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UAV- Mini-Piquero MK3 of double boom and H-Tale design

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**HOJA DE CALIFICACIÓN
DE TRABAJO DE FIN DE CARRERA**

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Quito, 21 de diciembre de 2021

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RESUMEN

El proyecto tiene como fin el rediseño y construcción de un Vehículo Aéreo no tripulado (UAV) para incorporarlo a operaciones de monitoreo de pesca ilegal y fauna marina en las Islas Galápagos. Para esto se pretende redimensionar las alas, el tren de aterrizaje, el fuselaje e incorporar una cola en H de acuerdo a la teoria de aeromodelismo. Los resultados obtenidos son verificados de acuerdo con las dimensiones establecidas en un diseño CAD. En el proceso de verificación no se presenta mayor disimilitud entre las medidas esperadas y obtenidas después de la construcción del UAV. Se logra la modificación del fuselaje, una cola en H, alas acortadas, un tren de aterrizaje redimensionado y peso esperado de 2.8 kg. La modificación de los parámetros mencionados anteriormente deriva en la mejora de la eficiencia, estabilidad de vuelo, despegue y aterrizaje del UAV. Sin embargo, durante el proceso de manufactura se encontraron diversos obstáculos devido a la inexperiencia en la cosntrucción de aeronaves. Estos no permitieron que el prototipo del UAV presente de manera exacta las características teóricas consideradas y que este pierda control luego de su despegue en la prueba de vuelo. Finalmente, se presenta una discusion y recomendaciones para mejorar la efectividad y eficiencia de futuras iteraciones.

Palabras clave: Vehiculo Aereo no Tripulado (UAV), cola en H, aerodinámica, aeromodelismo, optimización , drone, vigilancia, doble boom, prueba de vuelo

ABSTRACT

The project aims to redesign and build an Unmanned Aerial Vehicle (UAV) to incorporate it into illegal fishing and marine fauna monitoring operations in the Galapagos Islands. For this, it is intended to resize the wings, the landing gear, the fuselage and incorporate an H-tail according to the theory of model aircraft. The results obtained are verified according to the dimensions established in a CAD design. In the verification process, there is no greater dissimilarity between the measures expected and obtained after the construction of the UAV. The modification of the fuselage, an H-tail, shortened wings, a resized landing gear and expected weight is achieved. The modification of the parameters results in the improvement of the efficiency, flight stability, take-off and landing of the UAV. However, during the manufacturing process various obstacles were encountered due to inexperience in aircraft construction. These did not allow the UAV prototype to present exactly the theoretical characteristics considered and for it to lose control after its take-off in the flight test. Finally, a discussion and recommendations are presented to improve the effectiveness and efficiency of future iterations.

Keywords: Unmanned Aerial Vehicle (UAV), H-tail, aerodynamics, aeromodelling, optimization, drone, surveillance, double boom, flight testing

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INTRODUCTION

One of the most important technological advances in the last decades are the unmanned aircraft vehicles or UAVs. These vehicles were designed to be remotely controlled and they offer high mobility in three-dimensional space, great flexibility, and high adaptability. Due to the above, this technology has unlimited possible applications and has provided attractive solutions in civil, industrial, security, aerial inspection, among others. With an increasing demand for these types of vehicles, their technology has been perfecting and optimizing to offer the desired work specifications. There is a wide variety of UAVs with different shapes, sizes, controllability, and working specifications. For this reason, it is important to acknowledge the last advances developed on the UAVs.

There are a lot of studies related to the UAV electric powered performance, these are based on fixed-weight plane model because the battery's weight remains constant during discharging. The study states that it is possible to extend the electric powered UAV´s endurance by dumping exhausted batteries out of the UAV in flight. The results show that a higher battery dumping ratio results in improving endurance of the aircraft, however, there must be a low weight batteries ratio in the aircraft, and it must be divided into even packs. There is an increase of 17% endurance of the UAV compared to a traditional fixed-weight energy optimization method (Chang & Yu, 2015).

Problem Statement and Project Specification

Before stating the project's objective and scope, it is important to mention the problem that it is intended to solve. Illegal fishing has become one of the biggest problems around the Galapagos Islands area since it has one of the most diverse sea life in the world. In this way, Ecuador has proposed several solutions with the aim of reducing illegal fishing, among these is the development of UAVs that allow monitoring and recognizing the focus where this problem occurs. UAVs are helpful because human integrity is not compromised and is one of the best alternatives to monitor this problem (Wu, 2021). Therefore, several projects of mechanical engineering students from USFQ have been carried out with the purpose of designing and building an optimal UAV that serves as a reliable surveillance and tracking device in the coastal areas of the Galápagos Islands. Hence, the project might be implemented by a public or private organization whose interests are aimed to the preservation of Galápagos Islands and its fauna.

The first developed project stated that the Galápagos UAV project would be carried out by different generations of USFQ students until a final design without flaws is achieved (López, 2012). For instance, on this first approach the author based his studies on the design production process and present fundamental characteristics of the UAV such as its dimensions, preliminary aerodynamic specifications, the first selection of manufacture procedures and materials and finally the first physical protype of the UAV. The subsequent projects focused on improving this first prototype with performance studies, weight reduction methods, structural optimization and tail and airfoil changes. Likewise, a second project was designed and manufactured a scaled version prototype, called Mini-Piquero (MP), with the purpose of optimizing the performance of the UAV and resources used. Even though this design successfully achieved a 13-minute time flight, it presented several complications and crashed before landing (Ñacata, 2018).

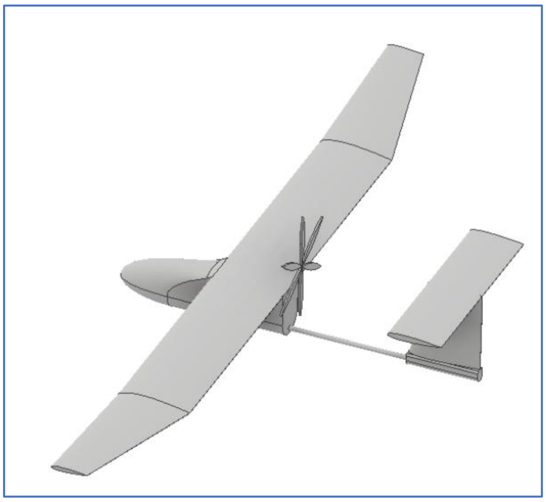


Figure 1 Mini Piquero Galápagos UAV (Ñacata, 2018)

For this reason, the project's main objective is to optimize and improve the MP by redesigning it. Ñacata explains that the possible causes of the accident include an incorrect balancing procedure of the UAV, poor bonding of parts by gluing, and a flawed angle of incidence for the motor (Ñacata, 2018). Therefore, it was stated that the landing gear needed modifications because it caused an instable take-off due to its dimensions.

The redesign of the MP, called throughout this paper Mini Piquero MK3 (MP-MK3), will tackle solely the components that will improve the functioning of the vehicle. As for the engine, it is expected that if positioned correctly at the center back part of the fuselage, it will provide enough push for a successful flight; a redesign of the tail to a boom-mounted type could provide an improved maneuverability according to the literature; an evaluation of the wing and boom dimensions will be performed to determine their efficiency; and finally, a larger landing gear is expected to bring stability at the take-off. Performing these modifications, the new MP will have an ideal maneuverability, stability, and flight. Figure 2 shows the proposed model MP-MK3.

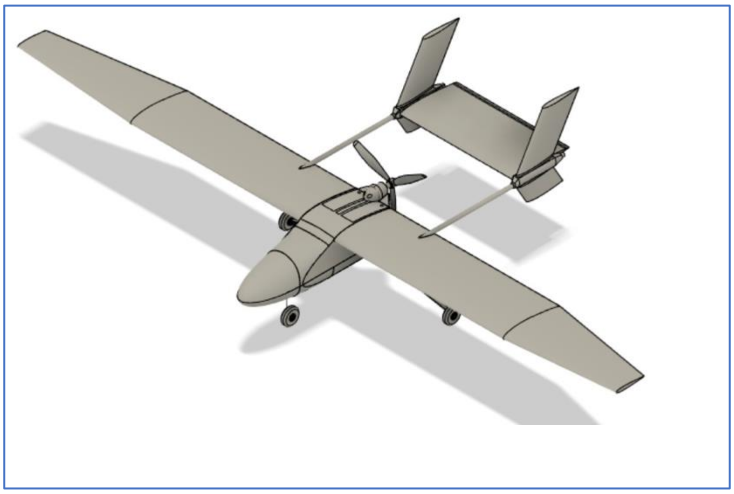


Figure 2 Mini Piquero MK3 3D Sketch

Finally, the flight plan is showcased in figure 3. There are five main steps on this plan with sub steps on each of them as shown in the following scheme:

1. Takeoff
    a. Systems initiation
    b. Moving on the floor
    c. Acceleration
2. Ascent
    a. Maneuver
3. Flight cruise
    a. Flight stability
4. Descent
    a. Deceleration
    b. Maneuver
5. Landing
    a. Deceleration and complete stop
    b. Systems turn off

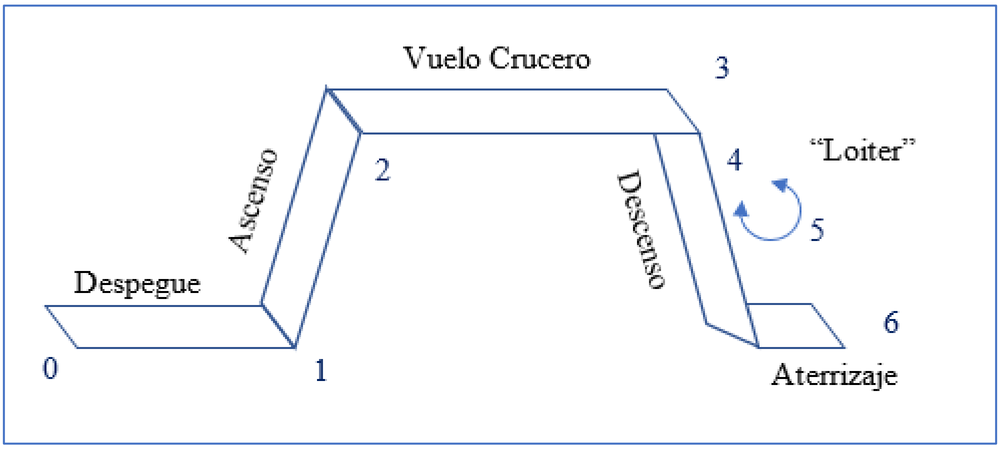


Figure 3 Flight plan

Objectives

- Redesign and construction of an unmanned aircraft vehicle: Mini-Piquero MK3 for surveillance purposes.
- Redesign and construction of the wings of the Mini-Piquero MK3 in order to improve stability and ease of handling during the flight phase.
- Redesign and construction of the landing gear that improves takeoff and landing efficiency, and the thrust required to lift the Mini-Piquero MK3.
- Redesign and construction of a new tail configuration to improve stability, resistance, and flight durability.
- Design and manufacture of 3D removable components in the fuselage in order to provide accessibility to the internal components of the UAV and to modify the center of gravity and the center of pressure of the Mini-Piquero MK3.

Design concepts and selections

In the design process of the Mini Piquero MK3, the influence of subsystems whose components are considered critical at the time of performing the aircraft's flight activities is considered.

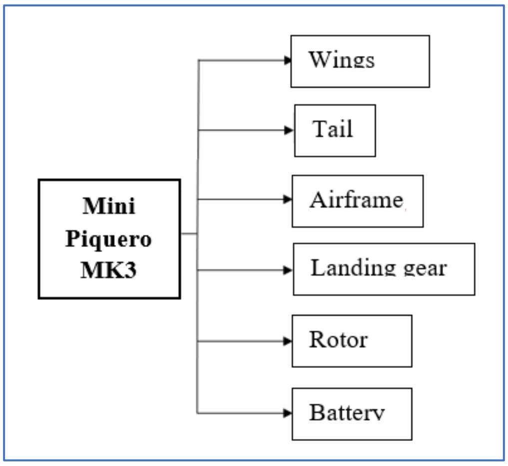


Figure 4 Critical subsystems for the UAV Mini Piquero MK3

Alternative solutions

Airfoils are the main structure of the wings and tail of airplanes. They provide the mentioned components with their representative shapes and in fact allow the plane to fly. Raymer states that the airfoil is the heart of an airplane in many aspects of its functioning. The design of the airfoil affects the cruise speed, takeoff distance, landing distance, stall speed, handling qualities, and aerodynamic efficiency throughout the whole flight (Raymer, 2004). Therefore, it is important to determine an ideal shape and configuration of the airfoil. Furthermore, previous works of the Piquero have not studied different alternatives for the airfoil and have used the same airfoil design. The following section will analyze five different airfoil profiles to determine an optimal one.

The five profiles selected for analysis are: NACA2412, NACA0012, NACA4512, SD7062, and Eppler 562. It is important to mention that the previous works of the Piquero utilized the NACA2412 for the UAVs' wings and the NACA0012 for the tail. Each of the profiles shape are shown in the following figures.

Figure 5 NACA 2412 airfoil profile (Airfoil Tools, 2021)

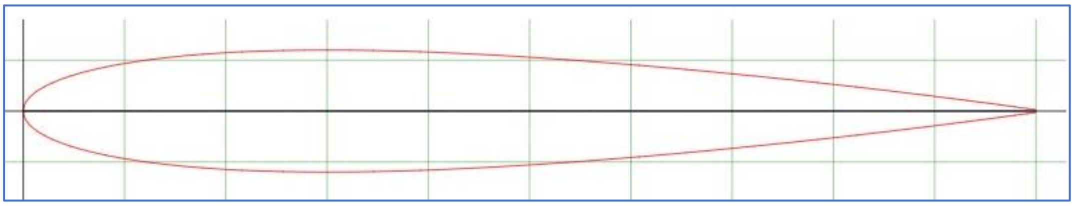


Figure 6 NACA 0012 airfoil profile (Airfoil Tools, 2021)

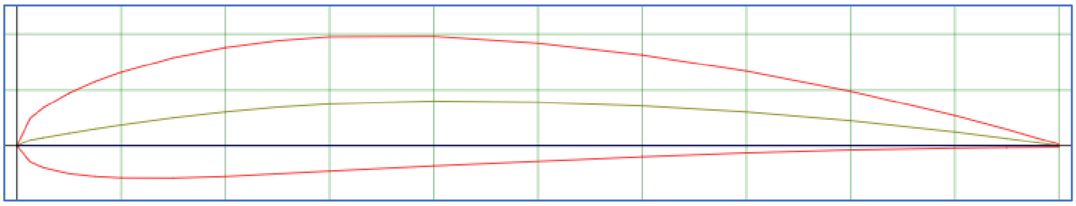


Figure 7 NACA 4512 airfoil profile (Airfoil Tools, 2021)

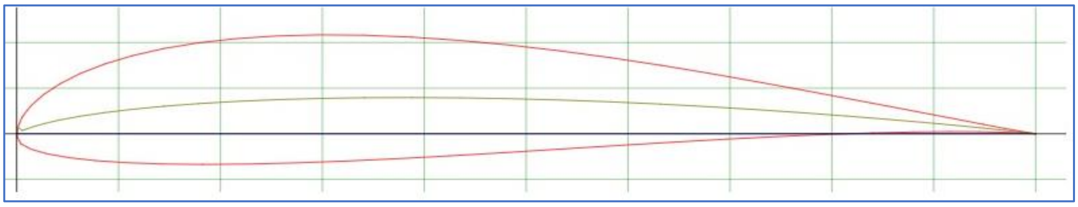


Figure 8 SD7062 airfoil profile (Airfoil Tools , 2021)

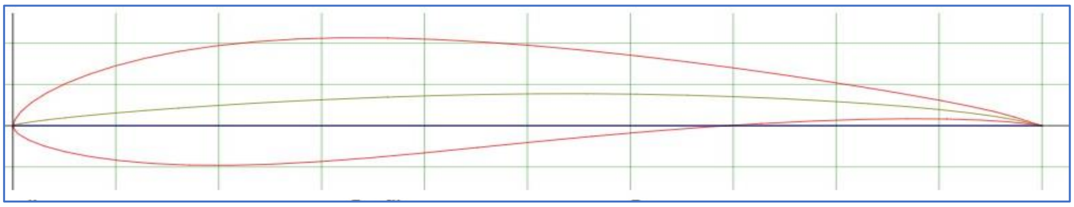


Figure 9 Eppler 562 airfoil profile (Airfoil Tools , 2021)

To determine the most suitable airfoil for the Piquero, ten different traits of each airfoil design will be evaluated. These are: angle of attack (AOA) when the lift coefficient (Cl) equals 0, maximum Cl, AOA of max Cl, Cl with neutral AOA (Clo), stall characteristics, minimum drag coefficient (Cd), Cl of minimum Cd, Cl to Cd ratio, drag bucket section, and construction complexity. Aerodynamic plots of the airfoils were developed with the aid of the software XFLR5 to determine the values of the traits. Succeeding, an explanation of each of the traits will be presented, as well as a matrix with the score earned by each airfoil.

- AOA when Cl equals 0: airfoils stop to produce lift (Cl=0) at a specific AOA; these AOA are usually negative. The larger magnitude of this AOA, the larger angle-range the airfoil will have to produce lift.
- Maximum Cl: a larger value of lift coefficient provides with a larger lift force. This yields the opportunity to carry more weight on the UAV.
- Cl with neutral AOA: a larger Cl with a neutral AOA suggests that the airfoil will provide a larger lift force at cruise flight.
- Stall characteristics: this trait describes the rate at which Cl begins to decrease after the AOA reaches a certain value. This trait is usually described qualitatively since the decreasing rate is irregular.
- Minimum Cd: a smaller Cd will yield a smaller drag force, which is sought in UAVs.
- Cl/Cd ratio: a larger Cl/Cd ratio explains that there will be a large lift force when compared to the drag force.
- Drag bucket section: the Cl vs Cd plot showcases a section where the air flow is majorly laminar. the larger this section is, the larger opportunity the UAV will have to fly in a laminar flow.
- Construction complexity: the wing-ribs will be produced by laser cutting. The simpler the airfoil, design the more likely the ribs will

In order to determine the characteristics of the airfoils, the Reynolds number needs to be calculated through the parameters found in the following table.

Table 1 Reynolds Number Calculation

Reynolds Number Calculation		
Height	2800	[m]
ρ	0.928	[kg/m3]
µ	1.720E-05	[N*s/m2]
V∞	13.4	[m/s]
AR	12	
Span	2.07	[m]
Chord	0.2	[m]
Speed of sound	335.65	
Mac	0.04	
Re	144610.233	
Re_cruise	150000	

The following table summarizes the scores obtained when comparing all the profiles with the mentioned categories. The highest score will yield the optimal profile for the application.

Table 2 Airfoil design selection

Parameter	Airfoil 1	Airfoil 2	Airfoil 3	Airfoil 4	Airfoil 5	Score				
Name	NACA2412	NACA 0012	NACA 4512	SD7062	Eppler 562					
Reynolds at Cruise	150000	150000	150000	150000	150000	-	-	-	-	-
AOA for Cl=0	-2	0	-3.8	-4.8	-4				1	
Clmax (highest is best)	1.27	1.02	1.42	1.59	1.58				1	
AOA of Clmax (highest is best)	12.5	11	14	13.9	11.8			1		
Clo	0.37	0	0.48	0.4	0.58					1
*Stall characteristics (A, B, C)**	B	C	B	C	A					1
Cdmin (lowest is best)	0.017	0.0125	0.018	0.02	0.023		1			
Cl of Cdmin (close to cruise is best)	0	-0.39	0.6	0.67	0.63				1	
(Cl/Cd) max (highest is best)	60	44	75	58	62			1		
Drag bucket starts at Cd	0.017	0.013	0.027	0.019	0.02	-	-	-	-	-
Drag bucket ends at Cd	0.025	0.017	0.029	0.026	0.025	1				
Construction (A, B, C)° (worth 2)	A	A	B	B	C	2	2			
**A=gentle, B, C=abrupt °A=simple, B, C=complex*	Sum:					3	3	2	3	2

The three profiles with the highest score are the NACA2412, the NACA0012, and the SD7062. Since the NACA2412 and the NACA0012 were previously manufactured, they earned the best score in the construction section. For that same reason, the present UAV will have the NACA2412 as the airfoil profile for the wings and the NACA0012 for the tail as symmetric airfoils are commonly chose for these components (Flores, 2006). Nevertheless, for future works an evaluation on the manufacturing of the SD7062 profile is proposed, since it offers several advantages on other categories.

Project Management

A Gantt chart is used to efficiently organize the activities to be performed throughout the project. This tool contributes to the planning of activities in a project. The elements that comprise it provide an overview of the project and facilitate its follow-up by means of date ranges where the activities to be carried out are distributed (UNADE, 2021). The following is the schedule of activities developed throughout the project of Redesign and Construction of an Unmanned Aircraft Vehicle (UAV) Mini Piquero MK3:

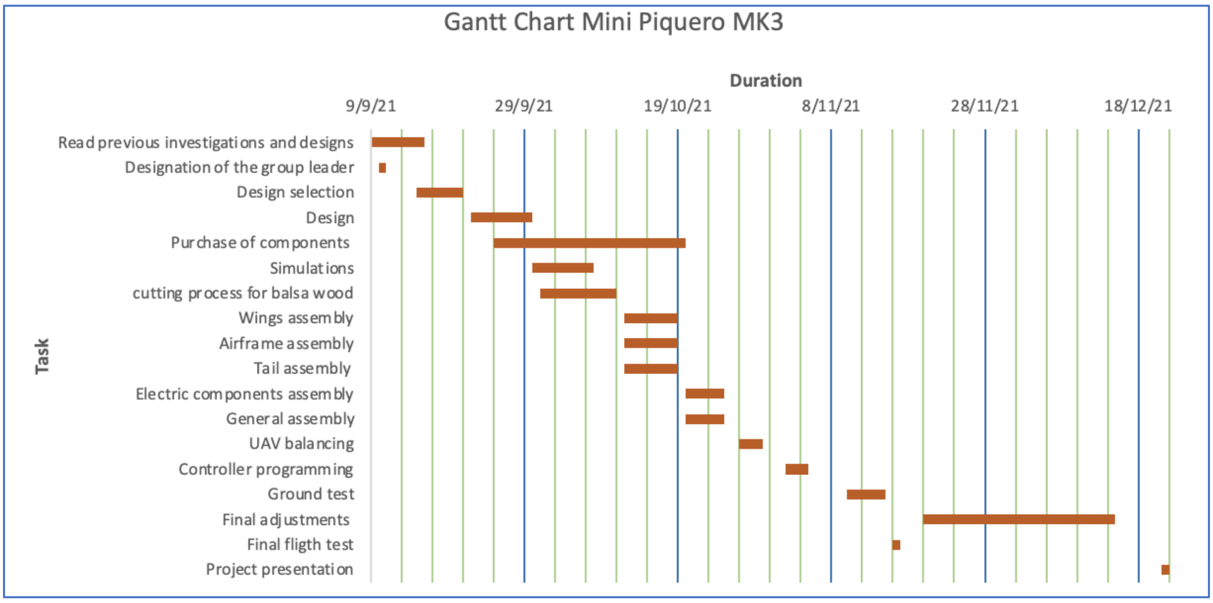


Figure 10 Gantt chart for the redesign and construction of the UAV Mini Piquero MK3

The figure shows the activities to be developed, from an investigation of previous thesis related to the construction of the aircraft to the final stage of presentation of the work. The orange bars represent the range of time available for the completion of the activities, start date and completion date. However, there were situations that have delayed the progress of certain project activities; electronic components had to be repaired and replaced. Similarly, activities related to simulation did not take place due to complex geometry factors present in the CAD designs.

Budget

The University had destined to this project a budget of $300 for the construction of the UAV. However, at the end of the project a cost statement was made, and it was concluded that $400 was used. Some of the most influential factors in arriving at this value were the unexperienced workers in the construction process and the high cost of materials. For this reason, it was decided that the members of the group should contribute financially to complete the project. It is considered that, with experienced workers and availability of the necessary materials, the $400 is enough to build the aircraft.

Two standards are selected to scientifically support the design, construction, and testing procedures of an Unmanned Aerial Vehicle. The first one explains the parameters to be met in the design and construction process of a UAV. The second discusses the safety standards to be met prior to the flight of the aircraft. Each standard and how they have been applied to the project is discussed below:

ASTM F2910-14

This standard specifies the requirements to be met in the design and construction process of an Unmanned Aerial Vehicle. The UAV must be designed and built to be used in a safe place when the aircraft is turned on. The construction took place in the materials laboratory of the University, when the aircraft was turned on, a firm hold was provided to avoid unnecessary movements. It is also specified that the aircraft must be designed and constructed in such a way as to minimize the risk of explosion, chemical hazard, fire, flammable liquids or gases, materials, or a combination of these. The Mini Piquero MK3 is an all-electric aircraft, thus avoiding the use of fuels that produce a fire, explosion or represent a chemical risk.

On the other hand, it is also specified that, during the manufacturing process, the manufacturer must determine the weight range of the aircraft and the location range of its center of gravity. The predominant material in the aircraft is balsa and aluminum, this contributes to obtaining a weight 2.8 kg including electronic components. The center of gravity of the Mini Piquero MK3 was identified with respect to its nose and the moment produced by each of the components with significant weight, the center of gravity was identified at 0.41m from the nose of the vehicle.

This leads to the satisfactory fulfillment of another important parameter: making sure that the center of gravity remains within the allowed range when this aircraft already has all its electronic components and other items. The center of gravity is located within the allowed range: as close as possible to the main gears (Sadraey, 2013). Likewise, in the construction of the UAV, easily obtainable materials were incorporated, whose cost would not be significant for the companies in case of imminent damage to the aircraft (ASTM, 2019).

eCFR part 107

This U.S. standard focuses on the preliminary procedures to be considered when flying a UAV. Before flying the Mini Piquero MK3 it was necessary to follow a component status verification protocol. This standard establishes that the batteries of the controller and the aircraft must be fully charged, and it is also essential to perform a general check of all the components of the aircraft to locate possible signs of damage and verify their general condition, verify the integrity of the engine and other electronic components, ensure proper alignment of ailerons, elevator, and stabilizers. For this, we had the help of a person with a lot of knowledge related to the design, construction, and handling of unmanned aircraft vehicles. The protocols of revision, alignment and mobility of ailerons, elevator and stabilizers were applied. This also met the standards of knowledge about how to properly fly a UAV, maneuvers, takeoff, and landing procedures. The flight test took place in a place with ample visibility and space to maneuver the aircraft (eCFR, 2021).

MATERIALS AND METHODS

Material and Component Selection

When selecting a construction material, the properties of each must be analyzed to determine the appropriate one. Different important parameters must be taken into consideration such as: price, construction, weight, density, and mechanical properties. Among the most common materials for the elaboration of UAV and the ones considered for this project are:

- Polystyrene (Flex foam)
- Raft or wood
- Carbon fiber
- Aluminum
- Plastic

- Steel (Martinez, 2020).

Table 3 shows the mechanical properties of different materials including balsa wood, the most popular material used for the construction of small aircrafts such as Mini Piquero MK3.

Table 3 Mechanical properties of different materials

Cores	Density $\rho(Kg/M^3)$	Modulus of Elasticity $E(Mpa)$	Shear Modulus $G(Mpa)$	Poisson Ratio v	Compressive Strength $\sigma_{Ult}(Mpa)$	Elongation $E\%$	Coefficient of Thermal Expansion $\alpha(°C^{-1})$	Coefficient of Thermal Conductivity $\lambda(W/M°C)$	Heat Capacity $C(J/Kg°C)$	Useful Temperature Limit T_{max} (°C)	Price 1993 (\$/Kg)
Balsa	100 to 190	2000 to 6000	100 to 250		8 to 18			0.05			11
Polyurethane foam	30 to 70	25 to 60		0.4						75	
Polystyrene foam	30 to 45	20 to 30		0.4	0.25 to 1.25					75	
Honeycombs											
Impregnated carton			50 to 350								
Impregnated glass fabric			100 to 600								
Aluminum	15 to 130		130 to 910		0.2 to 8						
Steel			550 to 1250								
Nomex®	25 to 50		10 to 40		0.2 to 2.5						

(Chipantiza, 2019).

The construction in raft and composite materials allows to ensure a low weight according to the dimensions and configuration of the UAV. In addition, the balsa is a material widely used in the construction of airplanes and gliders due to its low density and excellent resistance to vibrations. This selection is an indispensable factor for its long autonomy. However, the balsa presents a certain fragility against impact loads or vibrations during flight, so it is necessary to be careful at the time of assembly (Mejía, 2019).

Based on research on material selection, in the present study the balsa wood is used as a base material for the ribs of the wings, tail and fuselage due to its cost, ease of assembly and accessibility in the market. Also, one of the most important properties of balsa is its low weight to strength ratio, making it an ideal material for the construction of the aircraft.

Likewise, it is necessary to mention that aluminum is used in various parts of the UAV in order to improve flight stability and provide greater resistance to the moment of an impact or external vibrations. Specifically aluminum tubes were selected to manufacture the tail booms and the connection between the wings and the fuselage.

Another important parameter that must be selected for the development of a UAV is the selection of electrical components. While material selection is a key part of proper weight optimization during the flight phase, the electronic components allow to coordinate the movement of the UAV in the different stages of flight. The electronic components that are usually found in the manufacture of a UAV are:

- Servo motors
- Batterries
- Propellers
- Speed controller
- Receptor module
- Remote control

(Eslava, Martinez, Soto, Vera, & Gueverra, 2020).

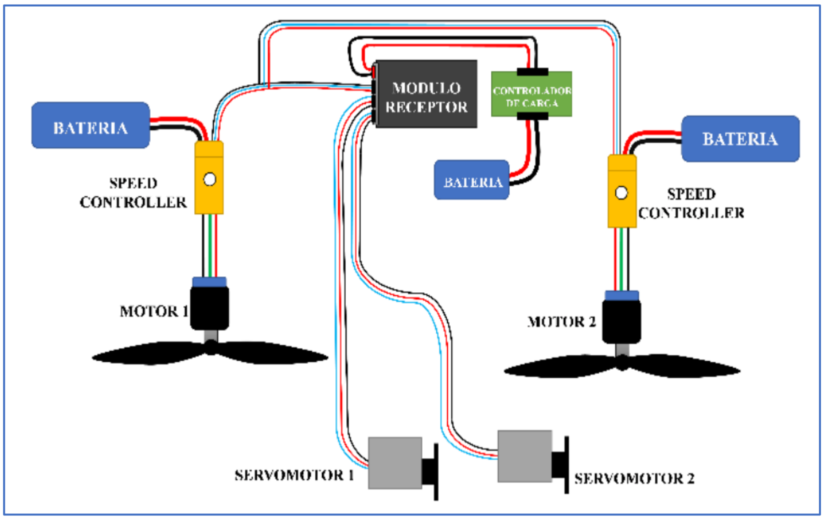


Figure 11 Basic electronic components and circuit for UAVs (Eslava, Martinez, Soto, Vera, & Gueverra, 2020)

Each of the electronic components had its main task that allows the correct electronic operation of the UAV. The connection between these components is shown in figure 11. The engine is one of the most relevant components that must be considered for UAV manufacturing. The engine gives the thrust of the plane's propulsion, therefore, if an engine is chosen that gives a lower thrust than the weight of the UAV, the aircraft will not be able to take off. Another important component to select is the battery because it is used to power all electronic components and must withstand weather, humidity, and dust situations. The battery is chosen based on the final weight of the UAV (Mejía, 2019).

According to the literature reviewed, the recommendations mentioned by the previous works on the Mini Piquero, and the needs established by the operational phases of flight and the weight of the UAV, the following electronic components are selected:

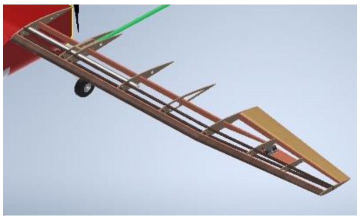
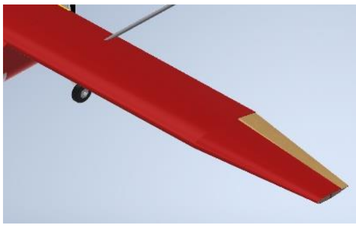
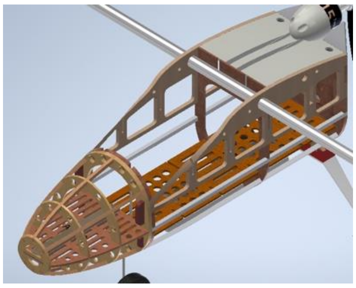
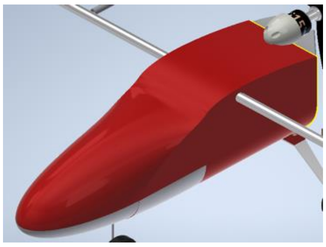
- 5 Servo motors MG90S
- Battery 5000 mAh
- Remote control Controller DX9 2.4GHz
- Receiver
- Battery turnigy power systems 4.0 lipo 3s 4000mAh
- Motor: turnigy 950 KV
- ESC 40A motor brushless hobbywing skywalker

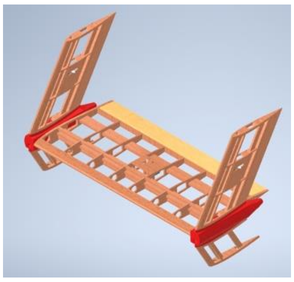
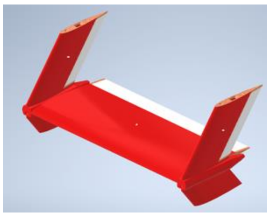
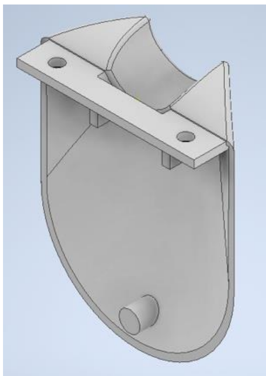
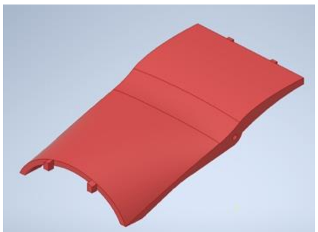
Design for Manufacturing

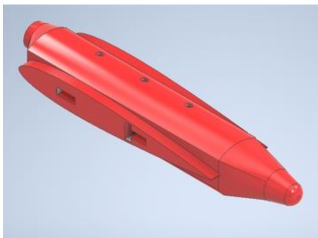
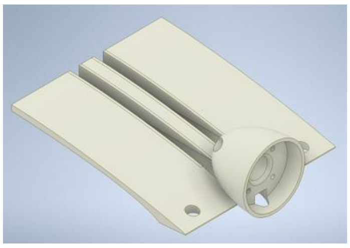
List of components for manufacturing

To identify which manufacturing process must be carried out in the manufacture of the UAV, it is necessary to identify the parts of the UAV that need to be manufactured. The following table shows the list of components for manufacturing.

Table 4 List of components for manufacturing

List of components for manufacturing	
Right wing skeleton	
Left wing skeleton	
Right wing	
Left wing	
Fuselage skeleton	
Fuselage	

Booms	
Tail skeleton	
Tail	
Landing gear	 
Fuselage back door	
Fuselage front door	

Right and left gaskets for booms	
Fuselage engine door	

A previous manufacturing study was carried out for each of the elements mentioned above. The following table provides the manufacturing processes necessary for the elaboration of the Mini Piquero MK3.

Table 5 Manufacturing process list

N°	Process list
1	Laser cut
2	Sanding and bent
3	Cut
4	3D print
5	Removal of excess material
6	Grinding
7	Drilling
8	Gluing and joining parts
9	Incorporation of Monokote

The tools and technologies that allow the Mini Piquero MK3 to be manufactured are detailed in the next table. These manufacturing technologies allowed the manufacture of all the list of components with acceptable tolerances.

Table 6 Manufacturing technologies

Manufacturing technologies	
Laser cut	
3D printer	
Drill	
CNC Milling machine	

The table shown below presents the materials needed for each manufacturing process. In addition, the cost necessary to carry out each activity is detailed.

Table 7 Manufacturing process and materials

Process	Materials	Cost
Raft laser cut	Balsa wood	$63
Bent	Balsa wood	$3
Sanding	Balsa wood and water sandpaper	$19
Glued	Balsa wood and glue	$0
Cutting and drilling of aluminum booms	Aluminum tubes, hand saw, milling machine, drill	$0
CAD modeling of parts	Pc with professional Inventor 2021	$0
3D parts printing	Prusa i3 Mk3S printer and filament	$40
Incorporation of electronic components	Battery, motor, ESC, Servo motors, Extensions	0$
Incorporation of Monokote	Monokote roll	$0

Flowchart

For the development of an optimal flowchart of the manufacturing processes, the following subcomponents are considered: Laser cut on the balsa wood, 3D parts printing, aluminum tube cutting, landing gear assembly, electronic components placement and joining and assembling parts.

This flowchart allows the different manufacturing activities to be carried out in a given order, reducing the costs and the manufacturing time of each of the aforementioned subcomponents. Based on the above, the flowchart for the development of the Mini Piquero MK3 is presented.

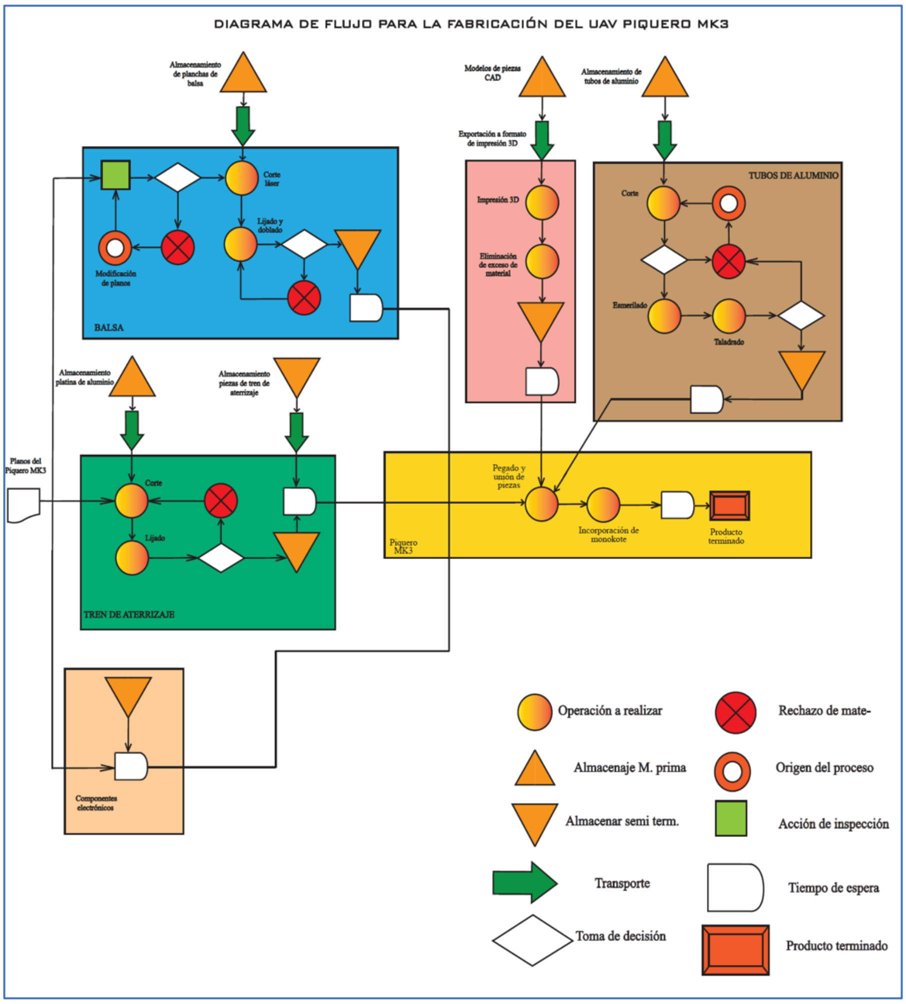


Figure 12 Flow chart for the manufacture of Mini Piquero MK3

Manufacturing program

To comply with the flowchart, a schedule is drawn up identifying the activities that must be carried out to make the MP-MK3. In this way, an orderly record is kept for each of the manufacturing processes. The schedule of activities for the manufacture of the UAV are listed below.

Table 8 Program of activities for the manufacture of the UAV

Process	Start date	Finish date	Entity	Responsible
Raft laser cut	10/11/2021	10/11/2021	ARTMAKEIT	Sebastián Arias
Bent	11/11/2021	11/11/2021	MK3 Group	Alejandro Torres
Sanding	11/11/2021	11/11/2021	Carpenter	Augusto Vallejo
Glued	11/11/2021	19/11/2021	MK3 Group	Alejandro Torres
Cutting and drilling of aluminum booms	11/11/2021	11/11/2021	MK3 Group	Lenin De La Cruz
CAD modeling of parts	1/11/2021	8/11/2021	MK3 Group	Augusto Vallejo
3D parts printing	15/11/2021	19/11/2021	USFQ	Sebastían Arias
Incorporation of electronic components	18/11/2021	19/11/2021	MK3 Group	Lenin De La Cruz
Incorporation of Monokote	22/11/2021	22/11/2021	MK3 Group	Alejandro Torres

Material's List

To carry out the activities of the schedule it is necessary to keep a record on the list of materials. In addition, it is necessary to add the costs of each of the components to have a rough idea about the total cost of the UAV. The next table indicates the material's list to build the UAV.

Table 9 Material's list

Item	Valor unitario ($)	Cantidad	IVA	Valor total
Motor electrico sin escobillas 1000kV	10,75	1	1,29	12,0
Bateria Lipo 3s 5000mAh 1C	71,40	1	8,568	80,0
Radio Transmisor y receptor de 6-10 canales	58,00	1	6,96	65,0
Micro servomotores MG90S	3,00	5	0,36	15,4
Cables para servo motores (50cm)	1,20	5	0,144	6,1
Hélices	3,00	1	0,36	3,4
Planchas de madera de balsa (3,5,10)mm de espesor	20,50	1	2,46	23,0
Madera de contrachapado	5,00	1	0,6	5,6
Rollo de Monokote	20,50	1	2,46	23,0
Tubo de Aluminio 6m	5,50	1	0,66	6,2
Juego de ruedas 3 piezas	6,25	1	0,75	7,0
UHU	1,20	1	0,144	1,3
Corte láser	10,50	1	1,26	11,8
Paquete de pernos + tuercas 1/4 in+ arandelas	3,00	1	0,36	3,4
Adhesivo epoxico	12,50	1	1,5	14,0
Impresión 3D base para el motor (por metro de PLA)	6,25	1	0,75	7,0
Aluminio para estabilizador	2,5	1	0,3	2,8
Cola para madera	1,25	1	0,15	1,4
Planchado de monokote	12,5	1	1,5	14,0

Based on the list of materials and the manufacturing processes used to make the mini Piquero MK3.The total manufacturing cost is $ 401.71.

Building process

First, balsa sheets of different thicknesses were laid out and subjected to a laser cutting process for subsequent sanding, assembly, and gluing. This process was carried out for the fuselage, wings, and tail structures:

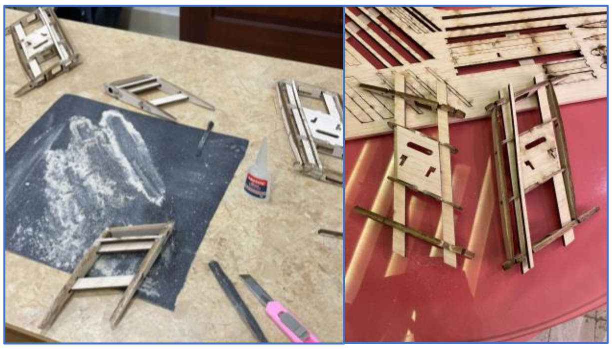


Figure 13 Cutting, sanding and assembly process.

Then, the electronic components are incorporated, such as the servo motors, battery, servo motor extensions, speed controller and receiver.

Figure 14 Electronics components incorporation process

Subsequently, the ribs of the wings, fuselage and tail were covered with a 1 mm thick balsa sheet.

Figure 15 Skeleton coating process

Once the ribs and the skeleton of the airplane are covered, the balsa surface is coated with the Monokote, using an iron.

Figure 16 Monokote coating process

The complex geometry of certain components, such as the ailerons, elevator, vertical stabilizers, engine base, fuselage cover and booms coupling make them difficult to machined. That is why it was decided to manufacture these parts with the help of a 3D printer based on a CAD model created in the design software Inventor.

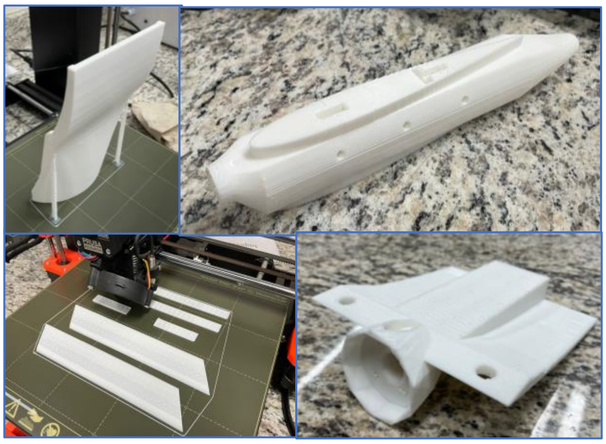


Figure 17 3D printed components

The wheels and the front part of the landing gear were purchased according to the calculations done. To manufacture the rear part of the landing gear, a 5mm thick aluminum plate was used, then a cutting, bending, and drilling process was carried out to finally obtain the desired geometry. The main landing gears are shown in the following figure:

Figure 18 Main landing gears system

3D printed parts are incorporated into the fuselage, wings, and tail. The wings and tail were incorporated to the fuselage by means of 13mm thick aluminum tubes:

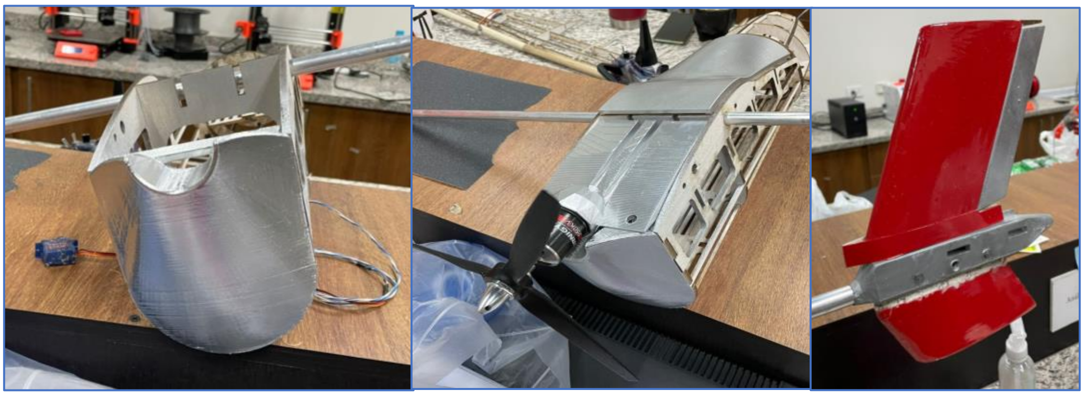


Figure 19 3D printed components, wing aluminum tube and tail tube assembly

Finally, the final prototype of the UAV Mini Piquero MK3 is shown in the following figure:

Figure 20 Final Prototype of the UAV Mini Piquero MK3

Tolerance check

This section presents the performance indicator based on the manufacturing processes used to make the UAV. The following table details the tolerances obtained for each manufacturing process. In this way, it can be mentioned that the elaboration of the mini Piquero presents a good assembly in each of its parts.

Table 10 Tolerance check

Process	Performance indicator
Raft laser cut	Dimensions are as desired
Bent	The dimensions are as desired, and the material has not suffered damage
Sanding	Dimensions are as desired
Glued	The glued between pieces is firm
Cutting and drilling of aluminum booms	Dimensions are as desired and there is not much tolerance variation
CAD modeling of parts	Modeled parts are in accordance with initial design requirements
3D parts printing	The part did not move during printing
Incorporation of electronic components	Components are working properly
Incorporation of Monokote	The Monokote adheres without major inconvenience to the raft

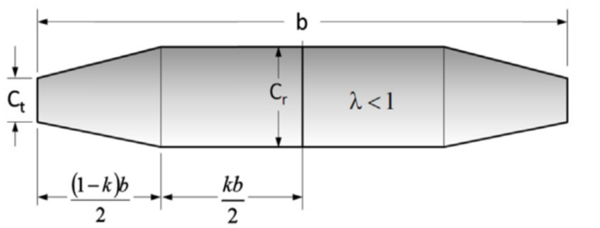
ENGINEERIGN ANALYSIS AND DESIGN

Design Report and Calculation

On the preliminary stage of the design of the Mini Piquero MK3 all the needed aerodynamic calculations were computed. Particularly, on this stage the calculation concerning to the geometrical dimension and characteristics of four critical components of the UAV were developed: wing calculations, tail calculations, landing gear calculation and wheel track calculations. All these calculations where strongly related to the weight of the UAV and the position of its center of gravity. Also, the selection of the configuration between battery, motor and propeller was defined based of the following results.

Wing Calculations:

Wing sizing and design are the fundamental traits to allow an airplane to fly because the wings are the surfaces where the lift force occurs. Several calculations are required to determine the dimensions of the wings based on the desired wing shape. The wing shape corresponding to the MK3 follows the equations and characteristics of the "semi-tampered" wing (Gudmundsson, 2014). The following figure stablishes the equations of the wing dimensions.



$$S = \frac{b}{2}\left[C_r(1+k) + C_t(1-k)\right] \qquad AR = \frac{b^2}{S} = \frac{2b}{C_r(1+k) + C_t(1-k)}$$

Figure 21 Semi-tampered geometry and equations

Before applying these equations, it is important to find the weight to area ratio (W/S) and the thrust to weight ratio (T/W). To find these values, a constraint graph for T/W must be plotted. Gudmundsson stablishes 6 constraint curves; on this analysis only 5 of them will be utilized as design criterion. These curves are named, and their equations are presented in the following list:

- T/W for a Level Constant-Velocity Turn: T/W required to maintain banking load factor

$$\frac{T}{W} = q\left[\frac{C_{D\_min}}{\left(\frac{W}{S}\right)} + k\left(\frac{n}{q}\right)^2\left(\frac{W}{S}\right)\right]$$

- T/W for a desired Rate of Climb: T/W required to achieve a climb rate

$$\frac{T}{W} = \frac{V_v}{V} + \frac{q}{\left(\frac{W}{S}\right)} C_{Dmin} + \frac{k}{q}\left(\frac{W}{S}\right)$$

- T/W for a desired Take-off (T-O) Distance: T/W required to achieve a ground distance at T-O

$$\frac{T}{W} = \frac{V_{LOF}^2}{2g * S_G} + \frac{q * C_{D\_TO}}{\left(\frac{W}{S}\right)} + \mu\left(1 - \frac{q * C_{L_{TO}}}{\frac{W}{S}}\right)$$

- T/W for a desired Cruise Airspeed: T/W required to achieve a cruise speed at a specific altitude

$$\frac{T}{W} = q * C_{D\_min}\left(\frac{1}{\frac{W}{S}}\right) + k\left(\frac{1}{q}\right)\left(\frac{W}{S}\right)$$

- T/W for a Service Ceiling (max altitude): T/W required to achieve the maximum altitude at which the UAV operates correctly

$$\frac{T}{W} = \frac{V_v}{\sqrt{\frac{2}{\rho}\left(\frac{W}{S}\right)\sqrt{\frac{k}{3 * C_{Dmin}}}}} + 4\sqrt{\frac{k * C_{Dmin}}{3}}$$

The values and description of the variables are presented in the following section. It is important to clarify that some values were obtained from a similar UAV design performed by García (2010). Likewise, some values were obtained from previous values stablished by Ñacata in his Piquero design (2018).

- $C_{D\_min} = 0.028$ for typical singled fixed gear (Gudmundsson, Table 3-1); minimum drag coefficient
- $AR = 11$ aspect ratio. According to Gudmundsson, typical GA aircrafts have AR ranging from 6-11.
- $k = \frac{1}{\pi * AR * e}$ lift-induced drag constant
- $e = 1.78 * (1 - 0.045 * \mathrm{AR}^{0.68}) - 0.64$ empirical estimation for straight wings (Gudmundsson, 2014).
- $q = \frac{1}{2} * \rho * V^2$ dynamic pressure at selected airspeed and altitude [N/m^2]
- $S =$ wing area [m^2]
- $T =$ thrust [N]
- $W =$ weight [N]
- $n = \frac{1}{\cos \phi}$ load factor for banking angle
- $\phi = 65°$ banking angle applied by Garcia
- $V = 13.89\ [m/s]$ airspeed stablished for MK3
- $V_{climb} = 10\ [m/\ s]$ UAV velocity at climb based on Garcia's design
- $V_V = V_{climb} * \sin(15.86°)$ vertical speed with climb angle of 15.86° based on Garcia's design
- $C_{L\_TO} = 0.70$ lift coefficient during T-O run (Gudmundsson, Table 3-1)
- $C_{D\_TO} = 0.045$ drag coefficient during T-O run (Gudmundsson, Table 3-1)
- $S_G = 15\ [m]$ ground run for takeoff; based on Ñacata's takeoff video
- $V_{LOF} = 10.91\ [m/s]$ liftoff speed according to Ñacata
- $\mu = 0.6$ ground friction constant

- $g = 9.81\ [m/s^2]$ acceleration due to gravity
- $\rho = 0.907906\ [kg/m^3\ ]$ air density at desired altitude

With all the values of the variables the graphs are plotted in function of W/S. With the aid of Engineering Equations Solver software, the following plot is obtained.

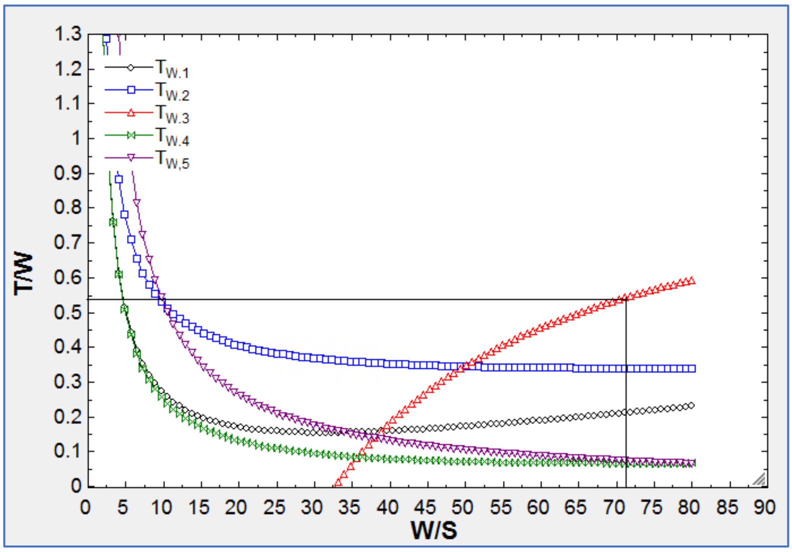


Figure 22 Constraint graph: T/W equations in function of W/S

The acceptable working region is located above all the curves. Any point below any of the curves is considered as unacceptable. First, an oversized W/S value is chosen, which will serve as a safety factor. In this case a value of 71.4 [N/m^2] was chosen. From there, the largest value of T/W that crosses a curve is selected; this will be the minimum T/W ratio required for the UAV. The value obtained from the plot is 0.5445. With the W/S ratio found, the required surface area can be calculated by dividing the UAV's weight by this ratio. The expected mass of the MK3 is 2.6 [kg], therefore the following calculation is performed:

$$S = \frac{W}{W/S} = \frac{2.6[kg] * 9.81\left[\frac{m}{s^2}\right]}{71.4\left[\frac{N}{m^2}\right]} = 0.3572\ [m^2]$$

With the wing area and the aspect ratio, the wingspan (b) of the selected wing geometry is calculated. Based on the following figure and equation for a semi tapered wing a rounded-up wingspan of 2 m is determined.

$$b = (S * AR)^{0.5} = (0.3572 * 11)^{0.5} = 1.9823\ [m] \approx 2\ [m]$$

The wingspan is rounded up to 2 [m] in order to ease the manufacturing of these parts. Then, the root and tip chord are choose based on the taper ratio λ. According to Gudmundsson, a taper ratio of 0.5 provide the wing with a good balance between low induced drag and good stall characteristics. Again, to ease the manufacturing of the wings a chord root of 200 mm is selected.

$$\lambda = \frac{Ct}{Cr}$$

$$0.5 = \frac{Ct}{200}$$

$$Ct = 100$$

With these values, the length of the tapered part of the wing and the length of the rectangular part of the wing is determined by calculating k:

$$k = \frac{2b}{AR * (Cr - Ct)} - \frac{Cr + Ct}{Cr - Ct} = 0.6363$$

By finding k and going back to the equations for the semi-tampered wing type, the dimensions of the wing can be found.

$$\frac{(1 - k)b}{2} = 0.3636\ [m]$$

$$\frac{kb}{2} = 0.6363\ [m]$$

Finally, according to Gudmundsson, typical wings feature a dihedral of 4º and 7º. In this case a 5º angle of cracked dihedral is selected (2014). Therefore, the dimensions and shaping of the wings are determined.

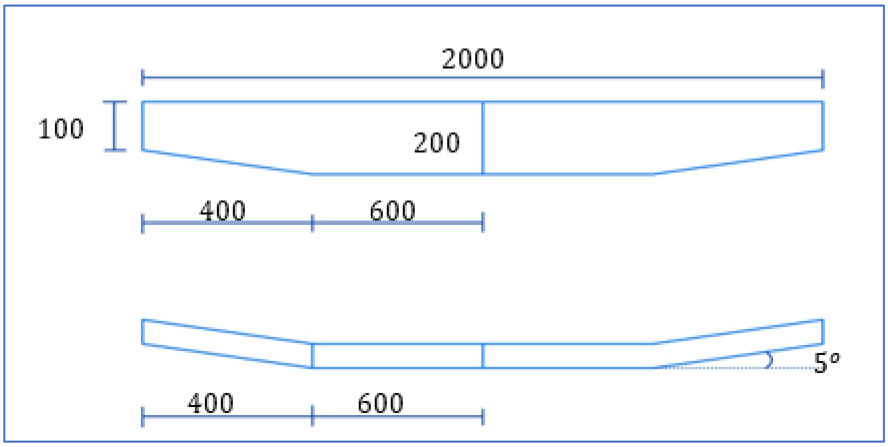


Figure 23 Final Wing Dimensions [mm]

Similarly, the minimum thrust required might be calculated from the constraint graph. Knowing that a minimum T/W ratio of 0.5445 is required and knowing that the estimated mass of the vehicle is 2.6 [kg], the estimated thrust required is obtained with the following formula:

$$T = \frac{T}{W} * W$$

Replacing the values, the thrust is found to be:

$$T = 0.5445 * (2.6 * 9.8)$$

$$T = 13.87\ [N]$$

Also, the estimated maximum lift force that the wings would experience during cruise flight is computed based on the maximum lift coefficient found for the mission characteristics and the airfoil chose:

$$L = c_l * \rho * \frac{V^2}{2} * S$$

$$L = 1.27 * 0.907906 \frac{kg}{m^3} * \left(13.89 \frac{m}{s} \right)^2 * \frac{0.3572}{2} m^2$$

$$L = 39.73\ [N]$$

Tail Calculations:

A boom-mounted tail is a set of two vertical mounted stabilizers including the horizontal wingspan, ventral fins and it's characterized by two longitudinal booms on the tail assembly. Aircraft with this configuration are more stable, easier to control and allowed aircrafts to present a pusher configuration. This tail design was especially popular during World War II and continues to be used in the production of the new aircrafts nowadays, due to its properties. This design is easy to identify immediately, as the configuration tends to stand out (Gudmundsson, 2013).

Table 11 Tail measurements

Reference span (wingspan) [m]	b_{ref}	1,9823
Reference area (wing area) [m^2]	S_{ref}	0,3572
Mean geometric chord [m]	C_{ref}	0,2
Aspect Ratio of wingspan	AR_1	11

To design the boom-mounted tail, the data of Ñacata´s horizontal tail was kept.

Table 12 Ñacatas's horizontal tail dimensions (Ñacata, 2018)

Horizontal Span [m]	B_{HT}	0,4
Horizontal Chord [m]	C_{HT}	0,2

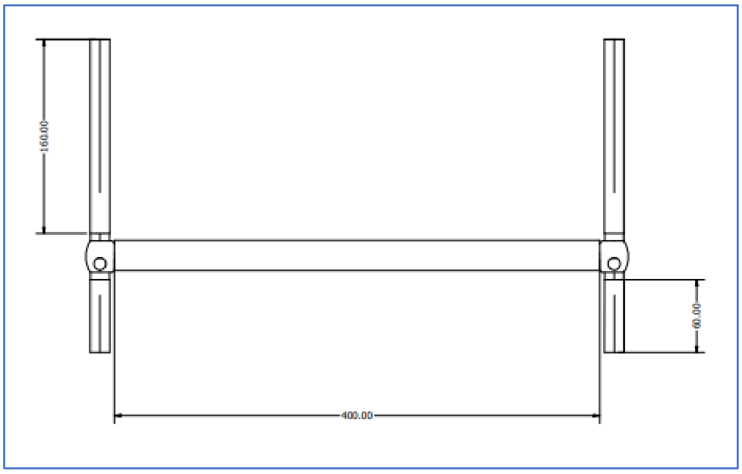


Figure 24 Final Horizontal Dimensions Sketch

To design the horizontal tail. The area and the aspect ratio have to be computed.

$$S_{HT} = b_{HT} * c_{HT}$$

$$AR_H = \frac{b_{HT}}{c_{HT}}$$

Table 4. Horizontal tail measurements.

Horizontal tail area [m^2]	S_{HT}	0,08
Horizontal Aspect Ratio	AR_H	2

To calculate the vertical tail dimensions. It's necessary to follow the next steps:

- Based on the General Aviation Aircraft Design book and the GA Aircraft (Tail configuration) model. We use the following data.

Table 13 Aviation Aircraft Design data (Gudmundsson, 2014)

	V_{HT}	V_{VT}
Sailplanes	0.50	0.02
Homebuilt	0.50	0.04
GA – single-engine	0.70	0.04

Table 14 Volume for horizontal tail and vertical tail

Horizontal tail volume [m^3]	V_{HT}	0,70
Vertical tail volume [m^3]	V_{VT}	0,04

- To obtain the vertical tail dimensions. The horizontal and vertical tail arm was calculated. But, in this step it is assumed that these two values are equal.

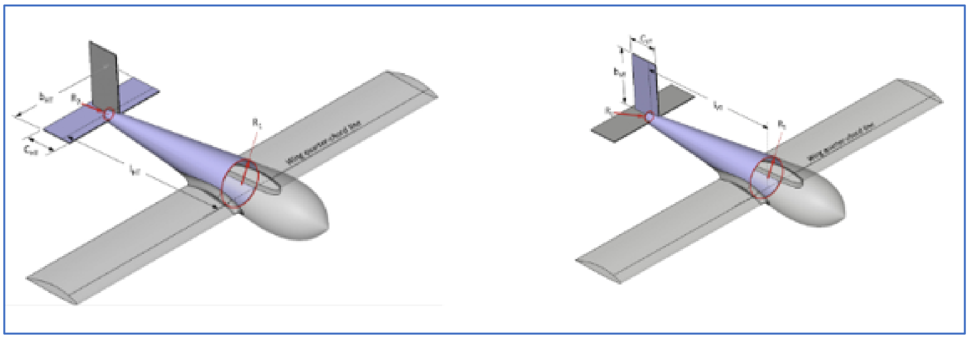


Figure 25 Tail dimensions structure

- To calculate the horizontal tail arm. The next equation is used:

$$I_{HT} = \frac{V_{HT} * S_{ref} * C_{ref}}{S_{HT}}$$

$$I_{HT} = 0.63\ [m]$$

- The vertical and horizontal tail arms are the same.

$$I_{VT} = 0.63\ [m]$$

- To calculate the vertical tail area. The next equation is used:

$$S_{VT} = \frac{V_{VT} * S_{ref} * b_{ref}}{I_{VT}}$$

$$S_{VT} = 0.045\ [m^2]$$

- But it's necessary to consider the total vertical area because we have the U tail configuration. For this reason, the vertical tail area is divided into two spans.

$$S_{VT} = 0.0225\ [m^2]$$

- With the new vertical area. The vertical span and chord must be calculated. It is assumed that the vertical aspect ratio is equal to 1,25. Due to it is the middle of horizontal aspect ratio.

$$b_{VT} = \sqrt{AR_{VT} * S_{VT}}$$

$$c_{VT} = \frac{b_{VT}}{AR_{VT}}$$

Table 7. Vertical Span parameters [m].

B_{VT}	0,168
B_{VT}	0,160

Table 8. Vertical chord parameters [m].

C_{VT}	0,135
C_{VT}	0,13

Note: To create the 3D model, we approximate the lower values due to tail weight issues.

Finally, the booms distance is calculated with the next equation:

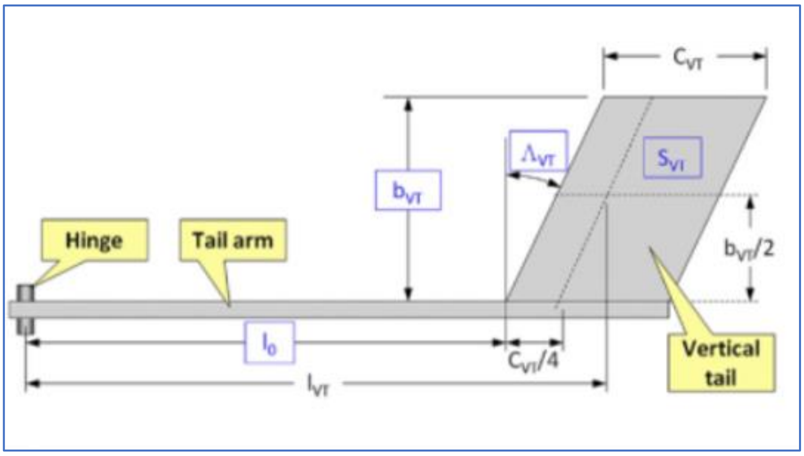


Figure 26 Tail and its parts (Gudmundsson, 2014)

Table 15 Final tail measurements for the Mini Piquero MK3

Angle [º and rad]	A_{VT}	30,00
Vertical Chord [m]	C_{VT}	0,13
Vertical Span [m]	B_{VT}	0,16
Vertical tail arm [m]	I_{VT}	0,63

This tail configuration has a range between 20-35º, so it is considering an angle of 30º. To calculate the ventral fins, a relationship of 3/8 with respect to vertical span is consider (Gudmundsson, 2014).

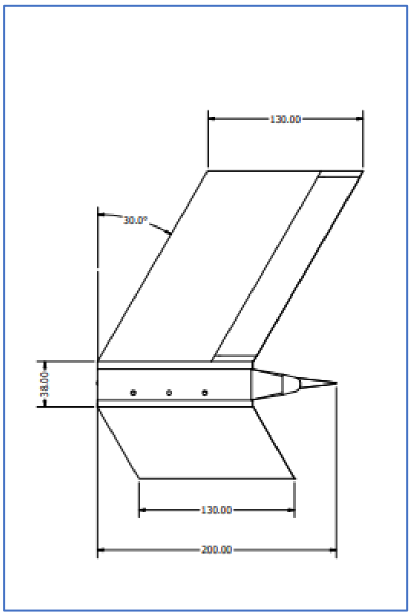


Figure 27 Final Ventral Fin Dimensions [mm]

Landing Gear Calculations:

The landing gear is another important structure in an aircraft, since it supports the UAV on the ground and helps it to take off, land properly and it helps as a shock absorber. As a preliminary step for the landing gear design, it is necessary to find the center of gravity of the MK3. It is important to know the weight of each component in the UAV such as the tail, battery, engine, receiver, and electronic speed controller and the distance of each one from a reference point which is called datum (Sadraey, 2013). These components are distributed over the aircraft as follows:

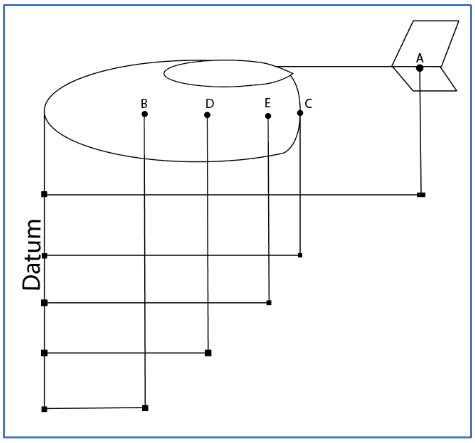


Figure 28 Location of components over aircraft MK3

The following step is to calculate the momentum of each component with respect from the datum reference point using the following formula:

$$M = W * d$$

Where:

$M = Momentum\ [N * m]$

$W = Weight\ [N]$

$d = distance\ [m]$

Table 16 Weights and momentums of aircraft Piquero MK3

	Component	**Weight (Kg)**	**Distance (m)**	**Momentum(N*m)**
A	Tail	0,30	0,91	0,27
B	Battery	0,45	0,05	0,02
C	Engine	0,20	0,51	0,10
D	Receiver	0,03	0,26	0,0078
E	Electronic speed controller	0,05	0,40	0,02
	Total	1,03		0,43
	Center of gravity (Fwd)		**0,43**	

Then, the total weight of the components will be calculated as well as the total momentum. With these data it is already possible to calculate the center of gravity CG of the MK3 by getting the variable d from the last formula, as follows:

$$d = \frac{Mtot}{Wtot}$$

$$d = \frac{1.03\ [N * m]}{0.4253[kg]}$$

$$\boldsymbol{d = 0.412\ [m]}$$

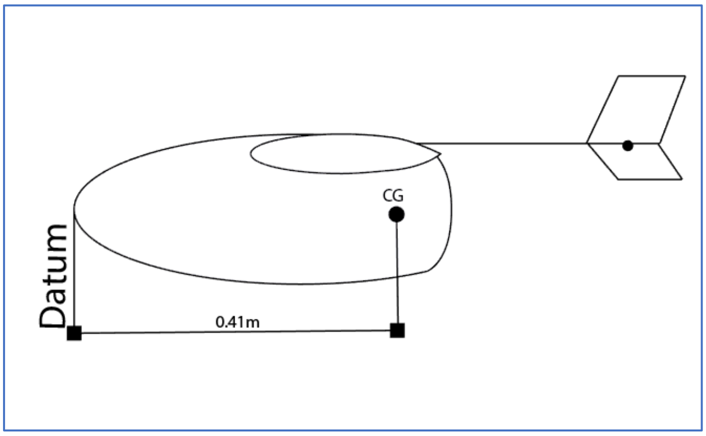


Figure 29 Location of center of gravity on the MK3

Main landing gear calculations:

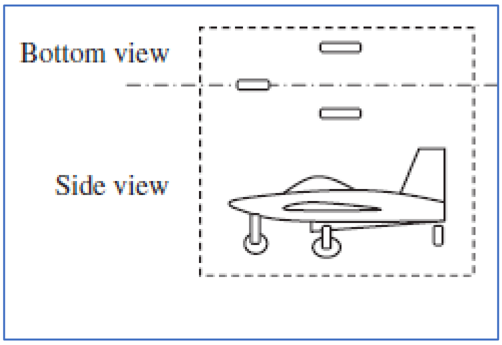


Figure 30 Tricycle landing gear configuration

The tricycle configuration has been chosen to be designed for the MK3. This landing gear configuration is one of the most used ones. The main gears are located as close as possible to the CG of the aircraft so they can carry much of the aircraft weight and load. Two main gears are at the same distance from the CG in both axis *x* and *y*, thus both can carry the same load (Sadraey, 2013). The main gears must share the range of 80%-90% of the total load and the nose gear the remaining 10%-20%.

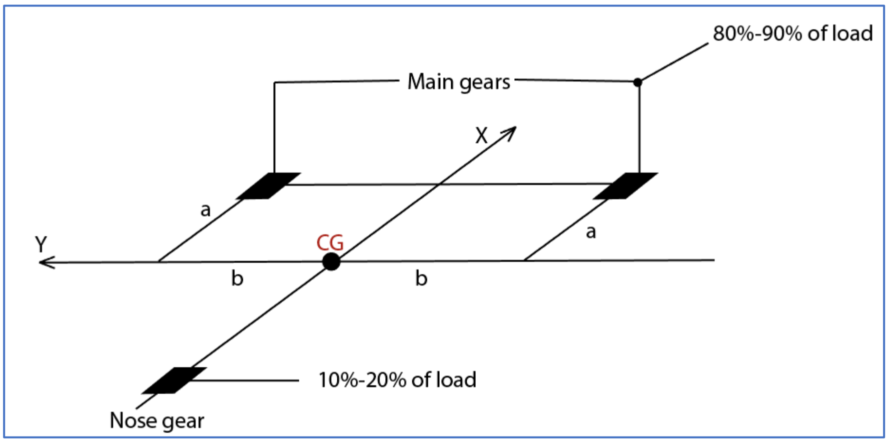


Figure 31 Main gears and Nose gear locations

Clearance angle:

In the design, it is necessary that the height of the landing gear prevents the tail from hitting the ground during takeoff or landing. An aircraft usually rotates about its main gear location at the takeoff and landing time, as follows:

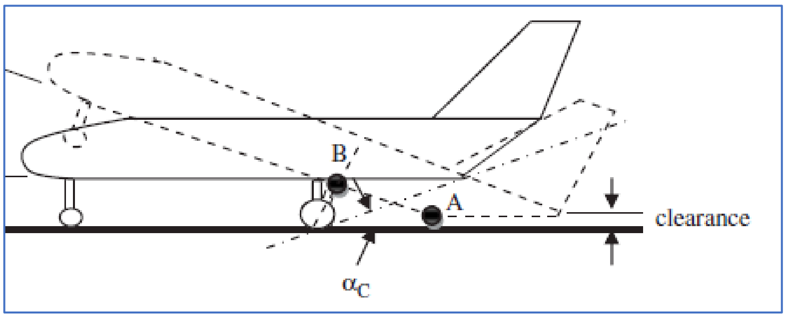


Figure 32 Clearance angle during takeoff

Tail impact with the ground is avoided by increasing the height of the landing gear or by checking that there is a clearance angle of less than 15° between the tail of the aircraft, the position of the landing gear and the ground (Sadraey, 2013). It is necessary to have in mind that the tail from the MK3 is located about the wing height and it is connected to them by booms, therefore, the aircraft is not following the traditional fuselage design.

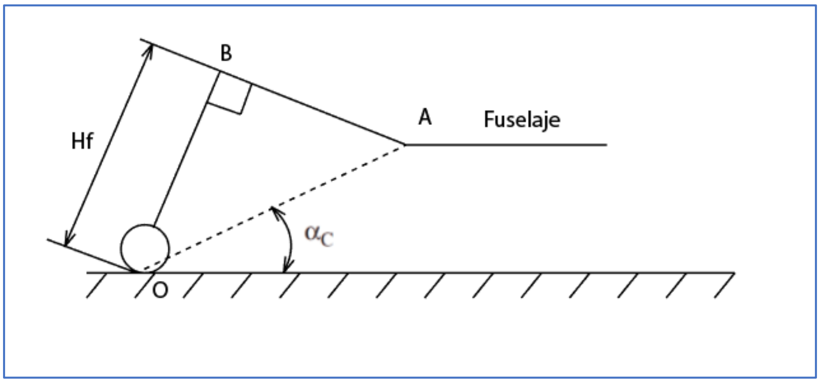


Figure 33 Distance AB and Hf at takeoff

For the MK3, the following data is given:

$$AB = 0.41\ [m]$$

$$Hf = 0.09[m]$$

Where *AB* is the distance from the landing gear on the *x* axis position to the aircraft tail and *Hf* is the distance from the ground to the fuselage.

The clearance angle is:

$$\alpha c = \tan^{-1}\left(\frac{Hf}{AB}\right)$$

$$\alpha c = \tan^{-1}\left(\frac{0.09}{0.41}\right)$$

$$\boldsymbol{\alpha c = 12.38°}$$

$$\alpha c \leq 15°$$

Therefore, the height of the landing gear is appropriate one.

Wheelbase distance:

It plays an important role in the load distribution between main gear and nose gear. This parameter is related to the ground controllability and stability since it is the distance between main and nose landing gears on the *x* axis (Sadraey, 2013). The center of gravity has been calculated in preliminary steps, now it is possible to sketch the loads acting on the aircraft on the *x* axis.

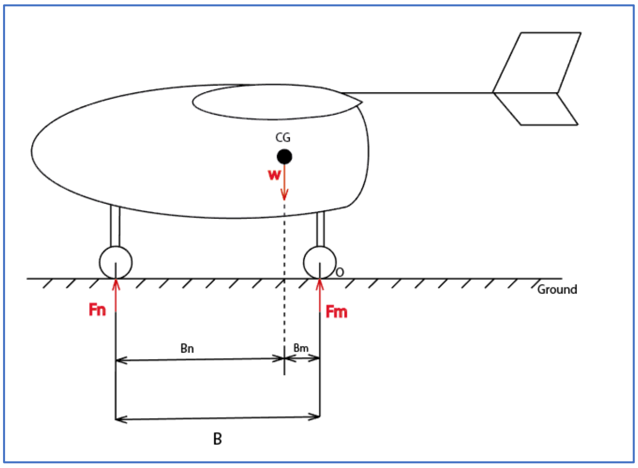


Figure 34 Forces acting on the aircraft MK3

To get the parameter B, calculate the sum of forces and moments with respect to point O as follows:

$$\sum Fz = 0$$

$$Fn + Fm = -W$$

$$\sum Mo = 0$$

$$-Fn * B + WBm = 0$$

$$B = \frac{Bm * W}{Fn}$$

Estimating an oversized weight of the aircraft:

W=3.5 kg

And knowing that the nose gear will carry a max load of 20% of the total load, then:

$$Fn = 0.2\,W$$

And the distance *Bm*

$$Bm = B - 0.235\ [m]$$

It is possible to calculate the distance between main gear and nose gear:

$$B = \frac{(B - 0.235\ [m]) * W}{0.2W}$$

$$0.2B = B - 0.235\ [m]$$

$$0.8B = 0.235[\mathrm{m}]$$

$$B = 0.293[m] \approx 0.3[m]$$

$$\boldsymbol{B = 0.3[m]}$$

Wheel track calculations:

The wheel track is the distance between the right and left main landing gears when looking at a front or top view, this parameter helps to the ground lateral control, ground lateral stability and structural integrity (Sadraey, 2013). The formula to calculate the wheel track comes as follows:

$$T = \frac{2Fc * Hcg}{m * g}$$

Where Fc is the centrifugal force, which is a disturbing moment able to overturn an aircraft during a turn due to centripetal acceleration, Hcg is the distance between the ground and the center of gravity on the z axis, m is the mass of the aircraft and g is the gravity.

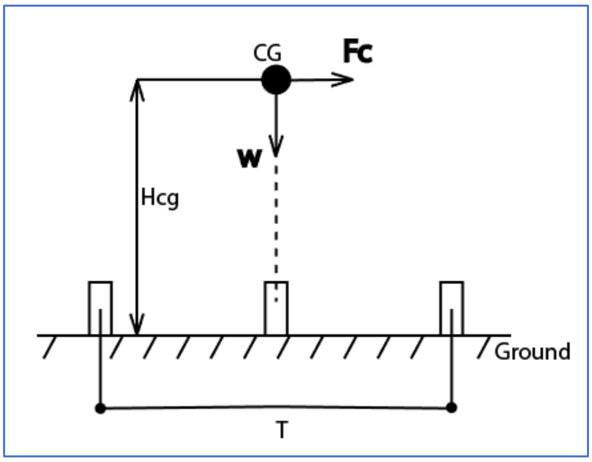


Figure 35 Front view of the MK3

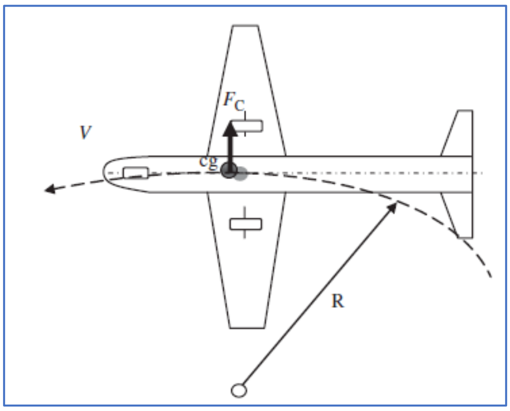


Figure 36 Conventional aircraft top view during a turn

The formula to calculate the centrifugal force is:

$$Fc = \frac{mV^2}{R}$$

Where:

m is the mass of the aircraft [kg]

V is the stall velocity [m/s]

R is the turn radio [m]

Having the following data:

$$m = 3[kg]$$

The average stall velocity for the MK3 is

$$V = 10\left[\frac{m}{s}\right]$$

And relating the example 9.4 from the book *Aircraft Design, a system engineering approach*, an aircraft with the same stall velocity has the turning radio of 30m, so it is possible to use the same turning radius:

$$R = 30[m]$$

Then, replacing the formula for *Fc:*

$$Fc = \frac{3\ [kg] * (10\frac{m}{s})^2}{30\ [m]}$$

$$Fc = 10\ [N]$$

Finally, replacing the result of *Fc* in the wheel track formula:

$$T = \frac{2 * 10[N] * 0.953[m]}{3.5[kg] * 9.8\left[\frac{m}{s^2}\right]}$$

$$\boldsymbol{T = 0.555[m]}$$

Finally, a landing gear sketch is presented with the distances obtained from the calculations:

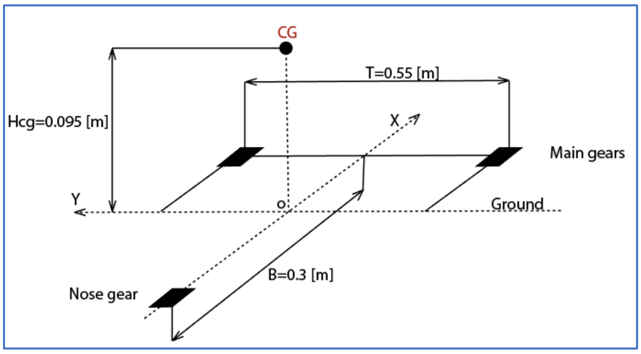
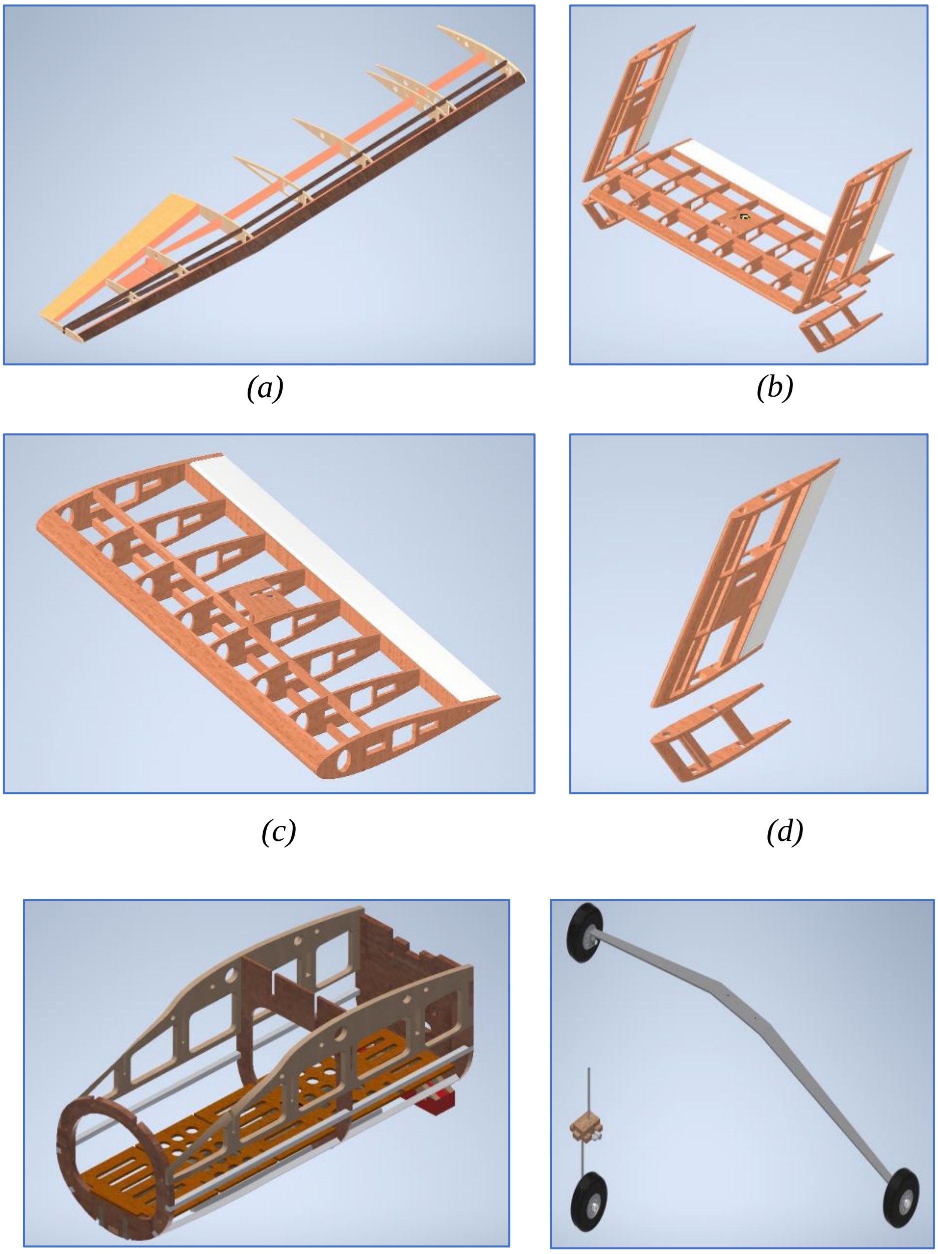


Figure 37 Main gears, center of gravity and Nose gear distances

CAD Design

After the necessary dimensions and geometries were computed and defined, all the components of the aircraft were created, modified, analyzed, optimized, and assembled using the computer aided designed software Autodesk Inventor 2021. As said before, the design of the nose, fuselage, wings, and tail ribs was done based on the airfoil chose for each of these components they obtained dimensions and previous work. The same applies to the landing gear components, ailerons, elevators, and tail booms.

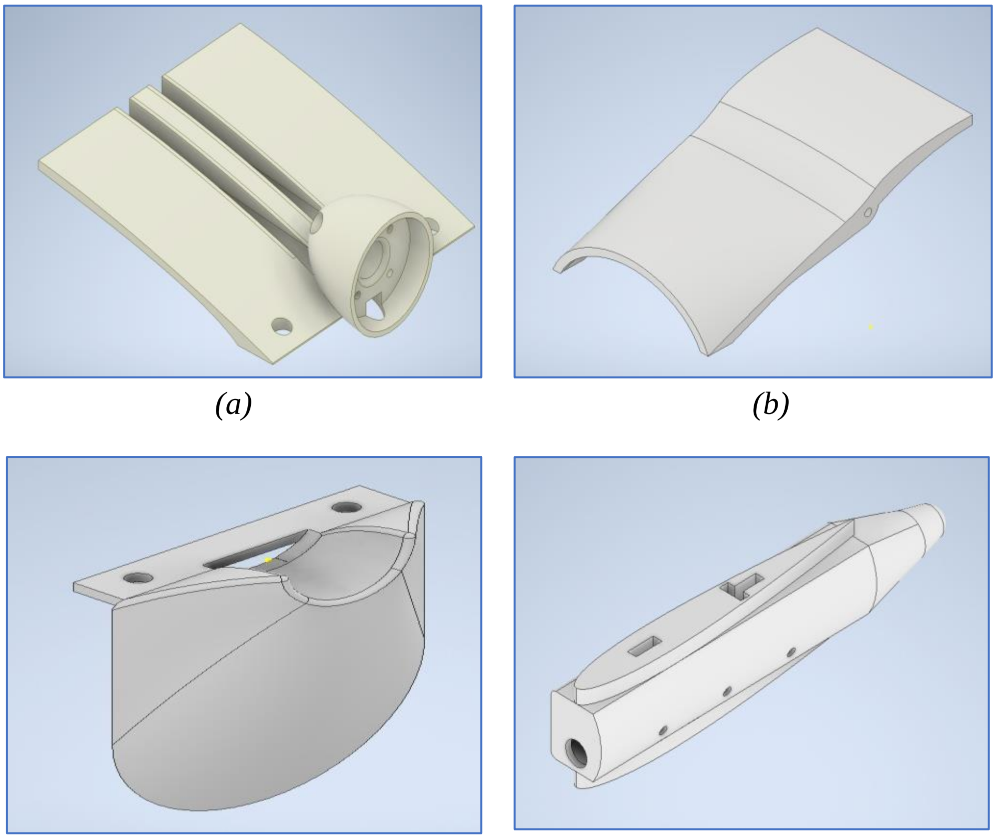


(a) (b) (c) (d) (e) (f)

Figure 38 CAD Components (a) Wing assembly. (b) Tail assembly. (c) Horizontal tail assembly. (d) Vertical tail assembly. (e) Fuselage assembly. (f) Landing gear assembly

After all these components were virtually created on the software, the assembly process begun, and a better perspective of the UAV design was obtained. Also, the CAD approach taken, allowed to determine specific details such as holes, cavities, joints, and extra parts before the actual manufacture of the aircraft.

With this assembly and specific measurements of the fuselage, it was possible to create four additional components. Three of these were destined for the fuselage and to serve as removable lids for an easy access to the internal components of the aircraft such as the battery, the UAV receiver, and the electrical connections. Two of these lids also serve as the structure to secure the electric motor and the propeller, one is located at the top of the UAV and the other at the back. The third one was designed with the objective of being the connection between the vertical and horizontal components of the tail.



(a) *(b)*

(c) *(d)*

Figure 39 CAD Additive manufacture components. (a) Motor and propeller lid. (b) Top lid. (c) Back lid. (d) Vertical and horizontal tail joint

These pieces were meant to be manufactured through additive manufacturing due to their complex geometry that secures the aerodynamic of the aircraft. It is also important to mention that, apart from the structural components, the electronic components were also replicated to obtain a more exact weight and location of the center of gravity of the aircraft trough Inventor tools.

Figure 40 CAD MK3 Assembly

MODIFICATIONS

Fuselage modifications:

One of the obstacles that previous designs encountered was to change the center of gravity in case it needed to be changed. This occurred because the inside components of the previous designs could not be accessed after covering the fuselage; therefore, the placing of the components could not be changed to fix the center of gravity to a desired position. Hence, it was opted to manufacture removable pieces for the fuselage. It was decided that the pieces should be manufactured by 3D printing since complex surfaces and shapes can be obtained through this method.

Furthermore, by utilizing specific printing material, pieces can be relatively light. As a matter of fact, one of these removable pieces served as a supporting structure for the motor of the aircraft as it kept the motor aligned with the tail and fuselage for an ideal pushing effect. Additionally, a final 3D piece was utilized in the fuselage as a back more aerodynamic part, which would improve the UAV's flight. Finally, some ribs of the fuselage were also removed to reduce the overall weight of the vehicle. The following image shows the 3D pieces applied on the fuselage.

Figure 41 Fuselage with 3D pieces

Wings modifications:

When defining pertinent modifications to be done to the wings, the subjection of decreasing the number of ribs from an aeromodelling master's student of Embry-Riddle Aeronautical University, was considered due to his experience and knowledge. Specifically, a total of six ribs were removed from the wings, helping to reduce the weight of the wings by 52 gr. The distances between the kept ribs were also modified.

With the same objective of reducing the weight of the aircraft and to optimize it, the geometric dimensions of the wings were rectified and generally reduced based on the calculations previously computed. Particularly, the wingspan was reduced from 2.18 meters to 2 meters, giving the aircraft better stability at take-off and flight. Also, the dihedral angle and semi-tapered dimensions were modified to provide the UAV with roll stability, improve the aileron effectiveness and improve the wing efficiency over a rectangular wing (Gudmundsson, 2014).

Landing gear modifications:

The previous model of the Piquero caused instability problems in takeoff and landing on irregular terrain. This is due to the fact that the distance between main tires was 198 cm, and the wingspan of the aircraft is 2.05 m. For these reasons and according to the calculations, it was decided to manufacture a support for the main tires of 55 cm span, making it more stable at the time of takeoff and landing. The previous and actual design for landing gear is shown in the following figures.

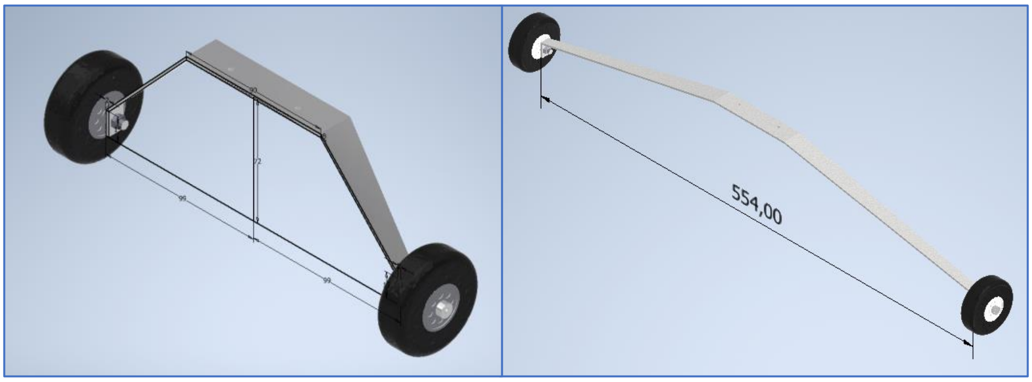


Figure 42 Previous and actual main gears design.

Tail modifications:

One of the observed problems in Ñacata´s model was the geometry and arrangement of the tail. The tail configuration is decided by studying the aerodynamic and stability requirements of the aircraft. A boom mounted tail is best suited when the vertical tail needs undisturbed airflow during high angles of attack. Also, the effectiveness of the elevator increases as the vertical tail give an endplate effect to reduce the induced drag (Sadraey, 2013).

The position of the tail lies immediately behind the propeller which causes a significant impact on the stabilizers due to propeller wake. In addition, it is necessary to mention that the axes and the middle of the tail boom must be aligned. The necessity of a larger control surface also results in more drag and adds a heavier weight. Designing an optimum boom mounted tail configuration will allow enhanced performance regarding at Ñacata´s model.

The ventral fin is added because it provides directional stability at supersonic speed. The lower fin shifts the aerodynamic center of the empennage downwards, which is improving the handling characteristics. Adding area below the centerline helps to reduce the roll contribution of the vertical tail in a sideslip, which improves handling characteristics (more directional stability AND lower yaw-induced roll) (Pieterse, 2015).

Also, at high angles of attack, the vertical tail is in the wake of the fuselage which reduces local dynamic pressure and, consequently, effectivity. The ventral fin then is in ideal flow conditions, so it can help to stabilize the aircraft at high angle of attack, just when the fuselage contribution to instability is largest (Pieterse, 2015). Finally adding this tail configuration (boom mounted tail) allows it to remain a pusher configuration.

SAFETY AND MAINTENANCE

Safety Through Design

In order to secure the welfare of everyone involve in the manufacturing and operation of the Mini Piquero MK3 and to also to have immediate solutions and protocols for probable errors and problems throughout the development of this project, a risk analysis was conducted. The following table illustrates the quantitative methodology took to carry out the risk analysis. Through this method, each risk is evaluated in terms of its probability of happening and the impact that it would have if it does.

Table 17 Quantitative risk analysis

Impact	5					
	4					
	3			X		
	2					
	1					
		1	2	3	4	5
		Probability				

A total of twelve possible risks were considered, however, the description of three of the higher qualification and more critical risks would be presented. The entire list can be found on annexes.

Table 18 Most critical risk and desired solution

Code	Description	Priority = Impact x Probability	Responsible	Desired Solution	Estatus	Observations
001	Starting the propeller with the motor can cut the operator's hand.	4x3 = 12	Augusto Vallejo	Avoid: Picking up the propeller when the engine is running.	Active	Indicate personal protective equipment.
002	In the event of a UAV collision, the propeller breaks and the pieces are directed towards a person causing serious injuries.	4x3= 12	Lenin De La Cruz	Secure: Design a housing to ensure that the propeller does not break.	Active	Indicate necessary and resistant materials for collision situations
011	Poor weight distribution producing flight instability.	4x3= 12	Augusto Vallejo	Ensure: That the position of the components in the UAV does not cause an imbalance and significant difference in weights through the balance of aircraft and repositioning of components.	Active	Before carrying out the flight tests, the stability of the plane must be ensured, being clear about its center of gravity, aerodynamic center, heavier parts, etc.

RESULTS AND DISCUSSION

Design results

Based on the calculations and estimations from the previous designs, several important traits of the UAV were defined. However, after building the vehicle some of the real traits differed from the approximations obtained. The following table showcases the expected traits vs the actual measured traits.

Table 19 Physical and Mechanical properties of Balsa Wood

Results	Expected	Measured
Mass [kg]	2.6	2.8
Center of gravity (distance from nose) [m]	0.41	0.46
Thrust [N]	13.75	19.6
Wingspan [m]	2	2.05
Distance from floor to fuselage [m]	0.09	0.14
Distance between wheels [m]	0.55	0.55

The expected mass was approximated to be 2.6 [kg], similar to Ñacata's design; however, the final mass measured for the MK3 was of 2.8 [kg]. The center of gravity determined in the Inventor software was of a distance of 0.41 [m] from the tip of the nose. Measuring the distance from the tip of the nose to the approximate center of gravity gave a distance of 0.46 [m]. The larger the distance, the more unstable the flight of the plane; however, the actual distance still satisfies the stability threshold for the flight. The minimum thrust required for the mass of 2.8 [kg] was of 13.75 [N]. To measure the thrust, a dynamometer was utilized; the tool could only measure up to 2 [kgf] and, in fact, the UAV surpassed this thrust force when measuring it. Therefore, the minimum thrust force achieved was of at least 19.6 [N]. It is important to mention that this thrust was achieved beacause the original 4000 mAh battery was changed to a 5000 mAh one, which is more powerful; The expected wingspan was of 2 [m] and the measured one was of 2.05 [m], a relatively small difference. The distance from the floor to the fuselage was expected to be of 0.09 [m]; however, the measured one ended up having 0.14 [m]. This difference occurred due to the available materials on the market and because more material needed to be utilized to assure a sturdy joint between the fuselage and the landing gear. Finally the wheel distance attained was the same as the expected, 0.55 [m].

Finally, the free body diagram at cruise of the aircraft is presented accompanied with a table where the principla aerodynamic characteristics of the Mini Piquero are presented.

Figure 43 Free body diagram at cruise

Table 20 Characteristics of Mini Piquero MK3

Free Body and Characteristics of Mini-Piquero MK III						
	Cruice Velocity [m/s]	Take Off Velocity [m/s]	Lift at Cruise [N]	Drag at Cruice [N]	Motor Trust [N]	Weight [N]
Mini-Piquero MK III	13.4	10.3	39.73	0.66	19.6	27.44

Flight results:

For the flight day, the UAV was taken to a grass field for aeromodelling at the outskirts of the city. There, the pilot suggested to make some alignments for the ailerons and servomotors so that the Mini-Piquero could fly correctly. Even though in the running distance on the ground the UAV had enough velocity and had a straight direction at takeoff, as the UAV was elevating, it lost control, turned to the right, and fell on its nose. Unfortunately, the nose, the fuselage, and a wing were severally damaged and the lack of time to repair them lead to no more flight attempts.

Discussions:

The results indicate several important points that may lead to improvements of future works on this topic. Even though the dimensions and weight of the UAV achieved were as expected, the construction of the vehicle could have been performed more efficiently and precisely. Firstly, the wings should have been constructed more carefully since they presented irregularities when compared to each other; this occurred due to the excessive removal of ribs that negatively affected the structure of the wings. Even more, the pilot recommended to utilize dihedral angles all through the wings since it can offer better stability for the flight.

Additionally, the weight of the tail was excessive considering that, at first, it was only held by the already weakened wing structure. For that reason, the support from the landing gear to the tail was added; nevertheless, this addition yielded a change of the center of gravity which was not beneficial for the flight. The pilot also suggested the removal of certain parts of the tail to reduce its weight; more specifically, he suggested to remove a few ribs from the structure and to remove half of the covering wood of the structure. On the other hand, the incorporation of 3D pieces on the fuselage became beneficial for the overall design; certain fuselage ribs were removed and so the weight of the UAV decreased.

The present work heavily focused on the aerodynamic improvement and optimization of the UAV. Therefore, the redesigned and creation of most components of the aircraft were meant to present smooth and continuous surfaces decreasing the amount of stagnation points. However, this decision resulted on having complex geometries on different components such as the top, back and front lids and the tail joints. Also, the CAD design was meant to represent all the necessary wholes and joints for the manufacture of the aircraft. For these reasons, the attempts of computing software simulations such a computational fluid dynamics and stress analysis failed. Specifically, the process of meshing presented a recurring problem on different software, allowing to affirm that the computational power needed to perform simulations like the ones mentioned before was not at disposal.

By obtaining a larger thrust than expected, thanks to the change of battery, the T/W ratio was vastly satisfied. This means that more weight can be put into the vehicle, and it will not affect the flight of the UAV. Therefore, the location of the center of gravity could be modified by strategically adding weights all throughout the UAV and more sophisticated components, like more powerful servomotors, may be added too. Even if no more weight is added, the T/W ratio obtained assures more than enough power for an ideal flight.

One of the most problematic stages trough the development of this project was the manufacture process of the UAV. On this stage the lack of experience when modeling and assembling all the components of the aircraft was evident. Throughout and at the end of the building process several obstacles were encountered; these complications brought undesired outcomes which needed new planning and modifications for the orginal design.

Respecting the 3D pieces, there was a lack of consideration on the dimensions for the holes where the screws, bolts, and nuts would fit; therefore, machining of the pieces needed to be performed. Likewise, the decision of 3D printing all the ailerons, stabilizers and elevator lead to extra weight that could have been avoided if the knowledge of how to machined these components in balsa wood was available. Additionaly, the a lack of planning on how structures would be joint, specifically the joints between the tail components, resulted on the purchased of several materials and supplies that were not contemplated on the design stage. Also, the monokote used for covering the aircraft was one of the supplies that was wasted the most; this due again to the inexperience on how to use it.

Moreover, when the first ground run test was made, it was found that the UAV did not move in a straight line because the front wheel was not correctly aligned. To solve this problem, the back wheels of the landing gear had to be assembled tilted to compensate the turning movement.

Finally, the most significant problem was the way the tail was supported by the wings. Since the tail had a significant weight and since the wings had ribs removed, the tail was positioned lower than where it was supposed to. Furthermore, this problem would produce critical stresses on the wings structure, which could lead the break of them. Therefore, a new supporting structure was designed. This structure consisted on aluminum pieces that come from the landing gear and 3D printed pieces that served as joints. This pieces gave more support to the tail and allowed it to be correctly aligned with the axis of the propeller. The following image demonstrates the end result of the structure.

Figure 44 Tail support from the landing gear

Due to all the previously mentioned complications, the manufacturing costs increased significantly from the $300 budget to a cost of approximately $400. Moreover, the time spent on the manufactured of the UAV ended being of around 3 weeks. This extensive amount of time was spent on the acquisition of raw materials, fabrication of the 3D pieces, and mostly on planning and developing solutions and changes to the initial design. However, it is strongly believed that the budget can be met, and the manufacturing time can be drastically decreased if all the materials, joints, and components needed are correctly designed, contemplated and at disposal.

As said before, the flying attempt of the aircraft was not successful, but it is not possible to be certain of the main reason of this failure. However, several aspects of the design and manufacture of the aircraft, as the presented before, can be pointed out as crucial factors that provoke the stall and loss of control of the aircraft as it took off. Nevertheless, it is believed that the main cause of the crash was the lack of a final balance of the UAV after the needed supports of the tail to the landing gear were added. The lack of time and underestimation of this added weight led to this error that could have drastically changed the position of the center of gravity of the aircraft from the one estimated initially. According to the literature, the center of gravity should be located at three quarters of the chord of the wings.

Also, before performing the flying attempt it was noticed that the right wing of the Piquero MK3 was not completely parallel to the ground but slightly bent towards it. This damage to the UAV was most probably caused during the transportation of the aircraft to the airstrip and it is suspected to have caused it to have a tendance to turn to right after take-off.

Furthermore, the pilot mentioned that several components could have a reduced weight if fabricated with a different material or some components could have even been removed; for example, the ailerons could be fabricated by wood sanding instead of 3D printing them. Finally, he added that for future projects, the front wheel should have a servomotor to control the takeoff and landing of the vehicle.

COCLUSIONS AND FUTURE WORK

Conclusions

The redesign of the UAV wings cannot be analyzed as expected due to the fact that the flight of the mini Piquero MK3 was not favorable. However, according to previous experiences and the recommendations of several engineers, this could be given due to the distance and the weight of the wings. In this way, a flow analysis must be carried out in the wings that allows us to understand what factor could influence the flight test.

The redesign of the new tail model has several imperfections due to the excessive weight of it. As said before, the obtained weight of the aircraft is acceptable, however, the ratio between the fuselage and the tail weight is not optimal. The increase of weight occurred because in the boom mounted configuration several components are added, such as the vertical stabilizers, the ventral fin, and the horizontal stabilizer. This configuration presents greater stability and flight rigidity, however, the increase in weight is notorious for which it was necessary to manufacture a support that connects the tail to the landing gear. This support ensured and stabilized the tail at the time of flight; but it is necessary to recalculate the center of gravity of the UAV to comply with the flight conditions.

The redesign of the landing gear yielded a better stabilization in the UAV's run before takeoff. In addition, by redesigning and modifying its previous dimensions, the support for the tail had the landing gear as a stable base. These supports provided greater support in both, the travel phase and the flight phase. It is necessary to mention that the landing gear did not present any fracture at the time of the UAV collision. Therefore, the redesign of the landing gear met the expected stability and support results.

The design and construction of a removable structure for the fuselage presented satisfactory results. Thanks to these pieces, the positioning of the different electronic components was facilitated and so it was for the relocation of the center of gravity; by having a removable section, the introduction of weights inside the fuselage could be easily performed. Therefore, the excessive weight of the tail could be easily compensated to bring more stability to the vehicle.

Recommendations

When working with balsa, one must be careful in the budling and assembling processes. Balsa is a fragile material, and it can easily break. Furthermore, surfaces and balsa pieces must be carefully glued, because if they are misplaced, it is difficult to place it correctly after the glue dried.

It is recommended to decrease the number of ribs the tail in order to reduce the total weight of the UAV. The number of ribs in the wings might be reduced if there is a correct support system for the tail instead of the wing structure only.

It is recommended to assure that the center of gravity is located at three fourth parts of the wing from its root. If the T/W ratio allows it, placing extra weights inside the fuselage might assure a correct positioning of the center of gravity. Therefore, better stability can be attainted for the flight.

For the elaboration of complex pieces, it is recommended a 3D printing manufacturing process. This process yields pieces with endurance and precision. When using this method, it is important to choose a material with relatively low density, so that the overall vehicle's weight can be minimized.

It is highly recommended to have guidance from experienced UAV pilots before and during the manufacturing phase. Aeromodelling is a very complex process and any kind of advice from people with successful results can be useful

Future Works

The present work leaves as guide the calculations and the design of a Mini Piquero MK3 that can serve as a base for future work that will be detailed below.

Tail weight reduction

This is one of the most important parameters to be analyzed in future work. To carry out this activity it is recommended to reduce the cover of the 1 mm balsa sheet. In addition, it is important to redesign the piece that join the stabilizers and the ventral fin to reduce its weight. Also, it is important to consider another means of manufacturing because balsa had certain limitations when presenting complex geometries. Another manufacturing process that could be used is 3D printing to solve this problem of complex parts.

Simulation

Simulation is another subject of study that is needed to know how the UAV would behave during the flight phase. In the present work, the simulation could not be carried out due to the complex geometries of some parts. For this reason, it is necessary to carry out a redesign that does not contain parts that generate an infinite mesh within the CFD software. To continue this work in the future, the design of parts with very small hollow surfaces should be avoided.

Removal of stress concentrators

The removal of stress concentrators must be focused on the redesign of the parts. In this way, it would help to have a better manufacturing process and to be able to generate an appropriate mesh for the simulation. To reduce the stress concentration, it is necessary to eliminate the holes in pieces with excessive dimensions and rounded with not very closed curvatures (Tail joins). In addition, a stress analysis must be made to know if the parts that make up the UAV work in an optimal state in the presence of external forces.

Fluid Analysis

In this study, parameters such as lift, drag, velocity, pressure, temperature, etc. must be considered. These study parameters will allow an idea of how the pressure and gravity center will behave when interacting with the air force. It will also allow predicting how the air fluid adheres to the boundary layer of the selected wing and tail profiles. Finally, it will allow us to interpret all the forces that interact during the flight phase.

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ANEXE A: ENGINEERING DRAWIGNS

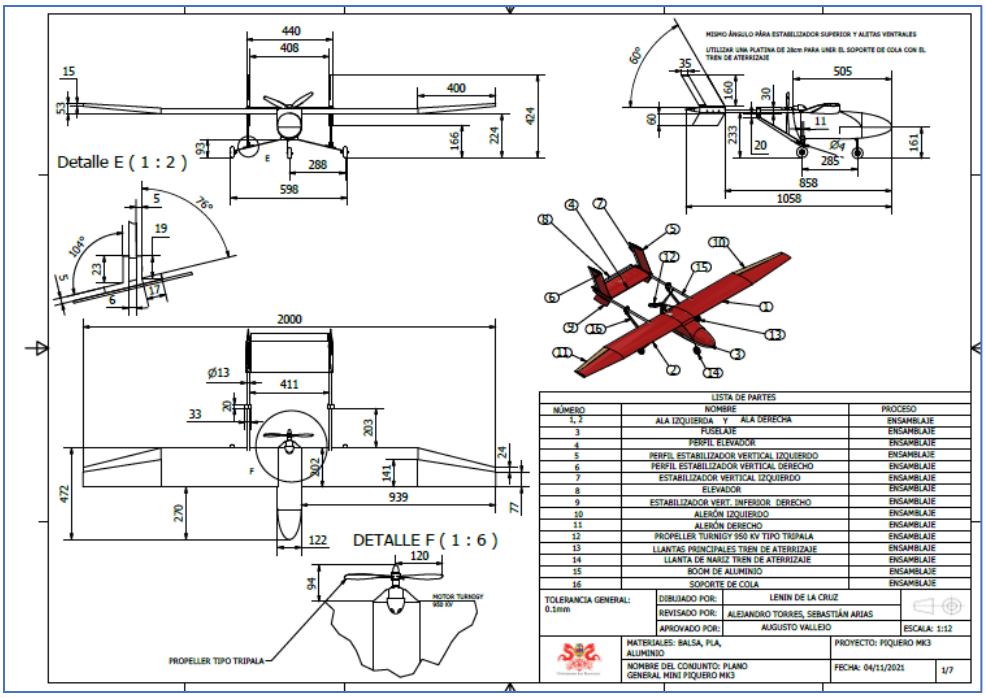


Figure 45 General assembly

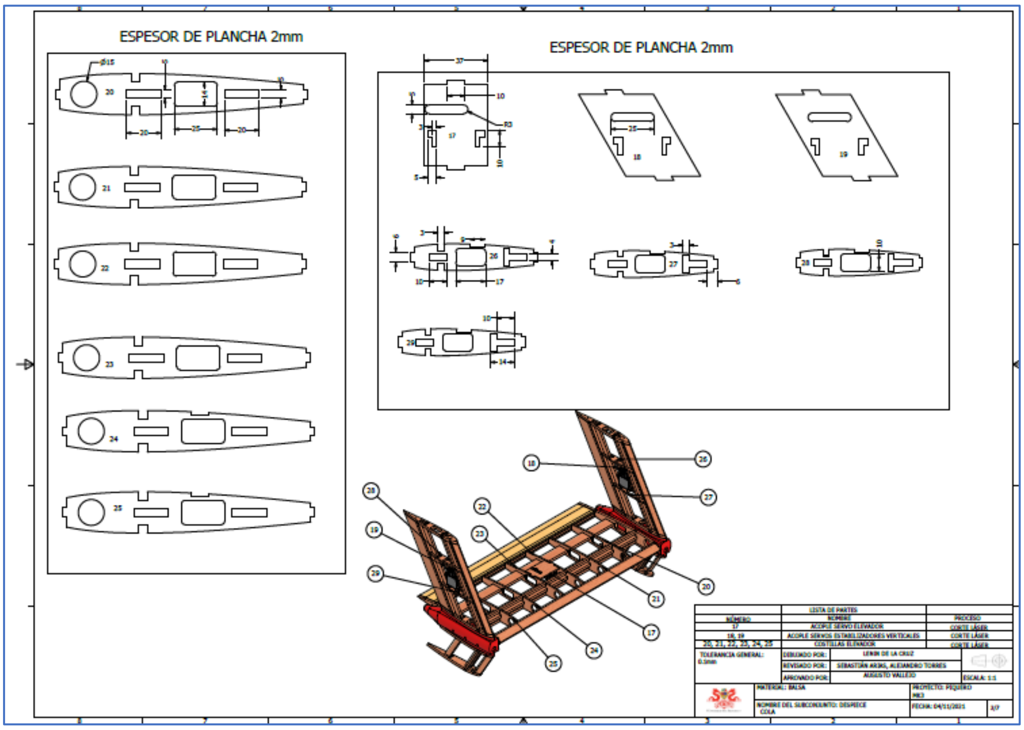


Figure 46 Tail assembly

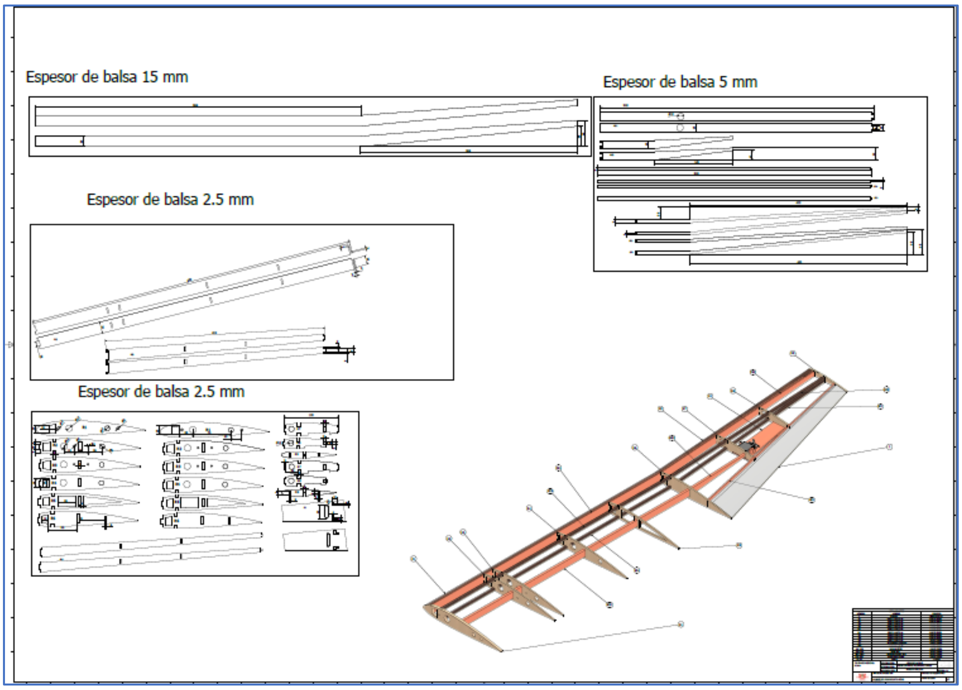


Figure 47 Wing assembly

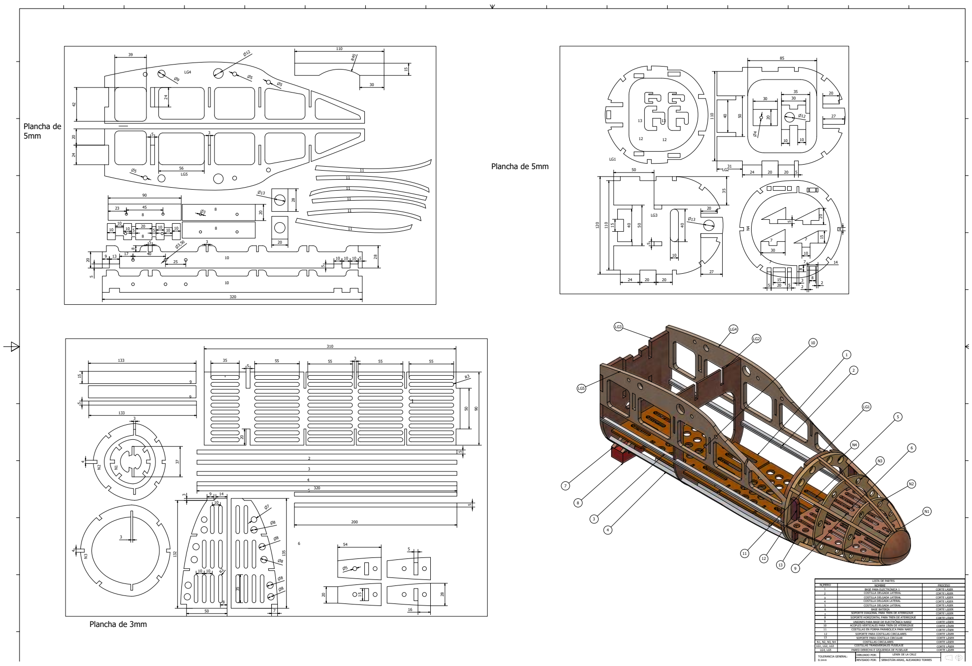


Figure 48 Fuselage Assembly

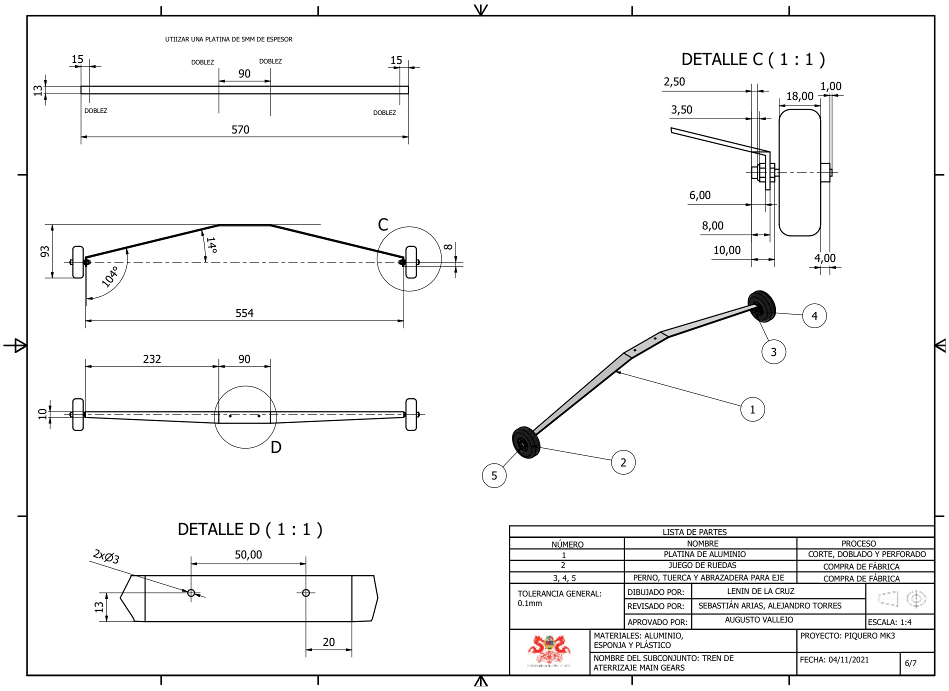


Figure 49 Landing Gear

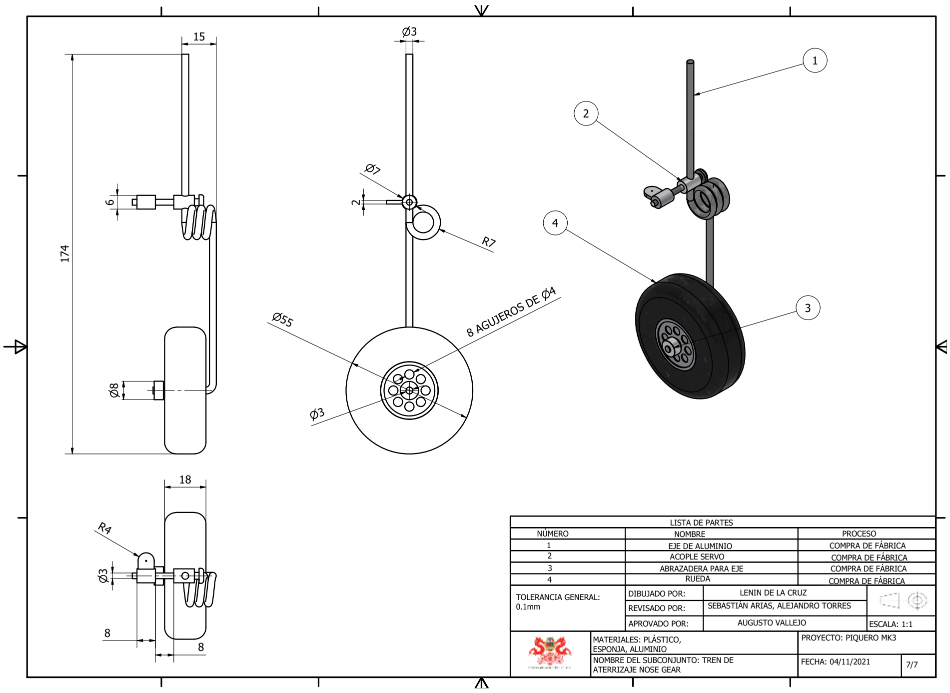


Figure 50 Front Wheel

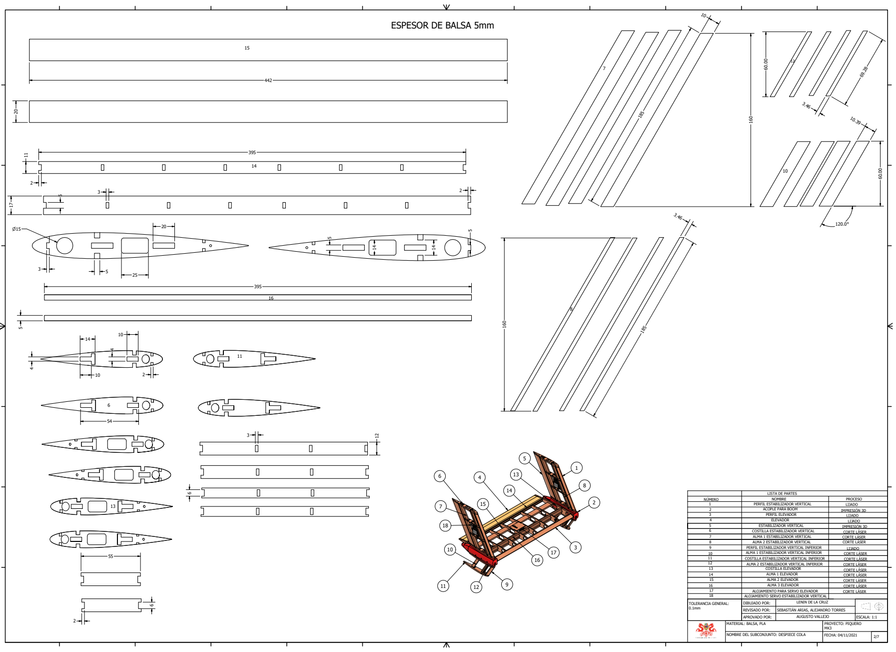


Figure 51 Technical Drawing for Laser Cutting

ANEXE B: OPERATION AND MAINTENANCE

Maintenance and Operating Manual

Operation:

1. Description and features:

   The Mini Piquero MK3 is an unmanned aerial vehicle which is maneuvered by a remote controller and a receiver. The range of control for the vehicle is from 200 to 400 meters in a radial distance. Furthermore, the UAV was designed to fly at about 30 meters above the ground level. The flight time estimated was of about 20 minutes; however, it is recommended to use it for 15 minutes only. Time flight adjustments may be applied by choosing a larger battery.

2. Steps of operation:
   a. Remove the 3D fuselage pieces
   b. Make sure the battery is charged
   c. Make sure the battery is connected to the speed controller and to the receiver.
   d. Make sure that the thrust joystick in the remote controller is at its minimum and turn on the controller
   e. Before activating the propeller, get familiar with the joysticks that move the specific parts of the vehicle (if possible, ask an experienced UAV pilot to operate the Piquero)
   f. Activate the propeller and make sure it is rotating in the correct direction (counterclockwise), otherwise reconnect the speed controller and the motor in a different order
   g. Maneuver the UAV with the remote controller

3. Assembly Drawing: Refer to annex A.
4. Safety information:

- Start operation:
    - Before manipulating the UAV, make sure the remote controller is turned off as well as the battery disconnected from the components
    - Make sure the moving pieces, like the ailerons, are correctly aligned
    - Make sure there is enough space for the plane to maneuver and for take-off
    - Do not touch or place anything close to the propeller since it can cause severe damage, or the motor can get damaged
    - Do not stand in the path of the vehicle

- Shut down:
    - Turn off the remote controller before manipulating the UAV
    - Carefully remove the 3D fuselage pieces to access the electronical components
    - Make sure to disconnect the battery so that it does not waste its energy while not in use
    - Put back the fuselage pieces to cover the inside of the vehicle

- Storage
    - Locate the vehicle at a closed area with enough space for it
    - Leave it laying on its wheels
    - Avoid any objects on top of the UAV

- Variables
    - Avoid flying the vehicle in places with radio interferences (cellphones, electric cables, etc.)

- Avoid flying the UAV with bad weather conditions

Maintenance:

Simple maintenance steps should be performed before and after every flight.

- Battery charge check: after and before every flight the battery charge should be determined. The battery could get discharged differently depending on how the vehicle was maneuvered.
- Servos checking before and after every flight, the servos mobility should be inspected. If any of them do not work correctly, a connection problem might be responsible for this.

Other type of maintenance:

- Parts cohesion: the parts should be well glued and aligned. In case any of the pieces is not correctly aligned, some type of reinforcement should be applied.
- Landing gear revision: landing gear assembly must be examined to determine if it correctly adjusted and aligned.
- Wing integrity: since the tail is sustained by the wings, the later undergoes stresses and forces that might damage the structure after several flights. In case the wing structure is damaged, wing replacement should be considered.

ANEXE C: SAFETY THROUGH DESIGN (RISK ANALYSIS)

Table 21 Risk analysis

Código	Descripción	Prioridad = Impacto x Probabilidad	Responsable	Decisión tomada	Estatus	Observaciones
001	EL encendido de la propela con el motor puede ocasionar cortes en la mano de los operarios.	4x3 = 12	Augusto Vallejo	Evitar: Coger la propela cuando el motor está encendido.	Vigente	Indicar equipo de protección personal.
002	En caso de una colisión del UAV, la propela se rompa y los pedazos se dirigan hacia una persona ocasionando heridas graves	4x3= 12	Lenin De La Cruz	Asegurar: Diseñar una carcaza para asegurar que la propela no se rompa.	Vigente	Indicar materiales necesarios y resistentes para situaciones de colisión.
003	Colision no intencionada con obtaculos o aves durante en la altura de vuelo del UAV.	4x2 = 8	Sebastián Arias	Evitar: Realizar pruebas de vuelo en areas con alto trafico aereo de otros UAVs, con alto trasnito de aves, o con espacio aereo no despejados.	Vigente	Un espacio aereo despejado no debe de contar con estructuras (antenas, lineas de tension, árboles, etc) ni con ningun tipo de trafico aereo.
004	Mal manejo en las maniobras del drone puede ocasionar accidentes o lesiones a las personas de su entorno.	4x3= 12	Alejandro Torres	Evitar: Manejar el drone sin previa experiencia	Vigente	Observar el manual de operaciones donde se detalla el procedimiento de vuelo o solicitar ayuda de un experimentado.
005	Mal ensamblaje del UAV puede ocasionar una separación de las partes durante el vuelo	4x2=8	Lenin De La Cruz	Asegurar: El buen ensamblaje, pegado y ajuste de piezas.	Vigente	Verificar integridad de las piezas después del pegado y ensamblaje con pernos
006	Intento de vuelo en condiciones atmosfericas adversas.	4x1=4	Sebastián Arias	Evitar: Intentar una prueba de vuelo en condiciones atmosfericas poco ideales para el UAV.	Vigente	Condicones adversas atmosfericas pueden concíderarse como lluvias leves o fuertes, vientos con altas velocidades, vientos cruzados, etc.

007	Un corte de energía en la parte electrónica debido a las turbulencias	4x3= 12	Lenin De La Cruz	Asegurar: Los cables mediante amarras plásticas	Vigente	Verificar las conexiones de los cables entre la batería, servos, esc y receptor.
008	Fallo del tren de atterrizaje en el despegue y aterrizaje.	4x3= 12	Alejandro Torres	Asegurar: Que el nuevo diseño del tren de aterrizaje evite los problemas de modelos anteriores y que la pista de aterrizaje sea adecuada.	Vigente	Verificar que la union y los pernos en el tren de aterrizaje no esten flojos, asi como tambien evitar que la pista de aterrizaje presente obstaculos para el UAV o terrenos irregulares.
009	Falla de comunicación entre controlador y receptor en el vuelo o interferencias.	4x2=8	Sebastián Arias	Asegurar: La buena comunicación entre controlador y receptor por medio de pruebas previas en tierra	Vigente	Las pruebas de tiempo prolongado en tierra ayudan a verificar la integridad y buen funcionamiento del controlador y receptor
010	No disponibilidad de elemtos electricos o materiales necesarios para la manufactura del UAV en el país.	4x3= 12	Augusto Vallejo	Asegurar: Que se esten considerando materiales y elemeos electronicos que se puedan adquerir en el pais o importar materiales con aticipación.	Vigente	Siempre considerar que en el caso de una importacion el cambio del material o elemento será mas complicado y tomara más tiempo.
011	Mala districución de pesos produciendo inestabilidad de vuelo.	4x3= 12	Augusto Vallejo	Asegurar: Que la posición de los componentes en el UAV no provoquen un desbalance y diferencia significativa de pesos mediante el balance de aeronaves y reposicionamiento de componentes.	Vigente	Antes de realizar las prueba de vuelo se debe asegurar la estabilidad del avion, teniendo claro cual es su centro de gravedad, centro aerodinamico, partes más pesadas, etc.
012	Multas y sanciones por vuelo en espacios no autorizados.	4x1=4	Alejandro Torres	Asegurar: Que el aerea donde se vaya a realizar las pruebas de vuelo sean designadas para el vuelo de UAVs.	Vigente	Las pruebas de vuelo no seran realizadas en espacios como universidades, calles de la ciudad, parques publicos. Siempre buscar espacios donde no hayan sanciones por volar UAVs o desginados para estos.

ANEXE D: BINDER COMPONENTS AND GANTT CHART

Table 22 Binder components and activities

Task	Start date	Duration in days	End date
Read previous investigations and designs	9/9/21	7	16/9/21
Designation of the group leader	10/9/21	1	11/9/21
Design selection	15/9/21	6	21/9/21
Design	22/9/21	8	30/9/21
Purchase of components	25/9/21	25	20/10/21
Simulations	30/9/21	8	8/10/21
cutting process for balsa wood	1/10/21	10	11/10/21
Wings assembly	12/10/21	7	19/10/21
Airframe assembly	12/10/21	7	19/10/21
Tail assembly	12/10/21	7	19/10/21
Electric components assembly	20/10/21	5	25/10/21
General assembly	20/10/21	5	25/10/21
UAV balancing	27/10/21	3	30/10/21
Controller programming	2/11/21	3	5/11/21
Ground test	10/11/21	5	15/11/21
Final adjustments	20/11/21	25	15/12/21
Final fligth test	16/11/21	1	17/11/21
Project presentation	21/12/21	1	22/12/21
Start date	9/9/21		
End date	21/12/21		

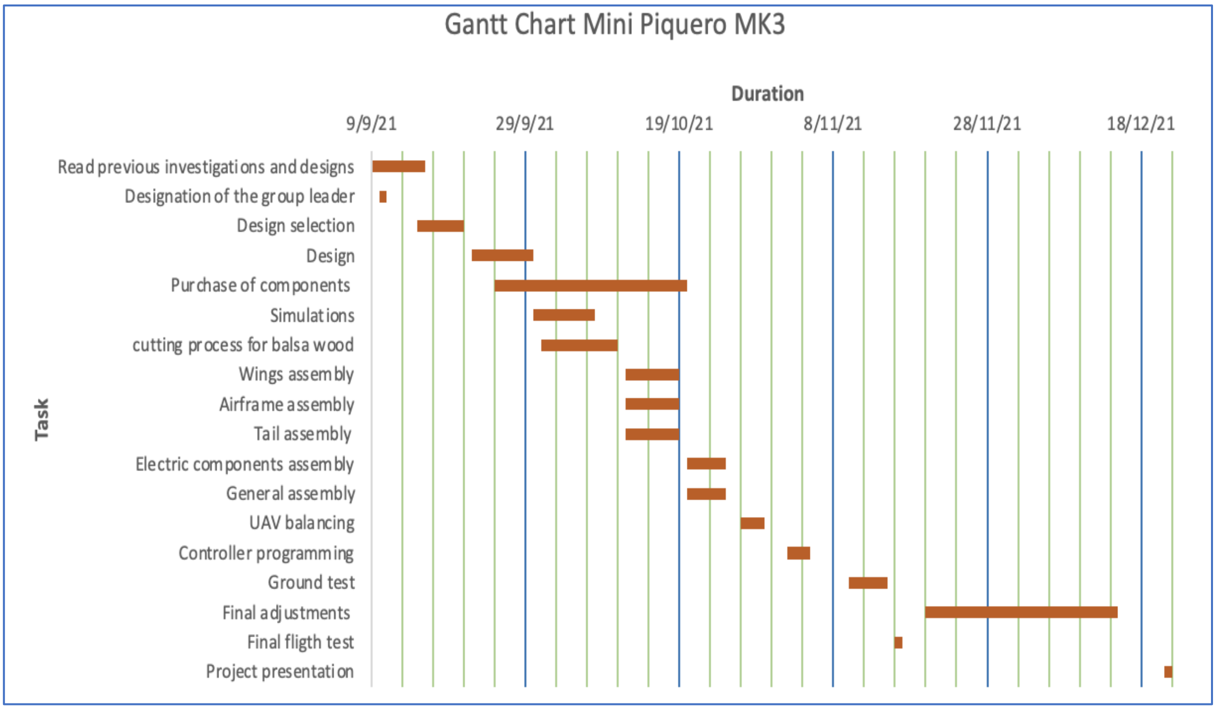


Figure 52 Gantt chart for the redesign and construction of the UAV Mini Piquero MK3

ANEXE E: FULL BUDGET AND EXPENSES

UNIVERSIDAD SAN FRANCISCO DE QUITO

Formulario de Reembolso y Liquidación de Gastos

SOLICITADO POR: Alfredo Valarezo

CARRERA / AREA: Ingeniería Mecánica — CENTRO DE COSTOS: 21204

Proyectos Capstone

TIPO DE GASTO

Docencia Nacional: 101000002 — Docencia Internacional: 101000003

Investigación: / Vinculación: Código Proyecto: — HUBI

Evento: Código Evento:

Administrativo: 501000001

Nº	FECHA DEL DOCUMENTO	NOMBRE DEL PROVEEDOR	No.FACTURA	TIPO DE GASTO	VALOR	PARA USO INTERNO VALOR NO REEMBOLSADO
1	11/11/2021	AUGUSTO GABELA *	7014	SUMINISTROS	33,50	
2	11/11/2021	AUGUSTO GABELA *	7013	SUMINISTROS	32,50	
3	11/11/2021	AUGUSTO GABELA *	7012	SUMINISTROS	36,00	
4	11/11/2021	ORTIZ VEGA NELSON FABIAN *	3,004E+12	SUMINISTROS	10,40	
5	09/11/2021	JUAN HIDROBO *	38739	SUMINISTROS	7,14	
6	16/11/2021	SETECO *	400190224	SUMINISTROS	19,92	
7	10/11/2021	FYBECA *	1,18001E+14	SUMINISTROS	5,04	
8	10/11/2021	LIZARZABURU HERNAN *	14035	SUMINISTROS	62,12	
9	11/11/2021	FYBECA *	1,18001E+14	SUMINISTROS	4,59	
10	16/11/2021	ORTIZ VEGA NELSON FABIAN *	3,004E+12	SUMINISTROS	24,20	
11	19/11/2012	GUERRERO DIAZ MARCO VINICIO	13662	SUMINISTROS	1,60	
12	22/11/2021	COMERCIAL CANOLASTRA CIA LTDA.	7,001E+12	SUMINISTROS	12,36	
13	10/22/2021	FYBECA	118001001052235	SUMINISTROS	2,76	
14						
15						
16						
17						
18						
19						
20						
21						
22						

TOTAL GASTOS 252,13

RESUMEN DE GASTOS:	
ALIMENTACION	-
TRANSPORTE	-
HOSPEDAJE	-
INSCRIPCION	-
PASAJES AEREC	-
SUMINISTROS	252,13
OTROS	-
TOTAL	252,13

Alfredo Valarezo

FIRMA DEL SOLICITANTE

NOMBRE FIRMA DE APROBACIÓN

22-NOV-2021

Eduardo Alv

Figure 54 Refund and Liquidation

Fybeca
Única en tu vida

R.U.C.: 1790710319001

FACTURA

No. 118-001-001052235

NÚMERO DE AUTORIZACIÓN
1011202101179071031900121180010010522355658032314

FARMACIAS Y COMISARIATOS DE MEDICINAS S.A. FARCOMED

FYBECA PASEO SAN FRANCISCO

Dirección Matriz2: KM CINCO Y MEDIO AV DE LOS SHYRIS N SN Y SECUNDARIA

Dirección Sucursal: PASAJE A SN Y VIA INTEROCEANICACC.PASEO SAN FRANCISCO SN VIA INTEROCEANICA

Contribuyente Especial Nro 5368

OBLIGADO A LLEVAR CONTABILIDAD SI

AMBIENTE: PRODUCCION

EMISIÓN: NORMAL

CLAVE DE ACCESO
1011202101179071031900121180010010522355658032314

Razón Social / Nombres y Apellidos: VALAREZO GARCES ALFREDO GUILLERMO
Identificació 1713449377
Fecha Emisión: 10/11/2021 — Guía Remisión:

Cod. Principal	Cod. Auxiliar	Cant	Descripción	Detalle Adicional	Precio Unitario	Descuento	Precio Total
100134231		1.00	PILAS ALCALINAS ENERGIZER B&CPILAS ALCALINAS ENERGIZER CR 2032 X2 UND		2.4600	0.00	2.46

Información Adicional

DESCUENTO 0
DOCUMENTO INTERNO 1269670
EMAIL avalarezo@usfq.edu.ec

SUBTOTAL 12%	2.46
SUBTOTAL 0%	0.00
SUBTOTAL No objeto de IVA	0.00
SUBTOTAL Exento de IVA	0.00
SUBTOTAL SIN IMPUESTOS	2.46
TOTAL Descuento	0.00
ICE	0.00
IVA 12%	0.30
IRBPNR	0.00
PROPINA	0.00
VALOR TOTAL	2.76

Forma Pago	Valor	Plazo	Tiempo
SIN UTILIZACION DEL SISTEMA FINANCIERO	2.76		

Figure 53 Expenses Bill

Fybeca
Única en tu vida

R.U.C.: 1790710319001
FACTURA
No. 118-001-001052334
NÚMERO DE AUTORIZACIÓN
1011202101179071031900121180010010523345658032312
AMBIENTE: PRODUCCION
EMISIÓN: NORMAL
CLAVE DE ACCESO
1011202101179071031900121180010010523345658032312

FARMACIAS Y COMISARIATOS DE MEDICINAS S.A. FARCOMED
FYBECA PASEO SAN FRANCISCO
Dirección Matriz2: KM CINCO Y MEDIO AV DE LOS SHYRIS N SN Y SECUNDARIA
Dirección Sucursal: PASAJE A SN Y VIA INTEROCEANICACC.PASEO SAN FRANCISCO SN VIA INTEROCEANICA
Contribuyente Especial Nro 5368
OBLIGADO A LLEVAR CONTABILIDAD SI

Razón Social / Nombres y Apellidos: VALAREZO GARCES ALFREDO GUILLERMO
Identificació 1713449377
Fecha Emisión: 10/11/2021
Guía Remisión:

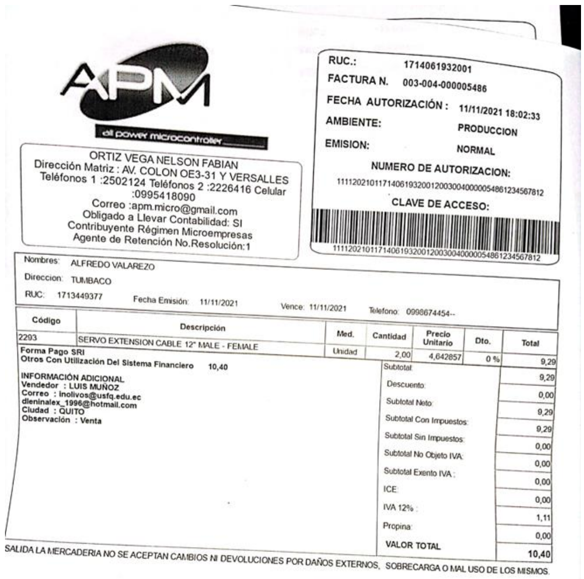
Cod. Principal	Cod. Auxiliar	Cant	Descripción	Detalle Adicional	Precio Unitario	Descuento	Precio Total
29167		1.00	PEGA INSTANTANEA B&CPEGA INSTANTANEA LA BRUJITA 5 GR.NUEVA		4.5000	0.00	4.50

Información Adicional
DIRECCION COLON 720 Y DIEGO DE
DESCUENTO 0
DEDUCIBLE ESCOLARES 4.5
DOCUMENTO INTERNO 1269770
EMAIL avalarezo@usfq.edu.ec

SUBTOTAL 12%	4.50
SUBTOTAL 0%	0.00
SUBTOTAL No objeto de IVA	0.00
SUBTOTAL Exento de IVA	0.00
SUBTOTAL SIN IMPUESTOS	4.50
TOTAL Descuento	0.00
ICE	0.00
IVA 12%	0.54
IRBPNR	0.00
PROPINA	0.00
VALOR TOTAL	5.04

Forma Pago	Valor	Plazo	Tiempo
TARJETA DE CRÉDITO	5.04	0	MESES

Figure 55 Expenses Bill 1



APM
all power microcontroller

ORTIZ VEGA NELSON FABIAN
Dirección Matriz : AV. COLON OE3-31 Y VERSALLES
Teléfonos 1 :2502124 Teléfonos 2 :2226416 Celular :0995418090
Correo :apm.micro@gmail.com
Obligado a Llevar Contabilidad: SI
Contribuyente Régimen Microempresas
Agente de Retención No.Resolución:1

RUC.: 1714061932001
FACTURA N. 003-004-000005486
FECHA AUTORIZACIÓN : 11/11/2021 18:02:33
AMBIENTE: PRODUCCION
EMISION: NORMAL
NUMERO DE AUTORIZACION:
1111202101171406193200120030040000054861234567812
CLAVE DE ACCESO:
1111202101171406193200120030040000054861234567812

Nombres: ALFREDO VALAREZO
Direccion: TUMBACO
RUC: 1713449377 Fecha Emisión: 11/11/2021 Vence: 11/11/2021 Telefono: 0998674454--

Código	Descripción	Med.	Cantidad	Precio Unitario	Dto.	Total
2293	SERVO EXTENSION CABLE 12" MALE - FEMALE	Unidad	2,00	4,642857	0 %	9,29

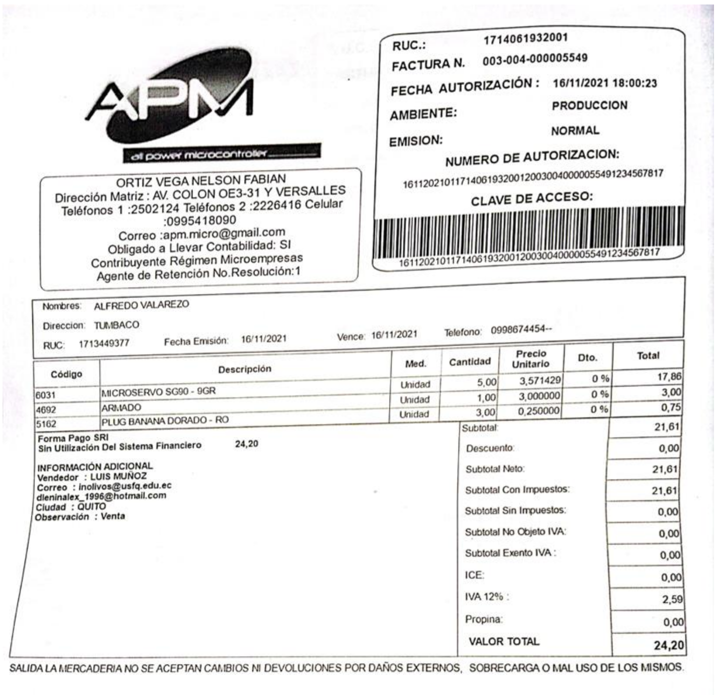
Forma Pago SRI
Otros Con Utilización Del Sistema Financiero 10,40

INFORMACIÓN ADICIONAL
Vendedor : LUIS MUÑOZ
Correo : lnolivos@usfq.edu.ec
dleninalex_1996@hotmail.com
Ciudad : QUITO
Observación : Venta

Subtotal	9,29
Descuento	0,00
Subtotal Neto	9,29
Subtotal Con Impuestos	9,29
Subtotal Sin Impuestos	0,00
Subtotal No Objeto IVA	0,00
Subtotal Exento IVA :	0,00
ICE	0,00
IVA 12% :	1,11
Propina	0,00
VALOR TOTAL	10,40

SALIDA LA MERCADERIA NO SE ACEPTAN CAMBIOS NI DEVOLUCIONES POR DAÑOS EXTERNOS, SOBRECARGA O MAL USO DE LOS MISMOS.

Figure 56 Expenses Bill 2



APM
all power microcontroller

ORTIZ VEGA NELSON FABIAN
Dirección Matriz : AV. COLON OE3-31 Y VERSALLES
Teléfonos 1 :2502124 Teléfonos 2 :2226416 Celular :0995418090
Correo :apm.micro@gmail.com
Obligado a Llevar Contabilidad: SI
Contribuyente Régimen Microempresas
Agente de Retención No.Resolución:1

RUC.: 1714061932001
FACTURA N. 003-004-000005549
FECHA AUTORIZACIÓN : 16/11/2021 18:00:23
AMBIENTE: PRODUCCION
EMISION: NORMAL
NUMERO DE AUTORIZACION:
1611202101171406193200120030040000055491234567817
CLAVE DE ACCESO:
1611202101171406193200120030040000055491234567817

Nombres: ALFREDO VALAREZO
Direccion: TUMBACO
RUC: 1713449377 Fecha Emisión: 16/11/2021 Vence: 16/11/2021 Telefono: 0998674454--

Código	Descripción	Med.	Cantidad	Precio Unitario	Dto.	Total
6031	MICROSERVO SG90 - 9GR	Unidad	5,00	3,571429	0 %	17,86
4692	ARMADO	Unidad	1,00	3,000000	0 %	3,00
5162	PLUG BANANA DORADO - RO	Unidad	3,00	0,250000	0 %	0,75

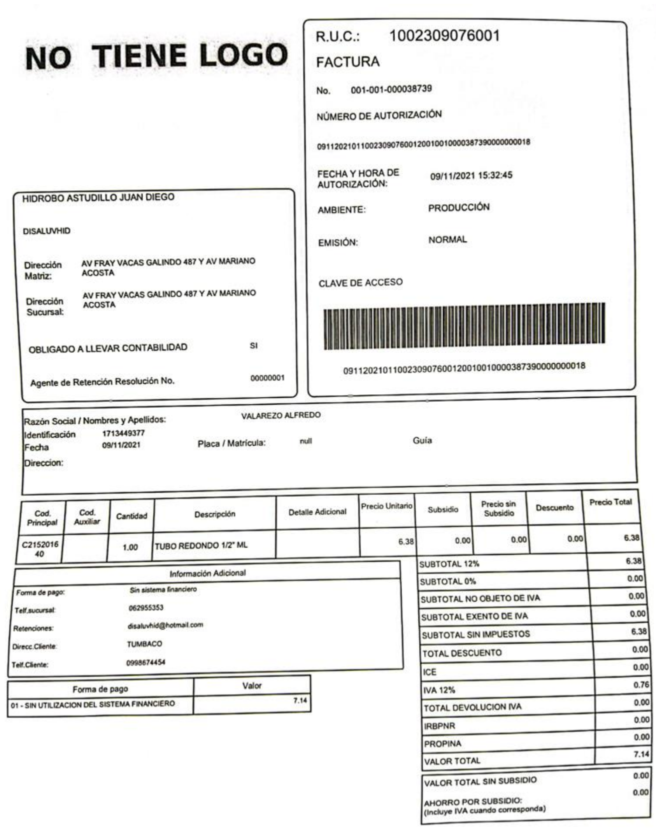
Forma Pago SRI
Sin Utilización Del Sistema Financiero 24,20

INFORMACIÓN ADICIONAL
Vendedor : LUIS MUÑOZ
Correo : inolivos@usfq.edu.ec
dleninalex_1996@hotmail.com
Ciudad : QUITO
Observación : Venta

Subtotal:	21,61
Descuento:	0,00
Subtotal Neto:	21,61
Subtotal Con Impuestos:	21,61
Subtotal Sin Impuestos:	0,00
Subtotal No Objeto IVA:	0,00
Subtotal Exento IVA :	0,00
ICE:	0,00
IVA 12% :	2,59
Propina:	0,00
VALOR TOTAL	24,20

SALIDA LA MERCADERIA NO SE ACEPTAN CAMBIOS NI DEVOLUCIONES POR DAÑOS EXTERNOS, SOBRECARGA O MAL USO DE LOS MISMOS.

Figure 57 Expenses Bill 3



NO TIENE LOGO

R.U.C.: 1002309076001
FACTURA
No. 001-001-000038739
NÚMERO DE AUTORIZACIÓN
0911202101100230907600120010010000387390000000018
FECHA Y HORA DE AUTORIZACIÓN: 09/11/2021 15:32:45
AMBIENTE: PRODUCCIÓN
EMISIÓN: NORMAL
CLAVE DE ACCESO
0911202101100230907600120010010000387390000000018

HIDROBO ASTUDILLO JUAN DIEGO
DISALUVHID
Dirección Matriz: AV FRAY VACAS GALINDO 487 Y AV MARIANO ACOSTA
Dirección Sucursal: AV FRAY VACAS GALINDO 487 Y AV MARIANO ACOSTA
OBLIGADO A LLEVAR CONTABILIDAD SI
Agente de Retención Resolución No. 00000001

Razón Social / Nombres y Apellidos: VALAREZO ALFREDO
Identificación 1713449377
Fecha 09/11/2021 Placa / Matrícula: null Guía
Direccion:

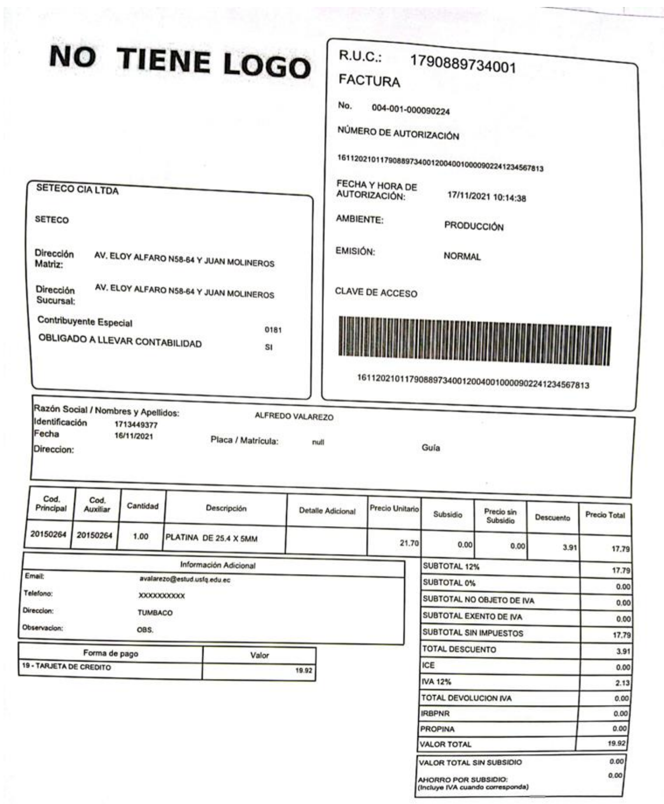
Cod. Principal	Cod. Auxiliar	Cantidad	Descripción	Detalle Adicional	Precio Unitario	Subsidio	Precio sin Subsidio	Descuento	Precio Total
C215201640		1.00	TUBO REDONDO 1/2" ML		6.38	0.00	0.00	0.00	6.38

Información Adicional	
Forma de pago:	Sin sistema financiero
Telf.sucursal:	062955353
Retenciones:	disaluvhid@hotmail.com
Direcc.Cliente:	TUMBACO
Telf.Cliente:	0998674454

Forma de pago	Valor
01 - SIN UTILIZACION DEL SISTEMA FINANCIERO	7.14

SUBTOTAL 12%	6.38
SUBTOTAL 0%	0.00
SUBTOTAL NO OBJETO DE IVA	0.00
SUBTOTAL EXENTO DE IVA	0.00
SUBTOTAL SIN IMPUESTOS	6.38
TOTAL DESCUENTO	0.00
ICE	0.00
IVA 12%	0.76
TOTAL DEVOLUCION IVA	0.00
IRBPNR	0.00
PROPINA	0.00
VALOR TOTAL	7.14
VALOR TOTAL SIN SUBSIDIO	0.00
AHORRO POR SUBSIDIO: (Incluye IVA cuando corresponda)	0.00

Figure 58 Expenses Bill 4



NO TIENE LOGO

R.U.C.: 1790889734001

FACTURA

No. 004-001-000090224

NÚMERO DE AUTORIZACIÓN

1611202101179088973400120040010000902241234567813

FECHA Y HORA DE AUTORIZACIÓN: 17/11/2021 10:14:38

AMBIENTE: PRODUCCIÓN

EMISIÓN: NORMAL

CLAVE DE ACCESO

1611202101179088973400120040010000902241234567813

SETECO CIA LTDA

SETECO

Dirección Matriz: AV. ELOY ALFARO N58-64 Y JUAN MOLINEROS

Dirección Sucursal: AV. ELOY ALFARO N58-64 Y JUAN MOLINEROS

Contribuyente Especial 0181

OBLIGADO A LLEVAR CONTABILIDAD SI

Razón Social / Nombres y Apellidos: ALFREDO VALAREZO

Identificación 1713449377

Fecha 16/11/2021

Placa / Matrícula: null

Guía

Direccion:

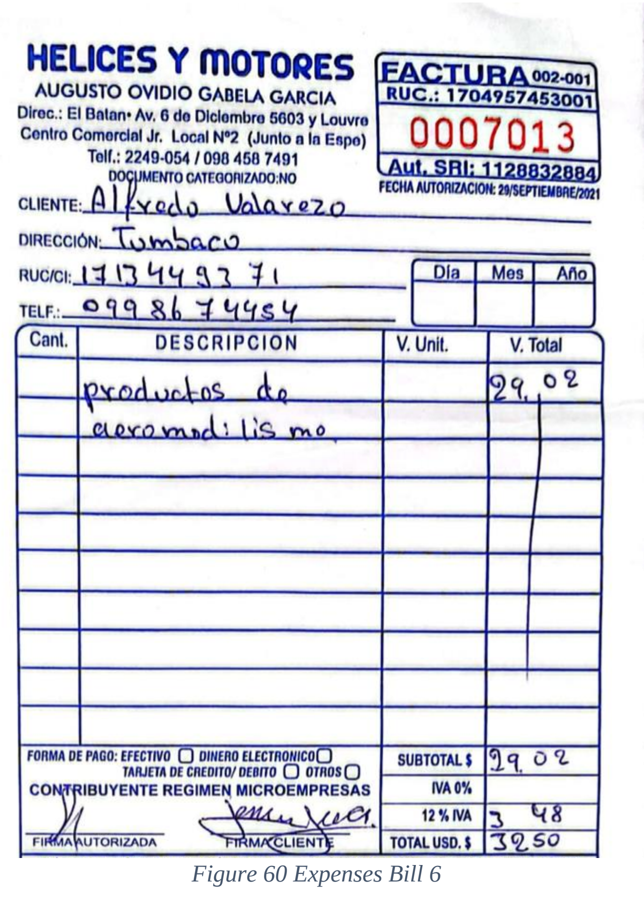
Cod. Principal	Cod. Auxiliar	Cantidad	Descripción	Detalle Adicional	Precio Unitario	Subsidio	Precio sin Subsidio	Descuento	Precio Total
20150264	20150264	1.00	PLATINA DE 25.4 X 5MM		21.70	0.00	0.00	3.91	17.79

Información Adicional	
Email:	avalarezo@estud.usfq.edu.ec
Telefono:	XXXXXXXXXX
Direccion:	TUMBACO
Observacion:	OBS.

Forma de pago	Valor
19 - TARJETA DE CREDITO	19.92

SUBTOTAL 12%	17.79
SUBTOTAL 0%	0.00
SUBTOTAL NO OBJETO DE IVA	0.00
SUBTOTAL EXENTO DE IVA	0.00
SUBTOTAL SIN IMPUESTOS	17.79
TOTAL DESCUENTO	3.91
ICE	0.00
IVA 12%	2.13
TOTAL DEVOLUCION IVA	0.00
IRBPNR	0.00
PROPINA	0.00
VALOR TOTAL	19.92
VALOR TOTAL SIN SUBSIDIO	0.00
AHORRO POR SUBSIDIO: (Incluye IVA cuando corresponda)	0.00

Figure 59 Expenses Bill 5



HELICES Y MOTORES

AUGUSTO OVIDIO GABELA GARCIA

Direc.: El Batan• Av. 6 de Diciembre 5603 y Louvre

Centro Comercial Jr. Local Nº2 (Junto a la Espe)

Telf.: 2249-054 / 098 458 7491

DOCUMENTO CATEGORIZADO:NO

FACTURA 002-001

RUC.: 1704957453001

0007013

Aut. SRI: 1128832884

FECHA AUTORIZACION: 29/SEPTIEMBRE/2021

CLIENTE: Alfredo Valarezo

DIRECCIÓN: Tumbaco

RUC/CI: 1713449371

TELF.: 0998674454

Día	Mes	Año

Cant.	DESCRIPCION	V. Unit.	V. Total
	productos de aeromodilismo		29,02

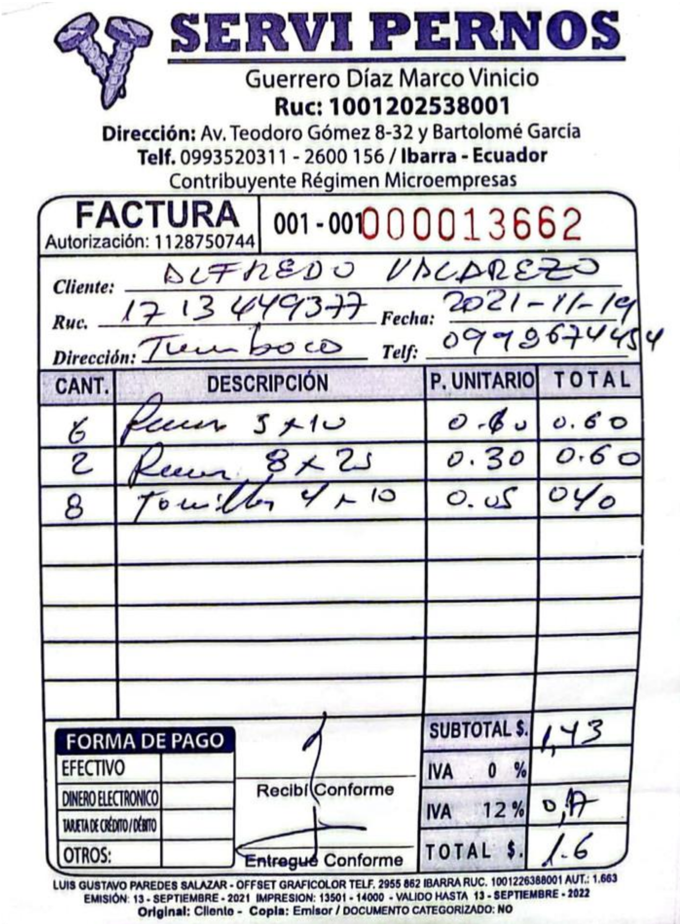
FORMA DE PAGO: EFECTIVO ☐ DINERO ELECTRONICO ☐ TARJETA DE CREDITO/ DEBITO ☐ OTROS ☐

CONTRIBUYENTE REGIMEN MICROEMPRESAS

FIRMA AUTORIZADA FIRMA CLIENTE

SUBTOTAL $	29 02
IVA 0%	
12 % IVA	3 48
TOTAL USD. $	32 50

Figure 60 Expenses Bill 6



SERVI PERNOS
Guerrero Díaz Marco Vinicio
Ruc: 1001202538001
Dirección: Av. Teodoro Gómez 8-32 y Bartolomé García
Telf. 0993520311 - 2600 156 / Ibarra - Ecuador
Contribuyente Régimen Microempresas

FACTURA
Autorización: 1128750744
001 - 001 000013662

Cliente: ALFREDO VALAREZO
Ruc. 1713449377 Fecha: 2021-11-19
Dirección: Tumbaco Telf: 0999674454

CANT.	DESCRIPCIÓN	P. UNITARIO	TOTAL
6	Pernos 5x10	0.10	0.60
2	Pernos 8x25	0.30	0.60
8	Tornillos 4x10	0.05	040

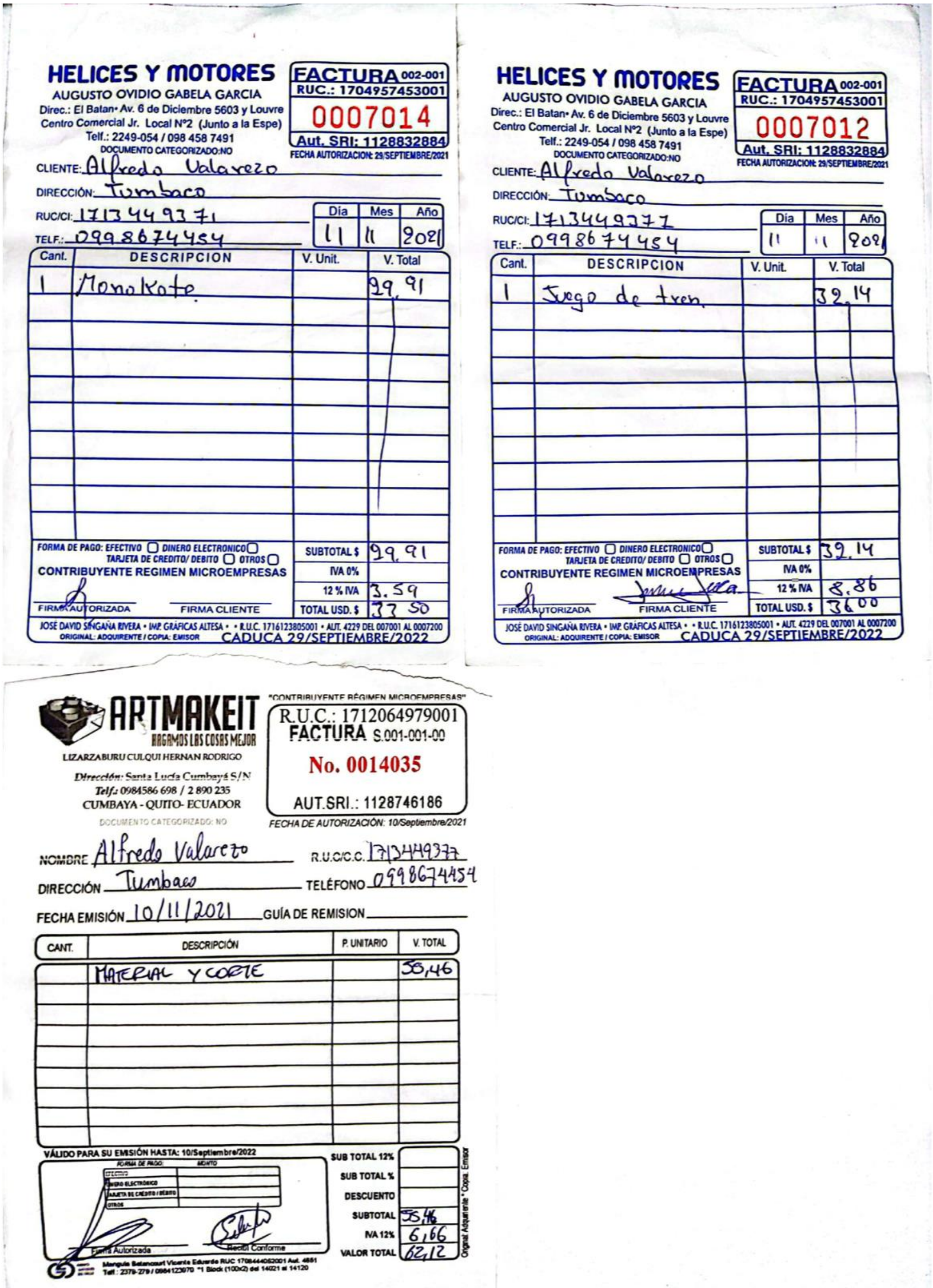
FORMA DE PAGO
EFECTIVO
DINERO ELECTRONICO
TARJETA DE CRÉDITO / DÉBITO
OTROS:

Recibí Conforme
Entregué Conforme

SUBTOTAL $. 1,43
IVA 0 %
IVA 12 % 0,17
TOTAL $. 1.6

LUIS GUSTAVO PAREDES SALAZAR - OFFSET GRAFICOLOR TELF. 2955 862 IBARRA RUC. 1001226388001 AUT.: 1.663
EMISIÓN: 13 - SEPTIEMBRE - 2021 IMPRESION: 13501 - 14000 - VALIDO HASTA 13 - SEPTIEMBRE - 2022
Original: Cliente - Copia: Emisor / DOCUMENTO CATEGORIZADO: NO

Figure 61Expense Bill 7



HELICES Y MOTORES
AUGUSTO OVIDIO GABELA GARCIA
Direc.: El Batan• Av. 6 de Diciembre 5603 y Louvre
Centro Comercial Jr. Local N°2 (Junto a la Espe)
Telf.: 2249-054 / 098 458 7491
DOCUMENTO CATEGORIZADO:NO

FACTURA 002-001
RUC.: 1704957453001
0007014
Aut. SRI: 1128832884
FECHA AUTORIZACION: 29/SEPTIEMBRE/2021

CLIENTE: Alfredo Valarezo
DIRECCIÓN: Tumbaco
RUC/CI: 1713449371
TELF.: 0998674454

Dia	Mes	Año
11	11	2021

Cant.	DESCRIPCION	V. Unit.	V. Total
1	Monokote		99,91

FORMA DE PAGO: EFECTIVO ☐ DINERO ELECTRONICO☐ TARJETA DE CREDITO/ DEBITO ☐ OTROS☐
CONTRIBUYENTE REGIMEN MICROEMPRESAS

SUBTOTAL $	99,91
IVA 0%	
12 % IVA	3,59
TOTAL USD. $	33,50

FIRMA AUTORIZADA — FIRMA CLIENTE

JOSÉ DAVID SINGAÑA RIVERA • IMP. GRÁFICAS ALTESA • • R.U.C. 1716123805001 • AUT. 4229 DEL 007001 AL 0007200
ORIGINAL: ADQUIRENTE / COPIA: EMISOR CADUCA 29/SEPTIEMBRE/2022

HELICES Y MOTORES
AUGUSTO OVIDIO GABELA GARCIA
Direc.: El Batan• Av. 6 de Diciembre 5603 y Louvre
Centro Comercial Jr. Local N°2 (Junto a la Espe)
Telf.: 2249-054 / 098 458 7491
DOCUMENTO CATEGORIZADO:NO

FACTURA 002-001
RUC.: 1704957453001
0007012
Aut. SRI: 1128832884
FECHA AUTORIZACION: 29/SEPTIEMBRE/2021

CLIENTE: Alfredo Valarezo
DIRECCIÓN: Tumbaco
RUC/CI: 1713449377
TELF.: 0998674454

Dia	Mes	Año
11	11	2021

Cant.	DESCRIPCION	V. Unit.	V. Total
1	Juego de tren		32,14

FORMA DE PAGO: EFECTIVO ☐ DINERO ELECTRONICO☐ TARJETA DE CREDITO/ DEBITO ☐ OTROS☐
CONTRIBUYENTE REGIMEN MICROEMPRESAS

SUBTOTAL $	32,14
IVA 0%	
12 % IVA	3,86
TOTAL USD. $	36,00

FIRMA AUTORIZADA — FIRMA CLIENTE

JOSÉ DAVID SINGAÑA RIVERA • IMP. GRÁFICAS ALTESA • • R.U.C. 1716123805001 • AUT. 4229 DEL 007001 AL 0007200
ORIGINAL: ADQUIRENTE / COPIA: EMISOR CADUCA 29/SEPTIEMBRE/2022

ARTMAKEIT
HAGAMOS LAS COSAS MEJOR
LIZARZABURU CULQUI HERNAN RODRIGO
Dirección: Santa Lucía Cumbayá S/N
Telf.: 0984586 698 / 2 890 235
CUMBAYA - QUITO- ECUADOR
DOCUMENTO CATEGORIZADO: NO

"CONTRIBUYENTE RÉGIMEN MICROEMPRESAS"
R.U.C.: 1712064979001
FACTURA S.001-001-00
No. 0014035
AUT.SRI.: 1128746186
FECHA DE AUTORIZACIÓN: 10/Septiembre/2021

NOMBRE Alfredo Valarezo R.U.C/C.C. 1713449377
DIRECCIÓN Tumbaco TELÉFONO 0998674454
FECHA EMISIÓN 10/11/2021 GUÍA DE REMISION

CANT.	DESCRIPCIÓN	P. UNITARIO	V. TOTAL
	MATERIAL Y CORTE		55,46

VÁLIDO PARA SU EMISIÓN HASTA: 10/Septiembre/2022

FORMA DE PAGO	MONTO
EFECTIVO	
DINERO ELECTRÓNICO	
TARJETA DE CRÉDITO / DÉBITO	
OTROS	

SUB TOTAL 12%	
SUB TOTAL %	
DESCUENTO	
SUBTOTAL	55,46
IVA 12%	6,66
VALOR TOTAL	62,12

Firma Autorizada — Recibí Conforme
Original: Adquirente * Copia: Emisor
Mengula Betancourt Vicente Eduardo RUC 1708444052001 Aut. 4881
Telf.: 2379-279 / 0984123970 *1 Block (100x2) del 14021 al 14120

Figure 62 Expenses Bill 8

ANEXE F: CALCULATIONS AND RESULTS

Table 23 Air properties and aerodynamic results

AIR PROPERTIES					
height	2013	[m]	q	87.58210559	[SI]
ρ	0.907906	[kg/m3]	Wo	92	[kg]
μ	1.71267E-05	[N*s/m2]	S	1.125	
V∞	13.89	[m/s]	CLmax (3D)	0.933727012	
AR	8		Clmax (2D)	1.037474458	
b	3	[m]			
c	0.375	[m]			
Re	276121.8085				
Re_cruise	3x10^5				

Table 24 Wings results

Wing Load	1.5	lb/ft^2	
Wing Load	7.323645	kg/m^2	
UAV Mass	2.6	kg	
Wing Area	0.35501448	m^2	
Aspect Ratio	12		(6-12)
Span	2.06401883	m	
Chord	0.17200157		(Rectangular wing)
Wing Span	2.07	m	
Wing Chord	0.18	m	
Wing Area	0.3726	m^2	
Horizontal Stab Area (Theoretical)	0.07452	m^2	
Horizontal Stab Chord	0.2	m	
Horizontal Stab Length	0.4	m	
Horizontal Stab Area (Real)	0.08	m^2	
Elevator	0.04	m	

Elevator	0.04	m
Vertical Stab Area (Theoretical)	0.026082	m^2
Vertical Stab Chord	0.2	m
Vertical Stab Length	0.15	m
Vertical Stab Area (Real)	0.03	m^2
Rudder Stab	0.06	m
Ailerons length	0.5175	
Ailerons width	0.054	
Wing LE to Horizontal Stab LE	0.414	

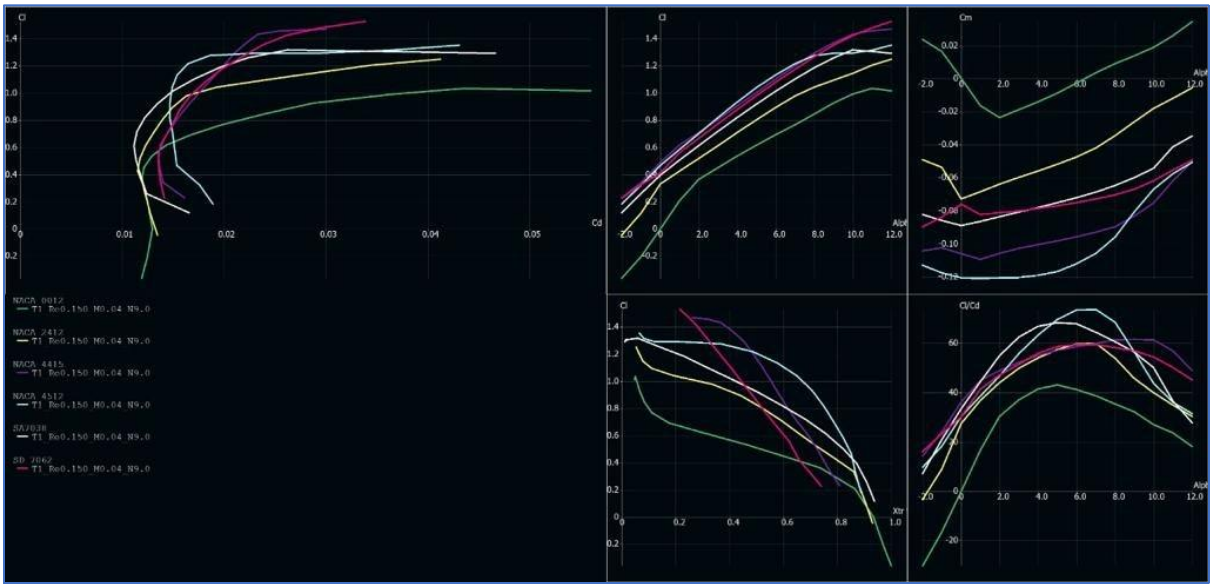


Figure 63 Airfoils aerodynamic coefficients curves