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BACHELOR'S THESIS

A CONCEPTUAL DESIGN OF TACTICAL FIXED-WING LOITERING MUNITION

By

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11201801007

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

BSD City 15345
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APPROVAL PAGE

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STATEMENT BY THE AUTHOR

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

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ABSTRACT

A Conceptual Design of Tactical Fixed-Wing Loitering Munition

by

Joddy Pranata

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Dr. Eng. Ressa Octavianty, Co-Advisor

This thesis presents a conceptual design report of a tactical fixed-wing loitering munition. As demonstrated primarily by the current Russo-Ukrainian war, loitering munitions offer crucial advantages on the battlefield. Their ability to loiter and strike with precision against hidden targets reduces the risk to manned aircraft, enables faster reaction times, and allows for mid-flight course correction or mission abort, minimizing collateral damage. Lethality, flexibility, and relative affordability make them valuable tools for both offensive and defensive operations at the infantry squad level.

The design process began with benchmarking analysis, where the specifications of currently available competitors were compared and analyzed. The mission requirements were defined based on the benchmark and the widely available reports on the use of loitering munitions in the Russo-Ukrainian war. From the mission definitions, the payload and avionics components were selected from the broadly available commercial off-the-shelf products. The fuselage design depended on how the components were arranged, while the wing's geometry was determined by the sizing correlation method.

Although no optimization effort was made on the sizing, the conceptual design from this thesis was estimated to have comparable performance with the competitors. The geometry of the loitering munition was $76.7\,\mathrm{cm}$ in length, $134.1\,\mathrm{cm}$ in width, and the mass was just $1.182\,\mathrm{kg}$. The loitering munition was estimated to have an endurance of $15.6\,\mathrm{min}$ and a range of $10\,\mathrm{km}$.

Keyword: *Aircraft Design, Loitering Munition, UAV, Fixed-Wing*

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I want to take this time to thank my Parents for their loving care and support since I started to live, without their support and advice, I might not be able to hold onto this program and finish what I started in this college.

I would also like to extend my gratitude to Triwanto Simanjuntak, PhD, and Dr. Eng. Ressa Octavianty for their guidance and support in this effort to complete this project, the Loitering Munition design project.

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Also, my gratitude to all of my colleagues, and friends from wherever I met in my journey from the start until so far, not only from the Academics, but also that supported my hobby side as part of making myself better every time, be it from Aviation, Motorsports, Model Kit, and Anime (especially cosplay) community.

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List of Abbreviations

LM	**L**oitering **M**unition
UAV	**U**nmanned **A**erial **V**ehicle
UAS	**U**nmanned **A**erial **S**ystem
LM-UAS	**L**oitering **M**unition - **U**nmanned **A**erial **S**ystem
COG	**C**enter **O**f **G**ravity
CAD	**C**omputer **A**ided **D**esign
RPM	**R**otation **P**er **M**inute
AOA	**A**ngle **O**f **A**ttack
ESC	**E**lectronic **S**peed **C**ontrol
SEAD	**S**upression of **E**nemy **A**ir **D**efense
SyAAF	**Sy**rian **A**rab **A**ir **F**orce
IAI	**I**srael **A**erospace **I**dustries
HSLR	**H**igh **S**peed - **L**ong **R**ange
HSHE	**H**igh **S**peed - **H**igh **E**ndurance
LOCAAS	**LO**w **C**ost **A**utonomous **A**ttack **S**ystem
MTOM	**M**aximum **T**ake-**O**ff **M**ass
GPS	**G**lobal **P**ositioning **S**ystem
AO	**A**rea of **O**perations
FCS	**F**light **C**ontrol **S**ystem
FCS-M	**F**light **C**ontrol **S**ystem - **M**odule
FCS-B	**F**light **C**ontrol **S**ystem - **B**ase
LIDAR	**LI**ght **D**etection **A**nd **R**anging
OSD	**O**n **S**creen **D**isplay
ABS	**A**crylonitrile **B**utadiene **S**tyrene
FCS-M	**F**light **C**ontrol **S**ystem - **M**odule
NACA	**N**ational **A**dvisory **C**ommittee for **A**eronautics
NASA	**N**ational **A**visory and **S**pace **A**dministration

OpenVSP	**Open V**ehicle **S**ketch **P**ad
RCS	**R**adar **C**ross **S**ection
HVT	**H**igh **V**alue **T**argets

Dedicated to my parents

CHAPTER 1
INTRODUCTION

1.1 Background

FIGURE 1.1: IAI Harpy, the first Loitering Munition in the world by Israeli Aviation Industries [2]

Ever since the introduction of so-called "kamikaze drones" that came along with Unmanned Aerial Vehicles in the late 1980s, the Loitering Munition gained popularity in the military defense industry as the better option for replacing the standard operations of aerial warfare by an Aircraft. From there, the loitering munition slowly gained its purpose originally from prioritizing destroying enemy air defenses in the form of "Suppression of Enemy Air Defenses" (SEAD), to nowadays, they can target oppressing infantries and light vehicles and provide the "extra pair of eyes in the sky" to the intended forces.

When Mr. Brennan explained the definition of loitering munition in his article at warontherocks.com entitled "*Loitering Munitions in Ukraine and Beyond*"[3], the loitering munition is always misunderstood as an aircraft, and is usually known to be as a missile controlled by a human in a control panel and will crash and explode into the target, hence its *Kamikaze* drone nickname.

FIGURE 1.2: McDonnell Douglas' F-4E Phantom II "Kurnass" on the skies of a city during Operation Mole Cricket 19

FIGURE 1.3: Illustration of F-15A Eagle "Baz" launching a missile against Syrian fighter in Operation Mole Cricket 19

The first combat that utilized the Unmanned Aerial Vehicles ever recorded was done by the Israel Defense Forces in Operation Mole Cricket 19 as part of the 1982's Lebanon War. During the battle stated in Yogev et. al's "*Revolution in military affairs - The operation mole cricket 19 as a case study for the technological race during the cold war*" [4], 13 SAM Batteries were destroyed, 3 neutralized, 26 combined Syrian MiG-21 and MiG-23 destroyed, and no one from the Israeli Air Force, including their UAV "Telem" and "Shadmit" and their planes destroyed.

FIGURE 1.4: AeroVironment Switchblade 300 launched from a gas tube[5]

It took 30 years, to finally see the maximum potential of Loitering Munitions by the United States Army to employ against oppressing forces as seen in the Late stages of the Afghan War in 2012 (which stated in Kapoor's "*Portable Attack Drones or Loitering Munitions*" in SP's Land Forces website[6].). The introduction of Aerovironment Switchblade family of Loitering Munitions (Seen in Fig. 1.4) gained its popularity in portable, simplified controls, and able to perform surgical strikes in the Afghan war despite being unable to hold on to the attack 8 years later. Despite the loss in the war, the United States decided to improve the Loitering Munitions as much as possible, to the point of not only the new, emerging manufacturers such as AeroVironment and AEVEX Aerospace that are able to create the new Loitering Munitions, but the big names in the defense industry such as Boeing and Lockheed Martin join the competition to create the equipment that will be the mainstay for modern warfare in years to come.

Meanwhile, in that year, the second Nagorno-Karabakh war introduced us further into the use of Loitering Munitions, as reported in Postma's "*Drones over*

FIGURE 1.5: Armenian ProMAQ's HRESH Loitering Munition, the Armenian answer to the Azerbaijani forces' utilization of Loitering Munitions [7]

Nagorno-Karabakh: A glimpse at the future of war?" at JSTOR[8], with the introduction of Armenian HRESH Loitering Munition (From Fig. 1.5) after the Azerbaijan forces utilized their supply of IAI Harop, Orbiter 1K, Orbiter 3, and SkyStriker that able to secure multiple vehicle and infantry kills which led to the cessation of all hostilities after 44 days since the war started.

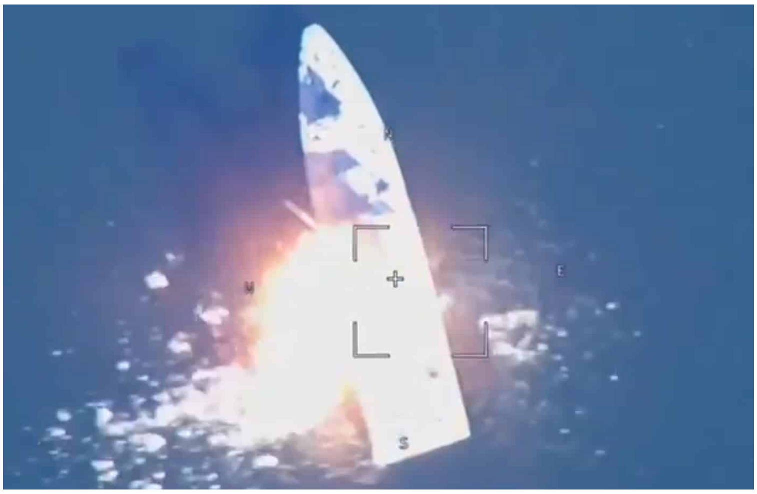


FIGURE 1.6: Ukrainian gunboat destroyed by a Russian Loitering Munition[9]

The biggest kicker for the Loitering Munitions was in 2022 and still happens as far as this thesis is written, during the height of the Russo-Ukrainian war, which Russian forces utilized the Geran-class Loitering Munitions to secure the destruction of Radar Installations used by Ukrainian forces, while the Ukrainians acquired the Switchblade Family and Phoenix Ghost of Loitering Munitions, as well as using commercially available quad-copters to do just that. Later in the war, Russian forces managed to destroy a naval gunboat from the Ukrainian forces with a Loitering Munition, finally done its first Naval kill with a Loitering Munition, as seen in Figure 1.6.

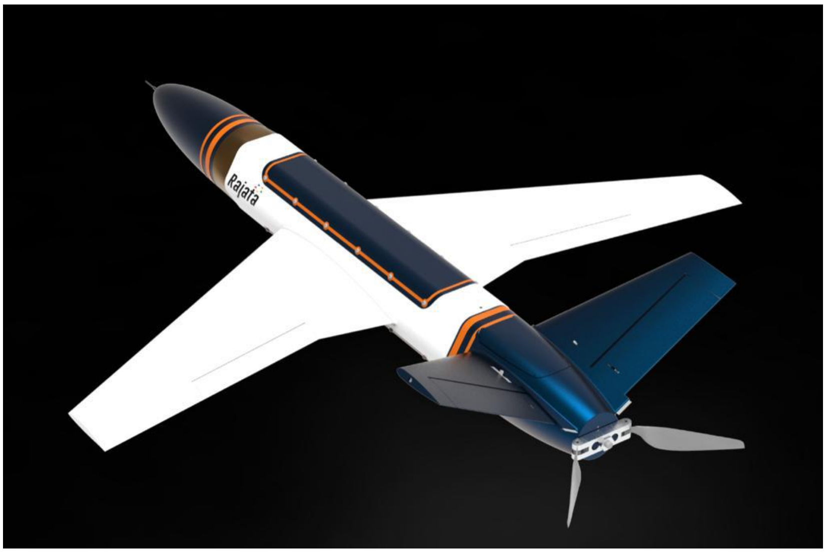


FIGURE 1.7: Dahana RAJATA, Indonesian's only Loitering Munition so far[10].

In response to this, the Indonesian defense holdings under the moniker DEFEND.ID with Dahana as its main manufacturer built the RAJATA Loitering Munition (Fig. 1.7), which took the benchmark from WB Electronics Warmate from Poland. While the tests and analysis suggest it is meant for light vehicle suppression, it does not restrict the possibility that other Loitering Munitions that will come can "join the party". From here, We decided to create a Loitering Munition that will act as a Fixed-Wing, Low-Cost, and Tactical Loitering Munition that hopefully, could get up to the task of maximizing the efforts in disabling the progress of oppressing forces.

1.1.1 The variants of Loitering Munitions and our selections

There are two major types of Loitering Munitions based on how the craft is flown just like in Flying objects in common, the Fixed-Wing and the Rotary-Wing Loitering Munition. From there, it is known that the fixed wing is basically the Aircraft form of Loitering Munition, while the rotary wing is meant for quad copter form of said object. There are some advantages and disadvantages of having each form seen in tab.1.1.

	Fixed-Wing	Rotary-Wing
Advantages	Long-Range and High-Endurance. Higher Service Ceiling	Hoverable and land before attack. Smaller Dimensions
Disadvantages	Unable to Hover Larger Dimension	Short-Range and Small-Endurance Lower Service Ceiling and vulnerable when Hovering.

TABLE 1.1: Advantages and Disadvantages of Fixed-Wing and Rotary-Wing Loitering Munitions

1.1.2 About Tactical Loitering Munitions

The Tactical Loitering Munition, as the name suggests, is the Unmanned Aerial System which utilizes small dimensions and is equipped with the necessary payload to not only detect enemies from long distances but to ensure the destruction of opposing forces/targets that may be suitable for said use. Technically speaking, it is either equipped with just a camera for Reconnaissance missions, or the explosive devices that usually are small (e.g. the AeroVironment Switchblade 300 has a 40mm explosive payload, and up to approximately 150mm with the UVision Hero 1250), depending on the design profile and operation. From there, the usual targets for Loitering Munition use are light vehicles, radar installations, infantries, artillery, or even heavily protected vehicles if the payload supports.

The lists of Tactical Loitering Munition missions so far are as follows:

- Tactical Reconnaissance.
- Close Air Support.
- Suppression of Aerial Defenses (SEAD).
- Interdiction.

1.2 Problem Statement

The problem that this thesis aims to address is to produce a conceptual design of a tactical loitering munition UAV that can be used for defense purposes, able to bring a small explosive payload — the same class of hand grenade — by an infantry squad. The UAV shall have comparable performance with the current competitors while also considering production cost and manufacturability.

1.3 Research Objectives

The objectives of this thesis primarily are to carry out a conceptual design of UAV that,

- Aimed to be used as a tactical drone used by squad-level infantry.
- Have endurance of $30\,\mathrm{min}$.
- Have a range minimum of $10\,\mathrm{km}$
- Able to bring maximum payload minimum of $200\,\mathrm{g}$.
- Statically and dynamically stable in both motion modes.

1.4 Research Scope and Limitation

The coverage of this thesis is defined as follows:

- Consider only the conventional fixed-wing configuration.
- Does not investigate the launch mechanism and air-to-ground communication station.
- Sizing is done based on a statistical approach and without optimization.
- Using e-calc for performance calculation and propulsion finder.
- Avionics components are selected from typical COTS available in the market.
- Although no cost analysis is needed, it's expected that the conceptual design shall prioritize material and manufacturing that allow cost efficiencies.

1.5 Significance of the Study

The design of this is expected to be:

- Used for comparative design for similar tactical UAVs used in defense purpose.
- Reviewed, optimized, and eventually built for the expected missions.

CHAPTER 2
LITERATURE REVIEW

2.1 Relevant Previous Works

In this section, six relevant works are summarized in this thesis. These works [1], [11]–[15] covers the latest in Unmanned Aerial Systems and subsequently, the loitering munition itself. Some of these are the main analyses of how the loitering munition works and some others are the experiments in the study of drones, ranging from modularity, elasticity, precision, and so on.

2.1.1 Switchblade: Wide-Mission Performance Design of a Multi-Variant Unmanned Aerial System

The paper by Maldonado et. al. [11] discusses how effective the re-configurable systems that would be used for Multi-role Unmanned Aerial Systems, the Switchblade. There were a few unique modules for the aircraft that could be used for the Switchblade Loitering Munitions style, including the VTOL capability with their modified fin modules.

The Switchblade was tasked to be light, Wide-Mission capable, and has modular platform planning systems, which could take two plane variants; High-Speed Long Range (HSLR) and High-Speed High Endurance (HSHE). The challenge is that the said aircraft could have constraints in the modularity of designs for wing designs. Not only is the wing modularity the constraint of the design but also the capability to commit multiple roles in the Unmanned Aerial System alone, hence the Multi-Variant and the Multirole use.

Conclusively, the conceptual design of the Multi-variant Unmanned Aerial System managed to address the trade-offs of flight performance across all variants.

The UAS will have different cruising speeds, ranges, and payloads to maintain lift-to-drag efficiency, Flight efficiency, and manufacturing costs. Their HSLR variant could hold on to acceptable cruise efficiency thanks to its wing design and intended cruise speed and payload, while later variants will include lesser wing area and airfoil camber to maximize the HSLR's flight efficiency.

2.1.2 Structural design and modal behaviors analysis of a new swept baffled inflatable wing

Mr. Ma et. al. [12] discussed the potential of a new idea called swept baffled inflatable wing. The idea of an Inflatable wing was once known by one of the tire manufacturer known as Goodyear Tyres from the United States, and it was a useful idea to maintain the airframe with an inflatable wing, the Aircraft that Goodyear built, the Inflatoplane which was made for the pilot who was shot down and fly away from hostile territory, but unfortunately came with a large disadvantage of low speed and low altitude capabilities, making it an easy target to destroy.

One of the major examples of an Inflatable Unmanned Aerial System is I-2000, which achieved a 42.7 percent weight reduction thanks to the Inflatable wing technology and can adapt to span changes and rapid discard thanks to pneumatic actuation. The paper discusses the Loitering Munition can launch from an aerial launch platform, and will react like how the common loitering munition acts.

In summary, the Swept baffled Inflatable wing is theoretically effective for Loitering Munition, because of better approximation and aerodynamic performance, better stiffness for the modal parameters of the structure, ability to maintain internal pressure and reduction of baffle sweep angle value, and improving flutter performance and reduced divergence performance.

2.1.3 An Experimental Determination And Numerical Analysis Of A Loiter Munition Unmanned Aerial Vehicle System

The paper from Saraçyakupoglu et.al. [13] discusses the experimental determination and numerical analysis of Loitering Munition, by calculating and analyzing the design criteria of Unmanned Aerial Systems within 4 scenarios. First off, the UAV is made as Loitering Munition, Mobile equipment, able to operate during day/night operations, long-endurance (2-3 hours), able to use GPS, and launched from a catapult.

The experiment finds a myriad of findings, ranging from performance, wing uses, best configurations of an LM-UAS, and much more. The experimental findings of the parametric approach for LM-UAS are the Aspect ratio, Taper Ratio, Wing Twist, Dihedral, Wing Incidence Angle, Wing Vertical Location, Wing Tips, Fuselage, Center of Gravity, Tail sizes, weight estimation, and operational environment with the potential adverse impact of the implementation of Novel Technologies.

In summary, the Loitering munition from the research prioritize stability as the main concern of the craft and the design does revolve with this matter in mind, with some changes to size estimation for the final decision, using Mid-wing, twin tail, and lighter body design to have 3 axes of stability and advantageous including operational costs, although there will be optimizations of their aerodynamic surfaces.

2.1.4 Optimal Design of Loitering Munition Trajectory in Complex Battlefield Environment

The paper led by Mr. Liu et. al. [14] discusses how the loitering munition able to thrive on the variety of battlefield conditions around the craft, be it jungle, mountain, desert, or even urban areas. The Loitering Munition is studied and built around specific needs of the munition depending on the majority of battlefield uses and how it works out (Roles in the field).

The Loitering Munition details include the schematics from the internal details, launch systems, a variety of environments, flight programs, Trajectory optimization and more. The results of the Loitering Munition launch suggest the higher the Launch angle, the H1/m will increase alongside its minimums for H1H2, making it perfect for jungle area launch when it requires a short time of launch.

Conclusively, the Loitering Munitions does show how different launch angle makes a difference in launching the craft and fits any kind of terrain situation, by determining the environment and appropriate situations.

2.1.5 Loitering Munitions-In Focus

The paper let by Mr. Gettinger et. al. [15] discusses the variety of loitering munitions that are available worldwide (up until 2017, as the paper was created), and looks at how the loitering munitions differ in size, shape, and performance to carry out the intended roles. Some of these are included during the Nagarno-Karabakh war between Azerbaijan and Armenian forces after Armenian forces discovered that the Azerbaijan forces used the IAI Harop loitering munition to destroy the bus filled with pro-Armenian volunteers.

The paper does specify every loitering munition available from the conceptual to well-known loitering munitions, although some could be classified as Long-Range Cruise Missile, including the WS-43 after it was known to have 60km range and loiters for half an hour. The paper also has some examples of rotary-winged loitering munition, the Tiger Moth by Lite Machines.

The paper summarizes that the loitering munitions would increase the capacity to discriminate the combatants and noncombatants easily thanks to the targeting systems, not only that, the loitering munitions have better precision then the guided missile at this time and could commit wave-off in case of collateral damage is ensured. The problem is that some loitering munitions could autonomously detect targets without any human control, which is a problem due to potential errors, which was exampled from the DARPA and USAF's joint project called “Low-Cost Autonomous Attack System” (LOCAAS). Considering the technology of Loitering Munitions, the counter-drone systems have to evolve, including the Electronic CounterMeasure suites that is proven during some loitering munition attacks in the Russo-Ukrainian War in 2022.

2.1.6 Preliminary Sizing Correlations for Fixed-Wing Unmanned Aerial Vehicle Characteristics

The research paper led by Verstraete D., et. al., [16] discusses the analysis of how an Unmanned Aerial Vehicle was preliminarily made and led from the Power needed, Wing needed, and even Endurance required to make it fit for performance.

The analysis started with the methodologies of data sets available for all kinds of Unmanned Aerial Systems and combining the independent parameters with regression constant to create the independent parameters. Then it will continue to the mission parameters with Payload Mass, Mission Endurance, and Geometrical Correlations such as Empty Mass, Wingspan, and Wing Area, then off to Powerplants including Engine and Performance Parameters and comparing the calculations with Manned Aircraft.

In conclusion, the paper, the relations to Unmanned Aerial Systems are successfully made and each powerplant variations are differentiated for the equations, which is great for finding the data needed when designing the said UAS. This paper will be instrumental in determining the methodology of our paper here, which will be seen in our next chapter.

2.2 Performance analysis and design of loitering munitions: A comprehensive technical survey of recent developments

Mr. Voskujil [1] discusses the analysis and design of loitering munitions that grew around us since the beginning of their existence in 1982 to this day. The Loitering Munitions do carry small tasks in said era including the first full usage of the militarized unmanned aerial system in Beqaa Valley in that year, to the first full usage of loitering munitions in the Nagarno-Karabakh war in 2017 up until this time in the Russo-Ukrainian war in 2022-2023.

The following subsections will discuss the key points of said papers and will be used as our reference for our thesis.

2.2.1 Basis of what needs of a Loitering Munition

The airplane in general has a lot of needs and requirements as needed in the Mission profile, based on the projected Mission Profile graph from Mr. Roskam's "Airplane Design Part I - Preliminary Sizing of Airplanes" we can launch a graph similar to the reference with multiple possibilities for the loitering munition as in figures 2.1, 2.2, and 2.3:

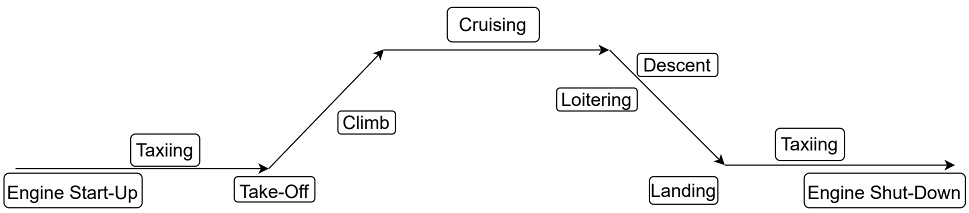


FIGURE 2.1: The example of the Mission Profile of an arbitrary airplane [17]

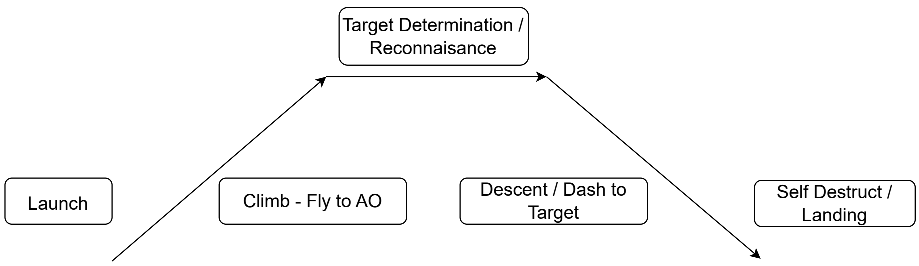


FIGURE 2.2: Normal flight condition, without wave-off/abort dash on target.

As stated in the mission profile, we determined that the loitering munition will have to either destroy the target from the area given or return it to the owner by landing the craft. The Loitering Munition generally follows these profiles. From there, we determined that the loitering munition would depend on the range and

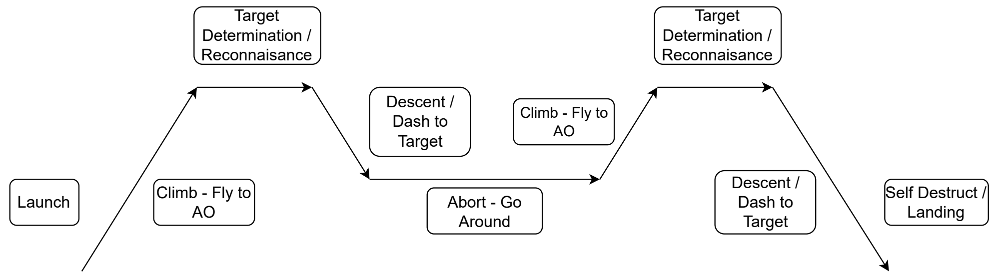


FIGURE 2.3: The example of the Mission Profile of an arbitrary airplane Source: Extended flight condition, with wave-off/abort dash on target.

endurance to detect and destroy enemies with minimum casualties. That would mean the craft will have a few crucial performance factors that will determine the quality of the said craft, as mentioned in Mr. Voskujil's "Performance analysis and design of loitering munitions: A comprehensive technical survey of recent developments" The loitering munition should prioritize:

- Loitering Endurance
- Terminal attack dive airspeed
- Precision trajectory control
- Agility and controllability
- Launch platform size

Primarily, the loitering munition has its mass and endurance like any aircraft, and we could determine the endurance based on the desired time between the loitering munitions that are provided in real life in comparison, which we will discuss more in the next chapter. To summarize, loitering munitions are required to have such characteristics for optimum performance, design, and configurations, as we see from Mr. Voskujil's Performance analysis and design of loitering munitions: A comprehensive technical survey of recent developments", The table. **??** shows these requirements

2.2.2 The Equipment of a Loitering Munition.

As we know in the previous chapter, the loitering munition is known to be another form of Unmanned Aircraft System (UAS), meaning that the said aircraft

TABLE 2.1: Summary of Performance Criteria, Design Requirements, and Suitable Configurations [1]

	Loitering Munition	Terminal Attack Dive Speed	Precision Trajectory Control	Launcher Size	Hover Capability for Urban Combats
Relevant design parameters	Low wing loading (W = S)	Powerful engine (Pbr;max)	High wing loading (W = S) and small lift curve slope	Foldable design or small wing span	Rotary Wing
	Propeller pitch optimized for cruise	Propeller pitch optimized for high speed operations	Direct lift control capability		
	High aspect ratio (A) wing and large Oswald efficiency factor (e)	Low zero-lift drag and wing area (CD0S)	Side force control capability		
		Large aircraft weight (W)	Primary control surfaces in front of centre of gravity		
Suitable Configurations	Conventional	Delta Wing	Cruciform	Tandem	Rotorcraft
		Cannard/Tandem	Cruciform		Tandem
	Delta Wing (Longitudinal Control)	Delta Wing			

is not flown by humans inside. Aside from the fact that the loitering munition is unmanned, the craft is known to be strapped with at least one explosive material that would guarantee damage. This would mean the aircraft's control system could be as simple as radio transmission like how we see the hobby RC aircraft, to as advanced as directing the aircraft via GPS and satellite imagery as we see from the most loitering munitions, ranging from DAHANA's own Rajata, up until the AeroVironment Switchblade family of loitering munitions.

2.2.3 Determining the Loitering Munition's Maximum Take-Off Mass (MTOM).

Based on what we discovered from the mission profile and requirements, we have to determine the Maximum Take-Off Mass of the loitering munition, which will be accessible if we have certain conditions met for the calculation, as from Mr. Voskujil's "Performance analysis and design of loitering munitions: A comprehensive technical survey of recent developments", there are some coefficients and correlations to the equations and Tables 2.2 and 2.3 show these regards to the said issue.

$$m_{\text{warhead}} \times \text{endurance} = F \times \text{MTOM}^{E} \tag{2.1}$$

- m(warhead): Warhead Mass, the total weight of the weapon's warhead. (kg)
- Endurance (usually e in formulas): Duration of aircraft airborne. (minutes)
- F: Fuel Flow Correlation.
- E: Endurance Correlation.

TABLE 2.2: Coefficients for the power law correlations of warhead mass and endurance with Maximum Take-Off Mass. [1]

Category	Warhead Mass Correlation with MTOM				Endurance Correlation with MTOM			
	N	A	B	R^2	N	C	D	R^2
Cruciform	9	1.2945	0.1168	0.9676	8	0.5447	14.3321	0.9187
Conventional	18	0.9422	0.2289	0.9109	17	0.6634	15.1273	0.5427
Canard	1	-	-	-	1	-	-	-
Tandem	4	0.7871	0.2109	0.6002	4	0.6519	11.5213	0.4603
Delta	4	0.8565	0.2892	0.9442	4	0.7076	6.6075	0.7877
Rotorcraft	4	1.7584	0.0514	0.9908	4	0.7228	7.1606	

TABLE 2.3: Correlation of the Product of Endurance and warhead mass (kg/min) with Maximum Take-Off Mass. [1]

Category	N	E	F	R^2
Cruciform	8	1.8409	1.6472	0.9803
Conventional	18	1.5831	3.6328	0.7947
Canard	1	-	-	-
Tandem	4	1.1369	5.1238	0.4071
Delta	4	1.5641	1.9111	0.9659
Rotorcraft	4	2.4630	0.3772	0.7836

2.2.4 Terminal Attack Dive Speed.

Loitering munitions are mandatory to dive at maximum speed to ensure faster and more precise explosions to opposing vehicles or infantry. There are some constraints to achieving and determining the Terminal Attack Dive Speed, including the aircraft material's maximum stress speed, powerplant's break power, propeller efficiency, drag coefficient, and others, as seen from Mr. Voskujil's "Performance analysis and design of loitering munitions: A comprehensive technical survey of recent developments".

$$P_{\text{br, max}}\eta_{prop}(V_{\text{max}}) - C_{D0}\frac{1}{2}\rho V_{\text{max}}^3 S - \frac{2W^2\cos^2\overline{\gamma}}{\pi b^2 e\rho}\frac{1}{V_{max}} + WV_{\text{max}}\sin\overline{\gamma} = 0 \tag{2.2}$$

- $P_{br,max}$: Maximum Breaking Power
- η_{prop}: Propeller Efficiency
- V_{max}: Maximum Velocity (Terminal Attack Dive Speed)

- C_{D0}: Initial Drag Coefficient
- ρ: Air Coefficient
- S: Wing Area
- W: Weight
- b: Wingspan
- e: Euler number
- $\overline{\gamma}$: Constant Descent Angle

2.2.5 Atmospheric Disturbances

Regarding aircraft being distracted by atmospheric conditions, such as meteorological or geographical situations, the plane will have to stabilize based on said situations and adapt within the Area of Operations (AO). One example of atmospheric disturbance is wind gusts, which will increase the load factor and deviate the plane from the flight path. As shown in this mathematical formula in Mr. Voskujil's "Performance analysis and design of loitering munitions: A comprehensive technical survey of recent developments"[1].

$$(\delta_{\mathrm{n}}) = K\frac{d(C_l)}{d\alpha} \times \frac{\rho U V}{W/S} \tag{2.3}$$

- δ_{n}: Increase of Load Factor
- $\frac{d(C_l)}{d\alpha}$: Lift Curve Slope
- W/S: Wing Load
- K: Relation Factor of gust to vehicle
- ρ: Air density
- α: Angle of Attack
- U: Velocity
- V: Volume

2.2.6 Agility and Controllability

Based on the factors given in destroying enemy infantry or light vehicles, the loitering munition should be able to maneuver and stabilize as the user commands.

Some aircraft configurations made it easier, including the Cruciform winged configuration that stabilizes and redirects the side force control, while Canard and Tandem configurations followed the idea. Taking to account Mr. Voskujil's "Performance analysis and design of loitering munitions: A comprehensive technical survey of recent developments"[1], the paper stated that there were significant challenges for directional stability and control, including the Delta winged design (i.e. Shahed-136 by Iranian manufacturers) the craft does not feature horizontal stabilizers and making the winglets also act as vertical stabilizers. This is also affected by each configuration and condition should the aircraft be damaged by enemy fire.

2.2.7 Launch System Size

Based on Appendix B.1 of Mr. Voskujil's "Performance analysis and design of loitering munitions: A comprehensive technical survey of recent developments"[1], there are two options for launching the Loitering Munition, which was:

- Rail Launch
- Canister Launch
- Hand/Manual Launch

Some of the options are made possible by certain conditions, such as Rail Launch, if the craft is meant to be deployed with light vehicles (Truck or Armored Personnel Carrier), while Canister launch is meant to be used for loitering munition that could be launched by infantry, for Hand/Manual Launch, is meant to be personnel throw the loitering munition airborne and immediately climb to the Area of Operations.

2.3 Mission Requirements

Every aircraft has its mission or purpose of their aircraft was built. Seeing every aircraft that has an experimental purpose, be it commercial or military use, The unmanned Aerial System also has its mission requirements, including the Loitering Munitions.

Table 2.4 shows the mission requirements that were issued and designed by us during the preliminary days of Loitering Munition Design, this is meant to be fit to against Military Personnel and Light Armored Vehicles. We used the average calculations of range, endurance, speed, and altitude data of each loitering munition that would fit our case and summarize our requirements stated here.

We gather most of the well known loitering munition data, ranging from the pioneer of loitering munitions like the Israel Aerospace Industries to the trending loitering munitions like WB Electronics and AeroVironment. We will discuss more of how we gather the data later in the next chapter about the research methodologies.

TABLE 2.4: Mission Requirements for the Loitering Munition

Manufacturing Process	
Equipments (Airframe)	Additive Materials (3D Printer based Plastic or viable materials) Using Basic/Intermediate 3D Printer for the Frames
Dimension	in millimeters
Length	<550
Width	Wingspan : <700 Folded Wings (Fuselage) : <80
Height	With Vertical Stabilizer : <200 Fuselage : <150
Mass	MTOM (Approx.): 5kg
Performance	
Airspeed	Cruising: Approx. 85kts Dashing: Approx. 100kts
Range	10km
Altitude	Minimum: 100m - 300m Service Ceiling: 4500m
Endurance	10 Minutes
Avionics	
Sensors	High Definition Camera with Gimbals EO/IR/NVG Camera Sensors
Flight Controls	GPS/INS Datalink Dedicated Tablet / Laptop for aircraft control Datalink for other military equipment
Countermeasures	ECM Countermeasure Suite (if possible)
Payload	
Warhead	40mm Armor Piercing Warhead 40mm High-Explosive Warhead

CHAPTER 3
RESEARCH METHODOLOGY

The Unmanned Aircraft system indeed has a lot to cover regarding how a system flies communicates and operates during a Mission. Loitering Munitions also do comes in a variety of shapes, such as flying wing, cruciform, conventional, Canard winged, and much more. The one that we made is basically in a simple tubed designed aircraft since some systems use the conventional fuselage, such as UVision's HERO family of Loitering Munitions, AeroVironment Switchblade, CH-901, WB Warmate, and much more.

Such designs surely have their technicalities needed to achieve the intended mission requirements. Including our design, and surely we need all the calculations needed to achieve the requirements, depending on the equipment we listed to have inside our system. The following details are our explanation of how we determine the Aircraft design.

3.1 The steps of our design.

The loitering Munition design is similar to what we expect of Aircraft in general, with some changes to requirements and similarities to the Unmanned Aerial System. In short, although it may be a conceptual and Preliminary design, it is still complex and should be done one step at a time. Based on the preparations and the procedures we had planned to begin the Thesis, there will be charts to describe the situation but with some twists to cut down the time needed to complete our project, which is shown in the following fig. 3.1

Some notes from the thesis research methodology:

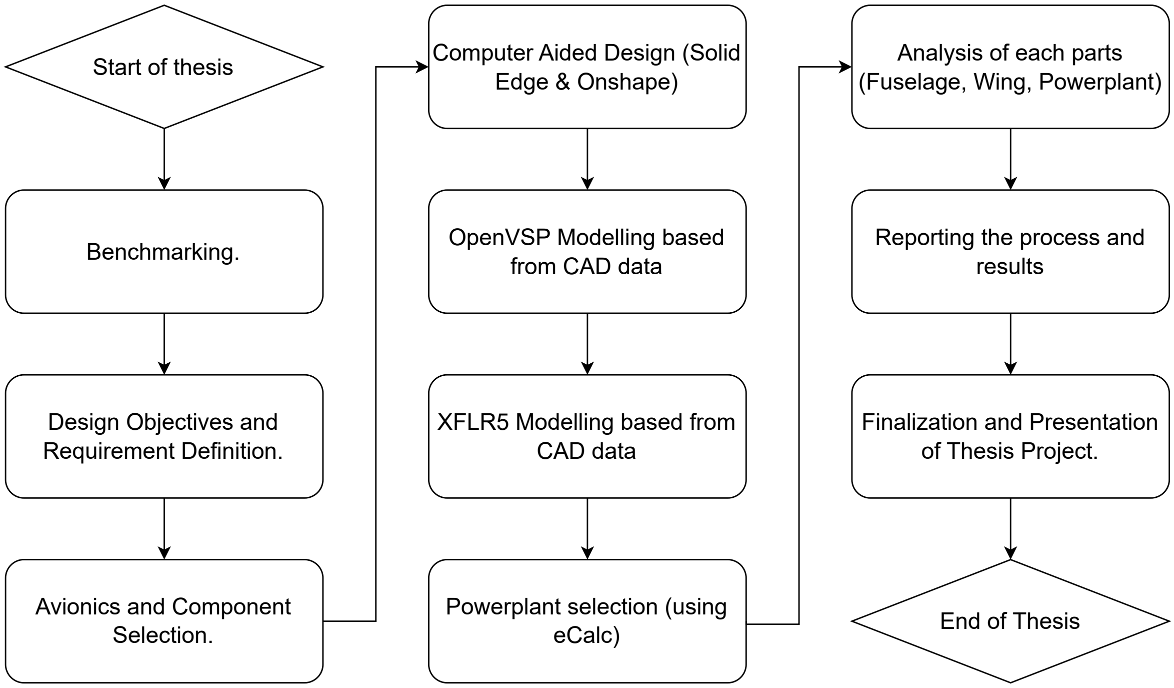


FIGURE 3.1: Thesis Research Methodology.

- Avionics and Component Selection are based on our previous project, the "*Conceptual Design of a Loitering Munition Based on AeroVironment Switchblade 300.*" to minimize the time needed to select our said equipment.
- Following each completion of Loitering Munition parts, we report each progress to minimize the time loss and maintain fresh knowledge of each discovery and progress.
- The finalization of the thesis program includes the refresh and final arrangements of the manuscript, with revisions in most parts needed.

3.2 Fuselage Equipment Selection and Measurements

The Fuselage designs are based on modules and suitable design dimensions. With that said the Fuselage design will start from Module selection and then up to Volume and design selection. The following is how we managed to determine the Fuselage from the components inside the design.

3.2.1 Fuselage Component Selections

The first part of knowing the Fuselage design is to know what equipment will be inside the fuselage of a loitering munition, which has the Flight Control systems, explosives, sensors, and more. The equipment we use are based on commercially available websites, not limited to locally available systems but also internationally available. The avionics that we selected is basically in use for commercial use Drones, meaning that the Loitering munition can be easily built without any specialized needs. From there, we will need the small FCS base that could be compatible with avionics that are deemed mandatory to use. These avionics are:

- Flight Control System (FCS) Module
- Global Positioning System (GPS) Module
- Radio Transmitter
- Electronic Speed Controller (ESC)
- On Screen Display Transmitter (OSD)
- LIDAR Sensor
- Camera Systems
- Pitot Tube

Later the avionics will be assembled with a Three-Dimensional Computer-Aided Design application, which will help us determine the assembly of each module needed to complete a Loitering Munition. As for the weapons, we will need to use technical specifications from public websites including from Aalen University. The website provides the necessary specification info including the Mass, Volume, and such.

3.2.2 Determining the Fuselage Design

The first step in determining the Fuselage length is to know the maximum width and height of all components that we include in our fuselage. From there, we can determine the effective diameter of our Fuselage design, which we can formulate by:

$$d_{\text{ef}} = \sqrt{d_1 \times d_2} \tag{3.1}$$

- d_{ef}: effective diameter
- d_1: Diameter (in this case, width)
- d_2: Diameter (In this case, height)

Then we can multiply the effective diameter by 8 to determine the Fuselage Length, as seen from this formula

$$l_{\text{fuselage}} = d_{\text{ef}} \times 8 \tag{3.2}$$

- l_{fuselage}: Fuselage Length
- d_{ef}: effective diameter

When the Fuselage length, width, and height are fully confirmed, we can open the Computer-Aided Design application to design the simplified components and fuselage itself, and the results will be discussed in the next chapter.

3.2.3 Determining the Loitering Munition's Inertia

The fuselage is also crucial to our determination of Maximum Take-Off Mass which will influence our determination of Endurance, targeted at 30 minutes or more, as stated in our Mission requirements. The following are equations that will help determine the crucial values of our Loitering Munition. The following Tables 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, and 3.8 is the specified table to determine the LM's Inertia from MTOM to Power respectively as seen in each list.

- Maximum Take-Off Mass ($\mathrm{m_{TO}}$)

$$\mathrm{m_{TO}} = \mathrm{A} \times \mathrm{m_{PL}^{B}} \tag{3.3}$$

- Endurance (E)

$$\mathrm{m_{PL}} \times \mathrm{E} = \mathrm{m_{TO}^{B}} \times \mathrm{A} \tag{3.4}$$

- Empty Mass ($\mathrm{m_E}$)

$$\mathrm{m_E} = \mathrm{A} \times \mathrm{m_{TO}^{B}} \tag{3.5}$$

TABLE 3.1: Coefficients for power-law fits of MTOM as a function of payload mass

Type	n	A	B	R^2	Mean $\left(\frac{m_{PL}}{m_{TO}}\right)$	$p_{B_0} = 1$
All	654	4.964	1.001	0.945	0.224	0.64
Battery	151	5.147	0.849	0.843	0.211	1×10^{-6}
Fuel Cell	15	4.180	1.027	0.825	0.221	0.54
Solar	15	15.872	0.690	0.912	0.199	2×10^{-3}
Piston	385	4.567	1.001	0.884	0.240	0.86
Turbine	82	4.752	1.076	0.932	0.164	0.09

TABLE 3.2: Coefficients for power-law fits of payload-endurance product as a function of MTOM

Type	n	A	B	R^2
All	597	0.107	1.487	0.878
Battery	139	0.096	1.615	0.827
Fuel Cell	12	0.588	1.603	0.891
Solar	8	0.242	1.525	0.462
Piston	363	0.080	1.603	0.830
Turbine	70	0.012	1.551	0.829

TABLE 3.3: Coefficients for power-law fits of empty mass as a function of MTOM

Type	n	A	B	R^2	Mean $\left(\frac{m_E}{m_{TO}}\right)$	$p_{B_0} = 1$
All	705	0.830	0.964	0.987	0.680	7×10^{-6}
Battery	164	0.858	0.977	0.966	0.749	0.86
Fuel Cell	21	0.815	1.018	0.984	0.723	0.11
Solar	19	0.988	0.989	0.977	0.758	0.92
Piston	401	0.699	0.994	0.974	0.658	0.39
Turbine	92	0.659	1.004	0.963	0.638	0.81

- Wingspan (b)

$$b = A \times m_{TO}^{B} \tag{3.6}$$

TABLE 3.4: Coefficients for power-law fits of wingspan as a function of MTOM

Type	n	A	B	R^2
All	836	0.828	0.370	0.760
Battery	227	0.822	0.572	0.830
Fuel Cell	31	0.973	0.583	0.923
Solar	37	2.331	0.502	0.900
Piston	421	0.642	0.421	0.810
Turbine	105	0.200	0.496	0.693

- Wing Area (S_W, based on MTOM)

$$S_W = A \times m_{TO}^{B} \tag{3.7}$$

- Wing Area (S_W, based on Wing Span)

$$S_W = A \times b^{B} \tag{3.8}$$

- Power (P)

TABLE 3.5: Coefficients for power-law fits of wing area as a function of MTOM

Type	n	A	B	R^2
All	272	0.161	0.659	0.779
Battery	52	0.192	0.737	0.819
Fuel Cell	11	0.170	0.825	0.995
Solar	33	0.599	0.861	0.910
Piston	130	0.111	0.678	0.882
Turbine	40	0.007	0.923	0.743

TABLE 3.6: Coefficients for power-law fits of wing area as a function of wingspan

Type	n	A	B	R^2
All	272	0.234	1.591	0.927
Battery	52	0.227	1.235	0.937
Fuel Cell	11	0.193	1.227	0.988
Solar	33	0.124	1.738	0.975
Piston	130	0.221	1.651	0.838
Turbine	40	0.327	1.605	0.887

$$\mathrm{P} = \mathrm{A} \times \mathrm{m}_{\mathrm{TO}}^{\mathrm{B}} \tag{3.9}$$

TABLE 3.7: Coefficients for power-law fits of Engine/Motor Power as a function of MTOM

Type	n	A	B	R^2	Mean $\left(\frac{m_E}{m_{TO}}\right)$	$p_{B_0} = 1$
All	408	90.58	1.099	0.922	140	1×10^{-6}
Battery	69	77.94	1.096	0.866	120	0.04
Fuel Cell	21	23.89	1.244	0.817	56	0.40
Solar	20	36.21	0.989	0.949	52	0.71
Piston	284	289.4	0.874	0.848	150	2×10^{-5}
Turbine	13	1357	0.748	0.656	220	0.15

Alternative for determining the Power (P):

$$\mathrm{P} = 105.9 \times \mathrm{PI}^{0.9175} \tag{3.10}$$

- Power Index (PI)

$$\mathrm{PI} = \mathrm{A} \times \mathrm{m}_{\mathrm{TO}}^{\mathrm{B}} \tag{3.11}$$

Type	n	A	B	R^2	Mean $\left(\frac{m_E}{m_{TO}}\right)$	$p_{B_0} = 7/6$
All	836	0.910	1.203	0.972	1.08	0.61
Battery	227	1.111	1.006	0.946	1.07	$< 1 \times 10^{-6}$
Fuel Cell	31	0.927	0.966	0.972	0.737	$< 1 \times 10^{-6}$
Solar	37	0.392	1.024	0.977	0.351	$3 \times 10^{-}5$
Piston	421	1.152	1.145	0.971	1.02	$1 \times 10^{-}6$
Turbine	105	1.982	1.118	0.939	1.70	0.09

TABLE 3.8: Coefficients for power-law fits of Engine/Motor Power as a function of MTOM

Alternative for determining the Power Index (PI):

$$\mathrm{PI} = \mathrm{b} \times \frac{\mathrm{m}_{\mathrm{TO}}}{\mathrm{b}^2}^{3/2} \tag{3.12}$$

- Wing Loading

After the discovery of Maximum Take-Off Mass and Wing Area, we can determine also the Wing Loading by dividing the said functions, as symbolized by $\frac{\mathrm{m}_{\mathrm{TO}}}{\mathrm{S}_{\mathrm{W}}}$. Alternatively, we can use this equation:

$$\frac{\mathrm{m}_{\mathrm{TO}}}{\mathrm{S}_{\mathrm{W}}} = 10.3 \times \mathrm{m}_{\mathrm{TO}}^{1/3} \tag{3.13}$$

3.3 Wings.

After defining the fuselage and analyzing the inertial to determine the needed aerodynamic characteristics, another crucial component that is in our Loitering

Munition is the Wings. Of course, the Aircraft will not be able to fly without its wings unless some constraints can be Some details may need our attention to ensure the stability of our Loitering Munition, such as the Airfoils, aforementioned wingspan, its related parts, and wing configurations. The following steps are our way of determining the craft.

3.3.1 Airfoils

Airfoils as in Britannica's definition[18], are described as any kind of shaped surface that will help the craft generate the lift and drag needed for Airborne objects, commonly found in aircraft and helicopters. From there, we can determine which airfoil that would generate sufficient aerodynamic characteristics be it from the main wing and its stabilizers. The commonly used airfoils found in flying objects are National Advisory Committee of Aerodynamics (NACA, superseded by the National Aeronautics and Space Agency (NASA).) Airfoils. There are 5 defined series of NACA Airfoils, which are shown in this list:

- NACA 4-Series, which defined the maximum camber in chord, its distance to tip, and maximum thickness in chord.
- NACA 5-Series, advanced airfoil with defined theoretical optimal lift, x coordinates for the point of maximum camber, and defined to be simple or reflex cambers.
- NACA 1-Series, redefined the airfoil approach by defining the minimum and maximum pressure area, lift coefficient, and thickness of a camber in chord.
- NACA 6-Series, improvised 1-series with defined minimum pressure area, lift coefficient's range and design, and whether laminar flow is maintained or not
- NACA 7-Series, airfoil approach that maximized the laminar flow details with determining the minimum pressure area in the lower and upper surface areas and defined the standard profiles used within the NACA airfoils.

Although there are defined NACA airfoils described in this list, there are also the supercritical airfoils which provide advanced aerodynamics, although it is interesting to use one, but due to the lack of further publicized details surrounding the supercritical airfoils, we decided to stay with the NACA airfoil.

One of the special requirements in designing the Loitering Munitions, stated from "*An Experimental and Numerical Analysis of a Loitering Munition Unmanned Aerial Vehicle System.*" by Tamer Saraçyakupoğlu et. al.[13], the Loitering Munition's main wing maximum thickness is stated to be at 12%, to maintain a lower stall speeds especially at leading-edge stall speeds. We will later discuss the results as usual in the next chapter.

3.3.2 Wing Configurations.

As far as we all know, there are a wide variety of wing configurations of an aircraft that we can use to provide suitable aerodynamic characteristics. Based on Voskujil's "*Performance analysis and design of loitering munitions: A comprehensive technical survey of recent developments*" ([1]) there are at least 6 confirmed Loitering Munition's configurations used which shown in this list:

- Conventional Fixed-Wing
- Cannard-wing
- Delta-wing
- Tandem-wing
- Cruciform-wing
- Rotorcraft

There are also other configurations available in wing design, including the Swept-wing be it standard or front-swept wing configurations, Oblique-wing configuration, blended wing-body design, and more. The remaining designs are whether deemed unnecessary for required aerodynamic characteristics or will cost higher than should be.

3.3.3 Calculations for Aerodynamic Characteristics

As for the basis of aerodynamic characteristics, there are a few factors that have to be done to establish the aircraft being stable in any situation with five factors be it in Longitudinal and Lateral modes:

- Phugoid, a Macroscopic mode of exchange between kinetic and potential changes.

- Short Period, vertical movement in a variety of pitch rates in a phase, usually well damped and in higher frequency
- Dutch Roll, combined pitch and yaw natural movement in 90$\deg$ phase, lightly damped movements.
- Roll Damping, When an aircraft rolls on its own but usually at a stable rate.
- Spiral, Heading divergence and is non-oscillatory, happens in a long time and generally unstable. Pilot handling is required.

Tc o identify the stability of an Aircraft, we will use the eigenvalues (A modal shape value) and eigenvectors (A matrix of frequency and damping modes), with four specific modes in two major modes (Lateral-Directional and Longitudinal). The following tab.3.9 shows its difference.

	Longitudinal mode	Lateral-Directional Mode
1	Two phugoid modes	Spiral mode
2	Two short period modes	Roll damping mode
3		2 dutch roll modes

TABLE 3.9: Difference of two modes of aircraft stability

An important note to remember is to confirm that the aircraft is stable in every mode, the eigenvalues for each mode must be negative. Otherwise the aircraft will be deemed unstable and might end up like a jumping Acumalaka frog.

3.4 Aircraft Powerplant Selection.

In deciding the Powerplant for the aircraft, some constraints that needed to be calculated before we can find the details from a website that we will use in later chapter. This includes the required speed (in eq.3.15) and thrust (in eq.3.16 and eq.3.17) at determined altitudes.

$$V = \sqrt{\frac{2 \times \omega}{\rho \times S \times C_L}} \tag{3.14}$$

$$T = \frac{1}{2} \times \rho \times V^2 \times S \times C_D \tag{3.15}$$

$$T = \frac{1}{2} \times \rho \times V^2 \times S \times (C_{D0} + k \times C_L^2) \tag{3.16}$$

CHAPTER 4
RESULTS AND DISCUSSIONS

In this chapter, we will talk about what we decided and made our Loitering Munition design, as fit to our mission requirement and profile. As we know, the loitering munition that we envisioned has to be fitted with an Additive Manufacturing process, which is meant to have Three-Dimensional printing materials (i.e. ABS Plastic material). Not only that, the Loitering Munition is expected to have equal capabilities of destroying enemy aggression as other systems have tested and performed in active service, such as AeroVironment Switchblade 300 series — shown in Fig. 4.1 — UVision Hero 30, WB Electronics Warmate, and much more.

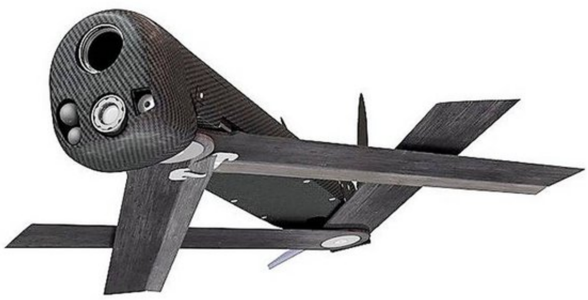


FIGURE 4.1: One of the best benchmarks in Loitering Munitions against infantry or light vehicles, AeroVironment Switchblade 300

4.1 Fuselage - Discussions and Results

Designing the Fuselage is the first step in finally realizing the aircraft design, at least in almost all cases, becomes the most crucial part of all Aircraft, even if the plane is made to be the flying wing. The Unmanned Aircraft System, which we know is small, is no exception to having a fuselage that will carry all crucial components. In this section, we will discuss how we managed to create a Fuselage as hoped in our Loitering Munition Design.

4.1.1 The Components Included and Width and Height Definition

The first step as mentioned in the previous chapter is to define the components that will be included in our Fuselage. Our target is to make the system fit to fly in either Radio Transmission or able to fly semi-autonomously. That would mean our Loitering Munition would have to launch from a canister and be able to commit our commands as intended, as other Radio-Controlled or auto-piloted aircraft do.

The Unmanned Aircraft System's component will include standard components from commercially available products spanned across Indonesia and the world. The Unmanned Aircraft System will include the Pixhawk series of Flight Control Systems and the list is on for our aircraft.

Flight Control System Module and Base - Pixhawk 6X

The Pixhawk 6X (Fig. 4.2) series is the Flight Control System that uses the PX4 Remote Aircraft system that is well known to be the advanced Open Source Autopilot system that would be commercially available and has a lot of compatibility for modules that we will choose later, as we will see the modules could fit in with PX4 system. The Pixhawk 6X's base will be in a mini-set variant since we target the small baseline design of our Loitering Munition.

- Name: Pixhawk 6X FCS set
- Equipment Type: Flight Control System
- Dimension (FCS-M) : $38\,\mathrm{mm} \times 55\,\mathrm{mm} \times 15.5\,\mathrm{mm}$
- Dimension (FCS-B) : $72.8\,\mathrm{mm} \times 43.4\,\mathrm{mm} \times 14.2\,\mathrm{mm}$
- Mass (FCS-M) : $0.0230\,\mathrm{kg}$
- Mass (FCS-B) : $0.0265\,\mathrm{kg}$

FIGURE 4.2: Pixhawk 6X FCS set

- Volume (FCS-M) : $32.395\,\mathrm{cm}^3$
- Volume (FCS-B) : $44.865\,\mathrm{cm}^3$
- Density (FCS-M): 0.00071 $\mathrm{kg\,cm^{-3}}$
- Density (FCS-B): 0.00059 $\mathrm{kg\,cm^{-3}}$

- Global Positioning System Module - M8N GPS Module

FIGURE 4.3: M8N GPS Module

The Global Positioning System as seen in Fig. 4.3 is one of the navigational systems that are now frequently used worldwide, and it is no wonder that we will use the GPS to let the Loitering Munition know where the system is, and crucially, know where will be the enemy target or the Area of Operations that involved with our operation.

- Name : M8N GPS Module
- Equipment Type: Global Positioning System Module
- Dimension : $20\,\mathrm{mm} \times 50\,\mathrm{mm} \times 5\,\mathrm{mm}$
- Mass : $0.0320\,\mathrm{kg}$
- Volume : $5\,\mathrm{cm}^3$
- Density : $0.00064\ \mathrm{kg\,cm}^{-3}$

Radio Telemetry System - 3DR Radio Telemetry

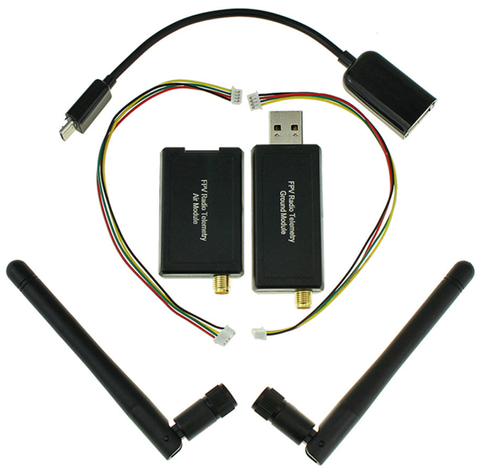


FIGURE 4.4: 3DR Radio telemetry Module

The Radio Telemetry system is the equipment that uses Radio Transmission to give the output data and the Aircraft also receives inputs from the control center (in another case, the pilots). We can order the said craft to fly within the location or self-destruct to destroy the enemy target according to our choice and timing. The following picture (Fig. 4.4) is the Radio Transmitter that we will use.

- Name : 3DR Radio telemetry Module
- Equipment Type: Radio Telemetry Module
- Dimension : $60\,\mathrm{mm} \times 40\,\mathrm{mm} \times 20\,\mathrm{mm}$
- Mass : $0.0320\,\mathrm{kg}$
- Volume : $64\,\mathrm{cm}^3$
- Density : $0.00078\ \mathrm{kg\,cm}^{-3}$

LIDAR Sensor - Holybro LIDAR Sensor

FIGURE 4.5: Holybro LIDAR System

The Light Detection and Ranging System (LIDAR for short, seen in Fig. 4.5) is the sensory system that measures the light property used to determine the range and pieces of information from a more extended range. This would mean that the LIDAR system is crucial for our Loitering Munition since we would like to determine the location of enemy aggression and sense if collateral Damage will occur.

- Name: Holybro LIDAR System
- Equipment Type: Light Detection and Ranging System (LIDAR)
- Dimension : $10\,\mathrm{mm} \times 40\,\mathrm{mm} \times 10\,\mathrm{mm}$
- Mass : $0.0240\,\mathrm{kg}$
- Volume : $4\,\mathrm{cm}^3$
- Density : $0.006\ \mathrm{kg\,cm}^{-3}$

4.1.2 PX4Flow Optical Flow Sensor

The Camera from Fig. 4.6, indeed is one of the most essential sensors to our loitering munition, to see what the aircraft sees from within.

- Name : PX4Flow Optical Flow Sensor
- Equipment Type: Camera
- Dimension : $15\,\mathrm{mm} \times 45.5\,\mathrm{mm} \times 10\,\mathrm{mm}$

FIGURE 4.6: PX4Flow Optical Flow Sensor

- Mass : $0.01\,\mathrm{kg}$
- Volume : $6.625\,\mathrm{cm}^3$
- Density : 0.0014 $\mathrm{kg\,cm}^{-3}$

Electronic Speed Controller - HobbyWing Skywalker Brushless Controller.

FIGURE 4.7: Hobbywing Skywalker Brushless Controller

The Electronic Speed Controller, ESC for short, is one of the regulators for our loitering munition that could be used to limit our Loitering Munition's speed since there will be a chance of Wings ripping apart and resulting in our aircraft being unable to regain flight status and crash into the ground. In Fig. 4.7 and the following list is the picture and specification of the selected component.

- Name: Hobbywing Skywalker Brushless Controller
- Equipment Type: Electronic Speed Controller
- Dimension : $65.5\,\mathrm{mm} \times 25\,\mathrm{mm} \times 8\,\mathrm{mm}$
- Mass : $0.039\,\mathrm{kg}$
- Volume : $13.6\,\mathrm{cm}^3$
- Density : 0.0029 $\mathrm{kg\,cm^{-3}}$

Pitot Tube - Pixhawk APM Pitot Tube Airspeed Sensor

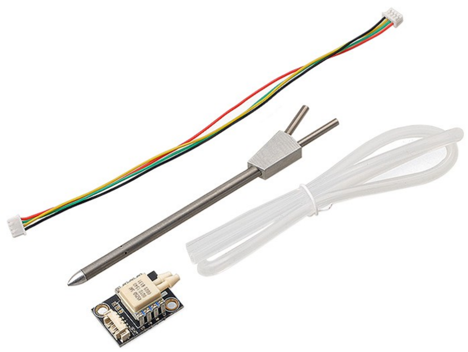


FIGURE 4.8: Pixhawk APM Pitot Tube Airspeed Sensor

Pitot tube, as the name suggests from the tube shown in Fig. 4.8, is the tube that will let the air in and measure its pressure to determine the Airspeed of the aircraft, which may be available in Indicated speed, and meant to be available to be processed to the On-Screen Display Module and then eventually to the Radio Telemetry and transmits data to the control center.

- Name: Pixhawk APM Pitot Tube Airspeed Sensor
- Equipment Type: Pitot Tube
- Dimension : $30\,\mathrm{mm} \times 10\,\mathrm{mm} \times 10\,\mathrm{mm}$
- Mass: Unknown
- Volume : $3\,\mathrm{cm}^3$
- Density: Unknown

On-Screen Display Module - Elec Holybro Micro OSD Module

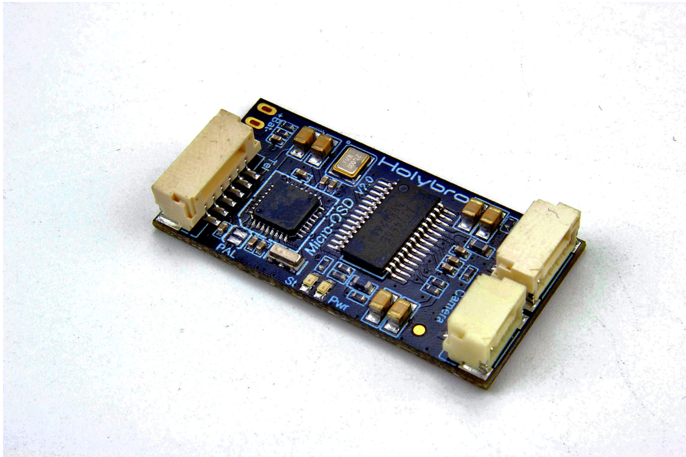


FIGURE 4.9: Elec Holybro Micro OSD Module

The On-Screen Display module as seen in Fig. 4.9 is meant to be the module that transmits information about the loitering munition to the control center, which is essential in knowing what happens to our aircraft.

- Name: Elec Holybro Micro OSD Module
- Equipment Type: On-Screen Display Module
- Dimension : $17.5\,\mathrm{mm} \times 35\,\mathrm{mm} \times 10\,\mathrm{mm}$
- Mass : $0.003\,\mathrm{kg}$
- Volume : $6.125\,\mathrm{cm}^3$
- Density : 0.00049 $\mathrm{kg\,cm^{-3}}$

Explosive Payload - 40mm Explosive materials

The Explosive Material, stylized in grenade launcher ammo in Fig. 4.10 is one of our key components that will be brought in our loitering munition. The data from the 40mm explosive will be using a source from Aalan University.

- Name: 40mm Explosive Material
- Equipment Type: Explosive Payload
- Dimension : $40\,\mathrm{mm} \times 40\,\mathrm{mm} \times 106\,\mathrm{mm}$
- Mass : $0.239\,\mathrm{kg}$

FIGURE 4.10: 40mm Explosive Material (Depicted as 40mm Grenade Launcher ammo)

- Volume : $532.544\,\mathrm{cm}^3$
- Density : 0.00045 $\mathrm{kg\,cm^{-3}}$

From all the components mentioned, we determined that the largest width of components available is 44.5mm, and we can round it up to 45mm for a minimum space. Then we can determine the skin thickness in terms of width will be 5mm and as a result, the total width of our Fuselage will be at 60mm.

As for the Height, we determined that the highest equipment that we could use is 45mm, and taken from the asymmetrical skin thickness for our lower and upper skin to be 5mm and 2.5mm respectively, we will make a total of 52.5mm.

4.1.3 Fuselage Dimension and creation

Based on what we determined to define the dimensions of our Loitering Munition from the previous chapter, we will start determining the effective Diameter of our Loitering Munition, by the formula given:

$$d_{\text{ef}} = d_1 d_2 \frac{1}{2} \tag{4.1}$$

- d_{ef}: effective diameter
- d_1: Diameter (in this case, width)
- d_2: Diameter (In this case, height)

Then we define the width and height that we discovered in our previous subsection, here is our calculation:

$$d_{\text{ef}} = \sqrt{60\,\text{mm} \times 52.5\,\text{mm}} \tag{4.2}$$

$$d_{\text{ef}} = 56.125\,\text{mm} \tag{4.3}$$

Then we can multiply it by 8 to define our supposed fuselage length:

$$l_{\text{fuselage}} = 56.125\,\text{mm} \times 8 \tag{4.4}$$

$$l_{\text{fuselage}} = 448.998\,\text{mm} \tag{4.5}$$

As a result, the calculation suggests that we could make 448.998mm of Fuselage Length, then in a round-up, we can make the Loitering munition's length of 450mm.

4.1.4 Designing the Loitering Munition and the Inertia Properties in CAD

Based on the data on the Fuselage we discussed last subsection, we can now start designing the Fuselage with a Computer-Aided Design application. We will use Solid Edge ST9 by Siemens since we have it in our arsenal at the moment and the first step is to make a simple design of the Fuselage, then we go to the components which are simplified for assembly. The following is the completed design of the Fuselage without its upper section Fuselage for details inside, shown in Fig. 4.11 and Fig. 4.12

After we create the CAD of our Loitering Munition, we can continue providing density details of our Loitering Munition, then we can simulate the inertia that we have for the fuselage of our Aircraft, which is seen in Fig. 4.13 and table. 4.1

4.1.5 Inertia Calculation from Mass to Wing determination

Based on Verstraete D., et. al.'s paper [16], We can determine the Maximum Take-Off Weight to the Power and Power Index for our Loitering Munition. We

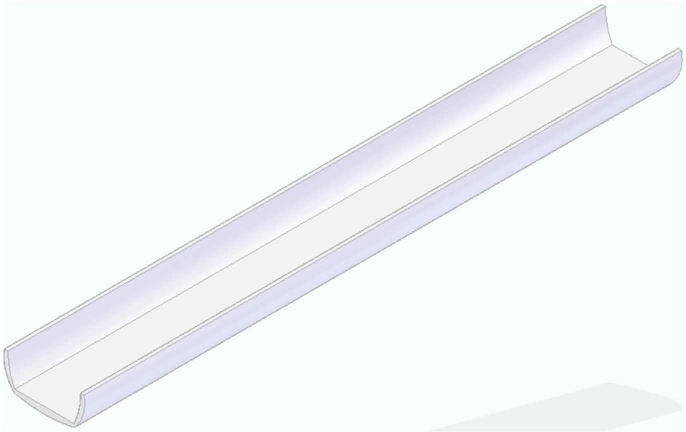


FIGURE 4.11: The lower side of the fuselage, without any components installed. (Source: Personal Documents)

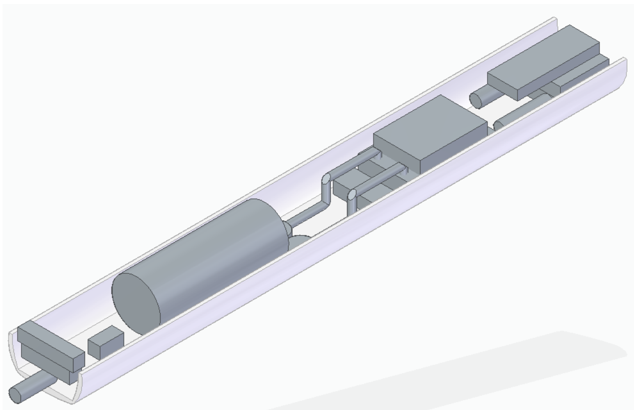


FIGURE 4.12: The lower side of the fuselage, with any components installed. (Source: Personal Documents)

FIGURE 4.13: Enclosed Fuselage with Center of Mass in Green dot and Center of Volume in Red dot (Source: Personal Documents)

TABLE 4.1: Further details of the Fuselage Inertia

Fuselage Total Mass (kg)	0.716
Fuselage total Volume (mm^3)	593850.684
Center of Mass (mm)	(-0.01, 215.49, -11.07)
Center of Volume (mm)	(0.00, 247.80, -12.10)
Mass Moments of Inertia (I_{xx}, I_{yy}, I_{zz}) ($\mathrm{kg\,m^{-2}}$)	(0.017, 0.00, 0.017)
Mass Moments of Inertia (I_{xy}, I_{xz}, I_{yz}) (m^2)	(0.00, 0.00, -0.01)

will start with the approximate Mass details, as instructed in Mr. Verstraete's paper.

Since the paper does not clearly state the definition of Payload Mass, we will use the assumption that is the mass of the inventory that is expandable and about to be brought and used, in this case, the 40mm explosive material, which stands at 0.239kg. We will also stretch our Payload to a maximum of 0.4kg to allow the flexibility of our Loitering Munition.

In the meantime, we will use the Battery as our constraint basis, given our Loitering Munition will only use said power supply instead of other offerings from said paper. After that, following Chapter 3's subsection of *Determining the Loitering Munition's Inertia* with the Tab. 4.2 as our summary for our Loitering Munition's power supply regression constants and exponents, we can start to determining the values from Equations 3.3 through 3.13 of this thesis.

TABLE 4.2: Summary of Regression Constant and Regression Exponent with Battery as a selected type for Loitering Munition

	Regression Constant (A)	Regression Exponent (B)
Maximum Take-Off Mass (MTOM, m_{TO})	5.147	0.849
Endurance (E)	0.096	1.615
Empty Mass (m_E)	0.858	0.977
Wingspan (b)	0.822	0.572
Wing Area (S_w)	0.192	0.737
Power (P)	0.277	1.235
Power Index (PI)	77.94	1.096

- Calculation using $\mathrm{m_{PL}} = 0.239\ \mathrm{kg}$
- Maximum Take-Off Mass, (Constraint and Coefficient Reference from Tab. 4.3)

$$\mathrm{m_{TO}} = \mathrm{A} \times \mathrm{m_{PL}^{B}} \tag{4.6}$$

TABLE 4.3: Coefficients for power-law fits of MTOM as a function of payload mass

Type	n	A	B	R^2	Mean $\left(\frac{m_{PL}}{m_{TO}}\right)$	$p_{B_0} = 1$
All	654	4.964	1.001	0.945	0.224	0.64
Battery	151	5.147	0.849	0.843	0.211	1×10^{-6}
Fuel Cell	15	4.180	1.027	0.825	0.221	0.54
Solar	15	15.872	0.690	0.912	0.199	2×10^{-3}
Piston	385	4.567	1.001	0.884	0.240	0.86
Turbine	82	4.752	1.076	0.932	0.164	0.09

$$\mathrm{m_{TO}} = \mathrm{A} \times \mathrm{m_{PL}^{B}} \tag{4.7}$$

$$\mathrm{m_{TO}} = 5.147 \times 0.239^{0.849} \tag{4.8}$$

$$\mathrm{m_{TO}} = 1.527\,\mathrm{kg} \tag{4.9}$$

Endurance, (Constraint and Coefficient Reference from Tab. 4.4)

$$\mathrm{m_{PL}} \times \mathrm{E} = \mathrm{m_{TO}^{B}} \times \mathrm{A} \tag{4.10}$$

$$0.239 \times \mathrm{E} = 1.527^{1.615} \times 0.096 \tag{4.11}$$

$$\mathrm{E} = 0.796\mathrm{h} \tag{4.12}$$

$$\mathrm{E} = 47.740\mathrm{m} \tag{4.13}$$

$$\mathrm{E} = 2,864.4\mathrm{s} \tag{4.14}$$

Empty Mass, (Constraint and Coefficient Reference from Tab. 4.5)

$$\mathrm{m_{E}} = \mathrm{A} \times \mathrm{m_{TO}^{B}} \tag{4.15}$$

TABLE 4.4: Coefficients for power-law fits of payload–endurance product as a function of MTOM

Type	n	A	B	R^2
All	597	0.107	1.487	0.878
Battery	139	0.096	1.615	0.827
Fuel Cell	12	0.588	1.603	0.891
Solar	8	0.242	1.525	0.462
Piston	363	0.080	1.603	0.830
Turbine	70	0.012	1.551	0.829

TABLE 4.5: Coefficients for power-law fits of empty mass as a function of MTOM

Type	n	A	B	R^2	Mean $\left(\frac{m_E}{m_{TO}}\right)$	$p_{B_0} = 1$
All	705	0.830	0.964	0.987	0.680	7×10^{-6}
Battery	164	0.858	0.977	0.966	0.749	0.86
Fuel Cell	21	0.815	1.018	0.984	0.723	0.11
Solar	19	0.988	0.989	0.977	0.758	0.92
Piston	401	0.699	0.994	0.974	0.658	0.39
Turbine	92	0.659	1.004	0.963	0.638	0.81

$$\mathrm{m_E} = 0.858 \times 1.527^{0.977} \tag{4.16}$$

$$\mathrm{m_E} = 1.297\,\mathrm{kg} \tag{4.17}$$

Wingspan, (Constraint and Coefficient Reference from Tab. 4.6)

$$\mathrm{b} = \mathrm{A} \times \mathrm{m_{TO}^{B}} \tag{4.18}$$

$$\mathrm{b} = 0.822 \times 1.527^{0.572} \tag{4.19}$$

$$\mathrm{b} = 1.047\,\mathrm{m} \tag{4.20}$$

$$\mathrm{b} = 1047.161\,\mathrm{mm} \tag{4.21}$$

- Wing Area, (Constraint and Coefficient Reference from Tab. 4.7)

TABLE 4.6: Coefficients for power-law fits of wingspan as a function of MTOM

Type	n	A	B	R^2
All	836	0.828	0.370	0.760
Battery	227	0.822	0.572	0.830
Fuel Cell	31	0.973	0.583	0.923
Solar	37	2.331	0.502	0.900
Piston	421	0.642	0.421	0.810
Turbine	105	0.200	0.496	0.693

$$\mathrm{S_W} = \mathrm{A} \times \mathrm{m_{TO}^B} \tag{4.22}$$

TABLE 4.7: Coefficients for power-law fits of wing area as a function of MTOM

Type	n	A	B	R^2
All	272	0.161	0.659	0.779
Battery	52	0.192	0.737	0.819
Fuel Cell	11	0.170	0.825	0.995
Solar	33	0.599	0.861	0.910
Piston	130	0.111	0.678	0.882
Turbine	40	0.007	0.923	0.743

$$\mathrm{S_W} = 0.192 \times 1.527^{0.737} \tag{4.23}$$

$$\mathrm{S_W} = 0.262\mathrm{m}^2 \tag{4.24}$$

$$\mathrm{S_W} = 262,295.355\mathrm{mm}^2 \tag{4.25}$$

Alternatively:

$$\mathrm{S_W} = \mathrm{A} \times \mathrm{b^B} \tag{4.26}$$

$$\mathrm{S_W} = 0.227 \times 1.047^{1.235} \tag{4.27}$$

$$\mathrm{S_W} = 0.240\mathrm{m}^2 \tag{4.28}$$

$$S_W = 240,248.126\text{m}^2 \tag{4.29}$$

- Power (P), (Constraint and Coefficient Reference from Tab. 4.8)

$$P = A \times m_{TO}^{B} \tag{4.30}$$

TABLE 4.8: Coefficients for power-law fits of wing area as a function of wingspan

Type	n	A	B	R^2
All	272	0.234	1.591	0.927
Battery	52	0.227	1.235	0.937
Fuel Cell	11	0.193	1.227	0.988
Solar	33	0.124	1.738	0.975
Piston	130	0.221	1.651	0.838
Turbine	40	0.327	1.605	0.887

$$P = 77.94 \times 1.527^{1.096} \tag{4.31}$$

$$P = 123.943\text{kW} \tag{4.32}$$

Alternatively:

$$P = 105.9 \times PI^{0.9175} \tag{4.33}$$

1^{st} Value Approximation:

$$P = 105.9 \times 1.701^{0.9175} \tag{4.34}$$

$$P = 172.412\text{kW} \tag{4.35}$$

2^{nd} Value Approximation:

$$P = 105.9 \times 1.721^{0.9175} \tag{4.36}$$

$$P = 174.271\text{kW} \tag{4.37}$$

- Power Index (PI), (Constraint and Coefficient Reference from Tab. 4.9)

TABLE 4.9: Coefficients for power-law fits of Engine/Motor Power as a function of MTOM

Type	n	A	B	R^2	Mean $\left(\frac{m_E}{m_{TO}}\right)$	$p_{B_0} = 1$
All	408	90.58	1.099	0.922	140	1×10^{-6}
Battery	69	77.94	1.096	0.866	120	0.04
Fuel Cell	21	23.89	1.244	0.817	56	0.40
Solar	20	36.21	0.989	0.949	52	0.71
Piston	284	289.4	0.874	0.848	150	2×10^{-5}
Turbine	13	1357	0.748	0.656	220	0.15

$$\mathrm{PI} = \mathrm{A} \times \mathrm{m_{TO}^B} \tag{4.38}$$

$$\mathrm{PI} = 1.111 \times 1.527^1.006 \tag{4.39}$$

$$\mathrm{PI} = 1.701\mathrm{kg}^{3/2}\mathrm{m}^{-1} \tag{4.40}$$

Alternatively:

$$\mathrm{PI} = \mathrm{b} \times \frac{\mathrm{m_{TO}}^{3/2}}{\mathrm{b}^2} \tag{4.41}$$

$$\mathrm{PI} = 1.047 \times \frac{1.527^{\ 3/2}}{1.047^2} \tag{4.42}$$

$$\mathrm{PI} = 1.721\mathrm{kg}^{3/2}\mathrm{m}^{-1} \tag{4.43}$$

- Wing Loading ($\frac{\mathrm{m_{TO}}}{\mathrm{S_W}}$)

1st Method (Blunt)

$$\frac{\mathrm{m_{TO}}}{\mathrm{S_W}} \tag{4.44}$$

1st Value

$$\frac{1.527}{262,295.355} \tag{4.45}$$

$$\frac{\mathrm{m_{TO}}}{\mathrm{S_W}} = 5.822 \times 10^{-6}\mathrm{kg\,mm^{-2}} \tag{4.46}$$

2nd Value

$$\frac{1.527}{240,248.126} \tag{4.47}$$

$$\frac{\mathrm{m_{TO}}}{\mathrm{S_W}} = 6.356 \times 10^{-6} \mathrm{kg\,mm^{-2}} \tag{4.48}$$

2nd Method (with Equations)

$$\frac{\mathrm{m_{TO}}}{\mathrm{S_W}} = 10.3 \times \mathrm{m_{TO}^{1/3}} \tag{4.49}$$

$$\frac{\mathrm{m_{TO}}}{\mathrm{S_W}} = 10.3 \times 1.527^{1/3} \tag{4.50}$$

$$\frac{\mathrm{m_{TO}}}{\mathrm{S_W}} = 11.861 \mathrm{kg\,mm^{-2}} \tag{4.51}$$

- Calculation using $\mathrm{m_{PL}} = 0.4$ kg
- Maximum Take-Off Mass, (Constraint and Coefficient Reference from Tab. 4.10)

$$\mathrm{m_{TO}} = \mathrm{A} \times \mathrm{m_{PL}^{B}} \tag{4.52}$$

TABLE 4.10: Coefficients for power-law fits of MTOM as a function of payload mass

Type	n	A	B	R^2	Mean $\left(\frac{m_{PL}}{m_{TO}}\right)$	$p_{B_0} = 1$
All	654	4.964	1.001	0.945	0.224	0.64
Battery	151	5.147	0.849	0.843	0.211	1×10^{-6}
Fuel Cell	15	4.180	1.027	0.825	0.221	0.54
Solar	15	15.872	0.690	0.912	0.199	2×10^{-3}
Piston	385	4.567	1.001	0.884	0.240	0.86
Turbine	82	4.752	1.076	0.932	0.164	0.09

$$\mathrm{m_{TO}} = 5.147 \times 0.4^{0.849} \tag{4.53}$$

$$\mathrm{m_{TO}} = 2.364 \,\mathrm{kg} \tag{4.54}$$

- Endurance, (Constraint and Coefficient Reference from Tab. 4.11)

TABLE 4.11: Coefficients for power-law fits of payload-endurance product as a function of MTOM

Type	n	A	B	R^2
All	597	0.107	1.487	0.878
Battery	139	0.096	1.615	0.827
Fuel Cell	12	0.588	1.603	0.891
Solar	8	0.242	1.525	0.462
Piston	363	0.080	1.603	0.830
Turbine	70	0.012	1.551	0.829

Type	n	A	B	R^2	Mean $\left(\frac{m_E}{m_{TO}}\right)$	$p_{B_0} = 1$
All	705	0.830	0.964	0.987	0.680	7×10^{-6}
Battery	164	0.858	0.977	0.966	0.749	0.86
Fuel Cell	21	0.815	1.018	0.984	0.723	0.11
Solar	19	0.988	0.989	0.977	0.758	0.92
Piston	401	0.699	0.994	0.974	0.658	0.39
Turbine	92	0.659	1.004	0.963	0.638	0.81

TABLE 4.12: Coefficients for power-law fits of empty mass as a function of MTOM

$$\mathrm{m_{PL}} \times \mathrm{E} = \mathrm{m_{TO}^{B}} \times \mathrm{A} \tag{4.55}$$

$$0.4 \times \mathrm{E} = 2.364^{1.615} \times 0.096 \tag{4.56}$$

$$\mathrm{E} = 0.963\mathrm{h} \tag{4.57}$$

$$\mathrm{E} = 57.78\mathrm{m} \tag{4.58}$$

$$\mathrm{E} = 3,466.8\mathrm{s} \tag{4.59}$$

- Empty Mass, (Constraint and Coefficient Reference from Tab. 4.12)

$$\mathrm{m_E} = \mathrm{A} \times \mathrm{m_{TO}^{B}} \tag{4.60}$$

$$\mathrm{m_E} = 0.858 \times 2.364^{0.977} \tag{4.61}$$

$$m_E = 1.989\,\text{kg} \tag{4.62}$$

- Wingspan, (Constraint and Coefficient Reference from Tab. 4.13)

$$b = A \times m_{TO}^{B} \tag{4.63}$$

TABLE 4.13: Coefficients for power-law fits of wingspan as a function of MTOM

Type	n	A	B	R^2
All	836	0.828	0.370	0.760
Battery	227	0.822	0.572	0.830
Fuel Cell	31	0.973	0.583	0.923
Solar	37	2.331	0.502	0.900
Piston	421	0.642	0.421	0.810
Turbine	105	0.200	0.496	0.693

$$b = 0.822 \times 2.364^{0.572} \tag{4.64}$$

$$b = 1.345\,\text{m} \tag{4.65}$$

$$b = 1344.616\,\text{mm} \tag{4.66}$$

Wing Area, (Constraint and Coefficient Reference from Tab. 4.14)

$$S_W = A \times m_{TO}^{B} \tag{4.67}$$

$$S_W = A \times m_{TO}^{B} \tag{4.68}$$

$$S_W = 0.192 \times 2.364^{0.737} \tag{4.69}$$

$$S_W = 0.362\text{m}^2 \tag{4.70}$$

$$S_W = 361,975.699\text{mm}^2 \tag{4.71}$$

Alternatively:

$$S_W = A \times b^{B} \tag{4.72}$$

TABLE 4.14: Coefficients for power-law fits of wing area as a function of MTOM

Type	n	A	B	R^2
All	272	0.161	0.659	0.779
Battery	52	0.192	0.737	0.819
Fuel Cell	11	0.170	0.825	0.995
Solar	33	0.599	0.861	0.910
Piston	130	0.111	0.678	0.882
Turbine	40	0.007	0.923	0.743

$$S_W = 0.227 \times 1.345^{1.235} \tag{4.73}$$

$$S_W = 0.327 \mathrm{m}^2 \tag{4.74}$$

$$S_W = 327,339.096 \mathrm{m}^2 \tag{4.75}$$

- Power (P), (Constraint and Coefficient Reference from Tab. 4.15)

$$P = A \times m_{TO}^{B} \tag{4.76}$$

TABLE 4.15: Coefficients for power-law fits of wing area as a function of wingspan

Type	n	A	B	R^2
All	272	0.234	1.591	0.927
Battery	52	0.227	1.235	0.937
Fuel Cell	11	0.193	1.227	0.988
Solar	33	0.124	1.738	0.975
Piston	130	0.221	1.651	0.838
Turbine	40	0.327	1.605	0.887

$$P = 77.94 \times 2.364^{1.096} \tag{4.77}$$

$$P = 200.114 \mathrm{kW} \tag{4.78}$$

Alternatively:

$$\mathrm{P} = 105.9 \times \mathrm{PI}^{0.9175} \tag{4.79}$$

1^{st} Value Approximation:

$$\mathrm{P} = 105.9 \times 2.640^{0.9175} \tag{4.80}$$

$$\mathrm{P} = 258.058\mathrm{kW} \tag{4.81}$$

2^{nd} Value Approximation:

$$\mathrm{P} = 105.9 \times 2.009^{0.9175} \tag{4.82}$$

$$\mathrm{P} = 200.854\mathrm{kW} \tag{4.83}$$

- Power Index (PI), (Constraint and Coefficient Reference from Tab. 4.16)

$$\mathrm{PI} = \mathrm{A} \times \mathrm{m}_{\mathrm{TO}}^{\mathrm{B}} \tag{4.84}$$

Type	n	A	B	R^2	Mean$\left(\frac{m_E}{m_{TO}}\right)$	$p_{B_0} = 1$
All	408	90.58	1.099	0.922	140	1×10^{-6}
Battery	69	77.94	1.096	0.866	120	0.04
Fuel Cell	21	23.89	1.244	0.817	56	0.40
Solar	20	36.21	0.989	0.949	52	0.71
Piston	284	289.4	0.874	0.848	150	2×10^{-5}
Turbine	13	1357	0.748	0.656	220	0.15

TABLE 4.16: Coefficients for power-law fits of Engine/Motor Power as a function of MTOM

$$\mathrm{PI} = 1.111 \times 2.364^{1.006} \tag{4.85}$$

$$\mathrm{PI} = 2.640\mathrm{kg}^{3/2}\mathrm{m}^{-1} \tag{4.86}$$

Alternatively:

$$\mathrm{PI} = \mathrm{b} \times \frac{\mathrm{m_{TO}}^{3/2}}{\mathrm{b}^2} \tag{4.87}$$

$$\mathrm{PI} = 1.345 \times \frac{2.364^{\,3/2}}{1.345^2} \tag{4.88}$$

$$\mathrm{PI} = 2.009\mathrm{kg}^{3/2}\mathrm{m}^{-1} \tag{4.89}$$

- Wing Loading ($\frac{m_{TO}}{S_W}$

1st Method (Blunt)

$$\frac{m_{TO}}{S_W} \tag{4.90}$$

1st Value

$$\frac{2.364}{361,975.699} \tag{4.91}$$

$$\frac{m_{TO}}{S_W} = 6.531 \times 10^{-6}\mathrm{kg\,mm}^{-2} \tag{4.92}$$

2nd Value

$$\frac{2.364}{327,339.096} \tag{4.93}$$

$$\frac{m_{TO}}{S_W} = 7.222 \times 10^{-6}\mathrm{kg\,mm}^{-2} \tag{4.94}$$

2nd Method (with Equations)

$$\frac{m_{TO}}{S_W} = 10.3 \times m_{TO}^{1/3} \tag{4.95}$$

$$\frac{m_{TO}}{S_W} = 10.3 \times 2.364^{1/3} \tag{4.96}$$

$$\frac{m_{TO}}{S_W} = 13.721\mathrm{kg\,mm}^{-2} \tag{4.97}$$

In summary, here are the Tables summarizing the equation results in Payload Mass of 0.239kg and 0.4kg which combined to Table. 4.17

TABLE 4.17: Summary of both 1st and 2nd Value Approximation of Loitering Munition's Characteristics

	A	B
Maximum Take-Off Mass (MTOM) (kg)	1.527	2.364
Endurance (E) (s)	2,864.4	3,466.8
Empty Mass (m_E) (kg)	1.297	1.989
Wingspan (b) (mm)	1,047.161	1344.616
Wing Area (1st Method) (S_W) (mm^2)	262,295.355	361,975.699
Wing Area (2nd Method) (S_W) (mm^2)	240,248.126	327,339.096
Power (1st Method) (P) (kW)	123.943	200.114
Power (2nd Method, 1st Value) (P) (kW)	172.412	258.058
Power (2nd Method, 2nd Value) (P) (kW)	174.271	200.854
Power Index (1st Method) (PI) ($\mathrm{kg}^{3/2}/\mathrm{m}$)	1.701	2.640
Power Index (2nd Method) (PI) ($\mathrm{kg}^{3/2}/\mathrm{m}$)	1.721	2.009
Wing Loading (1st Method (Blunt), 1st Value) ($\mathrm{kg\,mm^{-2}}$)	5.822×10^{-6}	6.531×10^{-6}
Wing Loading (1st Method (Blunt), 1st Value) ($\mathrm{kg\,mm^{-2}}$)	6.356×10^{-6}	7.222×10^{-6}
Wing Loading (2nd Method (with Equations)) ($\mathrm{kg\,mm^{-2}}$)	11.861	13.721

4.2 Wings - Discussions and Results.

The wings are another essential part of our aircraft, where the lift and drag will be produced. Over the years we have seen a lot of wing designs that could generate amazing effects from one another, see the first wing designs, to NACA standardized airfoils, and even the supercritical airfoils that would generate massive lift while keeping the aircraft stable with its fair share of drags.

Since the Loitering Munition does have a shorter fuselage and is lighter than most Unmanned Aircraft Systems, We need an airfoil that can generate as much lift but if we rely on a Supercritical wing, that would need a lot of effort and time to accomplish. That would mean we will use the samples based on NACA Airfoil Specifications.

4.2.1 Airfoil Selection.

As we told in the main section, we have to select the airfoil that would be useful for our Loitering Munition. Theoretically, we need an Airfoil that can generate as much lift as possible and would stabilize our craft vertically (hence the name Vertical Stabilizer.). From there, we started digging for some sources and we found

"An Experimental and Numerical Analysis of a Loitering Munition Unmanned Aerial Vehicle System." by Tamer Saraçyakupoğlu et. al.[13] that our Thickness to chord ratio should be at 12%, otherwise, the Loitering Munition will have a hard time maintaining its stall speed, particularly at leading-edge stall speeds, which meant that the Vehicle's leading edge would lose its lift and will prone to front heavy stall. That would mean we need to use particularly the NACA 5 Series to create an asymmetrical airfoil and to satisfy the t/c of 12%. In that case, we will use the NACA airfoil type 23012, which we will show its graphs in later parts **??**.

In the Vertical stabilizer part, it is fundamental that we have to keep the airfoils use symmetrical, otherwise, the aerodynamic characteristics of the vertical stabilizers will jeopardize the Aircraft by the lift differences in the lateral-directional part. For that particular reason, we will use the NACA 0009 as our Airfoil for the Vertical Stabilizer.

In summary, we have this table for our Loitering Munition's airfoils (See Table 4.18).

TABLE 4.18: Airfoil selection of Main Wing, Horizontal Stabilizers, and Vertical stabilizers.

	Wing Parts	Airfoil Selection
1	Main Wing	NACA 23012
2	Horizontal Stabilizers	NACA 23012
3	Vertical Stabilizers	NACA 0009

The reason why we select NACA 23012 is that the airfoil could achieve the aforementioned t/c of 12%, and we make the airfoil selection in uniform to reduce the time needed to ensure the aircraft's stability. As for the Vertical Stabilizers, we decided to use the NACA 0009 4-Class Airfoil since it is symmetrical and has sufficient t/c = 12%. From there, we can start defining and making the plane based on previous data that we discovered and determined each stability analysis of the Aircraft, which will have 2 candidates to follow.

4.2.2 The Aerodynamic Analysis

Since we would like to ascertain the Aerodynamic capabilities of our Loitering Munition and ensure our craft's Stability in multiple ways, We used two open-sourced applications that could do so, namely the XFLR5 by TechWinder and OpenVSP by NASA.

FIGURE 4.14: The logo of XFLR5

From there, we started to discover and learn about the XFLR5 by looking at the developer's tutorial videos on YouTube playlists.

From there, we can give our inputs to the XFLR5 on our NACA selection, starting from the NACA 23012 as our Main wing and Horizontal Stabilizer airfoil along with our NACA 0009 which was selected as our Vertical stabilizer. We can clarify that the aerodynamic characteristics of our selected Airfoil are viable to our Loitering Munition which as it stands requires a t/c ratio of 12%. Then we continued to experiment with the wings for our Loitering Munition as shown in Fig. 4.18, from there we started the design from 2 well-known wing configurations, which we will discuss in the following subsection.

4.2.3 The Aircraft wing configurations.

Since the calculations in the previous section "Inertia Calculation from Mass to Wing determination", we have a few suggestions for the design, from the Delta winged configuration or conventional wing configuration. There are some constraints that may be used in selecting one of the two configurations listed here:

1. Delta winged configuration:

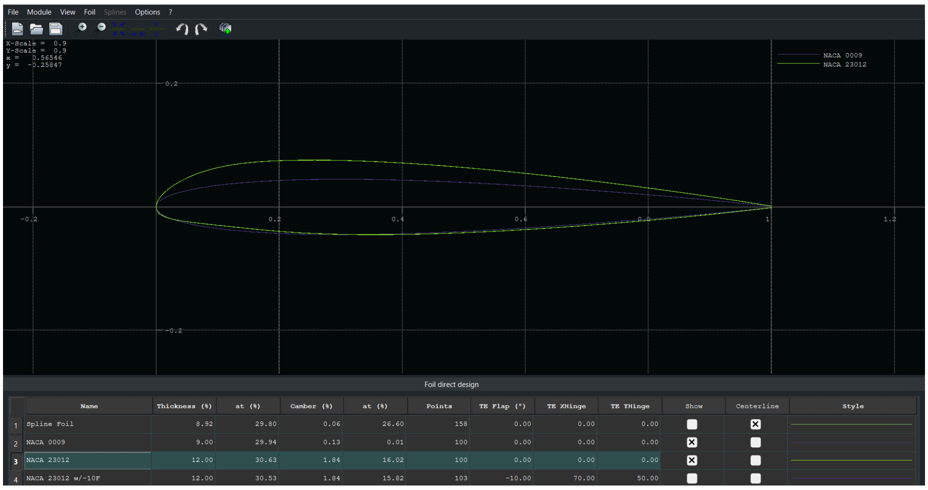


FIGURE 4.15: The Airfoil Design and Creation

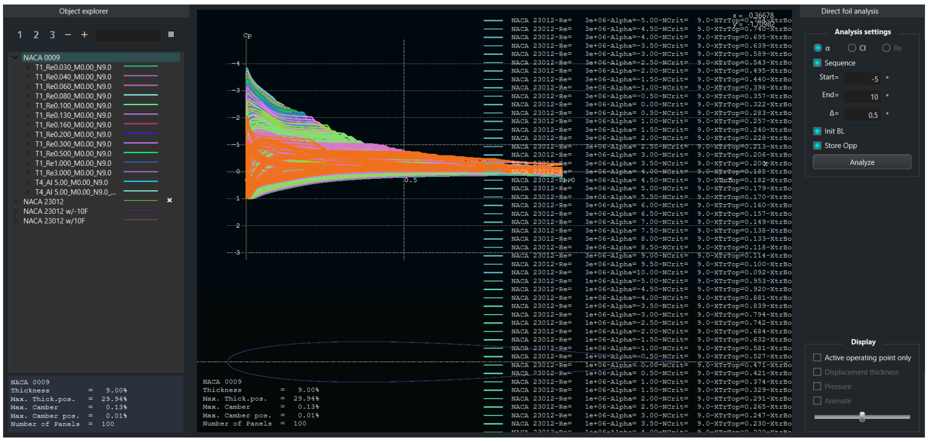


FIGURE 4.16: The Airfoil Direct Analysis - OpPoint View

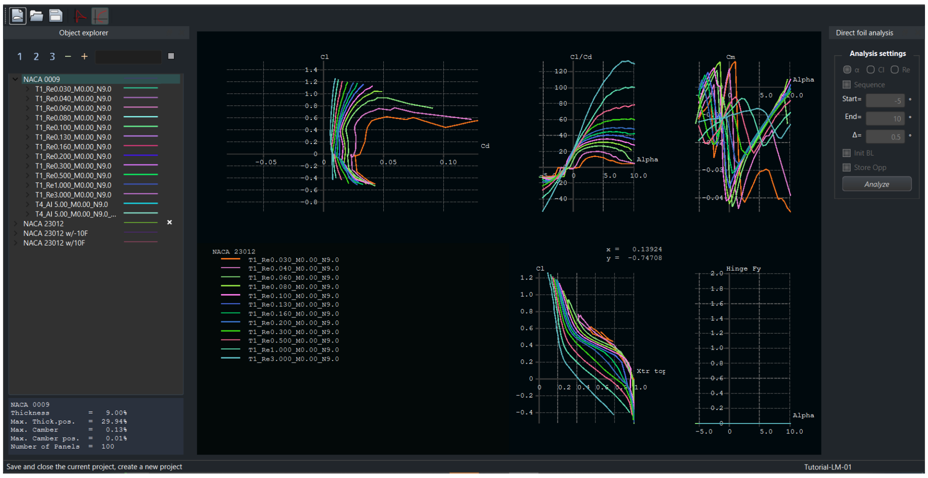


FIGURE 4.17: The Airfoil Direct Analysis - Polar View

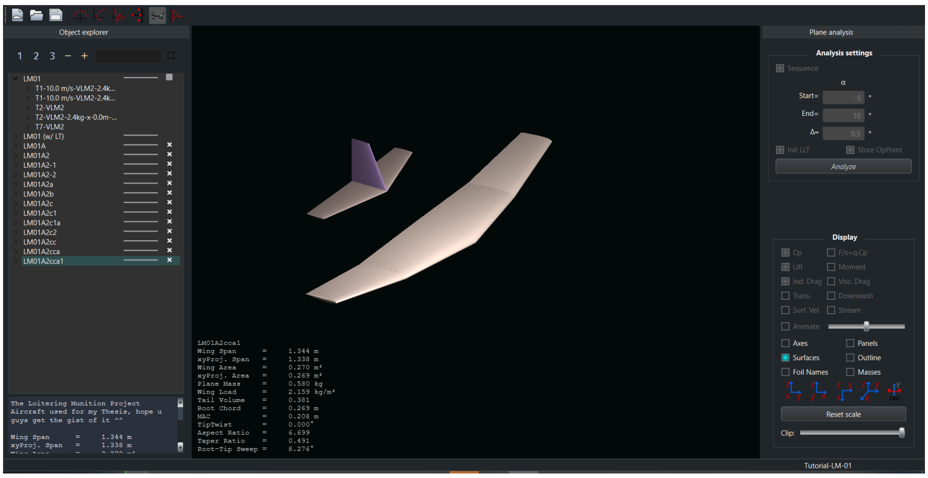


FIGURE 4.18: The Plane Diagram - 3D Diagram

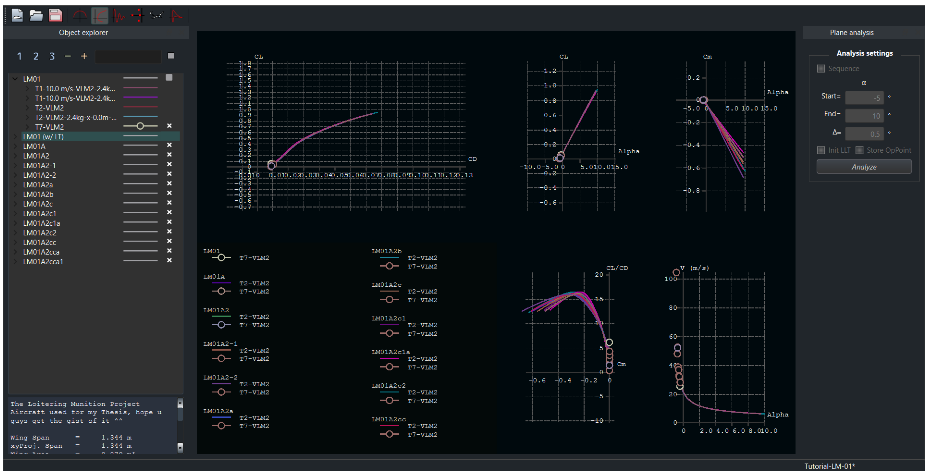


FIGURE 4.19: The Plane Diagram - Polar Diagram

- Theoretically far more stable wing design (+)
- Proven design based on real-life examples of IAI Harpy, IAI Harop, Shahed-136, and more (+).
- Large radar cross-section, due to the large presence of the wing configuration (-).
- Uncertainty of using Delta winged configuration (-).

2. Conventional winged configuration:
   - Simplified and mostly well-known design to have (+).
   - Less radar cross-section possibility (+).
   - Requires the Horizontal Stabilizer which may increase the cost of production by a bit (-).

Based on the theory, we can still try to design the craft based on 2 wing configurations at xflr5 which we made as in these Figures 4.20 and 4.21.

After we define these planes, we can start analyzing the aerodynamic characteristics, using the Type 2 analysis (Fixed lift analysis), with Ring Vortex (VLM2) option in viscous inertia which is shown with the constraints given in 4.22 and 4.23 :

After we define the analysis of our respective aircraft, we can start analyzing the aerodynamic characteristics with AOA characteristics starting at -5 degrees to 10 degrees with increments at 0.5 degrees, we found out that the Delta winged

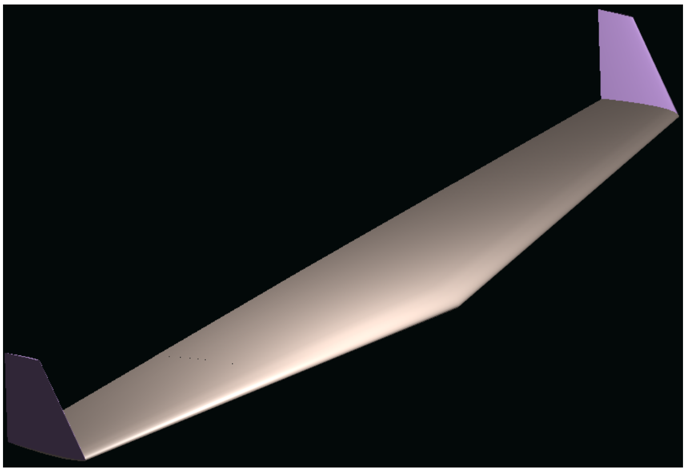


FIGURE 4.20: Delta winged configuration with 2 Vertical Stabilizers

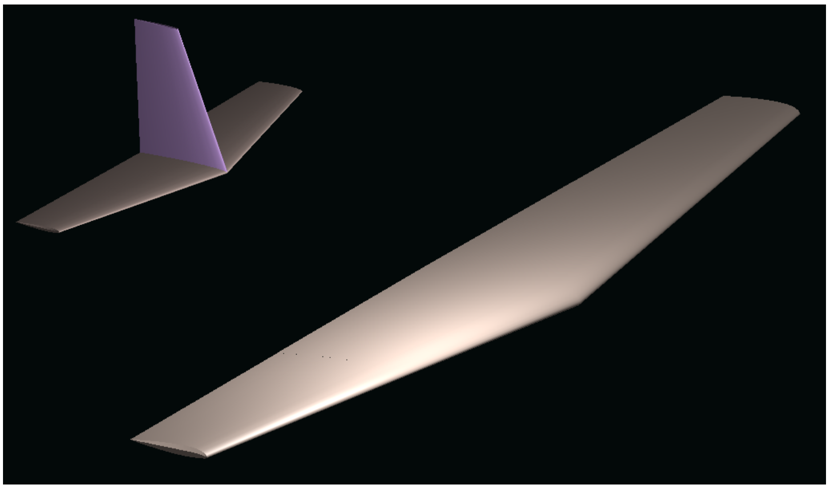


FIGURE 4.21: Simple Conventional Wing Configuration

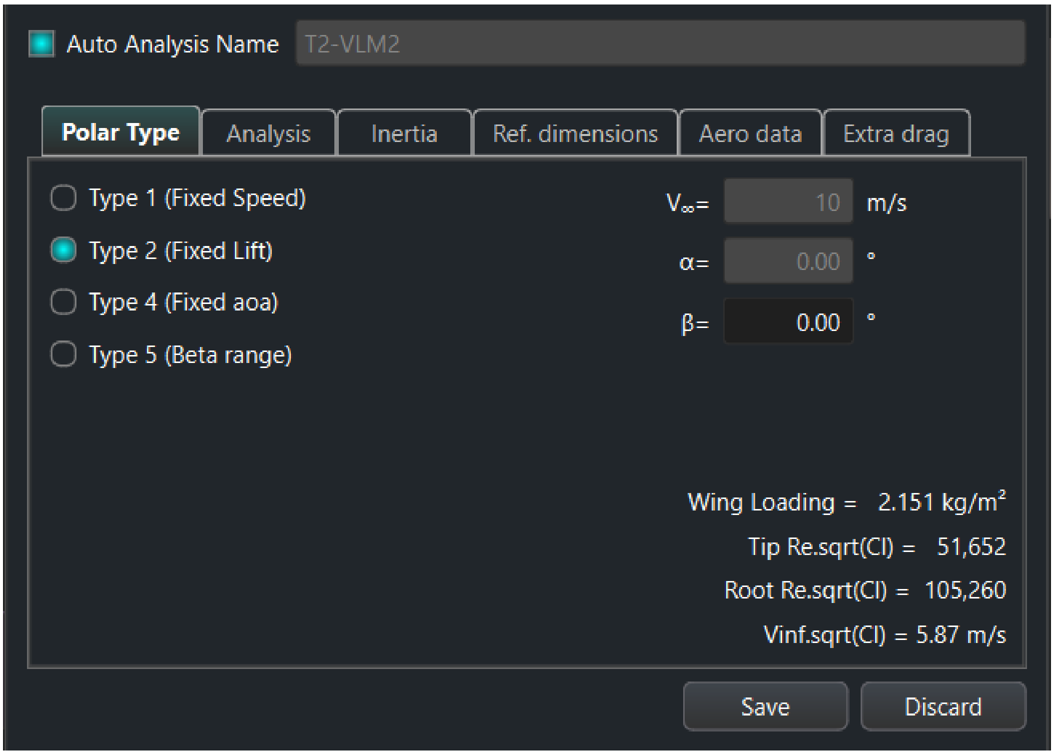


FIGURE 4.22: Part 1 of Analysis definition on XFLR5

configuration aircraft could do only at -1 deg to 6.5 deg to generate positive lifts. Meanwhile, the conventional wing configuration could generate more positive lifts at AOA -0.5 deg to 9.5 deg, making it fit for the buck, We also define the stability analysis of our candidates with the options given in Figures 4.24 and 4.25.

Based on these options given in the figures, we can start analyzing the stability characteristics of both configurations as it turns out, when we tested the stability analysis of both configurations, the delta-winged configuration suffered massive instability during Spiral longitudinal stability mode which showed with the large positive eigenvalue, which violated the stability condition for the eigenvalue shown in the following Table 4.19 and Figure 4.26.

Meanwhile, the Conventional-wing configuration showed no massive instability during the tests and we decided that we would commit to the conventional-wing design for the rest of the campaign due to the time remaining.

Based on the data, we decided to configure the Fixed-wing configuration and

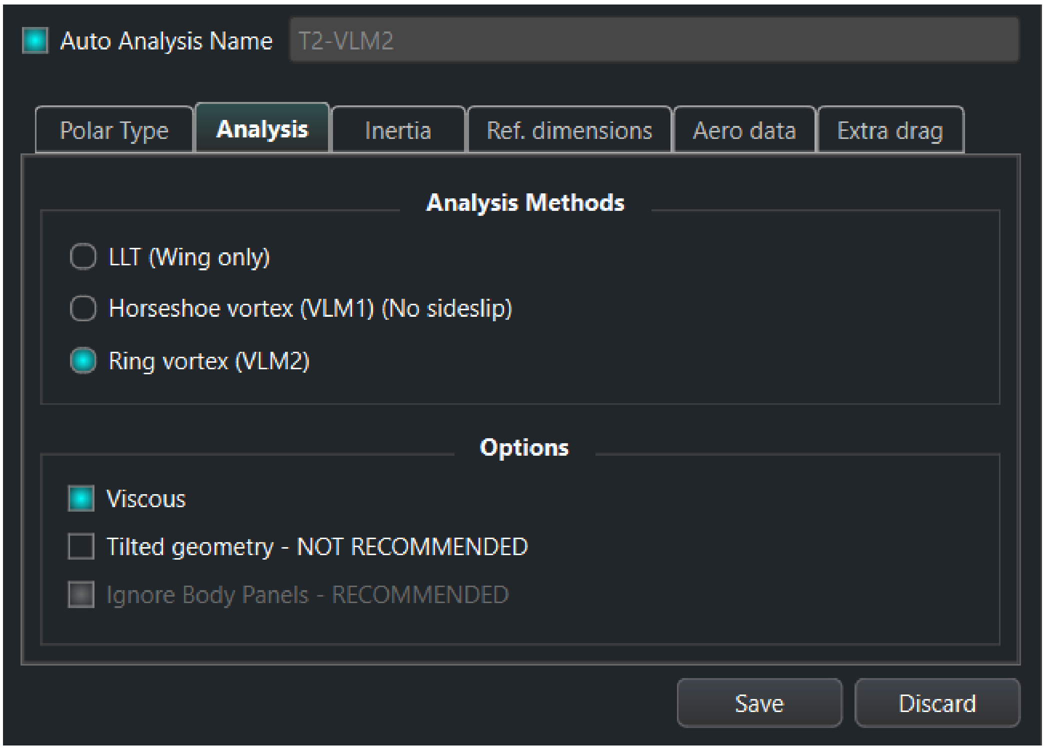


FIGURE 4.23: Part 2 of Analysis definition on XFLR5

TABLE 4.19: Summary of Eigenvalue and Eigenvector for Delta-wing configuration's Stability Analysis.

Longitudinal modes				
Eigenvalue:	-68.38+0i	-0.05463+-0.569i	-0.05463+0.569i	31.04+0i
Eigenvector:	1+0i	1+0i	1+0i	1+0i
	5547+0i	0.0007907+-0.0002158i	0.0007907+0.0002158i	-46.22+0i
	-7715+0i	0.03328+-0.000329i	0.03328+0.000329i	-125.9+0i
	112.8+0i	-0.00499+0.058i	-0.00499+-0.058i	-4.057+0i
Lateral modes				
Eigenvalue:	-109.2+0i	-0.7025+-2.671i	-0.7025+2.671i	0.0699+0i
Eigenvector:	1+0i	1+0i	1+0i	1+0i
	62.05+0i	-0.2435+-0.003185i	-0.2435+0.003185i	-0.3095+0i
	1.6+0i	-0.03082+0.07321i	-0.03082+-0.07321i	-1.796+0i
	-0.5681+0i	0.02354+-0.08497i	0.02354+0.08497i	-4.427+0i

the final result is the shortened empennage placement and size and the main wing includes the dihedral part. As seen in the figures 4.28 and 4.29, with emphasized Stability derivatives which defined the local moment and forces changed

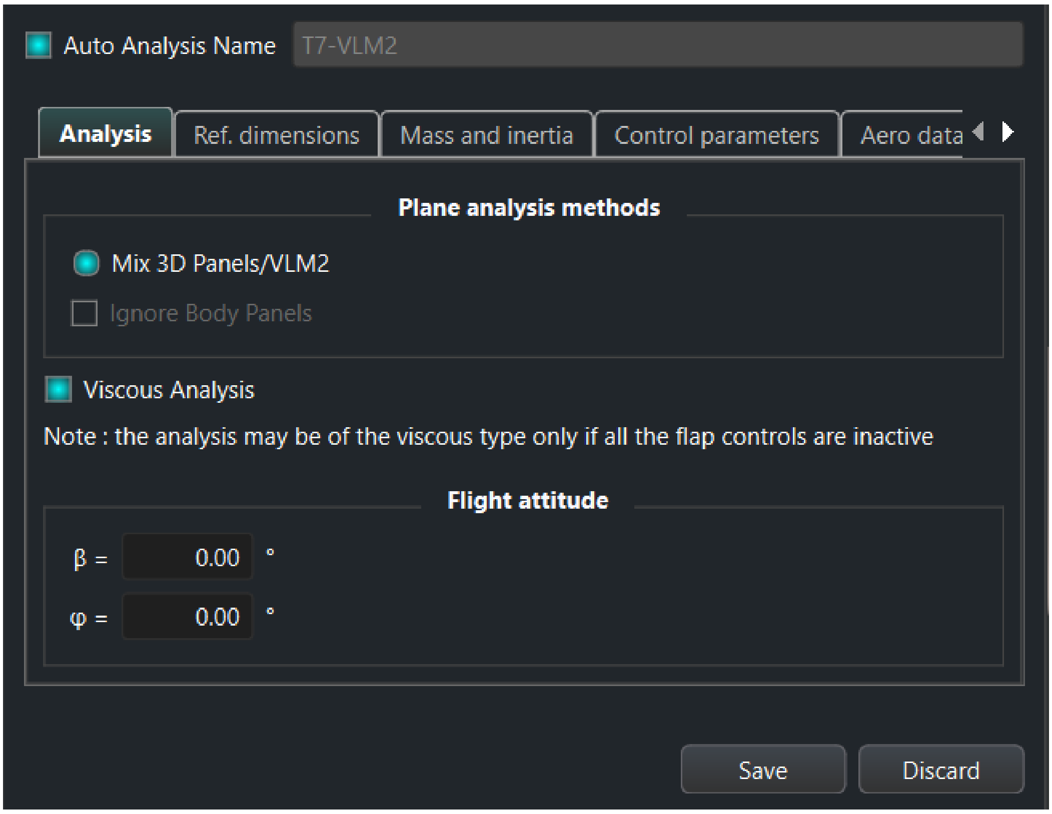


FIGURE 4.24: Part 1 of Stability Analysis definition on XFLR5

TABLE 4.20: Summary of Eigenvalue and Eigenvector for Conventional-wing configuration's Stability Analysis.

Longitudinal modes				
Eigenvalue:	-144.6+0i	-110.8+0i	-0.07738+-0.3386i	-0.07738+0.3386i
Eigenvector:	1+0i	1+0i	1+0i	1+0i
	2836+0i	-8.605e+04+0i	-0.008204+-3.129e-05i	-0.008204+3.129e-05i
	-1.483e+04+0i	2.939e+05+0i	0.01231+7.009e-05i	0.01231+-7.009e-05i
	102.5+0i	-2653+0i	-0.008095+0.03452i	-0.008095+-0.03452i
Lateral modes				
Eigenvalue:	-120.6+0i	-12.19+-29.67i	-12.19+29.67i	0.007118+0i
Eigenvector:	1+0i	1+0i	1+0i	1+0i
	373.4+0i	-0.08678+0.06658i	-0.08678+-0.06658i	0.03423+0i
	1.406+0i	0.3179+0.9843i	0.3179+-0.9843i	1.48+0i
	-3.097+0i	-0.0008917+-0.003291i	-0.0008917+0.003291i	4.809+0i

in an aircraft, eigenvalues, and eigenvectors in tables 4.21 and 4.22, the Loitering Munition is now deemed stable in mathematical analysis. From here, we can use this iteration for the upcoming advanced characteristics and powerplant selection, which we will designate as LM01Acca1.

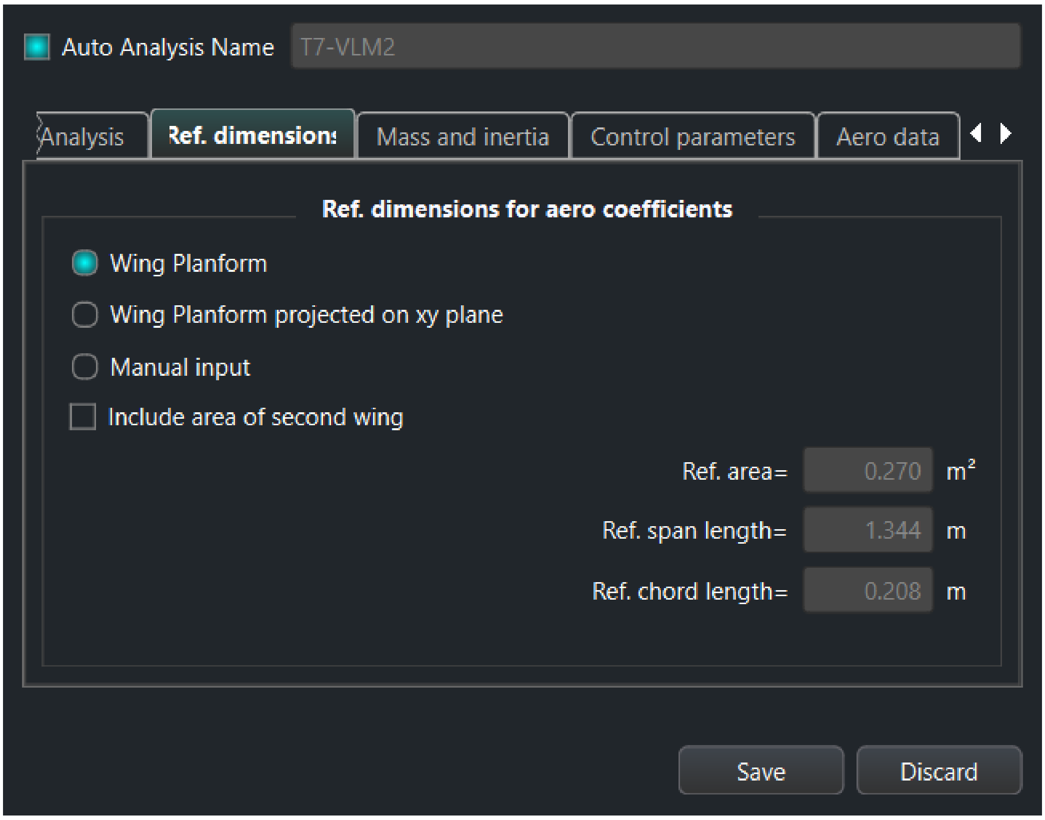


FIGURE 4.25: Part 2 of Stability Analysis definition on XFLR5

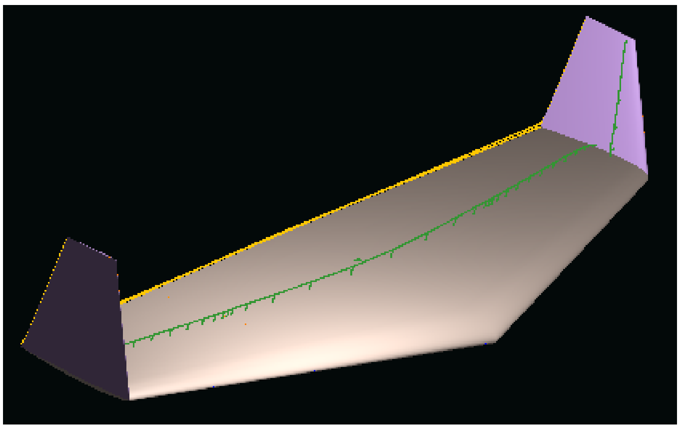


FIGURE 4.26: Part 2 of Stability Analysis definition on XFLR5

4.2.4 Advanced characteristics of LM01Acca

After we set the Aircraft wing characteristics in XFLR5 and managed to establish the optimum wing design for our craft, we would like to analyze the Inertia Lift,

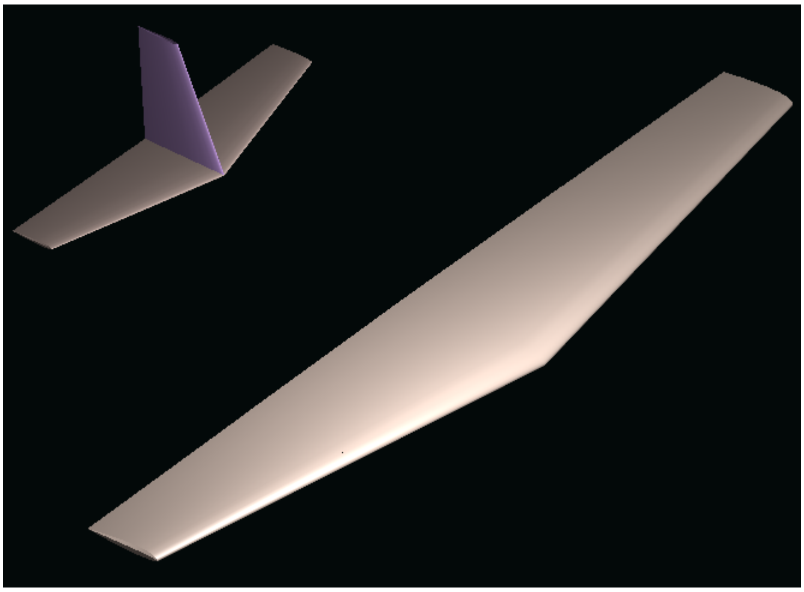


FIGURE 4.27: Part 2 of Stability Analysis definition on XFLR5

TABLE 4.21: Summary of Eigenvalues and Eigenvectors for Finalized Conventional-wing configuration's Stability Analysis.

Longitudinal modes				
Eigenvalue:	-126.2-109.8i	-126.2+109.8i	-0.1266-0.1887i	-0.1266+0.1887i
Eigenvector:	1+0i	1+0i	1+0i	1+0i
	-153.3-170i	-153.3+170i	-0.002633-1.936e-06i	-0.002633+1.936e-06i
	-327.9+754.7i	-327.9-754.7i	0.005269+1.041e-05i	0.005269–0.01296-0.01923i
	-1.483-4.691i	-1.483+4.691i	-0.01296+0.01923i	-0.008095+-0.03452i
Lateral modes				
Eigenvalue:	-194.4+0i	-7.829-36.7i	-7.829+36.7i	-0.007167+0i
Eigenvector:	1+0i	1+0i	1+0i	1+0i
	181.1+0i	-0.2661+0.007788i	-0.2661-0.007788i	-0.08436+0i
	-1.456+0i	0.08848-0.7273i	0.08848+0.7273i	2.221+0i
	-0.9315+0i	0.001277-0.006978i	0.001277+0.006978i	11.77+0i

Drag, and Momentum Coefficients. So we decided to analyze further with NASA's open-sourced aerodynamic analysis application, known as OpenVSP (4.30).

We can determine the craft based on the Fuselage, wing design, and propeller placement. Then we can analyze the results based on the design and the following Figures 4.31, 4.32, 4.33, 4.34, 4.35.

From there, we can analyze the Drag Coefficients (Inertia and Total) and Lift Coefficients, and we tried on 25 and 100 nodes. We will show the 100 nodes version of Aerodynamic Characteristic results and its graphs in Table 4.23, and

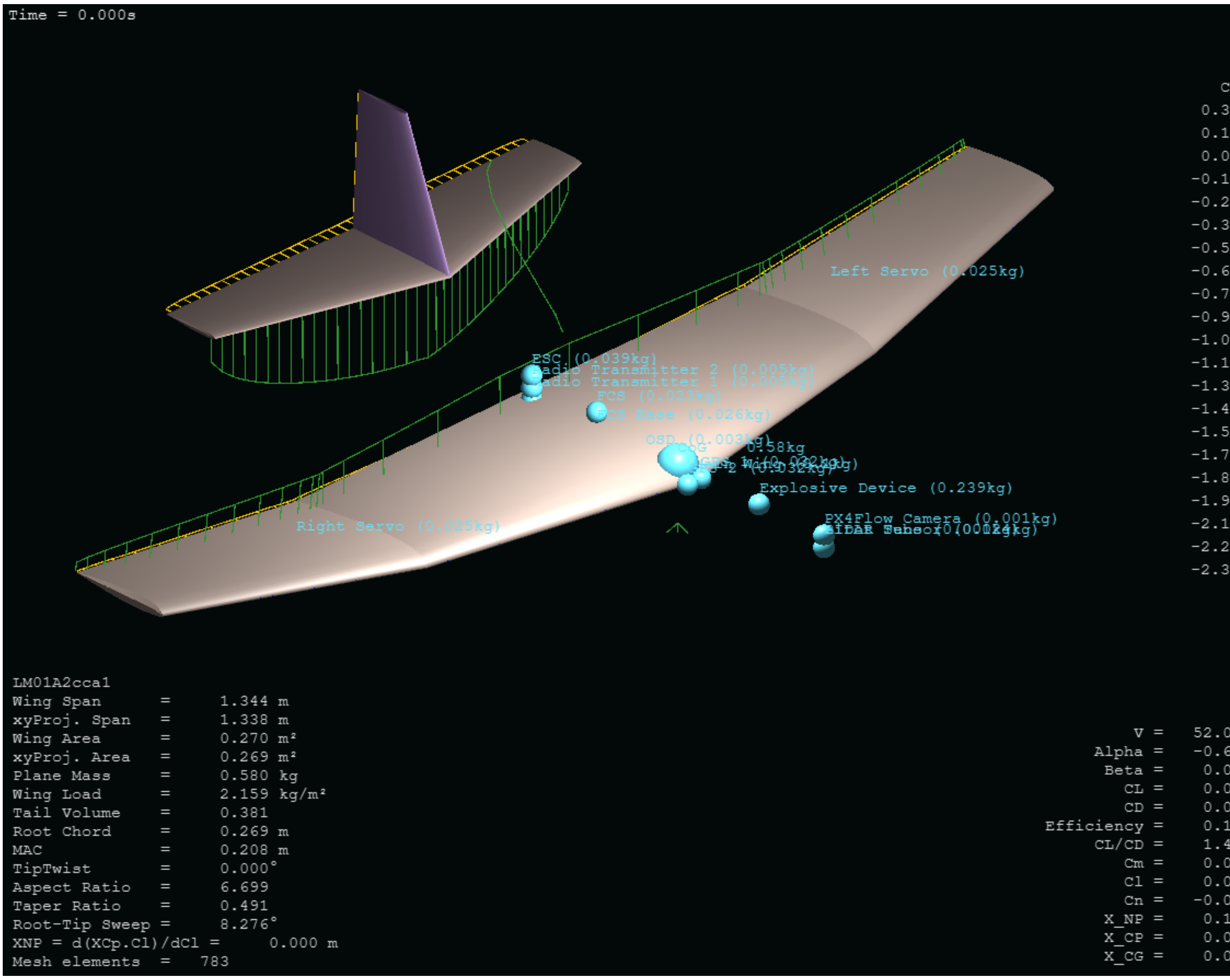


FIGURE 4.28: LM01Acca's XFLR5 Model in Isometric View

Figures 4.36 and 4.37.

TABLE 4.23: Aerodynamic Characteristics of LM01 based on 100 nodes

No.	alpha	CDo	CDtot	CL
1	-5	0.009773198	0.016994952	-0.425357864
2	-4.848485	0.009722981	0.016478435	-0.411545069
3	-4.69697	0.009674674	0.015978656	-0.397728502
4	-4.545455	0.009628291	0.015495888	-0.383908367

5	-4.393939	0.009583828	0.015030035	-0.370083992
6	-4.242424	0.009541283	0.014581072	-0.356255207
7	-4.090909	0.009500664	0.014149024	-0.342423293
8	-3.939394	0.00946197	0.013733878	-0.328588503
9	-3.787879	0.009425198	0.013335672	-0.31474888
10	-3.636364	0.009390363	0.01295449	-0.300906397
11	-3.484848	0.009357543	0.01259103	-0.28708678
12	-3.333333	0.009326558	0.012243653	-0.273236176
13	-3.181818	0.009297505	0.011913217	-0.259381086
14	-3.030303	0.009270375	0.011599668	-0.245521461
15	-2.878788	0.009245175	0.011303076	-0.231655823
16	-2.727273	0.00922191	0.011023452	-0.21778721
17	-2.575758	0.009200574	0.010760776	-0.203912028
18	-2.424242	0.009181164	0.010515031	-0.190029925
19	-2.272727	0.009163709	0.010286342	-0.176151557
20	-2.121212	0.00914818	0.010074512	-0.16226171
21	-1.969697	0.00913457	0.009879523	-0.148358198
22	-1.818182	0.009122905	0.009701349	-0.134444506
23	-1.666667	0.009113171	0.009539797	-0.120508479
24	-1.515152	0.009105407	0.009394118	-0.106526588
25	-1.363636	0.009100013	0.009259592	-0.092287458
26	-1.212121	0.009095153	0.009175539	-0.079130438
27	-1.060606	0.009093069	0.009084199	-0.065134116
28	-0.909091	0.009092864	0.009004968	-0.051052462
29	-0.757576	0.009094557	0.00894812	-0.037021638
30	-0.606061	0.009098229	0.008906687	-0.022884553
31	-0.454545	0.009103733	0.008884728	-0.008714211
32	-0.30303	0.009110971	0.008879616	0.005562133
33	-0.151515	0.009119874	0.008893243	0.020033386
34	0	0.009136309	0.00889424	0.030210678
35	0.151515	0.00915667	0.00889251	0.039650777
36	0.30303	0.00917074	0.008953724	0.054376921
37	0.454545	0.00918684	0.009030088	0.0686397

38	0.606061	0.009205277	0.009121916	0.082831209
39	0.757576	0.009225755	0.009230994	0.096841429
40	0.909091	0.009248626	0.009358776	0.111150757
41	1.060606	0.009273261	0.009500935	0.125026325
42	1.212121	0.009299204	0.009660185	0.139045375
43	1.363636	0.009327598	0.00983825	0.152924891
44	1.515152	0.009358254	0.010032251	0.167047717
45	1.666667	0.009391477	0.010247838	0.181226174
46	1.818182	0.00942456	0.010466503	0.19485792
47	1.969697	0.009460277	0.01070679	0.208620905
48	2.121212	0.009498582	0.010970304	0.222678791
49	2.272727	0.00953847	0.011247263	0.236574841
50	2.424242	0.009579713	0.011532497	0.250311667
51	2.575758	0.009623603	0.011843145	0.264359939
52	2.727273	0.009668879	0.012169693	0.278041305
53	2.878788	0.009715908	0.012510609	0.291833601
54	3.030303	0.009765178	0.012869064	0.30571401
55	3.181818	0.009816671	0.013245347	0.319671857
56	3.333333	0.009870587	0.01364208	0.333667942
57	3.484848	0.009923299	0.014038637	0.347028595
58	3.636364	0.009980786	0.014470424	0.361011291
59	3.787879	0.010037228	0.014909588	0.374473493
60	3.939394	0.010103557	0.015408723	0.389154056
61	4.090909	0.010161673	0.015854629	0.402524112
62	4.242424	0.010225739	0.016351423	0.416506303
63	4.393939	0.010290212	0.016838918	0.429839473
64	4.545455	0.010358206	0.017384668	0.443805946
65	4.69697	0.01042811	0.017933727	0.45773039
66	4.848485	0.010502356	0.01851701	0.471731489
67	5	0.010572992	0.019067318	0.485432466
68	5.151515	0.010645207	0.019658363	0.49877858
69	5.30303	0.010723709	0.020270157	0.512857014
70	5.454545	0.010802537	0.020909846	0.526653842

71	5.606061	0.010881641	0.021510284	0.540163856
72	5.757576	0.010964092	0.02216492	0.553974405
73	5.909091	0.011047404	0.022839481	0.567690875
74	6.060606	0.011133473	0.023550491	0.581607067
75	6.212121	0.011219012	0.024237767	0.595081163
76	6.363636	0.011310662	0.025014191	0.609111052
77	6.515152	0.011399842	0.02570904	0.622692946
78	6.666667	0.011491541	0.026456046	0.636437844
79	6.818182	0.011584251	0.027203585	0.650034174
80	6.969697	0.011681877	0.028007694	0.664107359
81	7.121212	0.01177583	0.028787164	0.67734516
82	7.272727	0.011875683	0.029656379	0.69151307
83	7.424242	0.011977305	0.030506554	0.705414229
84	7.575758	0.012081102	0.031377365	0.719343144
85	7.727273	0.012185285	0.032226689	0.732991735
86	7.878788	0.01228986	0.03311128	0.746502769
87	8.030303	0.012397027	0.033981475	0.759880268
88	8.181818	0.012502041	0.034828627	0.772731178
89	8.333333	0.012610261	0.035678025	0.785476098
90	8.484848	0.012717313	0.036522447	0.797748881
91	8.636364	0.012823738	0.037351914	0.809192445
92	8.787879	0.012932424	0.038119254	0.819556511
93	8.939394	0.013035429	0.038797168	0.825527164
94	9.090909	0.013238845	0.050143102	0.778213812
95	9.242424	0.01326865	0.042273617	0.820694922
96	9.393939	0.013398094	0.044853824	0.82534769
97	9.545455	0.013513178	0.045777038	0.838303112
98	9.69697	0.013625439	0.045704166	0.854911187
99	9.848485	0.013743937	0.045974383	0.870619418
100	10	0.013868367	0.046091499	0.887025917

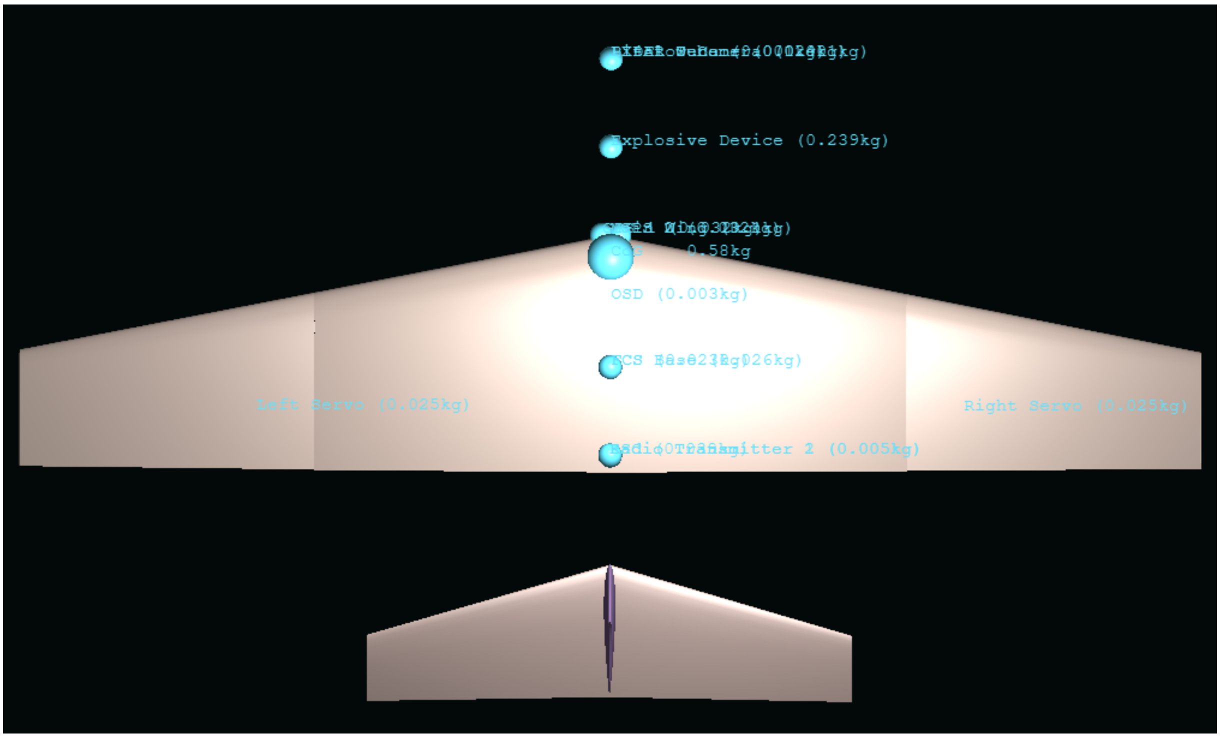


FIGURE 4.29: LM01Acca's XFLR5 Model in Top-Down View

FIGURE 4.30: The Logo of OpenVSP

4.3 Powerplant and Performance of Loitering Munition - Discussions and Results

Based on previous data on fuselage and wings (inc. Main and stabilizers), we proceeded to the Powerplant research. since we primarily focused on our Aircraft

TABLE 4.22: Summary of Stability Derivatives for Finalized Conventional-wing configuration's Stability Analysis.

Longitudinal derivatives	
Cxu	-0.016964
Cxa	0.061857
Czu	-3.2046e-06
CLa	5.1433
CLq	11.958
Cmu	-0.0013884
Cma	-2.811
Cmq	-10.957
Neutral Point position	0.13973m
Lateral derivatives	
CYb	-0.2539
CYp	-0.14135
CYr	0.16863
Clb	-0.080821
Clp	-0.45564
Clr	0.036839
Cnb	0.072338
Cnp	0.015014
Cnr	-0.047916

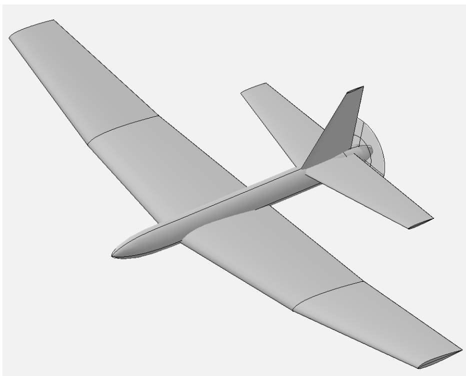


FIGURE 4.31: The OpenVSP iteration of LM01A

design rather than designing the powerplant, we decided to set ourselves with commercially available powerplants, with the assistance of a certain application to assist in the calculations of aircraft performance. The aircraft performance calculator that we mentioned is called eCalc by Markus Mueller. ECalc can help engineers, manufacturers, designers, and even hobbyists to determine most of the Aircraft's performance, preferably the Aircraft with electric drive, which is well known in the world of Radio-Controlled aircraft and Unmanned Aircraft Systems

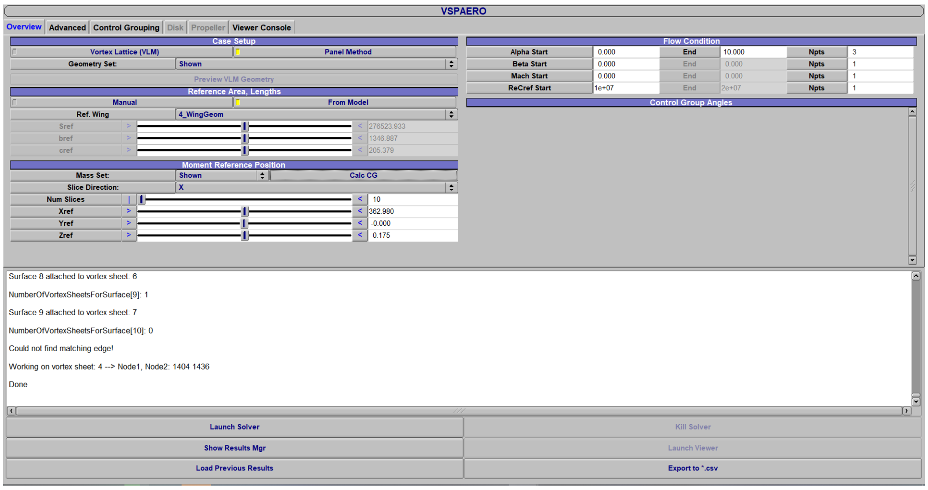


FIGURE 4.32: Options used for OpenVSP's AeroVSP analysis.

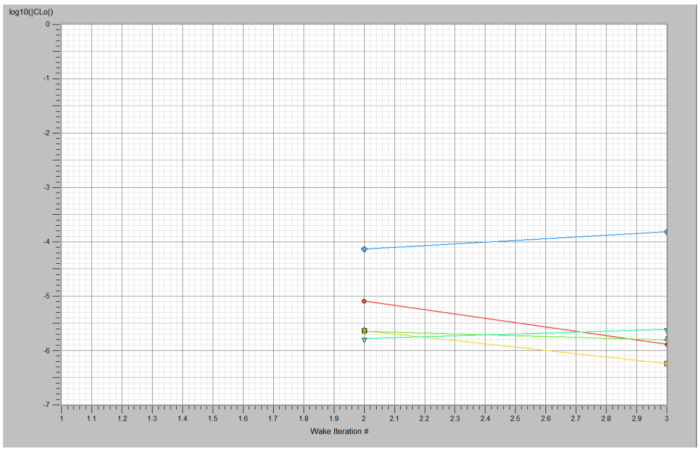


FIGURE 4.33: Lift Coefficient of LM01A

(UAS).

The eCalc, in general, could also provide the calculations for the rotary wing designs, which is well known in both quadcopter and helicopter designs, while also meant for electric cars and torque calculators for the industries. In general, here is the complete list of calculators that would help the engineers from a single website, the logo of eCalc in Figure 4.38 and, the home page design of eCalc in Figure 4.39:

1. Propeller Calculator (PropCalc)
2. Setup Finder

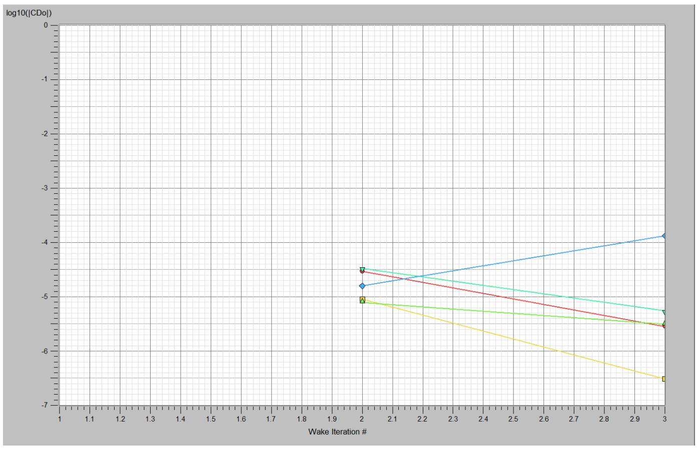


FIGURE 4.34: Drag Coefficient of LM01A

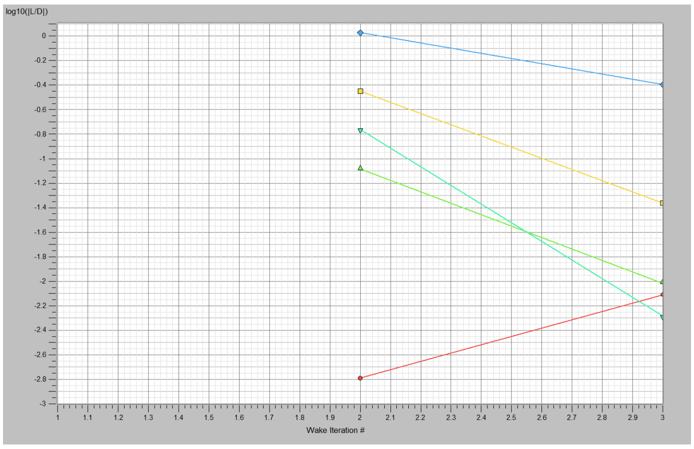


FIGURE 4.35: Lift to Drag Coefficient of LM01A

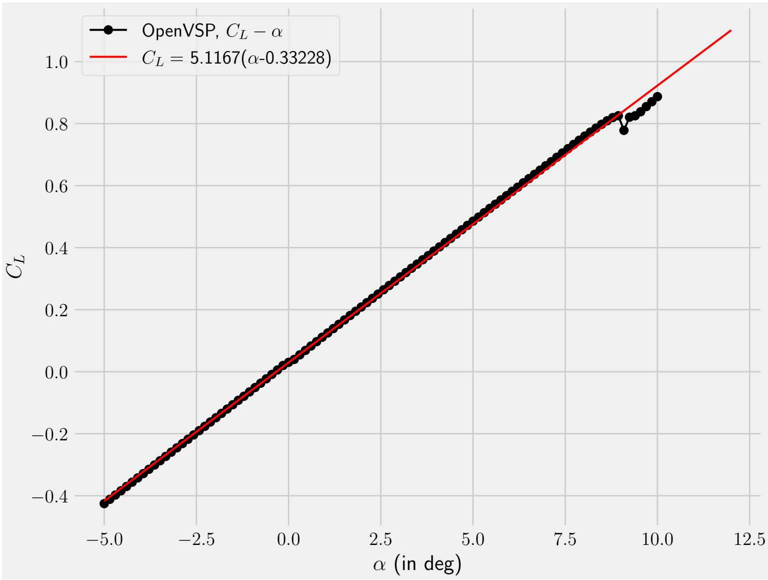


FIGURE 4.36: The Lift Coefficient polar graph for LM01A

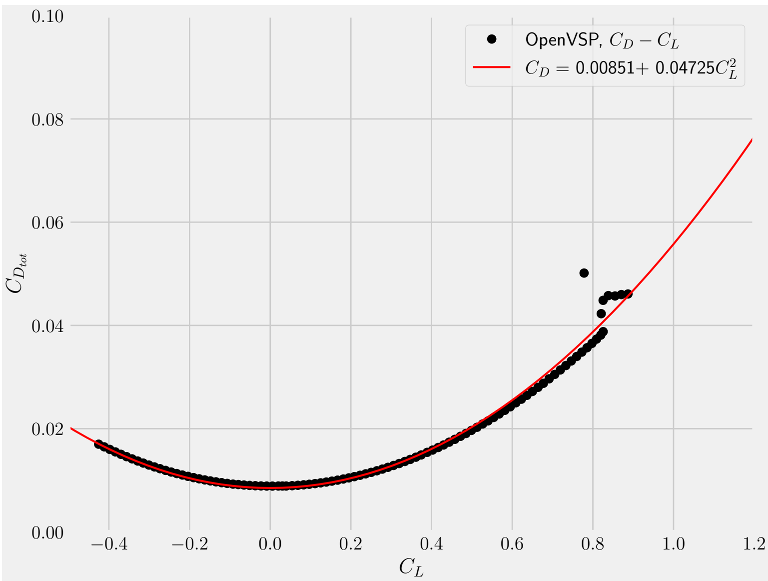


FIGURE 4.37: The Drag Polar graph for LM01A, based on 100 nodes

FIGURE 4.38: eCalc Logo

FIGURE 4.39: eCalc website

3. Performance Calculator (PerfCalc)
4. Center of Gravity Calculator (cgCalc)
5. Weight and Balance Calculator (wbCalc)
6. EDF Fan Calculator (fanCalc)
7. QuadCopter Calculator (xcopterCalc)
8. Helicopter Calculator (HeliCalc)
9. Electric Car Calculator (evCalc)
10. Electric Car Charging Calculator (chargeCalc)
11. Electrical Charging Comparison Indexx (chargeIndex)
12. Torque Calculator (torqueCalc)

We will use the first three calculators that would support our cause in determining the Aircraft's powerplant use and since we already have the center of Gravity and Weight and Balance calculations, we can use the data provided to ensure the success and accuracy of our Loitering Munition.

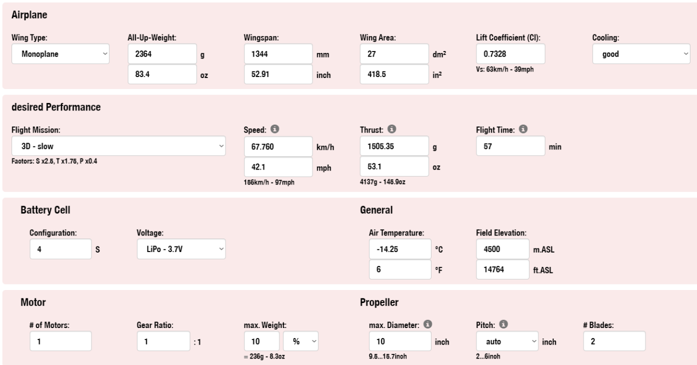


FIGURE 4.40: eCalc website

4.3.1 Setup Finder - Determining options of Loitering Munition

The setup finder of eCalc is simple, to let us sort the suitable configuration of defined factors, and since we have the prerequisite data available from XFLR5 while some need additional details, we can input the data and calculate the required thrust and its velocity at the desired altitude. The following equations 4.98, 4.99, and 4.100 explain the results of our available speed and thrust required at a level altitude of 4500 m.

$$V = \sqrt{\frac{2 \times 2.364\mathrm{kg} \times 10}{0.67452\mathrm{kg\,m^{-3}} \times 0.27\mathrm{kg}^2 \times (0.8 \times 0.916)}} = 67.760\mathrm{km\,h^{-1}} \tag{4.98}$$

$$T = \frac{1}{2} \times 0.67452 \times 67.760^2\mathrm{km\,h^{-1}} \times 0.27 \times (0.008 + (\frac{1}{\pi} \times e \times \frac{1.344^2}{0.27}) \times (0.8 \times 0.916)^2 \tag{4.99}$$

$$T = 1505.353\mathrm{g} = 1.505\mathrm{kg} \tag{4.100}$$

From there, we can start defining the setups available for the craft, using available sources from our initial definition and available results from XFLR5, seen from the Figure 4.40

From there, we discovered about 686 solutions available and we selected the combinations based on different battery options, motor selections, and ESC selections. There are 3 possible selections based on the constraints for now, which are shown in Table 4.24.

Number	Codenames	Electric Motor (rpm/V)	Battery Variant (mAh)	ESC Selected (A)	Propeller	Propeller Diameter and pitch (inch)	Propeller Blades
1	LM01Acca2	NeuMotors 4606MC-1495 (1495)	14,000	80	Carbon, Fold-prop (+7.0)	9 x 3	3
2	LM01Acca3	SunnySky X2850-1250 V3 (1250)	16,000	100	Carbon, Fold-prop (+7.0)	11.5 x 4	2
3	LM01Acca4	NeuMotors 1706/1.5Y (1255)	22,000	100	Carbon, Fold-prop (+5.0)	9.5 x 4.5	3

TABLE 4.24: Setup Selection of the Loitering Munition Powerplants.

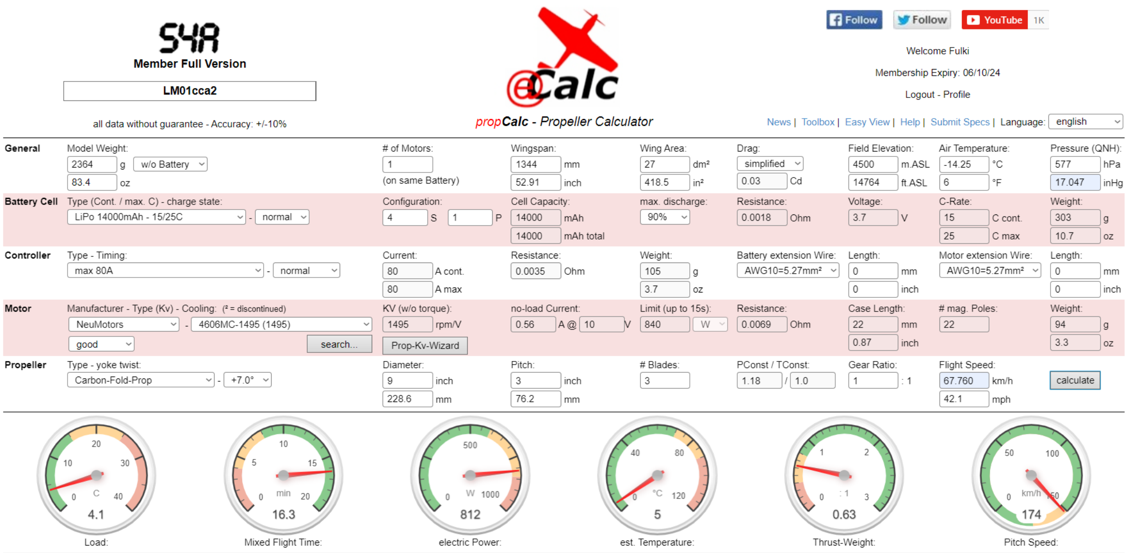


FIGURE 4.41: Propeller Calculation configuration and general results in gauge for LM01Acca2

4.3.2 Propeller Performance Calculator - Fitting the setup.

The aircraft performance is not always linear in one setup and another, and it needs careful selection and decision on powerplants. For that reason, we could have a try at simulating and calculating the results of simulations, ranging from flight time to flight speeds, making it sufficient to ensure the plane's capabilities met our initial requirements. From there, we have simulated every possible configuration for the aircraft in three options, and here are some results available based on the calculations provided on the website in Figures 4.41, 4.42, and 4.43 for LM01Acca2, 4.44, 4.45, and 4.46 for LM01Acca3, and 4.47, 4.48, and 4.49 for LM01Acca4.

Remarks:

Battery	
Load:	4.09 C
Voltage:	14.39 V
Rated Voltage:	14.80 V
Energy:	207.2 Wh
Total Capacity:	14000 mAh
Used Capacity:	12600 mAh
min. Flight Time:	13.2 min
Mixed Flight Time:	16.3 min
Weight:	1212 g
	42.8 oz

Motor @ Optimum Efficiency	
Current:	42.96 A
Voltage:	14.34 V
Revolutions*:	20374 rpm
electric Power:	616.0 W
mech. Power:	591.5 W
Efficiency:	96.0 %

Motor @ Maximum	
Current:	57.25 A
Voltage:	14.19 V
Revolutions*:	20012 rpm
electric Power:	812.2 W
mech. Power:	778.5 W
Efficiency:	95.9 %
est. Temperature:	5 °C
	41 °F
Wattmeter readings	
Current:	57.25 A
Voltage:	14.39 V
Power:	823.8 W

Propeller	
Static Thrust:	2267 g
	80 oz
Revolutions*:	20012 rpm
Stall Thrust:	- g
	- oz
avail.Thrust @ 67.760 km/h:	1796 g
avail.Thrust @ 42.1 mph:	63.4 oz
Pitch Speed:	174 km/h
	108 mph
Tip Speed:	862 km/h
	535 mph
specific Thrust:	2.79 g/W
	0.1 oz/W

Total Drive	
Drive Weight:	1552 g
	54.7 oz
Power-Weight:	237 W/kg
	108 W/lb
Thrust-Weight:	0.63 : 1
Current @ max:	57.25 A
P(in) @ max:	847.3 W
P(out) @ max:	778.5 W
Efficiency @ max:	91.9 %
Torque:	0.37 Nm
	0.27 lbf.ft
Climb Capacity:	9214 m
	30230 ft

Airplane	
All-up Weight:	3576 g
	126.1 oz
Wing Load:	132.4 g/dm²
	43.4 oz/ft²
Cubic Wing Load:	25.5
est. Stall Speed:	87 km/h
	54 mph
est. Speed (level):	160 km/h
	99 mph
est. Speed (vertical):	- km/h
	- mph
est. rate of climb:	11.6 m/s
(~25...30°)	2289 ft/min

share | performanceCalc | add to >> | Download .csv (0) | << clear

Motor Partial Load

Propeller	Throttle	Current (DC)	Voltage (DC)	el. Power	Efficiency	Thrust		Spec. Thrust		Pitch Speed		Speed (level)		Motor Run Time
rpm	%	A	V	W	%	g	oz	g/W	oz/W	km/h	mph	km/h	mph	(90%) min
3000	14	0.2	14.8	3.2	81.1	51	1.8	15.7	0.56	26	16	-	-	3449.4
4500	21	0.7	14.8	9.8	89.8	115	4.0	11.6	0.41	39	24	-	-	1131.6
6000	28	1.5	14.8	22.5	93.2	204	7.2	9.1	0.32	52	32	-	-	494.8
7500	36	2.9	14.8	43.2	94.8	318	11.2	7.4	0.26	65	41	-	-	257.1
9000	43	5.1	14.8	74.1	95.6	458	16.2	6.2	0.22	78	49	-	-	149.7
10500	50	8.0	14.7	117.1	96.0	624	22.0	5.3	0.19	91	57	-	-	94.4
12000	**58**	**12.0**	**14.7**	**174.5**	**96.1**	**815**	**28.7**	**4.7**	**0.16**	**104**	**65**	**-**	**-**	**63.2**
13500	**65**	**17.1**	**14.7**	**248.3**	**96.2**	**1032**	**36.4**	**4.2**	**0.15**	**117**	**73**	**-**	**-**	**44.3**
15000	**73**	**23.5**	**14.6**	**340.7**	**96.2**	**1273**	**44.9**	**3.7**	**0.13**	**130**	**81**	**101**	**63**	**32.1**
16500	81	31.5	14.6	453.7	96.2	1541	54.4	3.4	0.12	143	89	132	82	24.0
18000	89	41.2	14.5	589.6	96.1	1834	64.7	3.1	0.11	157	97	144	89	18.4
19500	97	52.8	14.4	750.4	95.9	2152	75.9	2.9	0.10	170	105	156	97	14.3
20012	100	57.2	14.4	812.2	95.9	2267	79.9	2.8	0.10	174	108	160	99	13.2

FIGURE 4.42: Detailed results from the propCalc for the LM01Acca2

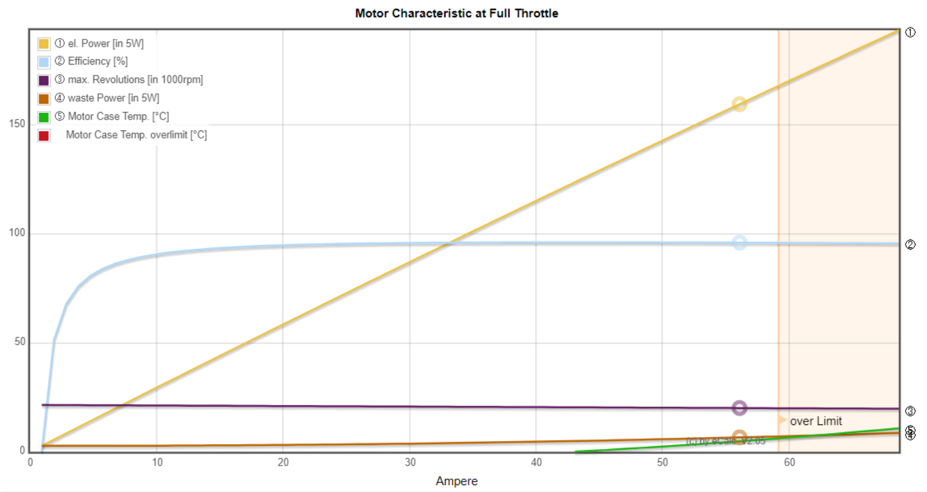


FIGURE 4.43: Motor Characteristics in Full Throttle graph for LM01Acca2

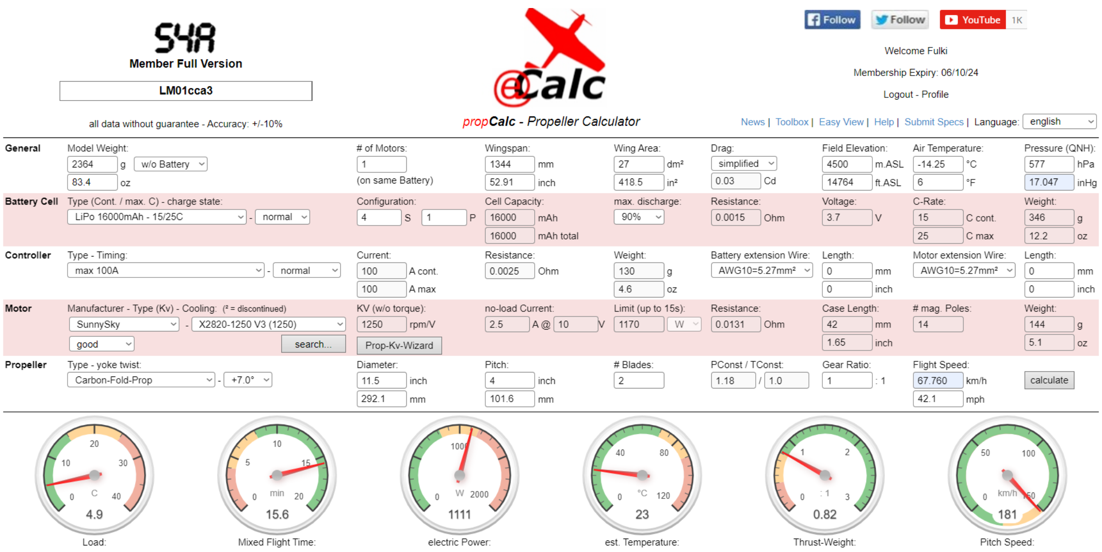
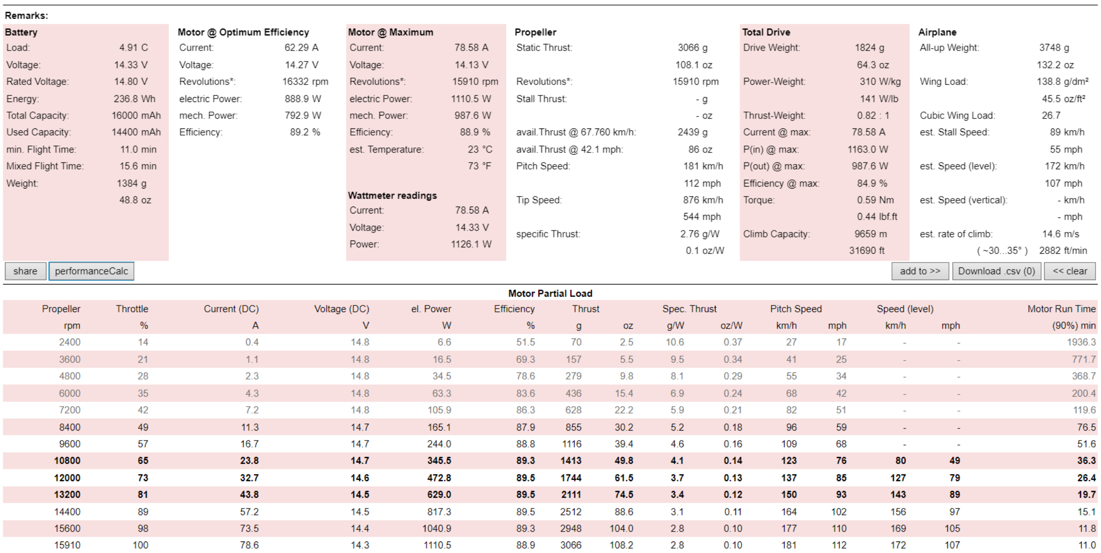


FIGURE 4.44: Propeller Calculation configuration and general results in gauge for LM01Acca3



Remarks:

Battery		Motor @ Optimum Efficiency		Motor @ Maximum		Propeller		Total Drive		Airplane	
Load:	4.91 C	Current:	62.29 A	Current:	78.58 A	Static Thrust:	3066 g	Drive Weight:	1824 g	All-up Weight:	3748 g
Voltage:	14.33 V	Voltage:	14.27 V	Voltage:	14.13 V		108.1 oz		64.3 oz		132.2 oz
Rated Voltage:	14.80 V	Revolutions*:	16332 rpm	Revolutions*:	15910 rpm	Revolutions*:	15910 rpm	Power-Weight:	310 W/kg	Wing Load:	138.8 g/dm²
Energy:	236.8 Wh	electric Power:	888.9 W	electric Power:	1110.5 W	Stall Thrust:	- g		141 W/lb		45.5 oz/ft²
Total Capacity:	16000 mAh	mech. Power:	792.9 W	mech. Power:	987.6 W		- oz	Thrust-Weight:	0.82 : 1	Cubic Wing Load:	26.7
Used Capacity:	14400 mAh	Efficiency:	89.2 %	Efficiency:	88.9 %	avail.Thrust @ 67.760 km/h:	2439 g	Current @ max:	78.58 A	est. Stall Speed:	89 km/h
min. Flight Time:	11.0 min			est. Temperature:	23 °C	avail.Thrust @ 42.1 mph:	86 oz	P(in) @ max:	1163.0 W		55 mph
Mixed Flight Time:	15.6 min				73 °F	Pitch Speed:	181 km/h	P(out) @ max:	987.6 W	est. Speed (level):	172 km/h
Weight:	1384 g						112 mph	Efficiency @ max:	84.9 %		107 mph
	48.8 oz			**Wattmeter readings**		Tip Speed:	876 km/h	Torque:	0.59 Nm	est. Speed (vertical):	- km/h
				Current:	78.58 A		544 mph		0.44 lbf.ft		- mph
				Voltage:	14.33 V	specific Thrust:	2.76 g/W	Climb Capacity:	9659 m	est. rate of climb:	14.6 m/s
				Power:	1126.1 W		0.1 oz/W		31690 ft	(~30...35°)	2882 ft/min

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Motor Partial Load

Propeller	Throttle	Current (DC)	Voltage (DC)	el. Power	Efficiency	Thrust		Spec. Thrust		Pitch Speed		Speed (level)		Motor Run Time
rpm	%	A	V	W	%	g	oz	g/W	oz/W	km/h	mph	km/h	mph	(90%) min
2400	14	0.4	14.8	6.6	51.5	70	2.5	10.6	0.37	27	17	-	-	1936.3
3600	21	1.1	14.8	16.5	69.3	157	5.5	9.5	0.34	41	25	-	-	771.7
4800	28	2.3	14.8	34.5	78.6	279	9.8	8.1	0.29	55	34	-	-	368.7
6000	35	4.3	14.8	63.3	83.6	436	15.4	6.9	0.24	68	42	-	-	200.4
7200	42	7.2	14.8	105.9	86.3	628	22.2	5.9	0.21	82	51	-	-	119.6
8400	49	11.3	14.7	165.1	87.9	855	30.2	5.2	0.18	96	59	-	-	76.5
9600	57	16.7	14.7	244.0	88.8	1116	39.4	4.6	0.16	109	68	-	-	51.6
10800	**65**	**23.8**	**14.7**	**345.5**	**89.3**	**1413**	**49.8**	**4.1**	**0.14**	**123**	**76**	**80**	**49**	**36.3**
12000	**73**	**32.7**	**14.6**	**472.8**	**89.5**	**1744**	**61.5**	**3.7**	**0.13**	**137**	**85**	**127**	**79**	**26.4**
13200	**81**	**43.8**	**14.5**	**629.0**	**89.5**	**2111**	**74.5**	**3.4**	**0.12**	**150**	**93**	**143**	**89**	**19.7**
14400	89	57.2	14.5	817.3	89.5	2512	88.6	3.1	0.11	164	102	156	97	15.1
15600	98	73.5	14.4	1040.9	89.3	2948	104.0	2.8	0.10	177	110	169	105	11.8
15910	100	78.6	14.3	1110.5	88.9	3066	108.2	2.8	0.10	181	112	172	107	11.0

FIGURE 4.45: Detailed results from the propCalc for the LM01Acca3

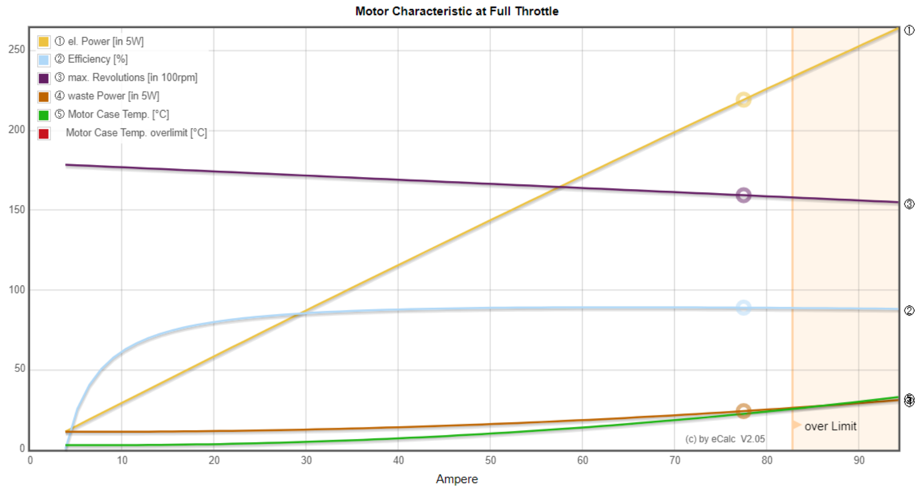

FIGURE 4.46: Motor Characteristics in Full Throttle graph for LM01Acca3

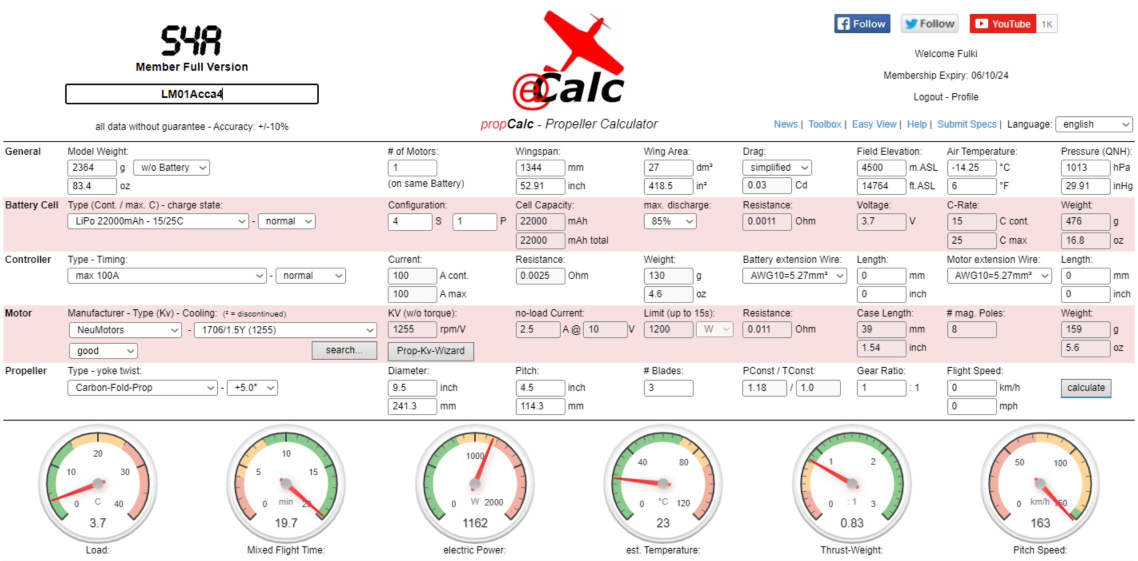

FIGURE 4.47: Propeller Calculation configuration and general results in gauge for LM01Acca4

Remarks:

Battery	
Load:	3.71 C
Voltage:	14.44 V
Rated Voltage:	14.80 V
Energy:	325.6 Wh
Total Capacity:	22000 mAh
Used Capacity:	18700 mAh
min. Flight Time:	13.7 min
Mixed Flight Time:	19.7 min
Weight:	1904 g
	67.2 oz

Motor @ Optimum Efficiency	
Current:	64.50 A
Voltage:	14.35 V
Revolutions*:	16627 rpm
electric Power:	925.9 W
mech. Power:	838.6 W
Efficiency:	90.6 %

Motor @ Maximum	
Current:	81.61 A
Voltage:	14.24 V
Revolutions*:	16258 rpm
electric Power:	1161.9 W
mech. Power:	1049.3 W
Efficiency:	90.3 %
est. Temperature:	23 °C
	73 °F
Wattmeter readings	
Current:	81.61 A
Voltage:	14.44 V
Power:	1178.4 W

Propeller	
Static Thrust:	3561 g
	125.6 oz
Revolutions*:	16258 rpm
Stall Thrust:	- g
	- oz
avail.Thrust @ 0 km/h:	3561 g
avail.Thrust @ 0 mph:	125.6 oz
Pitch Speed:	163 km/h
	101 mph
Tip Speed:	739 km/h
	459 mph
specific Thrust:	3.06 g/W
	0.11 oz/W

Total Drive	
Drive Weight:	2412 g
	85.1 oz
Power-Weight:	283 W/kg
	128 W/lb
Thrust-Weight:	0.83 : 1
Current @ max:	81.61 A
P(in) @ max:	1207.8 W
P(out) @ max:	1049.3 W
Efficiency @ max:	86.9 %
Torque:	0.62 Nm
	0.46 lbf.ft
Climb Capacity:	10551 m
	34616 ft

Airplane	
All-up Weight:	4268 g
	150.5 oz
Wing Load:	158.1 g/dm²
	51.8 oz/ft²
Cubic Wing Load:	30.4
est. Stall Speed:	72 km/h
	45 mph
est. Speed (level):	148 km/h
	92 mph
est. Speed (vertical):	- km/h
	- mph
est. rate of climb:	12.8 m/s
(~35...40°)	2518 ft/min

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Motor Partial Load

Propeller	Throttle	Current (DC)	Voltage (DC)	el. Power	Efficiency	Thrust		Spec. Thrust		Pitch Speed		Speed (level)		Motor Run Time
rpm	%	A	V	W	%	g	oz	g/W	oz/W	km/h	mph	km/h	mph	(85%) min
2400	14	0.5	14.8	7.3	46.0	78	2.7	10.6	0.37	24	15	-	-	2254.8
3600	21	1.2	14.8	17.6	64.8	175	6.2	9.9	0.35	36	22	-	-	940.8
4800	27	2.4	14.8	35.7	75.6	310	10.9	8.7	0.31	48	30	-	-	462.3
6000	34	4.4	14.8	64.5	81.7	485	17.1	7.5	0.27	60	37	-	-	255.5
7200	42	7.3	14.8	106.7	85.3	698	24.6	6.5	0.23	72	45	-	-	154.1
8400	49	11.3	14.8	165.2	87.5	951	33.5	5.8	0.20	84	52	-	-	99.4
9600	56	16.6	14.7	242.9	88.9	1242	43.8	5.1	0.18	96	60	-	-	67.4
10800	64	23.6	14.7	342.7	89.7	1571	55.4	4.6	0.16	108	67	83	52	47.6
12000	71	32.2	14.7	467.6	90.2	1940	68.4	4.1	0.15	120	75	110	68	34.8
13200	**79**	**43.0**	**14.6**	**620.5**	**90.4**	**2347**	**82.8**	**3.8**	**0.13**	**132**	**82**	**121**	**75**	**26.1**
14400	**87**	**56.0**	**14.6**	**804.7**	**90.5**	**2793**	**98.5**	**3.5**	**0.12**	**144**	**90**	**132**	**82**	**20.0**
15600	95	71.6	14.5	1023.1	90.5	3278	115.6	3.2	0.11	156	97	142	88	15.7
16258	100	81.6	14.4	1161.9	90.3	3561	125.6	3.1	0.11	163	101	148	92	13.7

FIGURE 4.48: Detailed results from the propCalc for the LM01Acca4

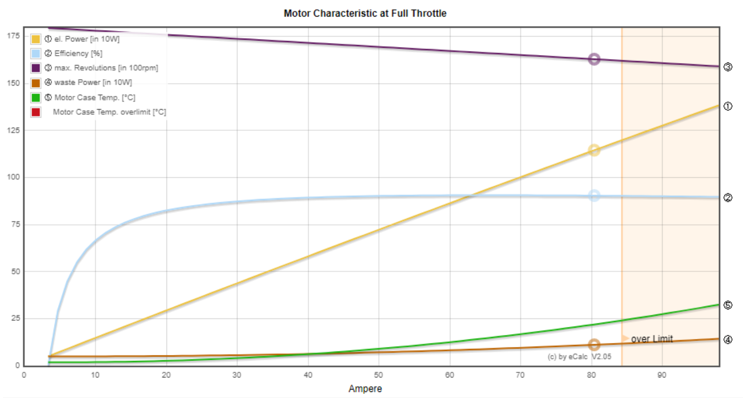

FIGURE 4.49: Motor Characteristics in Full Throttle graph for LM01Acca4

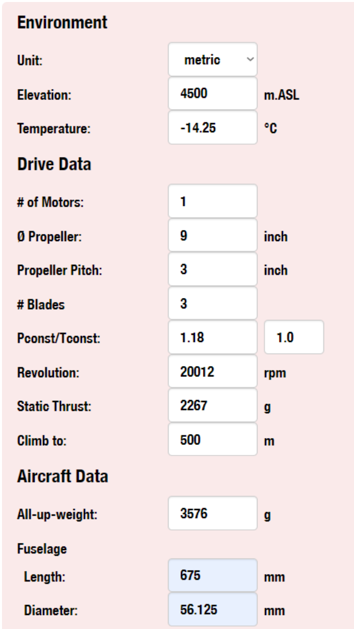

FIGURE 4.50: Propeller Calculation configuration and general results in gauge for LM01Acca2

4.3.3 Performance Calculator - Advanced calculations of Loitering Munitions.

After the Propeller Calculations for the Loitering Munitions, we can continue on the calculations for the advanced performance calculations for our Loitering Munition, which will define the Best Range Speed, Rate of Climb, time to height (at 4500m), and 3D Capability. LM01Acca2 figures ranged from 4.50, 4.51, 4.52, 4.53, while LM01Acca3 covers 4.54, 4.55, 4.56, 4.57, and LM01Acca4 covers 4.58, 4.59, 4.60, and 4.61.

4.3.4 Summary of all Loitering Munition specifications.

In a nutshell, the Loitering Munition does come in three powerplant selections that would hopefully, fit the requirements, with the shortlist as follows:

1. LM01Acca1: Base aircraft without any powerplants attached.
2. LM01Acca2: Used the 14000mAh Battery, 80A ESC, and NeuMotors' 4606MC-1495 electric motor.

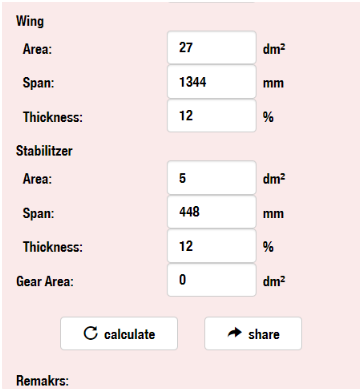

FIGURE 4.51: Propeller Calculation configuration and general results in gauge for LM01Acca2 (Con't)

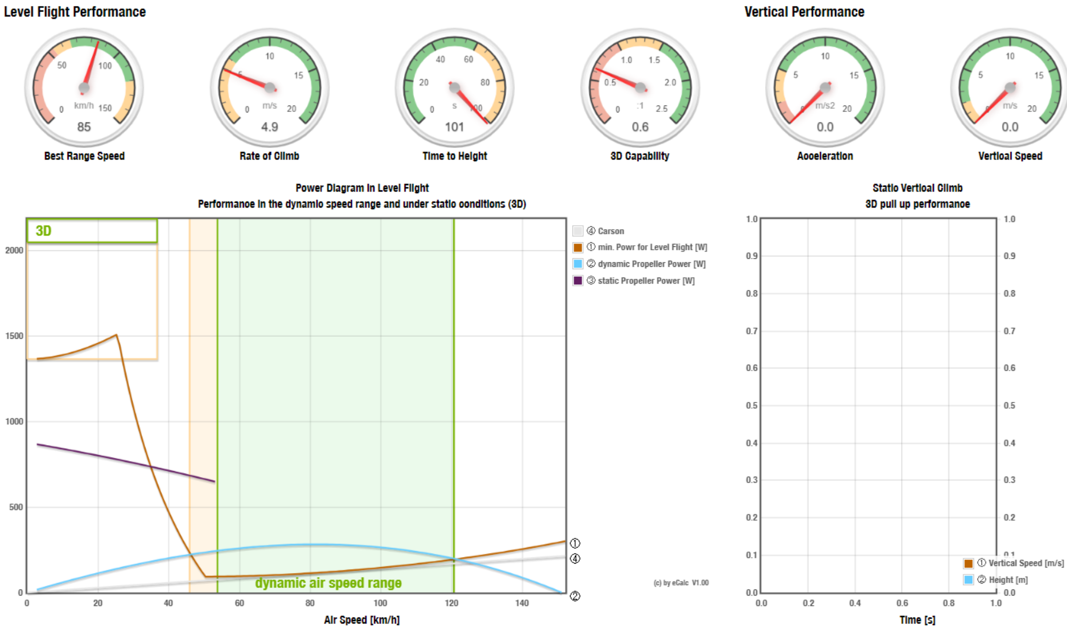

FIGURE 4.52: Propeller Calculation configuration and general results in gauge for LM01Acca2 (Con't)

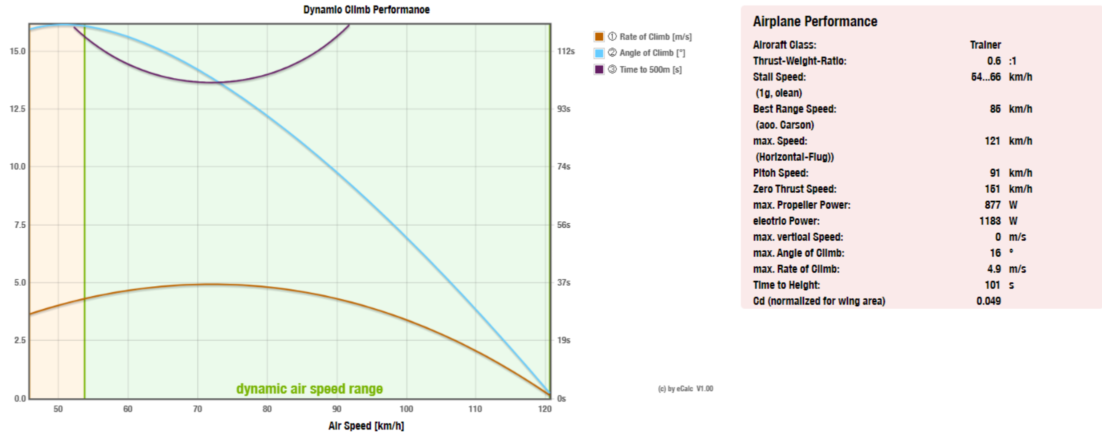

FIGURE 4.53: Propeller Calculation configuration and general results in gauge for LM01Acca2 (Con't)

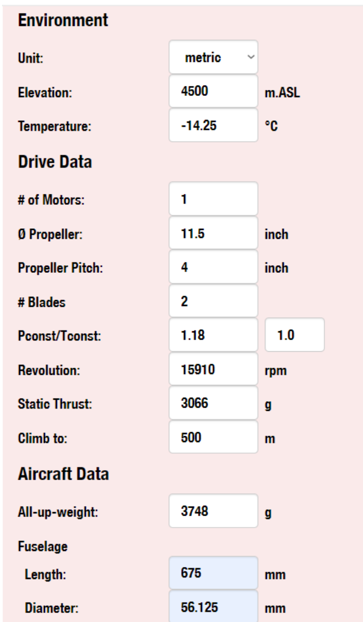

FIGURE 4.54: Propeller Calculation configuration and general results in gauge for LM01Acca3

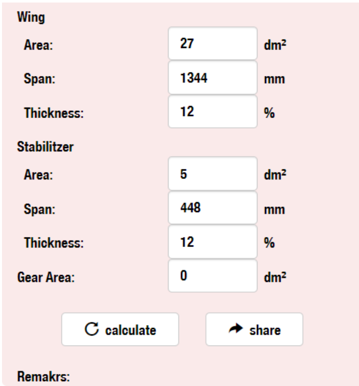

FIGURE 4.55: Propeller Calculation configuration and general results in gauge for LM01Acca3 (Con't)

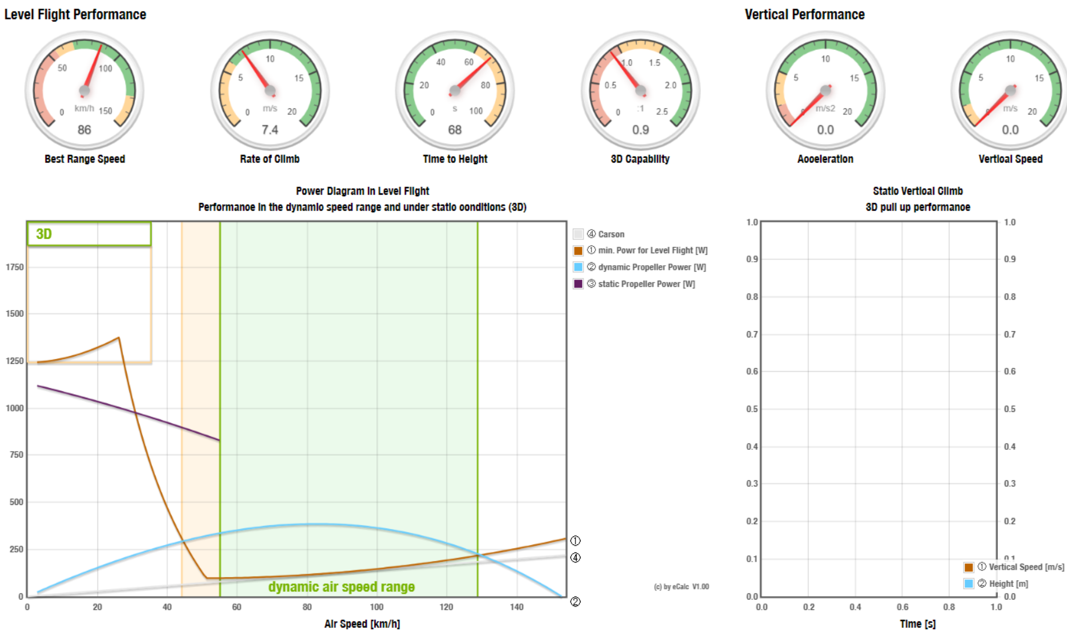

FIGURE 4.56: Propeller Calculation configuration and general results in gauge for LM01Acca3 (Con't)

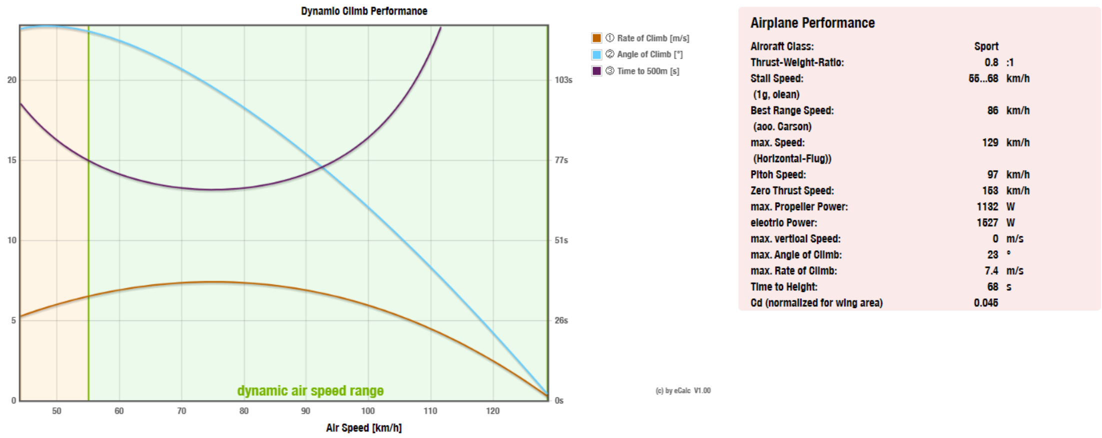

FIGURE 4.57: Propeller Calculation configuration and general results in gauge for LM01Acca3 (Con't)

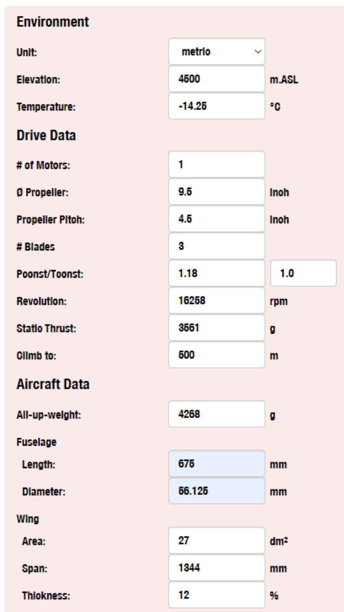

FIGURE 4.58: Propeller Calculation configuration and general results in gauge for LM01Acca4

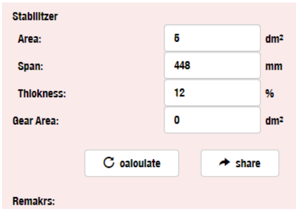

FIGURE 4.59: Propeller Calculation configuration and general results in gauge for LM01Acca4 (Con't)

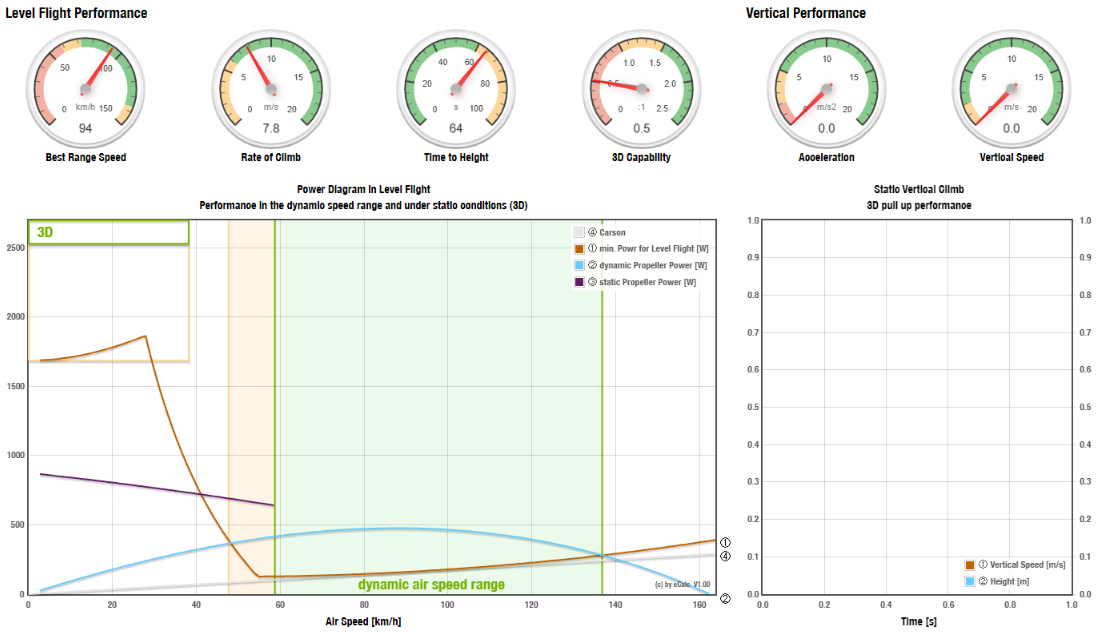

FIGURE 4.60: Propeller Calculation configuration and general results in gauge for LM01Acca4 (Con't)

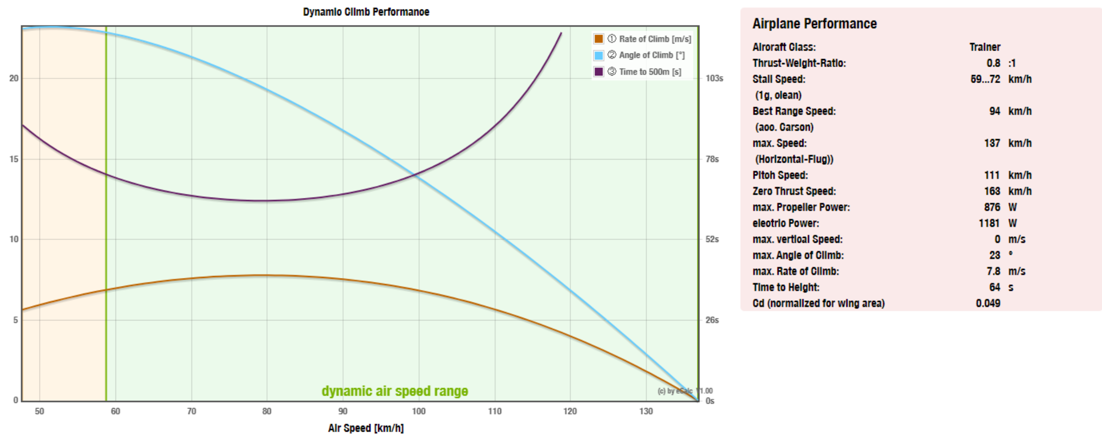

FIGURE 4.61: Propeller Calculation configuration and general results in gauge for LM01Acca4 (Con't)

3. LM01Acca3. Used the 16000mAh Battery, 100A ESC, and SunnySky's X2820-1250 electric motor.
4. LM01Acca4. Used the 22000mAh Battery, 100A ESC, and NeuMotors' 1706/1.5Y electric motor.

After calculating both of propeller and performance of Loitering Munitions in each variation, we can summarize in Table 4.25 the Performance data comparison to the earlier Initial requirements.

TABLE 4.25: Summary of all Loitering Munition Variation performance specifications.

No.	Specifications	Initial Requirements	LM01Acca2	LM01Acca3	LM01Acca4
1	Total Mass (kg)	<5	3.576	3.748	4.268
2	Endurance (mins)	>10	16.3	15.6	19.7
3	Cruising Speed (4500m, knots)	>85	86.401	92.881	79.821

After 3 different variations, the LM01Acca3 which uses a 16000mAh Battery, 100A ESC, and SunnySky's X2850-1250, have balanced results between all 3 variations, which has longer than 5 minutes of initial requirements of Endurance which is 10 minutes. The Cruising Speed exceeded 7 knots which helps the performance status to be better than our initial target of 85 knots. In the meantime, the LM01Acca3's Powerplant to MTOW ratio of 0.262 and thrust-to-weight ratio of 0.82, which shown should be theoretically enough to maintain stability but needs more in-depth analysis of Aircraft stability itself.

4.4 Additional and unmentioned parts of LM-01.

As mentioned in this chapter, there are a few parts that have not mentioned yet in designing the LM-01 due to time constraints, ranging from the Detailed frame for our Fuselage design, Control Surfaces, Modularity, and much more, which we will share in this section. Keep in mind that this will be the focus of advancing the design in case anyone would like to continue this adventurous project.

4.4.1 Detailed Frame for Fuselage and Wings.

If we would define the detailed frame itself, the frame is meant to have the rib-section of our fuselage and wings. That would mean it will have the detailed modules, ribs, and skin for our fuselage while the wings are not just usual skins, but also have the spars (a long stick to connect between the ribs), and the airfoil ribs which shape our wings to desired aerodynamic characteristics. The Frame section of the craft is still not yet determined as we speak in this thesis. But theoretically, the Loitering Munition should have tenths of millimeters of space for our fuselage frame ribs and wings should have a spar and ribs for maintaining the aerodynamics and lowering the structure weight. In the meantime, we have to also consider the structure strength alone of the fuselage and wings to prevent shear, strain stresses, wings breaking off, and much more. For that reason, we would have to estimate it further but would be done in detailed design.

Furthermore, the Loitering Munition's post-self-destruct sequence must ensure that the majority of the front section of the craft is destroyed, to ensure the shrapnel assists the hit of opposing units. That would require additional stress tests to ensure the front section could help destroy the target. This signifies the need for a detailed frame for the fuselage and required stress tests to identify the effectiveness of front-side fuselage shrapnel in extending the damage to said units.

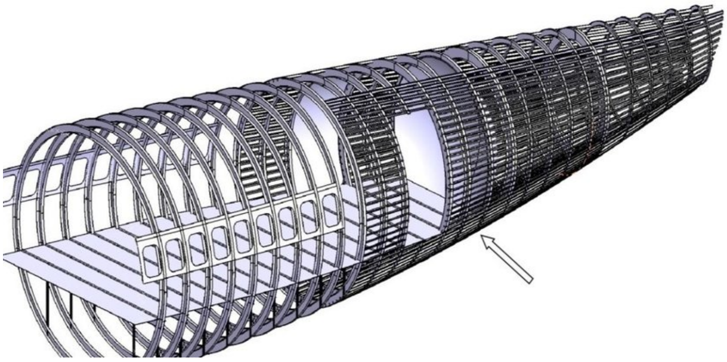

FIGURE 4.62: Example of Aircraft's Fuselage and Empennage Structure

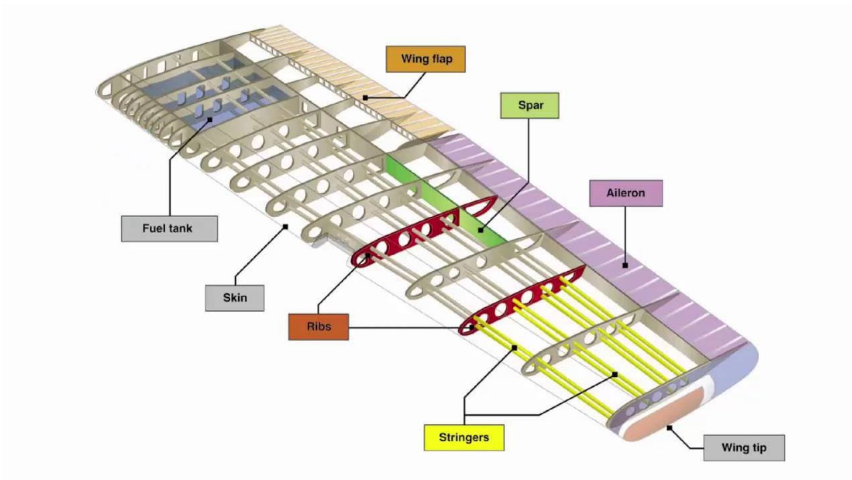

FIGURE 4.63: Detailed review of Wing Frame.

4.4.2 Control Surfaces for Loitering Munition.

The control surfaces, as we know, are the wing parts that would manipulate the aerodynamic characteristics by deflecting the wind direction to ensure the craft capable of reaching the desired angle for rotation axes. From there, we would define that the craft will have the traditional control surface presets (See fig.4.65), which has:

- Flaps, increasing drag and therefore capable of increasing lift and establish lower stall speed for the craft.

FIGURE 4.64: Aerovironment Switchblade 300 after committed self-destruct.

- Elevator, which manipulates the winds to X-Axis, which meant to increase or decrease the pitch angle.
- Aileron, which manipulates the winds to Y-Axis, which is meant to increase or decrease the roll angle.
- Rudder, which manipulates the winds to Z-Axis, which is meant to increase or decrease the yaw angle.

In the meantime, we could use other options in the control surface which lower the quantity of surfaces used. Including the combination of Flap and Aileron which came to the name Flaperon, while the Elevons are elevators and ailerons combined. They may sound better since we could reduce the *Radar Cross-Section* (RCS) in case the craft will turn or pitch up or down at all. There is another option that may destroy the original constraint of cost reduction, which is the Fluidic Flight Control Systems which uses Bleed Air Actuators that redirect aerial flow to augment the pitch, yaw, and roll of an aircraft. Surely, this will help the reduction of *Radar Cross-Section* (RCS) of our LM-01, but considering the development is still in progress and only one unmanned aerial vehicle that being tested to have this system, that would add up the development time and cost.

Therefore, it would be great for now if we select the Flaperon/Elevons (Based from F-1's Control Surface, seen in fig.4.66) for the LM-01, but that would be the subject of the future.

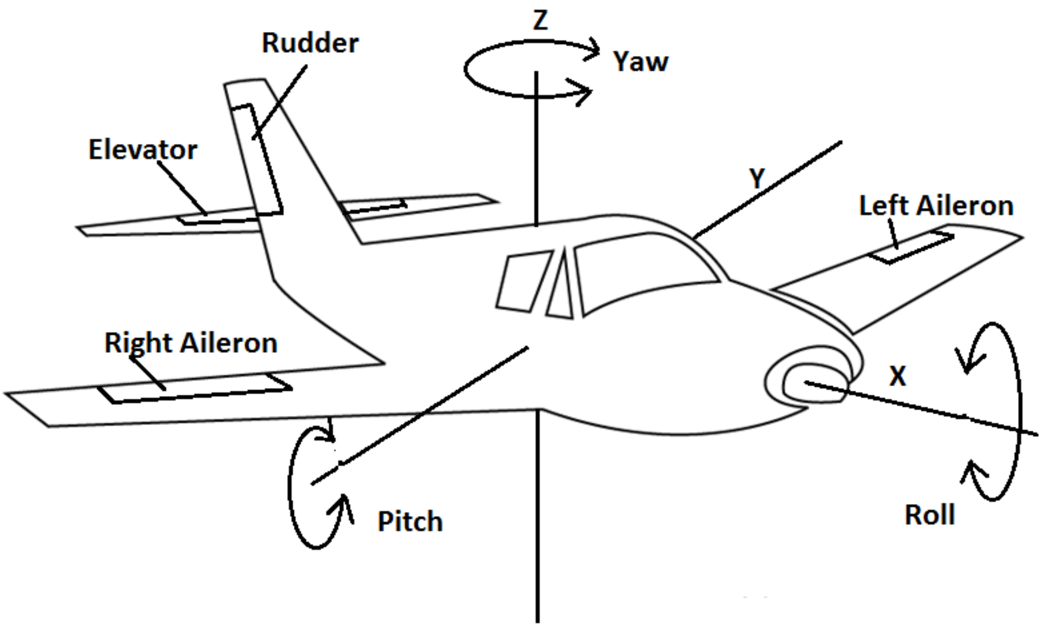

FIGURE 4.65: Conventional Control Surfaces and its angular motions.

In the meantime, there are two major options to direct the craft with control surfaces, either with hydraulic actuation or Fly-By-Wire actuation. The Hydraulic actuation uses hydraulic fluids to move the control surfaces as needed, while the Fly-By-Wire system directs the control surfaces with the electronic signals, which can stabilize the craft despite all the aerodynamic instability as seen in F-16 Fighting Falcons by General Dynamics/Lockheed Martin and Eurofighter Typhoon which will be seen in fig.4.67. Since the Fly-By-Wire system is now the popular option to be used in Unmanned Aerial Vehicle, it would be great to use the latter option for our craft, which hopefully, be able to receive and do the commands in a matter of milliseconds.

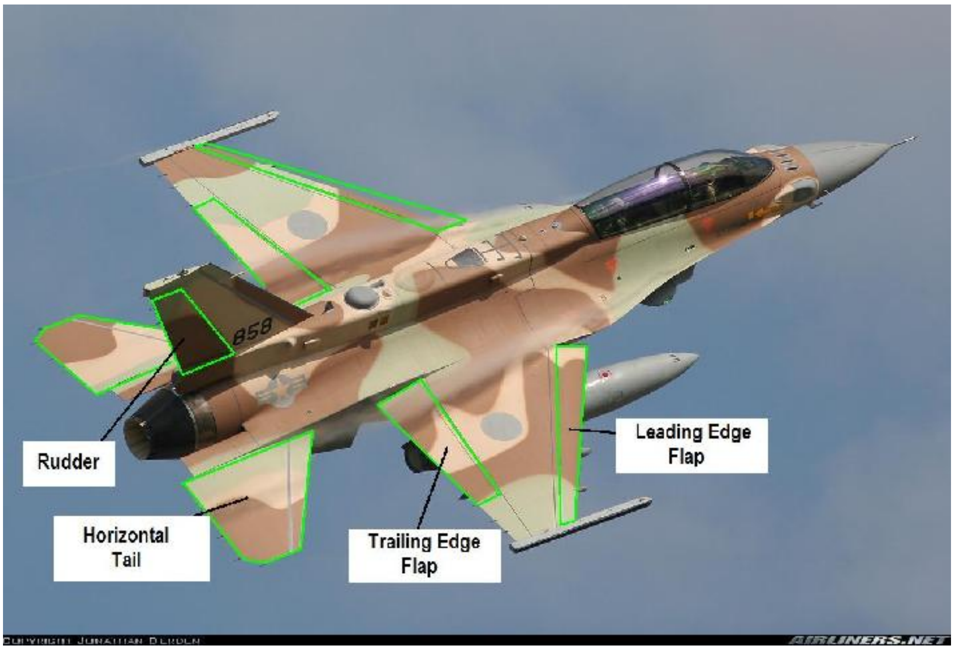

FIGURE 4.66: F-16 Fighting Falcon's Control Surface diagram, includes Flaperons and Elevons/Tailerons

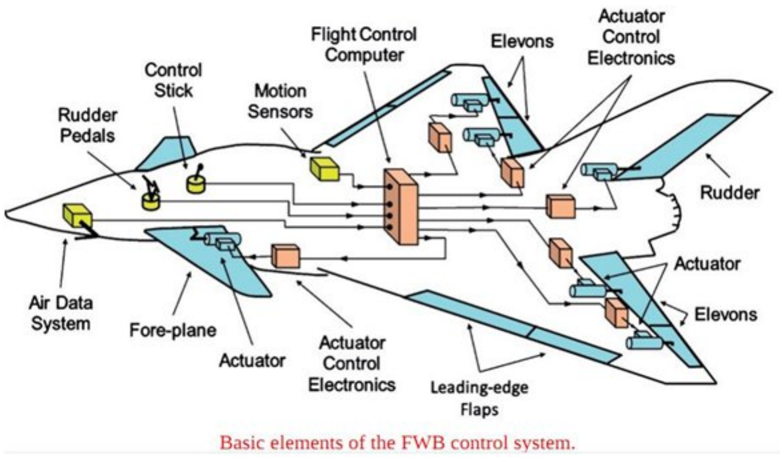

FIGURE 4.67: Fly-By-Wire (FBW) structure, exemplified by Eurofighter Typhoon.

4.4.3 Launching Mechanism of LM-01

In regards to how to launch the Loitering Munition, there are a few options to launch the Loitering Munition which is listed down below:

- Cold or Hot launch, which uses the same mechanism as Missiles but placed in single or multiple canisters, as seen in IAI Harpy and Shahed-136/Geran (Seen in fig.4.68)
- Parent Assisted Launch, defined as the Munition will either drop or launch from associated aircraft or vehicles or even boats, which will utilize the craft to fly within the area of operations easily. (see fig.4.69 for example)
- Gas Assisted Launch, which uses the pressurized gas within the specified tube or rail to catapult the craft, as seen in AeroVironment Switchblade for tube use (seen in fig.4.70) and DAHANA Rajata for Rail use Gas Assisted Launch (Seen in fig.4.71)
- Manual Launch, defined by simply throwing the craft to the skies, As seen in SYPAQ CORVO Loitering Munition.

For some options that include the Cold or Hot launch and Parent Assisted launch may require additional resources and increased operating costs, since our target is that the craft can be launched by infantry. That would narrow the launching mechanism into the last two mentioned in the list, which is the Gas Assisted Launch and Manual Launch. Again, due to limited time constraints we had to assume that these two would be tested in the future.

4.4.4 Target Identification and Guidance for LM-01.

The Target Identification and Guidance systems are essential to know which one is a friendly or hostile craft used by the said infantries. That being said, there are a few components that have already added to the list that could be used to determine the unit affiliation and its surroundings which are listed here:

- Camera, the drone's eyes
- Global Positioning System (GPS), basically the locator of loitering munition's position.
- Radio Telemetry, transmitting and receiving the unit commands and potentially transmit the data to other units in data-link form
- Flight Control System (FCS), Basically the brain of the craft which can be coded to have logic and guidance system required for the mission.

FIGURE 4.68: Cold or Hot Canister launch, shown by IAI Harpy launching.

FIGURE 4.69: Iranian Loitering Munition attached to a helicopter, refering to Parent Assisted Launch mechanism.

FIGURE 4.70: AeroVironment Switchblade 300 launched in gas pressurized tube.

FIGURE 4.71: Dahana RAJATA with the gas pressurized rails.

There are a few guidance systems that would help the loitering munitions effectiveness in succeeding in the mission. Some may taken from various examples since the benchmarked loitering munitions still disclosed their guidance systems.

- Pre-Planning, In other words, we can target the opposing unit first before

launching the craft or planning the routes to conduct the reconnaissance missions or assessing the damage before proceeding to target.
- Manual guidance, This would mean launching the craft without any plans and proceed to manually control the craft.

From there, we have two large options in regards to guide the craft since it is unmanned and only able to fly with peripherals outside of the craft, which shown in this list:

- Using the manual controller with a smartphone as its display for the Camera and OSD transmission
- Using the proprietary tablet or specialized application that could be used in a tablet or smartphone to connect and control the specific craft.

4.4.5 The Potential Operators of LM-01.

For the Operators of LM-01, we would consider multiple operators and would be glad to have this in their arsenal, which includes:

- Army (Seen in fig.4.72), since this is the main user of the Loitering Munition, regularly conducts reconnaissance and Close Air Support by destroying Infantries, Vehicles, and Installations.
- Special Forces (Seen in fig.4.73), which could use the Loitering Munition to potentially destroy special installations or even conduct the assassination of High-Value Targets (HVT).
- Navy (Seen in fig.4.74), which could be used by a certain boat that could destroy nearby hostile sea targets, but with a constraint that once it lands, it would be almost impossible to recover.

FIGURE 4.72: The Indonesian Army in platoon formation.

FIGURE 4.73: The Indonesian Special Forces (Kopassus) in parade formation.

FIGURE 4.74: Indonesian navy crews in parade with their ships.

CHAPTER 5
SUMMARY, CONCLUSION, RECOMMENDATION

5.1 Summary

Based on these results, we can now post the results of our efforts in Designing the Loitering Munition, with the full specifications, Three-View Drawing, and its finalized body design in Table 5.1, Figures 5.1 and 5.2.

TABLE 5.1: Final Specification of LM-01 "Raven"

	Specifications		Sub-Specifications
1	Dimensions (mm)	Length	766.88
		Width	1,341.11
		Height	220.17
2	Materials	Aircraft	High-Impact ABS Plastic
		Propeller	Carbon Fiber
3	Propulsion	Propeller	Carbon Foldable-Prop (+7.0deg, 11.5 cm × 4 cm, 2 Blades)
		ESC (A)	100
		Battery ($\mathrm{MA\,h}$)	16000
		Motor	SunnySky X2820-1250 V3
4	Component Weight (kg)	Aircraft Structure	0.75
		Avionics	0.2075
		Propeller	0.62
		Payload	0.239
		MTOW	2.364
		Powerplant to MTOW Ratio	0.262
5	Aerodynamics	Wingspan (Main Wing) (mm)	1,341.11
		Wingspan (Horizontal Stab.) (mm)	550
		Wingspan (Vertical Stab.) (mm)	169.77
		Wing Area (m^2)	0.270
		Aspect Ratio	6.699
		Airfoil (Main Wing)	NACA 23012
		Airfoil (Horizontal Stab.)	NACA 0009
		Airfoil (Vertical Stab.)	NACA 0009
6	Performance	Endurance (min)	15.6
		Range (Approx. km)	10
		Ceiling (m)	4500
		Thrust to Weight Ratio	0.82

As for the name of the Loitering Munition, after a few days of considering the names of this Loitering Munition, we decided to call the craft, LM-01 "Raven". Of course, this Loitering Munition is not yet completed due to a lack of control

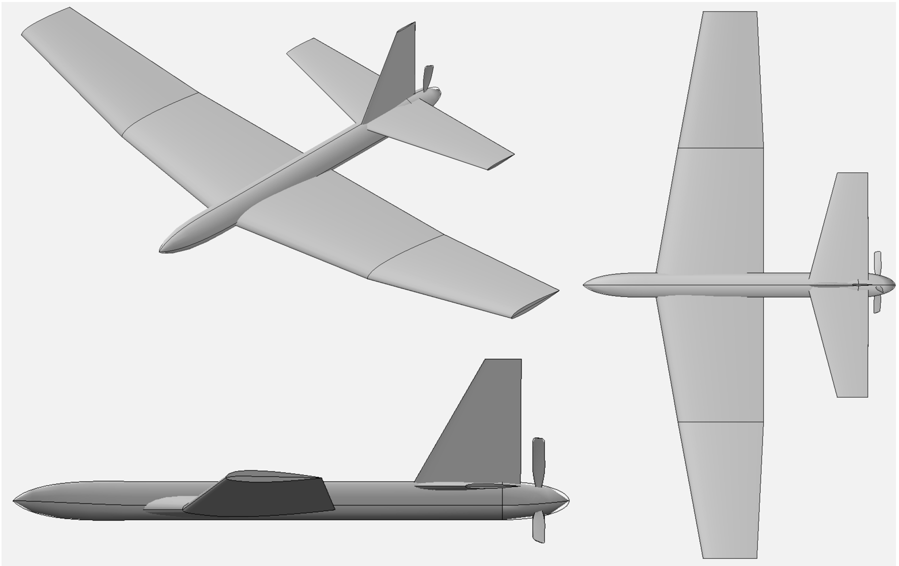

FIGURE 5.1: Final Result of LM-01 "Raven" design in OpenVSP.

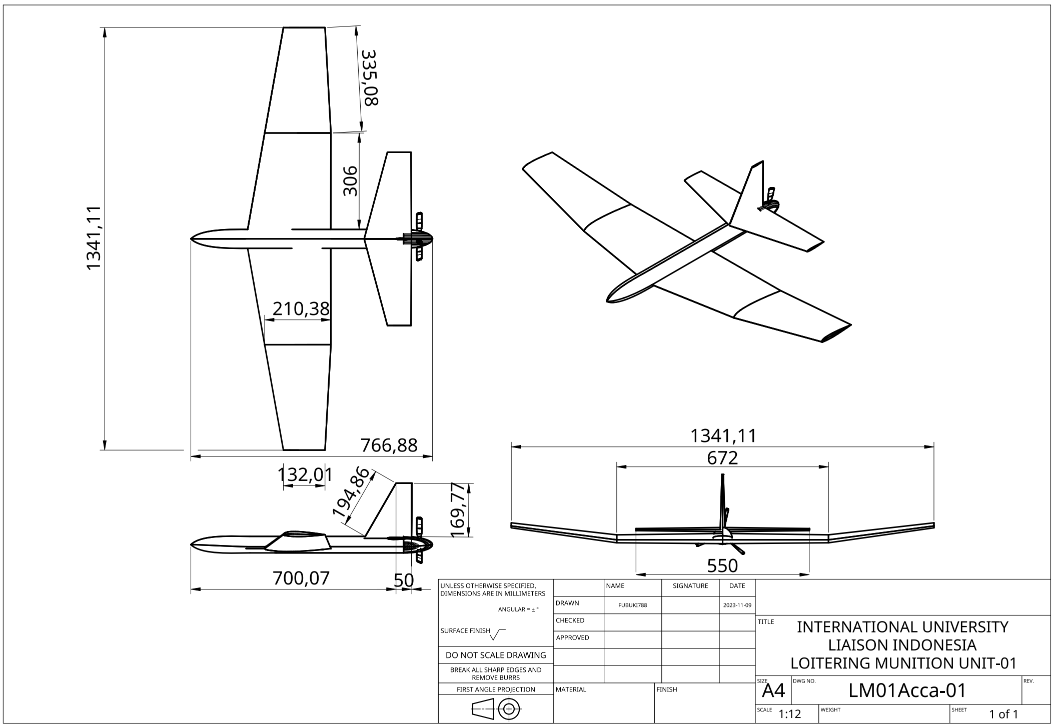

FIGURE 5.2: Final Result of LM-01 "Raven" design in Three-View Drawing form.

surfaces. Still, we can tell that this Loitering Munition fits what we envisioned so far as being the Low-Cost and Tactical craft, accomplishing our original target.

5.2 Conclusions

In a nutshell, this is the list of LM-01's conclusion:

- A conceptual design of a fixed-wing loitering munition for tactical purposes has been completed and complied with the initial requirements.
- The conceptual design is estimated to have $3.8\,\mathrm{kg}$ of total mass, endurance of about 15 minutes with a cruising speed of 92.9 knots, and Range of approximately $10\,\mathrm{km}$ — details are given in the previous table.
- The design was shown to be statically and dynamically stable.
- The design is not fully finished yet, since it lacks control surfaces, detailed aircraft frame as part of the detailed design.

We hope that we or someone Interested in advancing this design will bring the fruition of what we have started in this program.

5.3 Recommendations

We would like to press on some things to those interested, including us who built the "Raven" itself. The list of recommendations includes:

- Continuing the Loitering Munition Design to the Detailed Design, including the addition of Control Surface and re-evaluation of flight performance simulations using standard mathematical tools in flight mechanics for our Loitering Munition. Hopefully, this loitering munition will be able to reach prototyping and could show the world, that we are here not just for show.
- Explore the manufacturing methods and alternative materials which allow lower cost and easier production. This will not only help with this project, but also useful when developing newer Unmanned Aerial Systems (UAS) or even new aircraft designs.
- Pitching the Idea of this design to the local Design Bureau to realize this craft, to maximize the efforts of creating the indigenous craft.

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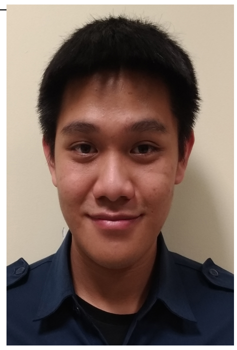

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