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DESIGN AND FABRICATION OF ROTOR WINDMILL WATER PUMPING

Under the direction of

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Dedication

To my father, who instilled in me a strong work ethic, perseverance, and determination. Your guidance and wisdom have shaped my character and taught me the value of hard work and resilience. Thank you for your constant encouragement and for always pushing me to reach for the stars.

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I dedicate this thesis to my family and SAHRAOUI family, whose unwavering support and encouragement have been instrumental in my academic journey. Their love, understanding, and belief in my abilities have been a constant source of motivation.

Furthermore, I extend my deepest gratitude to my friends and colleagues who have provided me with support, encouragement, and intellectual stimulation along the way. Their presence has made this journey enjoyable and memorable.

Lastly, I would like to dedicate this thesis to all those who strive for knowledge and seek to make a positive impact in their respective fields. May this work contribute to the collective advancement of knowledge and inspire others to pursue their academic aspirations.

With all my love and appreciation.

Naserddine CHAIB

Abstract

This study focuses specifically on utilizing wind power to generate mechanical energy for the purpose of water pumping. It aims to address the water needs of isolated sites, particularly in the windy areas of the Algerian highlands.

The main goal of this project is to design and construct a windmill rotor that can be used for water pumping, with a primary focus on assisting and easing the challenges faced by small-scale farmers.

To begin the project, we conducted an extensive review of literature that encompassed different types of wind turbines, their operating principles, key components, and their characteristics.

Following that, we developed a strategy for designing and calculating the various components of the windmill rotor.

Lastly, we focused on the practical realization of the wind turbine rotor, encompassing the manufacturing stages of its components.

Keywords:

Wind, Turbine, Energy, Horizontal Axis, Windmill,Rotor

ملخص

تركز هذه الدراسة بشكل خاص على استخدام طاقة الرياح لتوليد الطاقة الميكانيكية لغرض ضخ المياه. ويهدف إلى تلبية الاحتياجات المائية للمواقع المعزولة، لا سيما في المواقع التي تهب فيها الرياح داخل المرتفعات الجزائرية.

الهدف الرئيسي لهذا المشروع هو تصميم وبناء طاحونة هوائية يمكن استخدامها لضخ المياه، مع التركيز بشكل أساسي على مساعدة وتخفيف التحديات التي يواجهها صغار المزارعين.

.للبدء، أجرينا مراجعة شاملة للأدبيات تشمل أنواعًا مختلفة من توربينات الرياح ومبادئ تشغيلها ومكوناتها الرئيسية وخصائصها

.بعد ذلك، وضعنا استراتيجية لتصميم وحساب المكونات المختلفة للدوار

أخيرًا، ركزنا على التحقيق العملي لدوار توربينات الرياح، بما في ذلك مراحل تصنيع مكوناته.

الكلمات مفتاحية:

الرياح، التوربينات، الطاقة، المحور الأفقي، الطاحونة الهوائية، الدوار

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g - Acceleration due to gravity.

ω - Angular Velocity.

A_B - Area of one blade.

C_P -Coefficient of power.

ρ - Density.

D -Diameter.

F -Force.

H -Head.

P_h -Hydraulic Power.

$\dot{m}$ -Mass Flux.

M -Moment.

N_B -Number of Blades.

P_T -Power Extracted From wind.

R -Radius.

v -Speed of Wind.

A_S -Swept Area.

λ - Tip Speed Ratio.

T -Torque.

C_t -Torque Coefficient.

V -Velocity.

P_w -Wind Power.

General Introduction

General Introduction

Each of us will need some sort of water source for drinking, bathing, washing clothes, preparing food, and for irrigation. We can get water from various sources like lake, river, ponds, open well, borehole. So, we have to pump the water from the source and use the water for various purposes. Agriculture, an important sector of our economy, represents 14.7% of the country's GDP and contributes to export revenues of approximately $63 million. In Algeria, the area of irrigated agricultural land amounts to 1.43 million hectares. This was confirmed by the Minister of Agriculture and Rural Development, highlighting an increase of 780,000 hectares over the past 10 years. There are more than 1.2 million farms and nearly 70% of farms have an area of less than 10 ha. The fact remains that, over the past two decades, the agricultural sector, which represents nearly 13% of the active population.

Irrigation can improve agricultural yields by 50%. The use of renewable energies for pumping and irrigation therefore not only reduces greenhouse gas emissions, but also limits the costs associated with the purchase of diesel or kerosene while improving incomes for small farmers. Additionally, regions that are off-grid or without reliable access to electricity due to constant power outages can benefit from renewable energy.

One of the current concerns in Algeria is the revaluation of agricultural land in arid and semi-arid areas in order to achieve food self-sufficiency, curb the rural exodus to the north and settle populations.

This study focuses on the application of wind power for the production of mechanical energy used for pumping water. This technique is well suited to meet the water needs (agriculture, domestic consumption, etc.) of isolated sites, in particular a few windy sites located in the Algerian highlands. The choice of the latter was based essentially on the importance of the existing wind deposit and on the presence of shallow underground water resources (the maximum limit of the depth of the well imposed in this study is 60 meters/ground).

Our project is to design and construction in the first stage a wind turbine rotor for pumping water that comes to help and reduce the suffering of small farmers.

This dissertation is organized as follows:

- **Chapter 1:** A literature search citing the different types of wind turbines, their operating principle, the main components of a wind turbine, and these characteristics.
- **Chapter 2:** Concerns the strategy adopted for the design and calculations of the various components of the rotor.
- **Chapter 3:** Focuses on the realization of the wind turbine rotor and the manufacturing stages of these components.

And finally, a general conclusion.

CHAPTER 1

Literature Review

1.1) Renewable Energy: Meeting the Increasing Demand

Renewable energy encompasses energy generated from natural processes that are consistently replenished, such as sunlight, geothermal heat, wind, tides, water, and various forms of biomass. Unlike finite resources, renewable energy sources cannot be exhausted and are continuously renewed, making them vital for a sustainable future.

Alternative energy, on the other hand, refers to energy sources that serve as alternatives to fossil fuels. It generally indicates non-traditional energies with low environmental impact. The term "alternative" is used in contrast to fossil fuels, as they offer a different approach to energy generation. While alternative energy sources typically have minimal environmental harm, they may not always fall under the category of renewable energy, which can have varying degrees of environmental impact.

The benefits of renewable energy extend to customers, the environment, and the bottom line of corporations. However, in the United States, renewable energy, including solar, wind, hydropower, and biomass, only accounts for approximately 10 percent of total energy used and 13 percent of total electricity generated. Despite the significant increase in corporate contracts for renewable energy, there are challenges when it comes to scaling up renewable power penetration in the market.

The primary challenge lies in the supply of renewable energy, which depends on adequate infrastructure for delivery. Historically, U.S. utilities have made decisions regarding energy generation fuels, with limited incentive to increase the proportion of renewables in the energy mix or explore technologies that encourage such a shift.

Although there is a strong demand for renewable energy from corporations, the problem lies in accessing a sufficient supply. While retail customers in many states can arrange to purchase solar or wind power from local utilities, large companies require extensive resources and expertise to access renewable energy options at the scale they need, assuming those options are even available.

To address this issue, attention should be focused on the demand side, where multinational corporations are joining forces to amplify their preference for greater renewable power. By leveraging their collective influence, these companies aim to drive change and encourage the development of more accessible and scalable renewable energy solutions.

It is crucial to create an environment that supports and encourages renewable energy growth. By fostering collaboration between corporations, governments, and energy providers, we can overcome barriers, streamline processes, and pave the way for a future where renewable energy plays a significant role in meeting our energy needs sustainably.

1.1.1) Definitons :

- **The wind:**

is the natural movement of air from areas of high pressure to areas of low pressure, caused by the uneven heating of the Earth's surface.

- **Wind power**:

is a form of renewable energy that harnesses the power of the wind to generate electricity. It involves the use of wind turbines, which are tall structures equipped with large blades. As the wind blows, it causes the blades to rotate, which in turn drives a generator to produce electrical energy. Wind energy is considered environmentally friendly as it does not emit greenhouse gases or contribute to air pollution during operation. It offers several advantages, including a sustainable and abundant energy source, reduced reliance on fossil fuels, and the potential for energy independence. Wind farms, consisting of multiple wind turbines grouped together, are often located in areas with consistent and strong wind patterns to maximize energy production. Wind energy plays a crucial role in the global transition towards a cleaner and more sustainable energy system.

- **Windmill**:

is a machine or structure that uses the power of the wind to generate mechanical energy, typically used for tasks such as grinding grain, pumping water, or generating electricity. It consists of a tall tower with large blades or sails that capture the wind's energy and convert it into rotational motion. This motion is then harnessed to perform various tasks through a system of gears and machinery. Windmills have been used for centuries and continue to be used today, particularly for renewable energy production.

1.1.2) History of Wind power :

The history of wind power dates back thousands of years to ancient civilizations. Humans have been harnessing the power of wind for various purposes, including transportation, grinding grain, and pumping water.

One of the earliest recorded uses of wind power is the sailboat, which allowed ancient seafaring civilizations to navigate across bodies of water using wind as a propulsive force. Windmills, which are structures with rotating blades, have been in use for centuries to grind grains into flour. These early windmills were predominantly horizontal-axis windmills and were prevalent in regions such as Persia (present-day Iran) and the Middle East.

During the late 19th and early 20th centuries, wind power began to be used for generating electricity. In 1887, Scottish engineer James Blyth built the first known wind turbine to generate electricity. However, it was not until the 20th century that wind power gained significant traction as an electricity-generating technology.

The development of wind turbines progressed over time, with advances in aerodynamics, materials, and control systems. The Danish company Vestas, founded in 1945, played a crucial role in the modernization of wind turbine technology. The oil crisis of the 1970s and growing environmental concerns fueled further interest in renewable energy, including wind power.

Throughout the late 20th century and into the 21st century, wind power saw exponential growth. Governments and organizations worldwide started investing in wind energy projects, resulting in larger and more efficient wind turbines. Offshore wind farms also emerged as a viable option, capitalizing on strong and consistent winds over the ocean.

Today, wind power has become one of the fastest-growing sources of renewable energy. Wind turbines are capable of generating large amounts of clean electricity, contributing to efforts to reduce reliance on fossil fuels and combat climate change. Technological advancements continue to improve the efficiency and cost-effectiveness of wind power, making it an increasingly important component of the global energy mix. (1)

1.1.3) Advantages of Wind Power:

Wind energy offers numerous advantages, as outlined below:

- Unlimited and Free Resource: The wind is an abundant and limitless resource. It is freely available in nature, making wind energy a sustainable and renewable source of power.

- Clean and Green Energy: Wind power is a clean source of energy as it does not produce harmful emissions or pollutants during operation. It significantly reduces the carbon footprint and helps combat climate change.

- Zero Greenhouse Gas Emissions: Wind energy generation does not emit greenhouse gases, which are major contributors to global warming and climate change. By utilizing wind power, we can reduce our reliance on fossil fuels and mitigate the environmental impacts associated with them.

- Eco-Friendly Alternative: Compared to fossil fuels, wind energy is environmentally friendly. It does not contribute to air pollution, acid rain, or water pollution, making it a cleaner and more sustainable option for power generation.

- Cost-Effectiveness: Wind power has become increasingly cost-effective over time. Technological advancements, economies of scale, and falling equipment costs have made wind energy competitive with traditional fossil fuel-based energy sources. As a result, wind power offers long-term cost savings.

It's important to note that these advantages are not limited to the ones mentioned here, as wind energy also contributes to energy independence, job creation, and local economic development. (2)

1.1.4) Disadvantages of Wind Power:

Alongside its advantages, wind power technology also presents certain disadvantages, as mentioned below:

- Wildlife Impact: Wind turbines can pose a risk to birds and bats that may collide with the rotating blades. This can lead to fatalities and raises concerns for the conservation of certain species. Additionally, the potential impact of offshore wind power plants on marine life is still being studied, and their consequences are not yet fully understood.

- Noise Pollution: The construction and operation of wind turbines can generate noise, both onshore and offshore. This noise can have potential effects on nearby communities, as well as wildlife in the vicinity of wind farms.

- Location Remoteness: Wind power plants are often situated in remote areas with ample wind resources. This remoteness can result in increased transportation costs for equipment, maintenance, and grid connections. It may also necessitate the development of additional infrastructure to facilitate the transportation of electricity to populated areas.

- Safety Concerns at Sea: Offshore wind farms can pose challenges for marine traffic, particularly during nighttime. The absence of sufficient lighting can make it difficult for maritime vessels to navigate through wind farm areas, potentially leading to safety hazards.

It is important to address these disadvantages through proper site selection, wildlife impact assessments, noise mitigation measures, and appropriate safety regulations. Continued research and development efforts aim to minimize the negative impacts associated with wind power and optimize its environmental and societal benefits. (2)

1.1.5) Project specifications:

A horizontal axis wind turbine comprises several essential components, each serving a specific function in its operation. These components, including the pump, generator, shaft, bearing, rotor, and blades, are crucial building blocks that are carefully designed or selected to meet engineering standards.

- **Pump:** The pump is responsible for drawing wind energy and converting it into mechanical power. It acts as the driving force behind the turbine's operation.

- **Shaft:** The shaft provides the mechanical connection between the turbine's rotor and the generator. It transfers rotational energy from the rotor to the generator, enabling the conversion of mechanical power into electrical power.

- **Bearing:** Bearings play a crucial role in supporting and enabling the smooth rotation of the wind turbine's components. They reduce friction between moving parts, ensuring efficient operation and minimizing wear and tear.

- **Rotor:** The rotor is a vital part of the wind turbine that captures wind energy. It consists of a hub and a set of blades that rotate when exposed to the wind. The rotor's design is crucial for efficient energy capture and maximizing power output.

- **Blades:** The blades of a wind turbine are designed to capture the kinetic energy of the wind. They are aerodynamically shaped to optimize the conversion of wind energy into rotational motion. The material, length, and shape of the blades are carefully selected to ensure optimal performance.

Throughout the design process, engineering standards are followed to ensure the components meet safety, efficiency, and reliability requirements. These standards dictate factors such as load capacities, material strength, and performance criteria.

In this study, we will design and manufacture ROTOR (Blades + Hub) only.

1.1.6) Objectives:

The primary goal of the project was to develop a windmill rotor design with specific key characteristics. These characteristics included:

- **Enhanced Torque Characteristics:** The aim was to improve the torque characteristics of the windmill compared to existing designs. This implies optimizing the design to generate more rotational force or torque from the wind, enabling better energy conversion and power generation.

- **Enhanced Efficiency**: The objective was to improve the overall efficiency of the windmill design compared to existing models. This involved maximizing the conversion of wind energy into mechanical or electrical energy, ensuring that the windmill operates at its highest potential efficiency.

- **Low-Cost Model**: Another important aspect of the design was to create a windmill that is cost-effective. The focus was on minimizing the production and operational costs associated with the windmill, making it an affordable option for implementation.

1.1.7) SCOPE OF DESIGN:

The design of a windmill encompasses a vast array of components, requiring comprehensive data analysis and examination of actual drawings. For our specific design, we focus primarily on the rotor assembly, consisting of the blades and the hub.

The design process commenced with an analysis of existing windmill designs and their operational conditions. This initial exploration provided valuable insights and served as a foundation for developing a customized windmill design specifically tailored to the Laghouat region and potentially nearby areas.

To achieve optimal design characteristics such as torque and power output, a range of calculations and structural analyses were conducted. These analyses involved evaluating factors such as aerodynamic performance, load capacities, and structural integrity. Through these assessments, we aimed to ensure that the windmill design would be capable of delivering efficient and reliable performance.

It's important to highlight that designing a windmill involves an iterative process, continually refining and optimizing the design based on the analysis results. This iterative approach allows for adjustments and improvements to be made to achieve the desired design characteristics.

By leveraging data analysis, examination of existing designs, and conducting structural calculations, our windmill design aims to meet the specific requirements and operating conditions of the Laghouat region.

1.2) Literature Review:

1.2.1) Site selection:

The location of a windmill plays a crucial role in determining its viability. It is essential for the site to have sufficient wind power to drive the windmill and should be free from obstructions that may cause turbulence. To assess the suitability of a site, the wind speed and climatic conditions are examined over a year and recorded on a wind map. This data is then analyzed to evaluate the site's potential.

To ensure optimal performance, windmills are often positioned on hilly areas or equipped with tall towers to elevate the rotor above any potential obstacles. In the case of our windmill project, a specific site had already been identified, eliminating the need for site selection. However, a thorough analysis was conducted to determine the site's suitability, yielding the following findings:

- The recorded wind speeds in Laghouat ranged from 3.8m/s to 5m/s throughout the year 2022, representing the maximum and minimum wind speeds. This indicates that the site is suitable in terms of wind availability. (3)

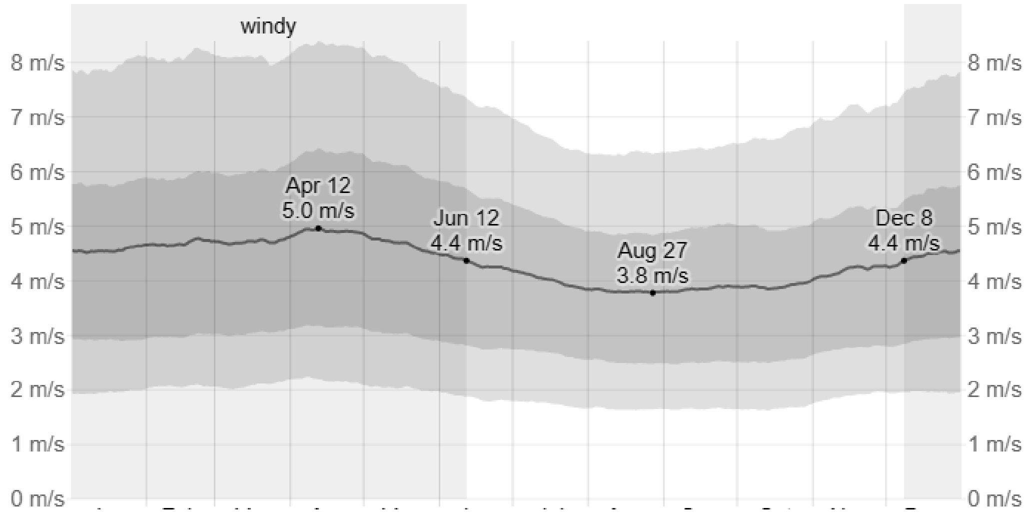

Figure 1: *Average Wind Speed in Laghouat (3)*

- The location of the windmill was strategically chosen to be away from tall buildings and trees, minimizing obstructions to the wind flow.

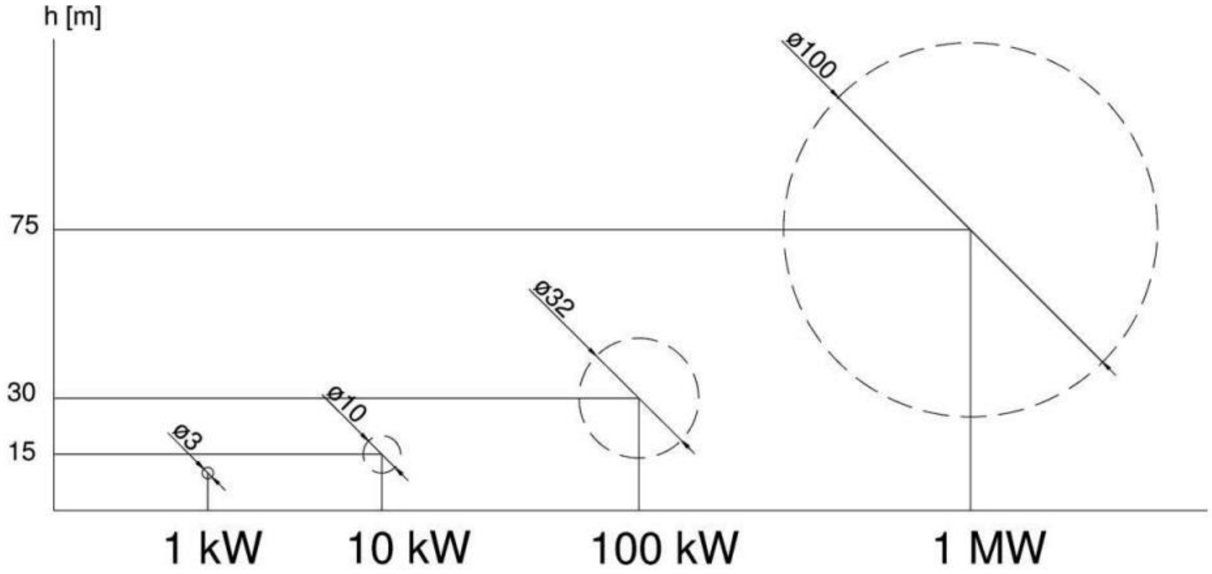

***Figure 2**:Size comparison of horizontal axis wind turbines at the reference speed of 8m/s.*

1.2.2) Classification of Wind Turbines:

There are two major categories of wind turbines: those with a horizontal axis and those with a vertical axis. Each category consists of various types, and there is also a wide range of wind-driven machines that may not necessarily be classified as "turbines" and can sometimes have unconventional designs. Each type and category has its distinct characteristics, advantages, and disadvantages, which will be discussed below (4)

1.2.2.1) Vertical axis wind turbine (VAWT):

This type of turbine is classified into three families:
reaction-driven turbines, aerodynamic action turbines, and mixed or hybrid turbines.

- **Reaction-Driven Turbines:**

A classic example of wind turbines that many of us are familiar with is the pinwheel, which we often played with as children. Technically referred to as pannemones (derived from the ancient Greek words "pan," meaning every, and "pneumon," meaning air), these wind turbines are designed to rotate irrespective of the wind direction.

- **Aerodynamic Action Turbines:**

The Darrieus rotor, a classic example developed in France between the two World Wars, stands out as a prominent wind turbine design. In recent years, there has been an increasing public interest in the Gorlov rotor, which is essentially a modified version of the Darrieus rotor. The Gorlov rotor incorporates blades with a unique torsion, enhancing its visual appeal and offering improved starting torque characteristics. This innovation has captured the attention of wind energy enthusiasts and researchers alike. (5)

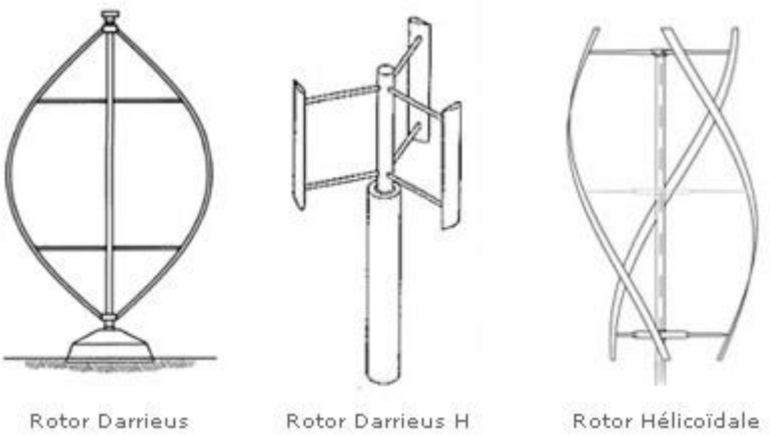

Figure 3: *Rotor Darrieus & Rotor Gorlov (5)*

- **Hybrid Turbines:**

These turbines initiate their operation through the differential reaction forces and, as their rotational speed increases, they employ a mechanism for generating aerodynamic lift. One commonly encountered type is the Lafond turbine, which is a pneumatic adaptation of hydraulic turbines. Another notable design is the Gyromill® rotor, originally developed and patented by the MIT (Massachusetts Institute of Technology) during the 1970s oil crisis. However, it was subsequently acquired by a division of the McDonnell-Douglas® aircraft manufacturer, which eventually ceased operations in the 1990s. There is also the Cycloturbine, a mixed-action wind turbine patented in the mid-nineteenth century, which periodically resurfaces in internet blogs and e-zines.

In the present volume, we will not deal with the design of Lafond turbines, Gyromill®, or Cycloturbine, because they feature mediocre performance and their construction is rather complicated. (5)

1.2.2.2) Horizontal Axis Wind Turbines:

Horizontal axis wind turbines are classified into two families:
slow and fast turbines.

- **Fast Turbines:**

Fast wind turbines, commonly featuring two to four blades (often three), are primarily utilized for electricity generation. One advantage of fast turbines is their relatively lighter weight compared to slow wind turbines, attributed to their lower solidity coefficient. However, they do have a notable drawback in terms of low starting torque. Stable operation typically requires wind speeds exceeding 5m/s since lower wind speeds result in low Reynolds numbers (Re) and mediocre aerodynamic performance of the airfoils.

Blades of fast turbines can be designed with fixed or variable pitch, with or without torsion, and with either upwind or downwind rotor orientations. Upwind rotors are directed using a rudder, while downwind rotors rely on rotor eccentricity/conicality or servomotors in conjunction with wind direction sensors. Various materials such as wood, aluminum, and fiber-reinforced resins can be used for blade construction.

It is possible to also build sail rotors, although such type is not commercially diffused, being suitable for “do-it-yourself” models. Figure 4 shows some constructive sketches and Figure 5 illustrates the different types of blades

.

Fast turbines have better aerodynamic performances than slow turbines do.

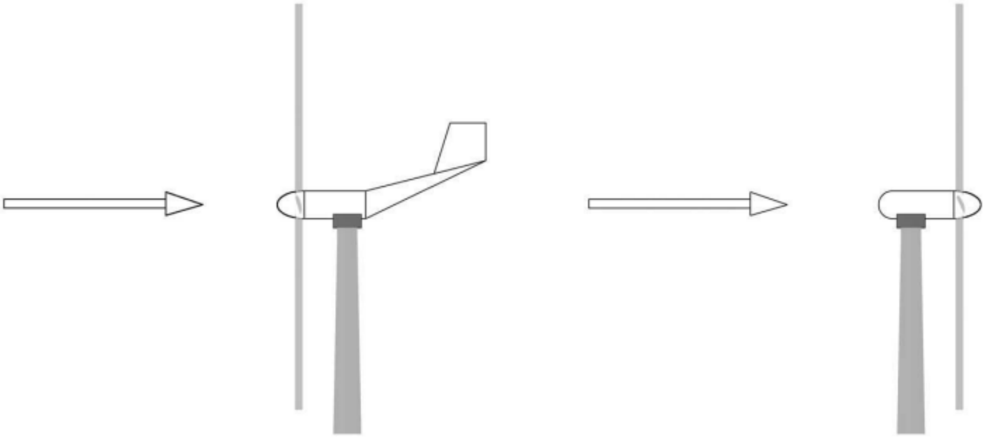

Figure 4: *Upwind and downwind rotors.*

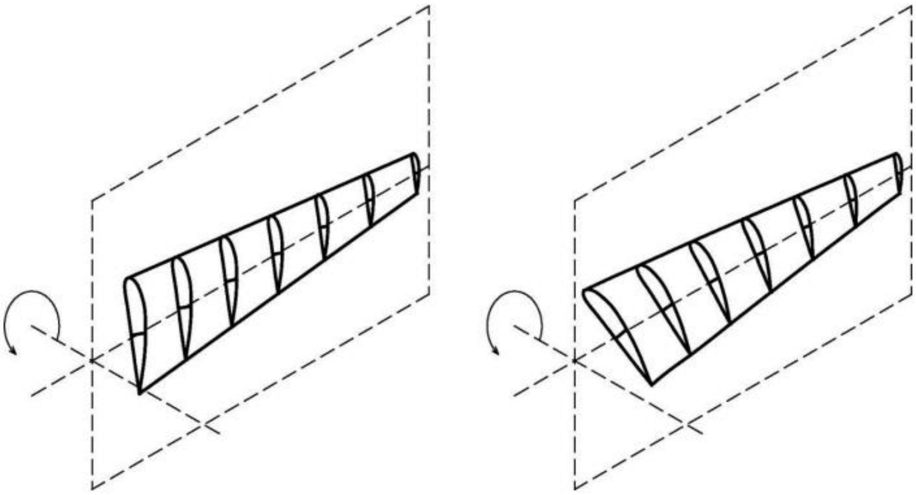

Figure 5: *Flat blade (left) and twisted blade (right).*

The dotted parallelogram indicates the rotation plane and the round arrow the rotation sense. (4)

- **Slow Wind Turbines:**

These types of wind turbines were first introduced in the United States around 1870 and gradually spread to other parts of the world. An interesting example is the Province of Buenos Aires in Argentina, where the National Directorate for Energy Conservation and New Sources estimated at the end of the 1980s that approximately one million windmills of this type were installed and operational for pumping water. These windmills had an average power output of 300W with the local winds, resulting in a total average power employed for pumping water for agriculture of 300MW. This is equivalent to a small thermoelectric plant running continuously throughout the year. This data highlights the potential of wind power beyond electricity generation, which has been the predominant focus in recent years.

Slow wind turbines, on the other hand, are particularly well-suited for pumping water. Windmills are widely used in developing countries, with most commercial models being variations of the American design developed in 1870. Slow wind turbines have a high solidity coefficient (σ) and high starting torque, allowing them to start even with weak wind speeds of 2 to 3m/s, even under load. These turbines typically have a larger number of blades ranging from 12 to 24. However, these blades are often just curved metal plates, resulting in lower aerodynamic performance. Manufacturers generally prioritize increasing the rotor diameter rather than improving efficiency by employing profiled blades, as the latter would raise manufacturing costs. (4)

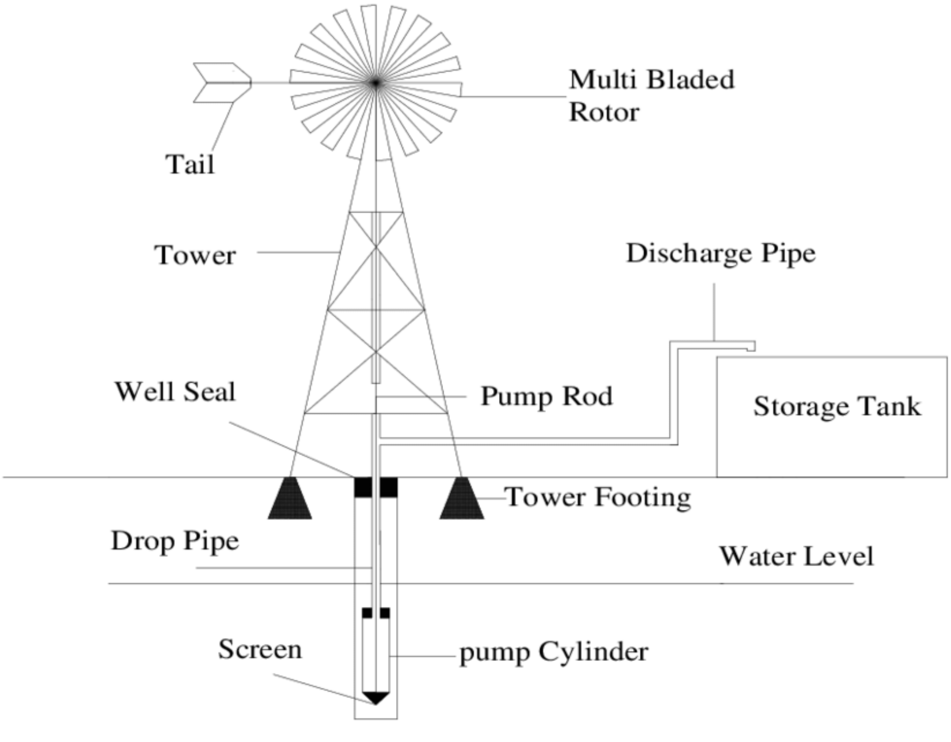

Figure 6: *Schematic diagram of windmill water pumping system*

1.3) Rotor Water Pumping Windmill:

1.3.1) Blades:

Before talking about the blades, I need to define them first. Blades of a wind turbine are airfoils shaped. When the blades rotate through air they produce the aerodynamic force. They are the parts that are responsible of generating the lift. The lift is a component of the aerodynamic force that the fluid, in this case wind, exerts on the blades while they are rotating It is perpendicular to the approaching flow direction. And it is different from the drag force that is the other component of the aerodynamic force that is parallel to the direction of the flow. Generally, the lift moves from bottom to top in an upward direction, but sometimes it can go in different directions with respect the right angles of the flow. In other words, it is the force used to make the rotor of the wind turbine rotate that is produced when the blades face the wind properly.

In the wind turbine business, the blades play an important role when it comes to generating electricity. They are the major component that turn the rotor shaft. So the design of the blade matters a lot because it affects the efficiency of the wind turbine as a whole, thus affects the energy production. The blades efficiency depends on three factors: the weight, the length, and the strength. That is why it is crucial to have longer and lighter blades as of to meet the production need.

1.3.2) Blades Components:

The blades of a wind turbine are not a one-unit part. They are composed of many parts joint together to create the airfoil shape. Each of the parts has a different and important role in the wind turbine blade. (4)

- **Blade Tip:** The blade tip is located at the outermost part of the blade. In modern wind turbines, it is typically designed as a pitch-regulated tip, allowing for control of the blade's angle. Some older wind turbines may have stall-regulated blades with a pivoting tip. The blade tip serves as a primary mechanism to slow down the wind turbine's rotation, and it can also function as an emergency brake in cases of overspeed. (6)

- **Leading Edge:** The leading edge of the blade is the part that first comes into contact with the wind. It receives significant attention in blade design because it plays a critical role in efficiently capturing the wind's energy. Compared to the trailing edge, the leading edge is generally thicker and smoother, without any defects or irregularities. (6)

- **Blade Root:** The blade root is responsible for connecting blades together and transferring the loads from the wind and blades to the main shaft of the turbine. In the past, blade roots were often square-shaped, but nowadays, most blade roots are rounded for improved performance and load distribution. (6)

- **Airfoil:** The airfoil shape refers to the overall profile of the wind turbine blade. It determines the aerodynamic characteristics and performance of the blade. The airfoil shape is carefully designed to optimize lift, minimize drag, and ensure efficient energy conversion. (6)

- **Trailing Edge:** The trailing edge is located at the end of the wind turbine blade. Traditionally, it had a knife-like edge, but to optimize the blade's strength-to-weight ratio, the knife edge has been replaced with a flat back airfoil design. This modification enhances the structural integrity and reduces weight, improving the overall performance of the blade. (6)

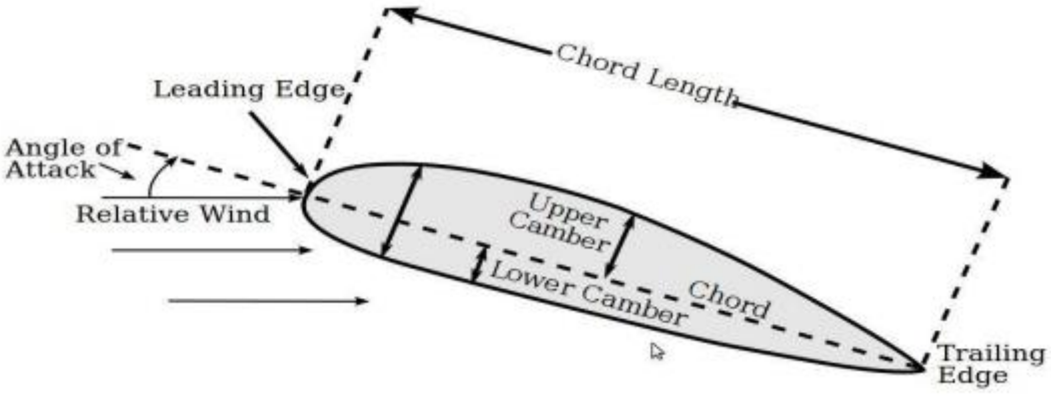

Figure 7: *Chord Length Image* (4)

- **Chord:** The chord refers to the straight line that extends from one side of the wind turbine blade's leading edge to the other side of its trailing edge. It represents the length of the blade and is typically measured in meters. The chord line is used as a reference to identify specific sections or parts of the wind turbine blade. (6)

- **Long Side:** Also known as the aero low-pressure side, round side, or structural high-pressure side, the long side of the wind turbine blade is responsible for creating a region of low pressure as the blade moves through the air. This side of the blade experiences lower air pressure, contributing to the generation of lift. The skin on this side of the blade is compacted, and it often curves back toward the downwind side of the blade. It is commonly referred to as the low-pressure side. (6)

- **Short Side:** Also referred to as the structurally low-pressure flat side, tension side, aero high-pressure side, or structurally low-pressure side, the short side of the wind turbine blade remains at atmospheric pressure, typically higher than the pressure on its opposite side. This section of the blade functions like a rope, providing structural support as the blade leans backward. It is primarily the upwind side of the blade and is commonly referred to as the high-pressure side. (6)

- **Lift:** lift is a component of the aerodynamic force that is generated when the wind interacts with the wind turbine blades. It is perpendicular to the direction of the approaching airflow and contributes to the rotational motion of the rotor, enabling the wind turbine to generate power. (6)

- **Drag:** Drag is the other component of the aerodynamic force acting on the wind turbine blade. Unlike lift, drag force acts parallel to the direction of the wind flow. When the blade interacts with the wind, it experiences resistance, resulting in drag force. While drag force can have some benefits, such as preventing excessive power absorption in strong winds, it also poses challenges by reducing energy production. Erosion of the leading edge of the blade can increase drag force and negatively affect blade performance. Additionally, incorrect placement of vortex generators can amplify drag. (6) (7)

- **Vortex Generators:** Also known as zippers, vortex generators are devices added to the aero low-pressure side of the blade to enhance lift and prevent stall. They create swirling motion in the airflow, helping to maintain attachment of the air to the blade surface and reducing drag force. Vortex generators play a crucial role in improving the overall aerodynamic performance of the wind turbine blade. (6)

- **Trip Tape:** Trip tape is used to create controlled disturbances in the airflow. Although it may introduce some additional drag force, its purpose is to prevent the occurrence of significant undesired drag and stall effects. By strategically placing trip tape, the wind turbine blade's performance can be optimized and potential performance-degrading issues mitigated.

- **Pitch Marks:** Pitch marks are markings usually located at the root of the wind turbine blade and are aligned parallel to or along the chord line of the airfoil. They assist in the proper installation and adjustment of the blade pitch. Pitch marks are crucial for achieving the desired pitch angle of the blade, which affects the performance and power output of the wind turbine. (6)

- **Root Cuff:** Also known as a shark fin in the USA Wind Power Group vocabulary, the root cuff is the transition point where the rounded-shaped blade root transforms into the current airfoil shape of the blade. It is typically wider and has a larger chord than other parts of the blade. The root cuff provides structural support and facilitates the smooth aerodynamic flow between the blade root and the rest of the blade. (6)

1.3.3) Theory and Theoretical Calculation:

To successfully execute the project, several calculations need to be performed both before and after the manufacturing process to ensure the desired outcome. These calculations play a crucial role in determining the efficiency and performance of the windmill.

Let's explore some of these important calculations: (7)

1.3.3.1) Tip Speed Ratio (λ):

The tip speed ratio is the ratio of the speed of the blade tips to the speed of the wind. It helps determine the optimal rotational speed for the wind turbine. The tip speed ratio is calculated by dividing the rotational speed of the blades by the wind speed.

$$\lambda = \frac{\omega_R}{U_0} \qquad [1]$$

1.3.3.2) Swept Area A_s:

The swept area of a wind turbine refers to the area covered by the rotating blades as they move through the wind. It is an essential parameter for determining the amount of wind energy captured by the turbine. The swept area is typically calculated by multiplying the length of the rotor blades by the diameter of rotation.

$$A_s = \frac{1}{4}\pi D^2 \qquad [2]$$

1.3.3.3) Power Coefficient:

The power coefficient is the ratio of the actual power output (H_w) to the theoretical power in the wind (H_T).

$$POWER = FORCE \times VELOCITY$$

$$FORCE = RATE\ OF\ CHANGE\ OF\ MOMENTUM$$

But

$$MOMENTUM\ =\ MASS\ X\ VELOCITY$$

For a fluid of density (ρ). Flows through a cross-sectional area of A, the mass flow rate ($\dot{m}$) is given by:

$$\dot{m} = \rho A v \qquad [3]$$

$$AVERAGE\ FORCE = \frac{1}{2}\rho A v^2 \qquad [4]$$

$$H_T = \frac{1}{2}\rho A v^3 \qquad [5]$$

$$C_P = \frac{H_W}{H_T} = \frac{H_W}{0.125\rho\pi D^2 v^3} \qquad [6]$$

1.3.3.4) Specific Speed of the Windmill:

This is the angular velocity in revolution per minute at which a turbine will operate if scaled down in geometrical proportion to such a size that will develop unit power under unit head.

1.3.3.5) Cut in Speed:

This is the speed at which the turbine starts to produce any useful power. It this is the lowest speed at which power develop by the wind turbine (H_W) is greater than zero.

1.3.3.6) Cut out Speed:

This is the speed at which the turbine stops to produce any useful power. This is the highest speed at which power develop by the wind turbine is just zero.

1.3.3.7) Rated Wind Speed:

This is the wind speed at which the wind turbine is designed to achieve its maximum power output. It is an essential parameter for evaluating the turbine's performance and efficiency.

1.3.3.8) Torque Coefficient (C_t):

The torque coefficient is a measure of the efficiency of energy transfer from the wind to the turbine rotor. It is calculated by dividing the torque generated by the wind turbine by the available wind energy.

It is represented mathematically by:

$$C_{t=\frac{T}{\frac{1}{2}A_S\ v\ R}} \qquad [7]$$

Where:

T : The actual torque produced (Nm).

v: Wind speed ($^m/_S$).

A_s: Swept Area (m^2).

R : Radius (m)..

1.3.3.9) Rotor Solidity:

Rotor solidity refers to the ratio of the total blade area to the swept area of the rotor. It affects the aerodynamic performance of the wind turbine and is taken into consideration during the design process.

$$SOLIDITY = \frac{N_B A_B}{A_S} \qquad [8]$$

Where:

N_B : Number of Blades.

A_B: Area of one blade (m^2) .

A_S : Swept Area (m^2).

1.3.3.10) Thrust Coefficients (C_T):

The thrust coefficient measures the amount of force exerted by the wind on the wind turbine blades.

It is represented mathematically as:

$$FORCE\ OF\ THE\ WIND = \frac{1}{2}\rho A_s v^2 \qquad [9]$$

Thrust Force on the windmill (F_T):

$$F_T = \frac{1}{2}\rho C_T A_s v^2 \qquad [10]$$

$$C_T = \frac{F_T}{\frac{1}{2}\rho C_T A_s v^2} \qquad [11]$$

1.3.3.11) Wind Power:

Wind power refers to the amount of power extracted from the wind by the wind turbine. It is influenced by various factors, including wind speed, rotor size, and turbine efficiency

$$WIND\ POWER\ (P_W) = \frac{1}{2}\dot{m}v^2 \qquad [12]$$

Where (Mass Flux):

$$\dot{m} = \frac{d_m}{d_t} = \rho A v \qquad [13]$$

$$\rho = \ Density\ of\ air\ \ ({}^{kg}/_{m^3}). \qquad [14]$$

$$THUS\ POWER(P_T) = \frac{1}{2}\rho A v^3 \qquad [15]$$

Where A = Swept area of blades (m^2)

$$A = \ \pi R^2 \qquad [16]$$

Where R = Radius of the blade (m).

1.3.3.12) Efficiency in Wind Power Extraction:

The efficiency in wind power extraction is a function of power Coefficient C_P, where C_P, is the ratio of power extracted by the windmill to the total contained in wind sources.

$$C_P = \frac{P_W}{P_T} \qquad [17]$$

Where windmill Power Extracted:

$$P_T = P_W \times C_P = \frac{1}{2}\rho A v^3 \times C_P \qquad [18]$$

The Betz Limit is the maximum possible value for C_P which is equal to $\frac{16}{27}$ but the optimum possible for a multi-blade windmill is 30%.

1.3.3.13) Torque Extracted:

In the windmill used for pumping water, Torque output is key.

Torque is given by the ratio power extracted to rotor speed.

$$T = \frac{P_T}{\omega} \qquad [19]$$

Rotor Speed:

$$\omega = \frac{\lambda v}{R} \qquad [20]$$

Where:

v = Wind Speed $({}^{m}/_{s})$.

λ = Tip Seed Ratio.

R = length of Blade (m).

Thus:

$$T = \frac{P_T}{{}^{\lambda v}/_{R}} \qquad [21]$$

But: $P_T = \frac{1}{2}\rho\pi R^2 v^3 \times C_P$

Therefore: $T = \frac{\frac{1}{2}\rho\pi R^2 v^3 \times C_P}{\lambda v / R}$

$$T = \frac{1}{2}\frac{\rho\pi R^3}{\lambda} v^2 C_P \qquad [22]$$

CHAPTER 2

Design of Rotor for Windmill Water Pump

2.1) Design Challenges:

To design the rotor of a windmill water pump, several factors need to be taken into consideration. The rotor plays a crucial role in converting wind energy into rotational motion to drive the water pump. Here are the key steps involved in designing the rotor:

- **Determine the desired water pump specifications:** Start by defining the requirements of the water pump, including the desired flow rate, head (vertical lift), and the overall pumping capacity. These specifications will guide the design process.
- **Calculate the power requirements:** Calculate the power needed to operate the water pump based on the flow rate and head. This will help determine the size and capacity of the windmill rotor needed to generate the required power.
- **Select the rotor type:** There are various rotor types to choose from, such as horizontal-axis wind turbines (HAWT) or vertical-axis wind turbines (VAWT). Consider the specific application and site conditions to determine which rotor type is most suitable.
- **Determine the rotor diameter:** The rotor diameter affects the swept area and, consequently, the amount of wind energy captured. Calculate the rotor diameter based on the power requirements, wind speed at the installation site, and the desired efficiency.
- **Determine the number of rotor blades:** The number of blades impacts the efficiency and stability of the windmill. Typically, windmill water pumps have 12-24 blades. Consider factors such as wind conditions, rotor dynamics, and the desired performance of the water pump to determine the optimal number of blades.
- **Select blade design and profile:** The blade design should be aerodynamically efficient to capture the maximum amount of wind energy. Consider factors such as airfoil shape, twist distribution along the blade length, and blade chord length. Conduct computer simulations or wind tunnel testing to optimize the blade design for the specific application.

- **Determine blade material and construction**: Choose appropriate materials for the rotor blades, considering factors such as strength, weight, and durability. Common materials include fiberglass, carbon fiber composites, or wood. Ensure that the blade construction is robust to withstand the rotational forces and environmental conditions.

- **Design the rotor hub and connection:** Design a sturdy rotor hub that securely connects the blades to the main shaft. Consider factors such as load distribution, balance, and ease of maintenance. Use appropriate bearings and seals to minimize friction and ensure smooth rotation.
- **Perform structural analysis:** Conduct structural analysis of the rotor blades and hub to verify their strength and reliability. Consider dynamic loads, fatigue, and potential vibrations caused by blade rotations.
- **Prototype and testing:** Build a prototype of the windmill water pump rotor and conduct thorough testing to validate its performance, efficiency, and durability. Make any necessary adjustments or refinements based on the test results.

2.2) Design Procedure:

2.2.1) Proposed design requirements:

Proposed head: **20** $\boldsymbol{m}$

Proposed Volume Flow rate: 13.60 m^3 per day = $0{,}1574\ \ 10^{-3}\boldsymbol{m}^3$ per second

Taking the daily mean wind speed in Laghouat:

Highest daily mean = **5** $\boldsymbol{m/s}$**.**

Lowest daily mean = **3.8** $\boldsymbol{m/s}$**.**

Given the average wind speeds:

The lowest average mean wind speed was selected i.e.: **4** $\boldsymbol{m/s}$**.**

2.2.2) Calculation of the Rotor Radius:

Power required to pump the water is given by:

$$HYDRAULIC\ POWER : P_h = \rho g Q H$$

$$Substituting : \ g = 9.81\ m^2/s\,;\ Q\ =\ 0.1574\ \times 10^{-3} m^3\ ;\ H\ =\ 20\,m$$

$$1000\ \times\ 9.81\ \times\ 0.1574\ \times\ 10^{-3}\ \times\ 20$$

$$\boldsymbol{P_h} = 30.882\ \boldsymbol{W}$$

In order to the power required from the wind, various losses have to be considered.

The table below shows various losses (wind energy handbook). (8)

Table 1: *Power losses in a windmill*

Factor	**Typical efficiency**
Rotor to shaft	92-97%
Shaft to gear box	93-96%
Gear box	99 %
Pump	60-75%

$$EFFICIENCY = \frac{OUTPUT}{INPUT} \times 100\%$$

Hence before losses occur, the input power to the system is given by:

$$INPUT = \frac{OUTPUT}{EFFICIENCY} \times 100\%$$

- **Before pump loss:**

Average Efficiency of pump is 67.7%

$$P = \frac{30.882}{67.5} \times 100 = 45.751\,W$$

This is the power that is transmitted from the shaft to the pump.

- **Before shaft losses:**

  Average efficiency of the shaft from the gearbox to the pump is 94.5 %.

$$P = \frac{45.751}{94.5} \times 100 = 48.414\ W$$

  This is the power that is transmitted from the gearbox to the vertical shaft.

- **Before gearbox losses:**

  Average efficiency of the gear box is given as 99% which is the actual efficiency of the gears.

$$P = \frac{48.414}{99} \times 100 = 48.903\ W$$

  This is the total power transmitted from the horizontal shaft to the gearbox.

- **Before shaft losses:**

  Average efficiency of the shaft from the gearbox to the pump is 94.5 %.

$$P = \frac{48.903}{94.5} \times 100 = 51.750\ W$$

  This is the power that is transmitted from the gearbox to the vertical shaft.

- according to the **Betz limit** the maximum practical value of C_P is 0.3

$$P_w = \frac{51.750}{0.3} = 172.5\ W$$

  This is the power in the wind.

$$P_{w=}\frac{1}{2}\rho A v^3$$

$$R^2 = \frac{P_w}{\frac{1}{2}\rho v^3 \pi} = \frac{172.5}{\frac{1}{2} \times 1.2 \times \pi \times 4^3} = 1.430\ m^2$$

$$R = 1.2\ m$$

By using Safety factor 1.04

$$\boldsymbol{ROTOR\ RADUIS}: \boldsymbol{R} = 1.2 \times 1.04 \cong 1.25\ \boldsymbol{m}$$

$$\boldsymbol{Diametre\ of\ ROTOR} : \boldsymbol{D} = 2.5\ \boldsymbol{m}$$

$$\boldsymbol{Take\ hub\ radius}: \boldsymbol{r} = 0.5\ \boldsymbol{m}$$

2.2.3) Design of Blades:

2.2.3.1) Tip Speed Ratio λ :

In small wind turbine λ between 0.5 and 1.

We take ***1***

$$\boldsymbol{\lambda} = \frac{\boldsymbol{\omega R}}{\boldsymbol{v}}$$

$$\boldsymbol{\omega} = \frac{\boldsymbol{v}}{\boldsymbol{R}} = \frac{4}{1.25} = 3.2\ \boldsymbol{rad/s}$$

2.2.3.2) Profile and Blade angle:

Take hub radius: r = 0.5 $\boldsymbol{m}$ And following simple formulas are needed:

$$\lambda_r = \lambda \frac{r}{R}$$

$$c = \frac{2\pi r}{B} \times \cos\beta$$

$$\phi = \tan^{-1}[\frac{2}{3} \times \frac{1}{\lambda_r}]$$

$$\beta = \phi - \alpha$$

The air foil shape is Cambered plate (cp-100-050-gn). $\boldsymbol{\alpha}$ can be chosen from C_d/C_l is minimum value. (9)

$$\boldsymbol{\alpha} = 8°$$

$$\lambda_r = 1 \times \frac{0.5}{1.25} = 0.4$$

$$\phi = tan^{-1}[\frac{2}{3} \times \frac{1}{0.4}] = 59.036°$$

$$\beta = 59.036 - 8 = 51.036°$$

$$\boldsymbol{c} = \frac{2\boldsymbol{\pi} \times 0.5}{18} \times \boldsymbol{cos}\, 51.036 = 0.11\ \boldsymbol{m}$$

Table 2: *Result of blade chords and blade angles.*

Cross Section No	*R (m)*	$\boldsymbol{\lambda_r}$	$\boldsymbol{\alpha°}$	$\boldsymbol{\phi°}$	$\boldsymbol{\beta°}$	*C (m)*
1	*0.5*	*0.4*	*8*	*59.036*	*51.036*	*0.11*
2	*0.594*	*0.4752*	*8*	*54.52*	*46.52*	*0.143*
3	*0.688*	*0.5504*	*8*	*50.46*	*42.46*	*0.172*
4	*0.782*	*0.6256*	*8*	*46.82*	*38.82*	*0.213*
5	*0.876*	*0.7008*	*8*	*43.57*	*35.57*	*0.249*
6	*0.97*	*0.776*	*8*	*40.67*	*32.67*	*0.285*
7	*1.1158*	*0.9264*	*8*	*38.07*	*30.07*	*0.321*
8	*1.158*	*0.9264*	*8*	*35.74*	*27.74*	*0.358*
9	*1.25*	*1*	*8*	*33.69*	*25.69*	*0.393*

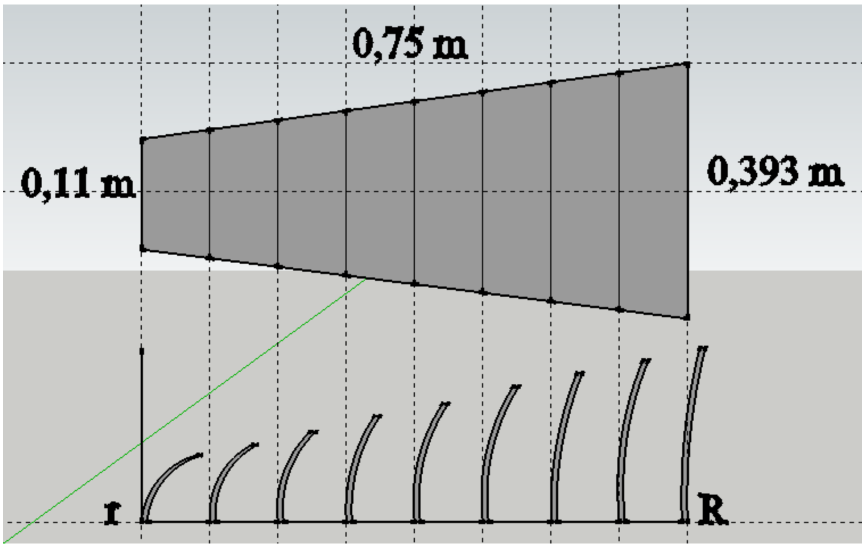

Figure 8: *Profile and Blade Angle of Various Sections.*

2.3) Final Blade Design:

$$C = 2R\sin\frac{\alpha}{2} \quad (chord)$$

$$A = \frac{\pi R\alpha}{180°} \qquad (Arc)$$

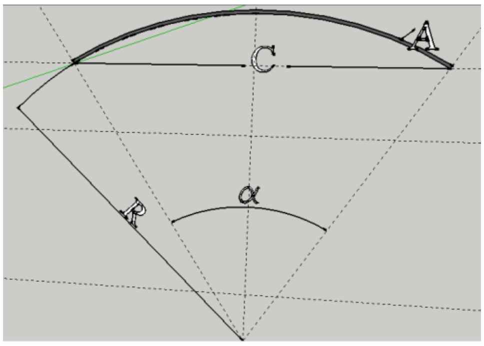

Figure 9: *Blade Angle*

$$C_R = 0.11 \ \rightarrow R = \frac{C}{2\sin\frac{\alpha}{2}} = 0.127\ m$$

$$\boldsymbol{A_R} = \frac{\boldsymbol{\pi R\alpha}}{180°} = 0.113\ \boldsymbol{m}$$

$$C_T = 0.393 \rightarrow R = 0.456\ m$$

$$\boldsymbol{A_T} = 0.405\ \boldsymbol{m}$$

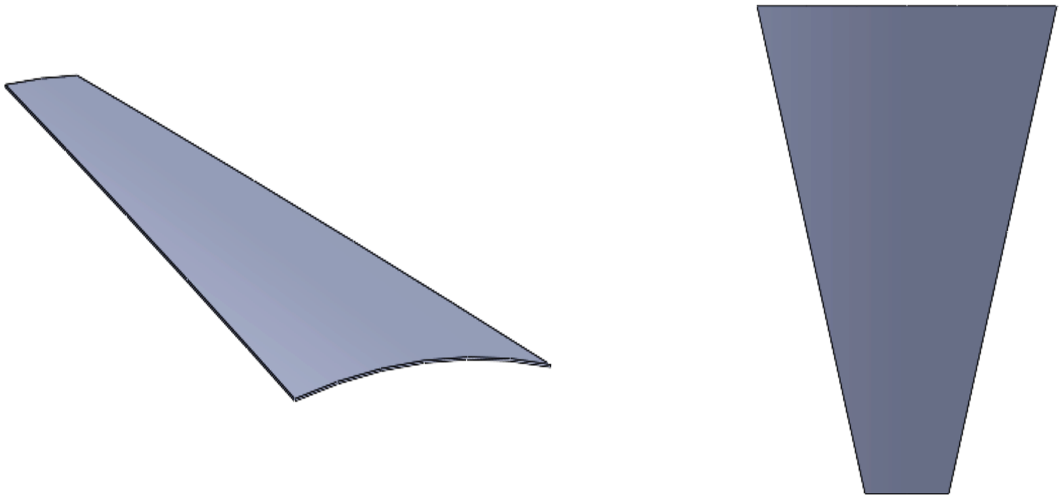

Figure 10: *Final Blade design*

2.4) Calculation for ROTOR:

- **Rotor swept area (A_S):**

$$A_S = \pi R^2$$

$$R = 1.25\ m$$

$$A_s = \pi R^2 = 4.91\ \boldsymbol{m}^2$$

- **Rotor Solidity:**

$$Solidity = \frac{N_B A_B}{A_S}$$

Where:

N_B– Number of Blades

A_B – Area of one blade (m^2)

A_S – Swept Area (m^2)

$$A_B = \frac{1}{2} \times 0.75(0.405 + 0.113) = 0.195\ m^2$$

$$Solidity = \frac{18 \times 0.195}{4.91} = 0.715$$

The solidity for the rotor design is 0.715 which meets the threshold to achieve the best torque characteristics. (4)

- **Rotor Speed:**

$$N = \frac{60\lambda v}{2\pi R}$$

$$N = \frac{60 \times 1 \times 4}{2\pi \times 1.25} = 30.56\ \boldsymbol{rpm}$$

- **Rotor Power:**

$$P_R = C_P P_{wind}$$

$$P_R = 0.3 \times 172.5 = 51.750\ \boldsymbol{W}$$

- **Rotor torque:**

$$T = \frac{P_R \times 60}{2\pi N}$$

$$T = \frac{51.75 \times 60}{2\pi \times 30.56} = 16.47\ \boldsymbol{Nm}$$

2.4.1) Result Data of Rotor:

***Table 3**: Result Data of Rotor*

Rotor Speed	30.56 rpm
Rotor Power	51.750 W
Rotor Swept Area	4.91 m^2
Rotor Solidity	0.715
Torque	16.47 Nm
Blade Length	0.75 m
Number of Blades	18
Blade Material	1.5-gauge Iron Plate
Type	Horizontal-Axis
Rotor Placing	Upwind Rotor

2.4.2) Design of the Rotor:

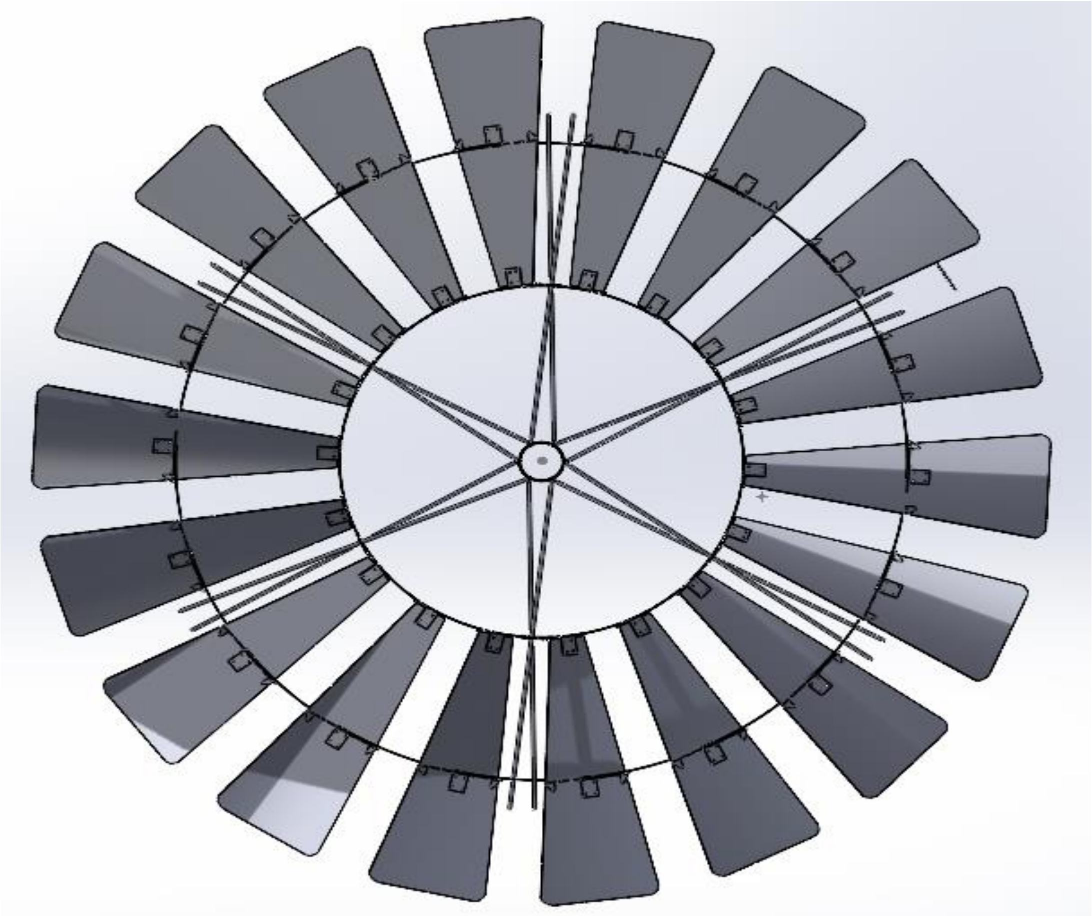

Figure 11 : *CAD of ROTOR Windmill*

2.5) Flow Over an Airfoil:

2.5.1) Introduction:

Computational fluid dynamics (CFD) is indeed a powerful tool for analyzing the blade shape of wind machines. It offers engineers the ability to simulate complete turbines under realistic conditions, providing valuable insights into the performance and behavior of the system. By utilizing CFD methods, researchers can investigate and refine wind-water pumping systems by exploring various blade designs and different materials for fabrication. This opens up opportunities to enhance the stability, efficiency, and cost-effectiveness of the system.

2.5.2) Blade Profile:

Cambered plate C=10% T=5% R=1.3 (cp-100-050-gn)

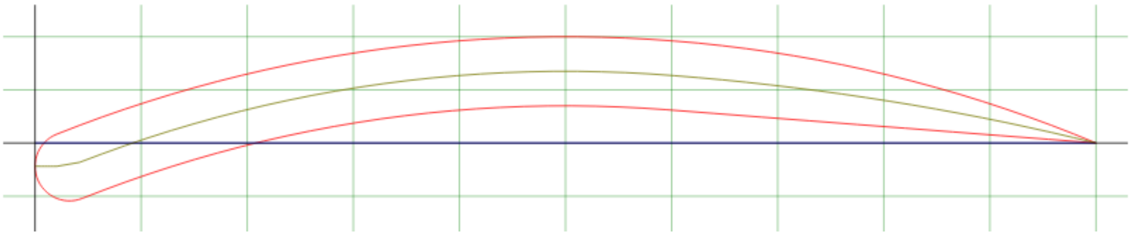

Figure 12: *Geometry for cambered plate type: cp-100-050-gn.*

2.5.3) Simulation:

This part of chapter provides instructions for creating a fluid volume and mesh around a cambered plate type: cp-100-050-gn and for analyzing the flow in FLUENT.

Steps show how to do simulation:

- 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.

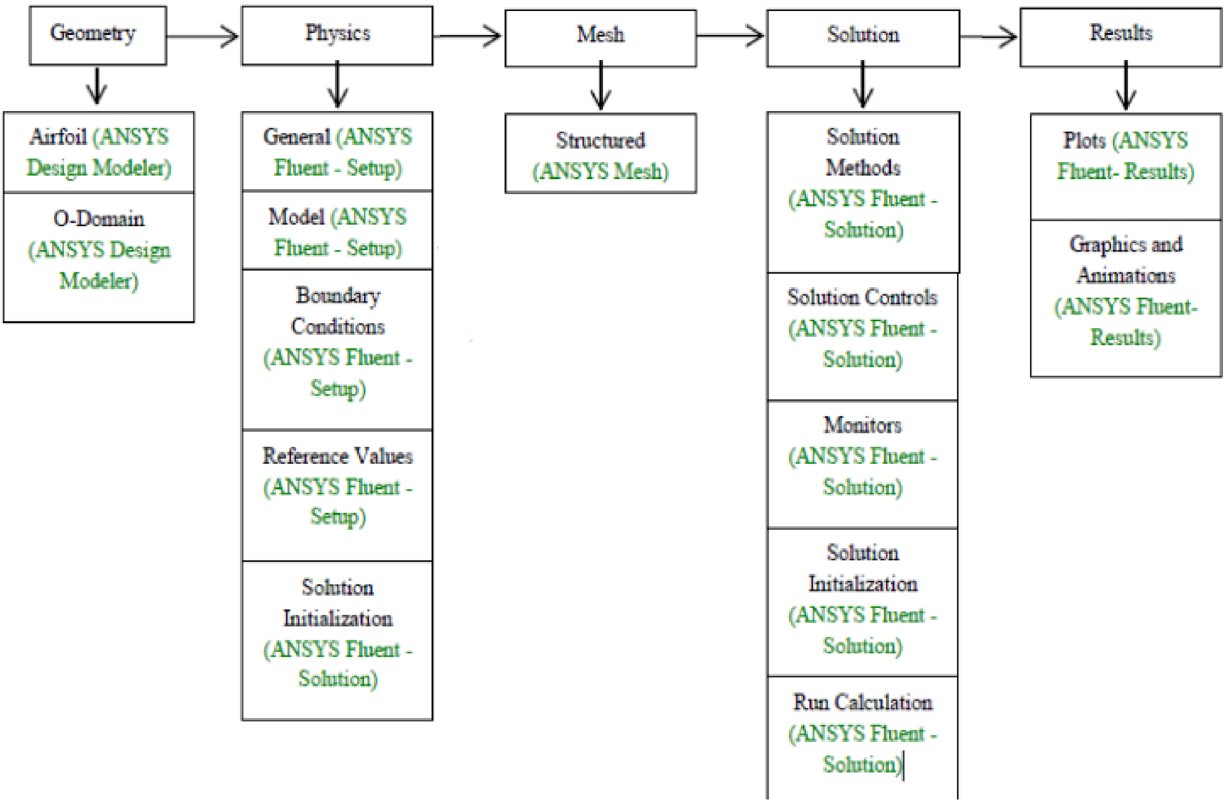

***Figure 13:** Scheme works on ANSYS*

2.5.4) Visualization of the results:

From the static pressure contour visualization; there is an appearance of high-pressure areas on the shock surfaces with red color and low-pressure zones with blue color. There is a pressure difference between the lower and upper surfaces. Then resultant pressure forces that act on the cambered plate in the direction of flow.

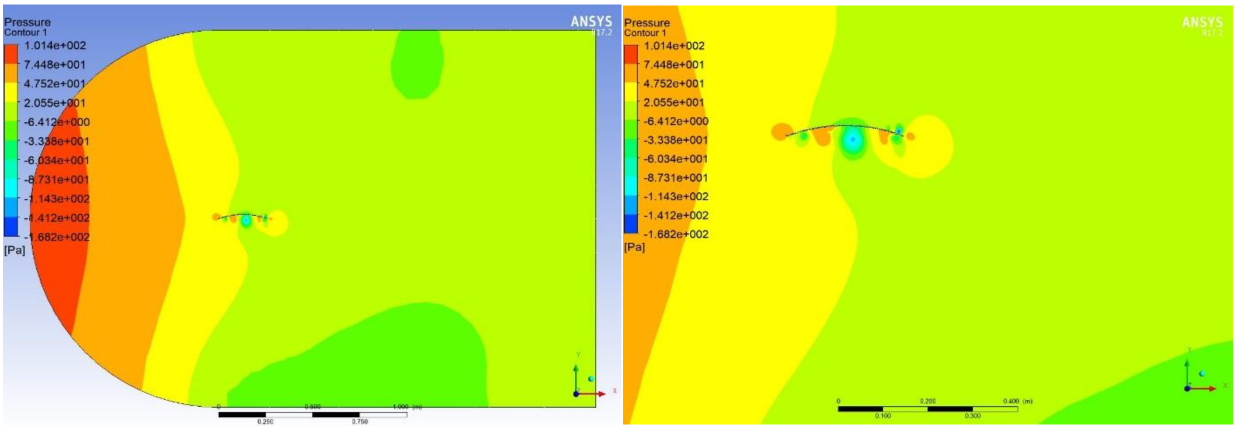

***Figure 14:** Pressure distribution at the cambered plate (v=5m/s, α =0°).*

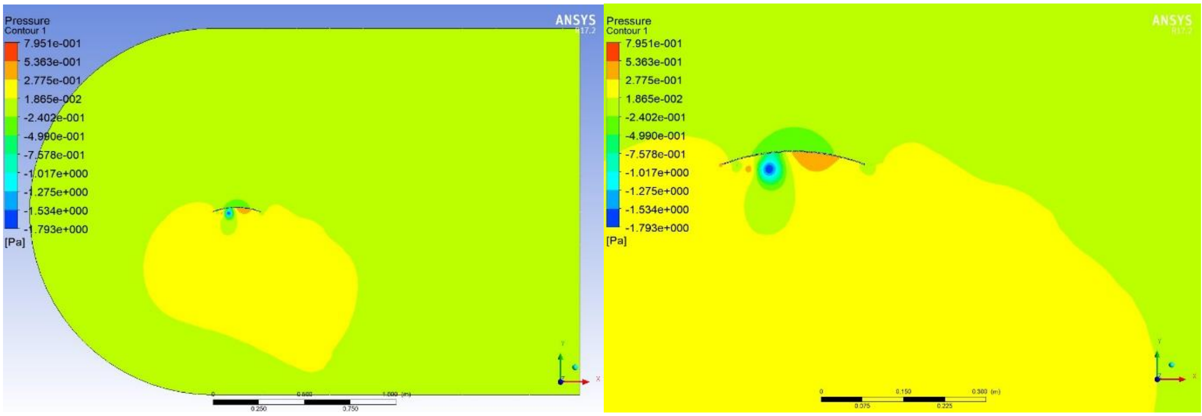

__Figure 15:__ Pressure distribution at the cambered plate (v=5m/s, α =7°).

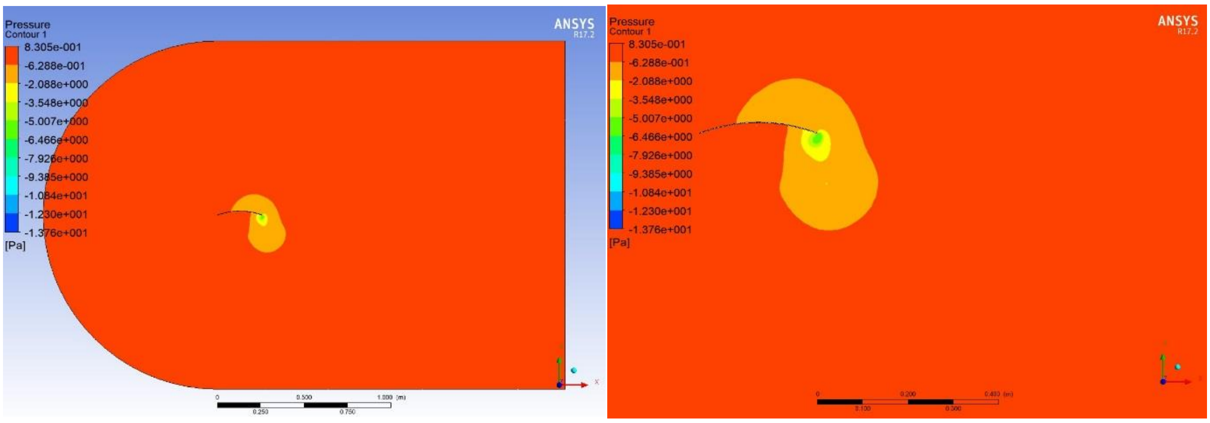

__Figure 16:__ Pressure distribution at the cambered plate (v=5m/s, α =13°).

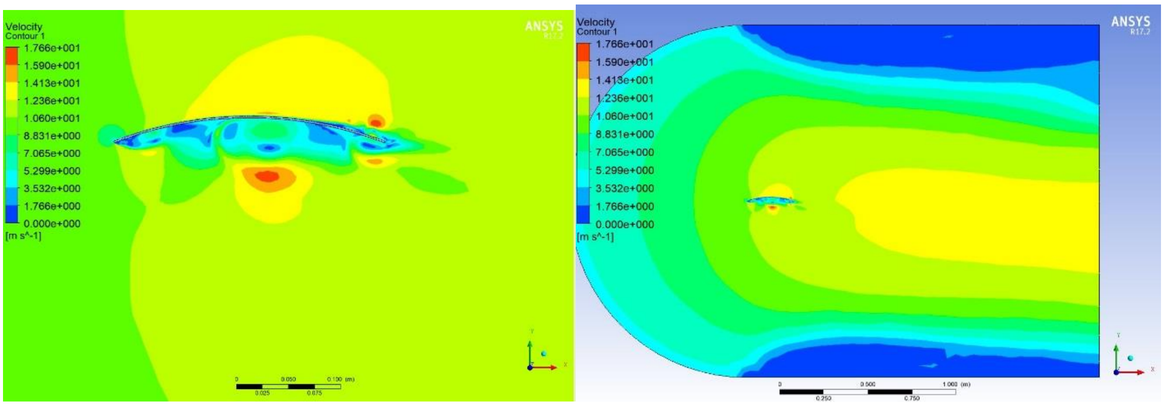

__Figure 17:__ Velocity distribution at the cambered plate (v=5m/s, α =0°).

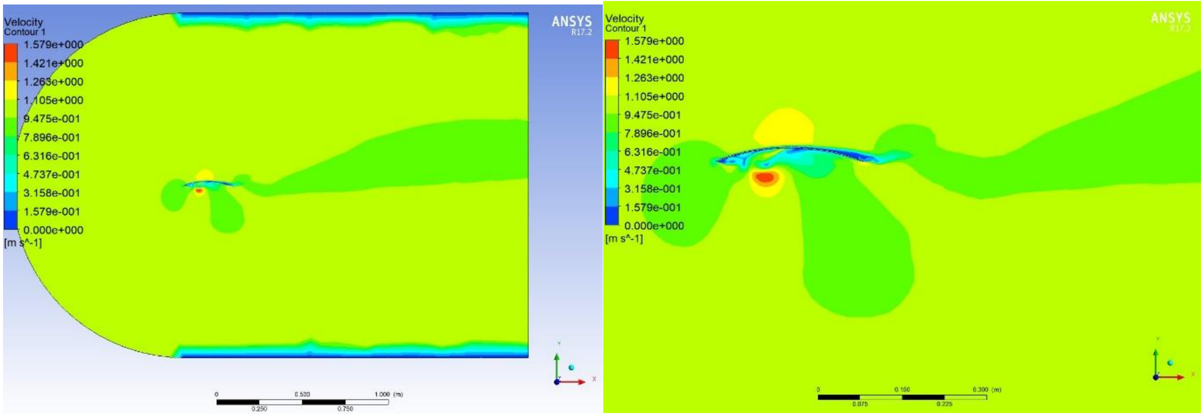

Figure 18: *Velocity distribution at the cambered plate (v=5m/s, α =7°).*

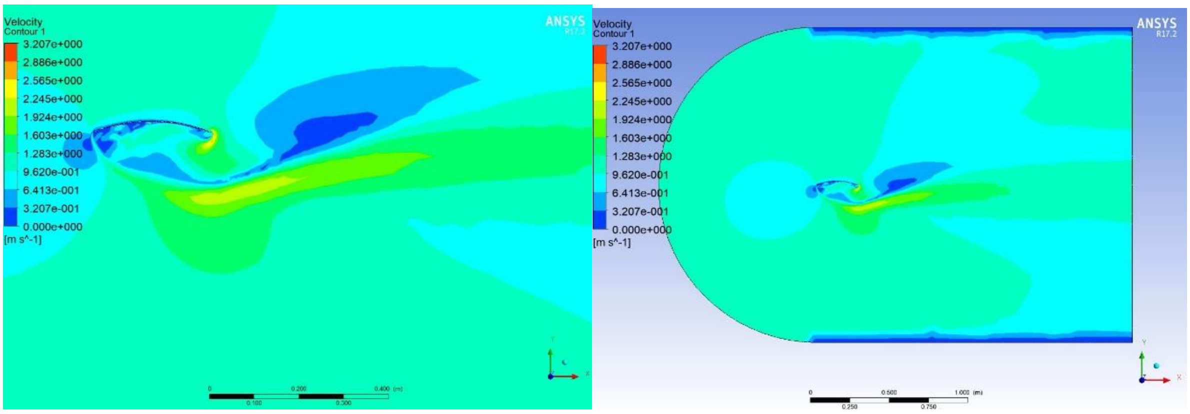

Figure 19: *Velocity distribution at the cambered plate (v=5m/s, α =13°).*

CONCLUSION:

As a result, the pressure and the velocity of the flow over a cambered plate used as blades of our future windmill, the objective of this simulation is to minimize the marge of the error between the classic method of calculation and simulation method. Also, this simulation can give a best model with an acceptable result in view of aerodynamics characteristics designed during the preliminary conception and aerodynamic design and finally we can move to execute the result in the next chapter intended for the manufacturing.

2.6) Windmill Rotor Design Strategy:

Most of the specialized bibliography establishes that the first stage in the design process of a mechanical device is to define a plan that establishes the necessary tasks that must be carried out during the development of the project. For each task, the plan must establish at least: the purpose, the personnel requirements and the time needed to perform the task (10). In the case of the Windmill Rotor design, the following general tasks were established:

1) Develop engineering specifications.
2) Generate a Windmill concept.
3) Analyze the concept.
4) Build the prototype.
5) Test and evaluate the prototype.
6) Correct and/or improve the product.
7) Generate product documentation.

1- Develop engineering specifications.

The objective of this task is to achieve an adequate understanding of the problem by generating customer requirements and evaluating other existing products in the market using the Quality Function Deployment (QFD) method. The estimated duration to complete this task is four weeks with a full-time person.

2- Design a Windmill rotor concept.

Based on the clear understanding of the required functions, a Windmill rotor concept will be proposed that meets the requirements specified by the customer. A full-time person will be needed working for five weeks.

3- Analyze concept.

Through techniques of resistance of materials, mechanical design, mechanical vibrations, computer-aided engineering, etc.; Carry out a complete engineering analysis that includes the calculation of the loads, stresses and deformations to which the chipper will be subjected. A period of six weeks is estimated to carry out said analysis.

4- Build a prototype.

Develop the concept proposed in task two to the point where the prototype can be physically materialized. This requires previously carrying out engineering drawings and establishing a bill of materials. It will take twelve weeks to complete this task.

5- Test and evaluate the prototype.

Field test a first version of the wood chipper to assess its ability to meet engineering objectives. Any new requirements that arise during this test will be added to the original list of specifications. The duration of the product evaluation will be set at four weeks.

6- Generate product documentation.

To finish the work, the documentation of the same will be carried out, including: the digital capture of all the stages of the project, cost estimation of the Windmill rotor, the conclusions and the respective recommendations. The time to complete this last stage is four weeks.

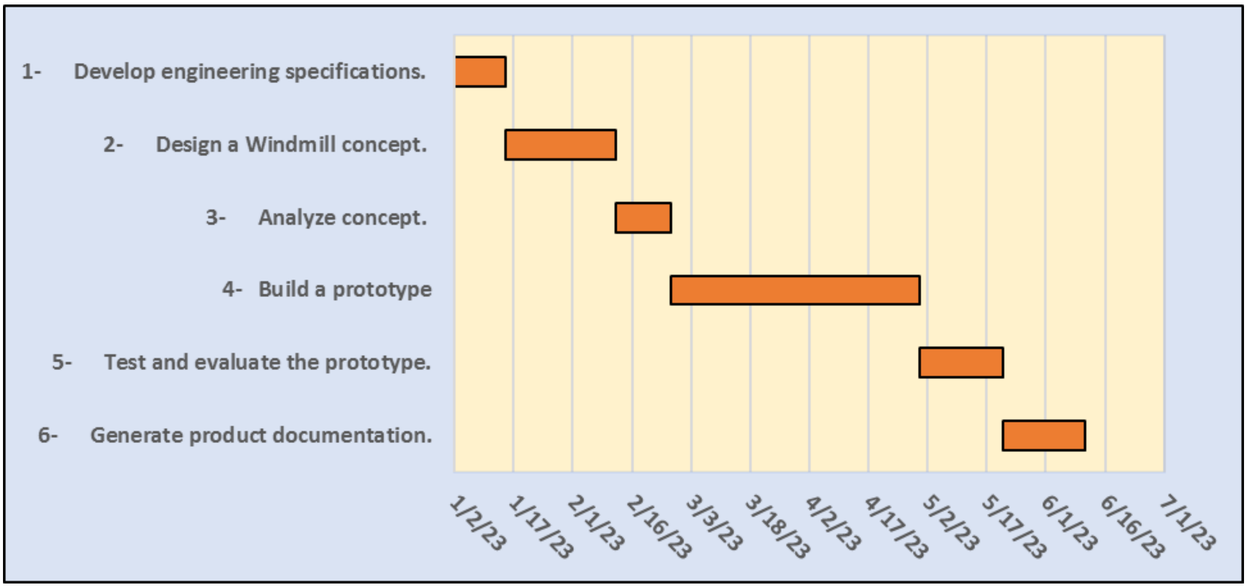

Figure 20: *Gantt chart for the Windmill Rotor project.*

2.6.1) Cost estimation

1. Budget:

Below are the costs associated with the construction of the prototype of the Windmill rotor unit. For this project, at least three main sources of expenses can be identified: expenses incurred for the acquisition of components from external sources, cost of raw materials, expenses for manufacturing and/or assembly, and indirect expenses. These items are detailed below:

- Expenditures from external sources refer to expenses from the purchase of Windmill rotor components (Sheet iron, screws, etc.) that do not need to be manufactured because they are acquired from already established suppliers.
- The cost of the raw material is that which originates from the acquisition of the necessary materials to build the parts of the machine that require specific processes (Hub, Model of blade).
- The cost of manufacturing and assembling the machine refers to the manufacturing cost of the unit, including the salary of the technical personnel involved in the work.
- Indirect expenses are generated as a result of costs caused by concepts such as: depreciation of machinery, administrative costs, sales expenses, etc. That is, they are the costs of indirect labor.

2. Cost of components from third-party providers

The following table summarizes the approximate budget of the commercial pieces that are purchased "prefabricated" and that are ready for assembly:

Table 4: *Budget for parts from external suppliers.*

Concept	**Description**	**Quantity**	**Subtotal**
Threaded shaft	Dia, 10 mm et L= 1 000m	12	2400 DA
Sheet iron	e = 1mm	3	7500 DA
Circular pipe	L = 300 mm, e = 3 mm	1	500 DA
Paint	2 colors, 2 L	2	600 DA
Assembly screws	different size		300 DA
Overs			2500 DA
		Total	13800 DA

CHAPTER 3

Fabrication of Rotor for Windmill Water Pump

3.1) Introduction:

In this chapter, we will explore Step-By-Step process of manufacturing rotor windmills, focusing on the rotor assembly. The rotor is a critical component of a wind turbine, responsible for capturing the kinetic energy from the wind and converting it into rotational motion. Understanding the manufacturing process will provide valuable insights into the intricate craftsmanship and engineering involved in creating these sustainable energy solutions.

NOTE: The Windmill Rotor was manufactured according to the available capabilities and machines

3.2) Fabrication Processes:

To manufacture a windmill rotor, we need some Process such as:

3.2.1) Cutting Process:

Process that used to remove material from a metalwork piece through the process of shear deformation. Single-point tools are used to remove material by means of one cutting edge, in shaping, turning, plaining and other similar operations.

3.2.2) Welding Process:

Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing fusion, which is distinct from lower temperature metal-joining techniques such as brazing and soldering, which do not melt the base metal.

3.2.3) Drilling Process:

Drilling is a cutting process that utilizes a drill bit to create a hole of circular cross-section in solid materials. The drill bit, typically a rotary cutting tool with multiple points, is pressed against the workpiece and rotated at high speeds, ranging from hundreds to thousands of revolutions per minute. As the bit rotates and applies downward pressure, it removes material and forms the hole. Drilling is commonly used in various industries for creating holes of different sizes and depths in materials such as metal, wood, plastic, and composites.

3.2.4) Turning Process:

Turning is a machining process that involves the removal of material to create rotational parts. It is commonly used to shape cylindrical or conical surfaces by cutting away unwanted material. The turning process is carried out using a turning machine or lathe, along with a workpiece, fixture, and cutting tool.

3.3) Tools and Machines used in manufacturing:

These are some of the tools and machines that we used in manufacturing:

Figure 21: *Riveter*

Figure 22*: Spot Welder*

Figure 23: *Drill Press*

Figure 24: *Dividing Head*

Figure 26: *Welding Machine*

Figure 25: *Grinding Wheel Machine*

3.4) Parts Detail:

3.4.1) Blades:

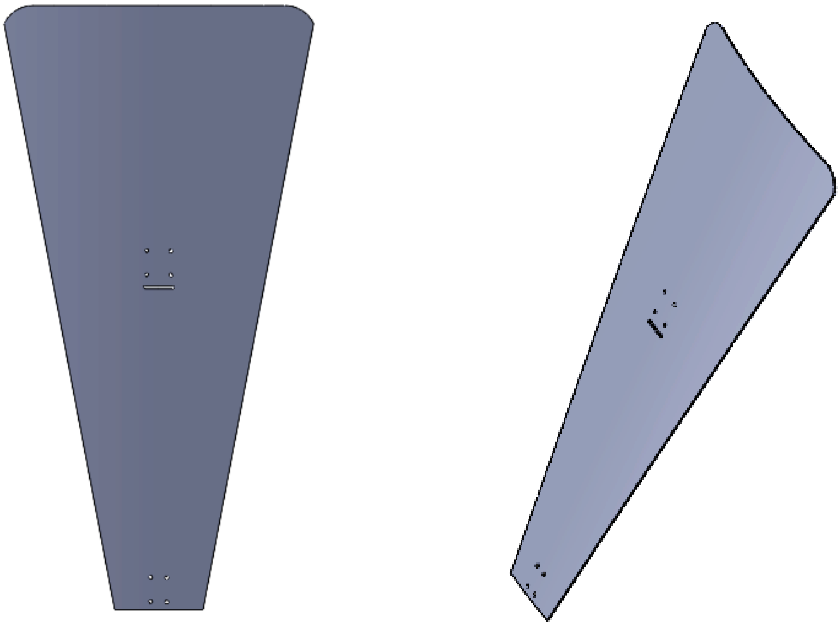

Figure 27: *Blade CAD Design*

First, we cut two metal plates into 18 blades using angle grinder

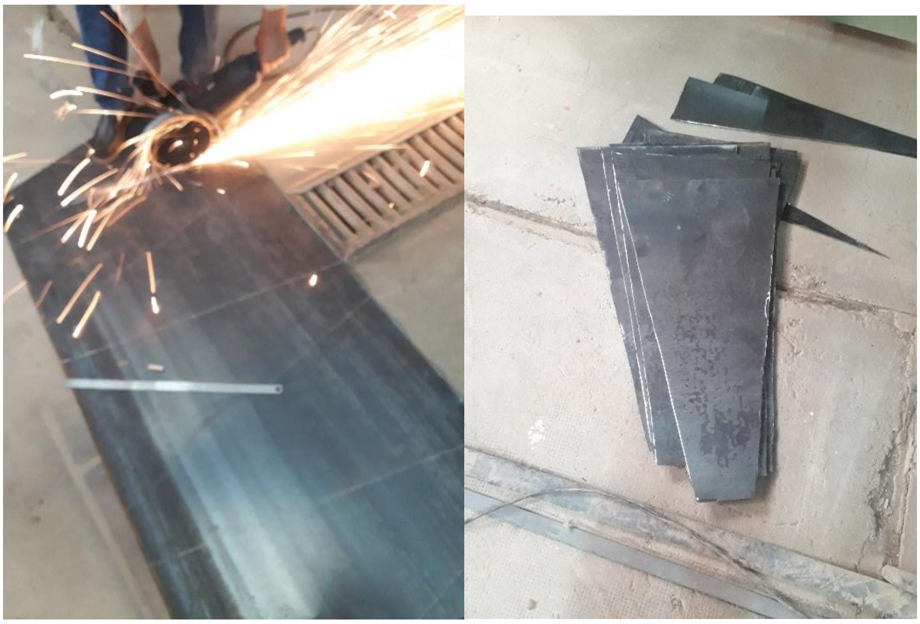

Figure 28: *Blade Cutting Process*

After cutting, we go to the grinding wheel machine to remove sharp areas and edges

Figure 29: *Blade Grinding Process*

After that, we drill support blade and exterior diameter

Figure 30: *Blade Drilling Process*

We then roll the blades at the angle chosen in the previous chapter

Figure 31: *Blade Rolling Process*

Finally, we cut the front edges for safety and aesthetics of the blade

Figure 32: *Blade After Cutting*

3.4.2) Metal Rip:

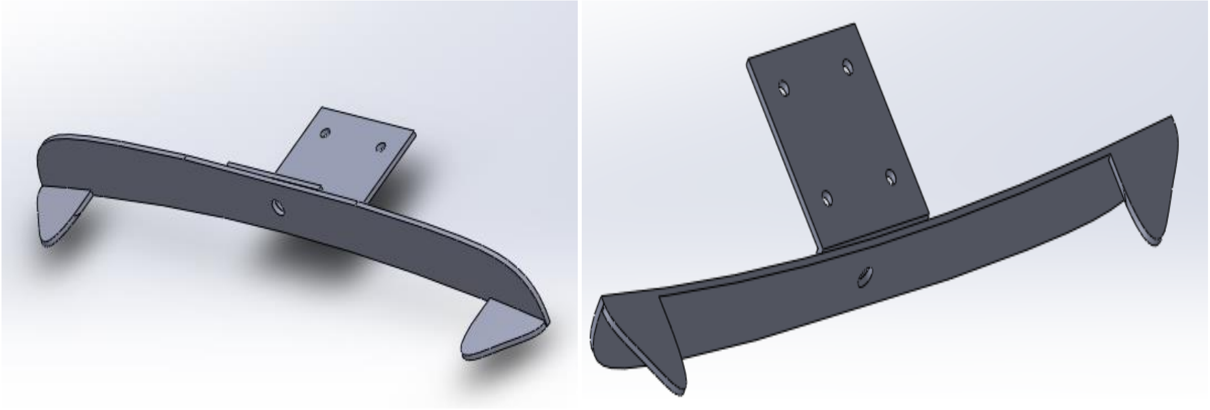

Figure 33: *CAD of Metal Rip*

We took the rest of the cut metal sheet and cut it to our metal rip design

Figure 34: *Metal Rip Cutting Process*

After we cut all the pieces of metal rip and support blade & rip, weld them together with spot welder

Figure 35: *Metal Rip Welding Process*

Then we do the drilling process with a drill press

Figure 36: *Metal Rip Drilling Process*

Figure 37: *Metal Rip*

3.4.3) HUB:

Manufacturing a hub was a little difficult because of its design and the traditional machines available to us

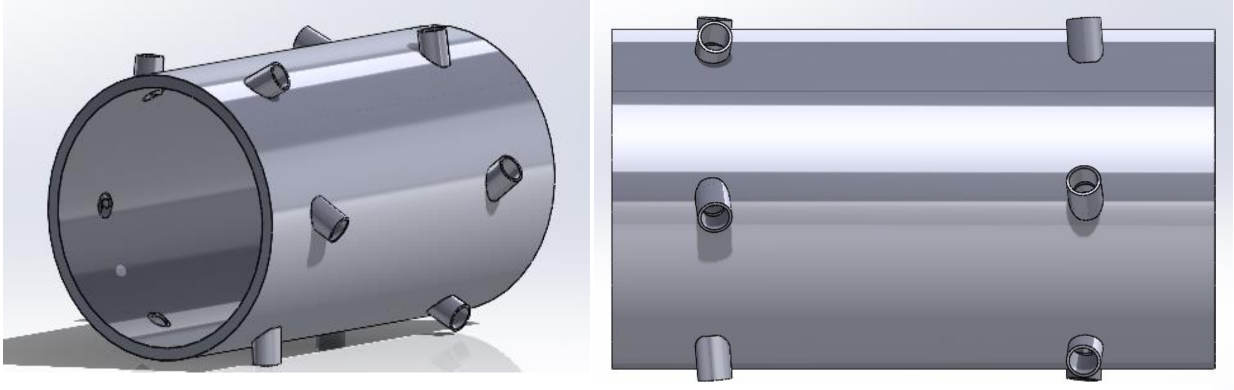

Figure 38: *CAD of HUB*

We found a suitable iron pipe to be a hub. We leveled its surface by lathing

Figure 39: *HUB Turning Process*

We determined the angles to be drilled with the dividing head and drilled them

Figure 40: *HUB Drilling Process*

Now to the difficult work, which is welding a long nut in the hub according to the specified angles.

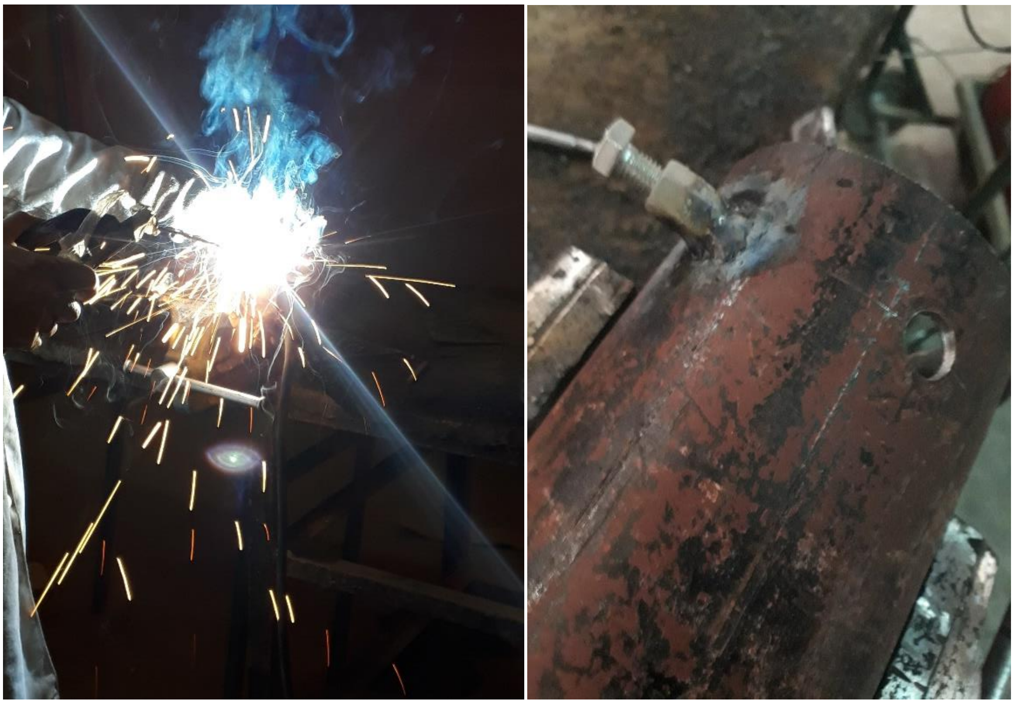

Figure 41:*HUB Welding Process*

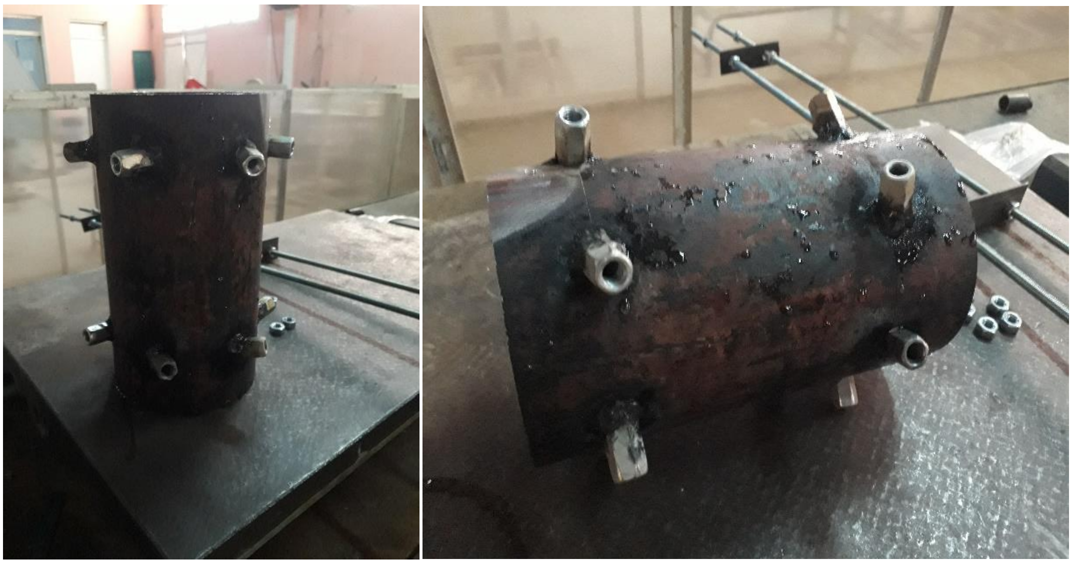

Figure 42: *ROTOR HUB*

3.4.4) Int & Ext Diameter:

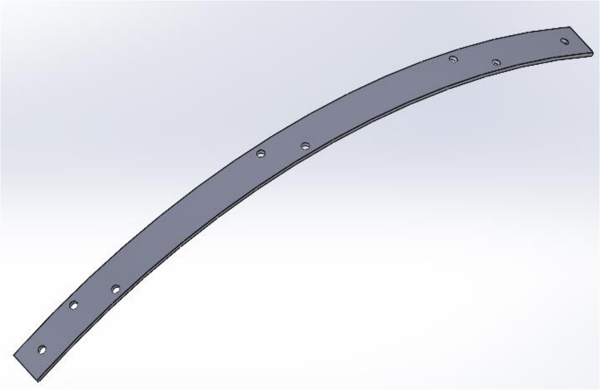

Figure 43: *CAD of INT Diameter*

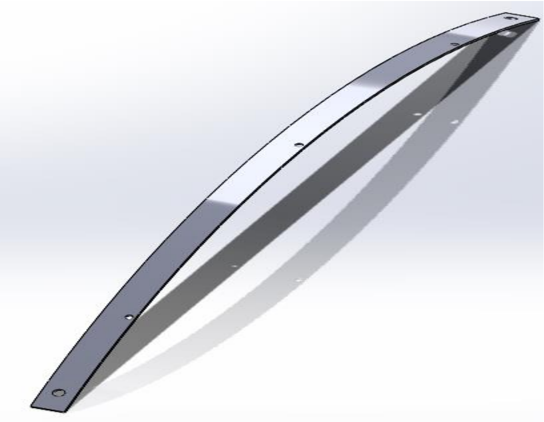

Figure 44: *CAD of EXT Diameter*

We bring a flat metal bar and cut it into six parts for the Int diameter and six parts for the Ext diameter, according to the measurements in the design
Then roll them by hand until they form a circle

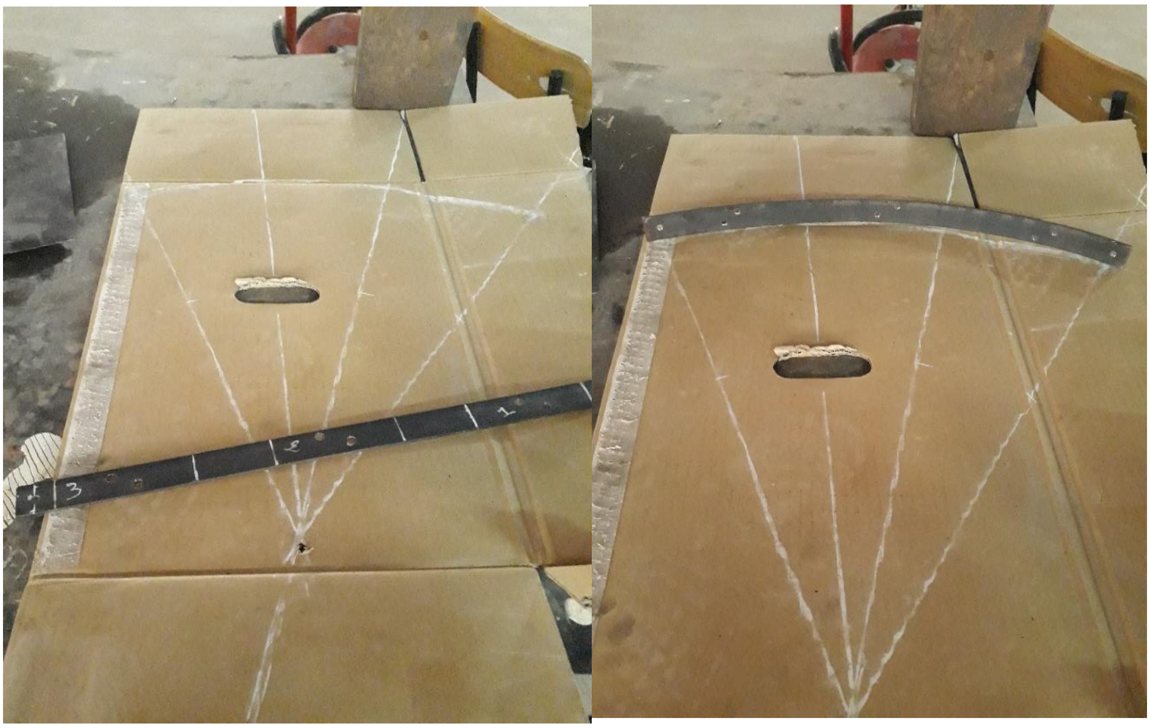

Figure 45: *INT Diameter Rolling Process*

Then we pierce them according to the size in the design

Figure 46: *EXT Diameter Drilling Process*

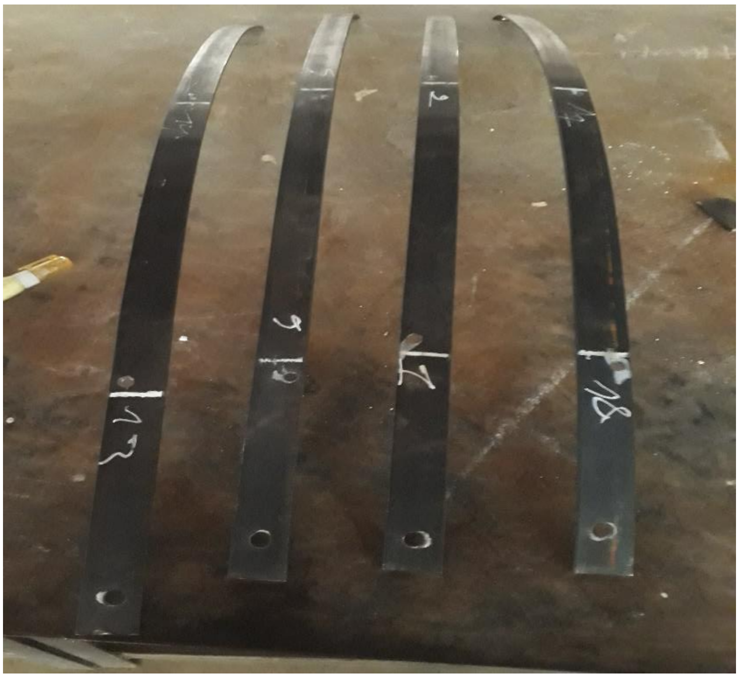

Figure 47: *EXT Diameter*

3.4.5) Support:

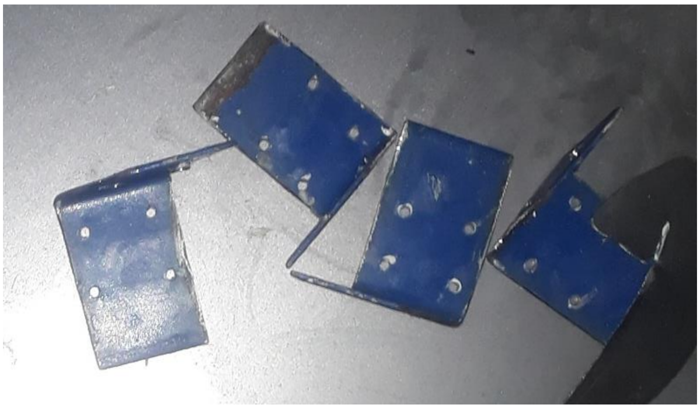

Figure 48: *Support Blade*

Figure 49: *Support EXT*

Figure 50: *Support ROD&INT*

3.4.6) Threaded rod:

We need 12 Threaded rods 1m long

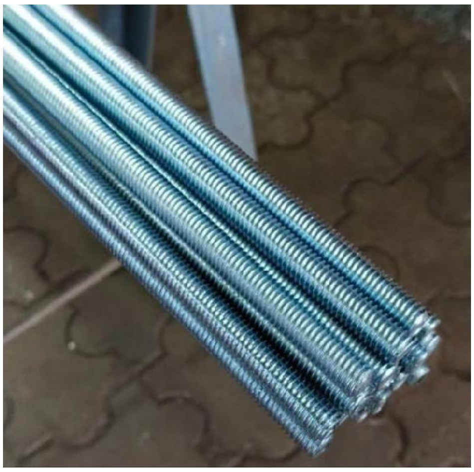

Figure 51: *Threaded rods*

3.5) Assembly:

The assembly of parts involves the process of joining individual components together to create a final assembly.

3.5.1) Connect Metal Rip and Support Blade on Blade:

Metal Rip and Support Blade are ready and connected on Blade

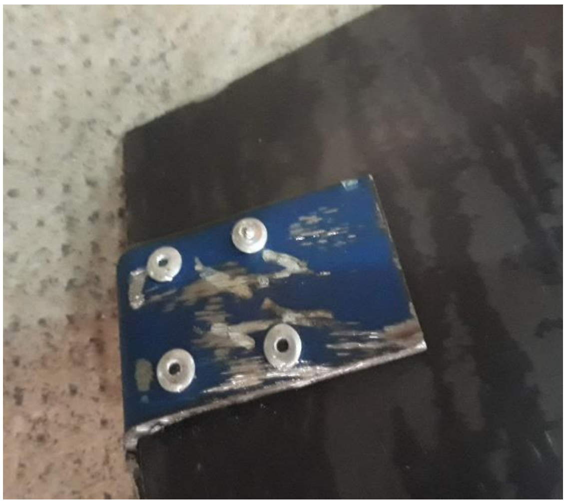

***Figure** 53: Support Blade on Blade*

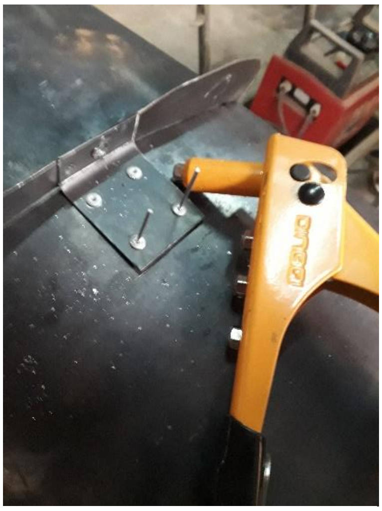

***Figure 52:** Connect Metal Rip on Blade*

3.5.2) Mounting Three Blades:

Install three blades as shown below, in order to obtain six assemblies

Figure 54: *Three Blades*

3.5.3) Connect The Hub With Threaded Rod and INT Diameter:

Hub is connected with Threaded Rod and INT Diameter

Figure 55: *Connect the Hub*

Figure 56: *HUB Assembly*

3.5.4) Mounting of Blades On Hub assembly:

Blades are ready to connecting in the hub assembly

Figure 57: *Blade and Hub Assembly*

Figure 58: *Mounting Blades on HUB Assembly*

3.5.5) Final Assembly:

Figure 59: *Final Assembly*

3.6) Final Model Picture:

Figure 60: *Final Model Picture*

3.7) Problem Solving:

While working on the project, various challenges were encountered, but through perseverance and problem solving, they were eventually overcome. These challenges provided valuable opportunities to develop skills, acquire knowledge, and gain experience in problem solving within tight timelines. Many issues required the application of critical thinking skills, such as selecting suitable materials, tools, and designs, as well as procuring tools from overseas. Dealing with these problems contributed to a greater understanding of how to navigate future obstacles in the project**.**

General Conclusions

General Conclusions

When a novice engineer is faced with a new design problem, his first hope is that the developed device will behave as planned in the design process. That is to say, that the mechanical component performs the task for which it was conceived in an adequate and efficient manner. In addition, the designer also expects to deliver the project on the specified date meeting the cost proposed in initial planning. Unfortunately, in reality, things can be very different than initially thought in the early stages of the design process. For example: the operation of the mechanism may differ from the desired behavior, the materials may not resist the loads to which they are going to be subjected, delays in the delivery dates, substantial increase in the budget, or all of these situations together.

In the case of our windmill rotor, the problems were not unrelated to the design. Perhaps the biggest problem in the design of the machine was the discrepancy in the delivery time of the final prototype; a delay of a month and a half can be reason enough to ruin the best of ideas (because of the spring holidays and the month of Ramadan).

The lack of a rolling machine was among the causes that led to errors in some rotor components and subsequent assembly errors. Speaking of the assembly of the rotor elements and because of the large dimensions of the components and also the lack of handling means, we encountered adjustment problems and balancing was difficult.

As for the successes of the project, it should be noted that the cost of the design was very low. In fact, the total investment made in the windmill rotor was really low, even compared to similar machines. It is estimated that if the errors mentioned before are corrected, the money needed to manufacture the rotor could decrease further.

On the other hand, the assembly quality of the prototype built is, without a doubt, superior to that of other machines available on the net.

Moreover, the manufacture of this type of product in Algeria makes it possible to generate sources of employment which are so essential in a developing country.

Finally, it is considered that despite the shortcomings committed during the design process, the objectives set at the beginning of the project have been achieve

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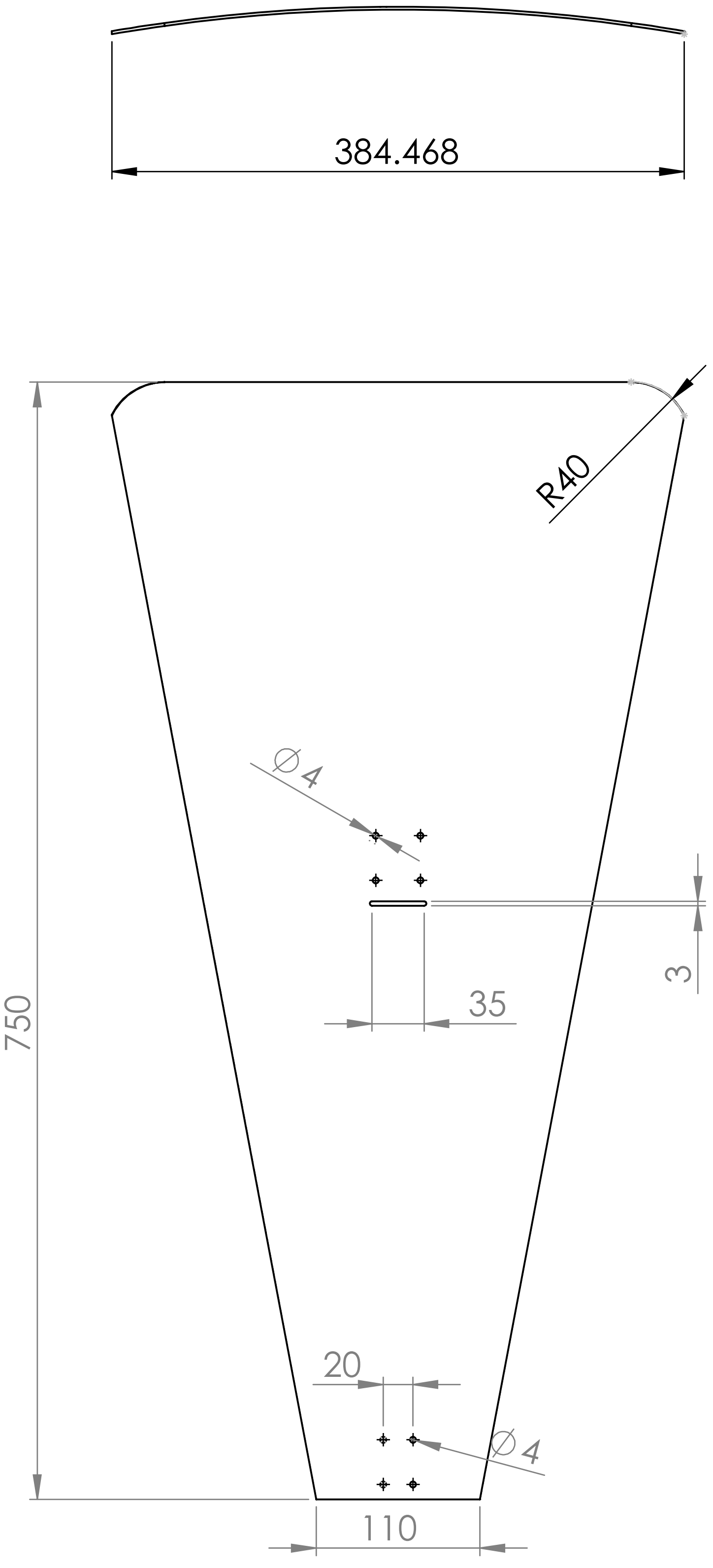
APPENDIX :

Parts Drawings



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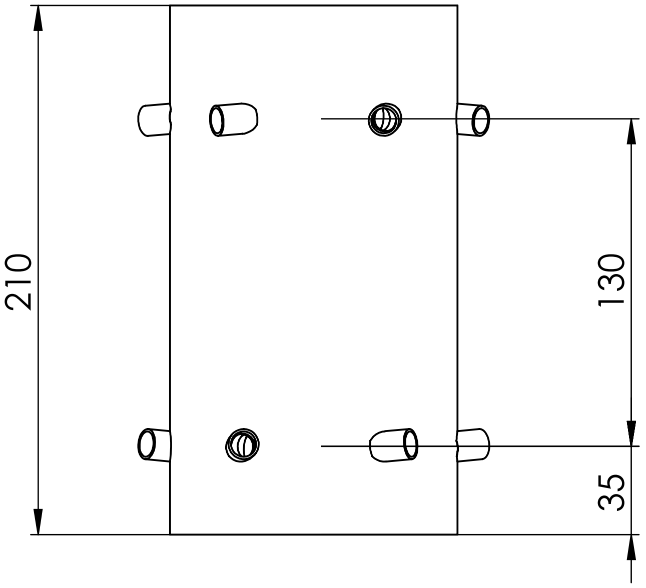

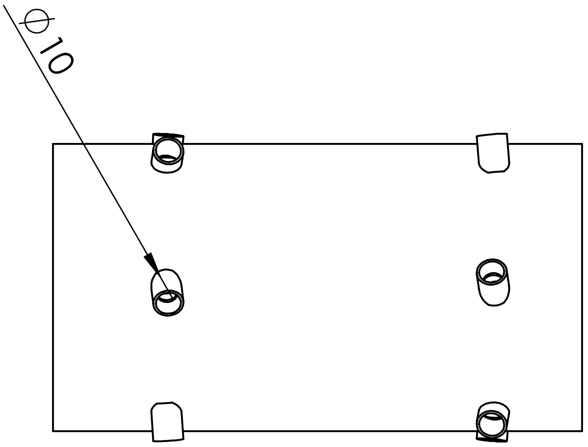

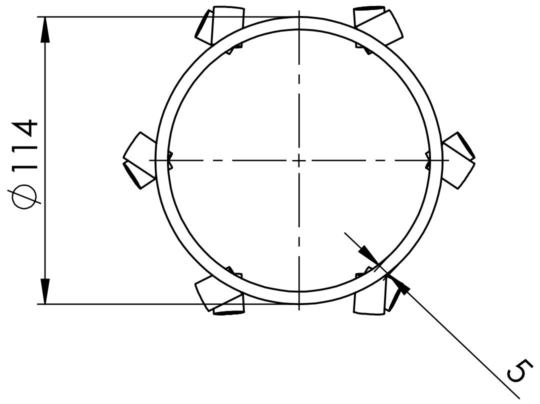

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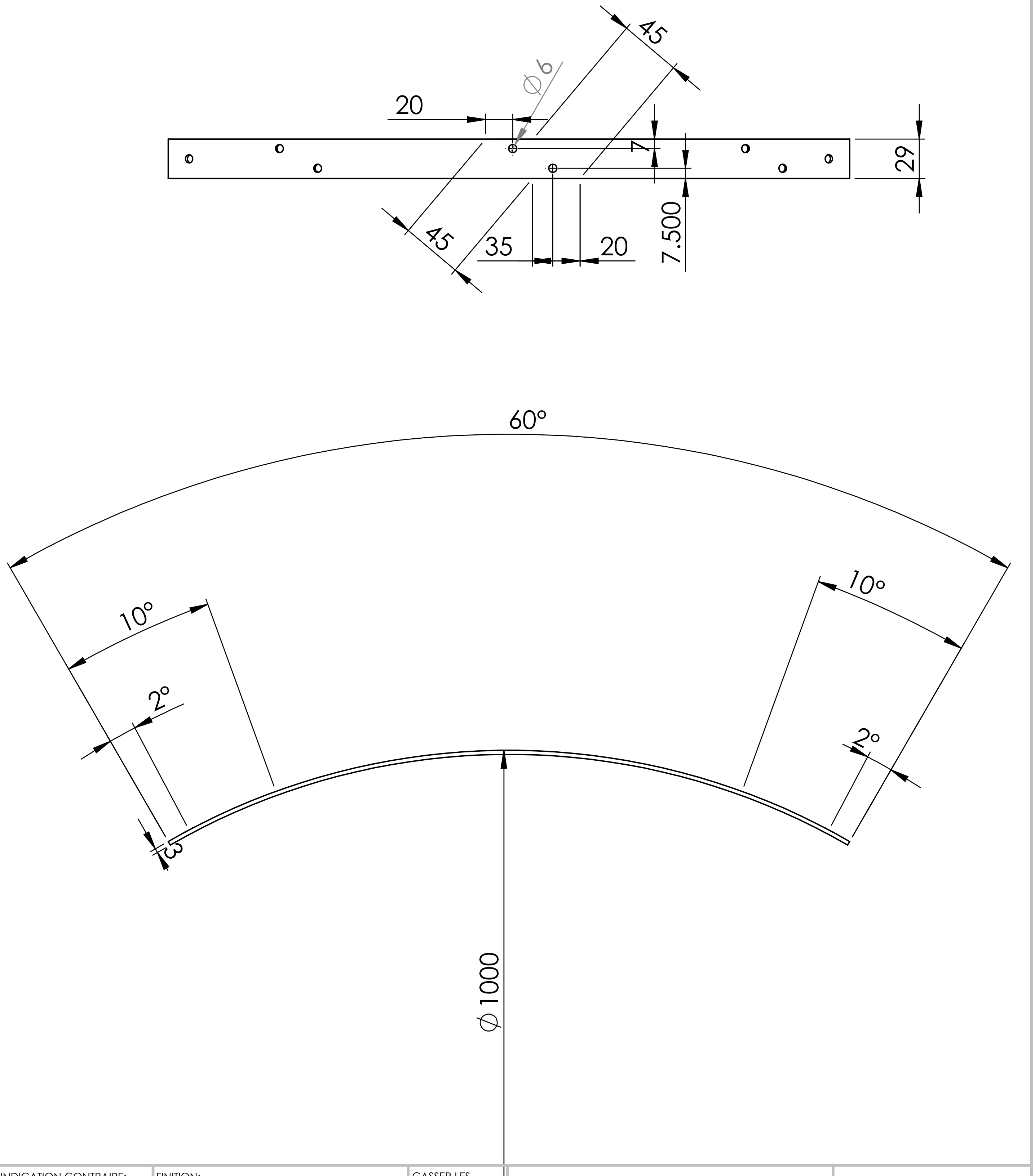

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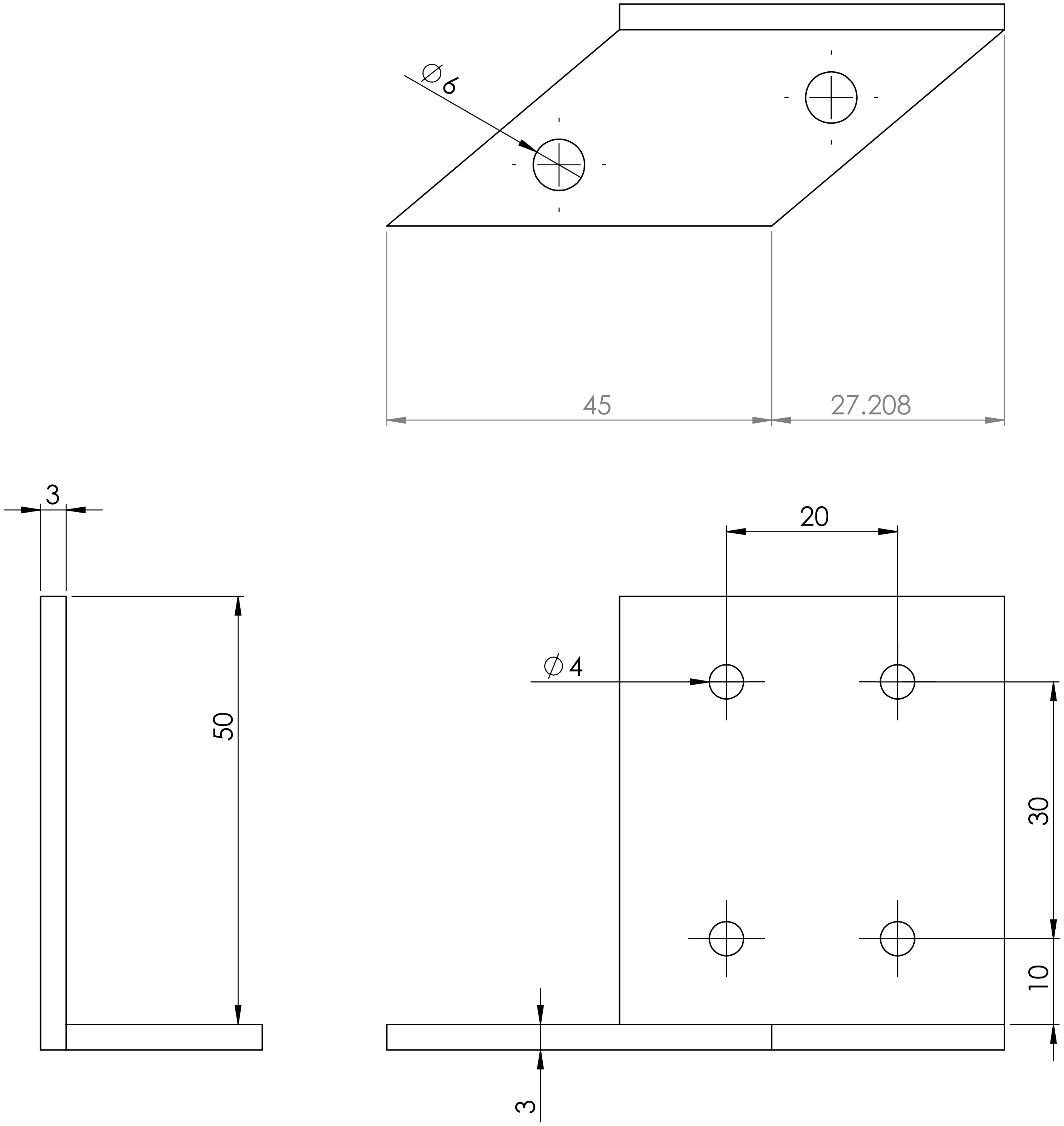

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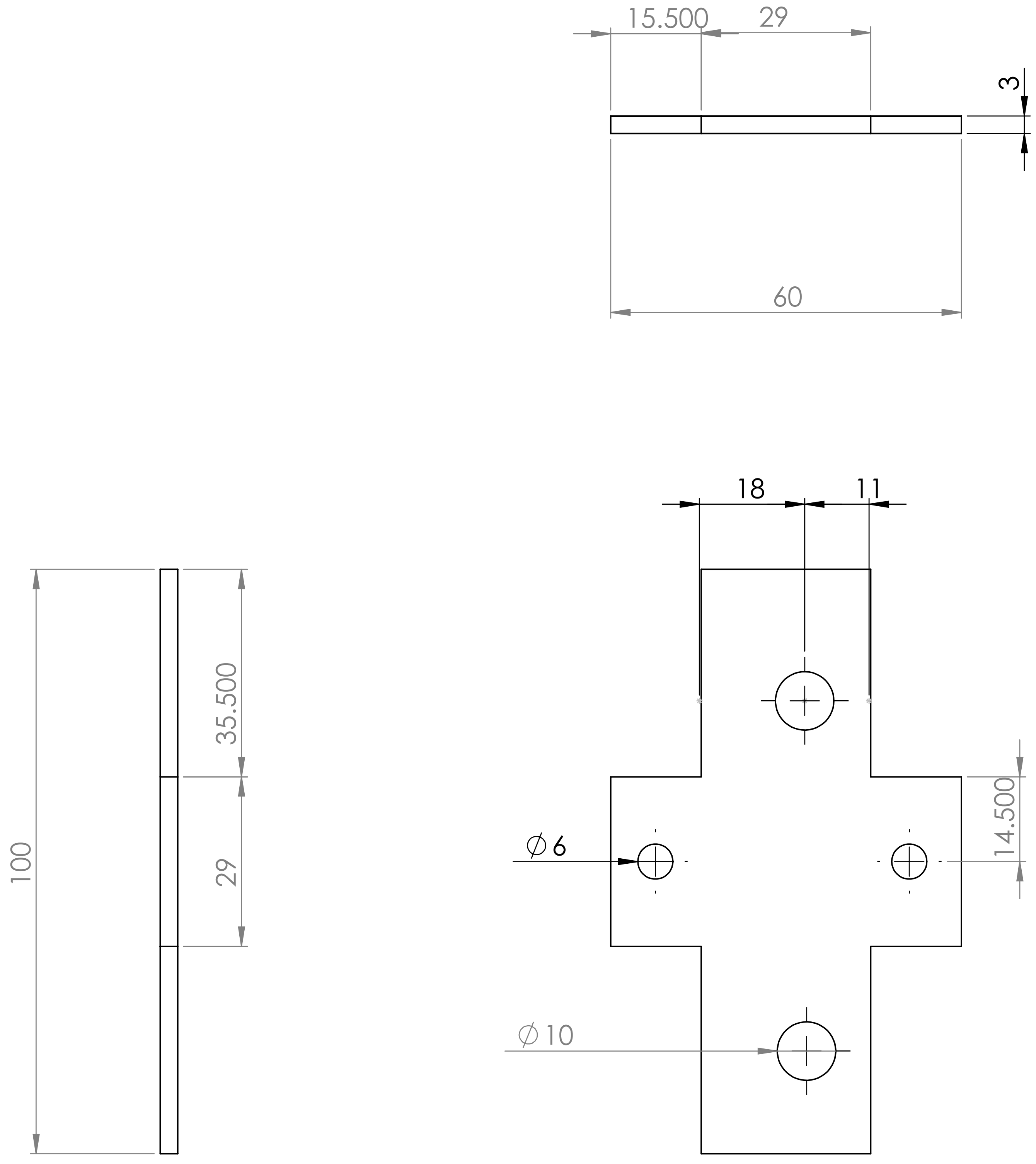

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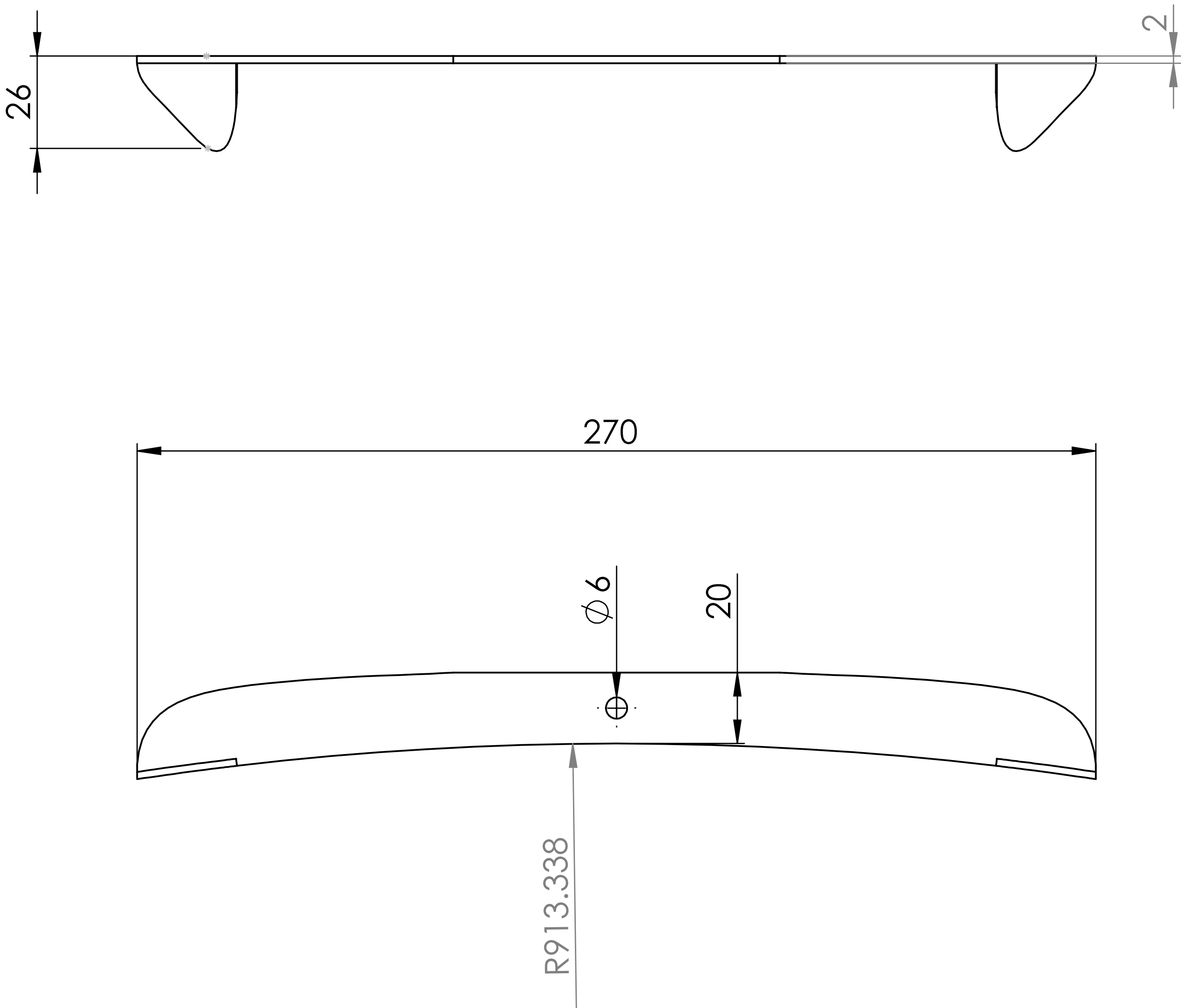

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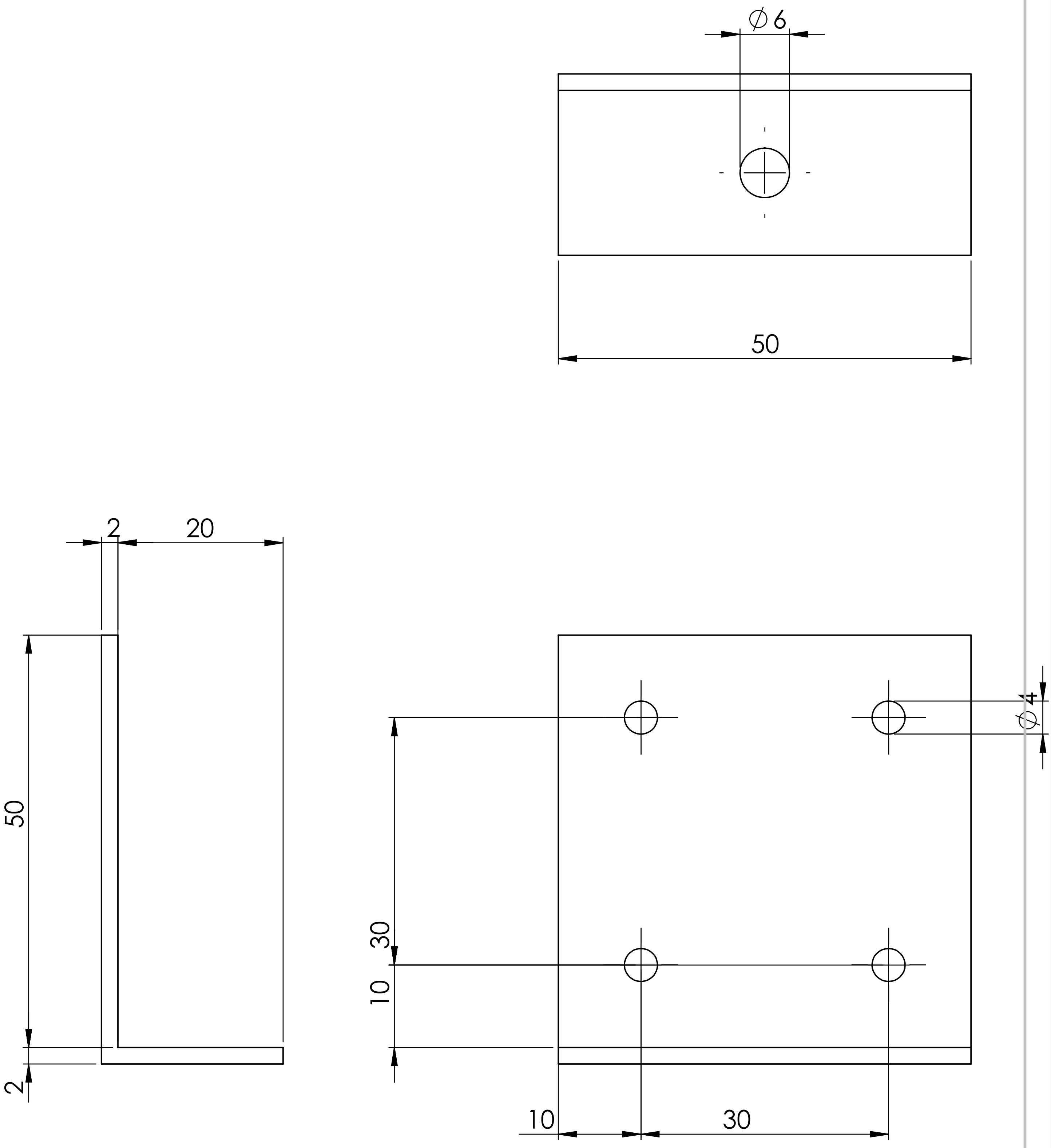

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