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**Conception et réalisation d'un mini Drone  
à Voilure Fixe**

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Faculty of Technology  
Institute of Aeronautics and Space Studies**



## **THESIS**

**In Partial Fulfillment of the Requirements for the  
Degree of Master in Aeronautics  
Specialty: Propulsion**

# **Design and realization of mini Drone Fixed-Wing**

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## *Acknowledgment*

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*Alacene Hachache*



## *Dedicate*

*With a blissful joy and an alarming happiness that I dedicate this humble work,  
fruit of moments of pain and glory:*

*To my dear mother and my brother*

*To my best uncle and my best doctor*

*To All my three families; my small family, my friends and my teachers.*

*To Dr. Ben Lahrech Md Cherif.*

## تلخيص

يتمحور موضوع التخرج حول دراسة، تصميم وتصنيع طائرة بدون طيار ذات شراع ثابت من الفئة الصغيرة وذات مهمة خاصة بالاستطلاع، الاستكشاف والتحقيق فيما يخص التلوث البيئي عن طريق حملها لأجهزة خاصة بهذا الأخير، تتميز هذه الطائرة بهيكل خفيف من مواد مركبة اذ يبلغ وزنها الكلي أقل من 4 كيلو غرامات ونصف، مزودة بكاميرا معدة للبت المباشر، بمحركين كهربائيين ذات اقلاع يدوي او بواسطة منصة إطلاق وخطاف كوسيلة للهبوط.

## الكلمات المفتاحية

طائرة بدون طيار، الاستطلاع والاستكشاف والتحقيق، تصميم، تصنيع وبناء طائرة

## Abstract

The purpose of this thesis is the study, design and manufacture of mini unmanned aerial vehicle (UAV) fixed-wing with a mission to investigate, reconnaissance and exploration environmental pollution by carrying special equipment. The aircraft is characterized by a lightweight structure of composite materials with a total weight less than 4 kg and half, equipped with a camera for direct transmission, two electric engines with a manual takeoff or by a launch pad and hook as a means of landing.

## Key words

Mini unmanned aerial vehicle (UAV), UAV study, design and manufacture.

## Résumé

Le sujet de la graduation est l'étude, la conception et la fabrication de mini-véhicules aériens sans pilote pour une mission d'enquête, reconnaître et d'explorer la pollution de l'environnement en portant des équipements spéciaux. L'avion est caractérisé par une structure légère en matériaux composites d'un poids total inférieur à 4 kg et un demi, équipé d'une caméra pour la transmission directe, de deux moteurs électriques à décollage manuel ou par une rampe de lancement et un crochet comme moyen d'atterrissage.

## Mots clés

Mini véhicule aérien sans pilote, étude, conception et fabrication d'UAV

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## LISTE OF SYMBOLS

<u>SYMBOLS</u>	<u>DESCRIPTION</u>
<b>A</b>	
$\alpha$	Angle of attack
$a$	Lift curve slope
<b>ac</b>	Aerodynamic center
<b>AR</b>	Aspect ratio
$AR_h$	Horizontal tail aspect ratio
$AR_v$	Vertical tail aspect ratio
<b>B</b>	
$\beta$	Descent angle
$b$	Wing span
$b_a$	Aileron span
$b_{ia}$	Aileron inner distance
$b_{oa}$	Aileron outer distance
<b>C</b>	
$C, C_w$	Wing chord
$\bar{c}, mac$	Main aerodynamic chord
$C_d$	Drag coefficient (profile)
$C_D$	Drag coefficient (aircraft)
$C_{D_0}$	Drag coefficient (aircraft) zero lift
$C_f$	Friction coefficient
$C_l$	Lift coefficient (profile)
$C_{l_\alpha}$	Lift curve slope (profile)
$C_L$	Lift coefficient (aircraft)
$C_{L_\alpha}$	Lift curve slope (Aircraft)
$C_m$	Moment coefficient
$C_{m_0}$	Moment coefficient at zero lift
$C_T$	Propeller thrust coefficient
$C_P$	Propeller power coefficient
<b>CG</b>	Aircraft center of gravity
<b>D</b>	
$D$	Propeller diameter
<b>G</b>	
$G(s)$	Open loop transfer function
$g$	Gravity
$\delta$	Control surface deflection angle
<b>H</b>	
$h_x, h_y, h_z$	$\vec{h}$ Components with XYZ
<b>I</b>	

$i$	Incidence angle
$i_h$	Horizontal tail construction angle
$I_{xx}, I_{yy}, I_{zz}$	Inertial moments with XYZ
$L$	Lift
$L_h$	Distance from aircraft CG to horizontal tail ac
$\lambda$	Taper Ratio
$M$	Mach number
$m$	Mass
$Q$	Dynamic pressure
$\bar{q}$	Dynamic pressure
$S$	Wing surface
$S, S_w$	Wing surface
$S_h$	Horizontal tail surface
$S_v$	Vertical tail surface
$S_a$	Aileron surface
$S_e$	Elevator surface
$S_r$	Rudder surface
$T$	Thrust
$T$	Thrust
$W$	Aircraft weight
$W$	Aircraft weight

## LIST OF ABBREVIATION

Symbol	Description
IAES	Institut d'aéronautique et des études spatiales (institute of aeronautics and astronautics)
UAV	Unmanned aerial vehicle
UAS	Unmanned aircraft system
RPV	Remotely piloted vehicles
ISTAR	Intelligence, Surveillance, Target Acquisition and Reconnaissance
VTOL	Vertical Take-Off and Landing
UCAV	Unmanned Combat aerial vehicle
MTOW	Maximum takeoff weight
CAD	Computer-aided design
CFD	Computational fluid dynamic
RC	Remote control
AOA	Angle of attack
3D	Three dimensions
2D	Two dimensions
CG	Center of gravity



## **INTRODUCTION:**

Aircraft or Unmanned Aerial Vehicle (UAV) design is an engineering technique of creating a flying object by considering balance between defined specifications, aspects and requirements. Aerodynamics, structures, weight, payload for a certain mission, production, cost, propulsion systems, stability and control are the main topics in aircraft design process.

The aircraft design process is a progressive procedure which can be described crudely as aircraft sizing and simple weight improvement, analysis, preliminary design and a more detailed optimization process, determination of requirements as well. Figure 1.1 describes the process. These processes incorporates crude subtitles, which are conceptual design, preliminary design and detailed design.

Unmanned Aerial Vehicle (UAV) has been developed and used for myriad practical purposes, from civilian tasks [1] into military missions [2]. UAV is widely used because it is safer and more convenient than manned aerial vehicle [3]. There are some types of UAVs, which are classified by various parameters such as weight, engine type, wing loading, maximum altitude, endurances and ranges. For civilian tasks, people commonly use multirotor type and fixed wing type because of easy-manufacturing.

To take a decision to design this UAV, a lot of odds and certain limiting factors has been taken as a consideration, viz avionics and electronics equipment payload that would need to be encased and secured within the fuselage, the minimum flight time necessary in the other meaning the possibility of carrying a payload (avionics as an example) as long as it can, for the purpose of investigate, reconnaissance and exploration environmental pollution by carrying special equipment in our case.

CAD software played an important role by making the estimation of weight and UAV dimensions and size more clear so it's decrease the marge of errors, the marge of time and the marge of cotes. Simulation of the configuration is a method to extract and confirm the results; furthermore, performance capacity of the design is estimated also.

**INTRODUCTION:**

An **unmanned aerial vehicle (UAV)**, commonly known as a drone, is an aircraft without a human pilot onboard. UAVs are a component of an unmanned aircraft system (UAS); which include a UAV, a ground-based controller, and a system of communications between the two. The flight of UAVs may operate with various degrees of autonomy: either under remote control by a human operator or autonomously by onboard computers. Compared to manned aircraft, UAVs were originally used for missions too "dull, dirty or dangerous" for humans. While they originated mostly in military applications, their use is rapidly expanding to commercial, scientific, recreational, agricultural, and other applications, such as policing, peacekeeping, and surveillance, product deliveries, aerial photography, smuggling, and drone racing. Civilian UAVs now vastly outnumber military UAVs, with estimates of over a million sold by 2015 [4].

**1.1 DEFINITION:**

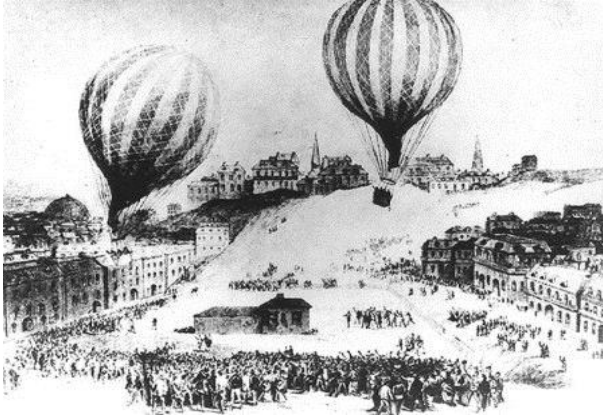
The term *drone*, more widely used by the public, was coined in reference to the early remotely flown target aircraft used for practice firing of a battleship's guns, and the term was first used with the 1920s Fairey Queen and 1930's de Havilland Queen Bee target aircraft. These two were followed in service by the similarly-named Airspeed Queen Wasp and Miles Queen Martinet, before ultimate replacement by the GAF Jindivik.

The term *unmanned aircraft system (UAS)* was adopted by the United States Department of Defense (DoD) and the United States Federal Aviation Administration in 2005 according to their Unmanned Aircraft System Roadmap 2005–2030. The International Civil Aviation Organization (ICAO) and the British Civil Aviation Authority adopted this term, also used in the European Union's Single-European-Sky (SES) Air-Traffic-Management (ATM) Research (SESAR Joint Undertaking) roadmap for 2020. This term emphasizes the importance of elements other than the aircraft. It includes elements such as ground control stations, data links and other support equipment. A similar term is an *unmanned-aircraft vehicle system (UAVS)*, *remotely piloted aerial vehicle (RPAV)*, *remotely piloted aircraft system (RPAS)*. Many similar terms are in use.

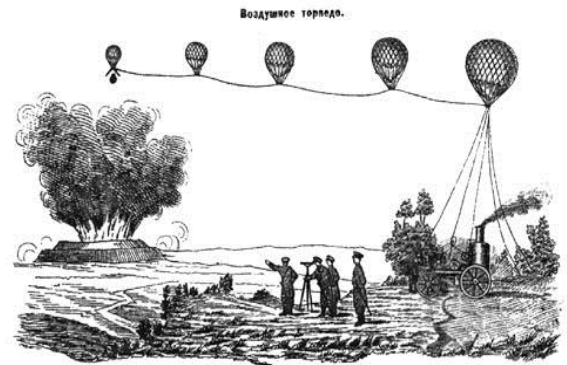
A UAV is defined as a "powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload". Therefore, missiles are not considered UAVs because the vehicle itself is a weapon that is not reused, though it is also unmanned and in some cases remotely guided. The relation of UAVs to remote controlled model aircraft is unclear. UAVs may or may not include model aircraft. Some jurisdictions base their definition on size or weight; however, the US Federal Aviation Administration defines any unmanned flying craft as a UAV regardless of size. For recreational uses, a drone (as opposed to a UAV) is a model aircraft that has first-person video, autonomous capabilities, or both [4].

***1.2 History:***

Unmanned Aerial Vehicles (UAVs) have been around for centuries and were solely used for military purposes. The earliest recorded use of a UAV dates back to 1849 when the Austrians attacked the Italian city of Venice using **unmanned balloons** that were loaded with explosives.



*Fig (I-1). Unmanned Austrians balloons*



*Бомбардировка с аэростата. "Воздушное торпеда" О. С. Костовича.*

*Fig (I-2). Unmanned balloons bomb*

Although balloons would not be considered a UAV today, this was a technology the Austrians had been developing for months before, which led to further advancements. In 1915, British military used aerial photography to their advantage in the Battle of **Neuve Chapelle**. They were able to capture more than 1,500 sky view maps of the German trench fortifications in the region.



*Fig (I-3). The aerial Photography of British military*

The United States began developing UAV technology during the First World War in 1916 and created the first pilotless aircraft. Shortly after, the U.S Army built **the Kettering Bug**. While continuing to develop UAV technology, in 1930 the U.S Navy began experimenting with radio-controlled aircraft resulting in the creation of **the Curtiss N2C-2** drone in 1937. During WWII, Reginald Denny created the first remote-controlled aircraft called **the Radioplane OQ-2**.

This was the first mass produced UAV product in the U.S and was a breakthrough in manufacturing and supply drones for the military.



*Fig (I-4). The Curtiss N2C-2*



*Fig (I-5). The Radioplane OQ-2*

Drones were previously known to be an unreliable and an expensive toy, but in the 1980's this attitude began to change. The Israeli Air Force's victory over the Syrian Air Force in 1982 contributed to this change. Israel used both UAVs and manned aircraft to destroy a dozen of Syrian aircraft with minimal losses. Further, in the 1980's, The U.S created **the Pioneer** UAV Program to fulfil the need for inexpensive and unmanned aircraft for fleet operations. In 1986 a new drone was created from a joint project between the U.S and Israel. The drone was known as **RQ2 Pioneer**, which was a medium sized reconnaissance aircraft.



*Fig (I-6). The RQ2 Pioneer*

More recently, in 1990 miniature and **micro** UAVs were introduced and in 2000 the U.S deployed the Predator drone in Afghanistan while searching for Osama Bin Laden. Although many of the most notable drone flights have been for military purposes, technology is continuing to advance and receive more attention. In 2014, Amazon proposed using UAVs to deliver packages to customers and some real-estate companies are using drones to shoot promotional videos. The uses of drones will continue to grow in many industries worldwide [5].



*Fig (I-7). Micro UAV*



*Fig (I-8). Amazon Drone*

### **I.3 UAV Classifications:**

With a growing number of UAVs being developed and flown in recent years there is the problem of classifying these new UAVs. As UAVs are used in a variety of applications it is difficult to develop one classification system that encompasses all UAVs. It has been decided that the UAVs will be classified into the two main aspects of a UAV, their performance specifications and their mission aspects. The specifications of a UAV include weight, payload, endurance and range, speed, wing loading, cost, engine type and power. The most common mission aspects are ISTAR, Combat, Multi-purpose, Vertical Take-off and landing, Radar and communication relay, and Aerial Delivery and Resupply. It is important to have a classification system for UAVs as when a specific UAV is needed for a mission it can be easily chosen from the wide variety of UAVs available for use.

#### **I.3.1/Classification by Performance Characteristics:**

UAVs can be classified by a broad number of performance characteristics. Aspects such as weight, endurance, range, speed and wing loading are important specifications that distinguish different types of UAVs and give rise to useful classification systems. The cost, wing span and maximum altitude are also features which can be considered to compare and classify UAVs. Further, the engine type and maximum power developed will also be examined and a classification based on these parameters will also be presented. All the UAVs considered in this report are presented in the following table which displays all the performance characteristics mentioned above. This table can be used as a reference to look up specific values of performance for any UAV [6].

Classification by performance characteristics is useful for designers, manufacturers and potential customers because it enables these groups to match their needs with the performance aspects of UAVs.

Important Performance Characteristics:

- a) Weight
- b) Endurance and Range
- c) Maximum Altitude
- d) Wing Loading
- e) Engine Type

a) Classification by Weight:

UAVs cover a wide range of weights, from micro UAVs which weigh only a few pounds, right up to the massive Global Hawk (Tier III) which weighs over 11 tonnes. The following graph shows the weights of all the UAVs considered and it can be seen that there are only a few that weigh more than two tonnes and the majority of UAVs are quite light. Upon examination of the subsequent graphs four classifications are proposed to distinguish UAVs by weight.

*Table (I-1). UAVs classifications by weight*

<u>Designation</u>	<u>Weight Range</u>	<u>Example</u>
Super Heavy	>2000 kg	Global Hawk
Heavy	200 – 2000 kg	A-160
Medium	50 – 200 kg	Raven
Light	5 – 50 kg	RPO Midget
Micro	<5 kg	Dragon Eye

- **The super heavy weight** UAVs which are those with take-off weights of over 2 tonnes. This classification will include the X-45, Darkstar, Predator B and Global Hawk.
- **The heavy weight** UAV which would be UAVs which weigh between 200 and 2000 kg. The ‘heavy weight’ classification would include all UAVs between the Outrider and the Fire Scout.
- **The medium weight** UAV which includes weights 50kg up to 200 kg. This includes the Raven up to the Phoenix. Another classification is the ‘light weight’ UAVs which are between 5 and 50 kg.
- **The micro UAV (MAV)** classification for UAVs under 5 kg. This included the Dragon Eye, FPASS, Pointer and SilentEyes. Many of the other performance characteristics are related to the weight of the UAV. For example more lift and thrust will be needed for increased weight therefore wingspan will increase and the type of power plant chosen will differ. The light weight UAVs use primarily electric motors while the super heavy weights commonly use turbo jets or turbo fan engines [6].

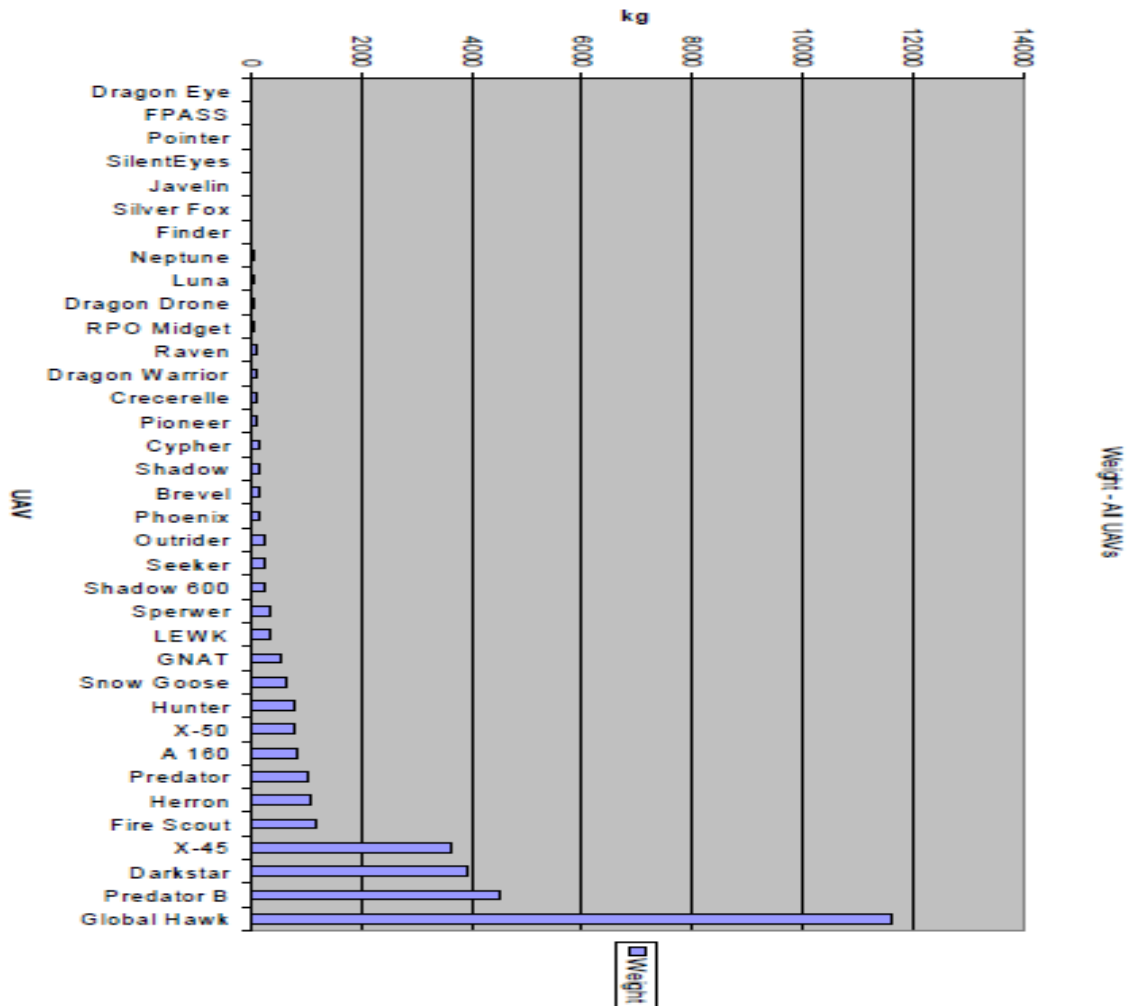


Fig (I-9). some UAVs weight example



Fig (I-10). Global Hawk



Fig (I-11). A-160



*Fig (I-12). Raven*



*Fig (I-13). RPO Midget*



*Fig (I-14). Dragon Eye*

**b) Classification by Endurance and Range:**

Another useful classification method for UAVs is to categorize them by endurance and range. These two parameters are usually interrelated as obviously the longer a UAV can stay airborne the larger its radius of operation is going to be. It is important to consider range and endurance because it enables the UAV designer to determine the type of UAV required depending upon how far the mission objective is from the launch site. Also it determines how regularly refuelling is required and would affect how much time can be spent with the UAV performing its task and how much time it needs to spend grounded [6].

Three classifications are proposed and these are long, medium and short endurance/range.

- **The long endurance** UAVs are those that can stay airborne for 24 hours or more. The range for these UAVs are also high, starting from 1500 km up to 22000 km for the Global Hawk.



- **The medium endurance** UAVs are those with endurance between 5 and 24 hours. These include the shadow 600 up to the Predator. This is the most common type of UAV.
- The third class is **the low endurance** UAV which have less than 5 hours endurance. These are used for short missions such as ‘seeing over the next hill’ which is a safer method of reconnaissance than sending troops into unfamiliar territory.

*Table (I-2). Range and Endurance*

<u>Category</u>	<u>Endurance</u>	<u>Range</u>	<u>Example</u>
High	>24 hours	>1500km	Predator B
Medium	5 – 24 hours	100 – 400 km	Silver Fox
Low	< 5 hours	< 100 km	Pointer



*Fig (I-15). Predator B*



*Fig (I-16). Silver Fox*



Fig (I-17). Pointer

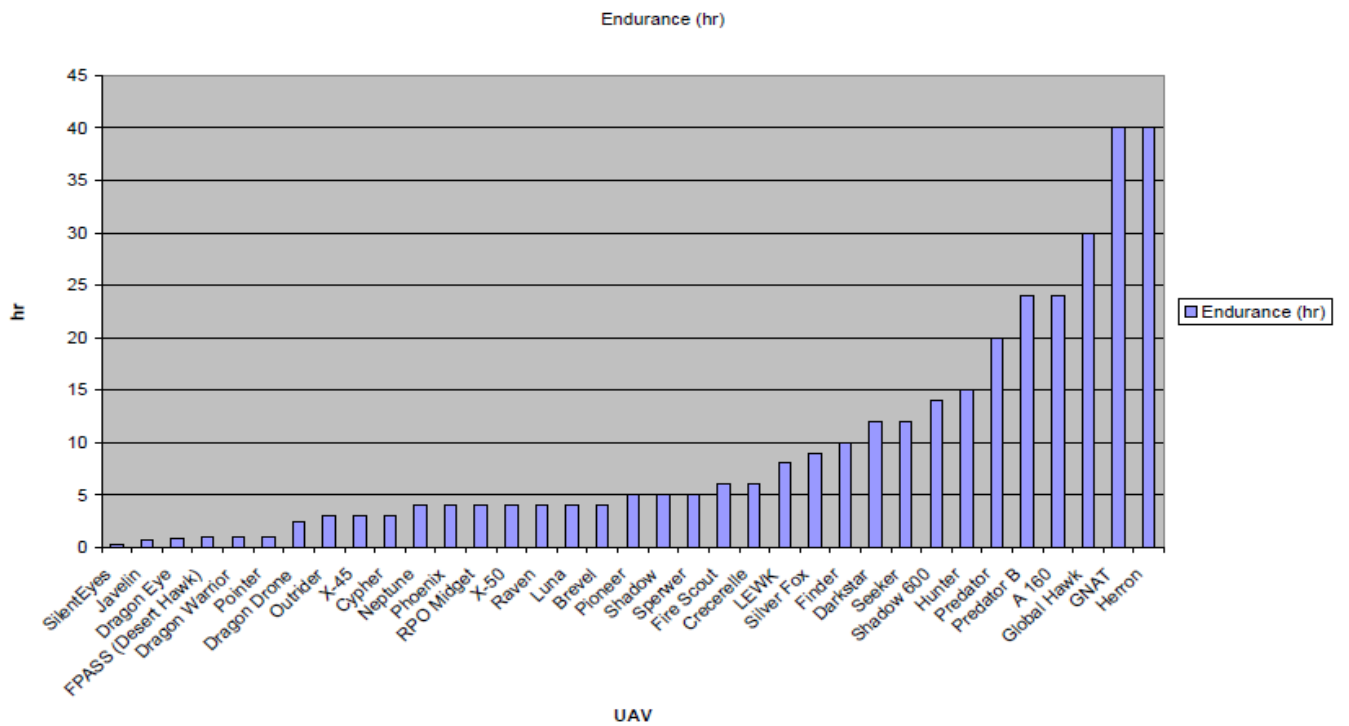


Fig (I-18). UAVs Endurance Example

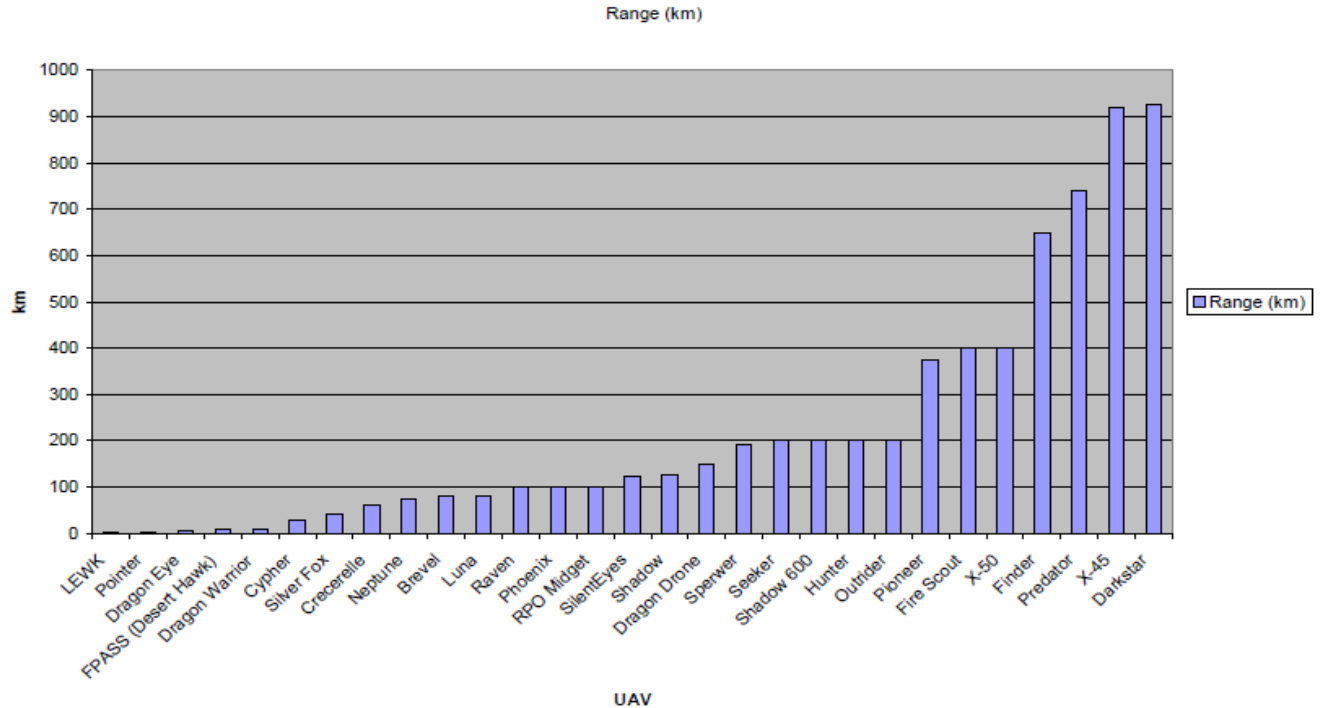


Fig (I-19). UAVs Range Example

### c) Classification by Maximum Altitude:

The maximum operational altitude, or flight ceiling, is another performance measure by which UAVs can be classified. This is also useful for designers or choosing a UAV to purchase so the customer can select a UAV that meets their altitude needs. Some UAVs in military situations are required with low visibility to avoid being detected and destroyed by the enemy therefore high altitude is an important requirement. Also for imaging and reconnaissance a high altitude is required to obtain images of the maximum amount of terrain [6]. A low, medium and high altitude classification is proposed for dividing the UAVs by maximum ceiling.

- **Low altitude** is any UAV that flies up to 1000m. These UAVs are the micro UAVs and include the FPASS, Pointer and Dragon Eye. These UAVs don't have much use at this stage and are primarily experimental.
- **Medium altitude** is the category of UAVs with maximum altitude between 1000m and 10000m. The majority of UAVs fall into this category.
- **High altitude** is all UAVs that can fly over 10000m. This includes the X-45, predator B, Darkstar and Global Hawk. There is concern that these UAVs may interfere with commercial and military manned aircraft and high tech collision avoidance systems are being developed and integrated into these UAVs that fly in populated airspace.

Table (I-3). Classification by Maximum Altitude

<u>Category</u>	<u>Max Altitude</u>	<u>Example</u>
Low	< 1000 m	Pointer
Medium	1000 – 10000 m	Finder
High	> 10000 m	Darkstar



Fig (I-20). Finder



Fig (I-21). Darkstar

#### **d) Classification by Wing Loading:**

Another useful way of classifying UAVs is using their wing loading ability. To calculate the wing loading of a UAV the total weight of the UAV was divided by the wing area.

- For the UAVs consider the wing loading values ranged from 5.34kg/m<sup>2</sup> for the relatively small Dragon Eye, to 211.84kg/m<sup>2</sup> for the high tech X- 50.
- Consequently to classify these UAVs using their wing loading values three classes have been created.
- The UAVs that have a wing loading above 100kg/m<sup>2</sup> are classified to be of high loading.
- For the UAVs that have a wing loading less than 100kg/m<sup>2</sup> but greater than 50kg/m<sup>2</sup>, these will be classified as medium loading.
- While the remaining UAVs with a wing loading of less than 50kg/m<sup>2</sup> will be classified as low loading [6].

Table (I-4). *Classification by Wing Loading*

Category	Wing loading kg/m <sup>2</sup>	Example
Low	<50	Seeker
Medium	50-100	X -45
High	>100	Global Hawk



Fig (I-22). Seeker

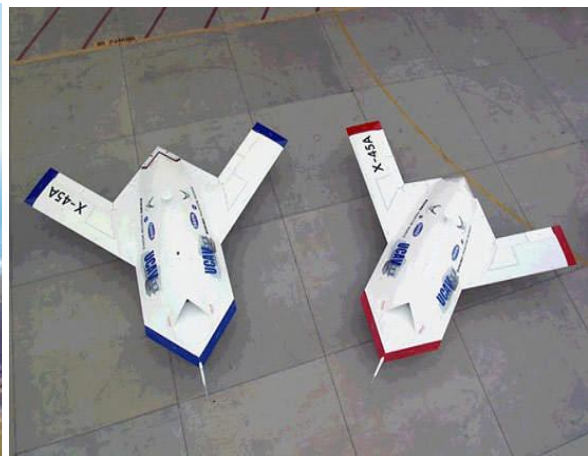


Fig (I-23). X-45

#### **e) Classification by Engine Type:**

As UAVs are used for a variety of different tasks they need different engines to complete these missions.

- Some of the different types of engines found in UAVs are Turbofans, Two strike, Piston, Rotary, Turboprop, Push and Pull, Electric, and Propeller. Out of these engine types the electric and the piston are the most common engines used in the UAVs considered in this project.
- As with the majority of aeronautical applications as the weight of the plane increases so does the size of the engine, this was found to be the same with UAVs.
- The lighter, smaller UAVs tended to use electric motors, while the heavier, battle ready UAV tend to use piston engines.
- Other UAV classifications that are affected by the type of engine in the UAV are endurance and range. A properly chosen engine will increase the endurance and range of a UAV [6].

UEL Rotary	Turbofan	Two- stroke	Piston	Turboprop	Electric	Push & Pull	Prop
Outrider	Global Hawk	Pioneer	Predator	Predator B	Dragon Eye	Hunter	LEWK
Shadow	Darkstar	RPO Midget	Neptune		FPASS		Sperwer
Shadow 600	Phoenix		Dragon Drone		Dragon Warrior		
Cypher	X-45		Finder		Pointer		
	X-50		A 160		Raven		
	Fire Scout		GNAT		Luna		
			Crecerelle		Javelin		
			Seeker				
			Brevel				
			Snow Goose				
			Silver Fox				
			Heron				

Table (I-5). UAVs Engine type

#### **I.4 Mission Aspects:**

Much of the development of unmanned aerial vehicles is military orientated. Different military mission requirements have created various types of UAVs. For this reason, it is often useful to categorize UAVs in terms of their mission capabilities.

According to the UAV Roadmap 2002, mission capabilities can be divided into the following categories:

- a) Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR)
- b) Combat (UCAV)
- c) Multi-Purpose
- d) Vertical Take-Off and Landing (VTOL)
- e) Aerial Delivery and Resupply

#### **a) ISTAR:**

ISTAR is a system using UAVs to gather enemy information, locate target and petrol hostile air space without risking lives of the operators. Often in battles, ground combat commanders require real time information of the upcoming enemy forces. For example, what type of enemy

defence is lying over the next hill? Gathering such information by reconnaissance UAVs is more effective and voids putting soldier lives at risk.

**b) UCAV:**

UCAV stands for unmanned combat aerial vehicles. This category contains aircraft that are highly maneuverable and are able to engage in air to air combat and also provide precision weapon delivery to surface targets. Comparing to the other UAVs, UCAVs have higher cruise speed but often shorter endurance [6].

All UCAVs are currently in experimental and testing stage. The design goals are:

- Engage in deep strikes using precision weapons such as bombs or guided missiles
- Used to complement manned fighter and bomber forces
- Highly adaptable to changing battle conditions
- Can provide 24/7 electronic attack
- Secondary missions include high-risk reconnaissance, surveillance and intelligence gathering
- Be refueled by Air-to-Air Refueling
- Operate independently, fully integrate with manned aircraft operations or execute multi-vehicle coordinated operations.
- Be deployed from one location and controlled by another.

**c) Multi-Purpose:**

Multi-purpose UAVs are usually modified reconnaissance UAVs that are weaponised. Their primary mission is usually interdiction and conducting armed reconnaissance against critical, perishable targets. These UAVs can also and strike using self-guided weapons. When arms are not required for the mission, multi-purpose UAVs are also very capable for reconnaissance, surveillance and target acquisition in support of the Joint Forces commander.

**d) VTOL:**

Vertical take-off and landing UAVs are those that are able to generate downward thrust and take off within very limited space. This section contains UAVs that overlaps with the other categories. However VTOL UAVs are selected to form a class of their own because the unique capability of takingoff and landing vertically is critical for some missions. For missions where run way facilities are inaccessible, such as operations in forest or bush areas, or launching and recovering from non-carrier battleships. Therefore it is obvious that VTOL UAVs are a very important fleet to the military [6].

- Hummingbird Warrior A-160.
- Fire Scout.
- Killer Bee.
- X50.



*Fig (I-24). Fire Scout*



*Fig (I-25). Killer Bee*



*Fig (I-26). X-50*

**e) Aerial Delivery/Resupply:**

The UAV in this category are designed for pin-point delivery of small cargo items such as ammunition and food supplies to Special Forces. The only UAV in this category is the CQ-10 Snow Goose.



*Fig (I-27). CQ-10 Snow Goose.*



- Consists of a central fuselage module which houses payload and fuel.
- GPS-based navigation and control system and the single piston engine driving a pusher propeller.
- Can be air-dropped or launched [6].

### **1.5 Unmanned aerial vehicle (UAV) (Drones) uses, advantages and disadvantages**

#### **1.5.1 UAVs advantages:**

Unmanned aerial vehicles are very popular because mass media networks patronize its functionality and efficiency when capturing videos and images. You will notice that drones are common in touristy areas due to travel blogger promotions. Video bloggers use drones to further increase the popularity of their videos; hence, promoting the device to other new vloggers. Travel companies use drones to maximize the tourism potential of an area that is popular to all tourists. There are many advantages of using Autonomous aircraft such as:

- ✓ It is able to fly into zones where it would be dangerous for a pilot
- ✓ It is capable of flying for long periods of time, while doing repetitive tasks, for up to 30 hours.
- ✓ No need for a qualified pilot to fly it.
- ✓ In the long run, will be cheaper than paying for personnel to do the task, with one Japanese radio-controlled helicopter can do the work of 15 labours [7] [8].

#### **1.5.2 UAVs Disadvantages:**

There are concerns or troubles in drones that affects user's navigation routine. A local government unit sometimes restricts the use of drones when there is an ongoing military conflict. Drones are also blocked from entering a restricted zone such as military facilities that are conducting experimentation and active military training inside their camps. These growing restrictions prompts drone users to consider the rules and regulations of drone usage to a certain area so that they will not be subjected to either ethical or legal violations. User violators are at risk for legal apprehension that could mandate them to pay for financial compensation or imprisonment for several days if caught violating laws.

However, despite the many advantages, there are also numerous disadvantages that need to be considered, such as:

- There is a possibility of a computer malfunction, resulting in the loss of control in the aircraft.
- There is an ethical question on the use of an autonomous system in combat situations, especially as a computer can't take the initiative, which can result in civilian deaths, as seen in March 2009, where 48 civilians were killed in Pakistan by an Israeli UAV.
- A psychological issue has also become apparent in the military use of Unmanned Air Vehicles, due to personnel being able to click a button and kill numerous people, and then go home, without being in a normal war situation [7] [8].

**Conclusion:**

The aim of this chapter is to guide us on the choice provided for in our study. Depending on the field of application and cost, the mini drone type is chosen for the study and the design that will follow in the next chapters

**INTRODUCTION:**

This chapter contains the design of our own UAV that can carry a surveillance, investigation, reconnaissance and exploration payload for a specific mission. The design process includes sizing and aerodynamic overall layout configuration. The choice of the aerial vehicle is inspired from the wide range of mini UAV class, where the skywalker is a leading enterprise in this field.

**II.1 Skywalker Profile:**

Skywalker Technology Co.,Ltd (short for skywalker tech) is an aircraft model enterprise that focused on developments and innovation of aeromodelling technology and integrated design, manufacture with sales. We are aimed at “everyone could easy to fly” and in pursuit of "Aircraft model is no longer a dream of a few people", keeping on creating the most easy product in aeromodelling market. At present, our most popular skywalker FPV series model aircraft have become the first choice among FPV players in the world for its beautiful and smooth appearance, reasonable structure, and excellent flying performance.

It was established in 2009 in Wuhan. Having simple and popular style, it has provided improvable OEM, ODM and self-owned brand. It has rich experience of cooperation with domestic and international model companies. It has faith we can offer professional, efficient and honest purchasing service to all the RC fans and make more and more popular RC products [9].

**II.2 The Main Specifications Desired of The UAV:**

The mission requirements supervise the design of a mini unmanned air vehicle. It is a fixed-wing UAV that must meet our requirements, which are summarized in the following table:

*Table (II-1). UAV Specifications*

	<b><i>Specifications</i></b>
Designated Task	Mini Unmanned Aerial Vehicle (MUAV)
Payload	Total Weight is Less Than 5 kg
Takeoff	Runway takeoff or Rubber Bands launch
Recovery	Runway landing, Recovery Wire Network r Anchor (wire + hook)
Altitude	300 ~ 400 m
Cruise Speed	50 ~ 70 km/h
Range	5 ~ 6 Radius base
Endurance	10 ~ 20 min

### II.3 Statistical Analysis of Available UAVs:

The following tables resume, devise and introduce data collections of UAVs systems which are: Performance, specifications (Weight, Geometry and Propulsion) and fight requirement.

*Table (II-2). Performance of UAVs [10]*

Sn	UAV Systems	Endurance (h)	Range (km)	Ceiling (m)	Service altitude (m)	Cruise speed (km/h)	Loiter speed (km/h)	Maximum speed (km/h)
1	RAVEN	1.5/1.8	10	426	30/152	-	20	57
2	DRAGON EYE	1	5	152	30/152	35	-	35
3	PUMA	4	10	152	30/152	-	25	50
4	SWIFT	1.25	10	150	30/150	-	32	82
5	POINTER	1.5	-	-	-	-	35	80
6	JAVELIN	2	-	300	300	-	32	80
7	EVOLUTION	1.5	-	-	-	48	-	65
8	AZIMUT	2	50	1500	300	50	36	120
9	BIODRONE	2.17	50	1500	300	60	36	120
10	ALADIN	1	5	150	150	-	45	90
11	ORBITER	1.5	15	4500	-	120	46	140

*Table (II-3). Weight, Geometry and Propulsion of UAVs [10]*

Sn	UAV Systems	WEIGHT			GEOMETRY		PROPULSION SYSTEM
		Launch (kg)	Payload (kg)	Empty (kg)	Wing Span (m)	UAV Length (m)	
1	RAVEN	1.9	0.18	1.72	1.4	0.9	Electric
2	DRAGON EYE	2.7	-	-	1.1	0.9	Electric
3	PUMA	5.5	-	-	2.6	1.8	Electric
4	SWIFT	2.8	0.18	2.62	1.1	0.9	Electric
5	POINTER	4.54	0.91	3.63	2.75	1.83	Electric
6	JAVELIN	6.8	-	-	2.44	1.83	Electric
7	EVOLUTION	3.72	0.68	3.04	1.64	0.98	Electric
8	AZIMUT	9	1.2	7.8	2.9	1.82	Electric
9	BIODRONE	12	1.2	10.8	3.4	1.8	Electric
10	ALADIN	3.2	-	-	1.46	1.53	Electric
11	ORBITER	6.5	1.5	5	2.2	1	Electric

The following table represent a different UAV with a different launch methods and different flight modes and navigation.

Table (II-4). Flight Requirement [10]

Sn	UAV Systems	Launch	Flight Modes		Navigation	
			Manual	Autonomous	Autopilot	GPS
1	RAVEN	Hand	Yes	Yes	-	-
2	DRAGON EYE	Hand, Bungee	Yes	Yes	-	-
3	PUMA	Hand	Yes	-	-	-
4	SWIFT	Hand, Bungee	Yes	Yes	-	-
5	POINTER	Hand	Yes	Yes	Yes	Yes
6	JAVELIN	Hand	Yes	-	-	-
7	EVOLUTION	Hand, Bungee	Yes	Yes	Yes	Yes
8	AZIMUT	Hand, Catapult	Yes	-	Three Axes	-
9	BIODRONE	Hand, Catapult	Yes	Yes	Three Axes	Yes
10	ALADIN	Hand, Bungee	Yes	-	Yes	-
11	ORBITER	Hand, Bungee	Yes	-	-	-

**II.4 Mission Analysis:**

Among the most common and dangerous problem that our mother nature suffers from is the pollution with all kinds; whether air, earth or sea and by knowing the problem we can solve it. UAV is the best answer for investigation, reconnaissance and exploration of this phenomenon and the mission requirements enable us to define the desired UAV typical mission, which is broken down into a number of different phases as shown in the figure bellow:

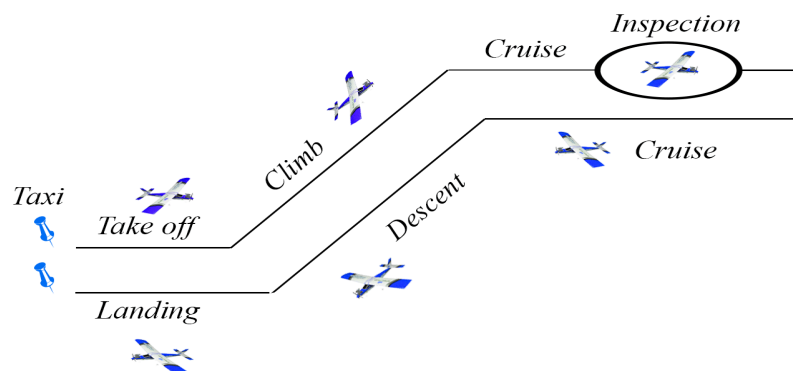
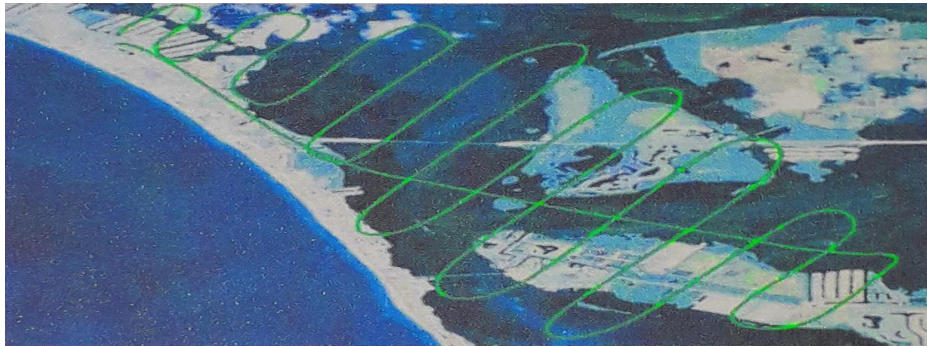


Fig (II-1). Mission Profile

The mission phases are defined as:



*Fig (II-2). Schema of mission profile with sinusoidal way*

**Phase 1: Taxi;** Engine start and warm up.

**Phase 2: Takeoff;** Use rubber band or manually launch and let UAV run on the ground.

**Phase 3: Climb;** UAV rising up on the air until it arrives to the specific altitude.

**Phase 4: Cruise 1;** UAV start its flotation in it specific altitude and specific zone and prepare itself for the desire mission.

**Phase 5: Loiter (inspection);** over the area way or area target required.

**Phase 6: Cruise 2;** back to the launch area.

**Phase 7: Descent;** UAV go down from the cruise level to the operator level preparing itself for touchdown.

**Phase 8: Landing;** which is the final target of our UAV mission when engines shutdown.

## **II.5 Phases of UAV Design:**

### **II.5.1 Conceptual Design:**

UAV design can be broken into three major phases, as depicted in Fig (II-3). Conceptual design is the primary focus of this these. It is in conceptual design that the basic questions of configuration arrangement, size and weight, and performance are answered. Conceptual design is a very fluid process. New ideas and problems emerge as a design is investigated in ever-increasing detail. Each time the latest design is analyzed and sized, it must be redrawn to reflect the new gross weight, batteries weight, wing size, engine size, and other changes. Early wind-tunnel tests often reveal problems requiring some changes to the configuration.

### **II.5.2 Preliminary Design:**

Preliminary design can be said to begin when the major changes are over. The big questions such as whether to use a canard or an aft tail have been resolved. The configuration arrangement can be expected to remain about as shown on current drawings, although minor revisions may occur. At some point in preliminary design, even minor changes are stopped when a decision is made to freeze the configuration.

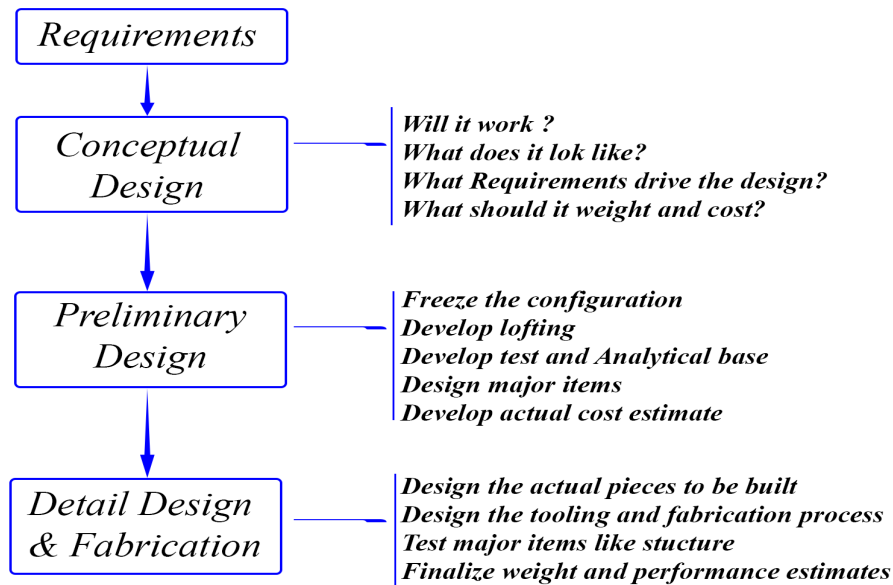


Fig (II-3). Three Phases of Aircraft Design [11].

During preliminary design the specialists in areas such as structures, recovery cable, and control systems will design and analyze their portion of the aircraft. Testing is initiated in areas such as aerodynamics, propulsion, structures, and stability and control. A mockup may be constructed at this point.

A key activity during preliminary design is "lofting." Lofting is the mathematical modeling of the outside skin of the aircraft with sufficient accuracy to insure proper fit between its different parts, even if they are designed by different designers and possibly fabricated in different locations. Lofting originated in shipyards and was originally done with long flexible rulers called "splines." This work was done in a loft over the shipyard; hence the name.

The ultimate objective during preliminary design is to ready the company for the detail design stage, also called full-scale development. Thus, the end of preliminary design usually involves a full-scale development proposal. In today's environment, this can result in a situation jokingly referred to as "you-bet-your-company." The possible loss on an overrun contract or from lack of sales can exceed the net worth of the company! Preliminary design must establish confidence that the airplane can be built on time and at the estimated cost [11].

### II.5.3 Detail Design:

Assuming a favorable decision for entering full-scale development, the detail design phase begins in which the actual pieces to be fabricated are designed. For example, during conceptual and preliminary design the wing box will be designed and analyzed as a whole. During detail design, that whole will be broken down into individual ribs, spars, and skins, each of which must be separately designed and analyzed.

Detail design ends with fabrication of the aircraft. Frequently the fabrication begins on part of the aircraft before the entire detail-design effort is completed. Hopefully, changes to already-fabricated pieces can be avoided [11].

## **II.6 UAV Sizing and Overall Layout:**

### **II.6.1.Configuration selection:**

Our configuration choice was based on Skywalker UAVs, this last enveloped the biggest technological environment in other meaning an analysis was prepared at this level and a decision was made about the configuration choice as summarized in the table below.

*Table (II-5).UAV Configuration*

<i>N</i>	<i>Character</i>	<i>Type</i>
1	Materials	Mainly composite
2	Manufacture	Modular
3	Wing configuration	Cranked wing
4	Wing location	High wing
5	Fixed or retractable	fixed
6	Engine type	Electrical engine
7	Number of engines	Two
8	Engine location	Under wing
9	Tail configuration	T-tail configuration
10	Recovery System	Recovery cable + hook

Recently, the composite materials took a high jump for aeronautical industry, weight is not a problem anymore, and we can provide almost 70% to 80% of knowing weight [12]. After using a fiber of glass and fiber of carbon as a reinforcement proportional to hypoxic resin as a matrix we can also provide with weight gain

- Easiest modeling pieces
- Strength and rigidity
- Light
- Middle chosen (Orthotropic, Isentropic ...).

For high mounted, fixed and cranked wing can provide more stability, decrease the ground effect and enough space to install motors under the wing for our mini UAV model. A cranked wing has a similar shape to elliptical wing and a large wing aspect ratio for better performance as well. The tail adopted is T-tail, as the high mounted wing it can decrease the ground effect and sail far than wing flow turbulence in comparison with V-tail configuration demands a complex control system, therefore, it is discarded.



**II.6.2. Take-off Weigh Estimation:**

Design takeoff gross weight can be broken into crew weight, payload weight, fuel weight (batteries), and the remaining (or "empty") weight but in UAV case we take as a consideration crew weight doesn't exist. The empty weight includes the structure, engines, recovery system, fixed equipment, avionics, and anything else not considered a part of crew, payload, or fuel. Equation (II.1) summarizes the takeoff-weight buildup.

$$W_T = W_{Crew} + W_{Payload} + W_{Fuel} + W_{Empty} \quad (II.1)$$

In our UAV case we have:

$$\begin{aligned} W_{Crew} &= 0 \\ W_{Payload} &= 0 \\ W_{Empty} &= W_{Avionics} + W_{Propulsion} + W_{Structure} \end{aligned} \quad (II.2)$$

The only unknowns are the fuel (batteries) weight and empty weight. However, they are both dependent on the total aircraft weight. Thus an iterative process must be used for aircraft sizing. The empty weight was established based on the design on the institute work experience. Finally, it's adjusted in the detail design using CAD software based on the internal structure weight defined. The table below regroups the different elements of UAV Estimated weight distribution.

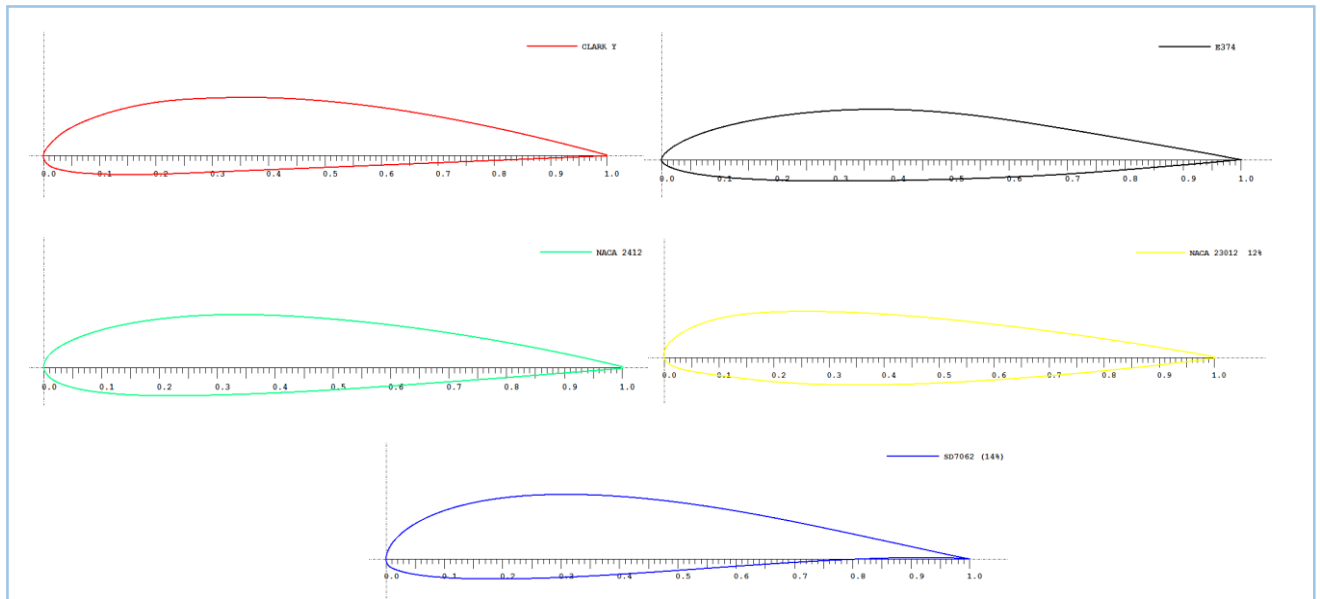
Table (II.6). UAV Weight estimation

<b>Component</b>	<b>N</b>	<b>Part Name</b>	<b>N</b>	<b>Element Weight (g)</b>	<b>Weight (g)</b>
<b>Overall Layout</b>	1	Fuselage	1	800	800
	2	Wing	1	1000	1000
	3	Wings connector	1	40	40
	4	Horizontal tail	1	150	150
	5	vertical tail	1	150	150
	6	Assembly glue	1	10	10
	7	Recovery cable + hook	1	40	40
<b>Propulsion and control system</b>	8	Engines	2	250	500
	9	controller (ESC)	2	145	290
	10	Propeller	2	35	70
	11	sensors	4	9	36
<b>Avionics</b>	12	camera Raspberry	1	20	20
	13	pollution sensor	1	10	10
	14	GPS LEA-6H	1	10	10
	15	SD card 32bit 2Mb	1	2	2
	16	Autopilot Wire Bundle	1	8	8
	17	Videos Transmitter	1	18	18
<b>Battery</b>	18	Battery (4S) or (6S)	2	1300	1300
<b>Total Weight</b>					<b>4454</b>

### II.6.3. Airfoil Selection:

The airfoil, in many respects, is the heart of the airplane. The airfoil affects the cruise speed, takeoff and landing distances, stall speed, handling qualities (especially near the stall), and overall aerodynamic efficiency during all phases of flight.

In the past, the designer would select an airfoil (or airfoils) from such a catalog. This selection would consider factors such as the airfoil drag during cruise, stall and pitching-moment characteristics, the thickness available for structure and fuel (battery), and the ease of manufacture. With today's computational airfoil design capabilities, it is becoming common for the airfoil shapes for a wing to be custom-designed. The figure (II.4) below represent candidate airfoils section which are Clark-Y, E374, NACA23012, NACA 2412, and SD7062 (14%).



*Fig (II.4). Candidate Airfoils Section*

Airfoil selection is based on many different and specific parameters that we should take it as a consideration:

- Have a high finesse (for the airplane wing in cruise mode).
- Being able to maintain lift at low speed, or with a small wing area (for maneuvering an approaching aircraft), requires reaching a large lift coefficient, which is favored by a large radius leading edge, a strong camber and a turbulent boundary layer.
- An airfoil with a relative thickness allow the presence of other elements inside the wing (for example mechanical systems for flaps and movable spouts in an airplane).

XfLR5 software is used in order to test a range of two dimensional airfoil sections in an attempt to find one which matched all of the design requirements. A group of useful airfoils was shortlisted at the initial phase, a decision making process will be done after analysis.

Such airfoils were not randomly selected out of the XfLR5 analysis but were rather handpicked based on their geometry. It is decided that the bottom of the airfoil was to be as flat as possible and has sufficient thickness in order to make fabrication of the wing easier. Also the airfoils were chosen based on the high maximum lift to drag ratio coefficient requirements predicted for the aircraft.

The figure below describes a sensitive analysis of the change of Reynolds number with change of the two main properties, the length represents the chord of the UAV model taken from 20 to 30 cm and the flight velocity from 50 to 60 km/h. Reynolds number is changed between 200 000 and 270 000, a Reynolds number around 250 000 is selected to analyzed the airfoils.

$$Re = \frac{\rho U L}{\mu} \quad (II.3)$$

Where:

$\rho$ : Air density between 300 and 400 m and it equal 1.019 [kg/m<sup>3</sup>].

$\mu$ : Viscosity at the same altitude equal to 1,819 10<sup>-5</sup> [kg/m s].

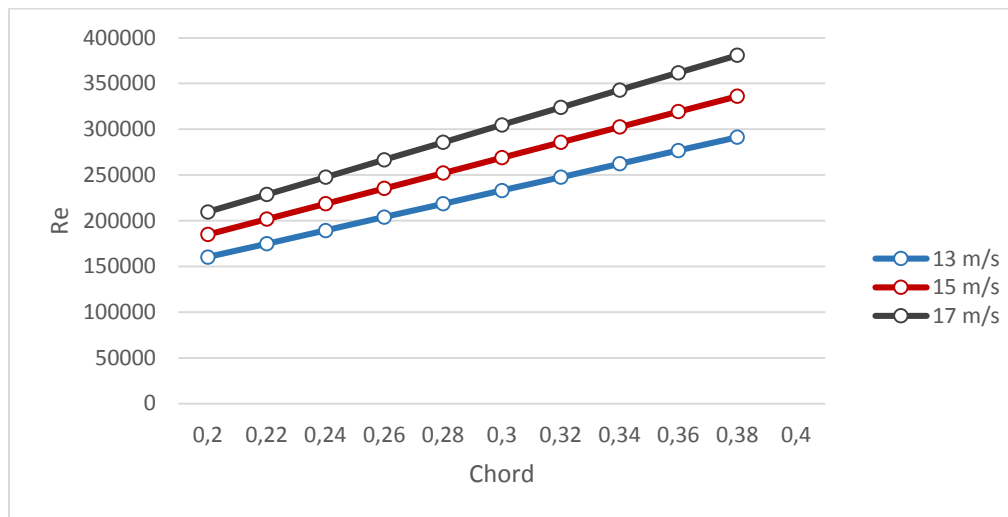


Fig (II.5). Estimation of flight Reynolds number

The Reynolds number which is about 250000 results from the expected flight velocities and wing chords. After we did chose the Reynolds number which is about 250000 a lot of parameters will be easy to define it ( for example lift, drag, pressure and moment coefficient ... ).which are going to determine by using XfLR5 and Profili Pro as software to be sure from our results.

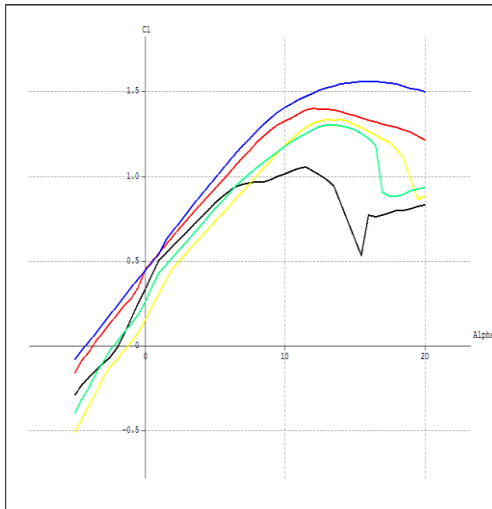


Fig (II.6). Lift coefficient vs AOA

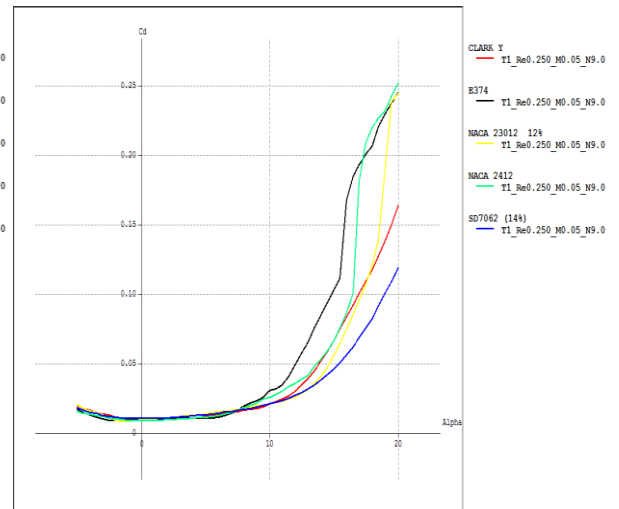


Fig (II.7). Drag coefficient vs AOA

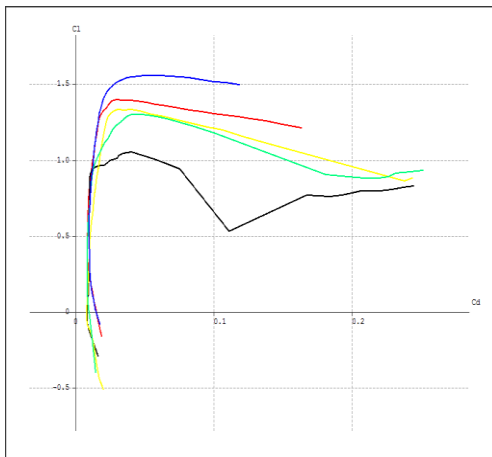


Fig (II.8). Lift to drag ratio curve

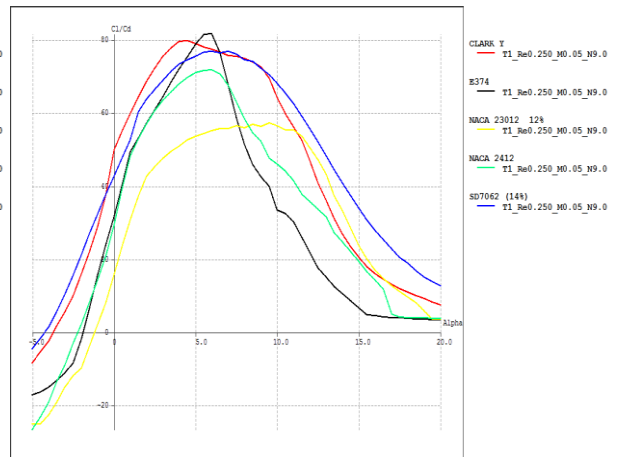


Fig (II.9). Lift to drag ratio vs AOA

The table below describes each airfoil in terms of its useful properties.

Table (II.7).Candidates airfoils

Airfoil	$C_{l \max}$	$\alpha_{\max}$ ( $^{\circ}$ )	$C_{l}/C_{d}$ at $\alpha_{\max}$	$C_{d \min}$ at $\alpha = 6^{\circ}$	Thickness max
<b>SD7062 (14%)</b>	<b>1.56</b>	<b>16</b>	<b>77</b>	<b>0.013</b>	<b>13.98% at 27.2%</b>
Clark-Y	1.4	12	79.6	0.013	11.71% at 28%
E374	1.05	11.5	81.5	0.011	10.92% at 37.1%
NACA23012	1.33	14	57	0.015	12% at 29.5%
NACA 2412	1.3	14	72	0.0125	12% at 29.5%

After considering the original airfoils carefully, the SD7062 14 % has important reasonable properties, where it has a good thickness which insure a space for structural design and make fabrication easier to us.

From simulation at XFL5 software of Clark Y airfoil between a Reynolds number about 140 000 to 350 000 is tolerable, regarding the small chord and low velocity conditions of mini UAVs.

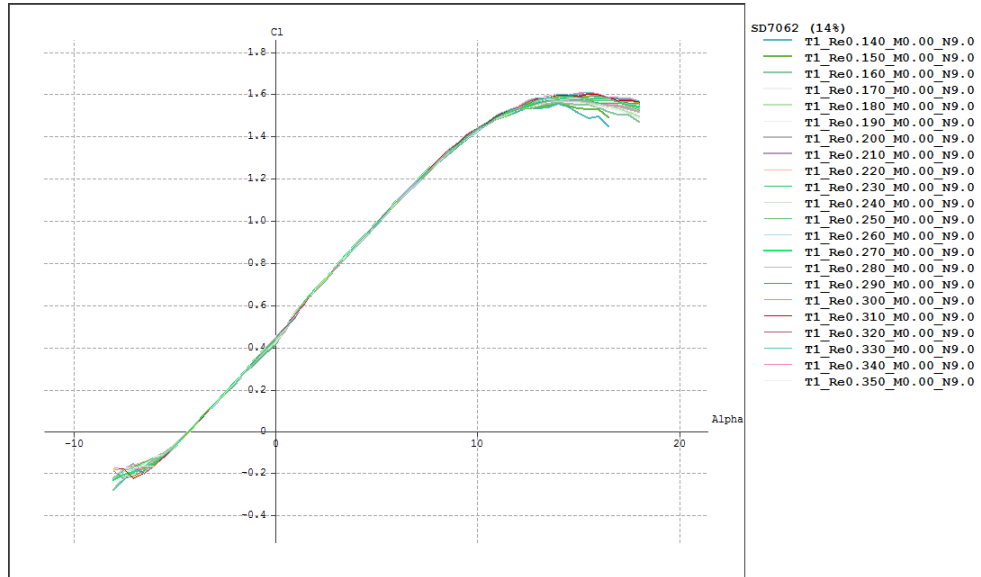


Fig (II.10). Lift coefficient vs AOA curve of SD 7062 14%

The SD 7062 14% airfoil wind tunnel test data curves realized by K. W Idiner and M Allen confirm the maximum and tendency of the lift coefficient curve and Lift to drag ratio curve , this is a SD 7062 (B) lift coefficient at Re=60 000 to 400000 additional Reynolds number test in [14].

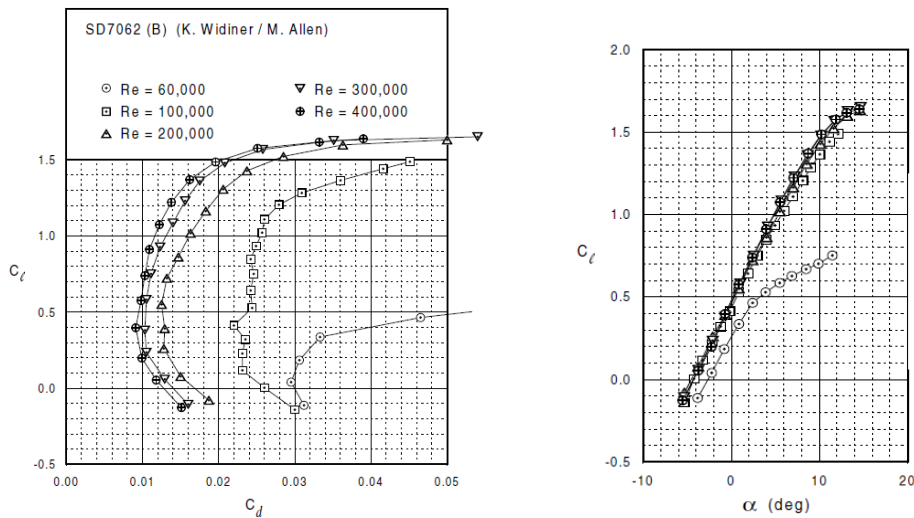


Fig (II.11). Lift to drag ratio curve and Lift coefficient vs AOA

**II.6.4.Wing Geometry design:**

The reference (trapezoidal) wing is the basic wing geometry used to begin the layout. Figures (II.10) show the key geometric parameters of the reference wing.

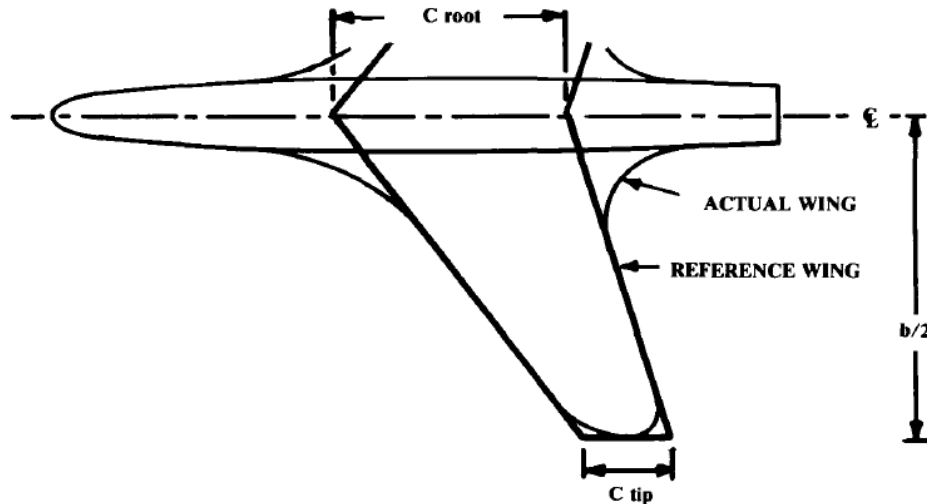


Fig (II.12).Wing geometry

**S** = Reference wing area

**C** =Chord

**AR** = Aspect Ratio =  $b^2 / S$

(II.3)

**t/c** =AIRFOIL THICKNESS RATIO (MAXIMUM THICKNESS/CHORD)

$\lambda$  =TAPER RATIO= $C_{tip}/C_{root}$

**b** =SPAN

Given:  $W/S, A, \lambda$

$$S = W / (W/S) \quad (II.4)$$

$$b = \sqrt{AR * S} \quad (II.5)$$

$$C_{root} = 2 * S / [b (1 + \lambda)] \quad (II.6)$$

$$C_{tip} = \lambda * C_{root} \quad (II.7)$$

The entire wing has its mean aerodynamic center at approximately the same percent location of the mean aerodynamic chord as that of the airfoil alone. In subsonic flow, this is at the quarter-chord point on the mean aerodynamic chord. In supersonic flow, the aerodynamic center moves back to about 40% of the mean aerodynamic chord. The designer uses the mean aerodynamic chord and the resulting aerodynamic center point to position the wing properly.

Also, the mean aerodynamic chord will be important to stability calculations. Figure 4.17 illustrates a graphical method for finding the mean aerodynamic chord of a trapezoidal-wing planform.

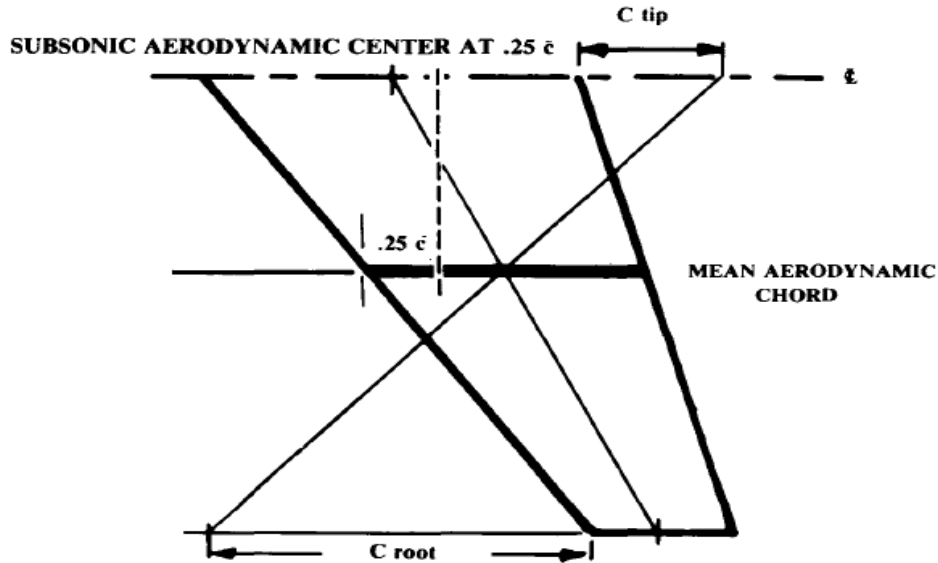


Fig (II.13). Mean aerodynamic chord.

The required reference wing area ("S") can be determined only after the takeoff gross weight is determined. The shape of the reference wing is determined by its aspect ratio, taper ratio, and sweep [11].

$$mac = (2/3) C \text{ root } (1 + \lambda + \lambda^2) / (1 + \lambda) \tag{II.8}$$

Before starting our wing planform design we should take as a consideration the advantages and disadvantages of our wing shapes and looking forward to avoid such problems in fabrication part. The following table explain briefly wing planform categories, advantages and disadvantages of each one.

Table (II.8). Wing categories, advantages and disadvantages

Wing	Advantages	Disadvantages
Elliptical	<ul style="list-style-type: none"> <li>✓ Lowest induce drag</li> <li>✓ Stalls evenly across spans</li> </ul>	<ul style="list-style-type: none"> <li>➤ Difficult to fabricate</li> </ul>
Rectangular	<ul style="list-style-type: none"> <li>✓ Constant Re reduce risk of tip stall</li> <li>✓ Easy to fabricate</li> </ul>	<ul style="list-style-type: none"> <li>➤ Higher induced Drag</li> <li>➤ Higher bending moments</li> </ul>
Tapered	<ul style="list-style-type: none"> <li>✓ Lower induced drag than rectangular planform</li> <li>✓ Smaller Bending moment</li> </ul>	<ul style="list-style-type: none"> <li>➤ Risk of tip stall</li> </ul>
Combined (Rectangular & Tapered)	<ul style="list-style-type: none"> <li>✓ Easier to fabricate</li> <li>✓ Approach advantages of elliptical</li> </ul>	<ul style="list-style-type: none"> <li>➤ Hazard of tip stall remains</li> </ul>

The combined (rectangular and tapered) was the wing selected from the previous table called cranked wing for better performance benefit with no sweep, dihedral or twist. A high wing had already been selected for roll stability therefore dihedral was unnecessary due to manufacturing complexity and the stability benefits from sweep were also not required.

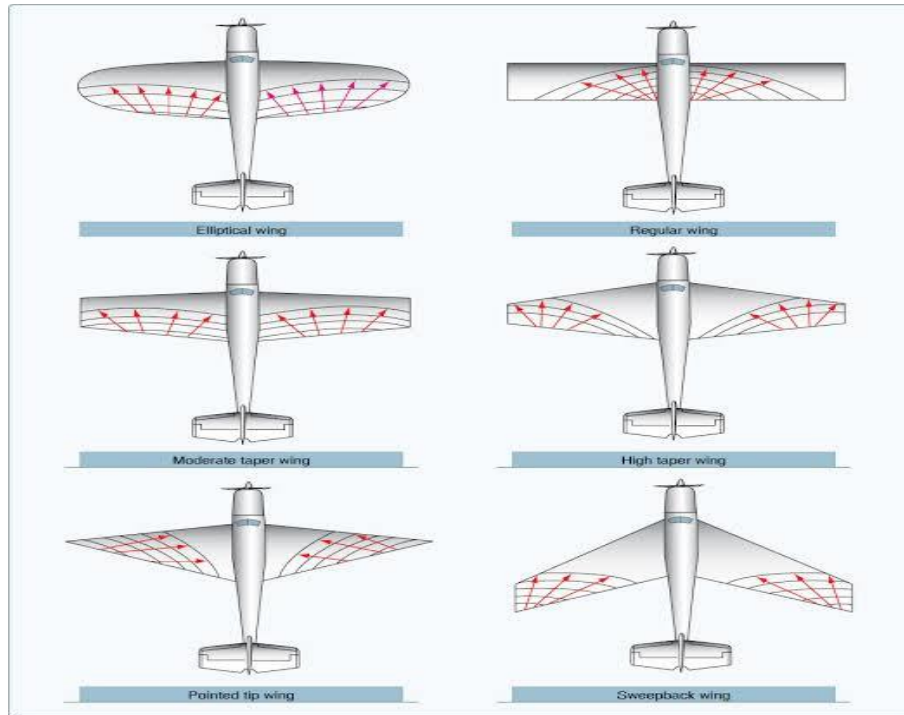


Fig (II.14). Wing profile categories

A cranked wing would help us to gain a better value for Oswald's span efficiency factor, which would reduce the drag due to lift. The positive effect gained of cranked wing was accepted.

It was common knowledge amongst the designer teams that our configuration would generate less drag in the air due to the recovery cable. The larger aspect ratio reduced lesser the induced drag and the design team hoped this could offset some of the extra parasite drag created from our configuration.

A value of  $C_{l_{max}} = 1.56$  from airfoil curve can be extract as a maximum airfoil lift coefficient designated by small "l" from figure II.11.

So  $C_{L_{max}}$  air vehicle (3D mini UAV) designated with "L" is less than  $C_{l_{max}}$  airfoil (2D), the maximum aircraft lift coefficient develops from maximum airfoil lift coefficient multiplied 0.9 to get max lift coefficient of wing, multiplied by 0.95 to get maximum complete aircraft lift coefficient  $C_{L_{max}}$  shown in the Eq.(II.8).



$$C_{Lmax} = C_{lmax} \times 0.9 \times 0.95 \tag{II.8}$$

$$C_{Lmax} = 1.56 \times 0.9 \times 0.95 = 1.33 \tag{II.9}$$

After we calculated  $C_{Lmax}$  let's now find the wing loading  $W/S$  from

$$W = \frac{1}{2} \rho S V_{Stall}^2 C_{Lmax} \tag{II.10}$$

From this equation (Eq. II.10):

$$W/S = \frac{1}{2} \rho V_{Stall}^2 C_{Lmax} \tag{II.11}$$

The weight of aircraft is about 4500 grams now, the table below regroups six UAVs has a weight around our design.

Table (II. 1). Typical mini UAVs weight consideration

Mini UAV	Weight (g)	Span (mm)	Surface (dm <sup>2</sup> )	Wing loading (g/dm <sup>2</sup> )
Single Soldier I	4500	2477	67	67,16
C-astral Barmor	4500	2300	67	67,16
Skywalker EVE-2000	4500	2240	49	91,84
Skywalker TITAN 21600	4500	2160	52,5	85,71
WALL-E2000	3000-4500	2030	48	62,3
Skywalker Kit	3000-4500	1880	49	61,22

$$V = \sqrt{\frac{W}{\frac{1}{2} \rho S C_{Lmax}}} \tag{II.12}$$

A sensitive analysis will be done and resumed in these tables:

Table (II.2). Single Soldier I or RQ-20B UAS Puma lift coefficient sensitive analysis

weight (kg)	Ro (kg/m <sup>3</sup> )	S (m <sup>2</sup> )	g (m/s <sup>2</sup> )	CLmax	V
4,5	1,225	0,67	9,81	1	10,371709
<b>Single Soldier I or RQ-20B UAS Puma</b>				1,1	9,8890363
				1,2	9,4680314
				1,3	9,0965903
				1,33	8,9934121
				1,4	8,7656938
				1,5	8,4684647

The sensitive analysis of Single Soldier I is similar to RQ-20B UAS Puma so we can chose one of them in our studies.

Table (II.11). C-astral barmor lift coefficient sensitive analysis

weight (kg)	Ro (kg/m3)	S (m2)	g (m/s <sup>2</sup> )	CLmax	V
4,5	1,225	0,67	9,81	1	10,3717087
<b>C-astral Barmor</b>				1,1	9,88903628
				1,2	9,4680314
				1,3	9,09659033
				1,33	8,99341206
				1,4	8,76569378
				1,5	8,46846473

Table (II.12). Skywalker EVE-2000 lift coefficient sensitive analysis

weight (kg)	Ro (kg/m3)	S (m2)	g (m/s <sup>2</sup> )	CL max	V
4,5	1,225	0,49	9,81	1	12,1280136
<b>Skywalker EVE-2000</b>				1,1	11,5636072
				1,2	11,071311
				1,3	10,6369716
				1,33	10,5163215
				1,4	10,2500423
				1,5	9,90248161

Table (II.13). Skywalker TITAN 21600 lift coefficient sensitive analysis

weight (kg)	Ro (kg/m3)	S (m2)	g (m/s <sup>2</sup> )	CL max	V
4,5	1,225	0,525	9,81	1	11,716774
<b>Skywalker TITAN 21600</b>				1,1	11,171506
				1,2	10,695903
				1,3	10,276291
				1,33	10,159732
				1,4	9,9024816
				1,5	9,5667061

Table (II.14). WALL-E2000 lift coefficient sensitive analysis

weight (kg)	Ro (kg/m <sup>3</sup> )	S (m <sup>2</sup> )	g (m/s <sup>2</sup> )	CL max	V
3 - 4.5	1,225	0,48	9,81	1	10,005101
<b>WALL-E2000</b>				1,1	9,5394893
				1,2	9,1333656
				1,3	8,7750538
				1,33	8,6755226
				1,4	8,4558535
				1,5	8,1691305

Table (II.15). Skywalker Kit lift coefficient sensitive analysis

weight (kg)	Ro (kg/m <sup>3</sup> )	S (m <sup>2</sup> )	g (m/s <sup>2</sup> )	Clmax	V
3 - 4.5	1,225	0,49	9,81	1	9,9024816
<b>Skywalker Kit</b>				1,1	9,4416458
				1,2	9,0396876
				1,3	8,6850509
				1,33	8,5865405
				1,4	8,3691245
				1,5	8,0853424

From this sensitive study the small value of the lift coefficient of these mini UAVs  $C_{L_{max}} = 1$  gives **9,9024816 m/s** flying velocity, the largest value of these mini UAVs  $C_{L_{max}} = 1.5$  gives **8.0853424 m/s** flying velocity.

The different  $C_{L_{max}}$  bring to mind different airfoils selection, our selection is SD 7062 14% airfoil with  $C_{L_{max}} = 1.33$ , imagine this airfoil was installed on these mini UAVs the velocities obtained are the stall speed of each aircraft which are resumed in this table:

Table (II.36). Typical mini UAVs velocities at  $C_{L_{max}} = 1.33$ 

UAVs	CL max	S(dm <sup>2</sup> )	W/S (g/dm <sup>2</sup> )	V stall (m/s)
<b>Single Soldier I</b>	1,33	67	67,16	8,99341206
<b>C-astral Barmor</b>	1,33	67	67,16	8,99341206
<b>Skywalker TITAN 21600</b>	1,33	52,5	85,71	10,1597318
<b>Skywalker EVE-2000</b>	1,33	49	91,84	10,516321
<b>Skywalker Kit</b>	1,33	49	61,22	8,58654053
<b>WALL-E2000</b>	1,33	48	62,5	8,6755226

The Skywalker EVE-2000 and C-astral barmor have 4500 grams takeoff weight and a Stall velocity range [10.516321 to 8.99341206] with our airfoil  $C_{L_{max}}$  calculated before, any Stall velocity in this range is acceptable as a first estimation at sea level.

Exanimate these Stall velocities range to see the adequate surface area using these two flowing equations.

$$W/S = \frac{1}{2} \rho C_{L_{max}} V_{stall}^2 \quad (II.13)$$

$$S = \frac{2.W}{\rho C_{L_{max}} V_{stall}^2} \quad (II.14)$$

Table (II. 47). Stall speeds iterations versus candidate surface area

UAV	Vstall (m/s)	Clmax	W/S (g/dm <sup>2</sup> )	S (dm <sup>2</sup> )
<b>Skywalker EVE-2000</b>	10,516321	1,33	91,84	49
<b>Skywalker TITAN 21600</b>	10,159732	1,33	85,71	52,5
<b>Single Soldier I</b>	8,9934121	1,33	67,16	67
<b>C-astral Barmor</b>	8,9934121	1,33	67,16	67
<b>WALL-E2000</b>	8,6755226	1,33	62,5	48
<b>Skywalker Kit</b>	8,5865405	1,33	61,22	49

A compromise between lower stall velocity limit and surface area should be done, large surface area remind us to a heavy wing structure and more cost, a 58.8 dm<sup>2</sup> surface area value refers to  $V_{stall} = 9.6$  m/s and  $W/S = 76.50$  (g/dm<sup>2</sup>) is acceptable.

A very light aircraft (VLA) that is certified with EASA3 may not have a stall speed greater than 45 knot = 23.15 m/s and it's the lowest speed certification; our result  $V_{stall} = 10.40$  m/s is acceptable.

$$V_s \leq 61 \text{ knot (FAR 23)} \quad (II.15)$$

$$V_s \leq 45 \text{ knot (EASA CS - VLA)} \quad (II.16)$$

Table (II.58). Reference area parameters results

<b>Take-off weight (g)</b>	4500
<b><math>C_{L_{max}}</math></b>	1.33
<b>Density (kg/m<sup>3</sup>)</b>	Sea level(1.225)
<b>Wing loading (g/dm<sup>2</sup>)</b>	76.5
<b>Wing area (dm<sup>2</sup>)</b>	58.8

After the define of wing area we move forward by using a simple calculation to determine the others wing parameters like span (b), main aerodynamic chord (mac) and aspect ratio (AR) (and taper ratio ( $\lambda$ ) in some cases).

An assumption that the wing of these mini UAVs is rectangular, the wings chords can be determined.

$$c = S/b \tag{II.17}$$

$$AR = b^2/S \tag{II.18}$$

Table (II.69). Mini UAVs wing parameters estimation

UAV	Span (b) (mm)	S (dm <sup>2</sup> )	Chord (mm)	Aspect Ratio (AR)
Skywalker EVE-2000	2240	49	218,75	10,24
WALL-E2000	2030	48	236,4532	8,585208333
Skywalker TITAN 21600	2160	52,5	243,05556	8,886857143
Skywalker Kit	1880	49	260,6383	7,213061224
Single Soldier I	2477	67	270,48849	9,15750597
C-astral Barmor	2300	67	291,30435	7,895522388

As a software the choice of XFLR-5 to design the wing planform closer to Skywalker EVE-2000 starting with 260 mm root chord to get an aspect ratio equal to 10.2 with a no swept wing from leading edge, based on the table above and an approximate geometrical study compare to an elliptical wing as shown in figures below.

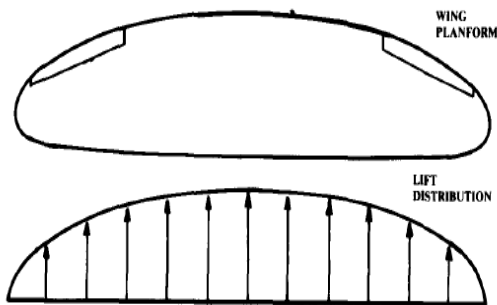


Fig (II.15).Elliptical wing [11]

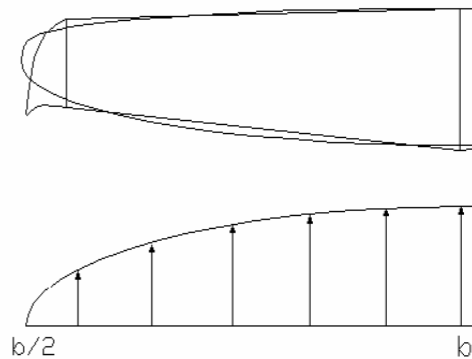


Fig (II.16).Approximate wing geometry to elliptical one [13]

From now and after our studies will be almost based on XFLR-5 to define others parameters like main aerodynamic chord and split position from rectangular sections to tapered wing sections and wing tip chord, with respect of smooth wing tip

The figure bellow Fig (II.17) represent our wing planform and its parameters because of using XFLR5 as a software

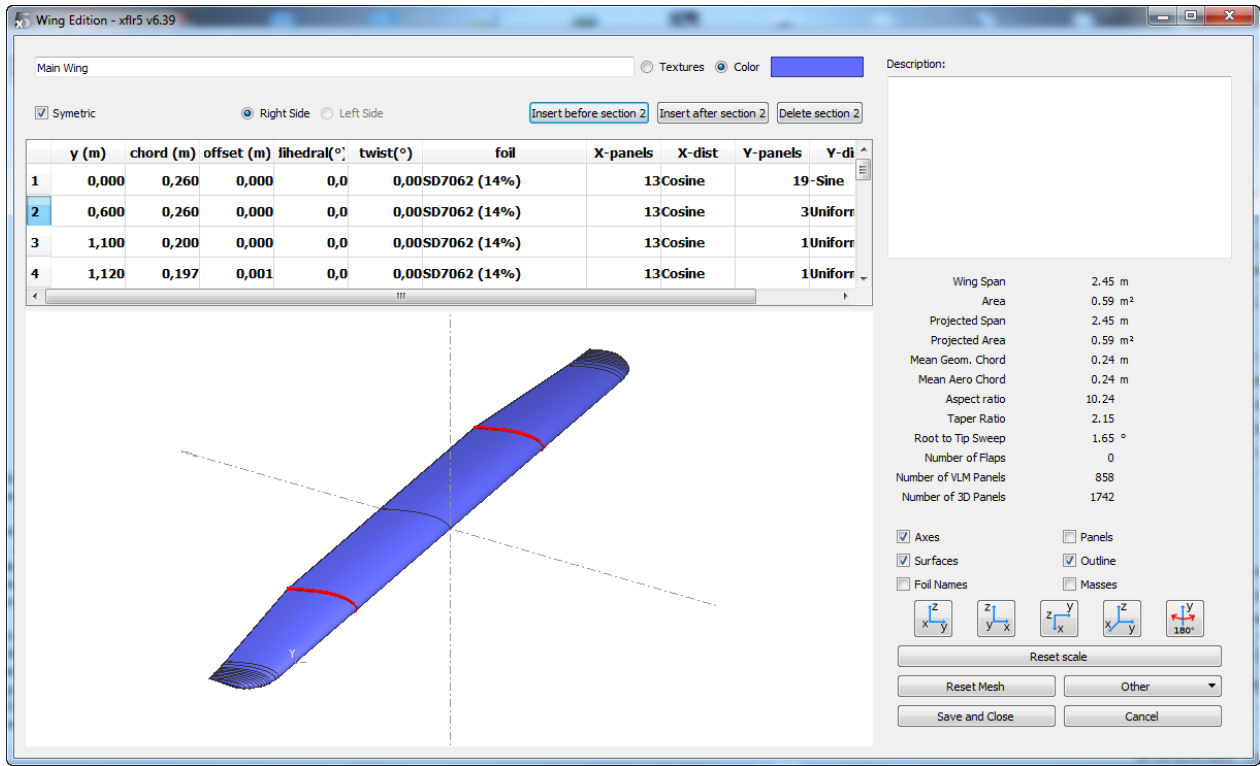


Fig (II.17).Wing plan form drawing (XFLR 5)

The table resume our result

Table (II.20).7 Wing parameters

$C_{root}$ (mm)	260
$C_{tip}$ (mm)	121
<b>Span</b> b (mm)	2450
<b>Aspect ratio</b> $AR = b^2/S$	10.2
<b>Main aerodynamic chord</b> mac (m)	240

Wing-tip shape has two effects upon subsonic aerodynamic performance. The tip shape affects the aircraft wetted area, but only to a small extent. A far more important effect is the influence the tip shape has upon the lateral spacing of the tip vortices. This is largely determined by the ease with which the higher-pressure air on the bottom of the wing can "escape" around the tip to the top of the wing.

Between rounded and sharp Wing-tip shape we made ours by decreasing airfoil chord

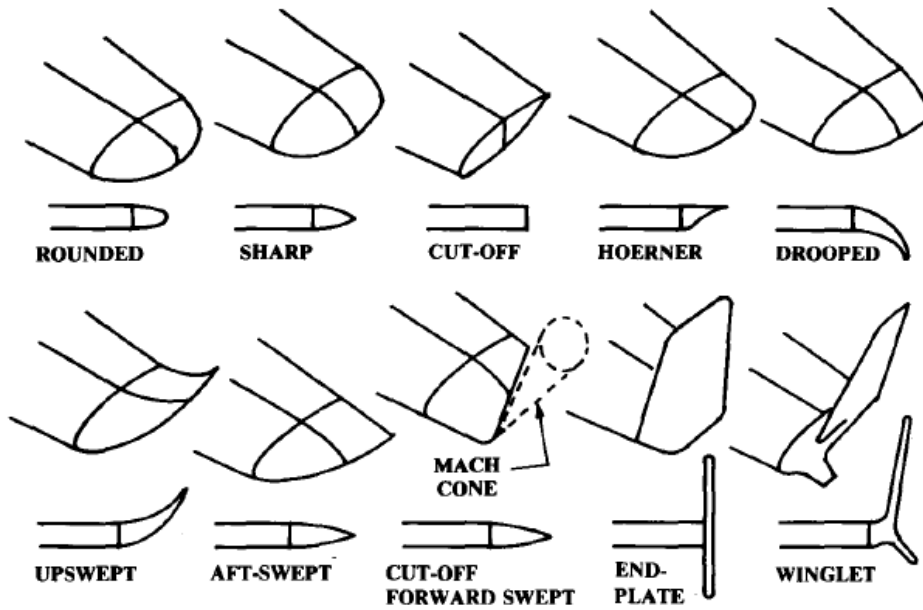


Fig (II.28). Wing-tip shape

A smoothly-rounded tip (when seen nose-on) easily permits the air to flow around the tip. A tip with a sharp edge (when seen nose-on) makes it more difficult, thus reducing the induced drag. Most of the new low-drag wing tips use some form of sharp edge. In fact, even a simple cut-off tip offers less drag than a rounded-off tip, due to the sharp edges where the upper and lower surfaces end. Fig (II.39) [11].

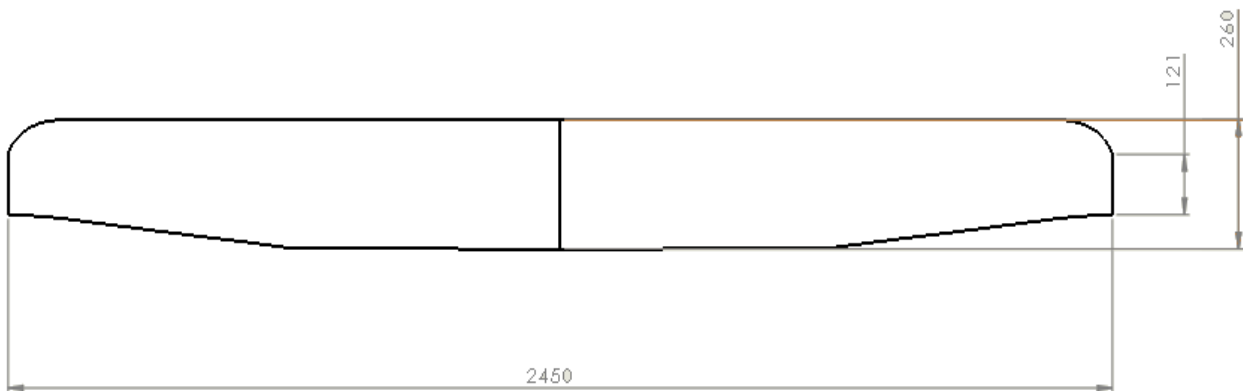
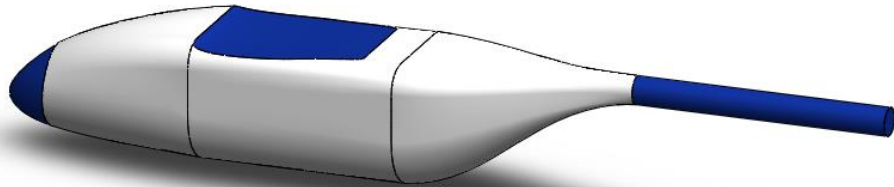


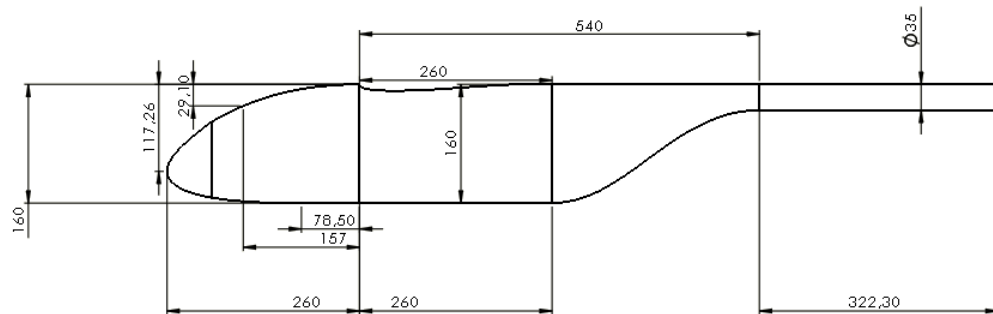
Fig (II.49). Wing dimensions

**II.6.5.Fuselage design:**

The aircraft fuselage is initially conceived as a blended wing-fuselage configuration due to inducing up to %40 higher lift to drag ratio. However, due to complexity and cost considerations, elliptical shape fuselage, which has similar characteristics to blended type is chosen. Such configuration allows smoother airflow around the aircraft. In addition, elliptical fuselage shapes can also be assessed as similar shape of an airfoil. However, fuselage having a rough elliptical shape will deteriorate the drag beyond transonic region [15].



*Fig (II.20). Fuselage configuration with an aft boom separated option*



*Fig (II.21). Fuselage dimensions*

The following table resume the results of our fuselage dimensions.

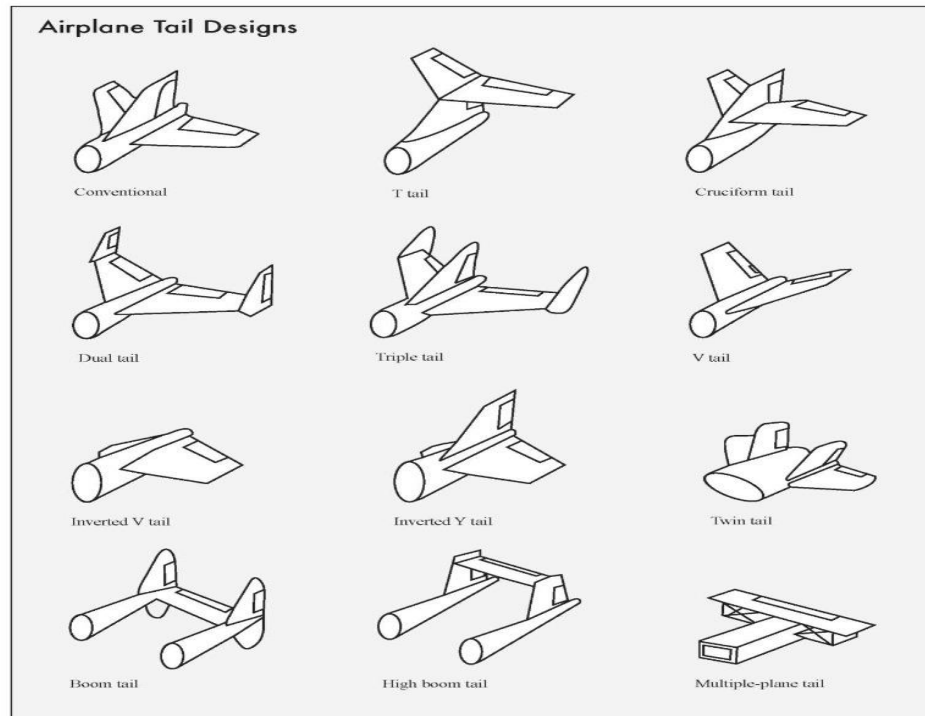
*Table (II.21) Fuselage dimensions Results*

	Our Fuselage
<b>Length (mm)</b>	1122.3
<b>Width (mm)</b>	180
<b>Height (mm)</b>	160



**II.6.6.Tail design:**

The empennage, also known as the tail or tail assembly, is a structure at the rear of an aircraft that provides stability during flight, in a way similar to the feathers on an arrow. The term derives from the French language word *empenner* which means "to feather an arrow". Most aircraft feature an empennage incorporating vertical and horizontal stabilizing surfaces which stabilize the flight dynamics of yaw and pitch, as well as housing control surfaces [16].

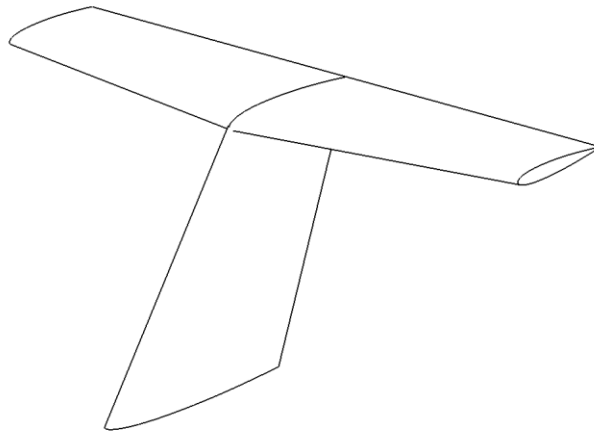


*Fig (II.22).Tails configurations*

In the T-tail design, a common variation of the conventional tail, the horizontal stabilizer is positioned at the top of the vertical stabilizer. The horizontal stabilizer is then above the propeller flow, or prop wash, and the wing wake. Because the horizontal stabilizer is more efficient, it can therefore be made both smaller and lighter. The placement of the horizontal stabilizer on top of the vertical stabilizer can also make the vertical stabilizer more aerodynamically efficient. By making the vertical stabilizer more effective, its size may be reduced. However, the horizontal stabilizer in the T-tail layout imposes a bending and twisting load on the vertical stabilizer, requiring a stronger, and therefore, a heavier, structure. These loads are avoided in the conventional design.

There is also the possibility that at the high pitch angle usually associated with landing the airplane, the horizontal stabilizer of the T tail will be immersed in the slower and more turbulent flow of the wing wake. In some cases, it is possible to compromise severely the control function of the horizontal tail.

Symmetrical airfoils are chosen exclusively for vertical tail planes. Symmetrical or virtually symmetrical airfoils with 9% to 12% relative thickness are chosen for horizontal tail planes. For example NACA 0009 or NACA 0012 (Abbott 1959) can be chosen. Asymmetrical horizontal tail plane airfoils are installed **upside-down** because the horizontal tail plane has to create negative lift.



*Fig (II.23). T-tail configuration*

The horizontal tail and vertical tail on almost all airplanes use a symmetric airfoil section. A popular choice is the NACA 0012 airfoil. We will use the same for our design on both the horizontal and vertical tails.

### II.6.7. Horizontal tail:

First, let's initiate a tapered horizontal tail as mentioned in the figures (II.23), the tail dimension and parameters was selected to satisfy the longitudinal stability and control.

The horizontal tail volume is an important key using Salsa J or Image J software helps to define an initial horizontal tail volume  $V_H$ , this method will be demonstrated on **Appendix A**.

$$V_H = \frac{L_h S_h}{C_w S_w} \quad (\text{II.19})$$

The taper ratio

$$\lambda = \frac{C_{tv}}{C_{rv}} \quad (\text{II.20})$$

The aspect ratio of the horizontal tail plane should be about half the aspect ratio of the wing. T-tail have a smaller aspect ratio of the vertical tail plane than conventional tails. This allow weight disadvantages to be kept to minimum.

Table (II.22) Conventional and T tail aspect ratios and taper ratios (Raymer 1989)

Type	Horizontal Tailplane		Vertical Tailplane	
	$A$	$\lambda$	$A$	$\lambda$
Conventional Tail	3.00 ... 5.00	0.3 ... 0.6	1.3 ... 2.0	0.3 ... 0.6
T-Tail	as Conventional Tail	as Conventional Tail	0.7 ... 1.2	0.6 ... 1.0

The table below estimates from SALSA J Software.

Table (II.23). Typical UAVs horizontal tail dimensions approximation

	Skywalker EVE 2000	Skywalker Observer	Pointer FQM 151A
<b>S<math>\omega</math> (m<sup>2</sup>)</b>	0,49	0,57	0,72
<b>C<math>\omega</math> (mm)</b>	218,75	205	255
<b>b<sub>h</sub> (mm)</b>	545	459	795
<b>C<sub>rh</sub> (mm)</b>	165	120	170
<b>C<sub>th</sub> (mm)</b>	122	95	110
<b>L<sub>h</sub> (mm)</b>	756	1168	1048
<b>Mac<sub>h</sub></b>	143,5	107,5	140

From these dimensions above, a half horizontal surface area can be calculated, using trapezoidal area equation calculation or by reproduction of the drawing surface

$$S_h = \frac{(C_{rh} + C_{th}) \frac{b_h}{2}}{2} \quad (\text{II.21})$$

Multiply by 2 to get the total horizontal surface area

$$S_h = \left[ \frac{(C_{rh} + C_{th}) \frac{b_h}{2}}{2} \right] \times 2 \quad (\text{II.22})$$

Table (II.24). Typical UAVs horizontal tail parameters estimation

	Skywalker EVE 2000	Skywalker Observer	Pointer FQM 151A
<b>Sh</b>	0,0782075	0,0493425	0,1113
<b>Vh</b>	0,551602286	0,493213864	0,63530719
<b>Taper ratio <math>\lambda</math></b>	0,739393939	0,791666667	0,647058824
<b>AR<sub>h</sub></b>	3,797909408	4,269767442	5,678571429

For our design a choice of horizontal tail volume  $V_H$  and distance  $L_{ht}$  will be selected, the range is taken from the estimations previously listed [0.49 to 0.64], [756 to 1168] respectively.

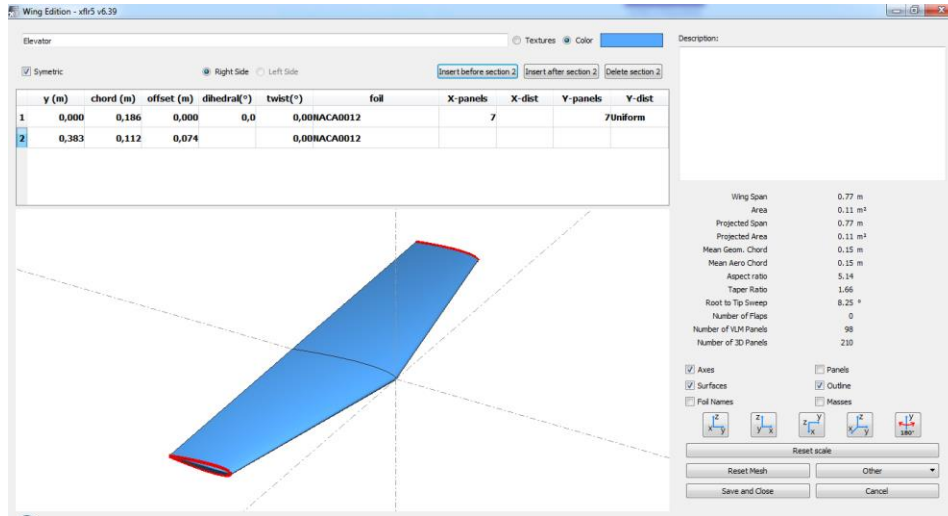


Fig (II.24). Horizontal tail drawing (XFLR5 software)

The defined parameters of the horizontal tail are regrouped on the table below.

Table (II.25). Horizontal tail parameters

Parameters	Chosen Values	Result
$\lambda$	[0,6 - 0,8]	0,6
VH	[0,49 - 0,65]	0,625
Lh (mm)	[756 - 1168]	760
Sh (m <sup>2</sup> )	[0,049 - 0,1106]	0,117
bh (mm)	[545 - 790]	767
Crh (mm)	[120 - 170]	186
Cth (mm)	[95 - 122]	112
mach (mm)	[107,5-143,5]	152
ARh	[3,8 - 5,6]	5

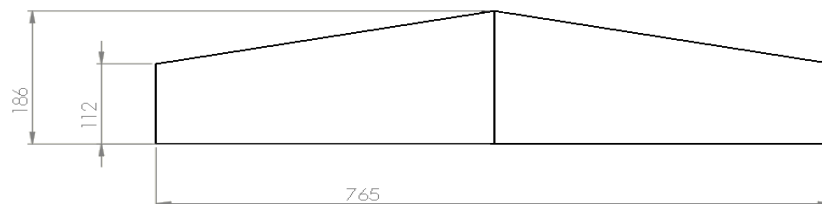


Fig (II.25). Horizontal tail dimensions

**II.6.8. Vertical tail:**

The vertical tail surface area is about 12 to 20% of the wing reference area. The vertical tail design is critical to takeoff, especially in tackling yawed ground speed resulting from a crosswind and/or asymmetric power of a huge aircraft. A large vertical tail can cause snaking of the flight path at low speed, which can be resolved easily by introducing a “yaw-damper” (a matter of aircraft control analysis). At cruise, a relatively large vertical tail is not a major concern. Sweeping of the vertical tail would effectively increase the tail arm  $L_v$ , an important dimension in sizing the vertical tail [15].

Leading edge sweep angle of the vertical tail for subsonic airplanes is usually  $20^\circ$ . Related equations are given below.

$$V_v = \frac{L_v S_v}{b S_w} \quad (\text{II.23})$$

The taper ratio of vertical tail;

$$\lambda = \frac{C_{tv}}{C_{rv}} \quad (\text{II.24})$$

The table below estimated from Image J software.

*Table (II.26). Typical UAVs horizontal tail dimensions approximation*

	<b>Skywalker EVE 2000</b>	<b>Skywalker Observer</b>	<b>Pointer FQM 151A</b>
<b>S<math>\omega</math> (m<sup>2</sup>)</b>	0,49	0,57	0,72
<b>C<math>\omega</math> (mm)</b>	218,75	205	255
<b>b<math>v</math> (mm)</b>	230	225	270
<b>C<math>rv</math> (mm)</b>	240	200	275
<b>C<math>tv</math> (mm)</b>	140	103	212
<b>L<math>v</math> (mm)</b>	900	600	1080

*Table (II.27). Typical UAVs vertical tail surfaces area estimation*

	<b>Skywalker EVE 2000</b>	<b>Skywalker Observer</b>	<b>Pointer FQM 151A</b>
<b>S<math>v</math></b>	0,043	0,034	0,066
<b>V<math>v</math></b>	0,035	0,018	0,036
<b>AR <math>v</math></b>	1,23	1,49	1,11

The horizontal tail volume  $V_v$  and distance  $L_v$  take a range [0.018 to 0.036] and [600 to 1080] from the estimations previously listed respectively.

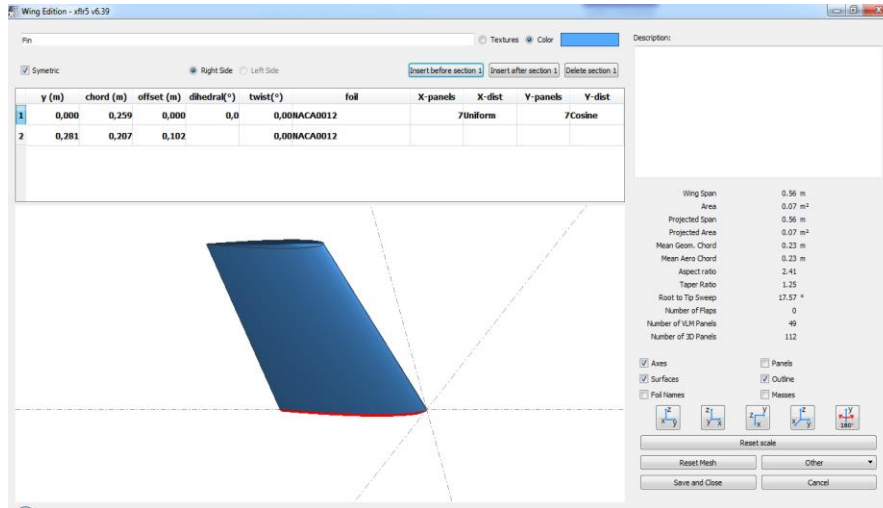


Fig (II.26). Vertical tail drawing

The parameters define and horizontal tail results regroup on the table below.

Table (II.28). Vertical tail parameters

Parameters	Chosen Values	Result
$\lambda$	[0,6-1,0]	0,8
$V_v$	[0,018-0,036]	0,03
$L_v$ (mm)	[600-1080]	650,5
$S_v$ (m <sup>2</sup> )	[0,034-0,066]	0,066
$b_v$ (mm)	[225-270]	281
$C_{rv}$ (mm)	[200-275]	259
$C_{tv}$ (mm)	[103-212]	207
$mac_v$ (mm)	/	234
$AR_v$	[0,7-1,2]	1,2

The following drawing illustrates the general horizontal tail dimension

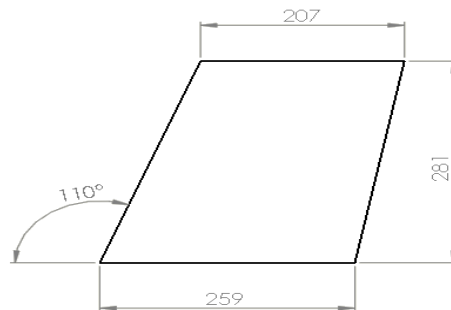
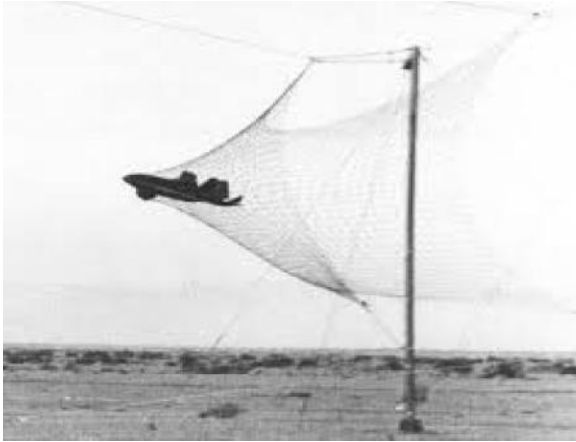


Fig (II.27). Vertical tail dimensions

**II.6.9. Recovery systems:**

Net recovery, Cable-Assisted Recovery or can be used based on my head in the restoration process, and in this case need to be manually steer the plane in the landing phase; since moving toward the network for example at the lowest speed, and stop the engine before the plane crashing into the network, which absorb the energy of motion. This method is valid and above almost all types of land, as well as over the ships; however, they need to be accurate, and the skill of workers directive.



*Fig (II.28). Net recovery*



*Fig (II.29). Cable-Assisted Recovery*



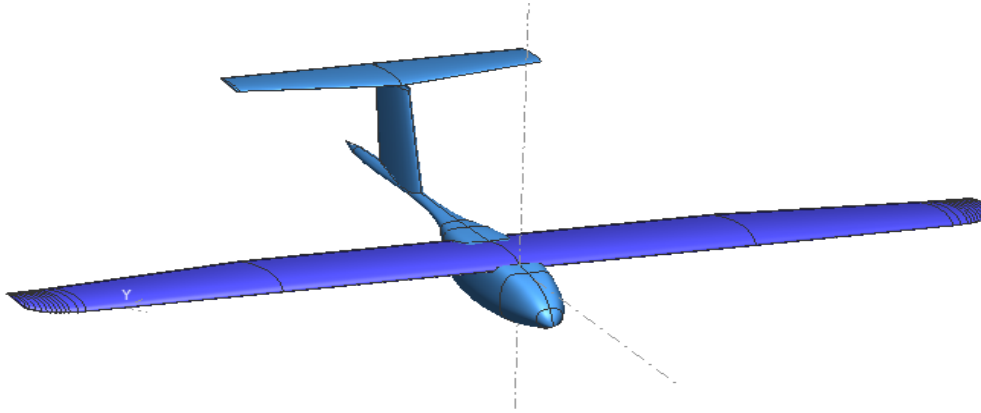
*Fig (II.30). Suspended cable recovery*

The main characteristics of suspended cable recovery are:

- Long enough to avoid been touching by the recovery support.
- The distance between rope knot or cable knot and gravity center long enough to make our UAV bend down.
- Strong enough to carry our UAV weight.
- Light for avoiding the change of gravity center.

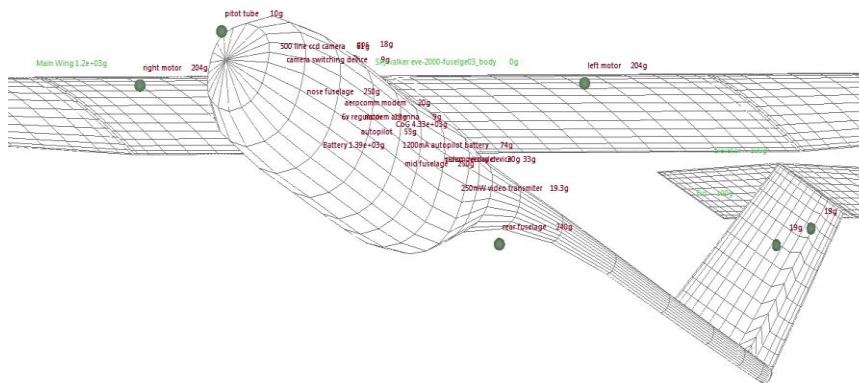
### II.7. Centre of gravity and inertial moment's estimation:

Using XFLR5 software, creation of the configuration and weights repartition was done.



*Fig (II.31). Whole configuration assembly (XFLR5 software)*

Assembly the model is one of the most important phases in the design, the wing construction angle and horizontal tail angle is well-defined with starting values of 2 degrees and -2.5 degrees respectively. A positive wing construction angle gives advantage to shorter the aircraft takeoff distance; horizontal tail angle permits enough force to rotate the aircraft nose up during takeoff and define the aircraft stability criteria's.



*Fig (II.32). Model assembly and weights repartition (XFLR5 software)*

For this configuration a forward CG location was chosen and the aerodynamic center will be back. A static margin of 15 percent will be purchase; it's clear that the horizontal tail and his incidence angle bring back the aerodynamic center of wing-fuselage configuration, the horizontal tail volume is 0.6 more than usual aircraft around 0.5



Let's begin with CG of 35 percent and simulate the model in the next chapter, and from CFD analysis of the curve of moment coefficient versus lift coefficient will revolved the aerodynamic center location and the static margin correspond to it.

This is a calculation form for a rough order of magnitude for the inertia tensor. Refer to the Guidelines for explanations.

Component inertias

Main Wing      Second Wing

Elevator

Fin

Body

Additional Point Masses

	Mass (g)	x (mm)	y (mm)	z (mm)	Description
3	203.500	-20.000	-400.000	-20.000	left motor
4	10.000	-360.000	0.000	-80.000	pitot tube
5	55.000	0.000	0.000	-100.000	kastler autopilot
6	18.000	-50.000	0.000	0.000	furuno gps
7	61.000	-220.000	0.000	-70.000	500 line ccd camera

Total Mass = Volume + point masses

Center of gravity

Total Mass= 4,586.300 g

X\_CoG= 80.025 mm

Y\_CoG= 3.401e-06

Z\_CoG= -54.968

Inertia in CoG Frame

Ixx= 5.684e-08 g.mm<sup>2</sup>

Iyy= 3.887e-08

Izz= 8.844e-08

Ixz= -88,392,903.294

Export to AVL      OK      Cancel

Fig (II.33) Model inertial moment's estimation

A weight repartition was done and the CG position was fixed at 35% of main aerodynamic chord, this CG position gives a distance of 80.012 mm from wing leading edge. In the next chapter this value will be discussed depending of the moment curve slope (aerodynamic center position) to maintain a static margin around 15%.

The inertial moments are:

$$I_{XX} = 0.568kg/m^2 \quad I_{YY} = 0.389kg/m^2 \quad I_{ZZ} = 0.884kg/m^2 \quad I_{XZ} = 0 kg/m^2$$

**II.8.CONTROL SURFACES:**

There are two main aspects to design the control surfaces, i.e. their position and size. Varying them will give different degrees of control effectiveness in terms of roll, pitch and yaw.

**II.8.1.Aileron control surface:**

The aileron requirements were obtained from Ref.01, the choice of values will be achieved from the following requirements.

Table (II.29).Aileron requirements

	Typical parameters [11]	Selected values
$S_a/S_w$	0.05 to 0.07	0.05
$b_a/b$	0.2 to 0.4	0.325
$b_{ai}/b$	0.6 to 0.8	0.55
$C_a/C$	0.2 to 0.25	0.296

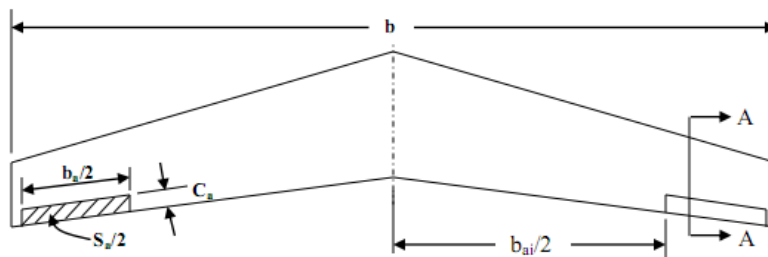


Fig (II.34). Aileron dimensions

Table (II.30). Aileron result values

$b_a/2$	40410 mm
$b_{ai}/2$	67690 mm
$C_a$	70 69 mm

**II.8.2.Elevator control design:**

Same as ailerons selection, the elevator selection values are:

Table (II.31). Elevator requirements

	Typical parameters [11 ]	Selected values
$S_e/S_h$	0.2 to 0.4	0.36
$b_e/b_h$	0.8 to 1	1
$C_e/C_{ht}$	0.2 to 0.4	0.35

The elevator dimensions values results are:

Table (II.32). Elevator result values

$b_e$	765 mm
$C_e$	52 mm

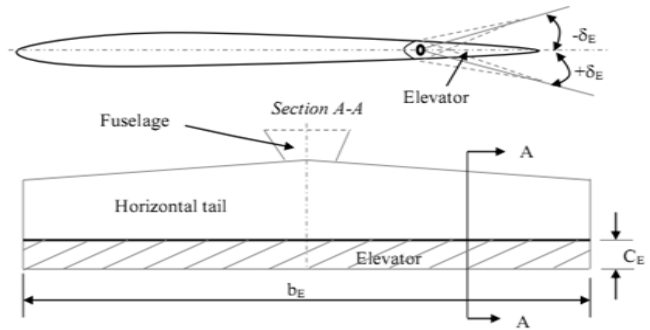


Fig (II.35).Elevator parameters

**II.8.3.Rudder control design:**

Continue with same Reference requirements [01], the rudder typical values and selection revealed also in these following tables:

Table (II.33). Rudder requirements

	Typical values [11]	Selected values
$S_r/S_v$	0.2 to 0.4	0.36
$b_r/b_v$	0.8 to 1	1
$C_r/C_{rv}$	0.2 to 0.4	0.35

The rudder dimensions values results are:

Table (II.34) Rudder result values

$b_r$	281 mm
$C_r$	90.6 mm

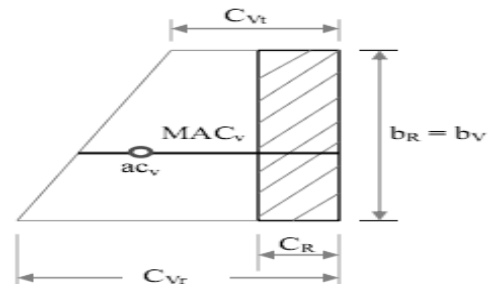
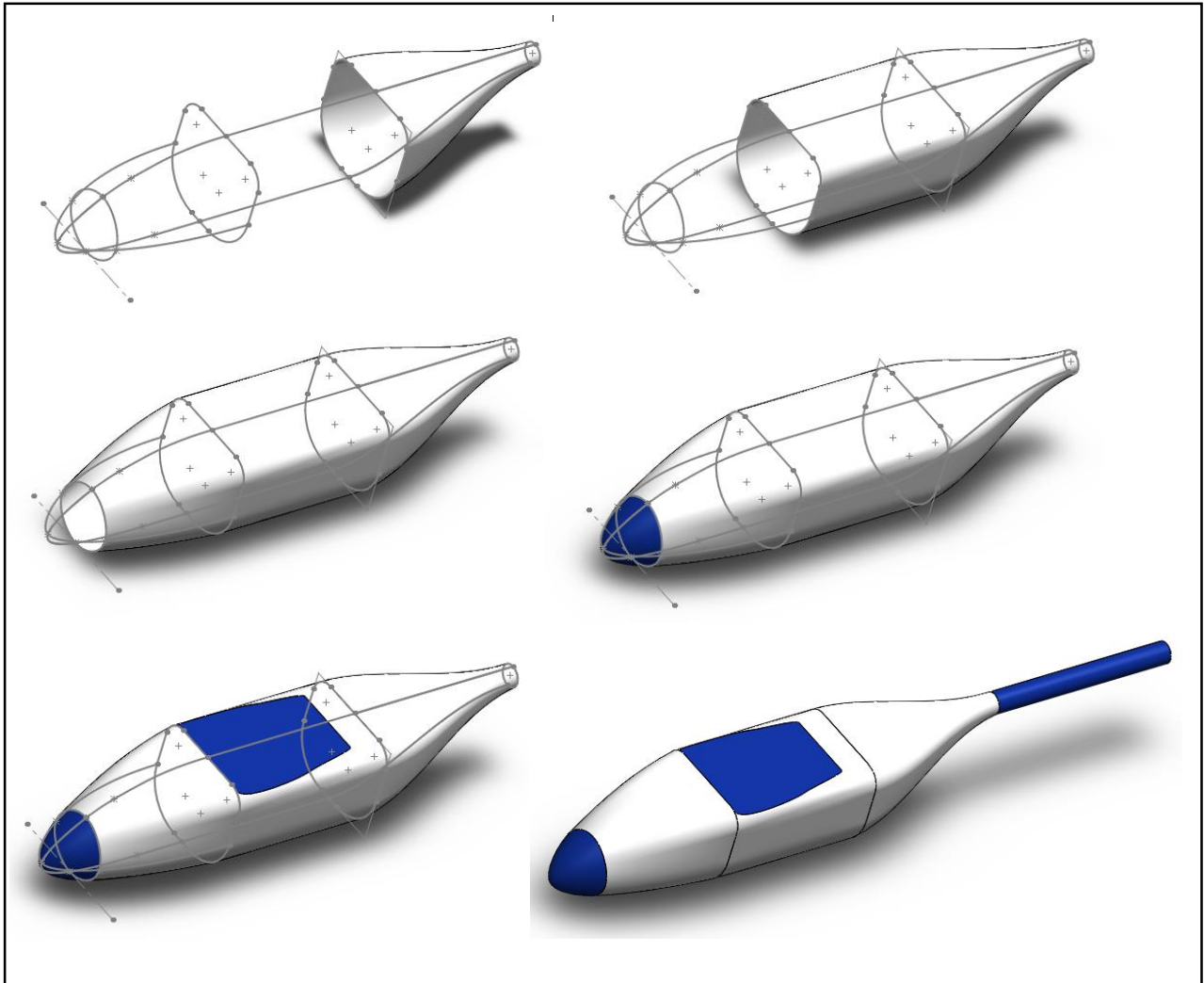


Fig (II.36) Rudder parameters

**II.9.3D Model conception (using SolidWorks software):****II.9.1.Fuselage conception:**

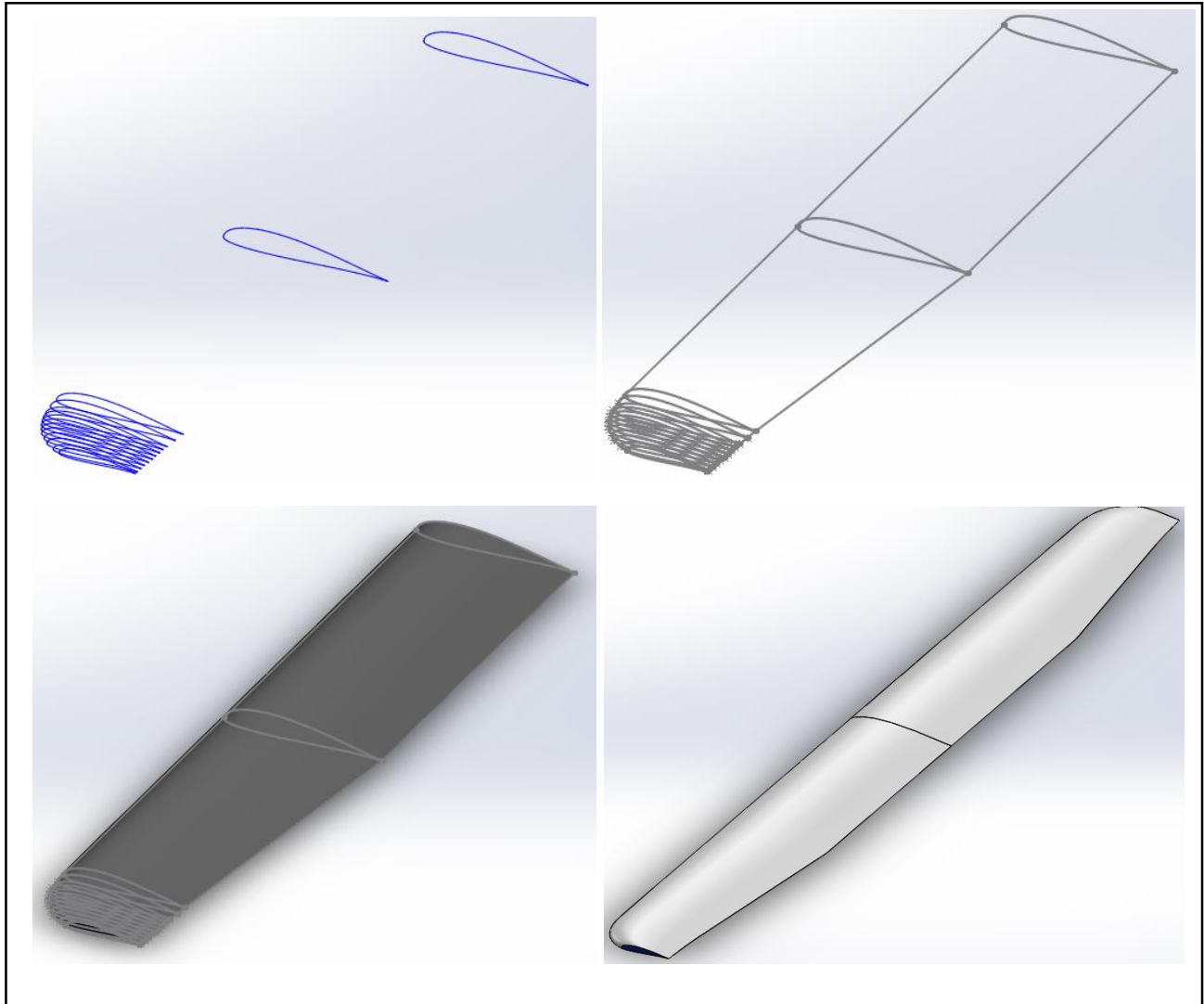
The fuselage component initiated with a 2D sketch in the symmetrical aircraft plan, this sketch defines the limits and the size of our fuselage. A 2D frames sketch added to define the thirds dimensions, these figures point up these steps



*Fig (II.37).Fuselage 3D model design*

**II.9.2.Wing conception:**

The wing three dimension SolidWorks software conception starts with import of Airfoil coordinates data (CaSD7062 .data) in APPENDIX B

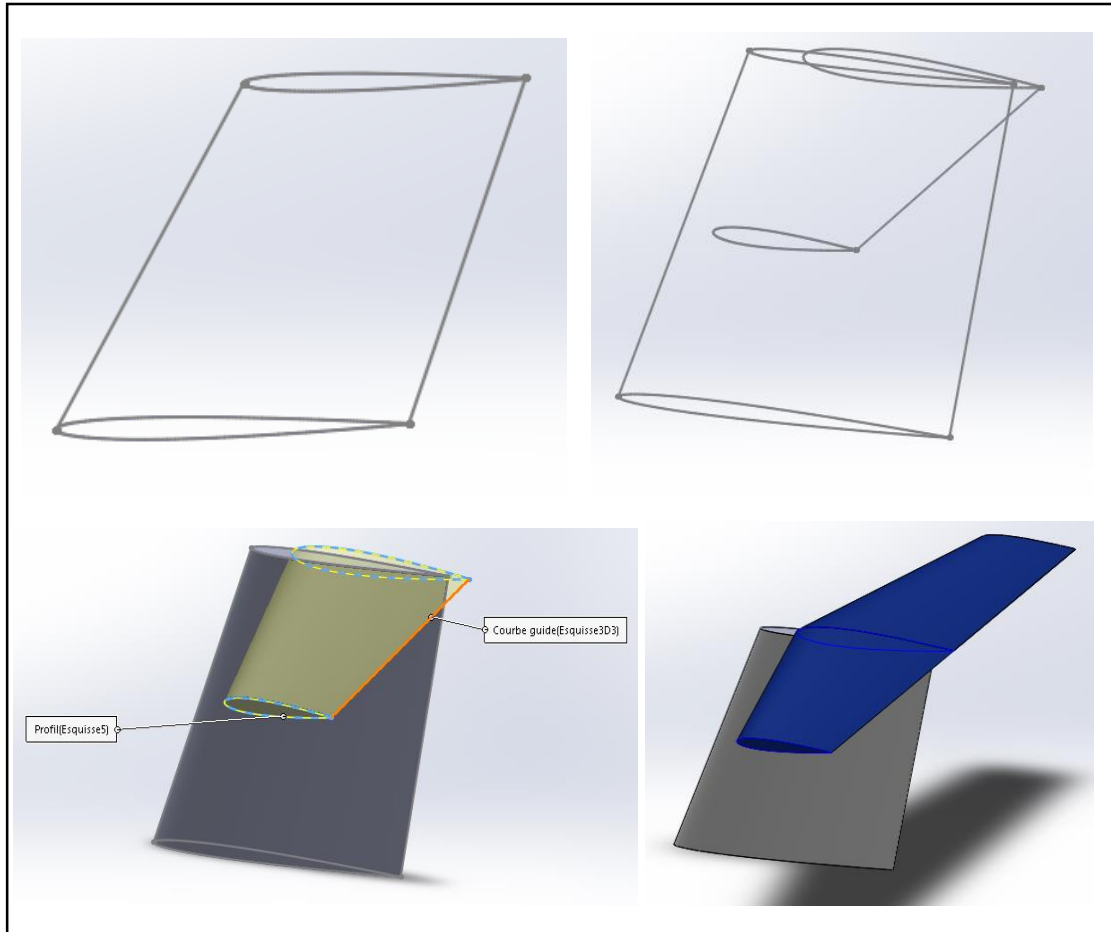


*Fig (II.58) Wing 3D model design*

**II.9.3.Tail conception:**

From the previous tail design section, the profile NACA0012 will use the coordinates NACA0012 presented in **APPENDIX B**.

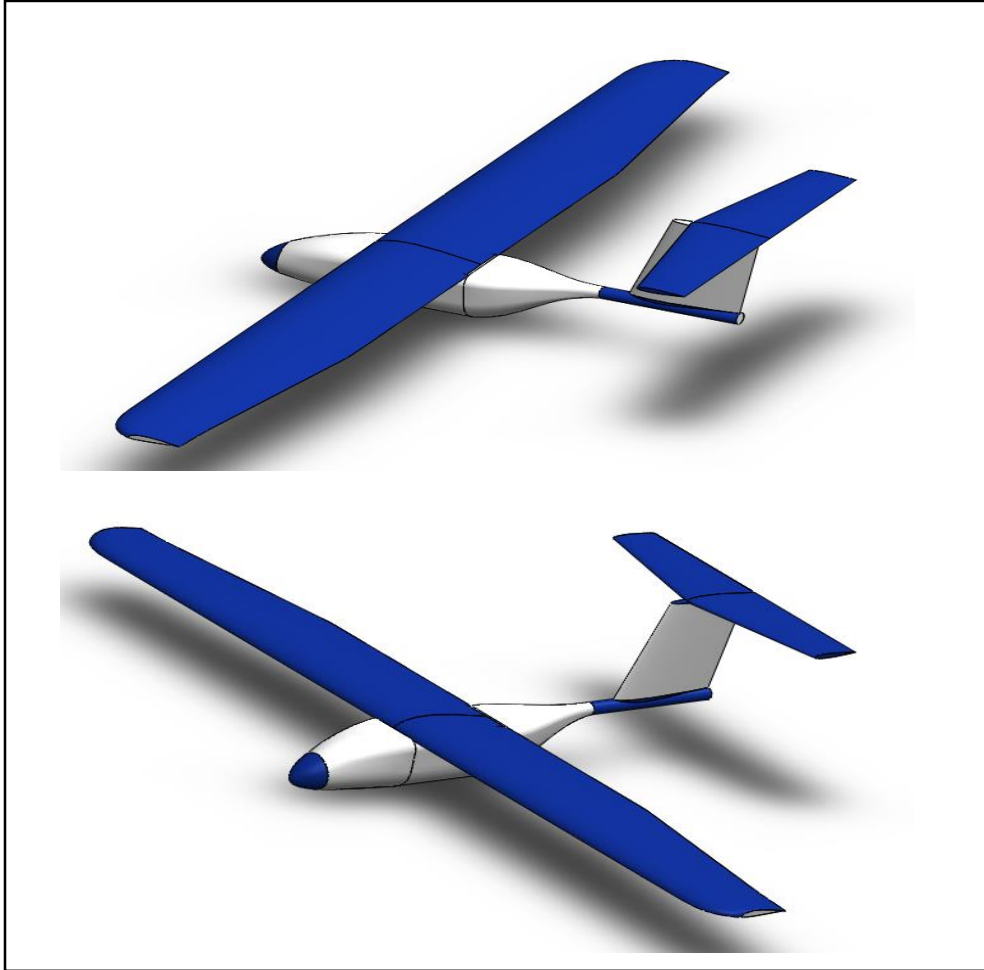
There is no difference between tail and wing conception steps, these five images helps to understand the way to draw the 3D tail concept.



*Fig (II.39)Tail 3D model design*

**II.9.4. Whole Model assembly:**

As a result, the whole model assembly will be achieved using the wing-fuselage and empennage



*Fig (II.40). Whole Model*

**CONCLUSION**

After get hold of the conception and the aerodynamic design, a 3D concept was established with respect of the different criteria's to minimize as possible the potentials of waste time in sizing and aerodynamics parameters choice review.

In this chapter we learned how to make our own concept from the wing to the empennage without forgetting the important phase of stability the next chapters will be a benefit tools to understand the previous choices and confirm the suitable selections and validating the concept.

*Table( II.35 )mini UAV White Nights overall sizing*

<b>Parameter</b>	<b>Result</b>
<b>Type</b>	Mini UAV (fixed wing)
<b>Weight</b>	4500 <i>grams</i>
<b>Wing span</b>	2450 <i>mm</i>
<b>Length</b>	1200 <i>mm</i>
<b>High</b>	540 <i>mm</i>
$V_c$	50 <i>km/h</i>
$V_{Stall}$	9.6 <i>m/s</i>
<b>CG position</b>	80.05 <i>mm</i>
$I_{XX}$	0.588 <i>kg/m<sup>2</sup></i>
$I_{YY}$	0.388 <i>kg/m<sup>2</sup></i>
$I_{ZZ}$	0.884 <i>kg/m<sup>2</sup></i>

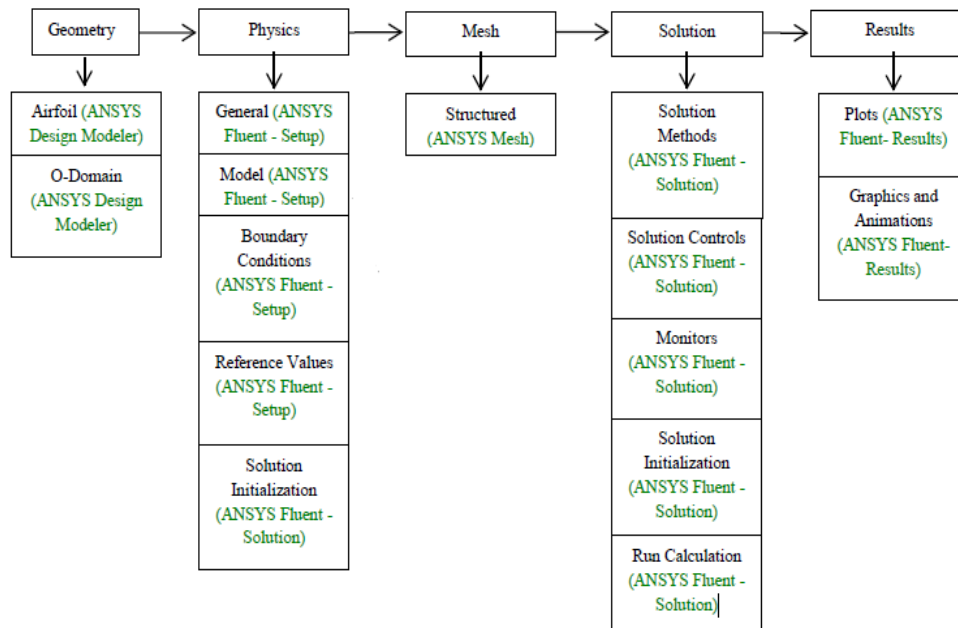


**INTRODUCTION:**

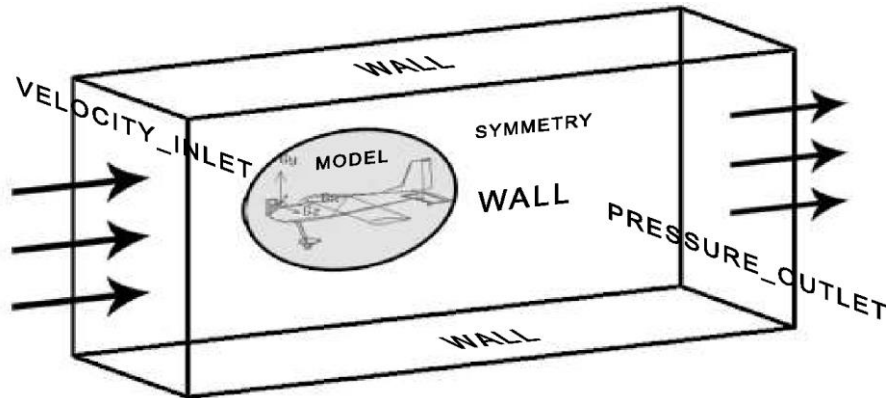
In this chapter we will present the different steps that allowed the numerical study of the aerodynamic flow around the White Nights. This illustrated tutorial allows the student to take these steps for a similar aircraft model on the ANSYS environment. Indeed in ANSYS Workbench we have worked and configured the geometry imported from the solid environment Works with a standard interchange format the model is taken in an enclosing block representing the computational domain. On ANSYS MESHING a great work has been done this part represents three quarters of the work it has to be given him a great attention a good mesh adapted to the problems will give a good physical solution of the flow the choice and the imposition of the boundary conditions in this step must be done properly for a logical digital solution. Finally, the algebraic system previously defined in each elementary volume will form a system of equations that are solved with numerical algorithms of finite volumes and finite elements on the FLUENT SOLVER.

This tutorial shows how to do the following:

- ✓ Launch ANSYS Workbench.
- ✓ Create a fluid flow analysis system Fluent in ANSYS Workbench.
- ✓ Create the White Nights geometry using ANSYS Design Modeler.
- ✓ Create the calculation mesh for the geometry using ANSYS Mesh.
- ✓ Set up the CFD simulation in ANSYS Fluent.



*Fig (III.1). Scheme works on ANSYS*

**III.1 Problem presentation:**

*Fig (III.2). Explanatory drawing of the problem.*

Fluent Ansys allows us to simulate our prototype White Nights aircraft in a digital wind tunnel to do its simulation in order to obtain the desired results as the aerodynamic coefficients and trace the fleece of the aircraft and to conclude its fineness, also see the distributions of the pressure and the speed around the plane and the current lines.

This analysis allows us to discuss the results and compare them with the experimental one to go out with a conclusion on the model validation analyzed.

- ✓ CFD Analysis and study of the results are carried out in 3 steps: pretreatment, and resolution of post-processing using fluent solver in ANSYS work bench.
- ✓ Outlet pressure outlet: Ambient atmospheric condition is imposed at the outlet.
- ✓ Symmetry: This is the speaker wall to see the analysis and reduce the calculation time
- ✓ Operating condition: The input speed taken for the aircraft 17 m / sec, for a different angle of attack.

**III.2. Work Launch:**

1. From the Windows Start menu, select Start> All Programs> ANSYS 16.0

This displays the ANSYS Workbench application window, which has the toolbox on the left and the Project Diagram on the right. Various supported applications are listed in the toolbox and the components of the analysis system will be displayed in the Project Diagram.

2. Create a new fluid flow analysis system running by the option double-clicking on the fluid flow (FLUENT) under the analysis systems in the toolbox.

3. Name the analysis.

- Double-click on fluid mechanics (FLUENT)
- Enter the elbow for the name of the analysis system.

4. Save the project.

- Select the Save option from the File menu in ANSYS Workbench.
- File → Save
- The Save As dialog box, where you can browse to your working folder and enter a specific name for the ANSYS Workbench project.

5. View the list of files generated by ANSYS Workbench.

ANSYS Workbench allows you to easily view the files associated with your project using the Files view. To open the Files view:

- Select the Files option from the View menu at the top of the ANSYS Workbench window.
- View → Files.

### III.2.1. Creating geometry in Design Modeler:

1- Select the desired domain in the box of the toolbox in follow one will have the scheme of project as shows the figure above.

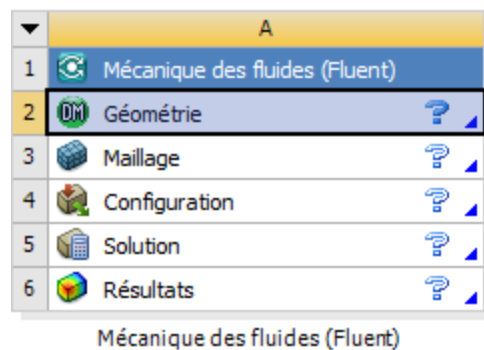


Fig (III.3). Geometry selection.

2-select the geometry in the project schema by double clicking to get the Ansys design modeler page.

3-Import the model

- After making the geometry on SolidWorks and saving it as a STEP format file.
- Selected the File menu.
- Select Import Geometry File  Importer le fichier de géométrie...

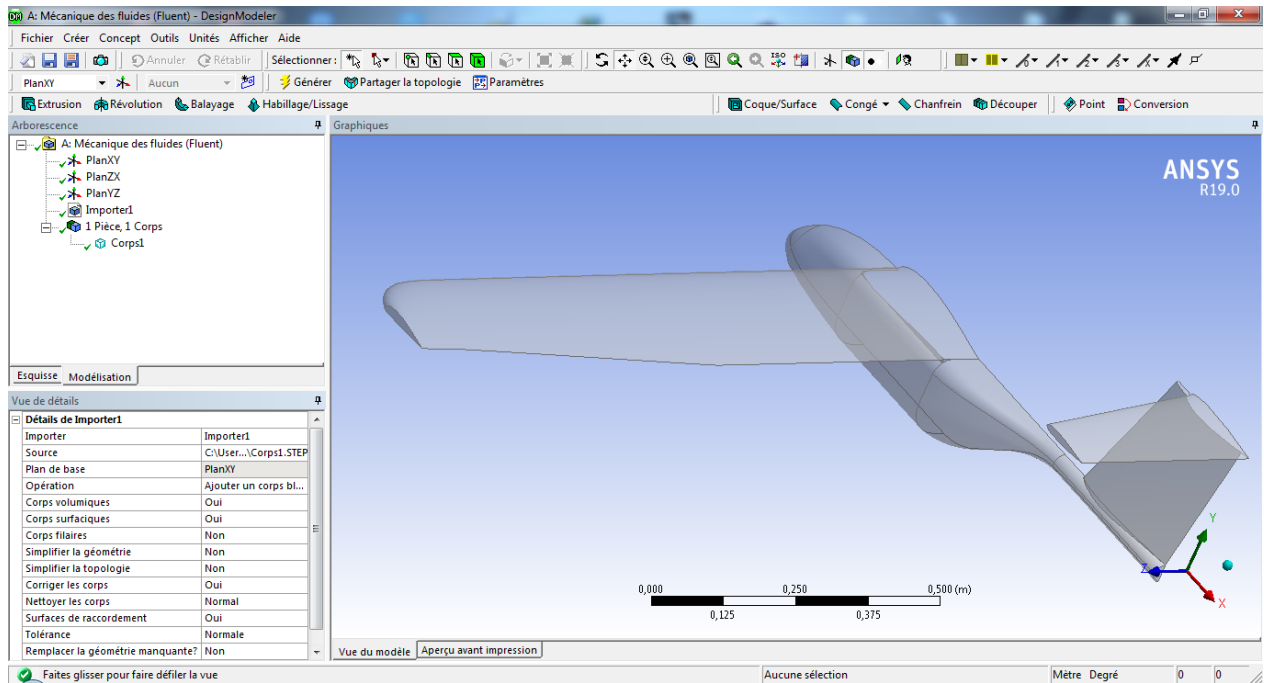


Fig (III.4). UAV in Design modeling

4-Encompass the plane end to define the boundary conditions In the menu bar select tools then encompass.

5- Remove the aircraft body:

The operation to delete the body serves to work with the surface that is to say the aerodynamics it intersects to study the surface of body not with the volume.

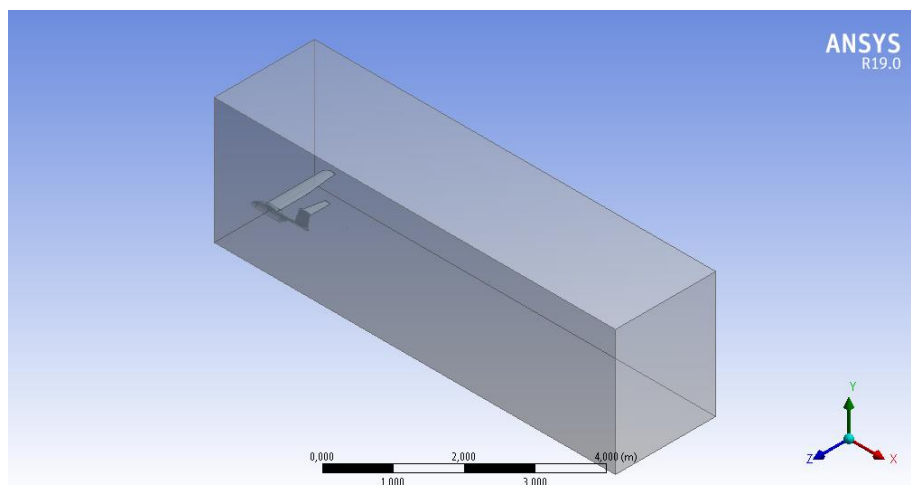


Fig (III.5). Creating the control volume.

The success of these steps performed in Ansys design Modeler that confirms with signs appears in Tree located to right, as is sign for each operation ( ✓ ).

In the project schema after completing and completing all operations we will have this notification that the creation in design modeler succeeded ( ✓ )

The  option means that our geometry realize is ready for mesh.

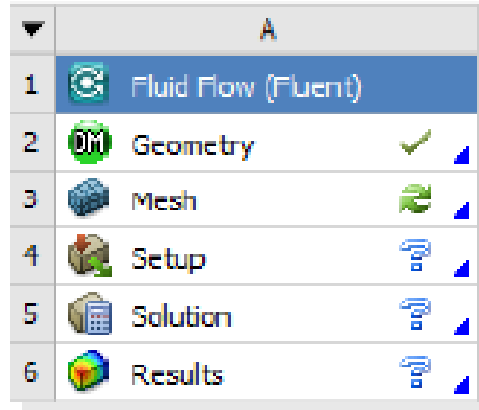


Fig (III.6). Project schema

**III.2.2.Mesh creation in ANSYS Mesh application:**

1-In the ANSYS Workbench project schema, double-click the Mesh cell in the fluid mechanics analysis system.

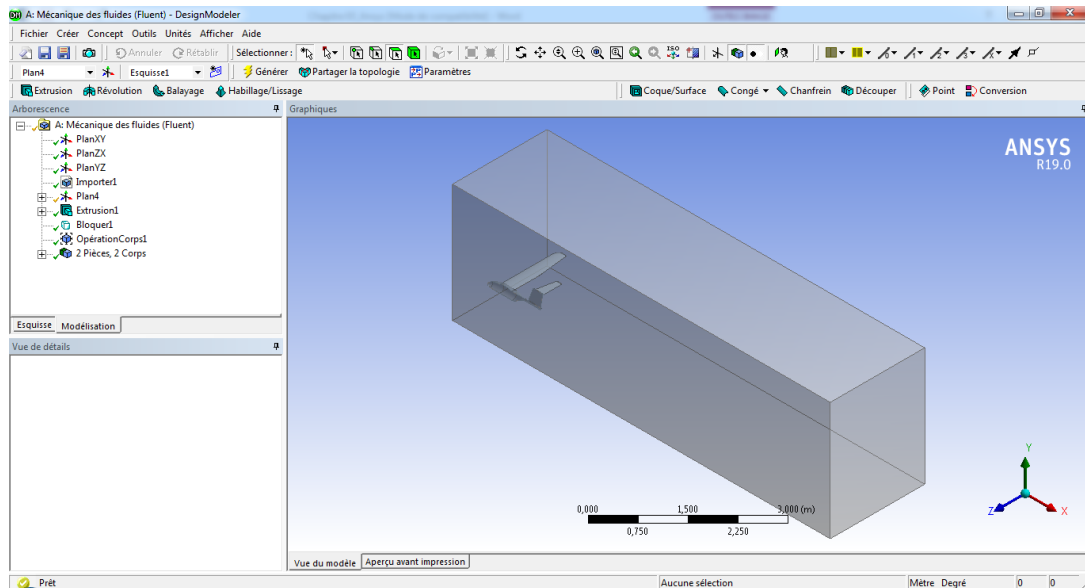


Fig (III.7). ANSYS mesh application

2- In outline, select the Mesh object to display the details of "Mesh".

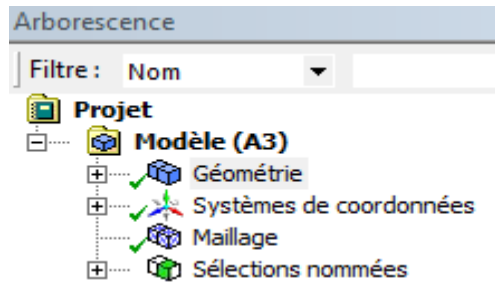


Fig (III.8). Mesh tree view.

3- In the "Mesh" details, set the following options under Default Settings;

- Physics Preference: CFD.
- Solver Preference: FLUENT.

4-define Under Dimensioning and the quality in the figure above.

[-]	<b>Affichage</b>	
	Style d'affichage	Couleur du corps
[-]	<b>Réglages par défaut</b>	
	Physique de préférence	CFD
	Préférence de solveur	Fluent
	Format de l'export	Standard
	Exporter le maillage de ...	Non
	Ordre des éléments	Linéaire
[-]	<b>Dimensionnement</b>	
	Fonction de taille	Courbure
	<input type="checkbox"/> Taille de face max	0,50 m
	Simplification du maillage	Oui
	<input type="checkbox"/> Taille de simplification	Par défaut (2,5e-003 m)
	<input type="checkbox"/> Taux de croissance	Par défaut (1,20 )
	<input type="checkbox"/> Taille min	Par défaut (5,e-003 m)
	<input type="checkbox"/> Taille de tétraèdre max	Par défaut (1,0 m)
	<input type="checkbox"/> Angle normal de cou...	Par défaut (18,0 °)
	Diagonale de la boîte e...	8,27650 m
	Aire de surface moyenne	2,13070 m <sup>2</sup>
	Longueur d'arête minim...	5,9114e-005 m
[+]	<b>Qualité</b>	
[+]	<b>Inflation</b>	
[+]	<b>Maillage d'assemblage</b>	
[+]	<b>Avancés</b>	
[+]	<b>Statistiques</b>	

Fig (III.9). View of details in ANSYS mesh.

5-Generate the mesh:

- In outline, right click on the Mesh object and select generate mesh
- A mesh will be generated on all surfaces using the global commands applied until now.

From the following figure it is clear that the aircraft is well refined around its outer surface, then the mesh begins to grow gradually away from the aircraft, the mesh refinement gives us more precision to get good results.

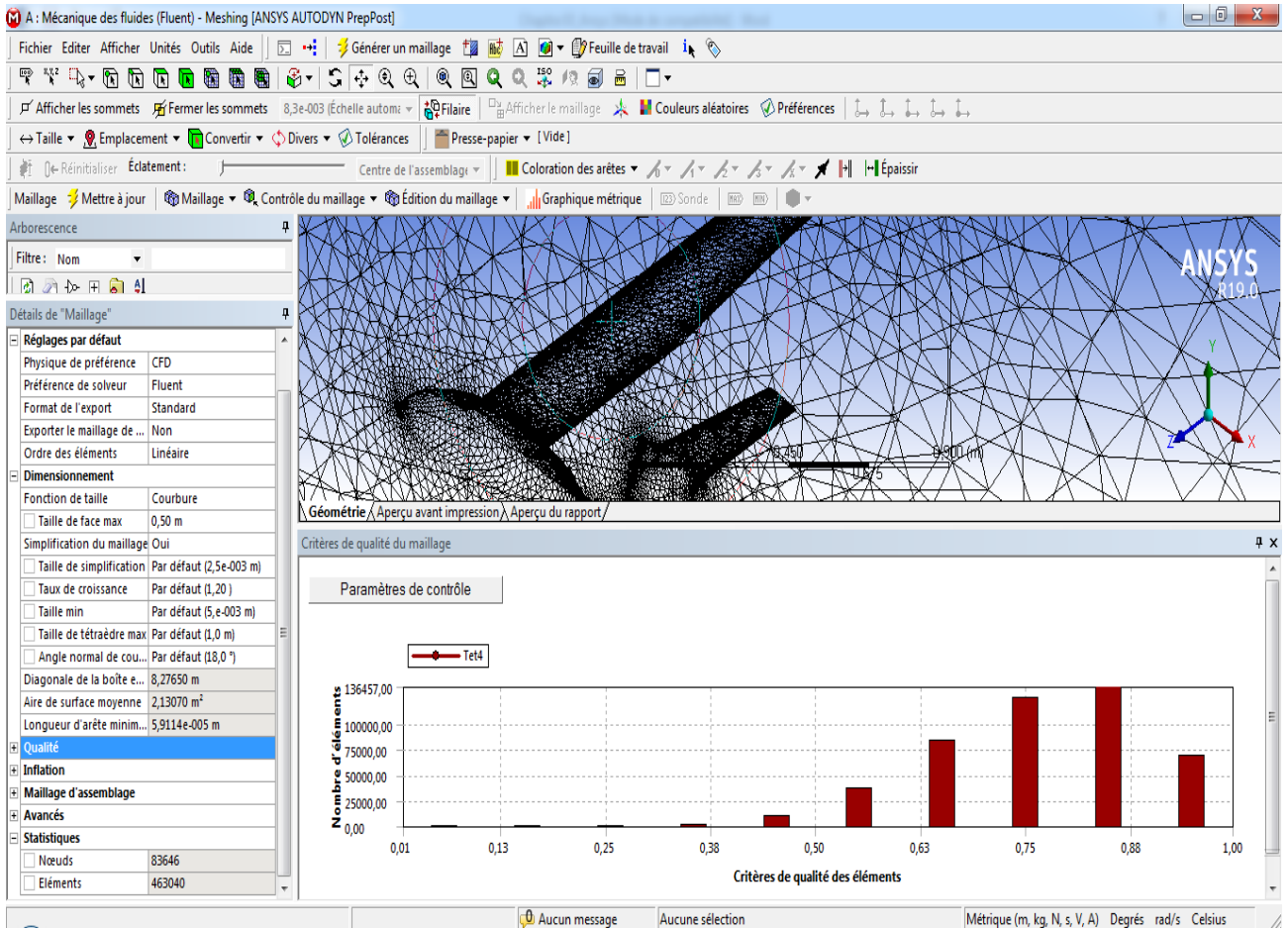


Fig (III.10).orthogonally quality, statistics and Mesh around the plane.

#### 6- Named selection:

In defining the boundary conditions of geometry to simplify our work later in ANSYS Fluent, we must label each limit in the geometry by creating named selections for the inputs, the output and the symmetry surface of the geometry. (The outer wall boundaries are automatically detected by ANSYS Fluent).

- Select the large input in the geometry that is displayed in ANSYS mesh
- By a right click and select the Create Named Selection option.
- For each step of the selection named in must select the option face.
- Select the symmetry face by clicking the right button this operation it is executable for all the named selection of this problem: Wall, Intel, outlet, symmetry.

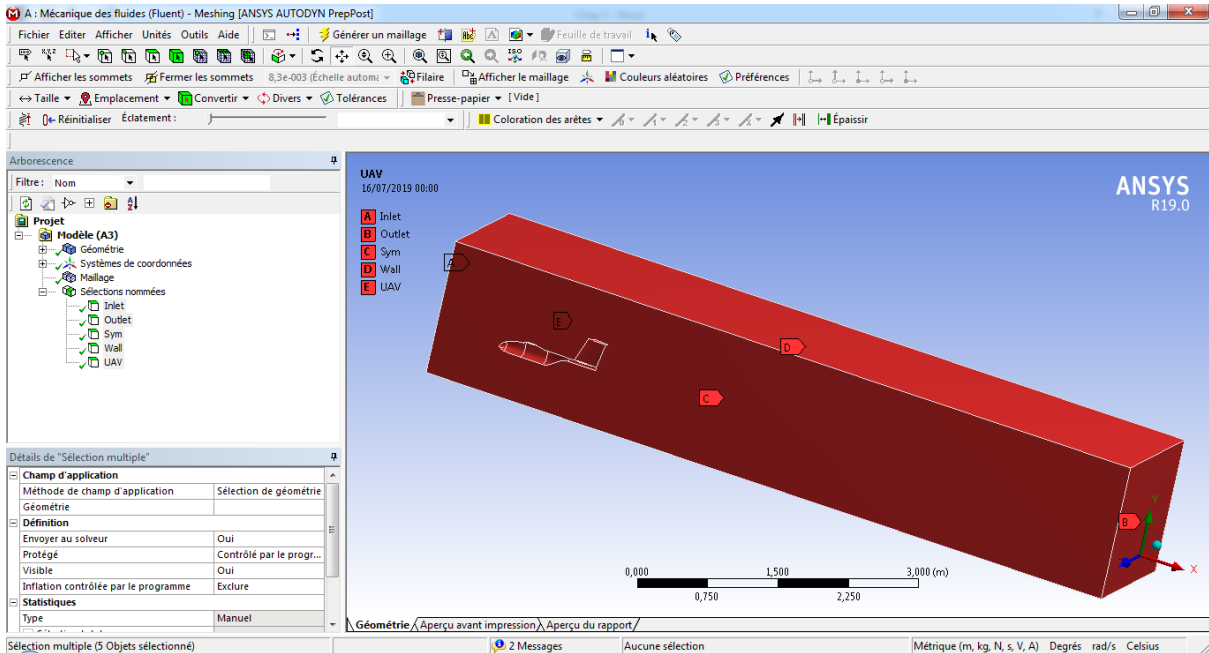


Fig (III.11). The named selection of symmetry.

When the mark ( ✓ ) appears on the mesh in the project diagram that is to say we can go to the next step which will be displayed by the mark ( ↻ ).  
 Leave the ANSYS workbench mesh and go now to CFD configuration and analysis in fluent ANSYS.

**III.2.3. Configuring CFD simulation in ANSYS Fluent:**

Now after creating the calculation mesh for the geometry of the aircraft, in this step, we will set up a CFD analysis using ANSYS Fluent, then examine the list of files generated by ANSYS Workbench.

1-Start ANSYS Fluent.

In the ANSYS Workbench project schema, double-click on the installation cell in Fluid Mechanics.

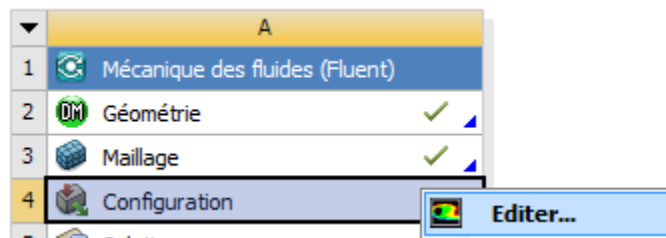


Fig (III.12). Configuration project schema.



You can also click on the Configuration cell to display the contextual menu where you can click Edit.

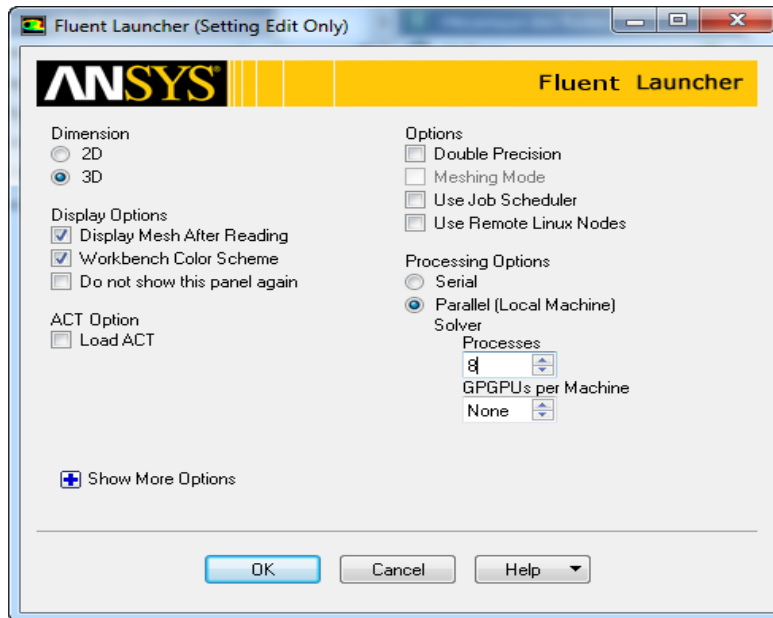


Fig (III.13). Fluent launcher.

By clicking OK the start of ANSYS Fluent is preparing.

2-Define the general parameters of the CFD analysis.

Click General in the tree to open the general tasks page where we can perform-related activities mesh and choose a solver.

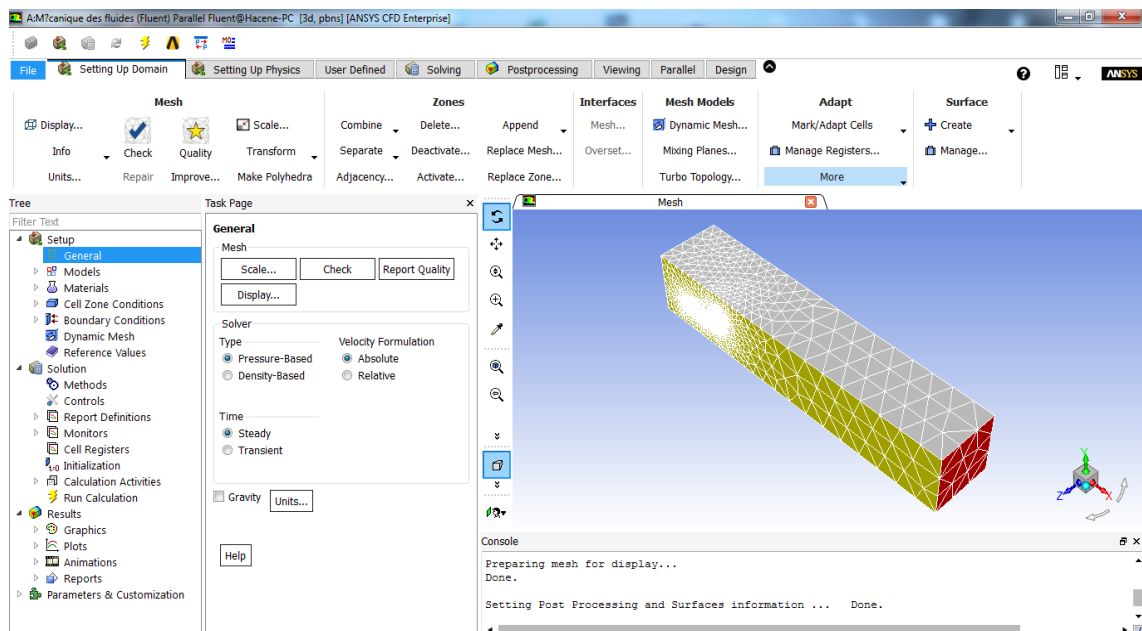


Fig (III.14). ANSYS Fluent.

### 3-Mesh Quality Report:

The quality of the mesh plays an important role in the precision and the stability of the numerical computation. Verifying the quality of our mesh is so it's an important step in achieving a robust simulation.

Minimum cell orthogonally is an important indicator of mesh quality. Orthogonally values can range from 0 to 1 with lower values indicating poorer quality cells. In general, the minimum orthogonally should not be less than 0.01 to the significantly larger mean value.

### 4-Setting Flow Model:

- Specify the laminar flow model using Problem Setup> Models> Viscous.
- Double click on the last one and select Laminar.

Our model (UAV) at a speed of 9.6 m / s and in atmospheric conditions the Reynolds number and the order 250,000 and 270,000 then we are in the laminar flow regime.

### 5-Specification of fluid used (Materials):

- The material is defined using Problem Setup> Materials.
- Click on air to open the Create / Edit Materials window.
- The density (Density) and the viscosity (Viscosity) are changed to 1.225 kg / m<sup>3</sup> and 1.7894 e-05 kg / (m-s) respectively.
- We click on Change / Create.

### 6-Boundary Conditions:

#### a-The input inlet condition:

For surface of entry one chooses the type of boundary condition Inlet-Velocity on clicks Edit one chooses 9.6 [m/s] in Velocity Magnitude because the sense of the speed is opposite to the plane vector of the plane following the Z axis.

#### b- La condition de sortie outlet :

Pour surface de sortie on choisit dans la direction de flux suivant l'axe Z on mit (1)

After this step we move to solution phase and we chose report plots and we chose the kind of power that we need after the selection of lift and drag coefficients we specify our UAV model.

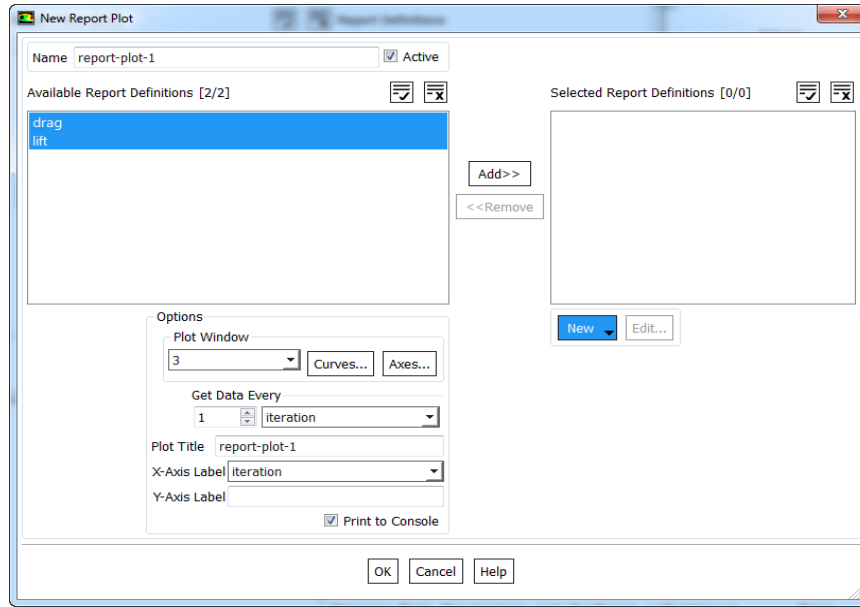


Fig (III.15). Report plot using drag and lift coefficients.

#### 7- Initialization of the solution (Initialization):

- Solution> Monitors> Solution Initialization is used.
- Inlet is selected under Compute from.
- Click on Initialize to initialize the solution.

#### 8- Run the calculation

- To start the solution, use Solution> Run Calculation.
- 1000 is entered for the maximum number of Iterations.
- Click on Calculate.

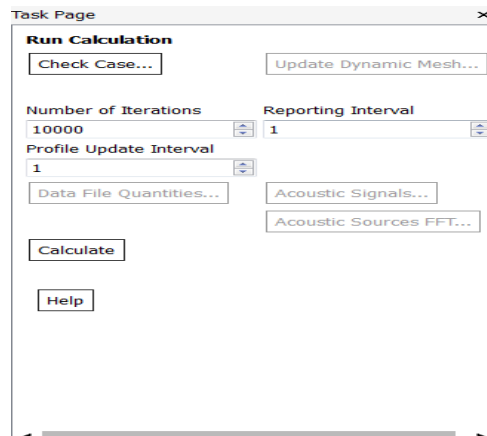


Fig (III.16). Run the calculation.

**III.2.4. Results and solutions:**

Influence of impact on the lift and the drag coefficients:

According to the ANSYS fluent software and the limitation of my pc, the results given in the following table were obtained for each angle of incidence (from -6 to 12 °):

Table (III.1). *CFD results.*

AOA	CL vs AOA	CD vs AOA	CL/CD vs AOA	Cl <sup>2</sup>	Cm
-6	-0,035	0,0395	-0,886075949	0,001225	0.1202
-4	0,17	0,0336	5,05952381	0,0289	0.0746
-2	0,36	0,04	9	0,1296	0.0322
0	0,57	0,048	11,875	0,3249	0.0100
2	0,75	0,056	13,39285714	0,5625	-0.0432
4	0,93	0,073	12,73972603	0,8649	-0.0813
6	1,11	0,095	11,68421053	1,2321	-0.1120
8	1,21	0,12	10,08333333	1,4641	-0.1483
10	1,28	0,152	8,421052632	1,6384	-0.1820
12	1,23	0,172	7,151162791	1,5129	-0.2289

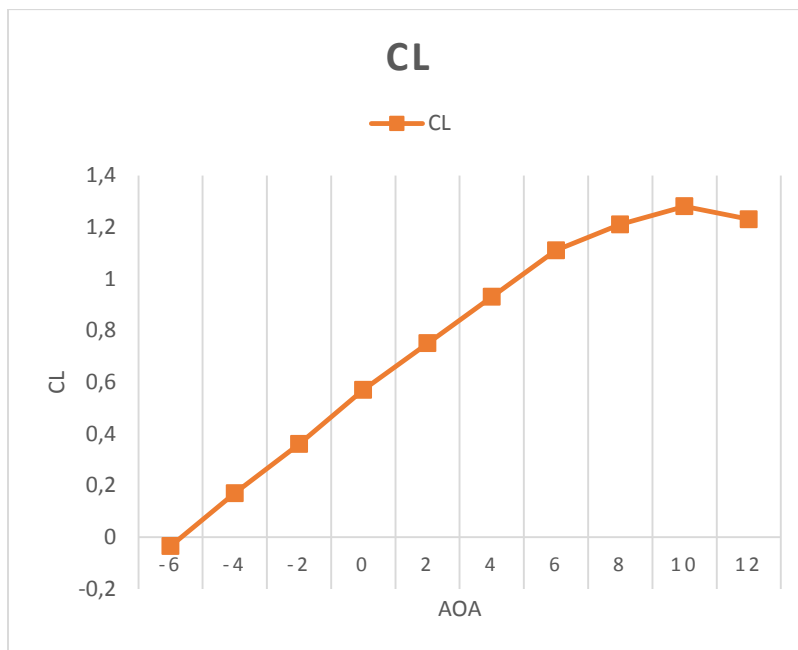


Fig (III.17). *CL vs AOA.*

The lift curve simulation result has the same tendency of the SD7062 14% 2D profile Figure II.11 (K. W Idiner and M Allen) and a maximum lift coefficient  $C_{L_{max}}$  of 1.50 at 11 degree; in other hand this result is less than  $C_{L_{max}} = 1.33$  which was assumed in the beginning, but steel an acceptable result taken in consideration a little increase of stall velocity in this level (without wind tunnel results).

From the graph which represents the variations of the coefficient of the lift  $C_L$  as a function of the angle of incidence, one draws marked points interpreted as follows:

When the angle of attack is zero; a positive lift coefficient of 0.55 is obtained

La Between the angle of incidence  $-6^\circ$  and  $11^\circ$ , the lift increases rapidly, the coefficient of lift  $C_L$  reaches the value 1.30. Which means that there is a rather large increase with the increase of the incidence on this section of the graph.

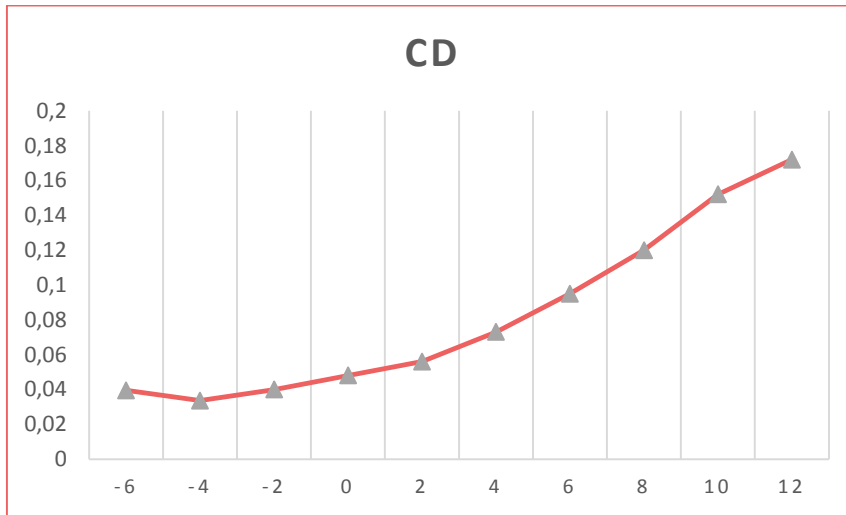


Fig (III.18).  $C_D$  vs AOA.

Figure III.17 shows the variation of drag coefficient as function of angle of attack. The lowest point of this graph  $C_D = 0.0336$  at  $-4$  degree is called minimum drag coefficient  $C_{D_{min}}$ . As the drag is directly related to the cost of flight,  $C_{D_{min}}$  is of great importance in airfoil selection.

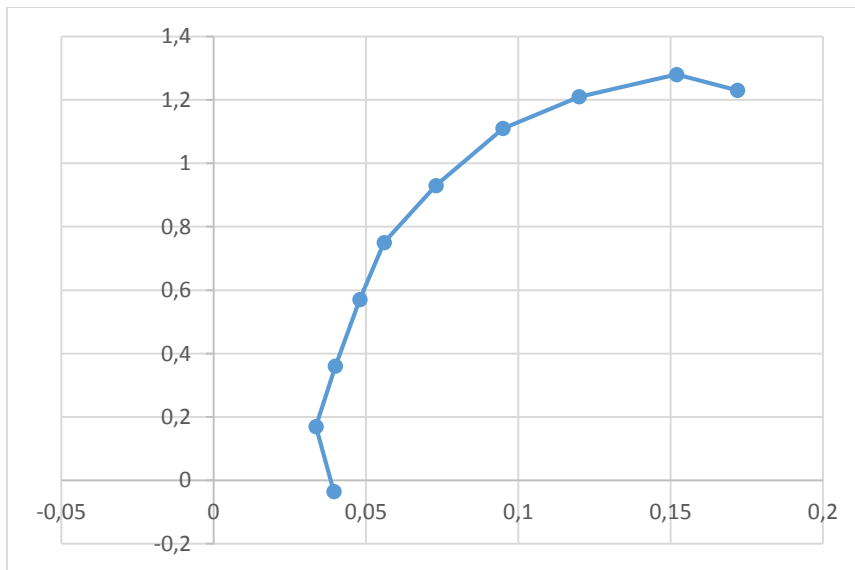


Fig (III.19).  $C_L$  vs  $C_D$ .

From the Polar graph a maximum lift to drag ratio is about  $C_L/C_D = 1.28$  at 10 degree angle of attack, to get the maximum range is perfect to fly near to this angle of attack.

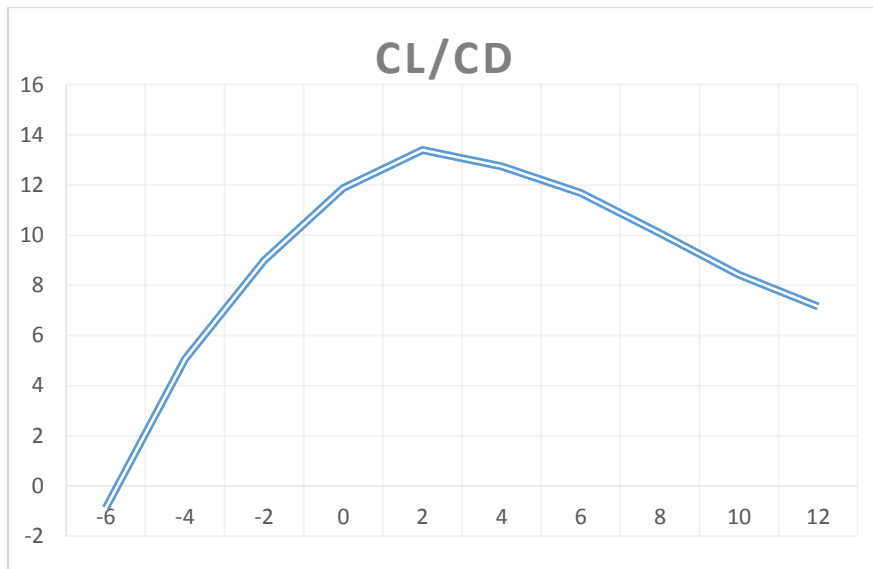


Fig (III.20). CL/CD.

Calculate cruise lift coefficient: From chapter II the mini UAV cruise velocity is 50 km/h and  $C_{Lmax} = 1.33$  at 300 m

$$C_{Lcruise} = \frac{W}{\frac{1}{2} \rho S V_C^2} \tag{III.1}$$

$C_{Lcruise} = \frac{0.45 \cdot 9.81}{\frac{1}{2} \cdot 1.19 \cdot 0.579 \cdot 13.89^2} = 6.64$ . From lift to drag ratio curve versus angle of attack has a better range between [3 to 8] of flying angles, the angle of attack is in the range.

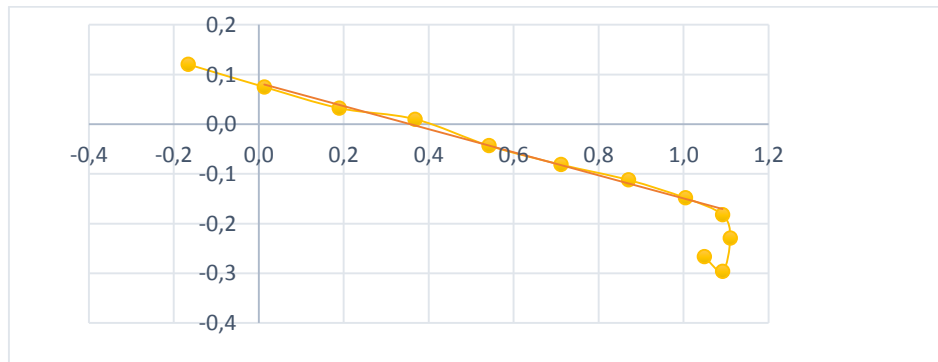


Fig (III. 21) Cm versus CL.

The moment coefficient versus angle of attack Figure III.18 simulates at CG of 35% from wing chord, the linear part of this curve gives the moment lift coefficient slope equal to

$$\frac{dC_m}{dC_L} = -23.21\%$$

The moment coefficient has a negative slope and a positive  $C_{m0} > 0$  that means the UAV is statically stable.

***III.2.5. Visualization of the results:***

From the static pressure contour visualization; there is an appearance of high-pressure areas on the shock surfaces (leading edge, nose plane and empennage surfaces exposed perpendicular to the flow) with red color and low pressure zones in (extrados wings) with blue color. There is a pressure difference between the lower and upper surfaces. Then resultant pressure forces that act on the aircraft in the direction of flow.

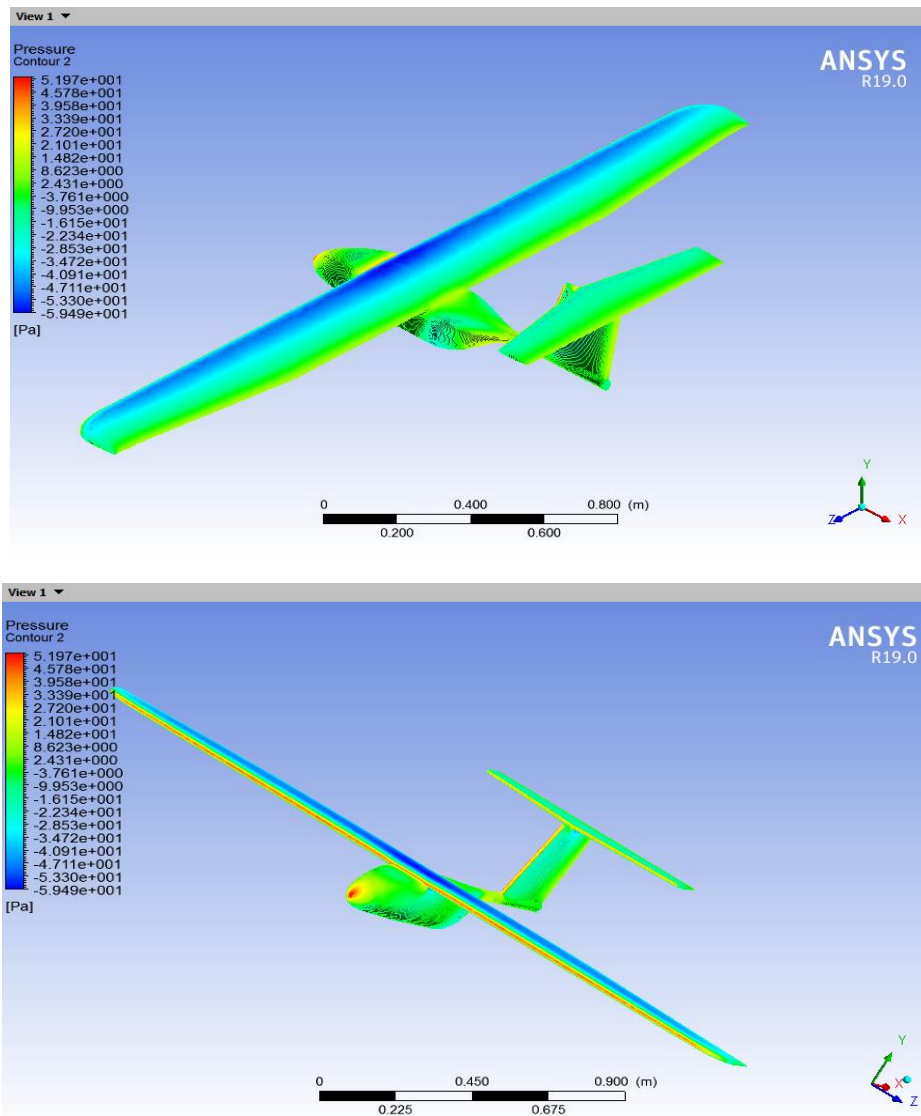


Fig (III. 22). Pressure distribution at the plane.

**CONCLUSION:**

As a result the marge of the error was small between the classic method and simulation method so This UAV model has an acceptable result in view of aerodynamics characteristics designed during the preliminary conception and aerodynamic design chapter II and finally we can move to execute the result in the next chapter named manufacturing.



**INTRODUCTION:**

Any flying apparatus depends primarily on the reduction of its weight to allow optimal performance and without affecting the robustness of the latter. A deliberate effort has been made throughout the design and construction to reduce weight while ensuring the structural integrity of the final product.

The main material was polystyrene which allowed us better maneuverability to form the different curvatures constituting our drone using a manual cutting machine in the case of wings and empennage but for the fuselage we used MDF for a good surface. The serious work environment and the follow-up of the plan put was essential in the success of the project as a whole.

**IV.1.Composite materials:****IV.1.1.Definition:**

A composite material results from the assembly of at least two materials of different nature, immiscible, complementing each other and making it possible to obtain a material whose overall performance is improved, with respect to a specific need, with respect to those of its elementary constituents.

Anisotropy and heterogeneity are the basic mechanical characteristics of composites. In general, there are three major families of composite materials:

*Table (IV-1). The family of composite materials.*

<b>Class</b>	<b>Examples</b>	<b>Components</b>	<b>Application</b>
<b>Organic matrix composites</b>	Carton, Tires, Laminates, Plastics, reinforced	Cellulose, Rubber, Fiberglass, Carbon, Boron Resins, Short Fibers	Packing transport network Light structures various
<b>Mineral matrix composites</b>	Concrete Composites C-C ceramics	Cement, sand, additives Carbon fiber Ceramic and ceramic fiber	Civil engineering Aerospace, aviation, sport, biomechanics, thermomechanics
<b>Metal matrix composites</b>		boron fiber carbon fiber	Aerospace

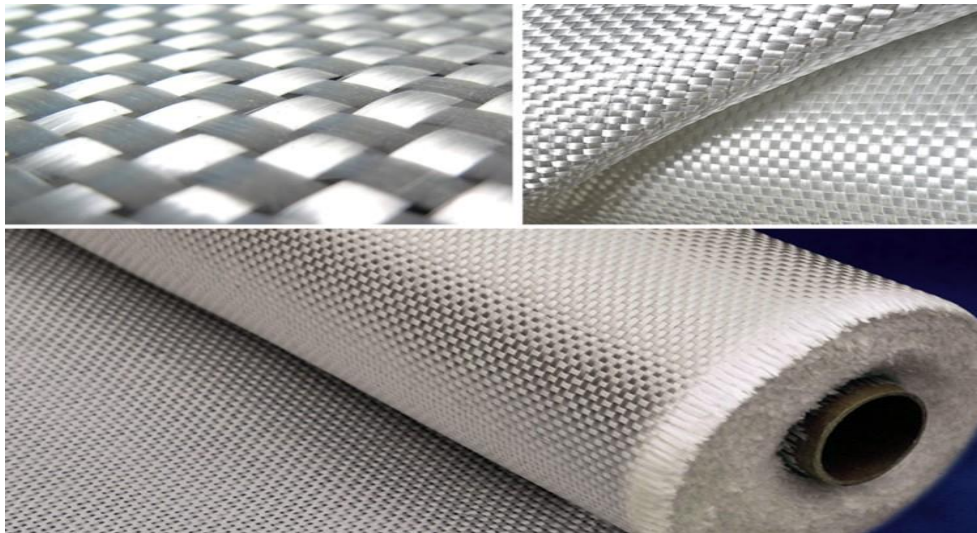
### IV.1.2. The Reinforcements:

Constituted by several hundreds / thousands of filaments with diameters ranging from 5 to 15 micron their roles consist in supporting the forces applied and in giving the composite its elastic rigidity and its resistance to fracture, possibly at high temperature, they must also be compatible with the matrix of the composite on the chemical plane.

The main types of reinforcements are distinguished by their geometry (particles, beads, short fibers, long fibers), by their arrangement, in particular for fibers (3D random, felts, 2D mat sheets, unidirectional layers, 2D weaves, 3D weaves). Or by their nature (fiberglass, carbon fiber).

#### IV.1.2.1. Fibers of glass:

The filaments are obtained by spinning glass (silica + sodium and calcium carbonates) in melt ( $T > 1000^{\circ}\text{C}$ .), through platinum alloy dies.



*Fig (IV.1). Fiberglass fabric*

Main advantages:

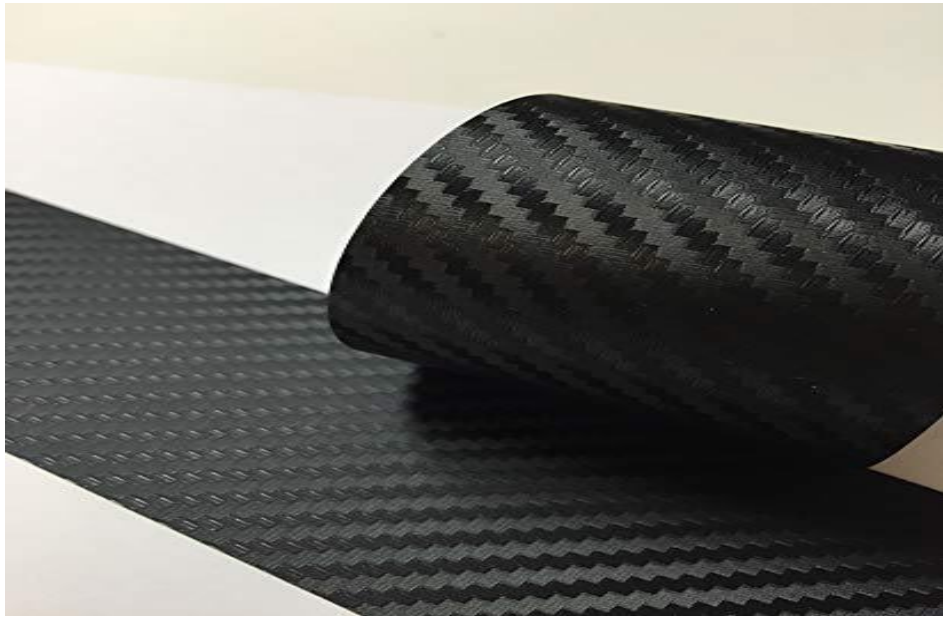
- Good thermal and electrical resistance.
- Good resistance to chemicals and moisture.
- Good compatibility with organic matrices.
- Low cost.

Main limitations:

- Medium mechanical characteristics including elastic stiffness.
- Low impact strength.

### IV.1.2.2 Carbon fibers:

Acrylic filaments of Tergal or rayon (obtained from distillation of coal or oil) are hot oxidized (300C) and heated to 1500 C in a nitrogen atmosphere. It remains then only the hexagonal chain of carbon atoms. Black and shiny filaments are obtained. The high modulus of elasticity is obtained by hot spinning [17].



*Fig (IV.2). Carbon fiber fabric.*

Main advantages:

- High tensile strength and high longitudinal rigidity.
- Very good temperature resistance without falling properties (up to 1500 ° C in non-oxidizing atmosphere).
- Inertia to corrosion and chemical agents.
- Coefficient of longitudinal dilation very low, or even zero.

### IV.1.2.3. Aramid fibers:

In particular, aramid fibers (Kevlar) have excellent characteristics of rigidity and tensile strength, good resistance to fatigue and impact, but poor compression and shear behavior (hence bending). They are most often used in combination with glass or carbon fibers [17].



*Fig (IV.3). Aramid (Kevlar) fiber*

Main limitations:

- Fragility to shock.
- Fragility when bending.
- High cost.

#### **IV.1. 3. The matrices:**

The matrix of a composite has the role of embedding the reinforcements, thus protecting them from the external environment, ensuring a homogeneous spatial distribution of the reinforcements, transmitting reinforcements the external forces and distributing them, and conferring its shape to the composite material part [18].

#### **IV.1. 3. 1. Organic matrices:**

Main advantages:

- Low density
- Low density
- Relatively low cost-material.
- Insensitivity to many chemical agents
- Easy and fast implementation, compatible with both prototyping and mass production.

Main limitations:

- Low temperature resistance.
- Sensitivity to moisture.

**IV.1.3.2. Metal matrices:**

The impregnation of reinforcements by a liquid alloy being a technically delicate operation, in practice only aluminum alloys are used in this type of technique, associated with fibers or particles of graphite or ceramic. They are easy to implement because their melting temperature is relatively low; their density is low and they are inexpensive. The compromise obtained between the toughness of the metal matrix and the stiffness of the reinforcements gives the composite interesting mechanical characteristics with respect to the alloy alone, especially above 200 °C [18].

Their high cost of implementation reserves metal matrix composites for aeronautical and space applications.

**IV.1.3.3. Mineral matrices:**

Main advantages:

- Low density.
- Good resistance to compression and high rigidity, even in temperature.
- Refractoriness and chemical inertness.

Main limitations:

- Sensitivity to shocks.
- Delicate and expensive implementation.

**IV.1.4. METHODS OF IMPLEMENTING COMPOSITE MATERIALS:**

In practice, the choice of a design will be guided by the satisfaction of various criteria, such as the maximization of rigidity, resistance, and / or the minimization of weight, cost, while respecting a set of constraints. . Thus, the design of an ideal composite material can be formulated as an optimization problem whose resolution will require the use of appropriate techniques to assist the designer in making decisions leading to structures with optimal properties [18].

The most used processes are:

**IV.1.4.1 Contact molding:**

Technology for producing prototype parts or simulation. The principle is to manually impregnate the reinforcements arranged in a mold. It is inexpensive and parts of any shape can be made but has a very low rate.

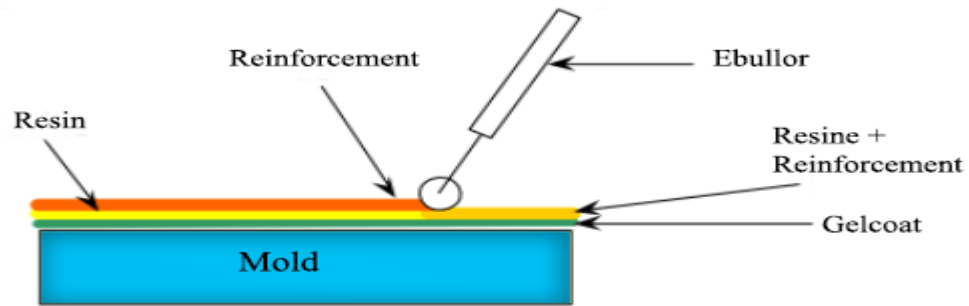
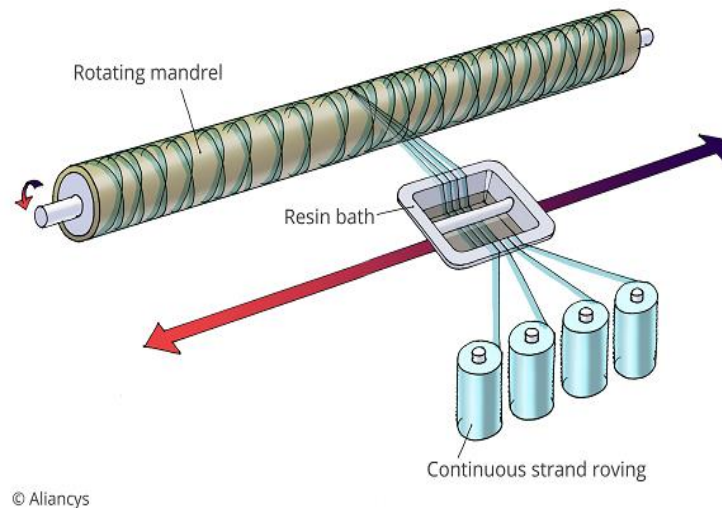


Fig (IV.4). Contact molding.

#### IV.1.4.2. Filament winding:

Technology for High Performance. The principle consists of a winding under tension on a mandrel rotating around its axis of continuous fibers previously impregnated with a binder. The advantages are the optimal arrangement of the reinforcements, the very good mechanical properties and the possibility of producing large parts with smooth internal surfaces [18].



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Fig (IV.5). Filament winding.

#### IV.1.4.3. SMC thermosetting compression (Sheet Molding Compound):

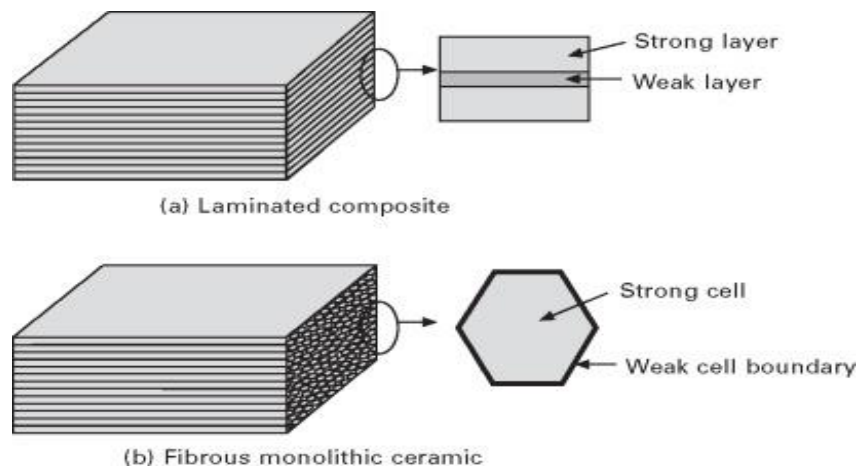
The principle consists in depositing pre-impregnated sheets in a heated counter-mold, compressing the material with a heated mold, polymerization then ejection of the part. Advantages: material cost, mechanical and thermal properties.

### IV.1.5. Types of structures in composite materials:

There are two types of structures in composite materials, monolithic and sandwiches, the second type being the most used in aeronautics.

#### IV.1.5. 1. Monolithic type:

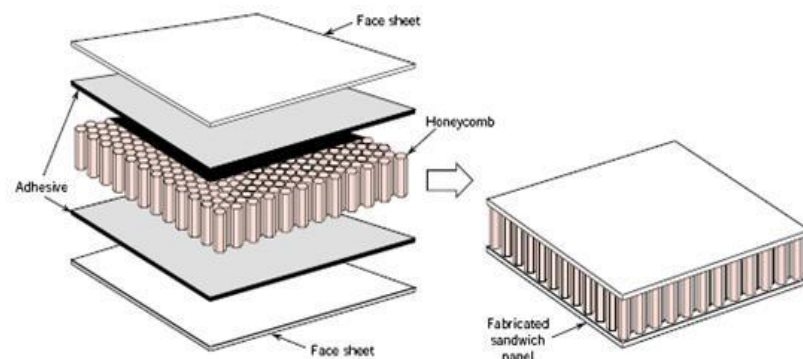
It is a stack of layers of resin-impregnated fabrics, a concept particularly suitable for hull construction.



*Fig (IV.6). Monolithic.*

#### IV.1.5. 2. Sandwich types:

It is a material composed of two soles (or skins) of great rigidity and thinness enveloping a core (or heart) of great thickness and low resistance. The whole forms a structure of great lightness. The sandwich material has a great lightness in flexion and is an excellent thermal insulator [17].



*Fig (IV.7). Honeycomb + composite*

**IV.1.6. Conception of aeronautical composite structure:**

In aeronautics, as in other industrial fields, the realization of structures requires an implementation of assembly techniques, penalizing as little as possible the material used.

In the case of assemblies of composite materials, the two main techniques currently used are:

- Sticking
- Mechanical fasteners.

Bonded assemblies are of interest for the realization of aeronautical structures where efficiency and lightness of links prevail. However, the preparation, implementation and control of collages can affect the financial aspect.

Generally in aeronautics, the structures are glued to ensure a distribution of stresses over a large area, and to guarantee a limitation of over-stresses by the geometry of the glued area. The advantage of this method is the lightness compared to riveted or bolted joints. Several structural and aerodynamic parts are laminate or sandwich for example in the A-380, the part that operates the junction between wings and fuselage is composite.

**IV.2. Realization Part:****IV.2.1. Fuselage construction:**

The final shape of the fuselage was based on the design and location of the given engine in the plane. It allowed the rationalization of the engine installed, as well as the place for all the other auxiliary systems.

The final design was carefully planned to ensure that everything could be completed with minimal complications.

Fuselage fabrication has been realized in four parts which are printing of the drawing based on SolidWorks after the fractionation of the 3d model into several pieces of thickness 14.7mm which is the same thickness of the MDF plate, after uncoupling at the carpenter then the centering and gluing of these pieces thanks to the AK fix sticks the third step is the weighting of the assembly to get the ideal shape of the fuselage al using the form template finally the finishing step with the crest.



The following figures present the fuselage fabrication step by step to attend the ideal shape without boom.



*Fig (IV.8). Fuselage construction steps.*

#### **IV.2.2. Manufacturing of wing and empennage:**

Wing and empennage cutting was done in three parts using the aluminum templates in the side face mode. This real scale copy will then become models that can be pinned to the Polystyrene block.

These models will serve as guides to a hot wire that can cut the side, front, and longitudinal sides of the block. After fixing the templates and their centering on the polystyrene plates, we go to cutting with hot wire.

After we cutting the polystyrene d 35 with hot wire a special shape on templates to decrease the weight of wings and empennage.

The following figures resent the different steps to make wing and empennage



*Fig (IV.9). Wing and empennage fabrication steps.*

For more strength we made our own spars based on composite material, for the wing we made a composite pipes cylindrical and conical shapes and putting them inside the model and the same method was applique for the boom or tail support but in empennage case we made a plate on composite with thickness about 1.25 mm which is depend on fiber of glass layers and a larger of 8mm in 25% of main aerodynamic chord.



*Fig (IV.10). Vertical tail spar.*



*Fig (IV.11). Horizontal tail spar.*



*Fig (IV.12). Conical spar.*



*Fig (IV.13). Cylindrical boom.*

**Strengthening**

For the reinforcement of the wing and the empennage, external side members of thickness of 4\*4 mm are used based on balsa wood, but because of the different bending stresses and much less torsion to which these surfaces are subjected, 2 spars are fixed, one of them (the cylindrical pipe with diameter of 22mm will be placed on the 25% of the rope each of the extrados and the intrados. The last remaining spars of 4\*4mm based on balsa will be fixed on the 65% of the rope each of the extrados and the intrados and finally with composite plate we made our own ribs with the same ship of templates and we cover the hole wing and empennage with fiber of glass with strengthening the weak part with carbon fiber.



*Fig (IV.14). Different steps for strengthening*

**IV.2.3. Stratification in a contact mold:**

There are several reasons why this process is one of the most beautiful ways to make parts, because these parts made in a female mold are generally easy and quick to build a short time is necessary to shape a foam core. The shape is in the mold and the part will duplicate this shape.

On the other hand, the parts are lighter or the resin can be better controlled because there is no foam to absorb it and little time will be spent in fact that the surfaces in contact with the mold are smooth and require less sanding for finishing.

The hardest work and the time to consume will be in pattern making, can spend a 2 weeks making mold and one day doing a pattern.



*Fig (IV.15). Construction of Skull, pedestal.*

Then spray 1-2 layers of wax and two layers of liquid release agent on the pattern to ensure unmolding of the piece at the latest.



*Fig (IV.16). Unmolding process.*

To make the mold, with a brush or spray gun, a thick layer of Gelcoat and applied on the half of the model. Let it heal until it is hard (layers of polyester resin can be used instead of the Gelcoat layer).



*Fig (IV.17). Application of Gelcoat and the realization of the 1st shell.*

The other mold half is made in the same way as the first half. Once the mold has hardened, at least 24 hours, holes are drilled through the separation guides. The separation of the two mold parts is done using a screwdriver and pieces of wood, and using a jigsaw and an electric sander, the edges of the molds are cut after that the uses of 15 layer of PVA will be apply on our mold to avoid any kind of suck between the mold and our structure .

Two layers of glass cloth is placed inside the next mold of a carbon fabric strip in the sensitive parts to reinforce the places where the piece will be fixed. Two second layer of glass cloth will be added next.



*Fig (IV.18). Applications of different fabrics for molding.*

Any excess resin is removed using a vacuum pump. The part is allowed to cure at least 6 h for parts made of polyester resin and at least 6 h for epoxy. At high temperatures, baking cycles can be as short as 5 minutes with special (fast) resin systems.



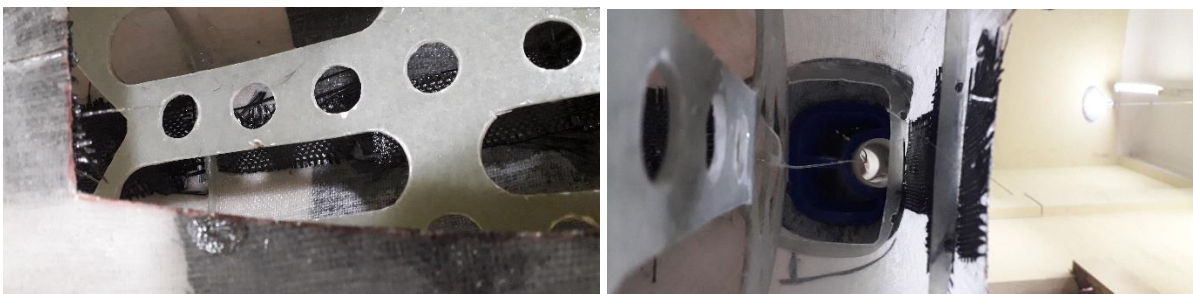
*Fig (IV.19). Application of the vacuum pump.*

A skeleton was built to increase the fuselage rigidity, based on the sections using the same previous method by making a plat of composite material and using 3d print to build the boom, vertical tail and horizontal guider.



*Fig (IV.20). Skeleton, boom and empennage guider*

Finally and after we realized our skeleton and all the necessary pieces for assembly we move to assembly part by using resin and micro balloon to past the different pieces plus carbon fiber.



*Fig (IV.21). Skeleton assembly.*

**IV.2.4.Recovery wire and boom test:**

The boom who is based on composite material should be strong enough to carry more than 4.5kg and the same thing for our recovery cable, the following pic present the test of both of recovery cable and the boom.



*Fig (IV.22). Test of both of recovery cable and the boom in the same time.*



**CONCLUSION:**

As a result after 3 months of hard work and a lot of white nights we secede for making our UAV named WHITE NIGHTS from the beginning to the end using the most of my knowledge and concentrate my all energy to manufacturing it piece by piece until the assembly of our final model, the following figure represent our last step which is the assembly of WHITE NIGHT at least I could leave my finger print in my university and in my institute of aeronautics and space studies.



*Fig (IV.23). WHITE NIGHTS*

## **GENERAL CONCLUSION**

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### **CONCLUSION**

Design a mini White Nights open payload carrier is attained. Main specifications are established and set as following; cruising altitude above 300m, endurance of approximately half hour, carrier payload of 400 grams, wing span of 2,45m. Takeoff gross weight estimation of 4.5 kg has also been performed during the initial steps of the design. In addition, sizing values created with a very interesting 2D mock up by SolidWorks software using specifics typical UAVs, various parameters are selected so as to obtain a convenient aerodynamic performance.

CFD methods are based on employment of Navier Stokes, continues equations and without energy equation in order to obtain rather realistic results. Laminar model are compared with results gathered in previous studies. Mesh independency test has guided the author to select an optimum mesh number and quality. In addition, effect of mesh number which is depending on my personal computer capacity in convergence and stability has also been depicted. Meshing process is based on a compromise between computational time and accuracy. Converge criteria are also strictly followed in each calculation.

The study has revealed the employment of the aerodynamic sizing method, and might be enough and adequate to reach desired performance in such mini UAV design.

Production part has confirmed all of our studies with high efficiency and was the winning card of our design which was based by 100% hand creation and on composite material that made the last step easier for us next to saving costs, reducing time and gaining weight.

## APPENDIX A: Dimensions Method

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### Using Image J software

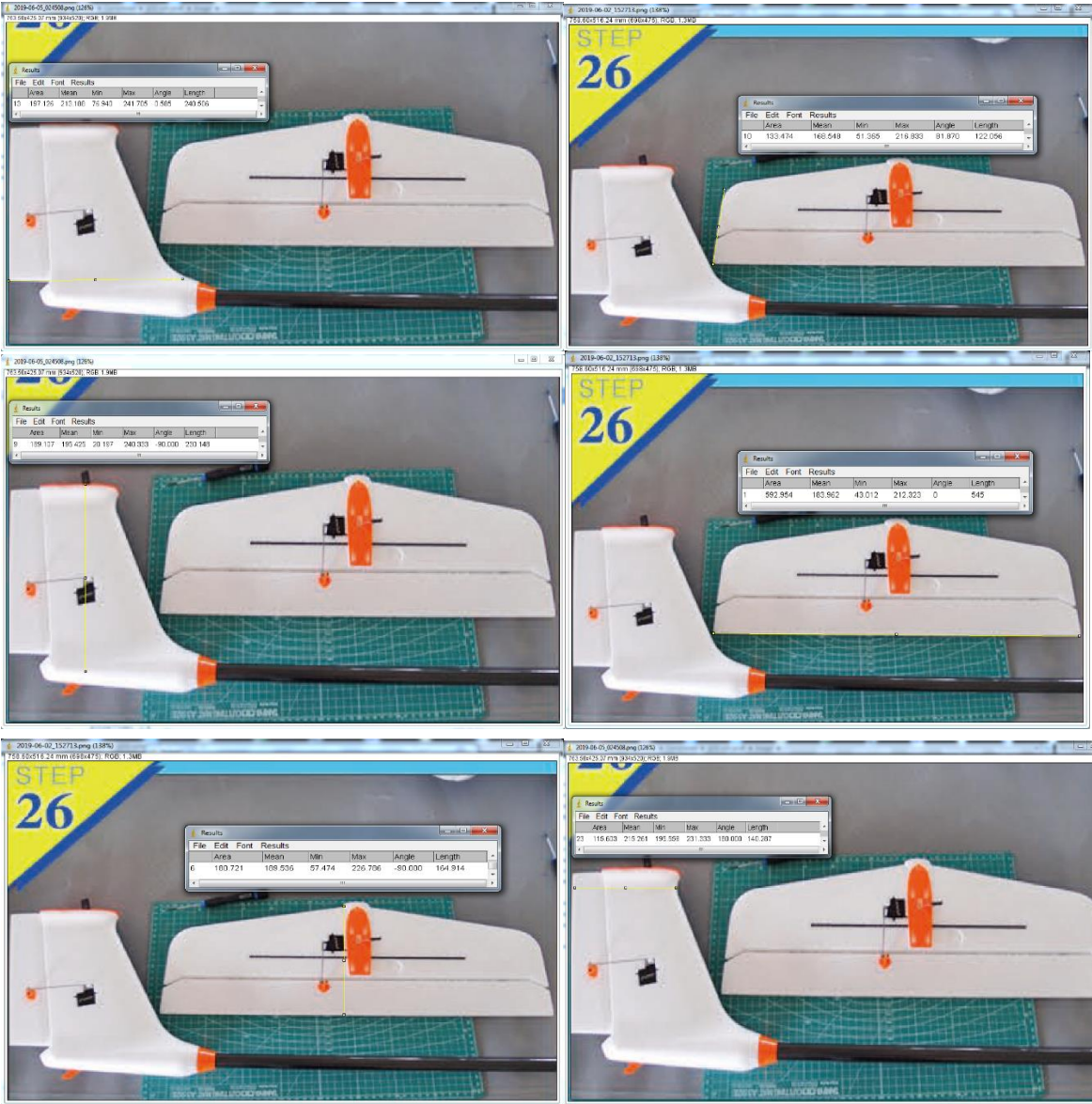
- Source picture confirmation
- Recognized one dimension from the 2D picture
- The dimensions must be on the same plane
- The measured dimensions must be in the same direction (case of picture stretching)



### Example 01: Skywalker EVE-2000

- 1- source: EVE-2000 Installation Instruction ([www.skywalkermodel.com](http://www.skywalkermodel.com) key skywalker\_eve\_2000\_manual)
- 2- recognized one dimension: Horizontal tail span 454mm
- 3- same plane: Workshop table

# APPENDIX A: Dimensions Method



**APPENDIX B: Airfoils Data Base.**

SD7062 (14%)			
1	0		
0,99652	0,00057	0,00103	0,00711
0,98634	0,00242	0	-0,00327
0,97004	0,00571	0,00425	-0,01115
0,94818	0,01036	0,01414	-0,01701
0,92127	0,01615	0,02991	-0,02205
0,88967	0,02289	0,05099	-0,02623
0,85381	0,03049	0,0771	-0,02948
0,81427	0,03885	0,10798	-0,03179
0,77166	0,04778	0,14328	-0,03319
0,72662	0,05702	0,18265	-0,03367
0,67973	0,06626	0,2257	-0,03327
0,63154	0,07517	0,27199	-0,03206
0,58254	0,08347	0,32105	-0,0301
0,53322	0,09089	0,37238	-0,02747
0,48402	0,09723	0,42547	-0,02426
0,4354	0,10229	0,47979	-0,02064
0,38779	0,10592	0,53477	-0,0168
0,34159	0,10801	0,58975	-0,01295
0,2972	0,10846	0,64403	-0,00927
0,25496	0,10722	0,69692	-0,00593
0,21521	0,10428	0,74768	-0,00307
0,17825	0,09965	0,79557	-0,00079
0,14432	0,0934	0,8399	0,00087
0,11363	0,08562	0,87998	0,00189
0,08637	0,07647	0,91518	0,0023
0,06269	0,06616	0,94491	0,00216
0,04272	0,05491	0,96864	0,00163
0,0265	0,043	0,98593	0,00092
0,0141	0,03081	0,99646	0,00027
		1	0

**APPENDIX B: Airfoils Data Base.**

---

NACA 0012			
1	0	0	0
0,99942	0,00134	0,00058	-0,00426
0,99767	0,00159	0,00233	-0,00843
0,99475	0,00199	0,00525	-0,0125
0,99068	0,00256	0,00931	-0,01647
0,98547	0,00328	0,01453	-0,02033
0,97912	0,00415	0,02088	-0,02407
0,97166	0,00517	0,02834	-0,02768
0,96309	0,00632	0,03691	-0,03116
0,95344	0,00761	0,04656	-0,03448
0,94273	0,00902	0,05727	-0,03764
0,93098	0,01055	0,06902	-0,04063
0,91824	0,01218	0,08176	-0,04344
0,90451	0,01391	0,09549	-0,04605
0,88984	0,01574	0,11016	-0,04846
0,87426	0,01764	0,12574	-0,05065
0,8578	0,01961	0,1422	-0,05263
0,84051	0,02163	0,15949	-0,05437
0,82242	0,02371	0,17758	-0,05589
0,80358	0,02583	0,19642	-0,05716
0,78403	0,02798	0,21597	-0,0582
0,76382	0,03015	0,23618	-0,05901
0,74299	0,03233	0,25701	-0,05958
0,7216	0,03451	0,2784	-0,05991
0,69968	0,03667	0,30032	-0,06002
0,6773	0,03881	0,3227	-0,0599
0,65451	0,04092	0,34549	-0,05957
0,63135	0,04298	0,36865	-0,05904
0,60789	0,04498	0,39211	-0,05831
0,58418	0,04691	0,41582	-0,0574
0,56027	0,04876	0,43973	-0,05632
0,53622	0,05052	0,46378	-0,05508
0,51208	0,05216	0,48792	-0,05369
0,48792	0,05369	0,51208	-0,05216
0,46378	0,05508	0,53622	-0,05052
0,43973	0,05632	0,56027	-0,04876
0,41582	0,0574	0,58418	-0,04691
0,39211	0,05831	0,60789	-0,04498
0,36865	0,05904	0,63135	-0,04298
0,34549	0,05957	0,65451	-0,04092

**APPENDIX B: Airfoils Data Base.**

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0,3227	0,0599	0,6773	-0,03881
0,30032	0,06002	0,69968	-0,03667
0,2784	0,05991	0,7216	-0,03451
0,25701	0,05958	0,74299	-0,03233
0,23618	0,05901	0,76382	-0,03015
0,21597	0,0582	0,78403	-0,02798
0,19642	0,05716	0,80358	-0,02583
0,17758	0,05589	0,82242	-0,02371
0,15949	0,05437	0,84051	-0,02163
0,1422	0,05263	0,8578	-0,01961
0,12574	0,05065	0,87426	-0,01764
0,11016	0,04846	0,88984	-0,01574
0,09549	0,04605	0,90451	-0,01391
0,08176	0,04344	0,91824	-0,01218
0,06902	0,04063	0,93098	-0,01055
0,05727	0,03764	0,94273	-0,00902
0,04656	0,03448	0,95344	-0,00761
0,03691	0,03116	0,96309	-0,00632
0,02834	0,02768	0,97166	-0,00517
0,02088	0,02407	0,97912	-0,00415
0,01453	0,02033	0,98547	-0,00328
0,00931	0,01647	0,99068	-0,00256
0,00525	0,0125	0,99475	-0,00199
0,00233	0,00843	0,99767	-0,00159
0,00058	0,00426	0,99942	-0,00134
		1	0

## APPENDIX C: Motors And Propellers Selection

- 1- STEP 1:** Depending what type of airplane you have, choose the thrust/weight ratio  $g/W$ :

**Example 1:** Scale flight , thrust/weight ratio = 0.70

**Example 2:** jet, Thrust/weight ratio = 1.5

Type of airplane	thrust-to-weight ratio	
Glider /trainer	0.35 to 0.55	
Scale Flight	0.60 to 0.70	
Sport and slow acrobatic	0.70 to 0.80	
Acrobatic fast	0.80 to 1.00	
Jets and 3D	1.00 to 2.50	

**Table 1**

**Result:** thrust/weight ratio

- 2- STEP 2:** Calculate how much thrust airplane needs

The calculation is: with the weight of the plane and the thrust/weight ratio, find the necessary thrust:

**Thrust = weight x thrust/weight ratio**

**Example 1:** plane weight =1200 g

Thrust/weight ratio = 0.70

Thrust = 1200 x 0.70 = **840 g**

**Example 2:** plane weight = 1200 g

Thrust/weight ratio = 1.5

Thrust=1200 x 1.5 = **1800 g**

**Result:** UAV thrust (g)

- 3- STEP 3:** Decide if the UAV is Fast or slow aircraft

**Step 3-** Decide if you want a fast or slow plane

The following table gives the values of air speed, according to the motor Kv (these values are for a fixed propeller pitch and a given battery voltage )

If you want a fast plane, choose high Kv

If you want a slow plane, choose low Kv

Kv	Air speed (Km/h)	Air speed (mph)
1000	70	43
2000	140	87
3000	210	131
4000	280	175

**Table 2**

**Result:** UAV  $k_v$  (kv)

Choosing the Kv

**Example 1:** choose a low Kv because I need more Thrust than speed. A Kv around 1000 will do the job.

**Example 2:** I want speed on a jet, but I don't want ducted fan, so I choose a Kv around 2500.



## APPENDIX C: Motors And Propellers Selection

### 4- STEP 4: Find the *power/thrust* ratio using *kv*

**Table 3: Find the ratio Watts/grams or Watts/ounce**

$$\frac{W}{g} = 0,17 * \frac{Kv}{1000} + 0,09$$

Kv	W/g	W/oz	Kv	W/g	W/oz	Kv	W/g	W/oz
500	0,175	4,95	1700	0,379	10,73	3400	0,668	18,90
600	0,192	5,43	1800	0,396	11,21	3500	0,685	19,39
700	0,209	5,91	1900	0,413	11,69	3600	0,702	19,87
800	0,226	6,40	2000	0,430	12,17	3700	0,719	20,35
900	0,243	6,88	2100	0,447	12,65	3800	0,736	20,83
1000	0,260	7,36	2200	0,464	13,13	3900	0,753	21,31
1100	0,277	7,84	2300	0,481	13,61	4000	0,770	21,79
1200	0,294	8,32	2400	0,498	14,09	4100	0,787	22,27
1300	0,311	8,80	2500	0,515	14,57	4200	0,804	22,75
1500	0,345	9,76	2600	0,532	15,06	4300	0,821	23,23
1600	0,362	10,24	2700	0,549	15,54	4400	0,838	23,72
			2800	0,566	16,02	4500	0,855	24,20
			2900	0,583	16,50	4600	0,872	24,68
			3000	0,600	16,98	4700	0,889	25,16
			3100	0,617	17,46	4800	0,906	25,64
			3200	0,634	17,94	4900	0,923	26,12
			3300	0,651	18,42	5000	0,940	26,60

**Result:** *power/thrust*

### 5- STEP 5: Calculate the needed power

**Step 5:** find the *power/thrust* ratio

With the *Kv* value, go to figure 1 or table 3 and find the **Power / thrust ratio**

**Example 1:** from table 3, with 1000 *Kv*, I find a *power/thrust* ratio = 0.26 W/g

**Example 2:** from table 3, with 2500 *Kv*, I find a *power/thrust* ratio = 0.515

**Example 1:** from step 2, I need 840 g of thrust, and using the *power/thrust* ratio= 0.26 calculate the needed power:

Power (W) = thrust x *power/thrust* ratio

Power (W) = 840 g x 0.26 W/g = **218 W**

**Example 2:** from step 2, I need 1800 g of thrust and using the *power/thrust* ratio = 0.515

Power (W) = 1800 g x 0.515 W/g = **927 W**

**Result:** Power (W)

### 6- STEP 6: Choose a motor

**Example 1:** we have 1000 *Kv* and 218 W (327 W)


**Example 2:** we have 2500 *Kv* and 927 W (1800 W)

Now, with this values we can go to manufacturer catalog and choose the motors.

I always recommend to choose higher values of the motor power (40 or 50 % more) to fly easily at 50 to 60 % throttle. The power value in parenthesis reflex this consideration.


## APPENDIX C: Motors And Propellers Selection

The following motor is selected using the steps listed above.



**Sunny Sky brushless  
outrunner motor**

### Specifications of the electric motor

Motor: V2216-12		KV: 800					
Technical Datas		Recommended Prop(inch)					
KV	800	Standard	3S-1045/1150				
Config-ration	12N14P		Max thrust	3S-1150			
Stator Diameter	22mm	4S-8040/8050	4S-9047/9050				
Stator Length	16mm						
Shaft Diameter	3mm						
Motor Dimension(Dia. x Len)	Φ27.8x34mm						
Weight(g)	75						
Idle Current(10V)(A)	0.3						
No. of Cells(Lipo)	2-4S						
Max Continuous current(A)180S	17A						
Max Continuous Power(W)180S	180W						
Max. efficiency current	(5-15A)>80%						
Internal resistance	175mΩ						
Tested with SunnySky motor 20A ESC							
Prop	Volts (V)	Amps (A)	Watts (W)	Thrust (g)	Thrust (oz)	Efficiency (g/W)	Efficiency (oz/W)
1047	7.4	5.8	42.92	510	17.99	11.88	0.42
	10	9.2	92	800	28.22	8.70	0.31
	11.1	10.5	116.55	960	33.86	8.24	0.29
11X7	7.4	5.8	42.92	510	17.99	11.88	0.42
	10	9.5	95	850	29.98	8.95	0.32
	11.1	10.9	120.99	1020	35.98	8.43	0.30
12X6	7.4	7.7	56.98	680	23.99	11.93	0.42
	10	12.1	121	1020	35.98	8.43	0.30
	11.1	13.8	153.18	1130	39.86	7.38	0.26

SunnySky V2216-12 KV800 Brushless Motor Test Data									
Voltage (V)	Propeller (inch)	Throttle	Current (A)	Thrust (g)	RPM	Power (W)	Efficiency (g/W)	Temperature* (°C) (°F)	
11.1 3S	APC 10x3.8	50%	2.1	320	4131	23	13.7	47	117
		65%	3.5	440	4825	39	11.3		
		75%	5.9	600	5560	65	9.2		
		85%	7.8	690	5991	87	8.0		
		100%	10.6	830	6548	118	7.1		
	APC 11x4.7	50%	2.8	390	3840	31	12.5	50	122
		65%	4.5	500	4431	50	10.0		
		75%	7.4	700	5065	82	8.5		
		85%	9.9	820	5477	110	7.5		
		100%	12.4	960	5862	138	7.0		
	APC 12x3.8	50%	2.9	410		32	12.7	53	127
		60%	4.3	530		48	11.1		
		65%	5.7	590		63	9.3		
		75%	8.1	690		90	7.7		
		80%	10.1	800		112	7.1		
	ZX 12x3.8 Carbon Fiber	50%	2.4	360		27	13.5	48	118
		60%	3.5	470		39	12.1		
		65%	4.3	500		48	10.5		
		75%	6.1	620		68	9.2		
		80%	7.4	710		82	8.6		
14.8 4S	APC 9x4.7	50%	2.9	410		43	9.6	43	109
		60%	3.8	460		56	8.2		
		65%	4.4	530		65	8.1		
		75%	5.8	640		86	7.5		
		80%	6.9	710		102	7.0		
	APC 10x3.8	50%	3.3	480	5074	49	9.8	55	131
		65%	5.4	650	5837	80	8.1		
		75%	8.1	810	6514	120	6.8		
		85%	11.9	1030	7182	176	5.8		
		100%	15.2	1210	7750	225	5.4		
	ZX 10x3.8 Carbon Fiber	50%	3.2	430		47	9.1	51	124
		60%	4.3	550		64	8.6		
		65%	5.1	620		75	8.2		
		75%	7.2	760		107	7.1		
		80%	8.8	860		130	6.6		
	ZX 11x4.7 Carbon Fiber	50%	3.9	530		58	9.2	85	185
		60%	5.5	680		81	8.4		
		65%	6.9	790		102	7.7		
		75%	9.5	910		141	6.5		
		80%	11	1020		163	6.3		
85%	13.9	1150		206	5.6				
100%	16.8	1320		249	5.3				

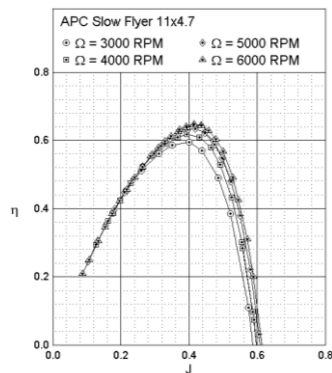
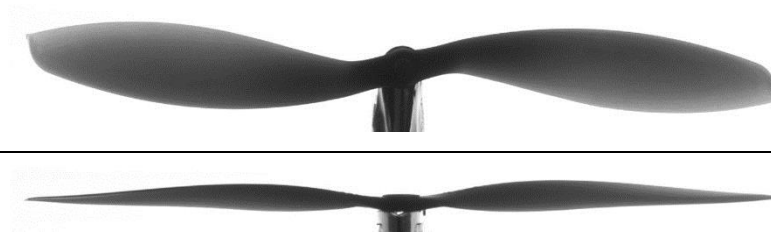
\*Temperature was measured after 10 minutes full throttle load in a 25°C (77°F) environmen

## APPENDIX C: Motors And Propellers Selection

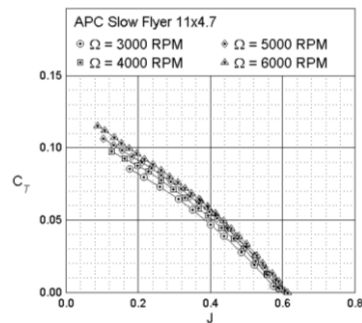
### Propeller *APC 11 × 4.7*

The propeller downloading from **UIUC Propeller Data Site**

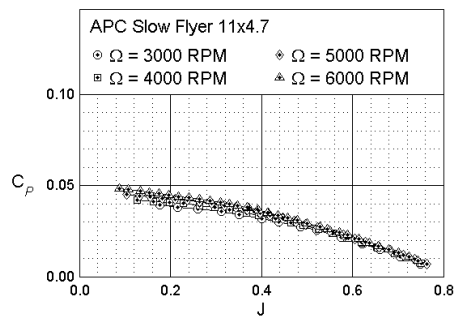
*APC 11 × 4.7*



propeller 11×4.7 Efficiency curve vs advanced ratio



propeller 11×4.7  $C_T$  curve vs advanced ratio



propeller 11×4.7  $C_P$  curve vs advanced ratio

# *Chapter I*

## *Introduction to unmanned aircraft*



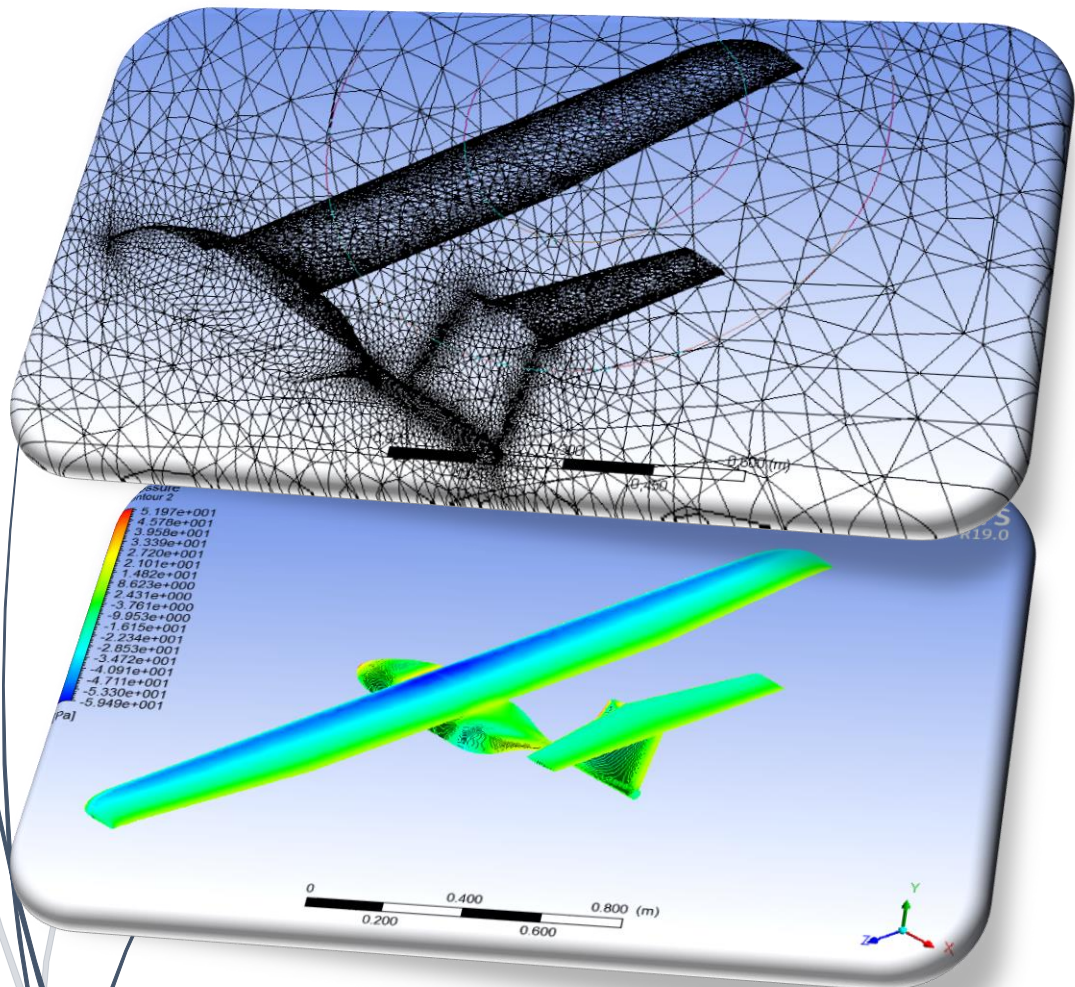
# *Chapter II*

## *Preliminary Conception And Aerodynamic Design*



# Chapter III

## *Numerical Simulation*



# *Chapter IV*

## *Production*



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