


FIGURE 4.22: ISR Operation Calculator Input

4.6.2 ISR Operations Results

After running the calculator with the desired inputs, the results are revealed. Displayed in Figure [4.23] and Figure [4.24] are the results predicted for the ISR configuration.

4.6.3 ISR Operations Results Highlight

This section highlights the important parameters that will be mentioned for the result summary later on. The quick Check Gauge reads:

- Positive continuous discharge rate: 28.5 C

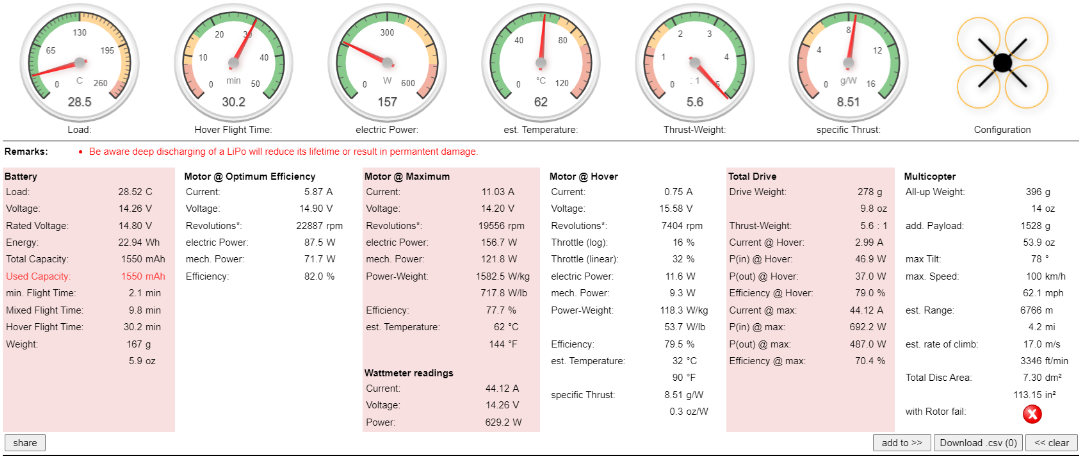


FIGURE 4.23: ISR Operation Calculator Result

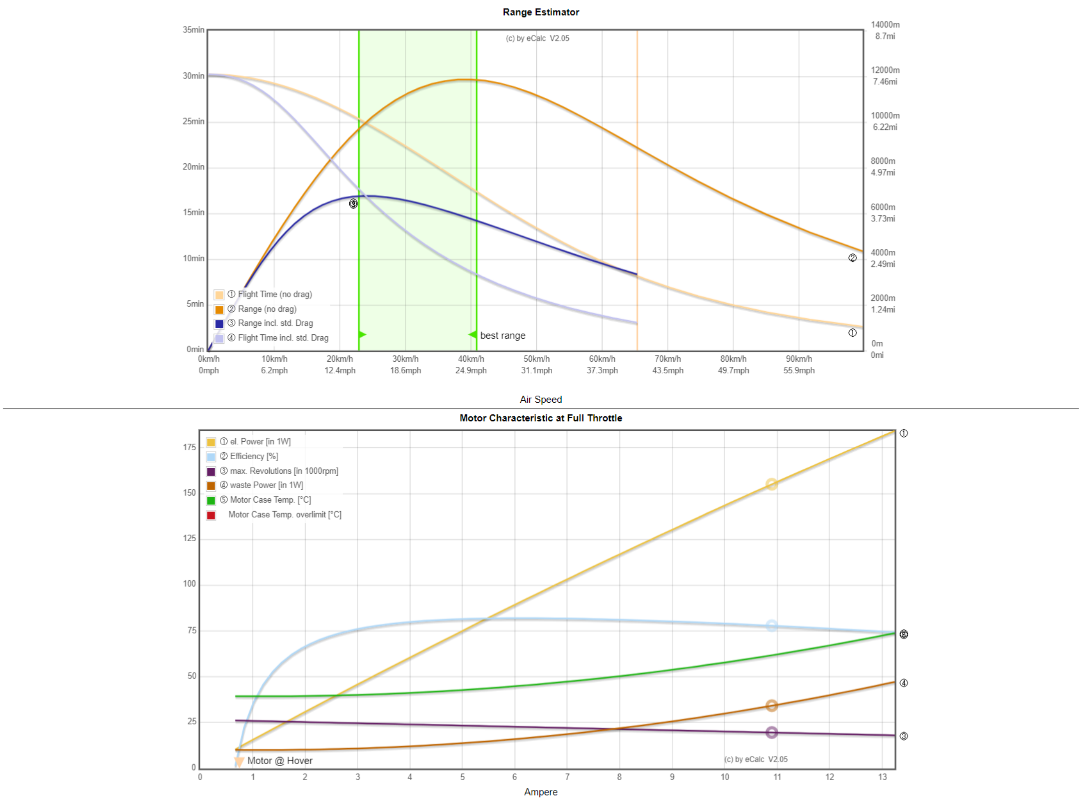


FIGURE 4.24: ISR Operation Calculator Graphical Result

- High possible hover flight time: 30.2 min
- Electrical power is within normal range: 157 W
- Predicted maximum temperature is within normal range: 62°C
- High indicated thrust-to-weight: 5.6
- Good thrust efficiency: 8.51

Moving onto the detailed results, we have:

- Minimal flight time: 2.1 min
- Mixed flight time: 9.8 min
- Hover flight time: 30.2 min
- est Temperature: 62°C (Motor @ Maximum)
- Throttle (linear): 32% (Motor @ Hover)
- All-up Weight: 396 g
- Additional Payload: 1528 g
- Maximum tilt: 78°
- Maximum speed: $100\,\mathrm{km\,h^{-1}}$
- est Range: 6766 m
- est Rate of climb : 17 m/s

4.6.4 Loitering Munitions Operations Input

The following inputs in Table [4.20] and Table [4.23] in the calculator shown in Figure [4.25] are made for Loitering Munition Operations. The overall weight for Loitering Munition Operations adds up to 853 grams as known from the weight estimations above. The weight is the only difference from the ISR counterpart.

General		
Parameter	Input	Unit
Model Weight	853	g
	(Incl Drive)	-
Frame Size	243	mm
Field Elevation	100	m
Air Temperature	30	^oC
Pressure (QNH)	1012	hPa

TABLE 4.18: General Inputs

Controller		
Parameter	Input	Unit
Type	55A	-
Current cont	55	A
Current max	55	A
Weight	4.375	g
Accessories	Camera	-
Current drain	0.09	A
Weight	9	g

TABLE 4.19: ESC Inputs

TABLE 4.20: Loitering Munition Operation Input

Battery Cell		
Parameter	Input	Unit
Type	1550 mAh	-
Charge state	full	-
Configuration	4S1P	-
Cell Capacity	1550	mAh
Max discharge	100	-
Resistance	0.0081	ohm
Voltage	3.7	V
C-rate cont	130	-
C-rate max	240	-
Weight	41.75	g

TABLE 4.21: General Inputs

Motor		
Parameter	Input	Unit
Manufacture	T-Motors	-
Type (Kv)	F2004-1700	-
Propeller		
Parameter	Input	Unit
Type	DJI	-
Diameter	6	inch
Pitch	3	inch

TABLE 4.22: Battery Cell Inputs

TABLE 4.23: Loitering Munition Operation Input (2)

4.6.5 Loitering Munition Operations Results

After running the calculator with the desired inputs, the results are revealed. Displayed in Figure [4.26] and Figure [4.27] are the results predicted for the Loitering Munition configuration.

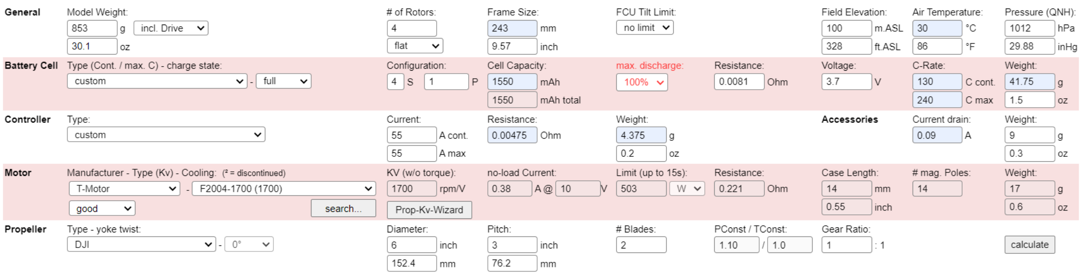


FIGURE 4.25: Loitering Munition Operation Calculator Input

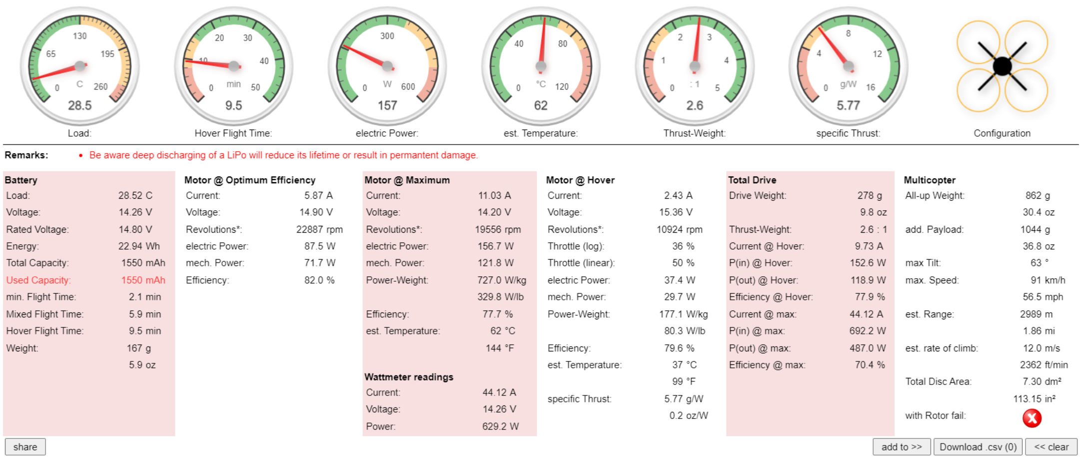


FIGURE 4.26: Loitering Munition Operation Calculator Result

4.6.6 Loitering Munition Operations Results Highlight

This section highlights the important parameters that will be mentioned for the result summary later on. The quick Check Gauge reads:

- Positive continuous discharge rate: 28.5 C
- Short possible hover flight time: 9.5 min
- Electrical power is within normal range: 157 W
- Predicted maximum temperature is within normal range: 62°C
- Good indicated thrust-to-weight: 2.6
- Good thrust efficiency: 5.77

Moving onto the detailed results, we have:

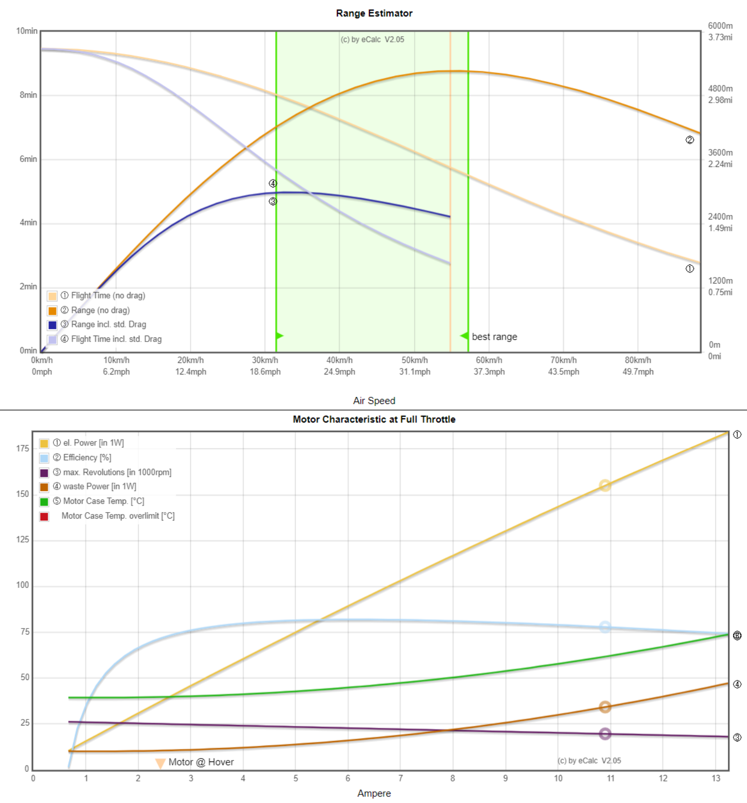


FIGURE 4.27: Loitering Munition Operation Calculator Graphical Result

- Minimal flight time: 2.1 min
- Mixed flight time: 5.9 min
- Hover flight time: 9.5 min
- est Temperature: 62°C (Motor @ Maximum)
- Throttle (linear): 50% (Motor @ Hover)
- All-up Weight: 862 g
- Additional Payload: 1044 g
- Maximum tilt: 63°
- Maximum speed: $91\,\mathrm{km\,h^{-1}}$

- est Range: 2989 m
- est Rate of climb : 12 m/s

4.6.7 ISR Operations Results Summary

After receiving the results from the calculator, the validity of the UAV concept performance can be declared. The calculator informs us that the UAV is able to operate at a safe temperature, estimated to reach a maximum value to **62°C**. Hence, we are able to proceed with the results. From the design requirements, we are tasked to prove the endurance, range and dash speed of the UAV. The utilization of the UAV is more focused towards providing the user additional situational awareness. The parameters given by the calculator summarizes the following:

1. **Max endurance**: Endurance is considered to be an important aspect to conduct ISR operations. Endurance directly translates to the maximum flight time the UAV is able to stay in the air to provide optimal intelligence. The maximum hover flight time reading shows that the UAV is able to stay static in the air for around **30.2 mins**, with the hovering throttle applied at **32%**. This hover flight time implies that the UAV remains in the same position from deploy to descend. This would make sense if the UAV is deployed to provide radial surveillance and descend back to the user. As far as maximum endurance is concerned, those are values the UAV could reach such feat. However, Such conditions does not cover any distance at all.

2. **Max range**: Illustrated in the mission profile in Figure [4.1], the UAV is assumed to survey the battleground with distance covered. If we were consider to cover the possible maximum range of the UAV. The results indicates that a potential total of **6766 m** distance is covered, with considered range radius of 3383 m, if the UAV is flown at a constant speed of around $24\,\mathrm{km\,h^{-1}}$. The UAV is able to accomplish max range, within **17 mins** of total flight time.

3. **Effective range and endurance - Scenario 1**: Urban environment settings will sometimes be crowded with various obstacles. Especially in a

metropolitan city, the surrounding areas will be densely populated by man made structures. Conducting ISR operations in these conditions requires covering intelligence within a close proximity. If the UAV is flown in open areas, surveying this specific environment is effectively done at low speeds when navigating through the obstacles. If we assume a constant speed of $10\,\mathrm{km\,h^{-1}}$ is needed to fulfill the objectives, the UAV is able to score around **27.5 mins** of total flight time. This is applicable only if the total range needed is around a distance of **4.5 km**. Furthermore, a limit is applied to the said distance if we were to recover the UAV, which will be half the maximum total distance. During this scenario, the maximum range before return would be **2250 m**. The range radius, marked in green, is illustrated in Figure [4.28], with the author's campus as a point reference. From the satellite image presents us that a distance radius of 2250 m is quite a large area that can be covered. Therefore, the values displayed are the optimal values for ISR operations conducted in open areas of a dense urban setting.

FIGURE 4.28: Illustration of 2250 m Radius Range

4. **Effective range and endurance - Scenario 2**: Another possible scenario

considered, is when intelligence is needed in a confined area. Navigating through the obstacles in confined areas would need extremely low speeds. Objects could be present within the vicinity while the UAV navigates through stairways, hallways, doorways, open windows and so on. For these circumstances, around **30 mins** of endurance can possibly be achieved if the UAV is flown at a constant speed of $3\,\mathrm{km\,h^{-1}}$.

From the result, we also know that the UAV is capable of taking off at 17 m/s or 61 km/h, and is able to tilt at 78°maximum. In addition, the high thrust-to-weight ratio indicates that the UAV is capable of high accelerations, making the UAV agile. The UAV is also capable of reaching a dash speed of $100\,\mathrm{km\,h^{-1}}$.

4.6.8 Loitering Munitions Operations Results Summary

Similar to the ISR configuration, the calculator confirms a safe estimated operating temperature at **62°C** for the Loitering Munition Operations. Here, the operational objectives are divided into two. The design requirements of the UAV should be accountable for both, Kamikaze defense operations and payload dropping operations.

1. **Max endurance**: The maximum hover flight time predicted by the calculator, is 9.5 mins. However, hover only flight is ineffective for loitering munition operations. The lowest possible speed that makes sense for these types of operations will be around $5\,\mathrm{km\,h^{-1}}$. To successfully conduct payload releasing, the UAV should be quick enough for a certain time frame, to avoid being shot down prior to reaching the target. However, we can assume one occasion where the UAV travels at a low speed. If the target is situated above the user, lets say at a high level of a building, the UAV could creep up its way towards the target. Slow speeds may be rare for loitering munition operations, but if that is the case, the UAV can stay in the air for up to **9 mins**. 9 minutes of air time will only provide the UAV a total range of **600 m**.

2. **Max range**: The max range estimated by the calculator is **2989 m**. The range is achieved if the UAV travels at around $36\,\mathrm{km\,h^{-1}}$. The UAV is able to stay in the air for only **5 mins** for the aforementioned readings.

3. **Effective endurance and range - Scenario 1**: The UAV needs to reach the target on time before being detected and shot down. To achieve the following, the operator's are required to maneuver the UAV and fly it at almost to high speeds. The calculator provides us a mixed flight time result. Mixed flight time is a product of combining hovering with full throttle flight. This may apply in situations where a 'detect and attack' strategy is used. First half of the flight is tasked to detect the targets and later on, proceed to attack after detection, at full throttle or high speeds. Such operations are limited to **5.9 mins** of flight time with total range below **2.8 km**. The effective range changes to **1.4 km** for payload dropping operations, since considering recovery of the UAV.

4. **Effective endurance and range - Scenario 2**: The calculator suggests that the minimal flight time for Loitering munition configuration is **2.1 mins**. The following value applies when full throttle is constant. In operations where the target is detected prior to the launch of the UAV, the flight can be focused to advance towards the said target. The minimal flight time dictates the outcome of a high-speed loitering munition attack. Surprisingly, the accounted range is enough to carry out the attack, achieving around **1.3 km** worth of range. The top speed of the UAV is said to possibly reach a maximum $91\,\mathrm{km\,h^{-1}}$.

Other values include for loitering munition operations are the achieved tilt maximum of 63°and an estimated rate of climb of 12 m/s or 43 km/h.

4.7 Other Tactical Loitering Munitions Operations

During military combat defense operations, one of the most important effective tactics in combat strategy for any country's arsenal is sabotage [44][45]. Sabotage is the act of attacking and or destroying the key supplies, manufacturing, strategic locations and even routes used for logistics and transportation, crippling the war engine itself. Sabotage operations vary on the mission objectives, it's ultimate goal is to weaken the enemy. Some sabotaging operations may include; Attacking key railways or transport routes that act as an attempt to disrupt enemy supply lines, disrupting an arms or artillery factory to limit enemy firepower, destroying fuel depots and/or transporting vehicles to limit enemy's mobility. Employing these tactics achieves some strategic aims that are crucial to the war effort. The goal about sabotaging or guerrilla warfare is to cripple enemy forces. The UAV in loitering munition configuration may be able to carry out there type of sabotaging operations.

4.8 Cost Estimations

Manufacture	Product	Cost
RunCam	Eagle 3 Night Vision	$69.99
Tattu	R-Line Version 4.0 1550mAh 4S 130C	$33.99
T-Motor	F7 FC	$137.90
T-Motor	F55A PRO II ESC	
Matek	ExpressLRS 2.4Ghz ELRS Receiver R24S	$19.99
T-Motor	FT800	$38.90
T-Motor	F2004 1700KV x4	$83.60
DJI	Mini 4 Pro/Mini 3 Pro Propellers x4	$9.00
	Total	$393.37

TABLE 4.24: Cost Estimation of Electronic Components

The total cost of the electronic components without including the servo, is at $393.37 as calculated in Table [4.24]. The material used for the UAV airframe, Polycarbonate Filament, costs around $70 to $200 per kg as we know previously. The estimation for the airframe material costs will be done by using the highest assumed value, which would be $200. The weight of the 3D printed airframe would eventually specify the required amount of materials needed. Accordingly, UAV for ISR operations needs 109 g of the PC material. 109 g of PC filament will cost $21.80. In total, the UAV for ISR operations would cost a total of $415.17. Loitering munition operations would need additional payload system components including a $13.49 servo. At a total material weight of 132 g for loitering munition components, $26.4 is needed. With the addition to the electronic components and the servo, the total for loitering munition UAV is $433.66.

Parameters	Total Cost	
	ISR Ops	LM Ops
Elec. Comp	$393.37	$393.37
Config	$21.80	$39.29
Total	$415.17	$433.66

TABLE 4.25: Total Cost Estimation of the UAV According to Operational Objectives

The total component costs of each respective configurations compared with the above mentioned commercial UAV used in present day battlefield is shown in Table [4.26]. The costs of both configuration is significantly lower than the slightly modified DJI Mavic Pro3.

UAV	ISR Ops Config	LM Ops Config	Mavic + Mod
Comp Cost	$415.17	$433.66	$2,398.00

TABLE 4.26: Cost Comparison

4.9 Assembly - Airframe

Mentioned in this research paper, the selection of the electronic components of the UAV concept can be adjusted to the user's desire. The components mentioned above are recommended by the author. Regardless, the frame components of the UAV can be adjusted accordingly. THis may include the modification to the mounting configurations present on the frame. The mounting configuration present in the UAV are 30.5 x 30.5 and 20 x 20 mm. Easy assembly is taken into consideration to provide easy access to interchanging the components if needed. Below are figures provided that supports the idea.

(A) Frame De-assembled   (B) Frame Assembled

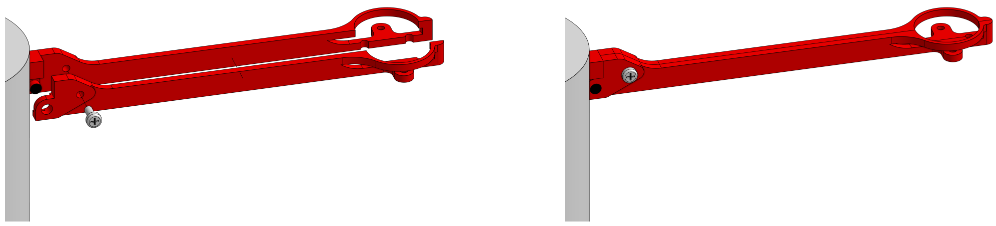
FIGURE 4.29: Frame Assembly

4.10 Assembly - Electronic Components

Further details to component placement and attachments are given below. The battery is assumed to be strapped independently onto the frame of the UAV.

(A) Shell De-assembled (B) Shell Assembled

FIGURE 4.30: Shell Assembly

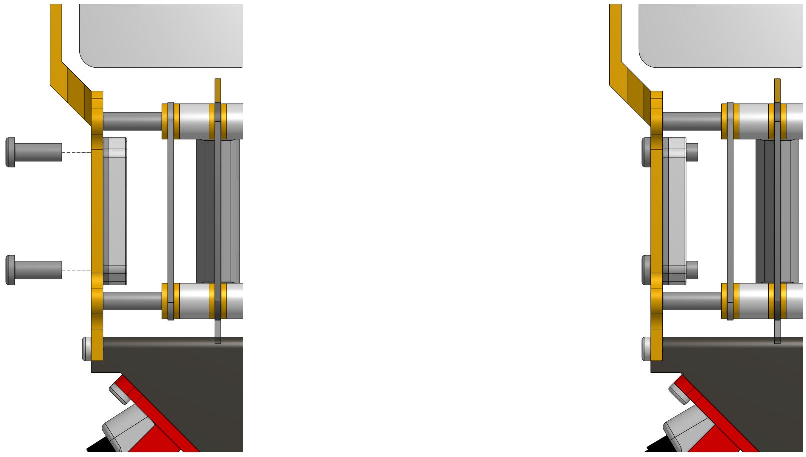


(A) Arm De-assembled (B) Arm Assembled

FIGURE 4.31: Arm Assembly

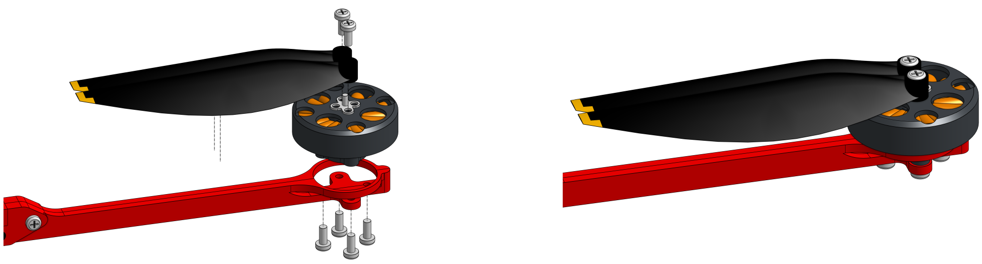
(A) Electronic Components De-assembled (B) Electronic Components Assembled

FIGURE 4.32: Electronic Components Assembly



(A) Electronic Components (2) De-assembled (B) Electronic Components (2) Assembled

FIGURE 4.33: Electronic Components (2) Assembly



(A) Electronic Components (3) De-assembled (B) Electronic Components (3) Assembled

FIGURE 4.34: Electronic Components (3) Assembly

CHAPTER 5
SUMMARY, CONCLUSION, RECOMMENDATION

5.1 Summary and Conclusion

The research is concluded by proving the validity of the UAV conceptual design through the determined Mission requirements and objectives. The results will settle the feasibility of the UAV concept. Although the UAV performance may differ with the scenario, the maximum performance values referred below are considered regardless of the scenario and more to the achieved maximum values of the calculator.

- The UAV is capable for carrying out ISR operations. The target is achieved through the presence of the camera mount on the UAV that provides access to equip the camera on-board.
- The same can be said for both loitering munition operations. Theoretically, the UAV is capable of carrying a fragmentation hand grenade and conduct kamikaze defense and payload dropping operations. The overall loitering munition weight does not impose any significant restrictions to the UAV.
- The overall weight achieved for ISR operations, at 387 g, is under the maximum weight objective of 400g. However, it does not fulfill the goal weight of being under 250 g. For loitering munition operations, the overall weight fails to be under the target weight, surpassing it by 53 g.
- In terms of the UAV performance, the ISR UAV is capable of reaching an endurance of 30.2 mins, slightly ahead of the objective target. In contrast however, the loitering munition UAV could only reach a flight time of 9 min, which is below the target.

- The acquired range for both configurations are above the target values, 1766 m above 5000 m for ISR and 1989 m above 1000 for loitering munition operations.

- The dash speed is the only objective goal that has been surpassed. Both the configurations are capable of reaching above 75 km/h, 100 km/h for ISR and 91 km/h for Loitering munition.

In conclusion, although some design requirement targets are not reached, the summary to the calculator results are satisfactory due to the nature of the operations. The conceptual design in this research utilizes off-the-shelf components and hence would naturally weight and sized more than the military counterparts that has custom components. Finally, the conceptual design, per item, is predicted to cost far lower than the set existing reference.

5.2 Recommendations

The scope of this conceptual design in this research study is considered limited, there is a wider approach that provides better and accurate results with additional analysis methods:

1. The UAV conceptual design doesn't stop at this stage, there are a lot of room for improvements to be made to optimize the performance and maximize operational effectiveness.

2. The performance analysis can be improved with better scientific sizing methods, the utilization of the online calculator could result in a slight or major errors in the results.

3. Further structural analysis can be made to check the structural liability of the UAV.

4. If possible, the dimensions of the UAV could be better if it were under 40 mm. If so, the UAV can be compatible with existing grenade launchers. The personnel won't need to carry an additional one-off launcher for the UAV if needed.

5. The UAV concept uses a latch mechanism paired with a servo as the actuator. The UAV weight can be minimized by adapting a more suitable release mechanism that uses lightweight components, reducing the overall weight from the current concept.

6. The consideration of the FFF material is chosen without testing the actual material strength through means of either physically or through structural analysis. It is later known that PU filament performs better in strength than ABS filaments, with a side note, that ABS filaments tends to be more brittle.

7. The UAV concept is not equipped with anti-jammer. The presence of these devices will cause the UAV to be ineffective and inoperable. An improved version should consider including an anti-jamming device for certain circumstances.

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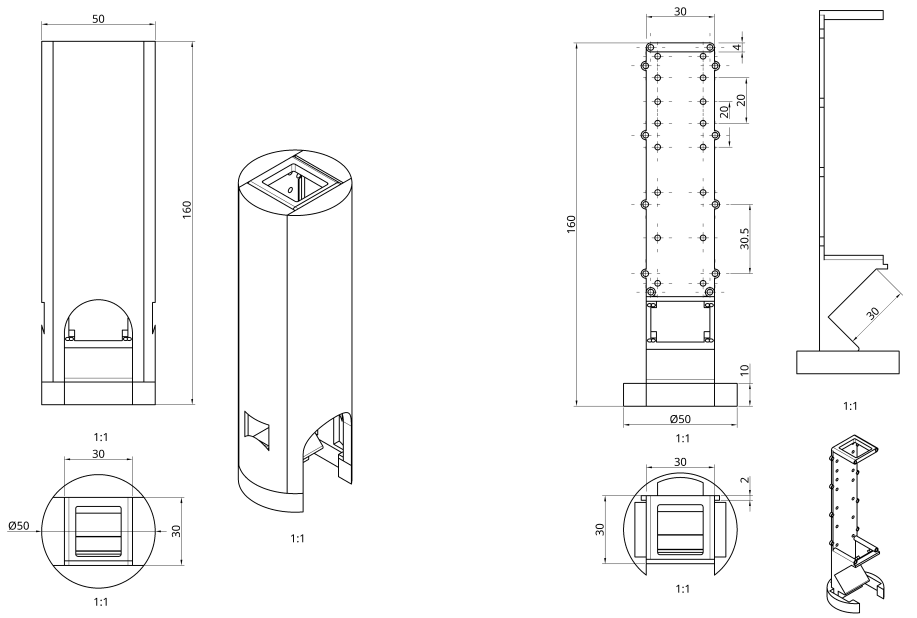
Appendices

Appendix A: Additional References



(A) Initial Airframe Dimensions (B) Initial Frame Dimensions

FIGURE 1: Initial CAD Dimensions

Initial Battery Selection				
Brand	mAh	Dimension	Length Adjustments	Weight
Flywoo Explorer (Hv)	900	50x16x26 mm	Fits	90.7g
Suitable Battery Selection				
Thunder Power	1300	70x30x38 mm	L8 mm	154
Tattu R Line	1550	76x38x30 mm	L14 mm	167g
Lumenier N20	1600	90x30x38 mm	L28 mm	185g
Lumenier	1800	104x35x20 mm	L42mm	182g

TABLE 1: Initial Battery Selection

Prop D		152.4 mm (6")				
Configuration		Without Payload				
Battery	mAh	900 Hv	1300	1550	1600	1800
	V Tot	15.2	14.8	14.8	14.8	14.8
	V/cell	3.8	3.7	3.7	3.7	3.7
Drive Weight	g	194	263	278	298	294
Total Weight	g	358	427	442	462	458
Hover Flight t	min	20.7	22.7	25.8	25	28.5
Elec Power	W	139	146	157	157	161
T/W		5.7/1	5/1	5.1/1	4.8/1	5/1
Specific T	g/W	8.91	8.21	8.09	7.92	7.95
Add Payload	g	1406	1404	1486	1467	1505
Max Tilt	deg	78	77	77	76	76
Max Speed	km/s	96	97	100	99	100
est Range	km	4.422	5.235	6.064	5.988	6.796
est ROC	m/s	16.4	16	16.5	16.3	16.6

TABLE 2: Battery Performance Results Using Initial Estimated Weight - Without Payload

Prop D		152.4 mm (6")				
Configuration		With Payload				
Battery	mAh	900 Hv	1300	1550	1600	1800
	V Tot	15.2	14.8	14.8	14.8	14.8
	V/cell	3.8	3.7	3.7	3.7	3.7
Drive Weight	g	194	263	278	298	294
Total Weight	g	547	616	631	651	647
Hover Flight t	min	11.2	13.2	15.3	15	17.1
Elec Power	W	139	146	157	157	161
T/W		3.7/1	3.4/1	3.5/1	3.4/1	3.5/1
Specific T	g/W	7.29	6.87	6.79	6.68	6.7
Add Payload	g	1220	1212	1294	1273	1312
Max Tilt	deg	72	70	71	70	71
Max Speed	km/s	93	94	97	96	97
est Range	km	2.862	3.577	4.194	4.189	4.752
est ROC	m/s	14.3	14	14.5	14.3	14.6

TABLE 3: Battery Performance Results Using Initial Estimated Weight - With Payload

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Curriculum Vitae

	Basic Information
Name	Fulki Shah Jahan
Place of Birth	Tasikmalaya, Indonesia
Date of Birth	14 June, 2001
Address	Sindangkasih, Ciamis, Jawa Barat, Indonesia
Year	**Education**
2019 - present	International University Liaison Indonesia (IULI)
2016 - 2019	SMAIT Insantama, Bogor (Senior High)
2015 - 2016	St Teresa's High School, Mumbai (Junior High)
2007 - 2015	Cumballa Hill High School, Mumbai (Elementary and Junior High)
Year	**Courses**
2022	Initial Flight Operations Officer Course - Merpati Training Center
2022	Boeing 737 CL and NG Dispatching Type Rating - Merpati Training Center
Year	**Seminars & Workshops**
2021	AIAA Composite Material Seminar
2020	Basic Maintenance Training Workshop - UNSURYA
Year	**Work Experiences**
2023	Flight Operations Intern - Asia Cargo Airlines
Year	**Projects**
2022	Baruna-1, Team Inferno - AIAA 2022 Undergraduate Aircraft Design Competition (Responsive Aerial Firefighting Aircraft)

2024	Small Scale e-VTOL UAV (Build and Fly) - National Formosa University
Year	Licenses
2023	Flight Operations Officer License - DGCA Indonesia
Year	Organizational Experiences
2020 - 2021	Vice Chair - IULI Student Executive Board
2021 - 2022	Treasurer - IULI Aviation Engineering Students Association
2020 - 2021	Public Relations - IULI Aviation Engineering Students Association
2019 - 2020	Arts and Music - IULI Student Executive Board
Year	Volunteering
2023	Event Support - Formula-E 2023 GulaVit Jakarta E-Prix
2019	Media Support - Orbit International Habibie Festival
2017	Young Rural Consultant and Fundraising - Lumbung Desa