ESCUELA TÉCNICA SUPERIOR DE INGENIEROS INDUSTRIALES Y DE TELECOMUNICACIÓN

Titulación :

INGENIERO TÉCNICO INDUSTRIAL MECÁNICO

Título del proyecto:

SOLAR BLIMP

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Pamplona, 27 de Junio.

CONTENTS

ABSTRACT

In broad terms, the following project could be perfectly divided into two different parts.

First, the design of the blimp, it was taken a previous documentation and then, it was made a research and a deep study about the equations needed for the design, and all the aspects which were involved in the design.

It was used *Solid Works Software* to draw the designs.

In the second part, there were considered CIGS solar cells as the most suitable cells for the blimp, basing on the requirements presented. Finally it was made a definitive design of the blimp with the solar cells allocated.

In addition, it was used *PV SYST 5.56 Software* which simulated and calculated the energy supplied by the solar cells.

To conclude it was used *CFD software* to find the power required to move the blimp. This value was compared with the power supplied by the solar cells.

ACKNOWLEDGEMENTS.

I have tried to do my best with this Project. It has given me the opportunity to learn about airships and solar energy. However, this would not have been carried out without the personal help and the motivation received. I would like to pass on my sincere thanks to every one of them.

Thank you to Richard Day for giving me the chance to be in charge of my project and suggesting me this topic.

I am really pleased to Dr Graham. First, because he let me the opportunity of attending all his meetings, and besides, for his constant supervision, personal encourage, guidance and patience showed.

Thanks to Klaus Link due to his help and explications about *Solid Work Software*.

Thanks to \`Fotolín´ and \`minizepp´ companies because they have answered all my emails rapidly and for giving me their time and attention.

Thanks to Graciela Manzanares, for lending me her laptop, when mine broke.

My appreciations also go to Sergio Sanz, Elena Izuriaga, and Beatriz Iriso for their support, valued opinions, good viewpoints and alternatives suggested.

I would like to dedicate all the work to my grandfather Jose Luis who is in the heaven, and I am sure that he would have enjoyed reading each page of this project.

Thank to my other grandfather Joaquin who is in the hospital, for teaching me that goals are achieved with perseverance and hard work.

And finally I would like to finish saying thank you to my mum, dad and little sister, for giving their support in this period of hard-work time and showed their affection, although they were far away.

1.INTRODUCTION

1.1) Introduction

From nearly all perspective, energy is absolutely a primary good for the development of the contemporary society. The availability, pricing and continuity of the accessible energy supply scope, are relevant values for the growth of any economy. However, the minimisation of the possible environmental impacts arising from production, transport, distribution and consumption processes is a significant factor due to the substantial dimension and the complexity of the amounts required to address the increasing demand.

In this connection, renewable energies emerge as a fundamental alternative to conventional energy sources. Thus, renewable energies, as their name suggests, are those that does not somehow entail long periods to be generated by the nature i.e. solar, wind, biomass, etc. unlike conventional energies which are so-called fossil fuels i.e. coal, petroleum, natural gas, uranium, which require enduring periods of millions years to their natural generation.

It will be important to take this energetic discussion forward in the right framework, since several different approaches can be adopted regarding this matter. Hence, whereas conventional stands undervalue renewable energies, other opinions are along the lines that an economical and efficient energy pattern, based exclusively on renewable sources is needed.

Having stressed that there is a need to further define and put in objective terms the situation, possibilities and perspectives in reference to renewable energy, from serious and verified procedures, it is necessary to clarify in a specific manner the potential solutions that can be provided for real applications.

Consequently, within this frame of reference come up the concept of ‘sustainable transport’. The serious environmental impact in terms of greenhouse gas emissions that is caused by the different modes of transportation, which contribute approximately to a third of CO_2 emissions in the world, as well as the growing demand for transport due to population increases, appropriate new technologies need to be developed in order to face these issues.

Many are the technologies related to the transport that have been developed and spread in recent years such as electric cars or solar vehicles. Furthermore, one of the most common forms of technology used for these purposes is the solar power. Being one of the most reliable natural resources, especially in those areas where the sun light is more than capable of producing energy throughout the year, many came forward with interesting project in which technologies, solar power and transport, went hand in hand.

This scenario of renewable technologies developments has given rise to the idea of the solar blimp.

A blimp is a non-rigid airship, a floating dirigible that has not keel, or internal supporting framework. The difference between a semi-rigid airship and rigid dirigible (Zeppelin) is that blimps do not have any rigid structure, neither a complete framework nor a partial keel, to help the membrane to maintain their shape. This dirigible´s physic principle is based on the greater pressure of the lifting gas (normally helium) inside the envelope and the strength of the envelope itself. It can be steered in the air using rudders and propellers.

The construction of a blimp is a purpose that comes with certain aims presented in the current national situation. The hypothesis about the usage of the blimp as a kind of transport around the world has been demonstrated. It is a device that clearly is economically feasible to transport cargo and passengers.

Airships were the first aircraft to enable controlled, powered flight, and were widely used before the 1940s, but their usage decreased over time as their capabilities were surpassed by airplanes. Their decline continued with several high-profile accidents, including the 1937 burning of the hydrogen-filled Hindenburg near Lakehurst, New Jersey, and the destruction of the USS Akron. Airships are still used today in certain applications, such as advertising, freight transportation, tourism, camera platforms for sporting events, aerial observation and interdiction platforms, where the ability to hover in one place for an extended period does not require speed and maneuverability.

Its usage as a mode of transportation is being more relevant than ever because it is very attractive thanks to the development of new materials and technologies. In the modern world, blimp is at its peak, presented in countries like USA, England, Russia, Holland and Germany. This last country was important due to a support in institutional level, with policies for development, which achieved its first goals with the launching of Cargo Lifter in the Fair

Worldof 2000, an airship capable to carry 160 tons, with a cruising speed between 80 and 100km. / h at a flight altitude of 2000 m, for a flight range of 10,000 km.

1.2) Background

In 212 B.C in Greece, a famous mathematic sets that an object immersed in fluid experiments a force equal to the weight of the fluid dislodged by the object. This became known as Archimede's Principle [1]. Archimede´s Principle can be implemented to objects with different densities. There are three different cases:

- If the density of the fluid is less than the density of the object, the object will sink.
- If the density of the fluid is equal to that of the object, the object will neither sink nor float.
- If the density of the fluid is bigger than the density of the object, the object will float.

2000 years later, this principle let people build the hot air balloon.

One English man, Roger Bacon, created a flight device with the shape of a balloon. But they were two French men, Montgolfier brothers who flew a hot air balloon many years later, in 1783. It was known as the first flight lighter than the air. People who attended this amazing event remained silent fascinated by that discovery. By that moment, air transport had started.

During several years, a lot of hot air balloons were built, and they were flown. But they were not be able to be controlled or be propelled. It was necessary to sort out these problems, due to the air only could lead them, without any control. Balloons achieved success by the moment that people studied the way to improve their characteristics.

A new French man, Henri Gifford, flew a balloon repulsed by vapor. This fact was very significant. It was moved by the speed of 6.7 m.p.h.

In 1863, Solomon Andrews invented the first controllable airship, although it had no motor.
In 1872 the French naval architect Dupuy de Lome, developed a manageable large globe, driven by a large propeller with a power equal to the force of eight people. The aim was to use it during the Franco-Prussian War as an improvement for communication between Paris and indoors, but the design was completed after the war ended.

Paul Haenlein flew an airship anchored to a rope in Vienna, powered by an internal combustion engine; it was the first usage of it to propel an air artifact.
In 1880 Karl Wolfert and Ernst Georg August Baumgarten, attempted to fly a powered dirigible in the open, but it crashed.

Gaston Tissandier in 1883 implemented the first electric flight, using a Siemens motor of 1.5 horsepower.

The first operational dirigible in the open was built for the French army by Charles Renard and Arthur Krebs in 1884.The vehicle, called "La France" was 51.85 m long and 1872 m^3 volume. It made a flight of 8 km in 23 minutes using an electric motor of 8.5 horsepower.

That was the first controllable airship which was able to return to its starting point regardless of wind.

In 1888, Wolfert´s airship flew propelled by combustion engine in Seesburgo. In 1896 a rigid airship created by Croatian engineer David Schwarz made its first flight at Tempelhof field in Berlin. After Schwartz's death, his wife Melanie received a payment of 12,000 frames from Ferdinand von Zeppelin due to an exchange of technical information about the dirigible.

In 1900, a German Count used a motor which made balloons fly. He was known as "the mad of Bodensee Lake". Those balloons become very famous and it was given the name of zeppelins. Zeppelins were named in honor of Count Ferdinand von Zeppelin, who experimented with designs of rigid airships in the 1890's. They flew at the speed of 18 mph and they had a metal structure which let them keep flying even the gas or the power failed. Zeppelin´s design was copied and improved around the world.

The beginning of the "golden age of the dirigibles" is marked by the launching of Luftschiff Zeppelin (LZ1) in July 1900, one of the most famous dirigibles of all ages. But the first flight of that airship, only took 18 minutes around The Bodensee Lake. During the following years, the construction of the dirigible fluctuated between success and failure. However, Von Zeppelin was not demoralized and continued firmly in commitment.

The new airship "Zeppelin IV" was ready for mid-July, in 1908. This ship had to pass an ascent test that took 24 hours. The town of Friedrichshafen,, where the new dirigible was, commission and military members arrived to attempt that event. Even the holidays of the German War Minister were interrupted for the same reason.

By that time, people could not understand that weather conditions influenced the flight and the majority of the people did not support the initiative of the zeppelin. The public demonstration of the "Zeppelin IV" ended in a failure because it caught fire.

Von Zeppelin withdrew from the investigation, but people started to consider him as a genius and 6 millions of frames were collected as incentives for investment.

At that moment a lot of zeppelins were applied for building.

Ferdinand von Zeppelin died being very famous at the age of 80, the March 8, 1917. Until that age, he continued its work successfully, becoming his dream true. More than hundred ships in ten years sailed the skies over Europe. Zeppelin airships were widely used during the First World War.

At the beginning of the First World War, Zeppelins had a cylindrical structure made of aluminum alloy and a fabric cover hull containing gas. Multiplane fins were used for control and stability, two gondolas for the crew under the hull and propellers attached to both sides. There was also a passenger cabin (between the two gondolas), and during the war, it was used as a store of bombs.

The possibility of using airships as bombers had been thought in Europe a long time ago before this was possible. They destroyed several cities and fleets. When Germany was defeated, the victors demanded the surrender of those zeppelins which were still intact and the closure of the factory. In 1919, due to The Treaty of Versailles, Germany got rid of all units and proceeded to close the factories.

Since Von Zeppelin built his first aircraft had passed twenty years, and in that period-and even more during the war period, the production was multiplied. Since the first aircraft until 1919, Germany had built 115 units.

Besides the mission of the airships was patrolling and escorting near the coasts. He also served as the organizer center for the convoys of ships, and used for naval search in rescue operations. They also were used for aerial photography, installation and cleaning of naval mines, transport of paratroops and personnel transport. Attacked the submarine with depth charges and, less frequently, with other weapons on board. They could compete with the low speed of the submarine, and bomb to destruction.

On the other hand, submerged submarines had no way to detect the approach of an airship, while these could see them from above.

In 1928, one dirigible of the famous Ferdinand von Zeppelin, made the most famous crossing of all ages. It was the Graf Zeppelin. It had more than one hundred thousand cubic meters of volume. This aircraft was based on the idea of his inventor, but his death did not let him build. The first Zeppelin moved 11,300 cubic meters and it had a pair of engines. It had exactly 105,000 meters and engines of 2,700 horsepower.

In the early days of airships, the most used gas was hydrogen, while in the United States used helium. Until 1950 they continued using hydrogen in the world for several reasons: lower density than helium, the difficulty of getting it outside from North America (the only producer) and also for economic reasons.

In 1937, the German dirigible Hindenburg caught fire while attempt to land at Lakehurst, New Jersey, after a long transatlantic voyage. 36 people died of the 97 people aboard. Although the causes of its destruction have never been clear, it is believed that it was an accident due to a strange cluster of circumstances, including the bad weather of that day, some unfortunate decisions of the crew and a discharge of electricity from the clouds, near a small hydrogen leak.

The Hinderbung was once the largest rigid airship built. It was made of duralumin; measuring 245 meters long and 16 bags of hydrogen inside were able to raise the aircraft by 200,000 cubic meters of gas inside. Its speed was 135 mph, thanks to four powerful diesel engines.

Hydrogen is extremely flammable, a feature that caused the Hindenburg disaster and other accidents. The lifting provided by the hydrogen is only 8% higher than helium. Over time, the balance between cost and safety has ended in the usage of helium.

Finally the idea of the zeppelin was changed. They were terrible weapons but inaccurate. Darkness, high altitudes and clouds reduced the success of those missions.

By that time and thanks to Von Zeppelin, Zeppelin had become a highly-developed kind of transport. Consequently, other variations of dirigible were created. They were designed in the same way as zeppelins but with some differences [2].

1.2.1) Different kinds of airships [3]

Rigid (Zeppelin): Characterized by having a rigid structure that holds multiple pressurized gas balloons. It has a keel frame inside the envelope. They always conserve the same shape which do not depends on the internal gas pressure. Its usage is mostly commercial.

Figure 1. Zeppelin

Non-rigid airships (blimps): Characterized by its shape depends directly on the internal gas pressure. In general, they are known as "blimps" and have smaller size and weight than rigid airships. There are indoors and outdoors models. Commonly they are used for entertainment, advertising and scientific explorations.

Figure 2. Blimp

Semi-rigid airships: like blimps, they need internal pressure to keep their shape, but they usually have articulated keel frames situated along the bottom of the envelope to give suspension and reduce the pressure.

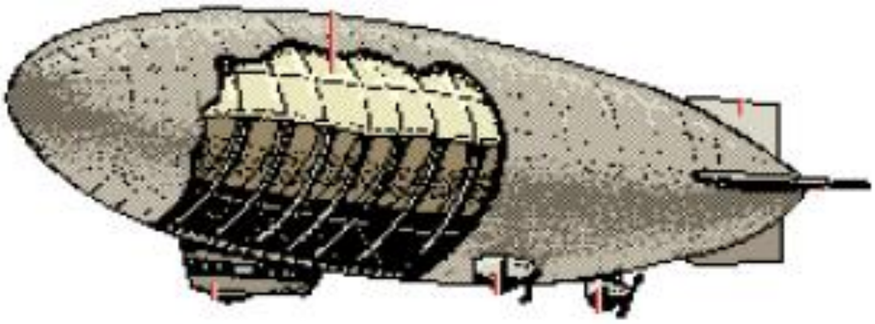


Figure 3. Semi-Rigid airship

Hybrid airships: Those prototypes that combine features of several aircrafts with different technologies.

They are not very common and are not produced with often.

Figure 4. Hybrid Airship

1.2.2) Technology selected

The blimp is the most economically efficient kind of dirigible, where low cargo volumes are handled, with routes between closed regions and preferably with no prior infrastructure like other kinds of transport. This research is the result of a comparative economical analysis about different kinds of dirigibles and other kinds of transport like planes.[4]

This research took into account the cost of the main component of the dirigible: the membrane, the ballonets, the engines, and the lifting gas. These components are proportional to the volume of the dirigible, which depends on the weight to hold as well.

As it was expected, the cost for building a plane it was the most expensive. Besides, for rigid and semi-rigid airships, the weight of the structure lead to the increment of the volume, without a significance of more payloads allowed. So, those kinds of airships were considered expensive and as a conclusion, blimps were the most feasible for this project.

The most important applications for blimps include freight and passenger transport, eco-tourism, advertising, surveillance, communications and mobile ship.

As aircrafts fly in low-altitudes, they do not have to face problems of the aircraft at high altitudes, which make them require less energy and power. Furthermore, they will be able to fly in any weather.

Comparing to the airplanes, a blimp have a lot of advantages:[5]

-They can carry heavy loads.

-Any engine failure is less critical than in an airplane.

-Can land almost anywhere without requiring significant infrastructure

-Greater autonomy

-Silent flight

-Less pollution

-Economical transportation.

-Excellent maneuverability

- It could help the development of remote and disconnected areas, where the transport is completely inefficient.

-The blimp fulfills all the requirements to be the most efficient kind of transport. Building an airship is the first step to master the most important technological aspects and being able to propose new ideas and improvements, to adapt to our world.

1.3) Aim

The idea of this project consists of a solar blimp. This purpose is based on covering the surface of the blimp with solar cells. Solar power will be supplied through the plates that surround its surface. This energy might generate the necessary energy to move the airship. Solar energy should power the airship during the daylights hours. This blimp will be used for recording videos and taking photographs from the air. Video-camera equipment will be connected to the bottom of the airship. They will stand hanging a few meters under the blimp.

If the solar blimp experienced a great acceptance, probably, it would be developed in another way for more important targets such as: aid humanitarian, transporting people, carrying doctors, foods, emergency equipment and other supplies, airships can fly to disaster areas and land directly where help is needed.

2. OBJECTIVES

The objectives enumerated below, show all the issues that are going to be studied and developed during the research of this project.

1. Design.

Establish the most important dimensions of the blimp, length, width and volume. Look into the most suitable shape for the membrane taking into account the aerodynamic.

2. Gas.

The lifting gas must be chosen. Hydrogen is the lightest gas, but due to its flammability is forbidden, so another light gas will be selected, considering its price, weight and availability.

3. Materials for the membrane.

Take the most suitable material for the membrane. It might be necessary to look into the different materials, their characteristics such as: resistance and price

4. Video-camera equipment.

It will be necessary to know the characteristic of the video-camera equipment, with its different parts and components and calculate the total weight.

5. Power.

Estimate the power needed to move the dirigible. It would be necessary to use software to determinate this value.

6. Kind of solar cells.

A survey of the different types of solar cells will be done. Their characteristics will be looked into, such as: their dimensions, weight, availability, efficiency, performance, manufacturers, prices…

7. Extensions of solar cells allocated.

Knowing the area of the membrane, it will be calculated the extension of solar cells that could be allocated.

8. Distribution of the solar cells.

The aerodynamic of the blimp will depend on the shape of the dirigible, but for generating as much energy as possible, solar panels must be inclined some degrees. The problem to deal is to choose the best way to supplied as much solar energy, without breaking the aerodynamic of the blimp.

9. Rest of elements of the solar installation

Enumerate and select the rest of devices as batteries, inverters of which the solar system consists.

10. Design the path of the flight

Choose a geographic point where the flight will take place. Design for each moment where will be the dirigible saying the latitude, the longitude and the altitude. Besides, take the weather and geographic conditions for this region.

11. Testing.

Choose suitable software and install in the pc. It will be necessary to manage it and after it simulate the different conditions (longitude, altitude) where the dirigible will be. Then, the software will calculate how much power is possible to get through the solar cells that surround the surface of the dirigible.

12. Conclusions

Feasibility.

3. LITERATURE REVIEW

Before starting this project it was necessary to do an exhaustive research about the theoretical aspects that concern this project.

Here are some of the most important aspects that have been considered:

3.1) Theoretical concepts of the blimp

Here there is a blimp for a well-known company (Goodyear) [6] and the different parts have been enumerated:

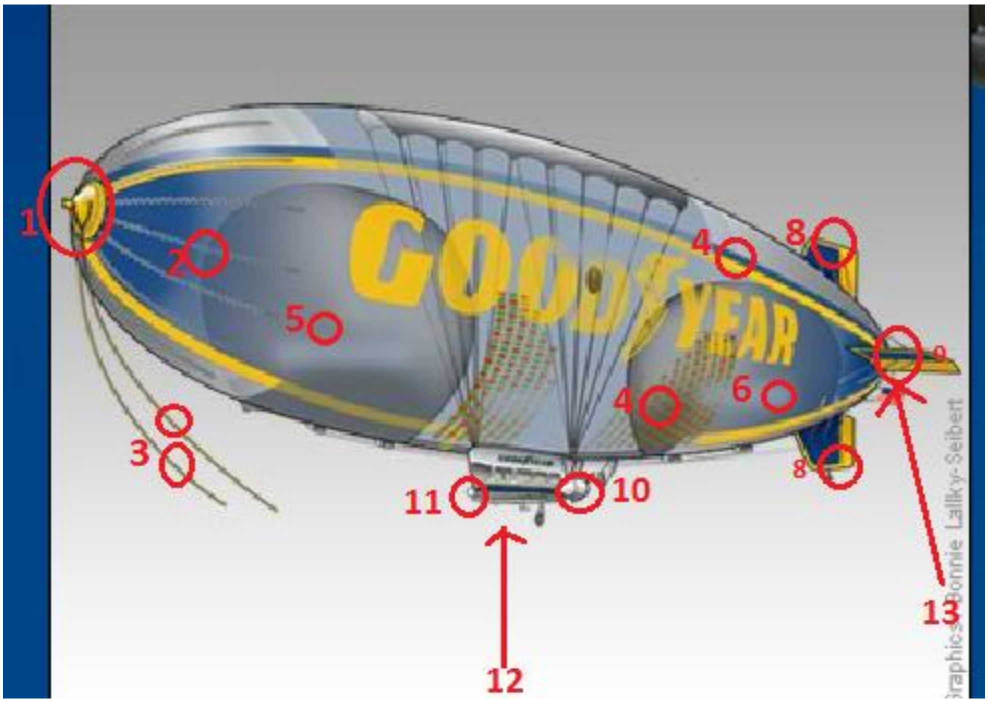


Figure 5.Goodyear Blimp

1) **Nose cone:** One of the few external rigid points of the blimp membrane. It holds the battens.

2) Nose cone battens: Battens are like fingers that start at the nose cone. They help the nose to distribute the stress throughout the blimp when it is connected to the mooring mast. Without the battens, the nose could be easily damaged.

3) Mooring lines: There are two ropes hanging from the nose cone of the dirigible. They fly free and people can control the movements of the blimp with these ropes during the landings and takeoffs.

4) Membrane: It is the biggest component of the blimp; it keeps the lift gas inside, and thanks to it, Archimede´s principle occurs.

5) Forward ballonets: (Air bag inside membrane) When the blimp rises and descends, the lift gas inside the membrane contracts and expands. The forward ballonet and aft ballonets compensate by letting air out through the valves as the ship rises and letting air in through the scoops when the ship descends.

6) Aft Ballonet: It works in conjunction with the other kinds of ballonets helping the blimp to support the typical movements of the dirigible (ups and downs)

7) Lift gas valve: this valve is situated on the exterior of the membrane. This does not allow the gas to reach some maximum pressures inside that could break the envelope.

8) Two rudders: One it is situated in front of the blimp and the other in the bottom of the dirigible.

They are used to let the blimp do the right and left movements.

9) Elevator: They are similar to rudders, but they are in charge of up and down movements.

10) Engines: They provide the dirigible´s thrust. They are able to fly at the speeds of 50 m.p.h.

11) Weather radar: It gives to the pilot the information about the weather conditions.

12) Gondola: There is the cabin for the crew.

13) Tail wheel: A tiny wheel located on the bottom of the dirigible.

14) Boost tab: It is a small movable part of the lower rudder that gives a passive assist to the main rudder movement.

**In this project all these details showed have not be taken into account, because they would have complicated the calculations seriously.*

3.2) Design of the blimp: theoretical aspects.

3.2.1 Membrane

The design of the membrane is in most cases, a slight variation of the ellipsoidal geometry, due to its good aerodynamic performance in the displacement. This geometry minimizes the frictional force with the air and optimizes the usage of the momentum generated by the engines.[7]

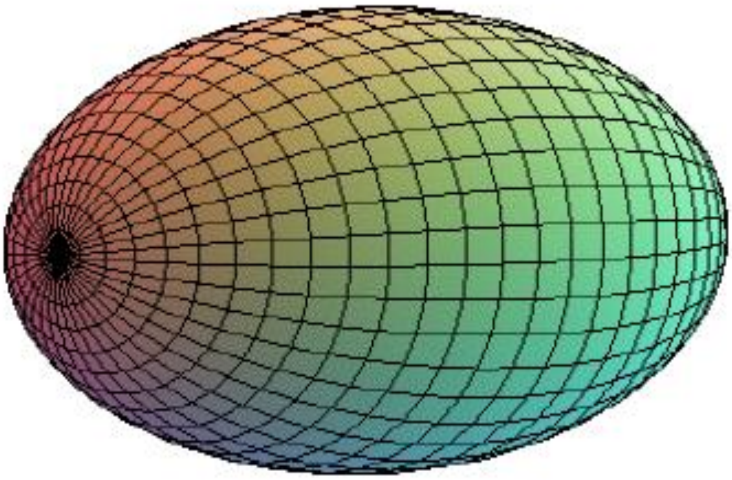


Figure 6. Ellipsoidal shape

There is a geometric aspect referred to the design costs and a direct relation to the value of "λ".This parameter is an aerodynamic indicator of the membrane and this should be close to 5.5 to ensure good horizontal scrolling.

However, the value of λ that minimizes the construction costs is 1. Then, λ= 1 corresponds to a perfect spherical shape, which maximizes the internal volume with the least possible area.

This implies a reduction in the cost of the membrane material. However, the sphere or similar geometries have high friction with the air, which causes more energy consumption.

In addition, the gondola design must be such that minimizes the aircraft weight and contributes to its aerodynamic. The dimensions of it are determined by the type of application depending on the usage of the airship. For instance, if it is a model for the transport of cargo, the gondola must have space to store, and a control cabin for the crew. In the case of airships intended for human transportation, there will be rooms for passengers, bathrooms, control cabin for pilots and other rooms. Finally, in the case of gondola that corresponds to a small-scale blimp for science investigation, the gondola will have a reduced space just to keep the required equipment.[8]

Figure 7.Gondola

It is necessary to remark that in this project it won´t be deal the design of the gondola because the most important aspects of this project only involves the part referred to the “balloon of the airship”.

3.2.2) Physic of the propellers.

A propeller is a mechanical device or rotary wing which is able to produce a parallel thrust to its axis of rotation at full motion.

Structural design consists of several blades or paddles, which are arranged at a specific angle (attack angle) respect to the rotation plane. [9]

3.2.3) Aerostatic equilibrium

The operation of an airship is based on Archimedes´ principle of buoyancy: "an object will experience an upward force equal to the weight of the displaced volume of the body of the object".

Combining it with the aerostatic equilibrium principle appears, the following equation:

$$(Vg*(\rho o-\rho g-)*g) + th = Ms * g$$

Vg: volume of gas

ρo: density of the air at the initial height

ρg: density of the lifting gas at the initial height.

g: gravity acceleration

th: vertical component of buoyancy

Ms: airship mass at taking of regardless of the air/gas mass.

The expression given above generates calculations with an acceptable degree of accuracy. However, this equation does not contemplate variations of temperature and pressure with the change of the body height.

However, focusing on this prototype designed for reduced distance trips, where thermal and barometric variations are insignificant, it is justified the usage of this equation to calculate the dimensions of the vehicle, as it is going to be showed in the following pages. [10]

3.2.4) Bernoulli theorem.

"The internal pressure of a fluid (liquid or gas) decreases at the same time that its speed increases ". This implies that the sum of the pressure and velocity remains constant all the time. This law is applicable in the horizontal movement of the airship: with higher speed, the relative velocity of the air particles that surround the dirigible will be greater and therefore, there will be lower pressure. [11]

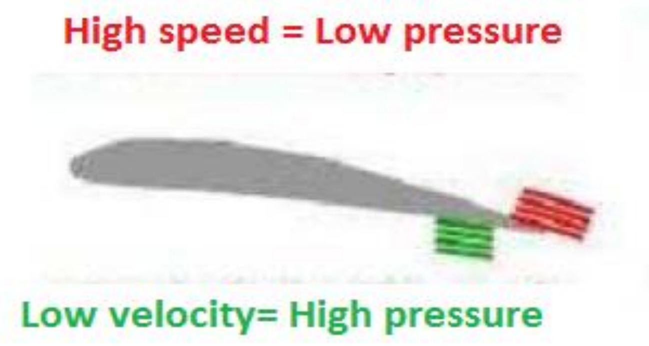


Figure 8. Bernoulli equation

3.2.5) Ventury effect.

Ventury experimentally reached the conclusion that by decreasing the cross sectional area, where fluid particles circulate, these fact will increase their speed. This effect is considered in the design of the aerodynamic silhouette of the wings and membrane used in the airships.[12]

3.2.6) Newton´s third law.

“For every action there is an equal and opposite reaction”

As a whole with the last two theorems, this law can explain the reason about air vehicles are allowed to fly.[13]

3.2.7) Lift and resistance.

As a result of the displacement of the dirigible through the air and the difference of pressures, a resultant aerodynamic strength, acts in the membrane and in the wings. This strength has two components:

One is perpendicular to the wind that comes into contact with the membrane. This component is the lifting force. The other is parallel to this wind, the resistance.

Assuming that the membrane and the wings of the dirigible have aerodynamic shapes, the components of the resultant force and the center of pressure vary depending on the angle at which the surface cuts the wind (attack angle). As much bigger is the inclination of the attack angle, greater will be the buoyancy (while not exceeds the critical attack angle).[14]

Therefore, airships have a number of mechanisms allowing them to change the position of its aerodynamic surfaces according to the flight requirements.

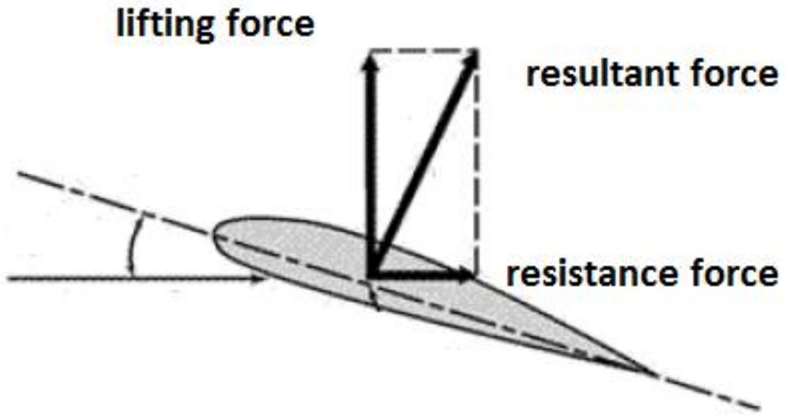


Figure 9.Resultant Force

3.3) Solar cells

3.3.1) Introduction

A solar panel is a module that uses the energy of solar radiation. The term includes the thermal solar panels used to produce hot water (usually domestic) and photovoltaic panels used to generate electricity (pv modules). This project will deal with this last kind of panels.

Photovoltaic panels are composed of numerous cells that convert light into electricity. The cells are sometimes called photovoltaic cells or solar cells. These cells depend on the light effect that produces positive and negative charges in two different types of semiconductor, and therefore, it is set up an electric field capable of generating current.

Photovoltaic panels are not only used to produce energy that can power a grid land but also they are used widely in electric vehicles, solar boats.

The yield of a solar cell is measured by the efficiency of converting sunlight into electricity. A solar cell does not convert all the sunlight projected on it, just a small amount of light captured. The current generation provides performance only from 12 to 15%. However, numerous researches have improved the current yield of each cell.
The new generation of cells has a yield of 20%, even some prototypes have 30%. Therefore it is very likely that the yield increases with time.

The amount of energy produced by a solar panel is measured in watts and is calculated by multiplying the electrical current and the voltage. [15]

3.3.2) History of the pv modules.

Although the efficient solar cells have only been available since the mid-50's, the scientific investigation of photovoltaic effect started in 1839 when the French scientist, Antonie Becquerel, discovered that an electric current could be produced by projecting and shining light on certain chemical solutions.

That effect was first observed in a solid material (selenium) in 1877. This material was used for many years for the photometers, requiring very small amounts of energy. The first solar cell was created in 1883 by Charles Fritts, who took a piece of semiconductor of selenium and covered with gold. This device presented an efficiency of 1%. A deeper understanding of those scientific principles was provided by Albert Einstein in 1905 and by Schottky in 1930. That study was necessary before efficient solar cells could be launched. A silicon solar cell that converted 6% of the sunlight that impinged on it into electricity was developed by Chapin, Pearson and Fuller in 1954, and that was the kind of cell used in specialized applications such as orbiting satellites in 1958.[16]

3.3.3) A simple explanation about how pv modules work

The operation of a solar pv module is based on the photovoltaic principle that was discovered by the physicist French Antoine Becquerel in 1839. After numerous experiments, he finds that some materials produce a small amount of electricity when they were exposed to the light. Sunlight consists of particles called photons. Some of the photons coming from the solar radiation, impact on the first plate of the panel surface, penetrating into it and being absorbed by the semiconductor materials such as silicon or gallium arsenide.

When photons meet a semiconductor material, some of them will be absorbed by the body, rather than reflected or passed through the body. If a photon is absorbed, its energy is transmitted to an electron in an atom of the cell, causing the displacement of it.

The electrons, atomic sub-particles that form part of the exterior of the atoms, and stayed in energy orbits, are hit by photons (interaction between both), releasing the electrons. This fact allows them to flow through the material and produce electricity. The positive charges created when the atoms lose their electrons, are called “holes” and flow in the opposite direction of the electrons in the solar panel. This hole attracts another electron of another near atom that will create a hole to be filled again with the new electron atom. This procedure is repeated one billion of times becoming an electrical current.

A chain of pv modules converts solar energy (radiation energy and dependent on the frequency of the photons) in a given particular amount of direct current, also called a DC which corresponds to a type of electrical current described as a loads of charges moving in one and unique direction through a circuit. Electrons move from lower potentials to the highest.
Optionally:
1. DC is taken to an inverter that converts direct current into alternating current (AC) (type of electrical power available in any home) of 120 or 240 volts.
2. AC power enters the home's electrical panel.
3. The electricity is distributed, with often, to the distribution line of lighting devices in the

house, because they do not consume too much energy, and are the most suitable to work properly with the current generated by the panel. [17]

3.3.4) Structure of the pv module.

A solar panel consists of several plates:

• Glass - layer of protection against the elements.

• Transparent adhesive - adhesive layer which joins the glass layer with the plate.

• Anti reflection coating - layer that prevents the reflection of sunlight for a maximum absorption of the energy by the cell.

• Front Contact - transmits electrical current.

• N-type Semiconductor - thin layer of silicon doped with phosphorus.

• P-type Semiconductor - thin layer of silicon doped with boron.

• Rear contact - transmits the electrical current.[18]

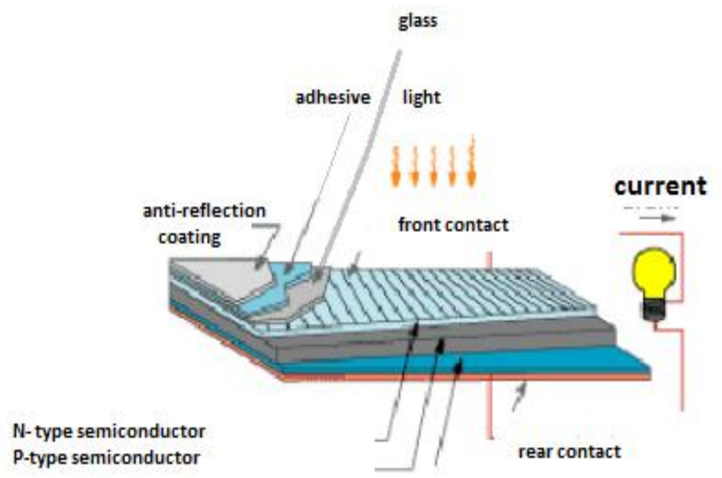


Figure 10.Pv module

3.3.5) Different kinds of solar cells [19]:

Nowadays, there are three different types of solar cells available in the stock market.

1) **Monocrystalline silicon solar cells :**

Monocrystalline silicon solar cells come from a single silicon crystal extracted from a bath of silicon molten. During the manufacturing process of the cells, the silicon wafers obtained from this single cylindrical glass is treated to convert them into Monocrystalline silicon solar cells.

In comparison to the multicrystalline silicon cells, the manufacture costs of monocrystalline are more complex and expensive. Their efficiency is 12% to 15% and higher than multicrystalline silicon cells. They have a lifetime of 20 to 25 years and are generally of blue uniform color.

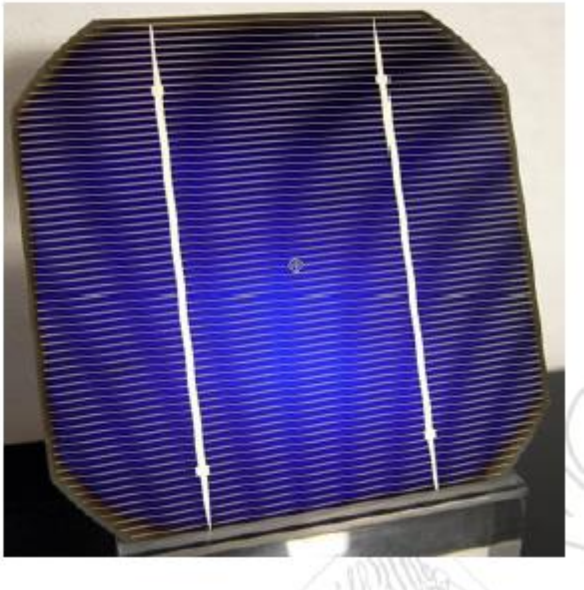


Figure 11.Monocrystalline cell

2) Multicrystalline silicon solar cells:

Multicrystalline silicon solar cells are manufactured from solar silicon molten in blocks. From this process result relatively large crystals with intercrystalline limits clearly visible. First, from the blocks of silicon, are taken rectangular blocks, which silicon wafers are cut. Subsequently, they will be processed for the manufacture of multicrystalline solar cells. The yield is 11% to 13%. They have a blue color but not uniform.

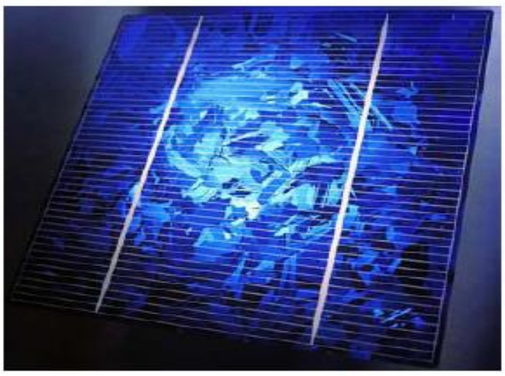


Figure 12.Polycristalline cell

3) Amorphous silicon solar cells.

Thin film solar cells also called thin film photovoltaic cells, belong to this section. They are fabricated by depositing one or more thin layers (thin film) on a substrate of PV material. The range of thickness of this layer varies from a few nanometers to tens of micrometers. Therefore, they are the lightest solar cells available all over the range of offers.

The main difference between the others, lies in they don´t follow a whole crystalline structure.

Besides, they take advantage the diffused light, therefore they are capable to produce electricity with low levels of irradiance (e.g.:in a cloudy day). In addition, thin film technology is characterized for having a slight involvement of the high temperatures in the efficiency of the cells.

Another great advantage of thin film cells are their great adaptability. As they are printed on substrates, some of this kind of solar cells can be used as curved and flexible cells. Due to the nature of amorphous silicon, it is allowed to curve panels or also applied to corners and inaccessible places. The other technologies (monocrystalline and polycristalline) consist of rigid structure and there is no choice for these new applications.

Taking into account that the weight (supported from the blimp) and the adaptation of the solar cells (to contribute to the aerodynamical shape), were two important aspects to consider, this last kind of solar cells were chosen to cover the surface of the blimp.

3.3.5*) Different types[20]

Many different photovoltaic materials are deposited with various deposition methods on a variety of substrates. Thin-film solar cells are categorized basing on the photovoltaic material used:

-Amorphous silicon (a-Si):

This kind of cells has a very light weight and can be flexible. "a-Si" cells can be deposited in substrates at low temperatures. That means that the substrates not only can be glass, but also could be plastic, leading them be up to roll-to roll technique. After being deposited, a-Si can be doped with p-type or n-type layers and form electronic devices. Once produced, this material can be cut into different sizes.

The characteristic of a-Si about printed it easily in a variety of materials; put its focus on the low prices and on the light weight of the deposited materials.

-<u>Cadmium Telluride (CdTe):</u>

On the one hand, CdTe solar cells are the unique thin film photovoltaic technology that exceeds crystalline silicon modules in cheapness. CdTe has experimented good acceptance and nowadays constitutes the second most used solar cell material in the world. The first is still silicon. The best efficiency registered for CdTe cells was about 16.5%.

The major advantage of this kind of cells was the low price to manufacture due to Cadmium is abundant and the process of manufacture was easy.

On the other hand, CdTe solar cells were not adaptable to flexible substrates.

-<u>Dye-sensitized solar cell (DSC) :</u>

Dye-sensitized solar cells are the latest-launched cells based on innovative technology. They are able to produce electricity using the sunlight energy absorbed by the dye. Variations in the irradiance angle, at which light is projected in the plane of the cells have minimal effect on efficiency because they take advantage of the diffuse light. In addition they can be printed in flexible substrates. These solar cells can be printed in low-cost substrates with an easy manufacturing process.

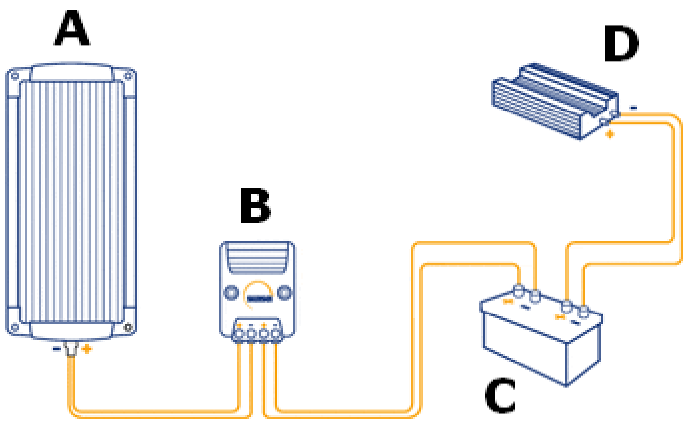
However the efficiency of this kind of solar cells is about 3% and it usage is limited to small devices.

-<u>Copper indium gallium selenide (CIS or CIGS):</u>

CIGS solar cells have several features which make them a valuable PV material. This kind of solar cells had a greater efficiency than a-Si solar cells. They had a stable performance for more than 20 years. They are able to be printed in flexible and semi flexible substrates. In comparison to a-Si solar cells, the costs of CIGS manufacturing process were lower than in a-Si processes due to the tools required were cheaper.

3.3.6) Sample of a solar installation.

Generally, a complete solar system consists of several pv modules, some batteries, a regulator and often an inverter.



A) PV MODULES

B) REGULATOR

C) BATTERY

D) INVERTER

Figure 13.Installation

The pv module (A) generates direct current (DC) that is stored in batteries (C). If the luminosity increases, solar cells will produce more energy, and this fact could damage the battery with an excessive tension. The regulator (B) governs this load to the battery, reducing the risks of overload.

Then, the inverter(D) converts the direct current (DC) into alternating current (AC) to use it for power appliances or for the electrical grid.

4 DESIGN PROCESS

4.1) Determination of the volume of a dirigible.

According to the conclusions of the books read [21], is known that reducing the cost of the airship structure, its comparative advantages over other kind of transport would increase.

This chapter shows the equations that define the size of any airship. The calculation is done here is not the definitive design of the blimp, but it shows the theory needed for design.

As it was explained before, the basic operating principle of an airship comes from the aerostatic equilibrium equation or "Archimedes buoyancy principle". For a first estimation it can be written as:

$$Vg \times (\rho o - \rho g) \times g) + th = Ms \times g \qquad (1)$$

Vg: volume of gas

ρo: density of the air at the initial height

ρg: density of the lifting gas at the initial height.

g: gravity acceleration constant.

th: vertical component of buoyancy

Ms: airship mass at taking of regardless of the air/gas mass.

4.1.1) Volume equation.

To determine the volume of the membrane in a blimp, firstly it will be defined the percentage of volume occupied by the lifting gas (without the ballonets total volume). This calculation is based on the maximum height during the flight and on the maximum increment of temperature through the flight:

$$DVg = \frac{Vg}{V} = \frac{1 - Kh}{1 - Kt} \qquad (2)$$

Vg: volume of gas within the blimp

V: Volume total of the dirigible

Kh: height change rate.

Kt: temperature change rate.

$$Kt = \frac{DT}{T} \qquad (3)$$

DT: is the variation of the temperature during the flight.

T: average of temperature during the flight.

$$Kh = 1 - \frac{\rho h \times To}{\rho o \times Th} \qquad (4)$$

ρh: density at "h" height

Th: temperature at "h" height

ρo: density at taking off(initial conditions)

To: temperature at taking off (initial conditions)

*"h" is the height of the cruising altitude referred to such altitude where airships are in horizontal trajectory most of the time during the flight.

To determinate the volume necessary it will be used the equation 1 (Archimede´s principle):

$$Vg \times (\rho o - \rho g) \times g) + th = Ms \times g \qquad (1)$$

The mass of the dirigible is:

$$Ms = Mk + Mpl = (Mconst + Mvar) + Mpl \qquad (5)$$

Mpl: mass of payload of the dirigible (passengers, load and equipments. In this case, the camera equipment.

Mk: sum of masses referred to the systems of the dirigible. Some of them do not vary, when the volume of the dirigible change (Mconst), and there are others than depend on this change

(Mvar). Mconst can be defined with precision during the design phase. However, Mvar depends on different factors: ballonets, strengthening front, stringing and empennage.

<u>4.1.2) Mass of the membrane.</u>

The mass of the membrane depends on its area, Aen, which this last also depends on the volume of the blimp:

$$Men = k \times \gamma\mu \times \mathbf{Aen} \qquad (6)$$

k: from 1.2 to 1.5

γμ: mass of 1$\mathbf{m^2}$ of area of the membrane's material

"Aen" can be defined as the following way:

$$Aen = 2.55 \times \left(\frac{4 \cdot \lambda^2}{\square \frac{\square}{\square}}\right)^{1/6} + 1.23 \times \left(\left[\frac{\square \cdot \lambda \cdot \square}{4}\right]\right)^{1/3} \times V^{2/3}$$

(7)

Aerodinamic parameter: $\lambda = \frac{L}{D}$ (8)

Rate of full of the membrane $\square = \frac{V}{VL}$ (9)

V: volume of membrane

VL: volume of the cylinder which contains the membrane

In the study of the airship a generic value of 2/3 is assumed. Variations around this value do not affect in the final result.

With this development, Men can be established in a new form:

$$Men = Ken * V^{\frac{2}{3}} \qquad (10)$$

4.1.3) Mass of the ballonets.

The shape of the airship ballonets have been defined as a part of the total area:

$$Mb = k1 \times k2 \times \gamma\mu \times \mathbf{Aen} \qquad (11)$$

k1: rate referred to the increment of mass due to the unions from 1.2 to 1.3

k2: the quotient between the area of the ballonets and the area of the membrane

γμ: is the unit mass of membrane´s material (same as the ballonets)

If: $$Kb = k1 \times k2 \times ken \rightarrow Mb = kb \times V^{2/3} \qquad (12)$$

The membrane will not have ballonets indoors. The reason for this determination is that has been tried to minimize the final dimensions of the blimp. Therefore, it led maximize the utilization of the interior volume of the membrane.

4.1.4) Strengthening front mass, stringing and empennage.

- Strengthening front mass: Mne

$$Mne = kne \times V^{2/3} \qquad (13)$$

kne between 0.1 -0.15(typical values)

-Mass of stringing: Mt

$$Mt = kt \times V^{2/3} \qquad (14)$$

kt between 0.18-0.22 (typical values)

-Mass of empennage: Mem

$$Mem = kem \times V^{2/3} \qquad (15)$$

$$kem = \gamma\mu \times \Delta em \qquad (16)$$

$\gamma\mu$ is the mass per unit of area of the dirigible

ΔAem: is the relative area of the empennage. It can be defined as:

$$\Delta Aem = \frac{Aem}{V^{2/3}} \qquad (17)$$

This should ensure the stability of the airship during the flight and it takes values between 0.3 and 0.4.

4.1.5) Equation of the volume.

From the analysis of the masses it can be concluded that:

$$Mvar = Men + Mne + Mt + Mem \qquad (18)$$

This is equivalent to say

$$Mvar = K \times V^{2/3} \qquad (19)$$

where K is the coefficient referred to all the masses, and is the sum of all coefficients of the components. The aerostatic equation now can be written as:

$$DVg \times (\rho air - \rho gas) \times g \times V) - (K \times g \times V\uparrow(2/3)) - ((Mconst + Mpayload) \times g) + th = 0 \qquad (20)$$

DVg: proportion of the volume of the gas within the total volume, depending on the pressure and the height.

ρa: air density.

ρg: density of the lifting gas.

g: gravity acceleration constant.

V: blimp volume, it is the unknown factor.

K: masses rate K=Ken+ Kb+ Kne+ Kt+ Kem.

Mcte: mass of the components that do not vary when the volume of the dirigible changes.

Mpl: mass of the payload of the blimp.

Th: vertical component of buoyancy.

4.1.6) λ factor:

λ rate is a dimensionless factor which comes from the quotient between L and D

$$\lambda = \frac{L}{D} \qquad (8)$$

Having a look around the different kinds of prototypes of blimps all over the world with similar dimensions, the most common value assumed for the λ was around 2.5-3. Comparing this value to 5.5 it is clear that there is a big difference between them. The main reason was based on the economic purpose of the manufacturer: get as much money, with the minimum investment.

The geometric shape that gets the maximum volume inside is the sphere. Assuming a low value for λ, the area of the membrane will be reduced as well. Taking into account that the cost of the membrane is one of the parameters that affects more the price of the dirigible, the usage of a low value for λ let manufacturers compete in the world market with high benefits.

Consequently appears the disadvantage that it was needed more power to supply the additional buoyancy due to the increment of drag.

For big commercial blimps, fuel price results more important and the λ rate values are closed to the optimal value 5.5.

In the current design, λ rate is assumed as 5.5, considering that it is the optimal value focusing on `the study of Ivchenko.´[22]

4.2) Application of the equation in the design.

The blimp that is wanted to be built has some simplifications around the main equation, which emerge from analyzing the input variables.

4.2.1) Input variables.

The input variables are divided into two different groups: those related to the environment which are atmospheric properties that vary with the flight height (such as pressure and temperature). On the other hand, the variables referred to the airship construction.

To set environmental variables, Seville (Spain) has chosen as the city where the blimp will fly.

The flying height will be one that allows a safe control of the dirigible. In this region of Spain, the highest building is 174 meters tall, so assuming 300 meters for the height might be enough. The flight direction will be set from the West to the East and from the East to the west in the return. The airship will belong to the family of non-rigid or Blimps, since its design is the optimal for this type of aircraft. The material for the membrane chosen should be lightweight to minimize the resulting volume. The small diameter of the ellipsoid will be allocated in a point which corresponds to the 40 % of the total length of the blimp.[23]

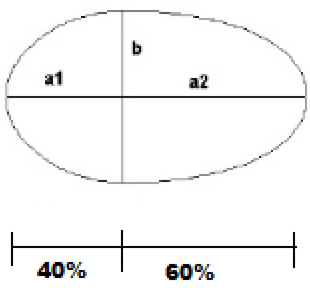


Figure 14.Silhouette

The lifting gas will be Helium. Actually the lightest gas is Hydrogen, but after "Heindinburg accident in 1937", the usage of Hydrogen as a lifting gas is forbidden because it is flammable. So Helium is the second lightest gas.

The initials variables taken for the design are shown in the following tables.

INPUT VARIABLES

Environmental variables

Initial height (m)	10
Maximum height (m)	300
Initial atmospheric pressure(Pa)	101700
Atmospheric pressure during the flight (Pa)	97700.32
Initial temperature(ºC)	18.6
Temperature during the flight (ºC)	16.8

Table 1.Enviromental variables

Blimp construction variables.

Helium density Kg/m^3	0.13
Air density Kg/m^3	0.86
λ factor	5.5
Filling up of membrane coefficient	0.67
Strengthening front coefficient	0.0
stringing coefficient	0.0
empennage coefficient	0.3
Unions coefficient	1.2
Membrane´s material density	0.1
Empennage density	0.5

Mass of Payload (kg)	1.5

Table2.Construction variables

It is necessary to emphasize that the design of the blimp was independent of the total weight of the solar cells. The blimp was designed separately and the aim of the project was based on analyzing the performance of the blimp, in terms of weight and energy.

4.2.2) Output variables.

The first term to calculate is DVG, or the fraction of gas floating in the total volume. As it has already stated, the DVg, or the fraction of gas within the volume flotation, depends on the variation of pressure and temperature reached during the flight. With higher flying altitude, the volume of the lifting gas will be less, allowing a volume of ballonets ensuring flight limits.

After doing some calculations, it has come to the conclusion that it is going to be supposed as 1, which means no ballonets.

Here there are the calculations to get DVg:

-City: Seville (South of Spain)

-Initial height: 10m

-Fly height/maximum height: the highest building in Seville is 178 m height, so with 200 m of maximum height it would be enough, but 300 meters of height will be assumed.

-Average temperature: 18.6 ºC

-Temperature during the flying: + 100 m height→ -0.6 ºC so: 18.6 – (0.6*3) =16.8 ºC

-Initial pressure: 101700 Pa

-Pressure during the flight: +10 m height→ -1 mm Hg

300 m = -30 mm Hg 760 mm of Hg-101325 Pa

30 mm of Hg - X X= 3999.67 Pa

So the pressure during the flight might be 97700.32 Pa

$$DVg = \frac{1 - Kh}{1 - kt} \qquad (21)$$

Where $Kt = \frac{DT}{T} = \frac{18.6ºC - 16.8ºC}{16.8} = 0.1071 \qquad (22)$

Where $Kh = 1 - \frac{ph * To}{ph * Th} = 1 - \frac{07700 * 10^3 * (273.15 + 18.6)}{101700 * 10^3 * (273.15 + 16.8)} = 0.0333$

(23)

$$DVg = \frac{1 - 0.033}{1 - 0.1071} = 1.06 \rightarrow 1. \qquad (21)$$

Once it was calculated, both equations were used to get the rest of results showed in the following table:

$$DVg \times (\rho air - \rho gas) \times g \times V) - (K \times g \times V^{\uparrow}(2/3)) - ((Mconst + Mpayload) \times g) + th = 0 \quad (20)$$

$$Aen = 2.55 \times \left(\frac{4 \cdot \lambda^2}{\square \frac{\square}{\square}}\right)^{1/6} + 1.23 \times \left([\frac{\square \cdot \lambda \cdot \square}{4}]\right)^{1/3} \times V^{2/3} \qquad (7)$$

Volume of the dirigible m^3	5.5
Area of the membrane m^2	19
Length m	6.8
Diameter m	1.24

Area of the cylinder m^2	26.48

Table3.Results

The most important result was" the area of the membrane", because it was necessary to know the available extension of membrane where solar cells will be allocated.

Furthermore, it was done a simulation using *Solid Works software* to check if the calculations were correct. This drawing was built basing on the ellipsoid silhouette (figure 11), with the length and the diameter obtained previously. Here it is shown the first approximation to the design of the blimp.

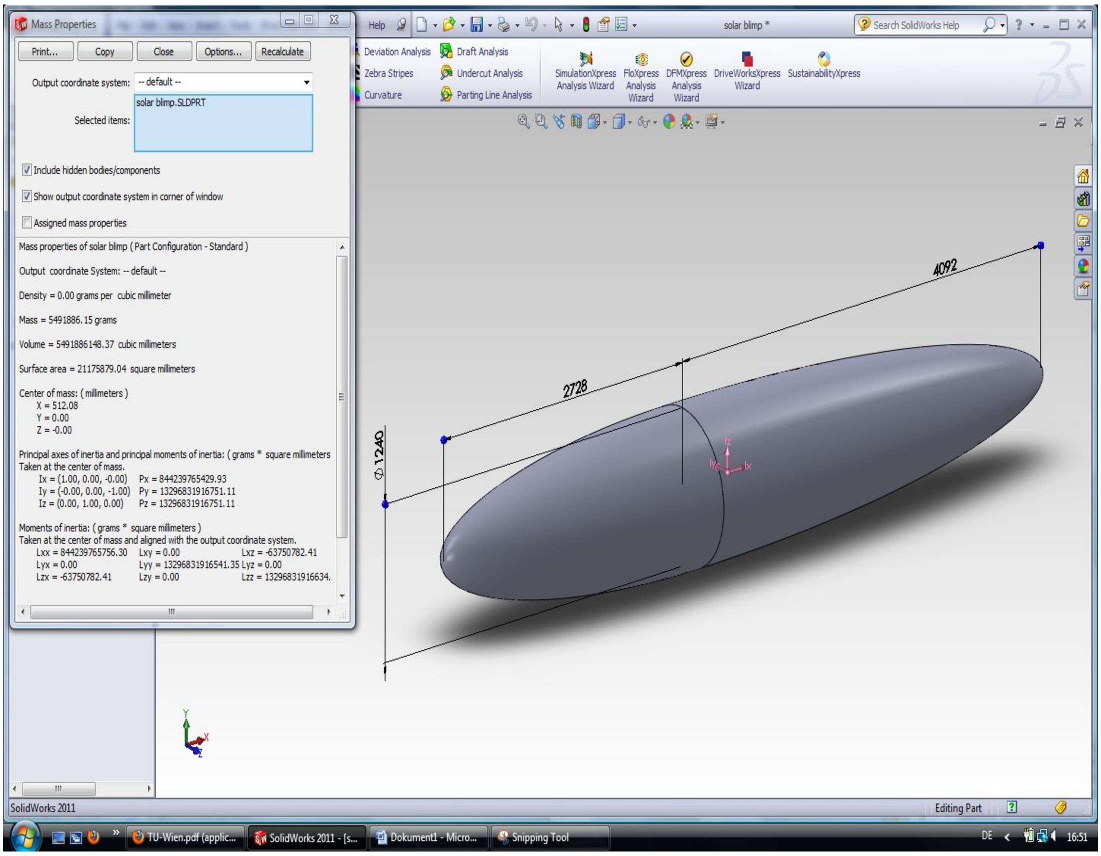


Figure 15.First design screen shot

The results obtained using the software, were very similar to those obtained with the calculations. Only the area of the membrane had varied but it was due to the equation number 7, was an accuracy estimation to get the actual value. It was considered that the software results were more reliable than the calculations, so here there are the final results that they were assumed:

Volume of the dirigible m^3	5.49
Area of the membrane m^2	21.17
Length m	6.8
Diameter m	1.24
Area of the cylinder m^2	26.54

Table4.Definitive results

4.3) Calculation of the bending moment

The center of buoyancy of the dirigible is the point where all the mass of the blimp can be allocated. It is easy to find if the outline of the membrane is considered as a revolution solid expressed as:

$$Y = f(x) \qquad (24)$$

Knowing that is an ellipsoid, the allocation of the centre of buoyancy is:

$$x = \frac{\square \int x \cdot y^2}{Vol} \qquad (25)$$

The center of the ellipse is situated at 40 % of the total length, so it is necessary to divide into two different outlines.For the first segment the ellipse will be:

$$l = \frac{x^2}{a1^2} + \frac{y^2}{b^2} \qquad (26)$$

$$y = \sqrt{b^2 - \frac{b^2 \cdot x^2}{a1^2}} \qquad (27)$$

For the second segment,the ellipse will be:

$$y = \sqrt{b^2 - \frac{b^2 \cdot x^2}{a2^2}} \qquad (28)$$

Here there are showed the dimensions used above:

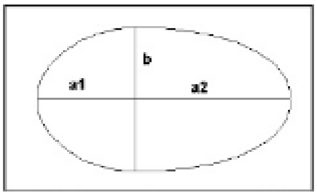


Figure 16.Silhouette

Volume is involved in the equation of the center of mass:

$$Vol = \square \int y^2 dx \qquad (29)$$

After replacing and solving, volume can be defined as:

$$Vol = \frac{2 \cdot \square \cdot b^2}{3} \times (a1 + a2) \qquad (30)$$

The center of buoyancy calculated with its equation and taking the origin in the center of the ellipse is:

$$\overline{x} = \frac{\square \cdot b^2 \cdot (a2^2 - a1^2)}{4 \cdot Vol} = \frac{3 \cdot (a2 - a1)}{8} \qquad (31)$$

Evaluating with the results obtained before:

Volume=5.49 cubic meters.

X center of buoyancy= 0.5115 meters.

The point (x=0.5115 m) corresponds to the maximum bending moment, and that is why is considered as the critical point requiring all the interest to analyze the stress of the membrane´s material.

Actually, within the centre of buoyancy, there are two important points: one lower and the other upper.

In the lower point, the bending moment will cause a maximum axial stress that could break the membrane due to go over the limit of flexibility of it. In the higher point, the bending moment will cause a compressive reaction that might try to lend the blimp and could generate a “knee”. The only way to sort out this problem is using the internal pressure of the lifting gas, because the membrane does not own stiffness to support it. [24]

Here there is a small diagram about the body of the blimp.

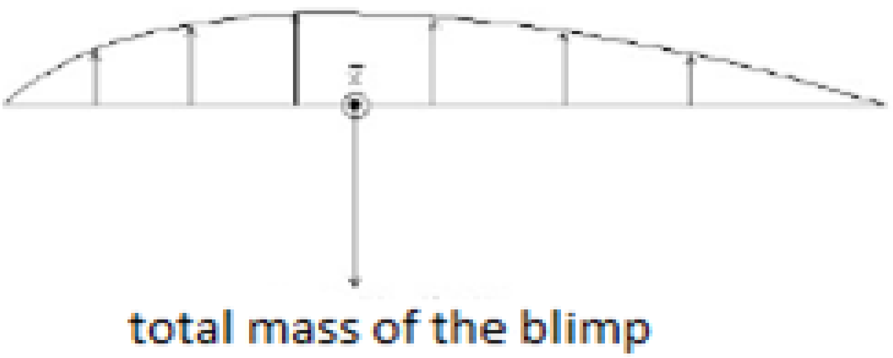


Figure 17.Body of the blimp

The following calculations have been done to solve the bending moment

$$M = -\int_{\bar{x}}^{a2} X \cdot dF \quad Lift \qquad (32)$$

$$M = \int_{\bar{x}}^{a2} [x * (\square] \rho air - \rho helio) \times g \times \square \times y^2 dx \qquad (33)$$

Finally:

$$M = \int_{\bar{x}}^{a2} [x * (] \quad \rho air - \rho helio) \times g \times \square \times (b^2 - (b^2 \times x^2)/ [a2]^2))dx$$
(34)

The solution using the previous conditions was:

Mx=35.08 N.m

4.3.1) Efforts

It is very important the effect of the internal pressure on the material of the envelope. Consequently, appears some stress along the tangential and radial directions. The longitudinal effort induced by the internal pressure can be expressed as:

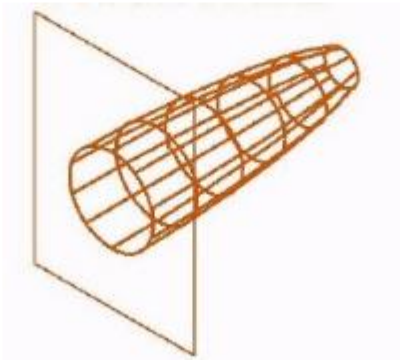


Figure 18.Longitudinal effort

$$\sigma l, pi = \frac{pi \times r}{2 \times t} \quad (35)$$

Where "r" is the ratio referred to the center of buoyancy, "t" is the thickness of the membrane and Pi is the internal pressure of the lifting gas.

In addition, the effect of the transversal effort induced by the internal pressure can be deduced establishing the equilibrium of strengths.

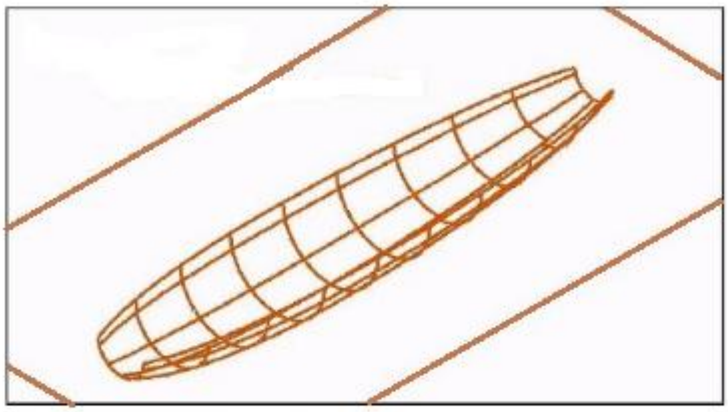


Figure 19.Transversal effort

That analysis resulted in the following equation:

$$\sigma T, Pi = \frac{Pi * b * (a1 + a2)}{t * (a1 + a2 + 2b + 2t)}$$

(36)

The effort induced by the bending moment causes lengthwise stress in the lower part; and compression stress in the higher part .The expression is [25]

$$\sigma l, flexion = \frac{M * r}{I} = \frac{M_{\bar{x}} * r}{\square * r^3 * t} \qquad (37)$$

4.3.2) Determination of the internal pressure

The most important variable studied along this previous analysis was the internal pressure. One approximation to its value can be simple made by setting the restriction to prevent the formation of a “double knee” in the top of the blimp. Mathematically, this restriction consists of limiting the resultant longitudinal effort only to stress along all the surface of the membrane:

$$\sigma l, Pi - \sigma l, flexion \geq \mathbf{0} \qquad (38)$$

$$\frac{Pi * r}{2 * t} - \frac{M_{\overline{x}} * r}{\boxtimes * r^{3} * t} \geq 0 \qquad (39)$$

The solution of this restriction involves clear the lower limit for the pressure of filling up the membrane. The result is:

$$Pi \geq \frac{2 * M_{\overline{x}}}{\boxtimes * r^{3}} \qquad (40)$$

With the previous conditions it was obtained:

Pi> 95.96 Pa

Actually it is a very low pressure. For the big dirigibles, the value of the internal pressure calculated using the last equation is about 1,5 KPa, very far-off the value that it is actually used in the commercial dirigibles.

For semi-rigid dirigibles and blimps (no rigid), the internal pressure is based on the difference of the propulsion pressure. The most typical value for the internal pressure of the lifting gas is commonly about 8 KPa.

4.3.3) Efforts due to the aerodynamic effects

This kind of efforts affects the membrane perpendicularly and there are basically differences of pressure which help the internal pressure to keep the shape of the dirigible. This kind of efforts, have not been taken in the analysis of the blimp but it is necessary to justify this fact taking into account the distribution of the pressure along the membrane.

The maximum pressure takes place at the tip and it is subjected to compression. Using Bernoulli equation its value is:

$$P2\text{-}P1 = \frac{1}{2} * p\ air * V^{2} \qquad (41)$$

The average of air in Seville is 9.28 Km/h, so ΔPressure=37.03 Pa.

It would be impossible that a deformity at the tip occurs due to the aerodynamic effects, when the dirigible is inflated at 8 KPa (value quite higher than the ΔPressure) . [25]

4.4) Materials for the membrane

This chapter shows the different alternatives considered for the selection of the membrane of the dirigible. The membrane and its materials form a fundamental part of the construction of the blimp. It is the most difficult part to build, because it is unique for each dirigible. It must be flexible to keep its ellipsoidal shape with the internal pressure of the lifting gas during the flight.

The membranes of the modern dirigibles are the element which have experimented a highly development in the last few years and that is why the blimp has rapidly gained in importance nowadays.

It was made a research about the most suitable materials.

The progress of the materials for the membrane has been important and recent. They fulfill all the requirements that need a material of the membrane of a dirigible.

-High resistance: the resistance influences how big can be the blimp.

-High resistance vs. the weight of the membrane to minimize the final weight of the blimp.

-Resistance to the environment, especially to the degradation due to the ultraviolet rays. This will let a long useful life reducing the costs of maintenance.

-High resistance in order to prevent tearing and let the blimp support knocks and impacts.

- Low permeability to helium, in order to minimize the leak of gas, which has immediate effect on operating costs.

-Laminates materials have all the best requirements and good characteristics of the common materials concentrated in a just single material.

4.4.1) Laminated material

A laminated material consists of three main layers, joined together by some adhesive: 1) Load and effort layer: The most suitable material for this layer is the polyester fibers, known as Dacron. Polyamides as Nylon and Aramid fibers such as Kevlar can also be used.

2) Gas retention layer: Another more time, the preferred material is polyester, but set in films, known as Mylar. Another successful material is the polyurethane with good acceptance and with the advantage of having environmental resistance.

3) Layer of environmental protection: The material used is known as Tedlar. It is lightweight in comparison to neoprene and polyurethane, the other two materials used as barrier against the environment.

The adhesive used to join the different layers is Hytrel. The experience of the manufacturers claims that this is the best alternative for the unions.

Apart from the adhesive used to get the layers together, a process of hot-sealing is required to put the different parts of the blimp as one unique piece. [26]

The next picture is a scheme of the laminated material.

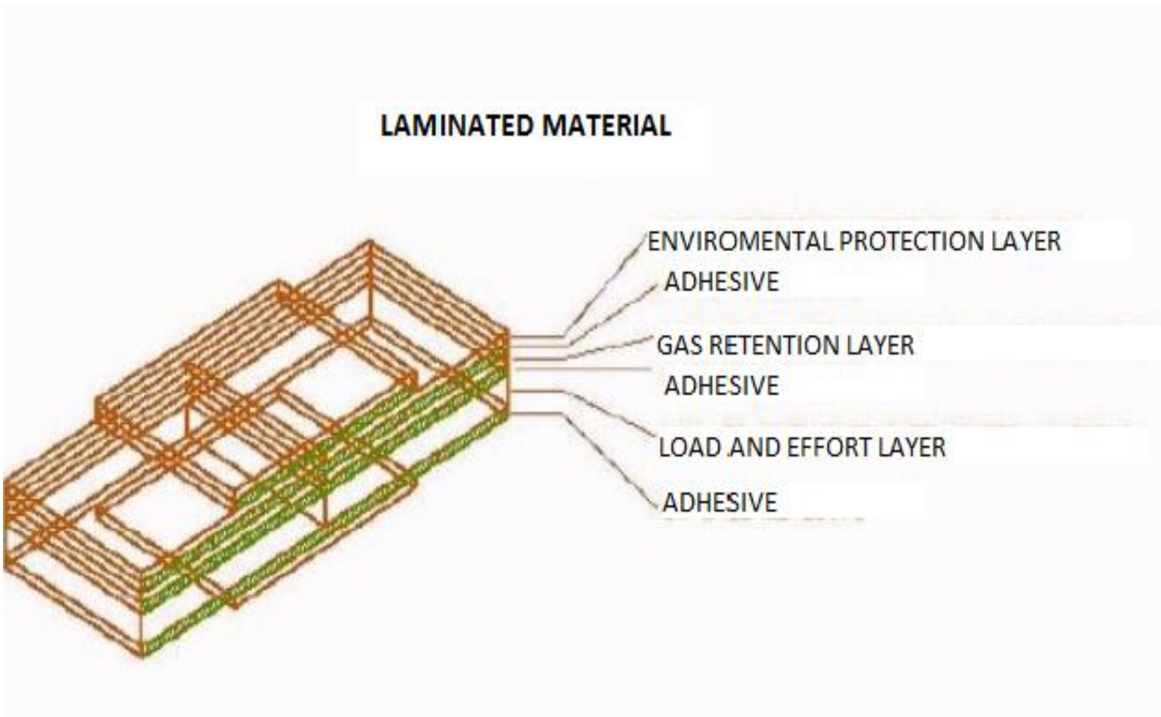


Figure 20.Laminated material

4.4.1.1) First alternative:

The first alternative for the material of the membrane of the airship is a laminated of two layers:

-A retention layer of helium

- Effort layer

For effort layer is used a laminated material made of oriented polypropylene with polyethylene and metallic. For the gas retention layer is used a polyester film, called Mylar, with low thickness and transparent.

-Effort layer:

The characterization of the material of the effort layer, mainly includes mechanical testing efforts to ensure a good safety factor against the different conditions encountered. There are several alternatives for the material effort layer. Basing the application requirements are not very demanding, it is allowed to choose a laminated economic commercial packaging, used for food and cosmetics.

It also presents a good performance for heat-sealing, the most economical way to unite two sheets of polymeric materials.

The polyethylene laminated oriented with polypropylene and a metal layer is an anisotropic material. That means that it behaves differently depending on the orientation of the fibers. Furthermore, it has a good behavior in terms of permeability to helium and heat-sealing for unions. Its main characteristics are:

-Thickness: 0.06604 mm

-Mass per unit of area: 60.45 gr/m^3

-Density 915.333 Kg/m^3

4.4.1.2) Second alternative

The second alternative considered was a laminated of aluminum foil material with polyethylene. The foil has a low permeability to gases. Besides, the quality of its heat-sealing exceeds the first alternative explained before. This fact makes aluminum foil very reliable for controlling the leaks of helium. Regarding the mechanical properties, the first alternative exceeds the second. The aluminum foil presents an importance tendency to tear, but with a

meticulous usage of it, it wouldn´t be a problem.
The behavior of foil is similar in a perpendicular and parallel direction to the previous alternative.

The most important characteristics of aluminum foil are:

-Thickness: .0725mm

-Density of the membrane per m^2. 0.15

4.4.1.3) Adhesive

The two basic considerations to have into account in the adhesive are if the mechanical behavior and chemical reaction are favorable, unfavorable or indifferent.
The first step is to determine the role of the adhesive in the mechanical properties. It must be noted that the membrane of the blimp will be able to support the solar panels.
The second consideration is the degree of chemical reaction that can have the adhesive in each layer.

According to these facts, the adhesive chosen was Boxer. It is made up of natural latex dissolved in toluene.[27]

4.4.2) Conclusion

The heat-sealing process of aluminum foil is significantly more reliable and offers a better finished and appearance that the heat-sealing process with propylene. This point and the other advantages explained before, justify the choice of aluminum foil is a material for the construction of the blimp.

The density of the aluminum foil is 0.98 g/m^2. But it is necessary to take this value incremented 1.5 times due to the unions and extras that will support the envelope.

$$1.5* 0.98 \text{ g}/m^2 = 147 \text{ gr}/m^2 = 0.147 \text{ g}/m^2$$

Total weight of the membrane is:

$$0.15 \text{ g}/ m^2 * 21.17 m^2 = 3.11\text{g}.$$

4.4.3) Manufacturers of the membranes

Attending the different companies that manufacture membranes all over the world, here there are shown some of them with different models and sizes [28]

Brand	**Volume (m^3)**	**Length (m)**	**L/D**	**Material**	**payload**	**Costs in USD**
Wcoast 9002	7.22	4.57	2.24	Polyurethane	4.36	852
Wcoast 9004	12.17	6.40	3.00	Polyurethane	7.49	1784
Wcoast 9006	42.73	9.14	3.00	Polyurethane	21.38	4995
Wcoast 6´gb	0.28	1.83	3.00	Mylar	4.47	240
Prototype	5.5	6.8	5.5	Foil of aluminum	1.5	600

Table 5.Membranes

4.5) Camera equipment

For the camera equipment, it was chosen a model of a Spanish company called “Fotolín”. This company uses an innovative new technology that incorporates a camera of 14.6 Mpxl with a wide angle entirely robotic.

The photo is got up going up the blimp to a perfect angle and height without losing any detail or resolution. It is the customer who can view, if desires, the live picture looking through a pair of color video glasses from the ground. The images can be taken easily by the customer.

The equipment is all organic with no pollution effects on the environment.

Figure 21. Camera equipment

The equipment chosen for this project was the model" FALCON 360". It consists of:

-The camera of 14.6 Mpxl with image stabilizer.

-Video glasses: Resolution of 640*480

-Platform: To support the camera. It is made of aluminum. With activation of 360-degree rotation, 110 ° vertical adjustment, zoom shot integrated.

-Video transmisor of 2.4 mHz with its receptor.

-Lithium batteries of 1200 ah. -Video monitor with RCA.

This equipment has a total weight of 1.5 Kg approximately. [30]

Figure 22.Camera and its platform

4.6) Solar cells.

4.6.1) Technology selected

Three different aspects were considered to choose the most suitable kind of pv module. These aspects were: flexibility, efficiency and lightweight. Basing on them, CIGS solar cells were chosen as the kind of cell to allocate in the surface of the blimp. [30]

4.6.2) Model.

It was made a research about the best companies with the highest efficiencies in CIGS cells. The best company was `Q.CELLS´ with an efficiency registered of 12.7 %. The model selected was `Q.SMART UF 75-95´ (Annex 1), a semi-rigid CIGS cell that could supply all the requirements needed by the blimp. In addition, this model was available in the software, so it could simulate estimating an accuracy result based on the data sheet of the solar cell.[31]

4.7) Designs

4.7.1) Designs

Assuming the dimensions of the pv module chosen, it was tried to allocate as many pv panels as it was permitted along the available surface of the membrane. Three different designs of the blimp were considered basing on the distribution of the modules.

4.7.1.1) First design.

The first design was based on the optimal angle of irradiance angle. This angle was determinate using the *PV SYST 5.56 software*. According to this software the optimal irradiance angle (plane tilt) for Seville was 32º and the optimal plane orientation (azimuth) was 0º (South).

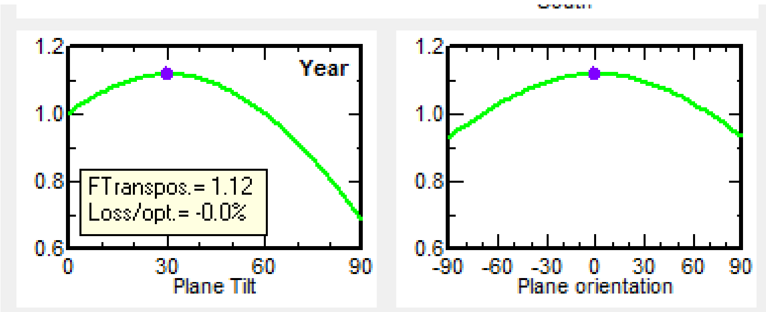


Figure 23.Optimization graphs

Basing on it, as many pv modules as it was possible, were allocated with the angle irradiance of 32º and with an azimuth of 1º.

It was used the *Solid Works software* to estimate the distribution. The following pictures show how the first design was.

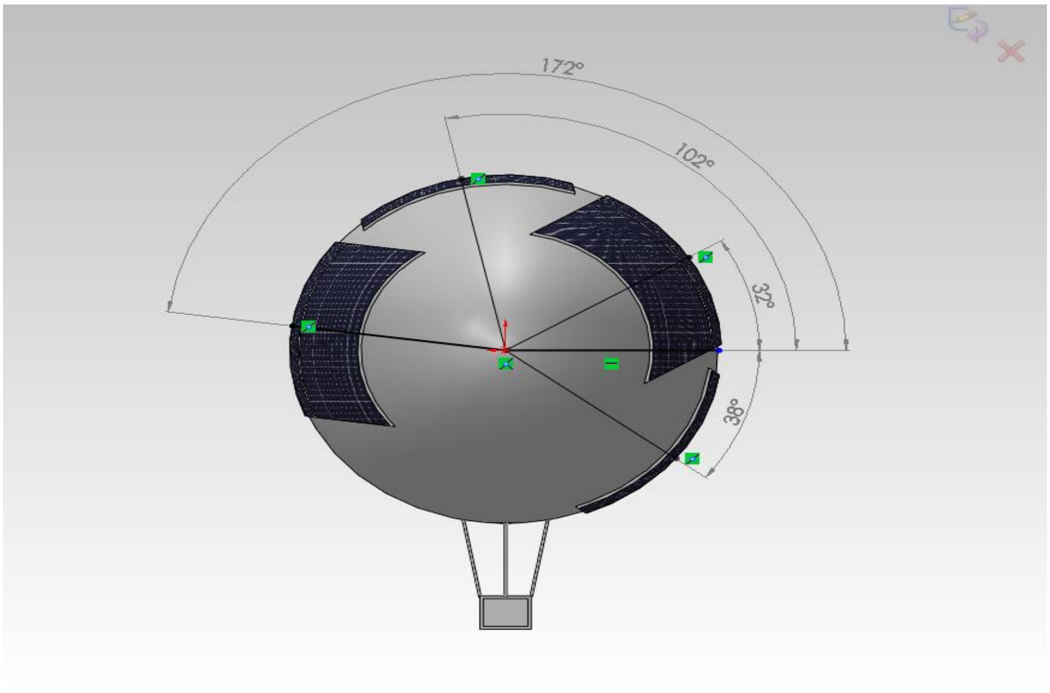


Figure 24.Angles sight

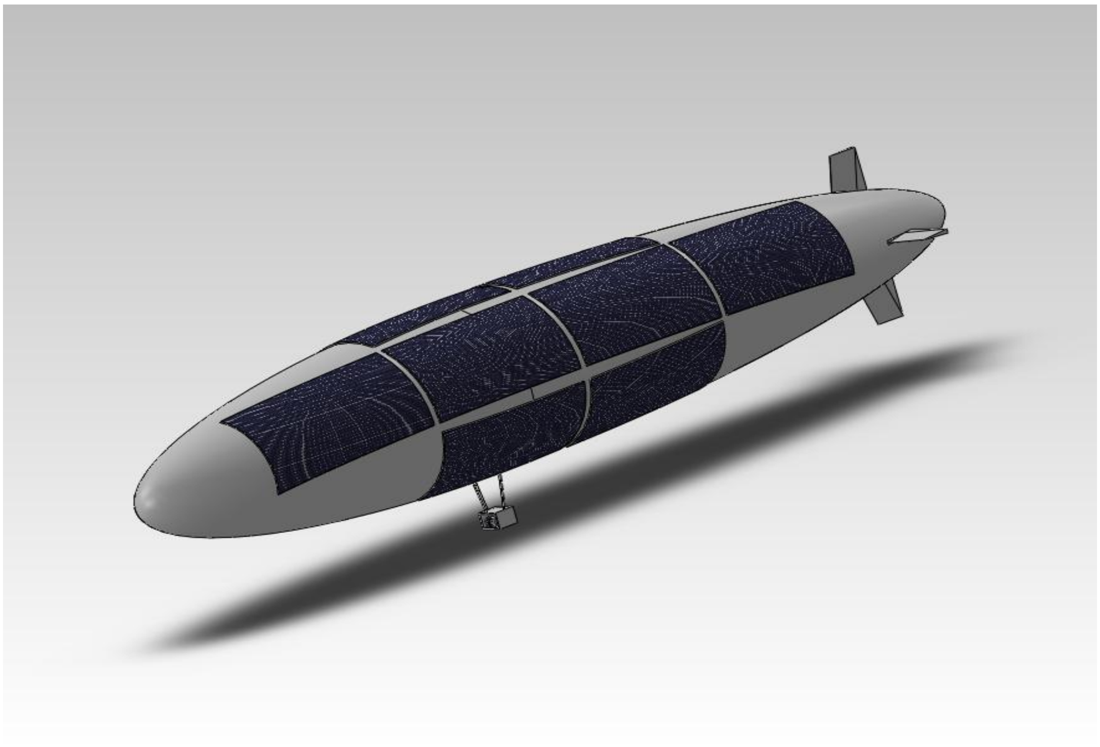


Figure 25.Front side sight1

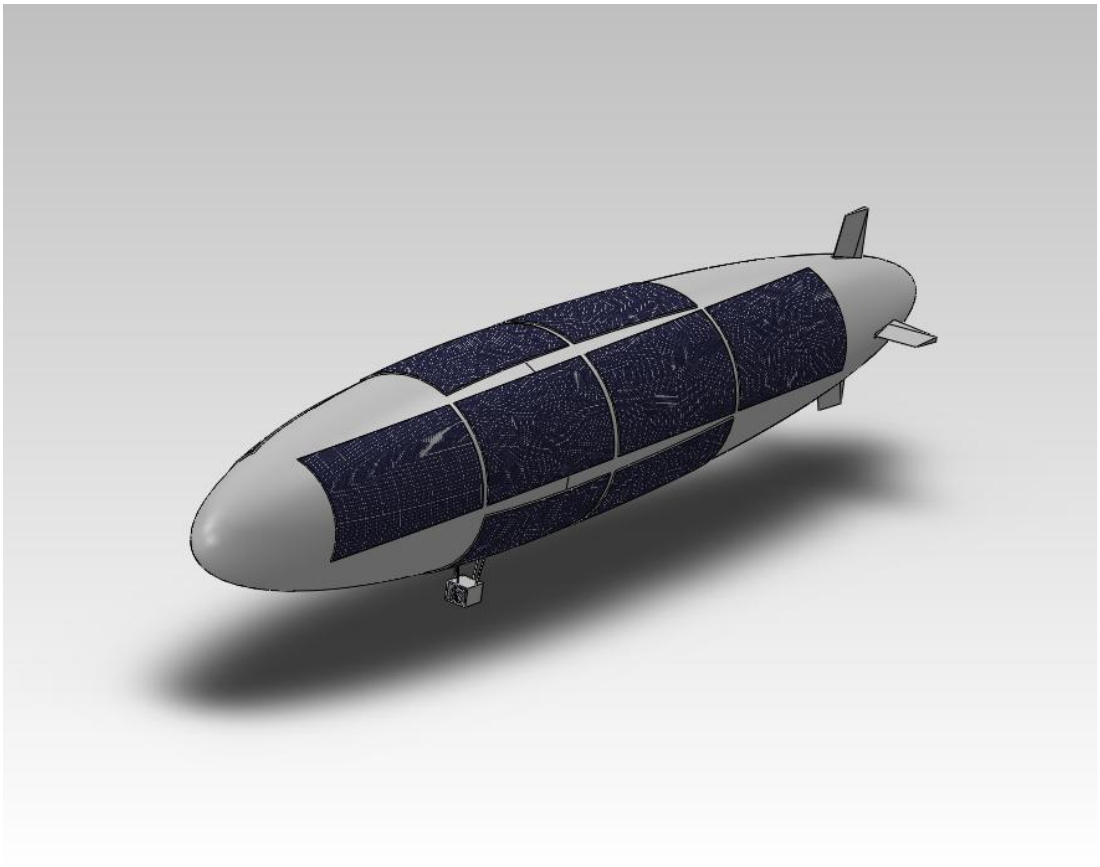


Figure 26.Front side sight2

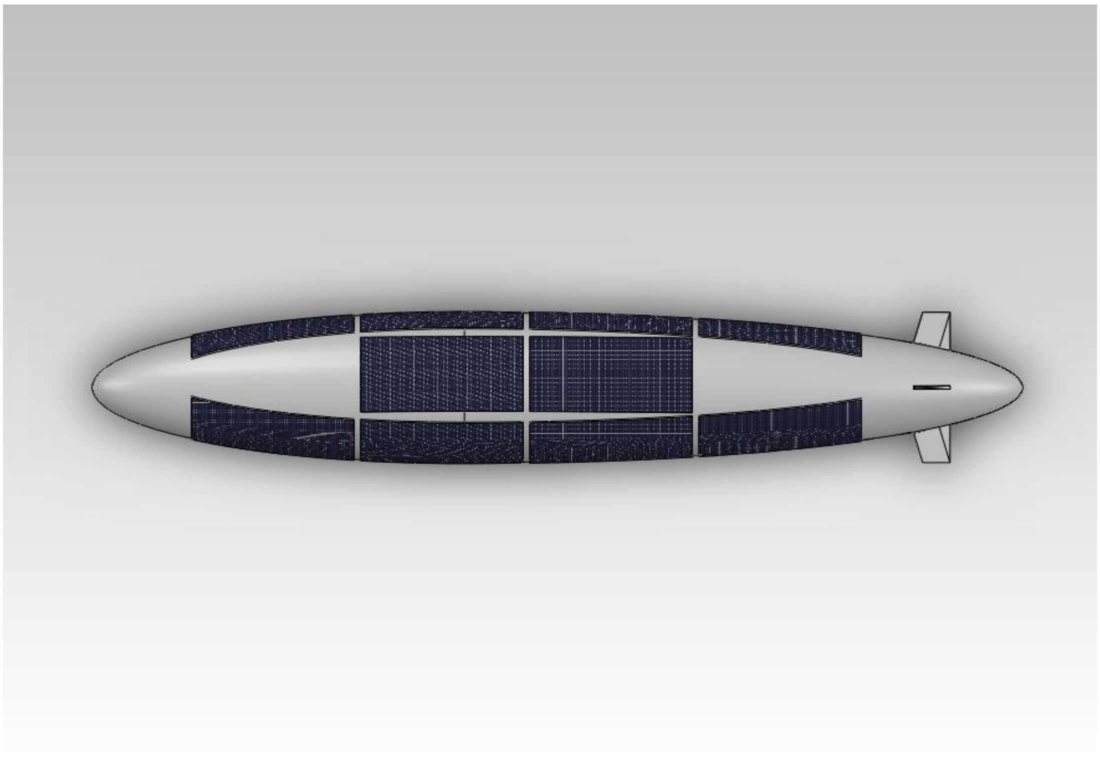


Figure 27.Top sight

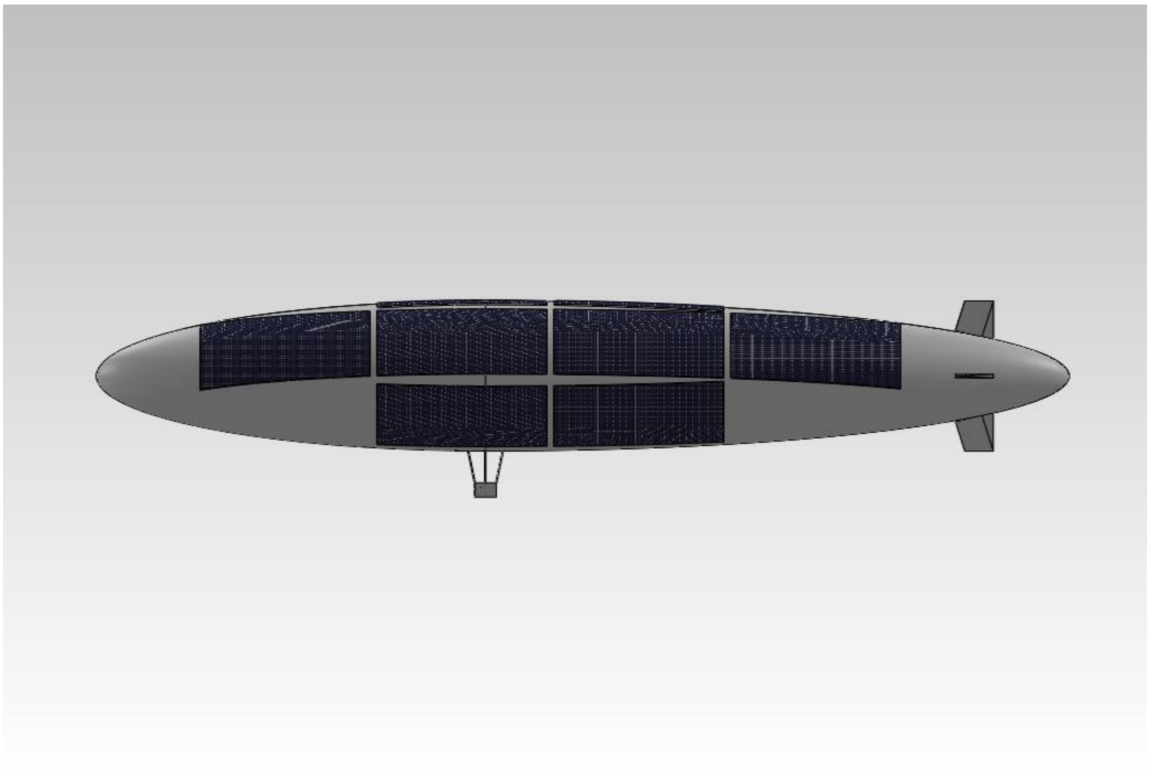


Figure 28.Back side sight

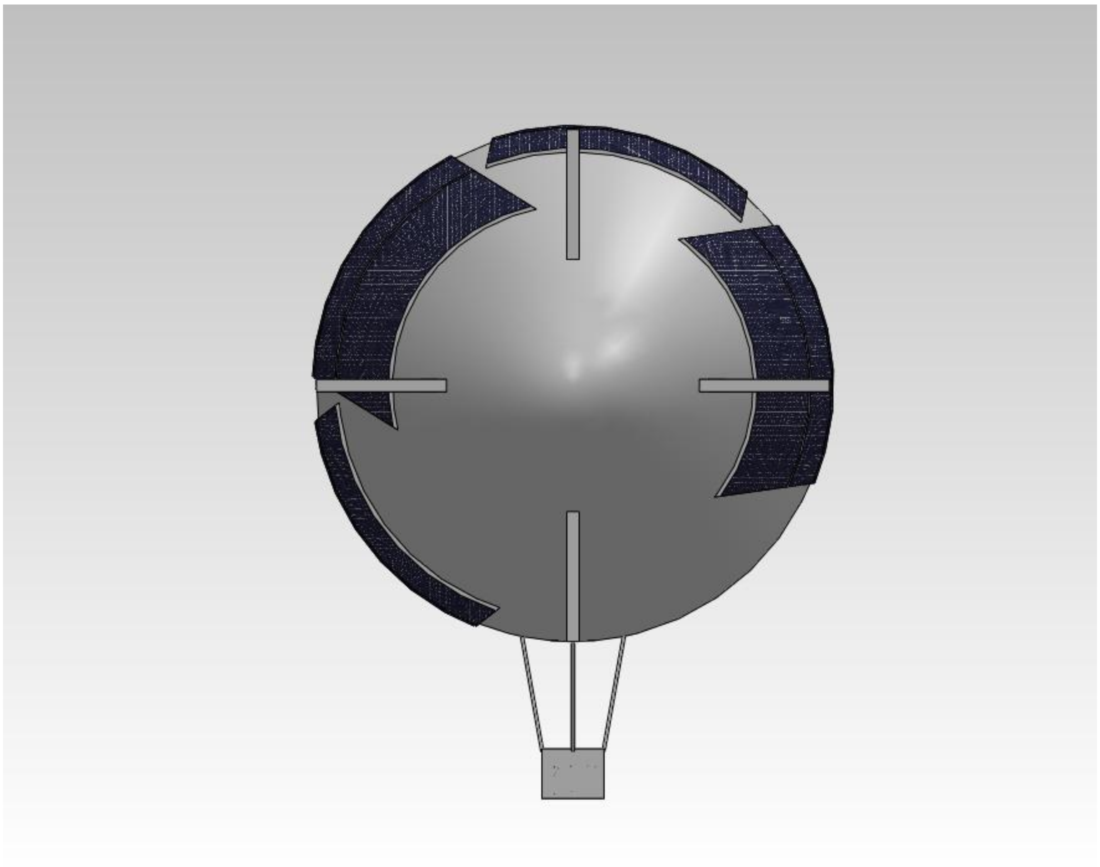


Figure29.Front-back sight

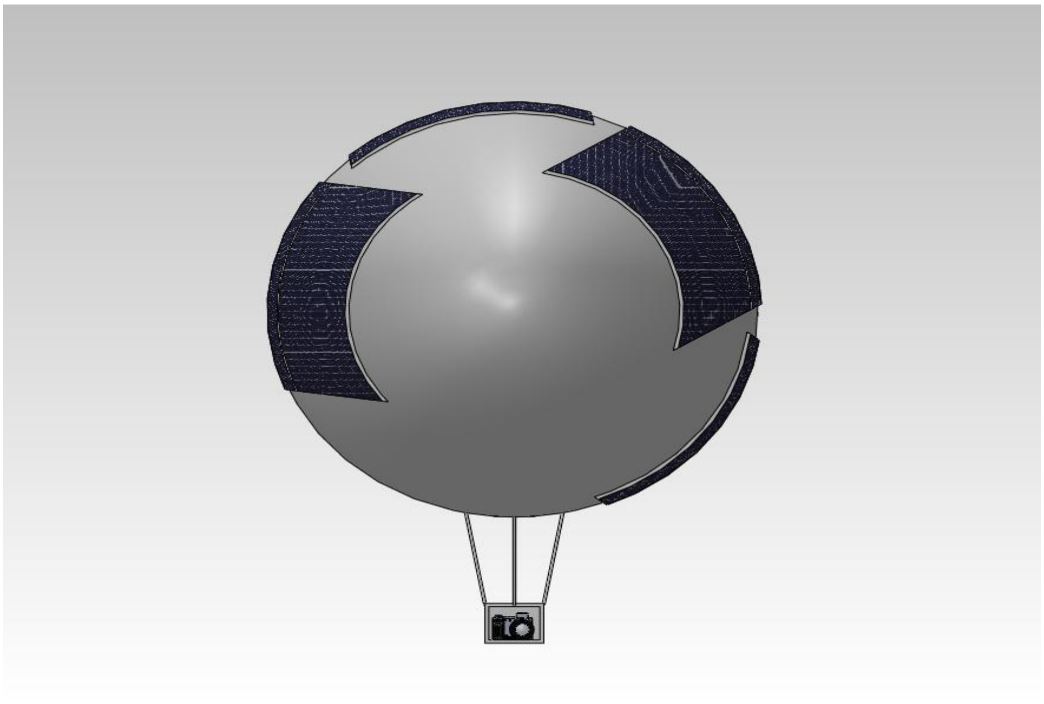


Figure 30.Front sight

This first design was rejected because the distribution of the pv modules were not symmetrical and the blimp was not in equilibrium. The angles were not the same in the different sides of the blimp. This not symmetrical distribution of the cells might dump the blimp. Besides, there were 6 solar modules in the front side and just 4 solar modules in the back side. Consequently, the blimp would have less energy in the return flight, and it must be the same energy in both directions of the flight.

After this failed design, it was reached the conclusion that the design must be the equilibrium between the energy supplied through the pv modules, and performance as well.

According to this fact, two new designs were considered combining the following aspects:

-performance: now the blimp stays in equilibrium. The same number of pv panels are establish in both sides of the blimp.

-energy: They will be allocated as many pv modules as possible with an angle close to the optimal angle of irradiance 32º.

Now, assuming the three different positions of the blimp, they will be explained the two next designs.

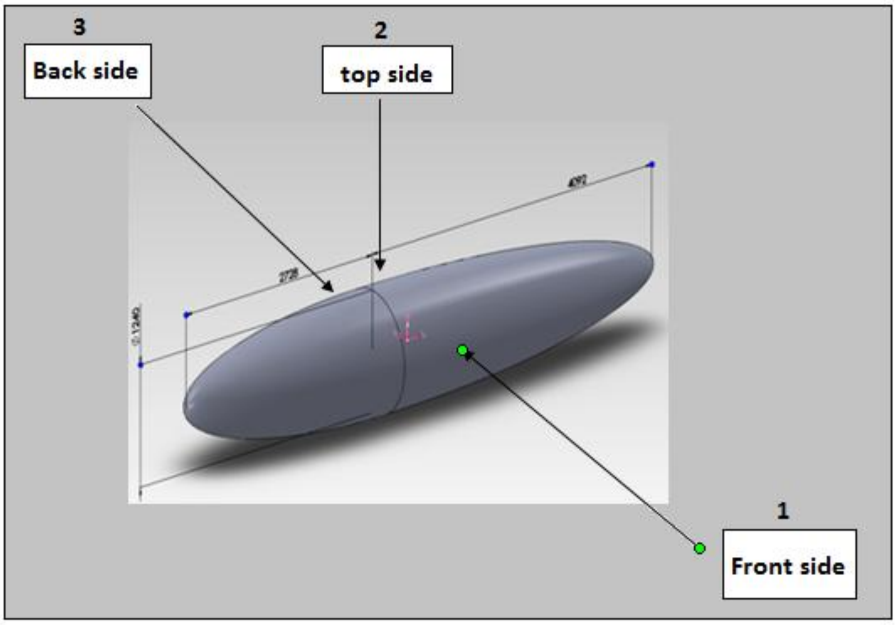


Figure 31.Blimp positions

4.7.1.2) Second design

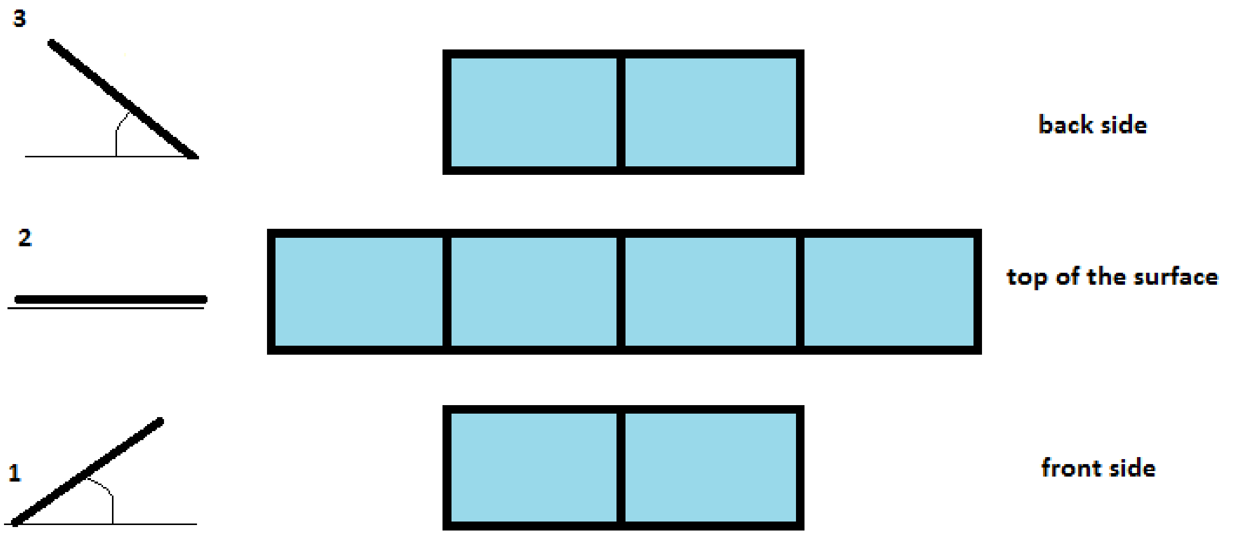


Figure 32.Second design

4.7.1.3) Third design

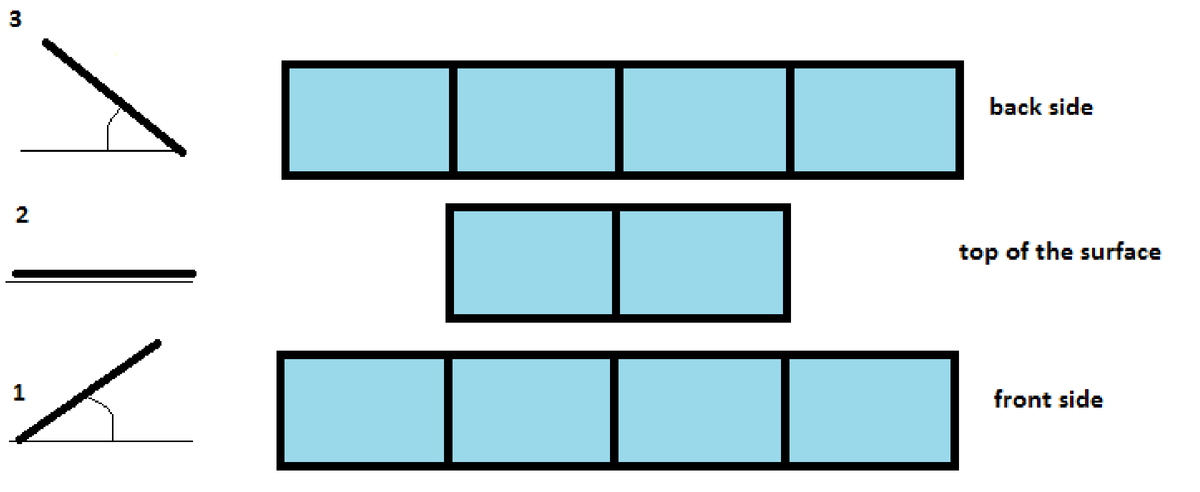


Figure 33.Third design

4.7.1.4) Conclusion

Paying attention to the aspects needed to consider, the symmetrical distribution of the pv modules were found in both design, so the pv modules will be in equilibrium.

However, the total number of pv modules were 8 in the second design and 10 in the third design. In addition, the first and the third row of the designs were the rows were the panels were going to be sloping some degrees near 32º (optimal irradiance angle), taking advance the surface of the blimp and without breaking the aerodynamic shape of the blimp. The second design had 4 pv modules distributed in this position and the third design had 8 modules in this position.

As a conclusion, the third design was chosen as the definitive design. It was used again *Solid Works software* to create the technical drawings.

4.8 Flight

4.8.1) Direction of the flight.

As it was assumed in the input variables, the direction of the flight will be from the West to the East direction and vice. The following pictures show a graphic example of two important aspects considered later:

-Latitude: Latitude gives the location of a place, heading north or south from the Ecuador and is expressed in angles ranging from 0 ° of the Ecuador, to 90 ° N to the North Pole or 90 ° S to the South Pole.

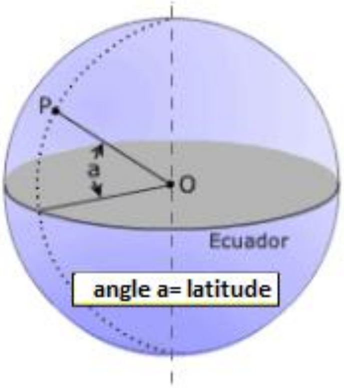


Figure 34.Latitude

-Longitude: This parameter provides the location of a place, heading east or west from the meridian of reference 0 °, also known as Greenwich. As latitude, is expressed in angles ranging from 0 ° to 180 ° E and 180 º W.

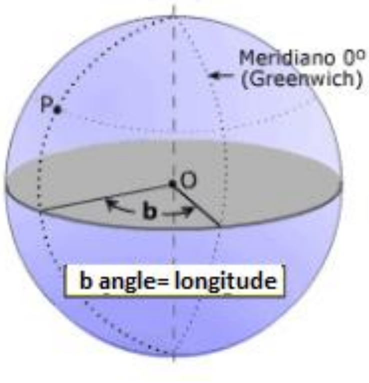


Figure 35.Longitude

Basing on these definitions and assuming the direction of the flight, only the longitude will vary while latitude will stay constant.[32]

4.8.2) Path of the flight.

It was supposed a path for the one-way flight showed in the following graph. It was assumed that the speed of the blimp was 35 Km/h and the autonomy was 2 hours.

It was considered a security factor of 1.6 to determinate the autonomy. Supposing that the blimp carried out the whole flight (75 minutes):

75 minutes/total flight *1.6 = 120 minutes = 2hours of autonomy.

These details were chosen basing on a survey done in order to look into the different commercial blimps with similar sizes and their speed and autonomy.

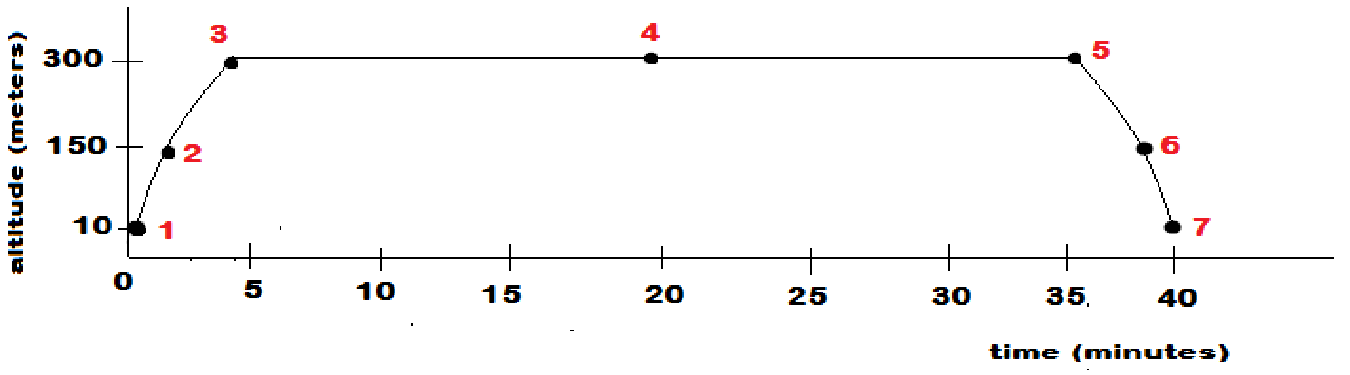


Figure 36.Path flight

The graph shows seven points marked with all their characteristics referred to each point collected in the table below. To determinate the variation of the longitude it was necessary to calculate using trigonometry concepts the length of the parallel 37.12º where Seville was allocated:

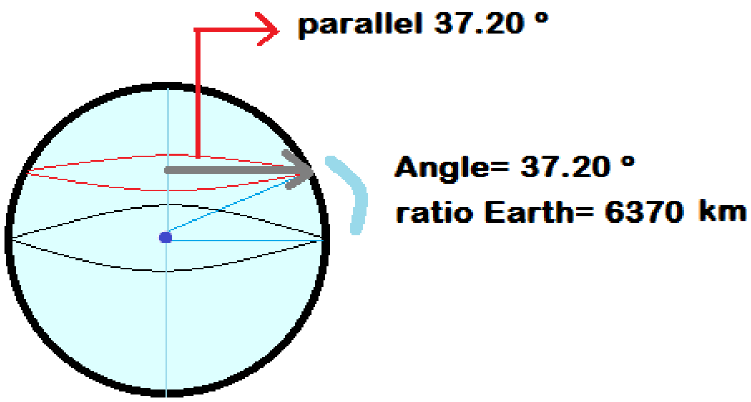


Figure 37.Paralell 37.20º

$$cos37.20º = \frac{ratio\ of\ the\ parallel}{6370Km} = 507.26\ Km$$

Longitude parallel 37.20º = $2 * \square * ratio = 31{,}913.98\ Km$

Equivalence = 88.64 Km/ º Latitude

This equivalence was used to determinate the position (longitude, latitude) of each point referred to the graph showed above.

It is necessary to emphasize that the path of the flight, was a simply supposition. It was not used any equation to determinate it and the relation between height and time did not correspond to any equation. Only it was assumed that the speed during the flight was 35 Km/h at the cruise height (300m) and for the taking offs and landings, the speed was supposed as 24 Km/h taking into account the adversities of these movements. This speed was based on the speed of blimps with similar dimensions of different companies.[32]

POINT	MINUTE	ALTITUDE (m)	LATITUDE	LONGITUDE
1	0	10	37.12º	-5º 26´
2	2.5	150	37.12º	-5º 26´ 40.8”
3	5	300	37.12º	-5º 27´ 21.6”
4	20	300	37.12º	-5º 33´
5	35	300	37.12º	-5º 39´15”
6	37.5	150	37.12º	-5´º 39´ 56”
7	40	10	37.12º	-5º 40´ 24.2”

Figure6.Flight details

These details were introduced in *PV SYST 5.56 Software*. This software estimates the amount of energy that was possible to get through the pv modules basing on the geographic parameters.

4.8.3) Position of the solar cells.

Another two parameters that determined the results of the software, were the tilt and the azimuth of the solar cells. Assisting the distribution of the pv modules in the surface of the blimp, there were 7 different positions of the cells.

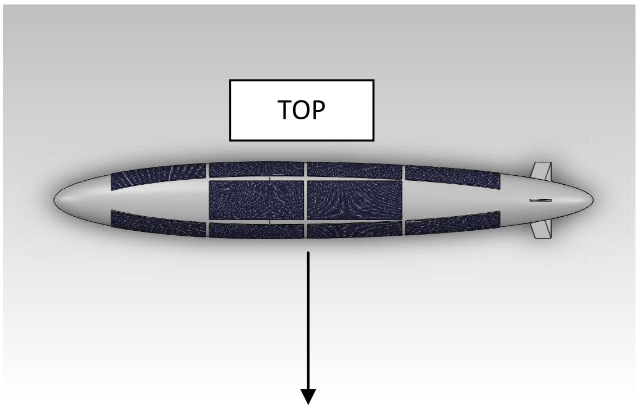


Figure 38.Top sight

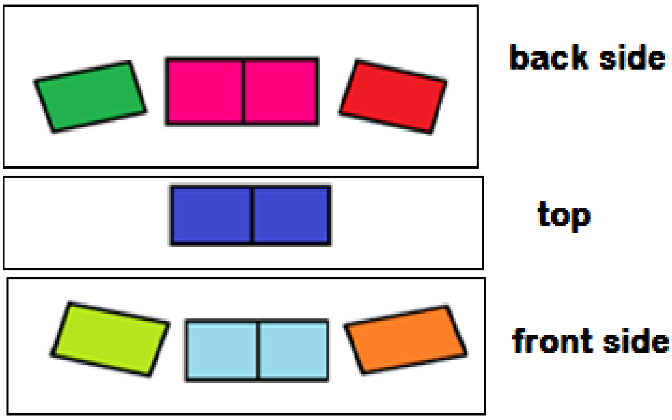


Figure 39. Solar cells distribution

Tilt: Angle determined by the inclination of the solar radiation on the surface.

Azimuth: Angle formed by the observer-South segment with the vertical projection on the horizontal segment of the solar position observer.[34]

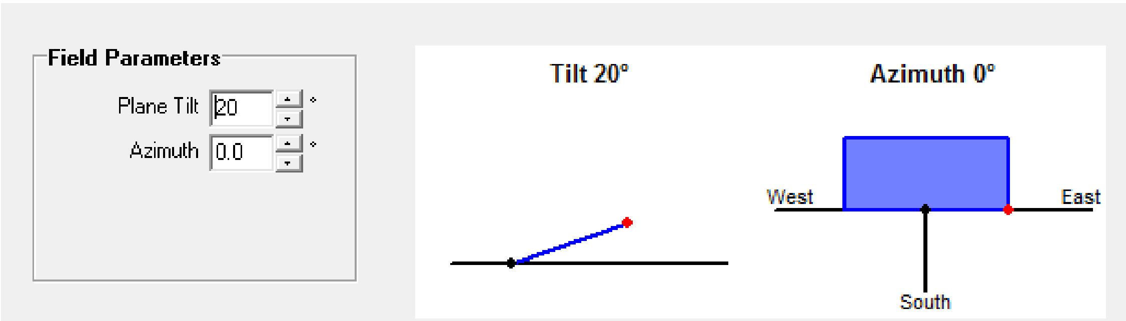


Figure 40.Azimuth and Tilt

Basing on the previous concepts, the tilt and the azimuth were established for each position. This table shows the results.

POSITION	TILT	AZIMUTH
1.	20º	0º
2.	20º	-8º
3.	20º	8º
4.	90º	0º
5.	20º	180º
6.	20º	-172º
7.	20º	172º

Table 7.Position of solar cells

4.9 PV SYST 5.56 SOFTWARE

Once defined the geographic parameters (latitude, longitude, altitude), the time and the different positions (angles) of the cells, this information was introduced in the software, which simulates for each imaginary situation, the energy obtained through the model of CIGS cell chosen before.

Here is, the first simulation as a clear example of what it was done and how were the results taken.

-First simulation→ Point 1 of the graph / Position 1 of the solar cells.

For the point 1 of the graph: altitude 10m / longitude:-5º 26´ / latitude 37.2º / time from point 1 to point 2 : 2.5 minutes

For the position 1 of the solar cells: tilt= 20º / azimuth =0º

These parameters were introduced in the software and the software provided several graphs with an hourly distribution of the irradiance. The graphs were available for all the days of the year. The graphs showed three different variables.[35]

-Irradiance: solar power that comes into a surface. It is expressed in Watts/hour

-Global incident in clear sky day: It represents the global radiation available under clear skies with no precipitations or clouds. In the graph it is represented by the blue line which shows the worst situation in a perfect day (referred to the weather inclemency)

-The global incident in the collector plane: Shows the actual maximum theoretical amount of energy that is registered. In the graphs, it is represented by the red line.

The unit for `the Global incident in clear sky day´ and `the global incident in the collector plane´ is $\frac{kwh^2}{m} day$. Besides, it is necessary to remark that the calculations always were based on peak power.

It was assumed that the flight could take place any day of the year within the daylight hours. That was the reason why there were taken the worst (always showed in the left) and the best day (always in the right) in the year attending the values of `global incidence in clear sky´. Here, are the two graphs of the worst day and the best day:

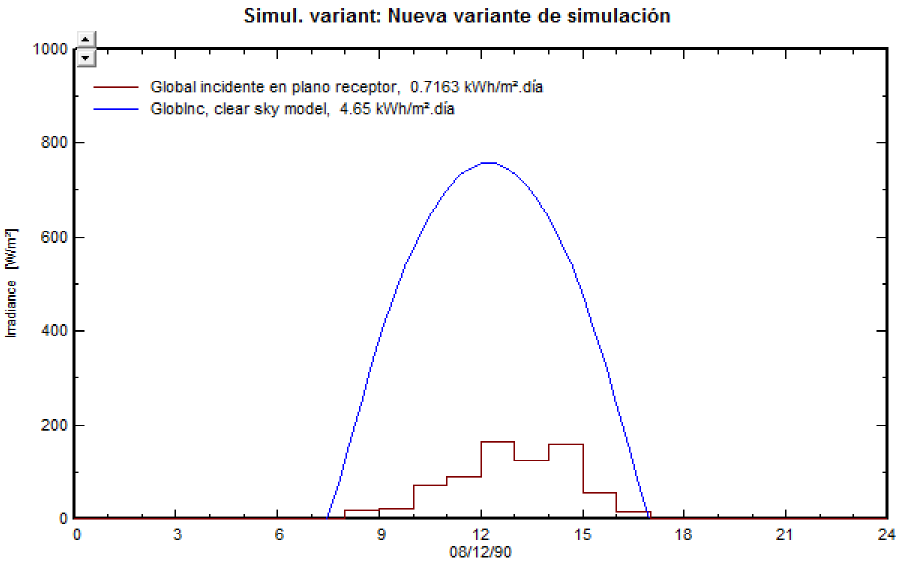


Figure 41.Graph 1.

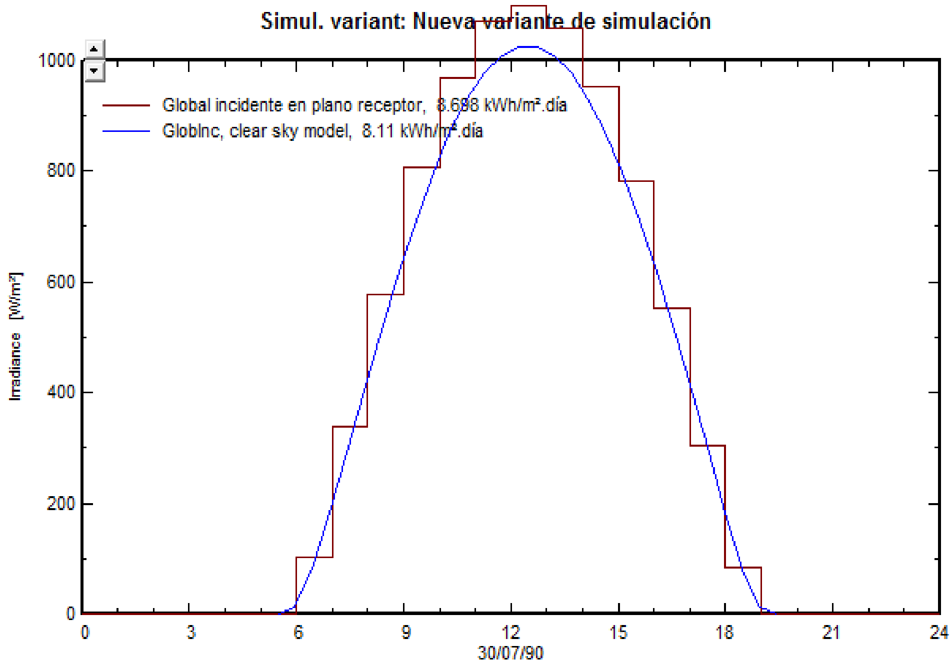


Figure 42.Graph 2

Then, basing on the values of the `global incident in collector plane" it was done the average for the worst and the best day. The reason to take the values of this variable rather the values referred to `clear sky model´, was because this last variable corresponds to the energy available for an ideal situation. However, the calculations had to take into account the inclemency of the weather

Average of global incident in collector plane: $\overline{x} = \frac{o.7163 + 8.686}{2} = 4.70\ \frac{Kwh}{m^2 day}$

The units for the `global in the collector plane´ were: [Kwh/$m^{\dagger}2\ day$] . In despite of a day has 24 hours, it is only possible to get energy within the sunlight hours. That was why an average of how many daylight hours was done in both graphs.

Average of hours of sunlight: $\overline{x} = \frac{13.2 + 8.5}{2} = 10.85\ hours\ of\ sunlight$

After that, it was calculated an average of `the global incidence in the collector plane´ per hour of sunlight.

$$4.70\frac{Kwh}{m^2 day}\times\frac{1 day}{10.85\ hours\ of\ sunlight} = 0.43\frac{Kwh}{m^2\ hour}$$

Finally, basing on the total area of the solar cells and on the time required to get the next point of the graph it was calculated the energy available.

$$0.43\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times 2cells\times\frac{1hour}{60\ min}\times 2.5min = 0.026875\ Kwh$$

These calculations were done for all the points of the graph combining the different positions of the solar cells.

Then all the results were plus and it was found the result of total energy available during the one-way flight.

4.10) CFD Software.

The definitive design was put in *CFD software* which simulated the performance of the solar blimp for a known speed (35 Km/h = 9.72 m/s). This software is able to provide the force needed to move the blimp.

Using the following equation, it was possible to get the power needed by the solar blimp.[36]

$$Power = Force * Speed$$

The power needed for the blimp was compared to the power supplied by the solar cells and it was determined the energy feasibility.

In the analysis of the blimp it was also possible to see the flow trajectory of the blimp, with the parts more affected by the drag.

5.RESULTS

5.1 Blimp dimensions

Volume of the dirigible m^3	5.49
Area of the membrane m^2	21.17
Length m	6.8
Diameter m	1.24
Area of the cylinder m^2	26.54

Table 4. Definitive resuls

5.2 Definitive design of the solar blimp

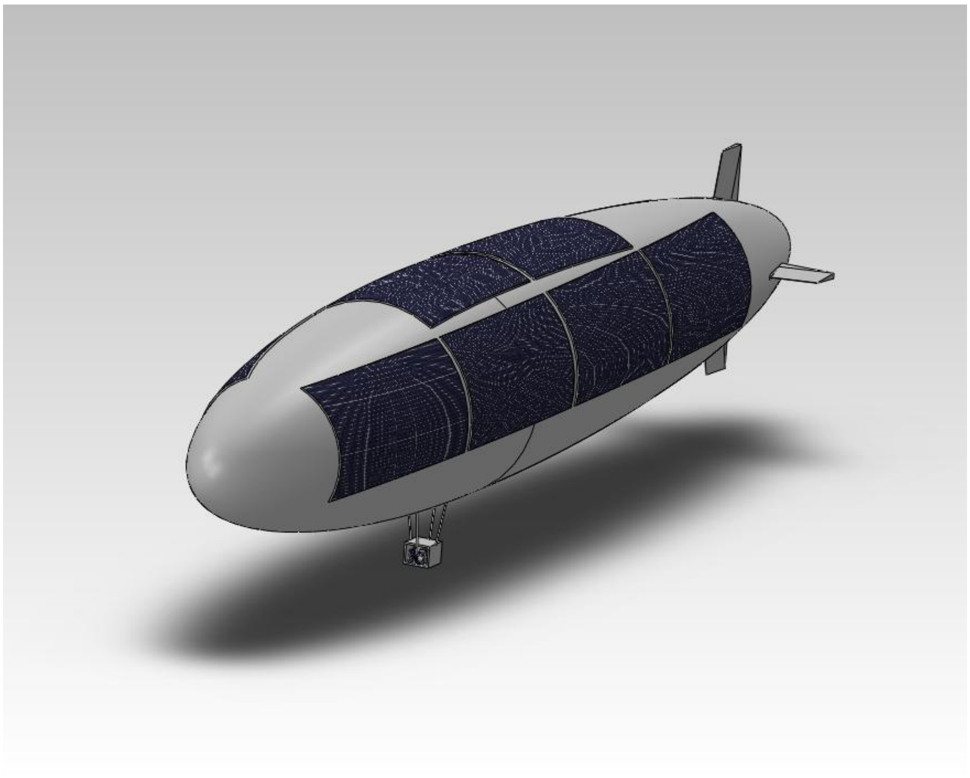


Figure 43.Front side sight.

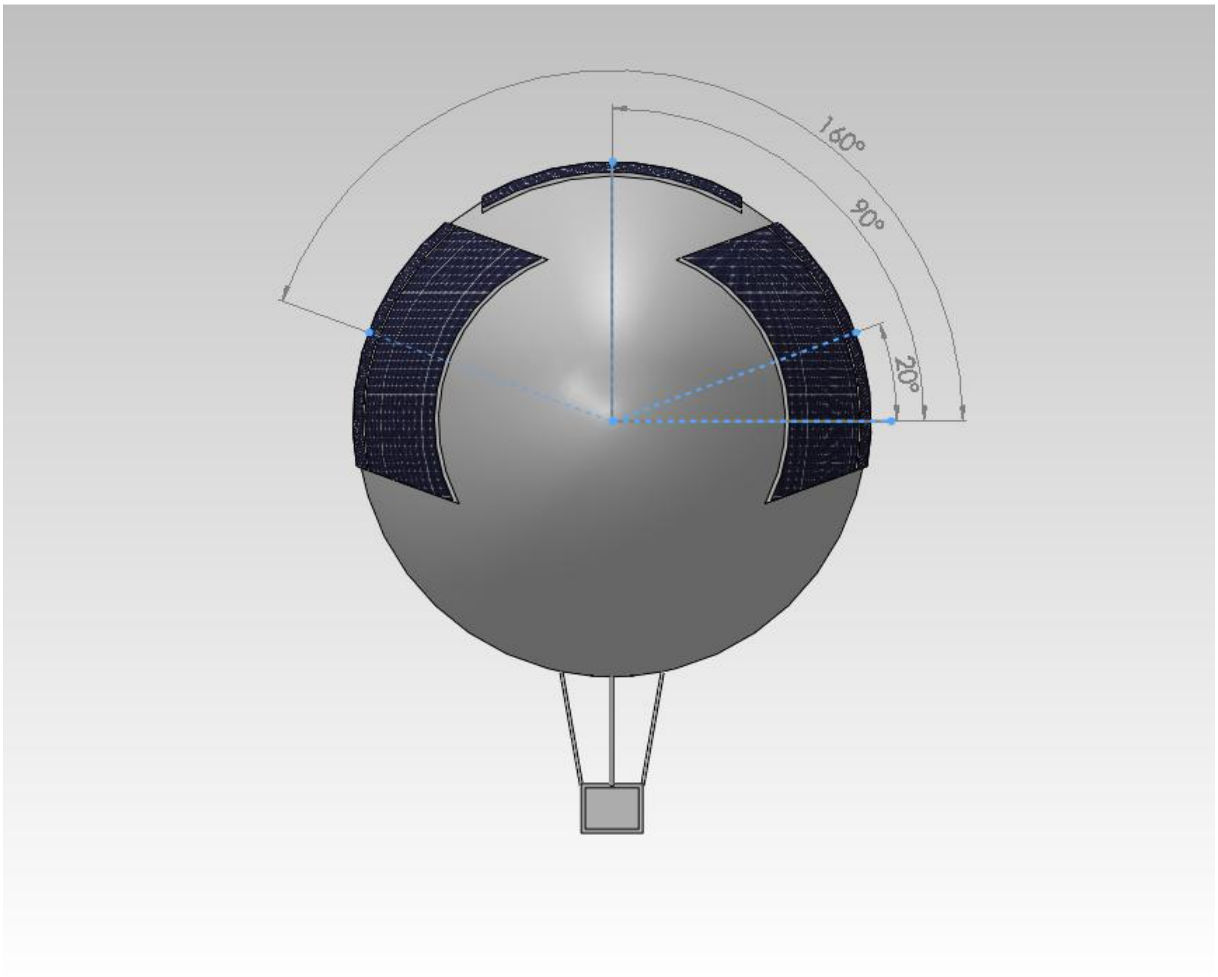


Figure 44.Angles sight

Figure 45.Top sight

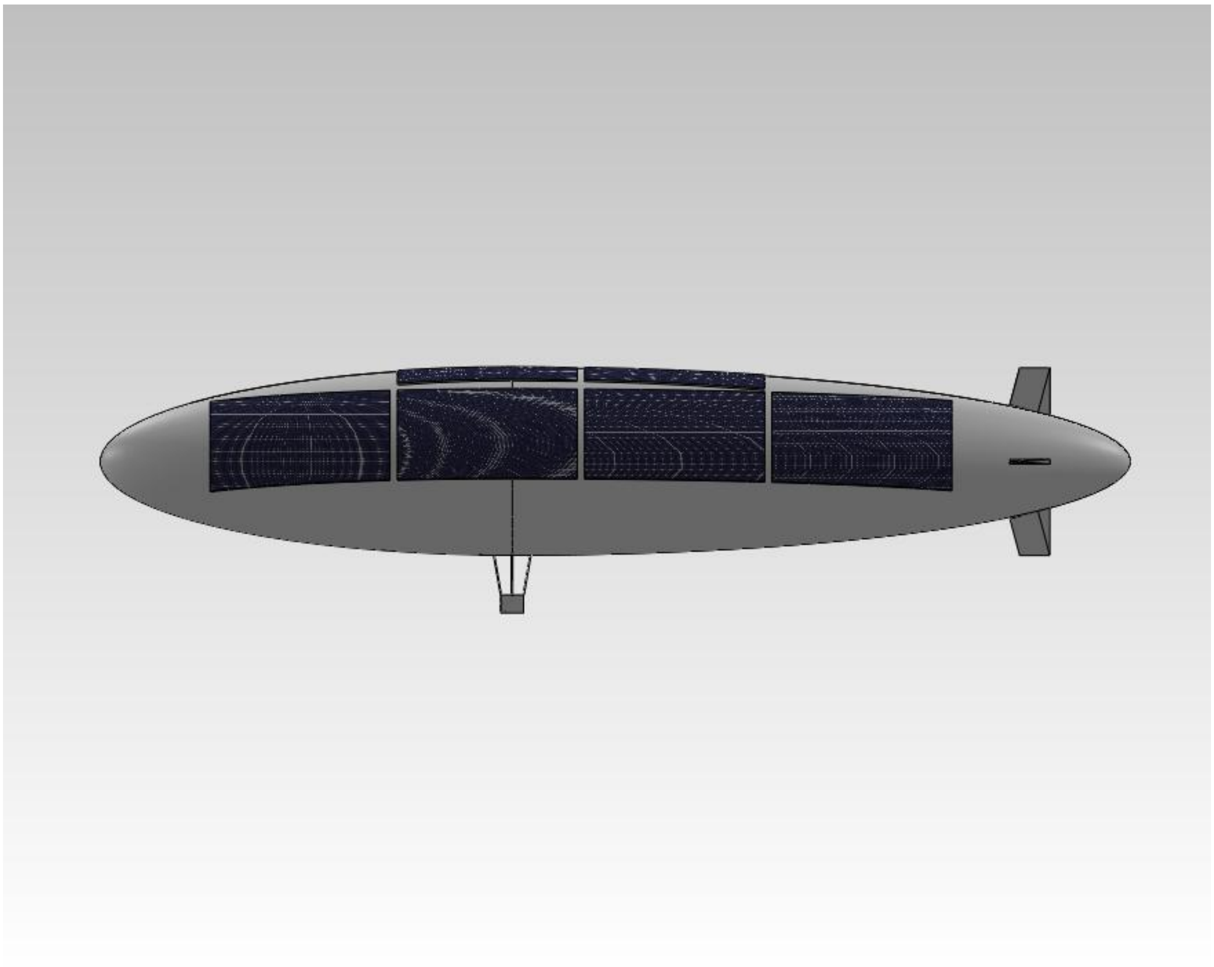


Figure 46.Back side sight1

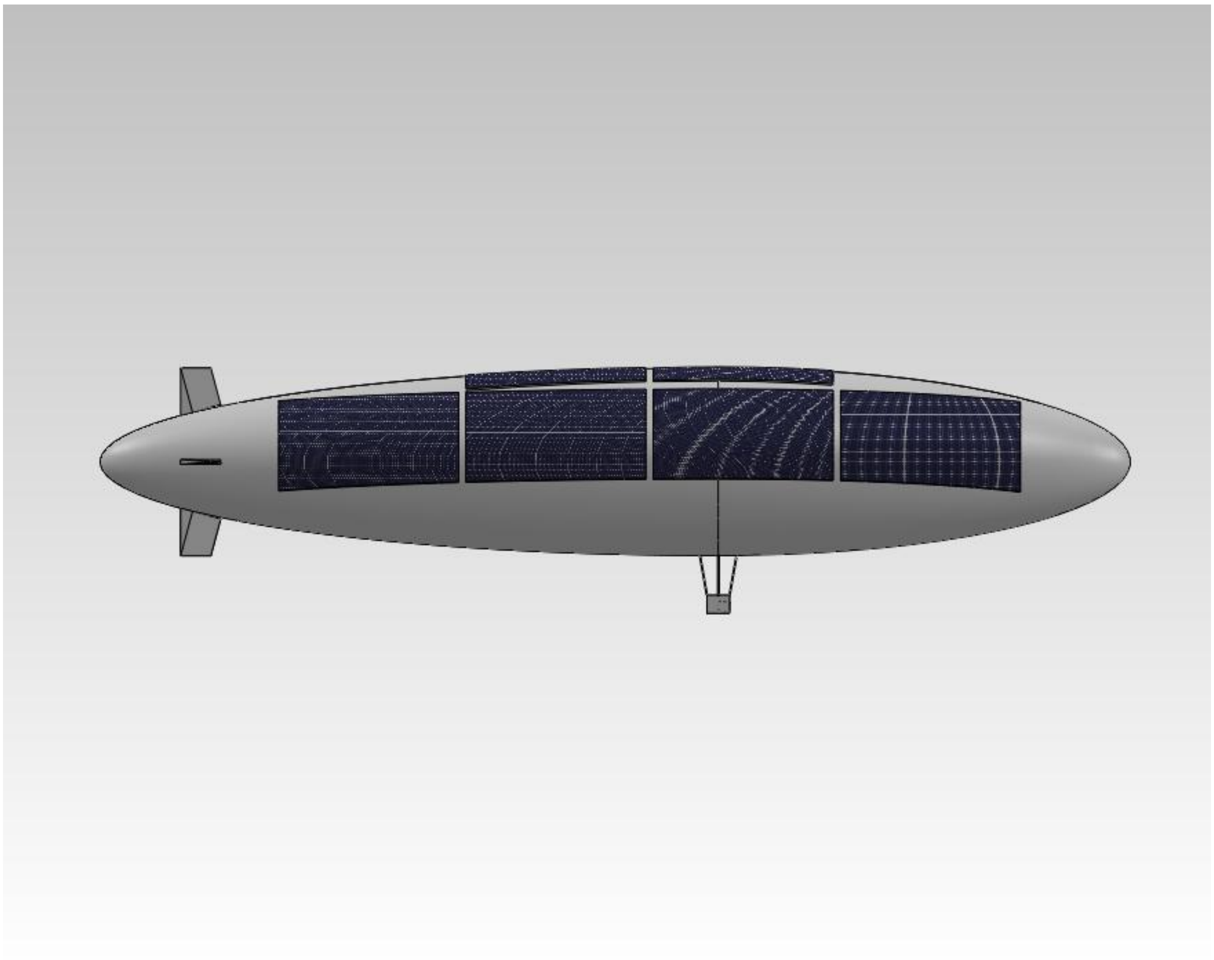


Figure 47.Back side sight

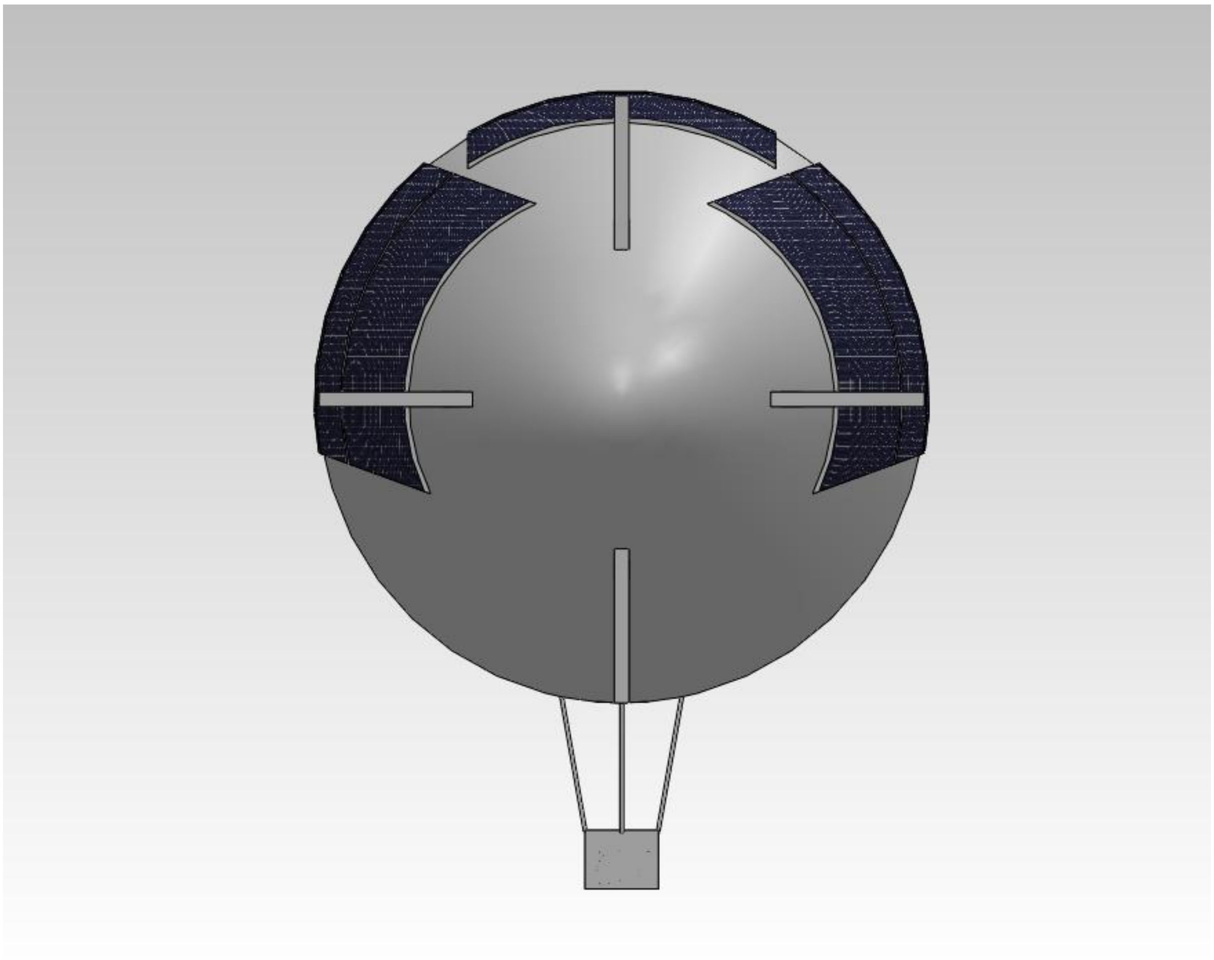


Figure 48.Back sight.

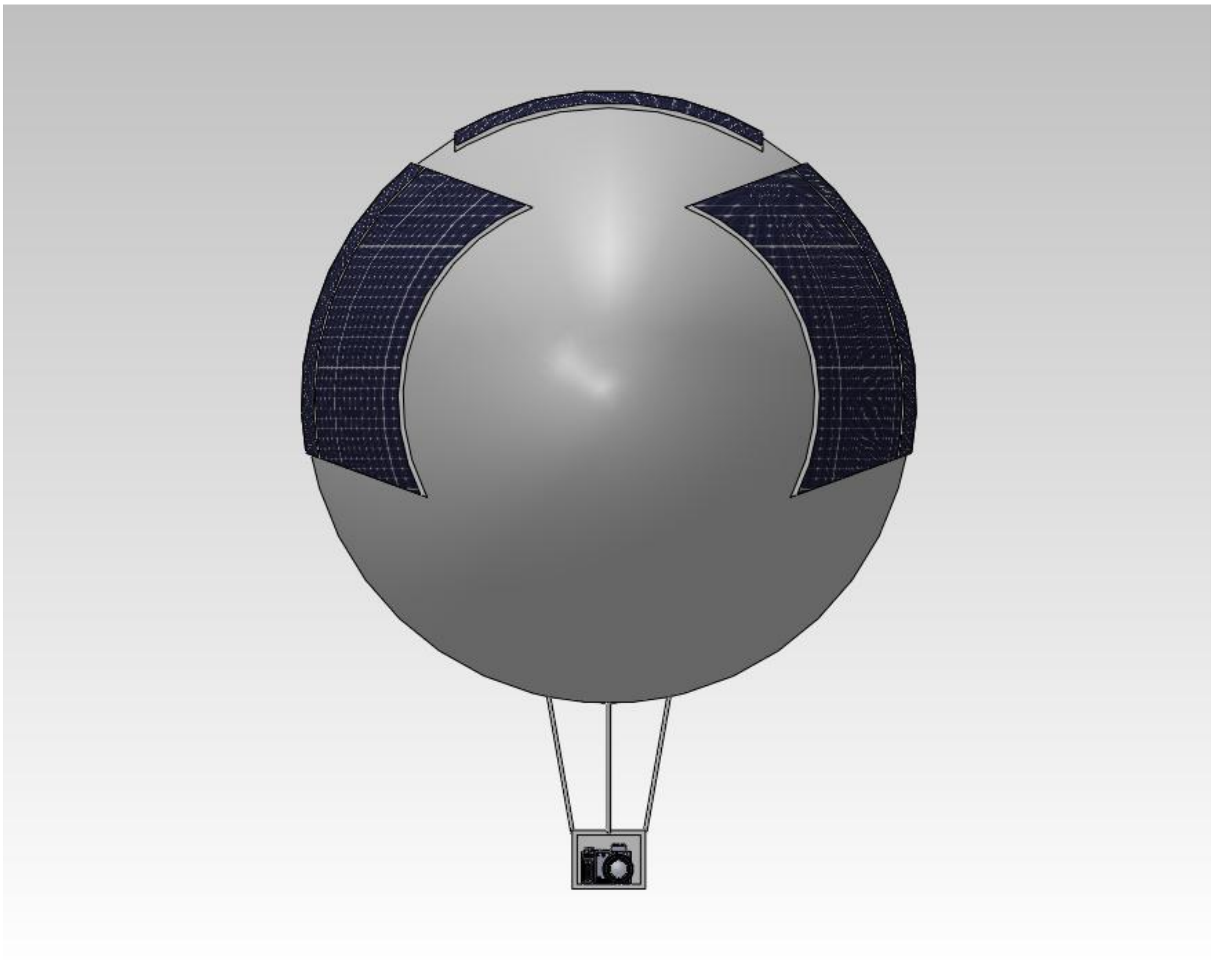
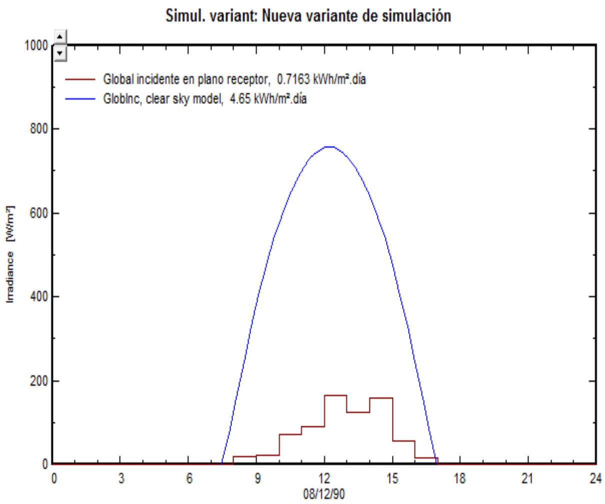
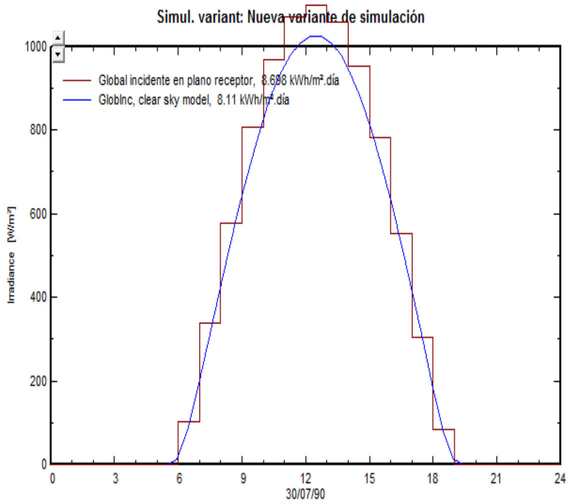


Figure 49.Front sight

5.3 Simulations in PV SYST 5.56

Point 1 of the graph/ Position 1 of the solar cells:





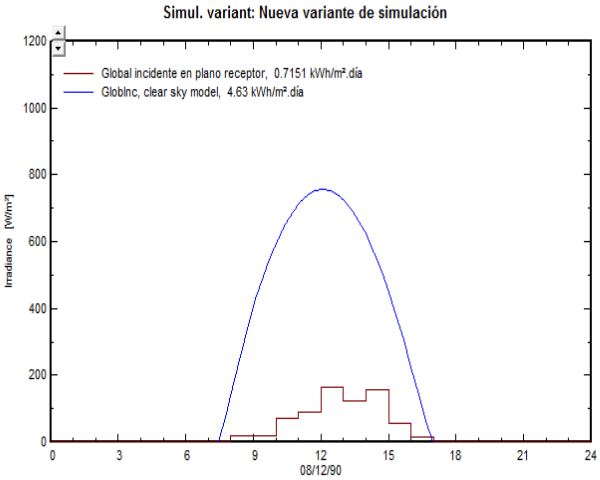
Average of global incident in collector plane: $\overline{x} = \frac{o.7163 + 8.686}{2} = 4.70\ \frac{Kwh}{m^2 day}$

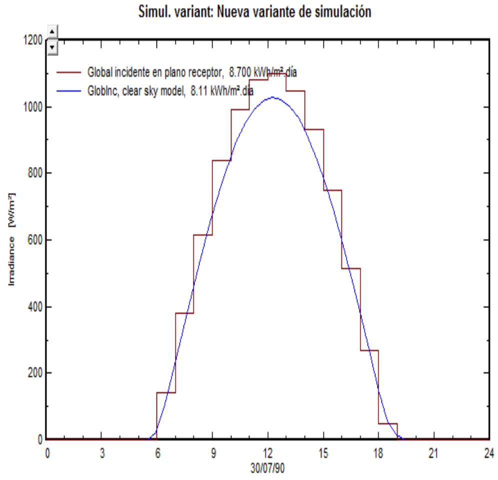
Average of hours of sunlight: $\overline{x} = \frac{13.2 + 8.5}{2} = 10.85\ hours\ of\ sunlight$

$$4.70 \frac{Kwh}{m^2 day} \times \frac{1 day}{10.85\ hours\ of\ sunlight} = 0.43 \frac{Kwh}{m^2\ hour}$$

$$0.43 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times 2 cells \times \frac{1 hour}{60\ min} \times 2.5 min = 0.026875\ Kwh$$

Point 1of the graph/ Position 2 of the solar cell:





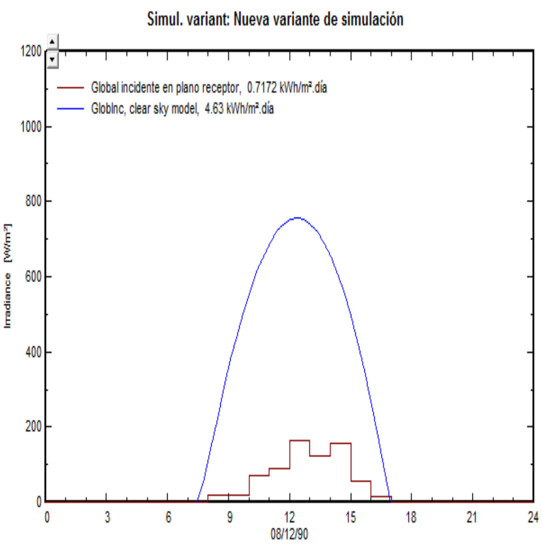
Average of global incident in collector plane: $\overline{x} = \frac{o.7151 + 8.700}{2} = 4.71 \frac{Kwh}{m^2 day}$

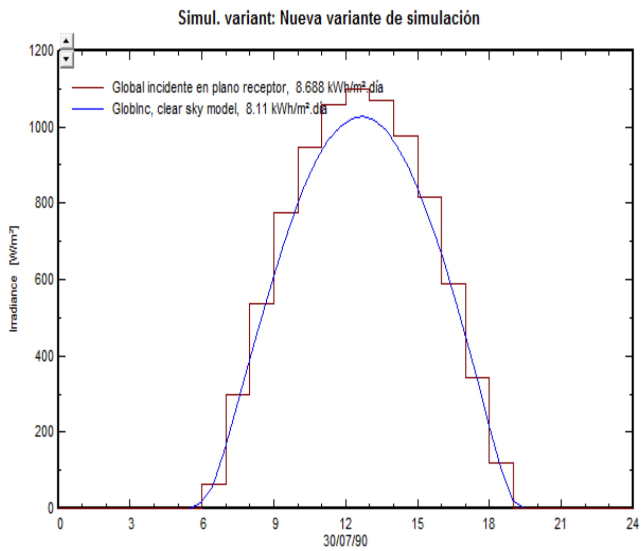
Average of hours of sunlight: $\overline{x} = \frac{9.5 + 13.2}{2} = 11.35\ hours\ of\ sunlight$

$$4.71 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.35\ hours\ of\ sunlight} = 0.41 \frac{Kwh}{m^2\ hour}$$

$$0.41 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 2.5 min = 0.0129\ Kwh$$

Point 1 of the graph/ Position 3 of the solar cell:





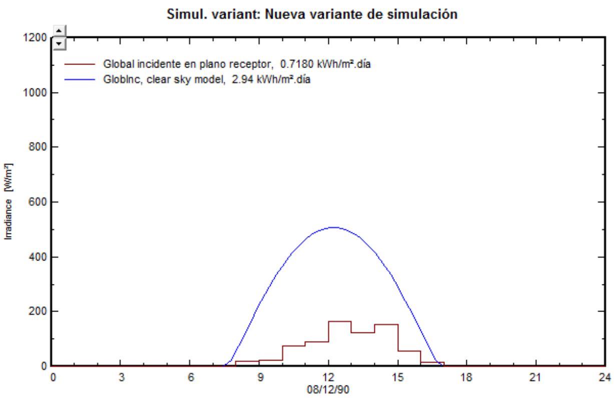
Average of global incident in collector plane: $\overline{x} = \frac{o.7172 + 8.688}{2} = 4.70\ \frac{Kwh}{m^2 day}$

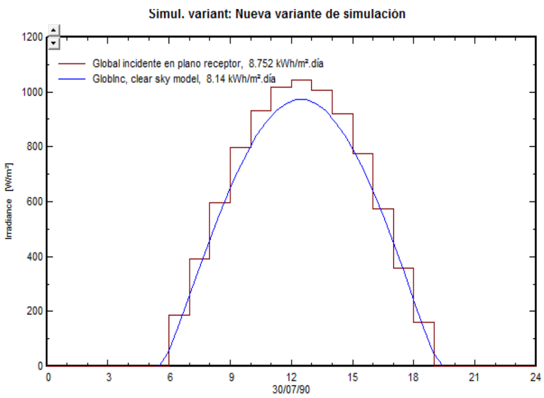
Average of hours of sunlight: $\overline{x} = \frac{9.5 + 13.4}{2} = 11.45\ hours\ of\ sunlight$

$$4.70 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.45\ hours\ of\ sunlight} = 0.41 \frac{Kwh}{m^2\ hour}$$

$$0.41 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 2.5 min = 0.0128\ Kwh$$

Point 1 of the graph/Position 4 of the solar cell:





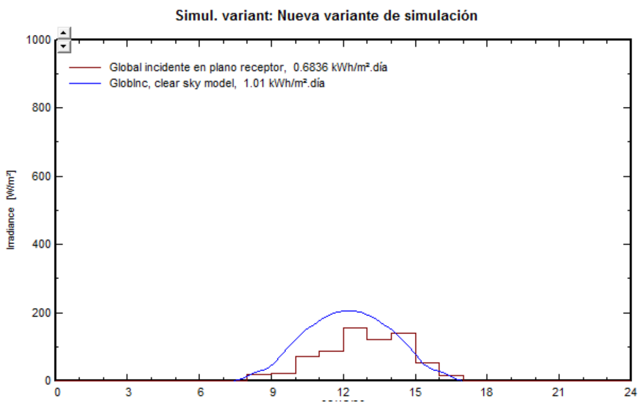
Average of global incident in collector plane: $\overline{x} = \frac{o.7160 + 8.752}{2} = 4.73\ \frac{Kwh}{m^2 day}$

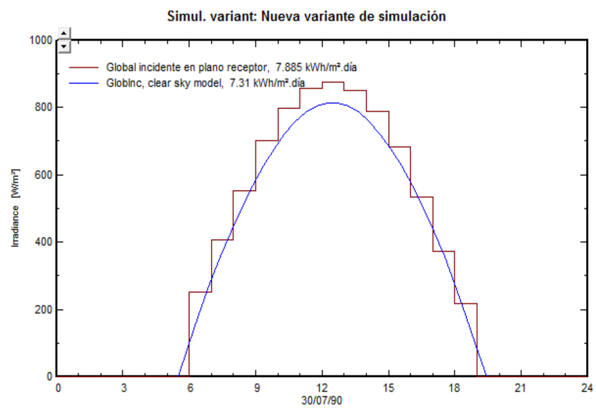
Average of hours of sunlight: $\overline{x} = \frac{9.5 + 13.2}{2} = 11.35\ hours\ of\ sunlight$

$$4.73 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.35\ hours\ of\ sunlight} = 0.42 \frac{Kwh}{m^2\ hour}$$

$$0.42 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times 2\ cells \times \frac{1 hour}{60\ min} \times 2.5 min = 0.02625\ Kwh$$

Point 1 of the graph/ Position 5 of the solar cells:





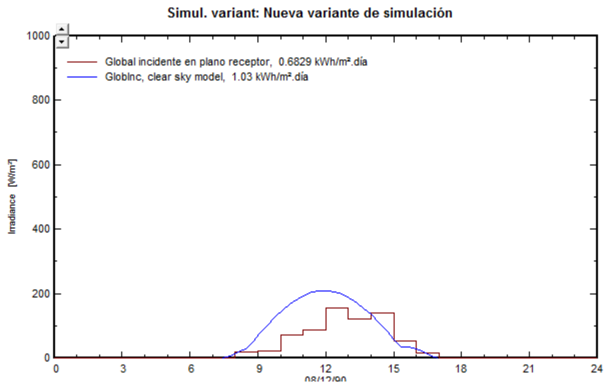
Average of global incident in collector plane: $\overline{x} = \dfrac{0.6836 + 7.885}{2} = 4.28\,\dfrac{Kwh}{m^2 day}$

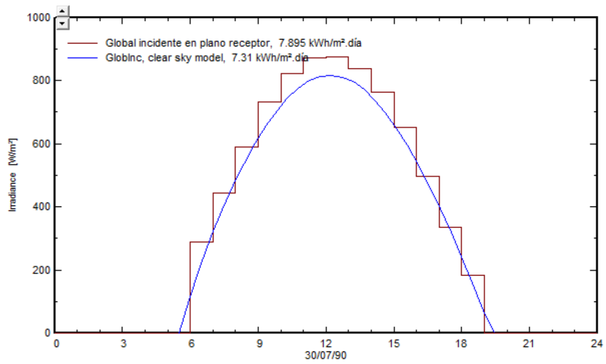
Average of hours of sunlight: $\overline{x} = \dfrac{8.6 + 13.5}{2} = 11.05\ hours\ of\ sunlight$

$$4.28\frac{Kwh}{m^2 day} \times \frac{1 day}{11.05\ hours\ of\ sunlight} = 0.38\frac{Kwh}{m^2\ hour}$$

$$0.38\frac{Kwh}{m^2\ hour} \times \frac{0.75m^2}{1\ cell} \times 2\ cells \times \frac{1 hour}{60\ min} \times 2.5min = 0.02375\ Kwh$$

Point 1 of the graph /Position 6 of the solar cell:





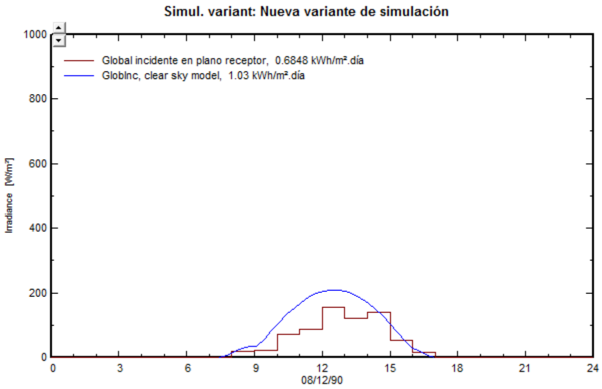
Average of global incident in collector plane: $\overline{x} = \dfrac{0.6829 + 7.895}{2} = 4.29\,\dfrac{Kwh}{m^2 day}$

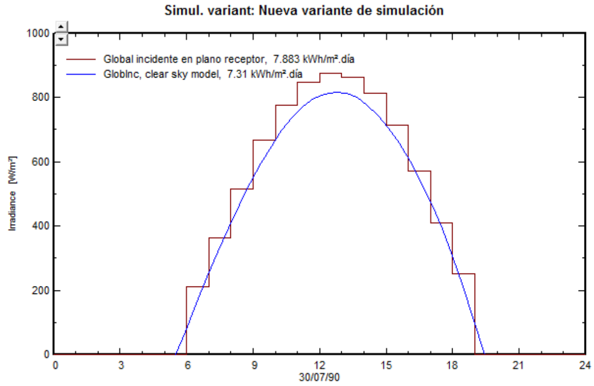
Average of hours of sunlight: $\overline{x} = \dfrac{8.6 + 13.6}{2} = 11.1\ hours\ of\ sunlight$

$$4.29\frac{Kwh}{m^2 day} \times \frac{1 day}{11.1\ hours\ of\ sunlight} = 0.38\frac{Kwh}{m^2\ hour}$$

$$0.38\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times\frac{1hour}{60\ min}\times 2.5min = 0.0118\ Kwh$$

Point 1 of the graph /Position 7 of the solar cell:





Average of global incident in collector plane: $\overline{x} = \frac{0.6848 + 7.863}{2} = 4.27\ \frac{Kwh}{m^2 day}$

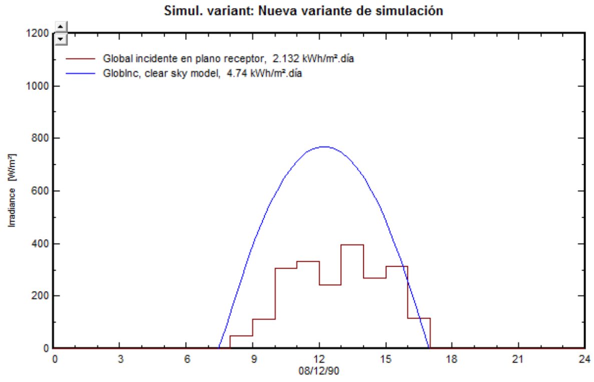
Average of hours of sunlight: $\overline{x} = \frac{8.6 + 13.6}{2} = 11.1\ hours\ of\ sunlight$

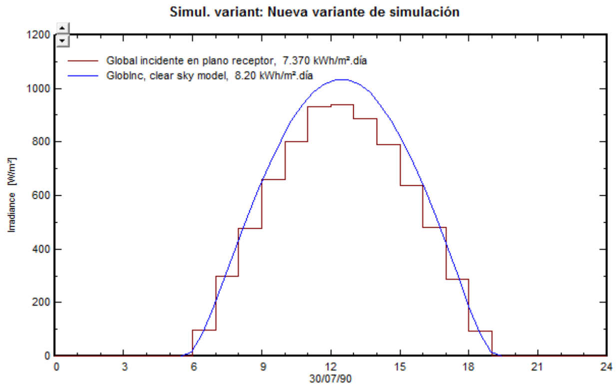
$$4.27\frac{Kwh}{m^2 day}\times\frac{1day}{11.1\ hours\ of\ sunlight} = 0.38\frac{Kwh}{m^2\ hour}$$

$$0.38\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times\frac{1hour}{60\ min}\times 2.5min = 0.0118\ Kwh$$

Total energy available from the Point 1 to the Point 2 of the graph= 0.100825 Kwh

Point 2 of the graph/ Position 1 of the solar cells:





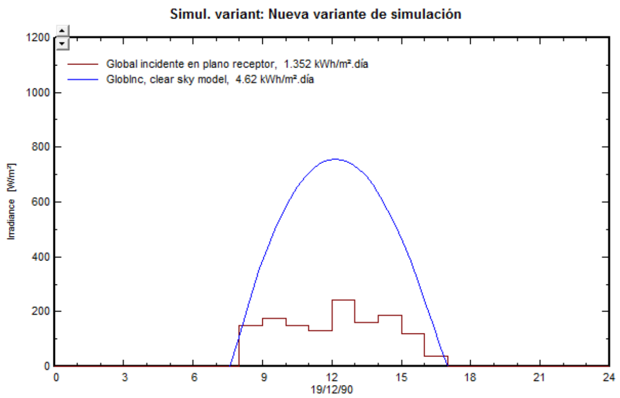
Average of global incident in collector plane: $\overline{x} = \frac{2.132 + 7.370}{2} = 4.75\ \frac{Kwh}{m^2 day}$

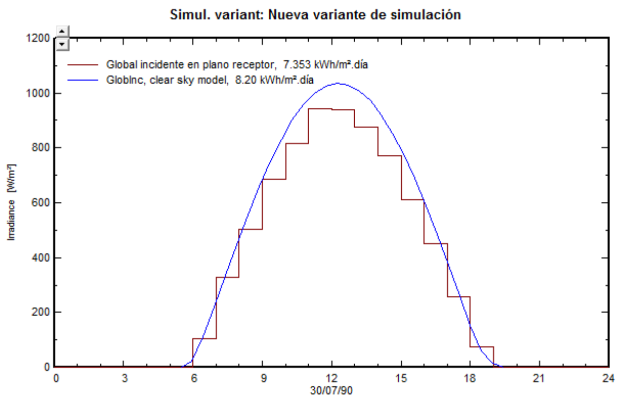
Average of hours of sunlight: $\overline{x} = \frac{9.5 + 13.4}{2} = 11.45\ hours\ of\ sunlight$

$$4.75 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.45\ hours\ of\ sunlight} = 0.41 \frac{Kwh}{m^2\ hour}$$

$$0.41 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times 2 cells \times \frac{1 hour}{60\ min} \times 2.5 min = 0.026\ Kwh$$

Point 2 of the graph /Position 2 of the solar cell:





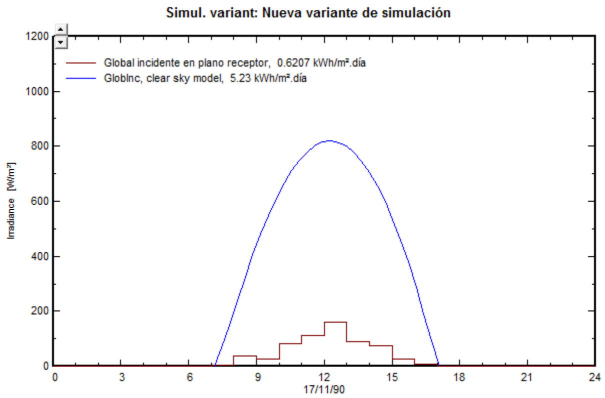
Average of global incident in collector plane: $\overline{x} = \frac{1.352 + 7.353}{2} = 4.35\ \frac{Kwh}{m^2 day}$

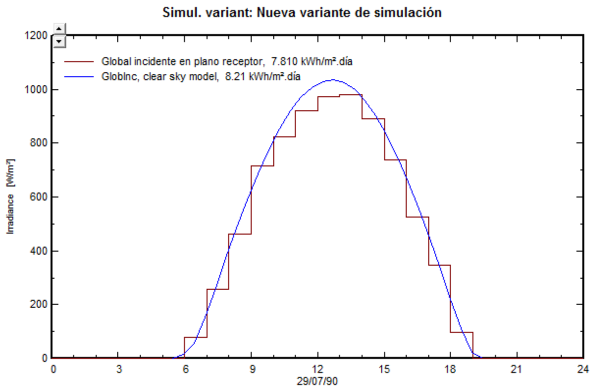
Average of hours of sunlight: $\overline{x} = \frac{9.5 + 13.4}{2} = 11.45\ hours\ of\ sunlight$

$$4.35\frac{Kwh}{m^2 day} \times \frac{1 day}{11.45\ hours\ of\ sunlight} = 0.38\frac{Kwh}{m^2\ hour}$$

$$0.38\frac{Kwh}{m^2\ hour} \times \frac{0.75m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 2.5min = 0.0119Kwh$$

Point 2 of the graph /Position 3 of the solar cell:





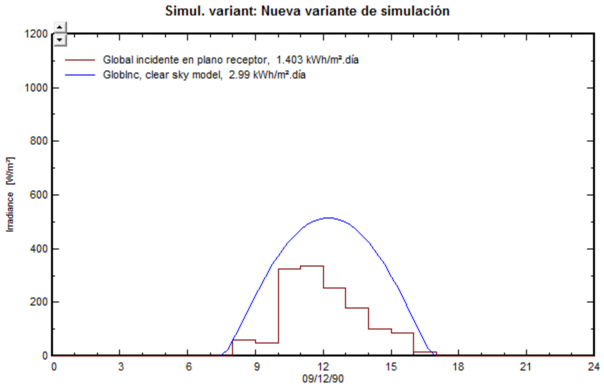
Average of global incident in collector plane: $\overline{x} = \frac{0.6207 + 7.810}{2} = 4.21\ \frac{Kwh}{m^2 day}$

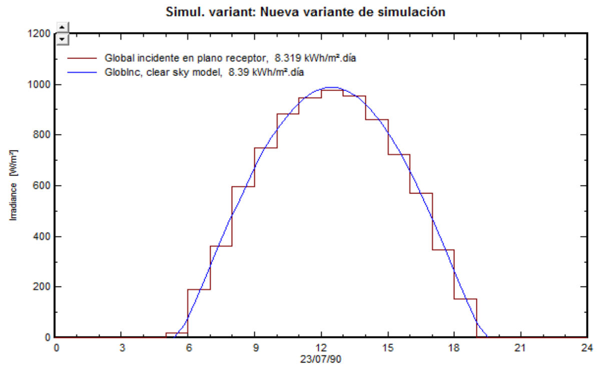
Average of hours of sunlight: $\overline{x} = \frac{9.75 + 13.4}{2} = 11.57\ hours\ of\ sunlight$

$$4.21\frac{Kwh}{m^2 day} \times \frac{1 day}{11.57\ hours\ of\ sunlight} = 0.37\frac{Kwh}{m^2\ hour}$$

$$0.37\frac{Kwh}{m^2\ hour} \times \frac{0.75m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 2.5min = 0.0113Kwh$$

Point 2 of the graph /Position 4 of the solar cell:





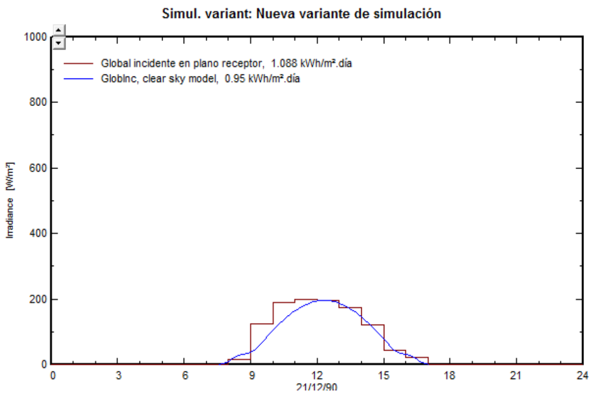
Average of global incident in collector plane: $\overline{x} = \frac{1.403 + 8.319}{2} = 4.861 \frac{Kwh}{m^2 day}$

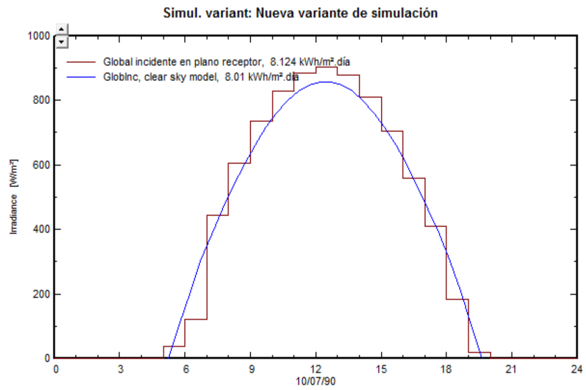
Average of hours of sunlight: $\overline{x} = \frac{9.75 + 13.4}{2} = 11.57 \; hours \; of \; sunlight$

$$4.21 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.57 \; hours \; of \; sunlight} = 0.37 \frac{Kwh}{m^2 \; hour}$$

$$0.37 \frac{Kwh}{m^2 \; hour} \times \frac{0.75 m^2}{1 \; cell} \times 2 cells \times \frac{1 hour}{60 \; min} \times 2.5 min = 0.0227 Kwh$$

Point 2 of the graph / Position 5 of the solar cells:





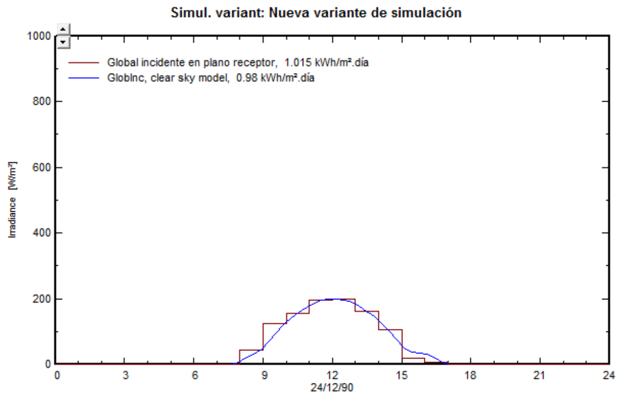
Average of global incident in collector plane: $\overline{x} = \frac{1.088 + 8.124}{2} = 4.606 \frac{Kwh}{m^2 day}$

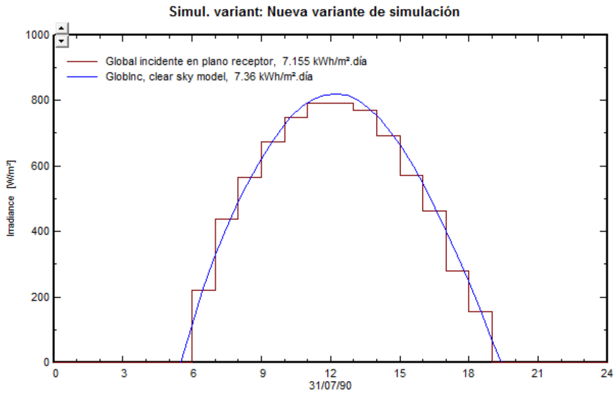
Average of hours of sunlight: $\overline{x} = \frac{9 + 14.5}{2} = 11.75 \; hours \; of \; sunlight$

$$4.606 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.75 \; hours \; of \; sunlight} = 0.39 \frac{Kwh}{m^2 \; hour}$$

$$0.39\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times 2cells\times\frac{1hour}{60\ min}\times 2.5min = 0.0246Kwh$$

Point 2 of the graph/ Position 6 of the solar cell:





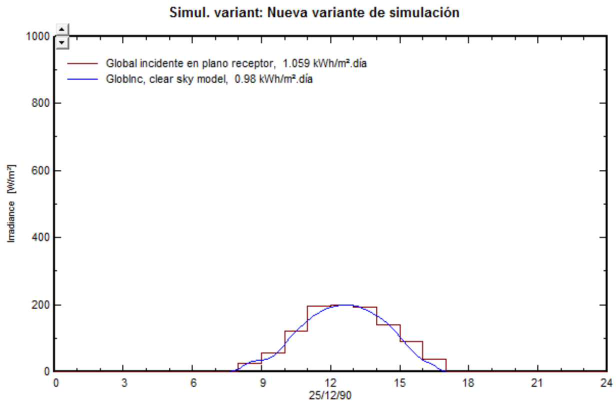
Average of global incident in collector plane: $\overline{x} = \frac{1.015 + 7.155}{2} = 4.085\frac{Kwh}{m^2 day}$

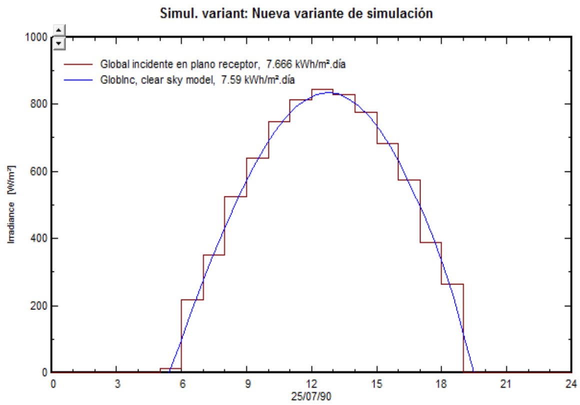
Average of hours of sunlight: $\overline{x} = \frac{9 + 13.6}{2} = 11.3\ hours\ of\ sunlight$

$$4.085\frac{Kwh}{m^2 day}\times\frac{1day}{11.3\ hours\ of\ sunlight} = 0.36\frac{Kwh}{m^2\ hour}$$

$$0.36\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times\frac{1hour}{60\ min}\times 2.5min = 0.0113Kwh$$

Point 2 of the graph /Position 7 of the solar cell:





Average of global incident in collector plane: $\overline{x} = \frac{1.059 + 7.668}{2} = 4.36 \frac{Kwh}{m^2 day}$

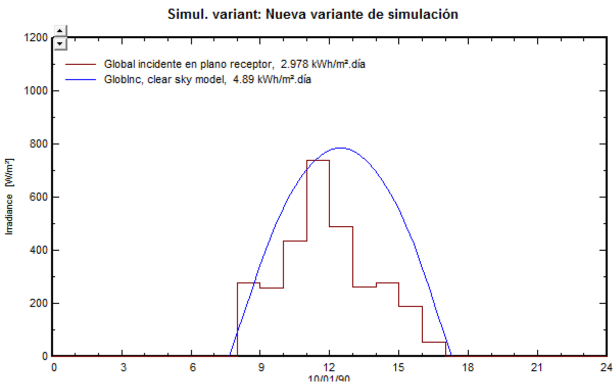
Average of hours of sunlight: $\overline{x} = \frac{9 + 14}{2} = 11.5 \text{ hours of sunlight}$

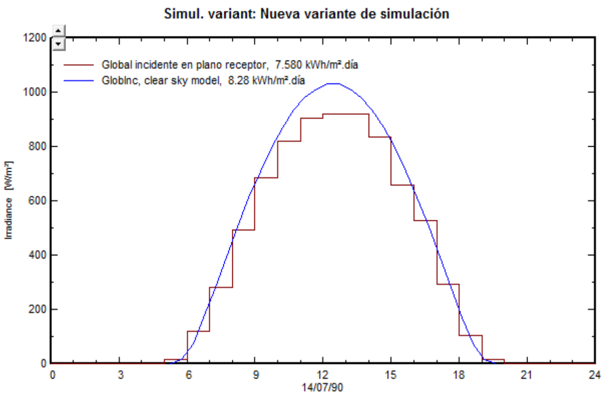
$$4.36 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.5 \text{ hours of sunlight}} = 0.38 \frac{Kwh}{m^2 \text{ hour}}$$

$$0.38 \frac{Kwh}{m^2 \text{ hour}} \times \frac{0.75 m^2}{1 \text{ cell}} \times \frac{1 \text{hour}}{60 \text{ min}} \times 2.5 min = 0.0119 Kwh$$

Total energy available from the Point 1 to the Point 2 of the graph= 0.1197Kwh

Point 3 of the graph/ Position 1of the solar cells:





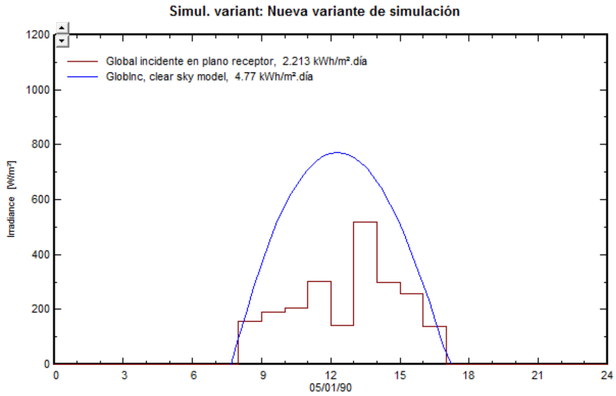
Average of global incident in collector plane: $\overline{x} = \frac{2.978 + 7.580}{2} = 5.3 \frac{Kwh}{m^2 day}$

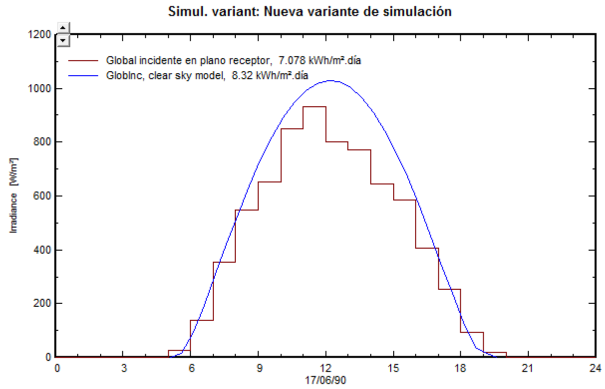
Average of hours of sunlight: $\overline{x} = \frac{9 + 14}{2} = 11.5 \text{ hours of sunlight}$

$$5.3\frac{Kwh}{m^2day}\times\frac{1day}{11.5\ hours\ of\ sunlight}=0.46\frac{Kwh}{m^2\ hour}$$

$$0.46\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times 2cells\times\frac{1hour}{60\ min}\times 2.5min=0.1716Kwh$$

Point 3 of the graph/ Position 2 of the solar cell:





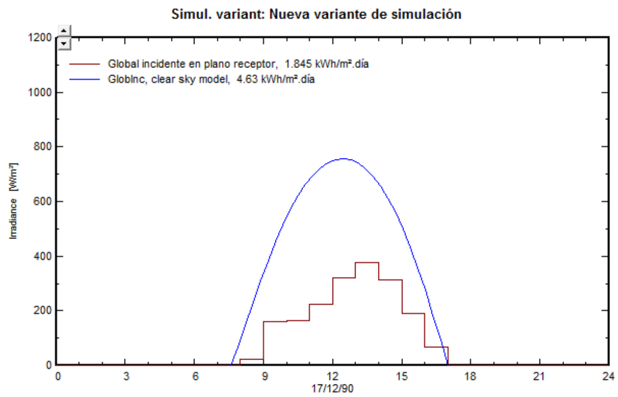
Average of global incident in collector plane: $\overline{x}=\frac{2.213+7.078}{2}=4.64\frac{Kwh}{m^2day}$

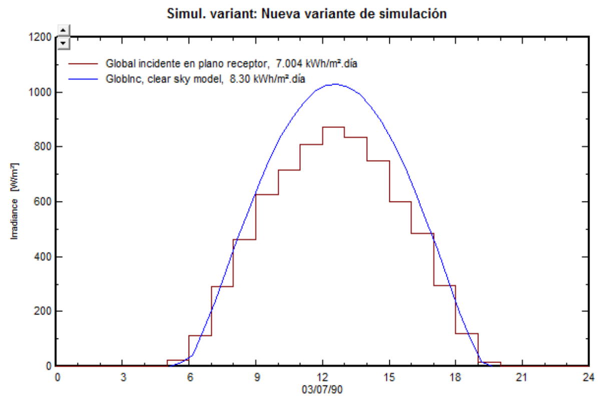
Average of hours of sunlight: $\overline{x}=\frac{8.6+14}{2}=11.3\ hours\ of\ sunlight$

$$4.64\frac{Kwh}{m^2day}\times\frac{1day}{11.3hours\ of\ sunlight}=0.41\frac{Kwh}{m^2\ hour}$$

$$0.41\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times\frac{1hour}{60\ min}\times 15min=0.0768Kwh$$

Point 3 of the graph/ Position 3 of the solar cell:





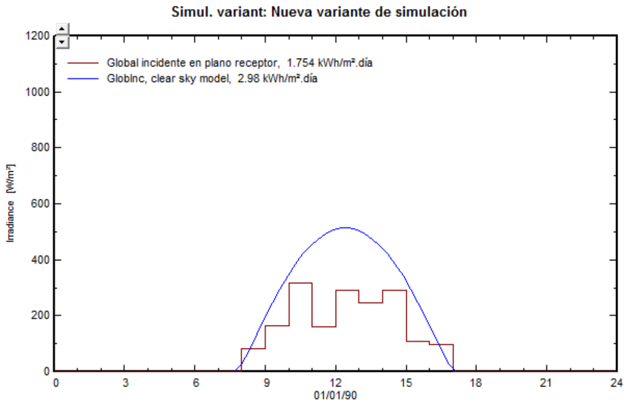
Average of global incident in collector plane: $\bar{x} = \frac{1.845 + 7.004}{2} = 4.42 \frac{Kwh}{m^2 day}$

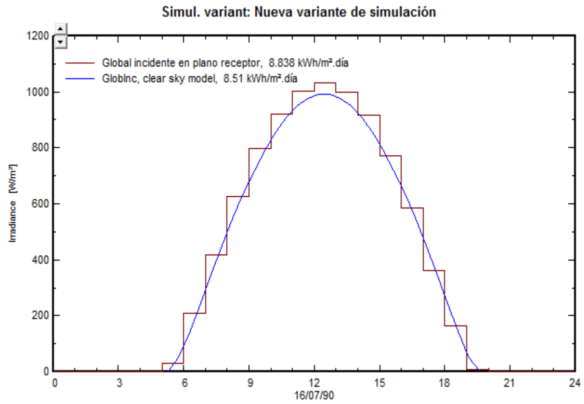
Average of hours of sunlight: $\bar{x} = \frac{9.5 + 14}{2} = 11.75\ hours\ of\ sunlight$

$$4.42 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.75 hours\ of\ sunlight} = 0.376 \frac{Kwh}{m^2\ hour}$$

$$0.376 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 15 min = 0.0705 Kwh$$

Point 3 of the graph / Position 4 of the solar cells:





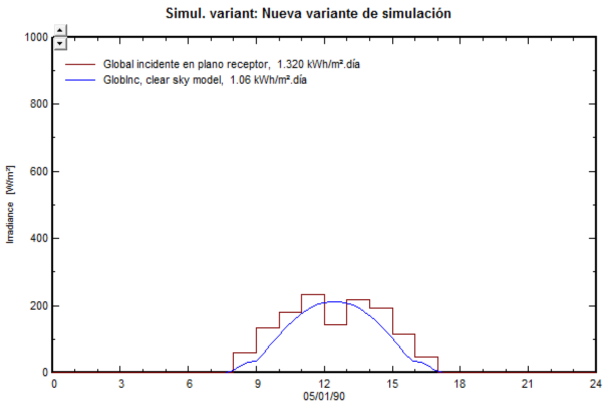
Average of global incident in collector plane: $\bar{x} = \frac{1.754 + 8.838}{2} = 5.29 \frac{Kwh}{m^2 day}$

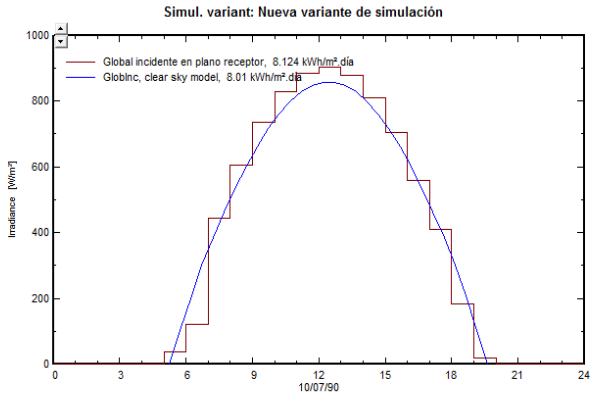
Average of hours of sunlight: $\bar{x} = \frac{9.2 + 14}{2} = 11.6\ hours\ of\ sunlight$

$$5.29 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.6 hours\ of\ sunlight} = 0.456 \frac{Kwh}{m^2\ hour}$$

$$0.456 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times 2\ cells \times \frac{1 hour}{60\ min} \times 15 min = 0.1710 Kwh$$

Point 3 of the graph/ Position 5 of the solar cell:





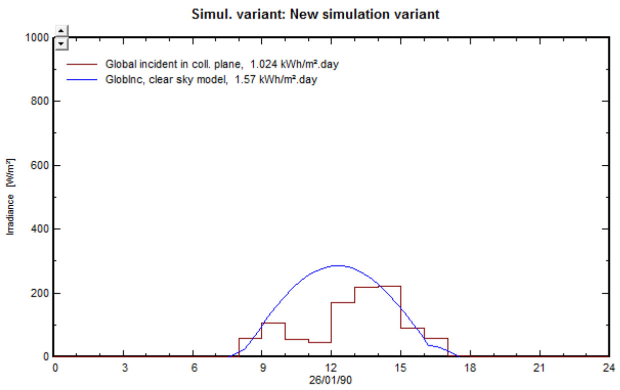
Average of global incident in collector plane: $\overline{x} = \frac{1.320 + 8.124}{2} = 4.72 \frac{Kwh}{m^2 day}$

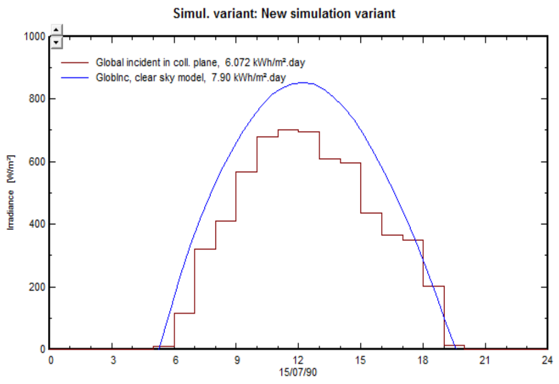
Average of hours of sunlight: $\overline{x} = \frac{9 + 14.2}{2} = 11.6 \text{ hours of sunlight}$

$$4.72 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.6 \text{ hours of sunlight}} = 0.407 \frac{Kwh}{m^2\ hour}$$

$$0.407 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times 2\ cells \times \frac{1 hour}{60\ min} \times 15 min = 0.1525 Kwh$$

Point 3 of the graph / Position 6 of the solar cell:





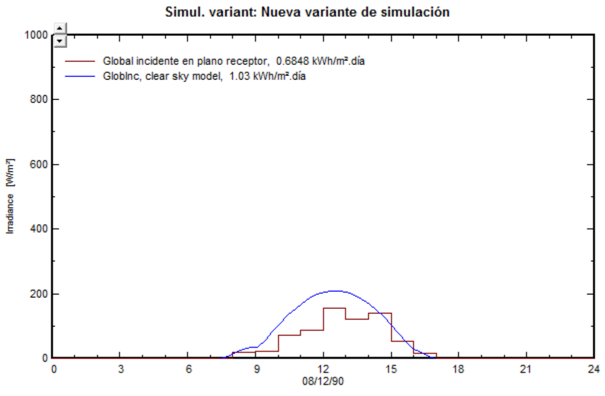
Average of global incident in collector plane: $\overline{x} = \frac{1.024 + 6.072}{2} = 3.656 \frac{Kwh}{m^2 day}$

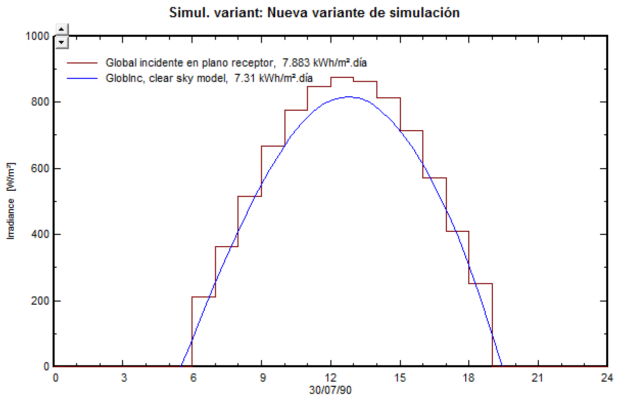
Average of hours of sunlight: $\overline{x} = \frac{9.4 + 15.75}{2} = 12.57 \text{ hours of sunlight}$

$$3.66\frac{Kwh}{m^2day}\times\frac{1day}{12.57hours\ of\ sunlight}=0.29\frac{Kwh}{m^2\ hour}$$

$$0.29\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times\frac{1hour}{60\ min}\times 15min=0.0546Kwh$$

Point 3 of the graph/ Position 7 of the solar cell:





Average of global incident in collector plane: $\bar{x}=\frac{0.6848+7.863}{2}=4.27\ \frac{Kwh}{m^2day}$

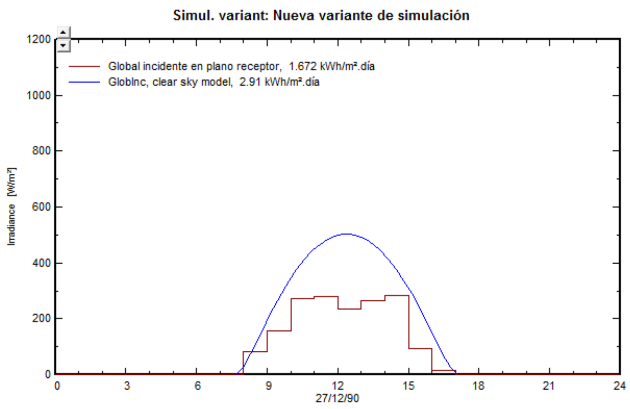
Average of hours of sunlight: $\bar{x}=\frac{8.6+13.6}{2}=11.1\ hours\ of\ sunlight$

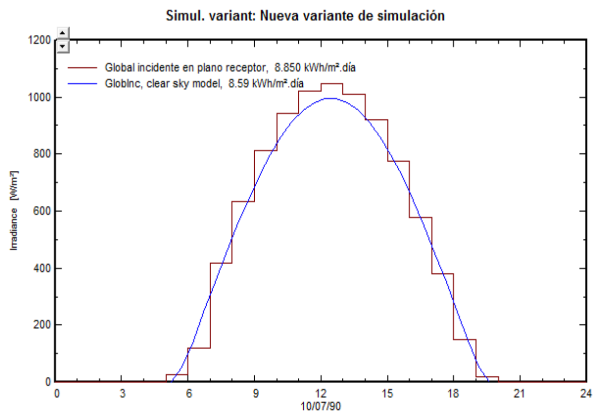
$$4.27\frac{Kwh}{m^2day}\times\frac{1day}{11.1\ hours\ of\ sunlight}=0.38\frac{Kwh}{m^2\ hour}$$

$$0.38\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times\frac{1hour}{60\ min}\times 2.5min=0.0118\ Kwh$$

Total energy available from the Point 2 to the Point 3 of the graph = 0.7088 Kwh

Point 4 of the graph/ Position 1 of the solar cells:





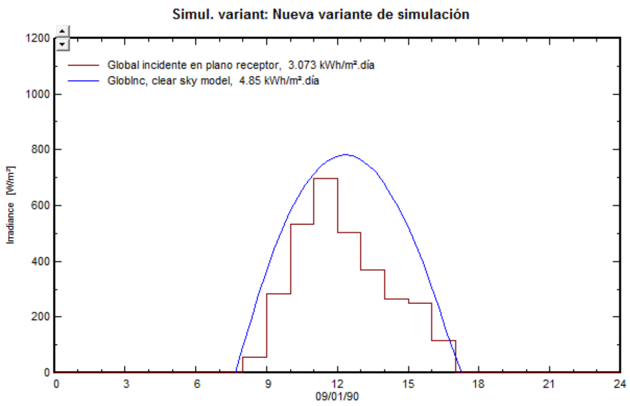
Average of global incident in collector plane: $\bar{x} = \frac{1.672 + 8.850}{2} = 5.261 \frac{Kwh}{m^2 day}$

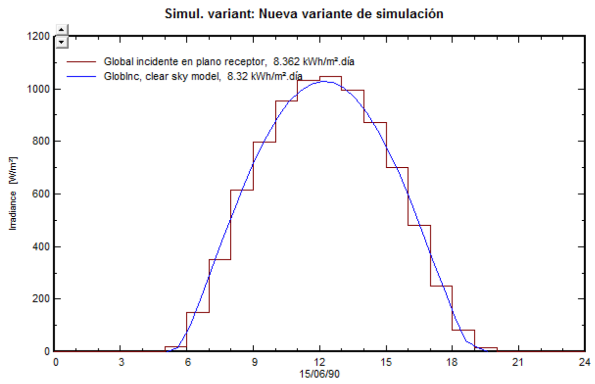
Average of hours of sunlight: $\bar{x} = \frac{9.2 + 14.75}{2} = 11.98\ hours\ of\ sunlight$

$$5.261 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.98\ hours\ of\ sunlight} = 0.44 \frac{Kwh}{m^2\ hour}$$

$$0.44 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times 2\ cells \times \frac{1 hour}{60\ min} \times 15 min = 0.1647 Kwh$$

Point 4 of the graph / Position 2 of the solar cell:





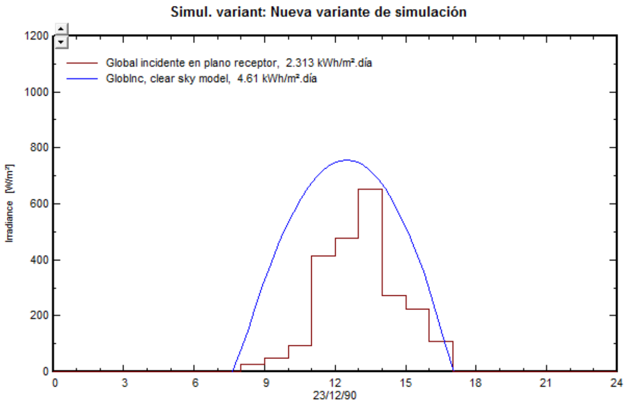
Average of global incident in collector plane: $\bar{x} = \frac{3.073 + 8.362}{2} = 5.72 \frac{Kwh}{m^2 day}$

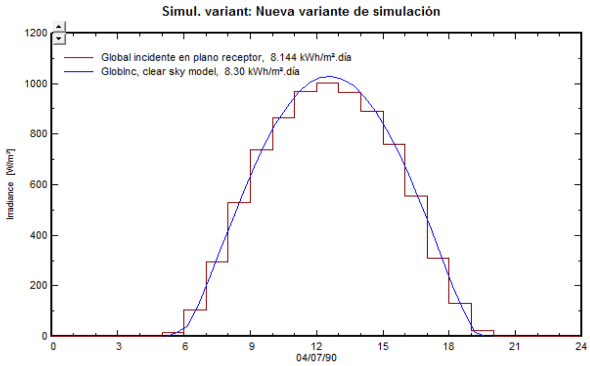
Average of hours of sunlight: $\bar{x} = \frac{9.4 + 14}{2} = 11.7 hours\ of\ sunlight$

$$5.72 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.7 hours\ of\ sunlight} = 0.49 \frac{Kwh}{m^2\ hour}$$

$$0.49\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times\frac{1hour}{60\ min}\times 15min = 0.091Kwh$$

Point 4 of the graph/ Position 3 of the solar cell:





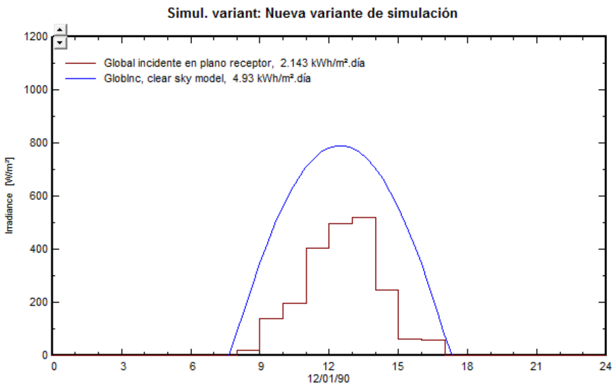
Average of global incident in collector plane: $\overline{x} = \frac{2.313 + 8.144}{2} = 5.23\frac{Kwh}{m^2 day}$

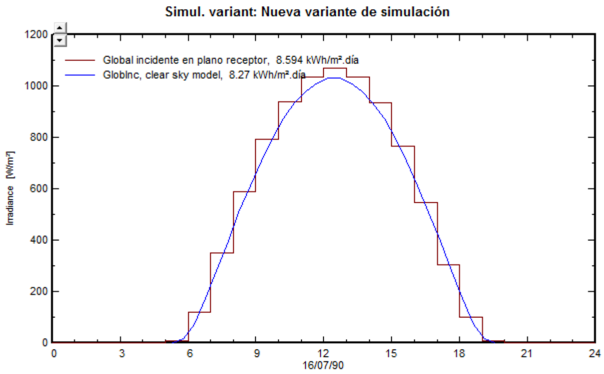
Average of hours of sunlight: $\overline{x} = \frac{9.2 + 14}{2} = 11.6 hours\ of\ sunlight$

$$5.23\frac{Kwh}{m^2 day}\times\frac{1day}{11.6hours\ of\ sunlight} = 0.45\frac{Kwh}{m^2\ hour}$$

$$0.45\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times\frac{1hour}{60\ min}\times 15min = 0.0845Kwh$$

Point 4 of the graph / Position 4 of the solar cells.





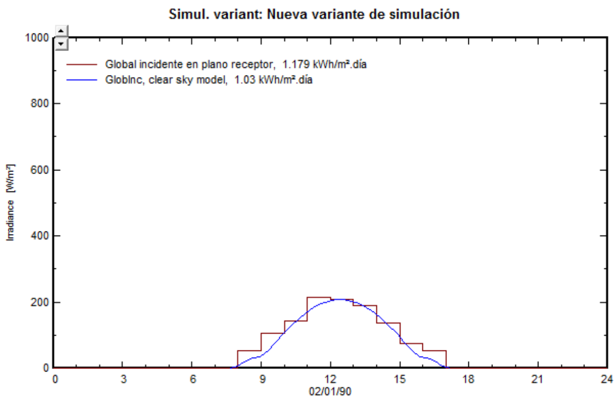
Average of global incident in collector plane: $\overline{x} = \frac{2.143 + 8.594}{2} = 5.37 \frac{Kwh}{m^2 day}$

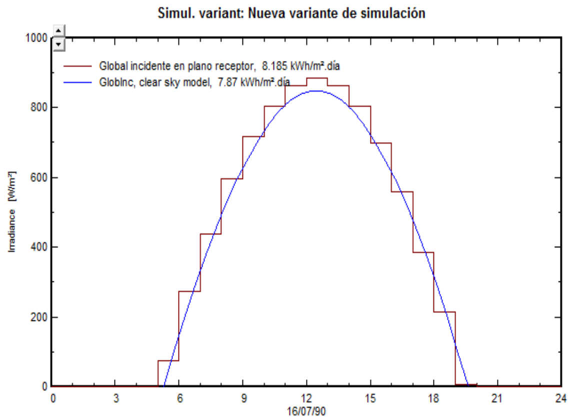
Average of hours of sunlight: $\overline{x} = \frac{9.4 + 15.2}{2} = 12.3\ hours\ of\ sunlight$

$$5.37 \frac{Kwh}{m^2 day} \times \frac{1 day}{12.3 hours\ of\ sunlight} = 0.44 \frac{Kwh}{m^2\ hour}$$

$$0.44 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times 2\ cells \times \frac{1 hour}{60\ min} \times 15 min = 0.1637 Kwh$$

Point 4 of the graph/ Position 5 of the solar cell:





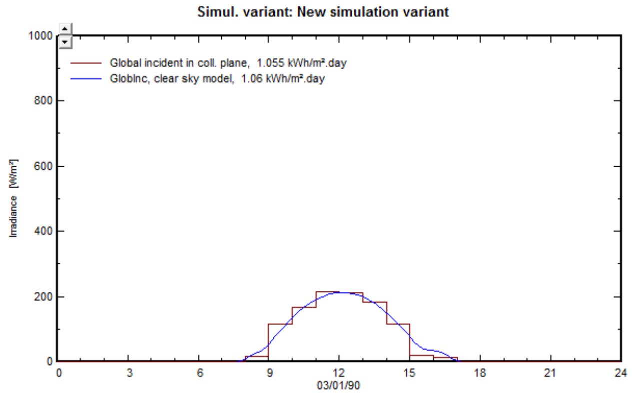
Average of global incident in collector plane: $\overline{x} = \frac{1.179 + 8.185}{2} = 4.68 \frac{Kwh}{m^2 day}$

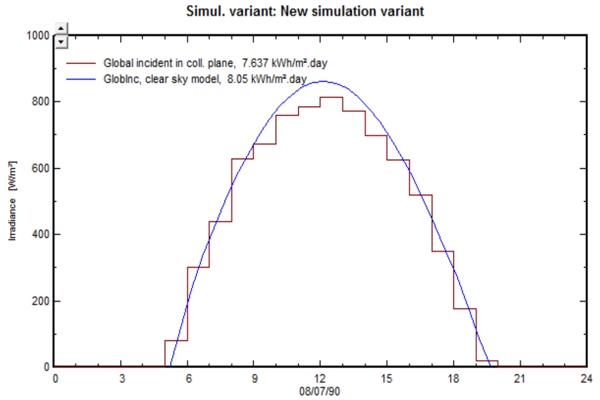
Average of hours of sunlight: $\overline{x} = \frac{9 + 14}{2} = 11.5\ hours\ of\ sunlight$

$$4.68\frac{Kwh}{m^2 day}\times\frac{1 day}{11.5\ hours\ of\ sunlight}=0.41\frac{Kwh}{m^2\ hour}$$

$$0.41\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times\frac{1 hour}{60\ min}\times 15 min=0.0768 Kwh$$

Point 4 of the graph/ Position 6 of the solar cell:





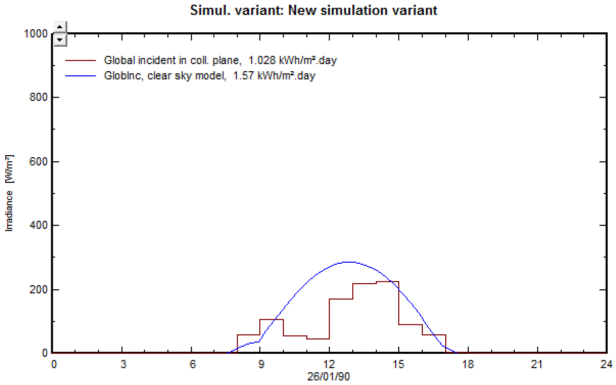
Average of global incident in collector plane: $\overline{x}=\frac{1.055+7.637}{2}=4.35\frac{Kwh}{m^2 day}$

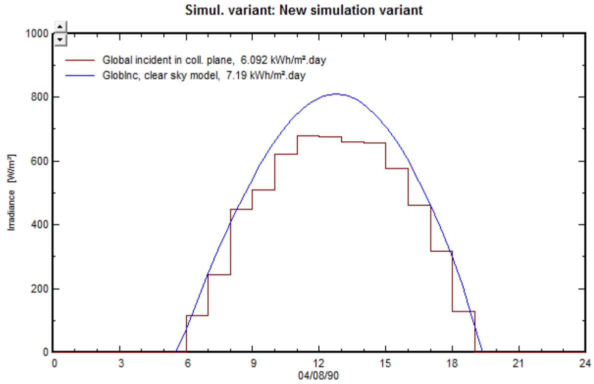
Average of hours of sunlight: $\overline{x}=\frac{9+14}{2}=11.5\ hours\ of\ sunlight$

$$4.35\frac{Kwh}{m^2 day}\times\frac{1 day}{11.5\ hours\ of\ sunlight}=0.38\frac{Kwh}{m^2\ hour}$$

$$0.38\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times\frac{1 hour}{60\ min}\times 15 min=0.0709 Kwh$$

Point 4 of the graph/ Position 7 of the solar cell:





Average of global incident in collector plane: $\bar{x} = \frac{1.028 + 6.092}{2} = 3.56 \frac{Kwh}{m^2 day}$

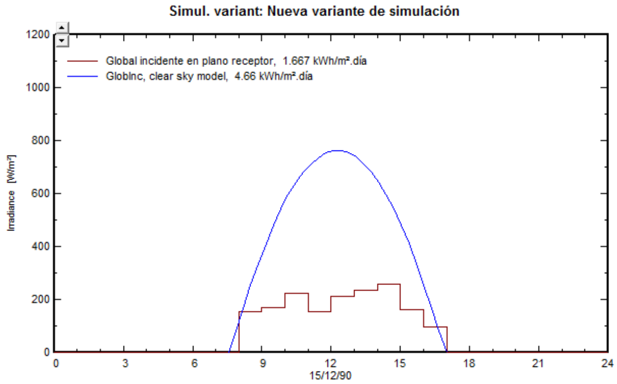
Average of hours of sunlight: $\bar{x} = \frac{9.5 + 14}{2} = 11.75 \text{ hours of sunlight}$

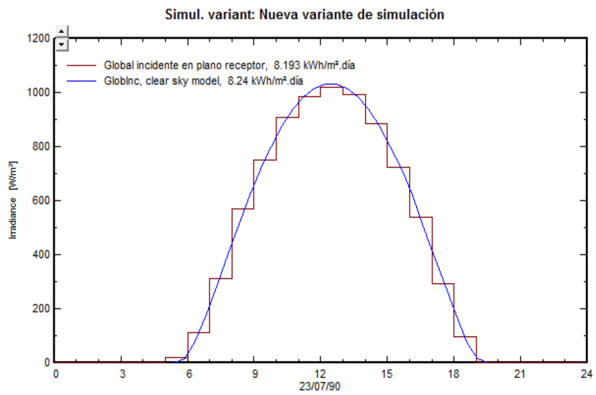
$$3.56 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.75 \text{ hours of sunlight}} = 0.30 \frac{Kwh}{m^2 \text{ hour}}$$

$$0.3029 \frac{Kwh}{m^2 \text{ hour}} \times \frac{0.75 m^2}{1 \text{ cell}} \times \frac{1 hour}{60 \text{ min}} \times 15 min = 0.0568 Kwh$$

Total energy available from the Point 3 to the Point 4 of the graph= 0.7084 Kwh

Point 5 of the graph/ Position 1 of the solar cells:





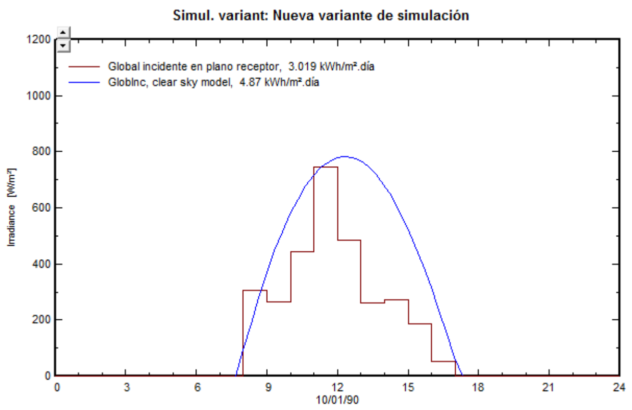
Average of global incident in collector plane: $\bar{x} = \frac{1.667 + 8.193}{2} = 4.93 \frac{Kwh}{m^2 day}$

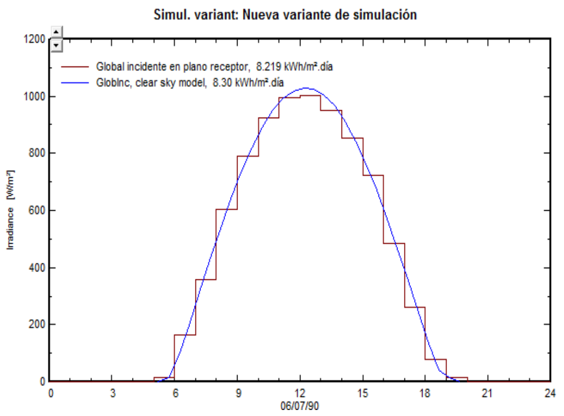
Average of hours of sunlight: $\overline{x} = \dfrac{9.5 + 13}{2} = 11.25\ \boldsymbol{hours\ of\ sunlight}$

$$4.93\frac{Kwh}{m^2 day} \times \frac{1 day}{11.25\ \boldsymbol{hours\ of\ sunlight}} = 0.44\frac{Kwh}{m^2\ \boldsymbol{hour}}$$

$$0.44\frac{Kwh}{m^2\ \boldsymbol{hour}} \times \frac{0.75m^2}{1\ cell} \times 2\ cells \times \frac{1 \boldsymbol{hour}}{60\ min} \times 15min = 0.165Kwh$$

Point 5 of the graph /Position 2 of the solar cell:





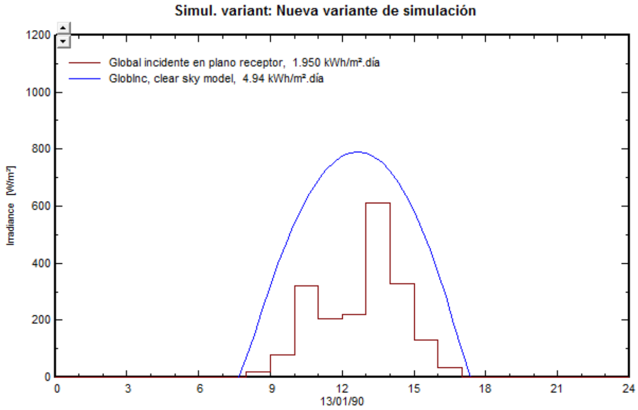
Average of global incident in collector plane: $\overline{x} = \dfrac{3.019 + 8.219}{2} = 5.619\dfrac{Kwh}{m^2 day}$

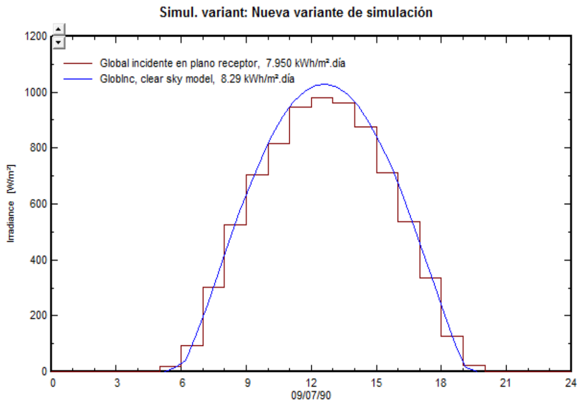
Average of hours of sunlight: $\overline{x} = \dfrac{10 + 14.2}{2} = 12.1\ \boldsymbol{hours\ of\ sunlight}$

$$5.619\frac{Kwh}{m^2 day} \times \frac{1 day}{12.1\ \boldsymbol{hours\ of\ sunlight}} = 0.464\frac{Kwh}{m^2\ \boldsymbol{hour}}$$

$$0.464\frac{Kwh}{m^2\ \boldsymbol{hour}} \times \frac{0.75m^2}{1\ cell} \times \frac{1 \boldsymbol{hour}}{60\ min} \times 15min = 0.082Kwh$$

Point 5 of the graph / Position 3 of the solar cell:





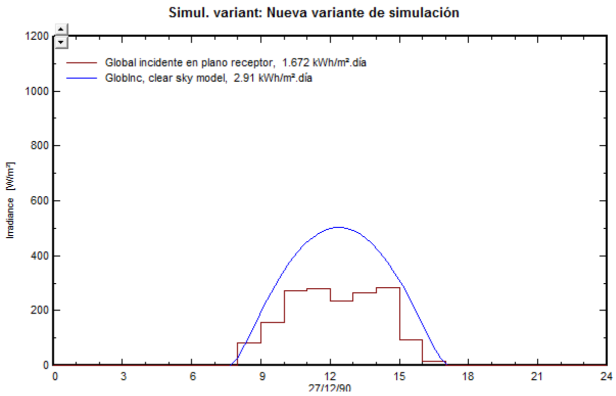
Average of global incident in collector plane: $\overline{x} = \frac{1.950 + 7.950}{2} = 4.95 \frac{Kwh}{m^2 day}$

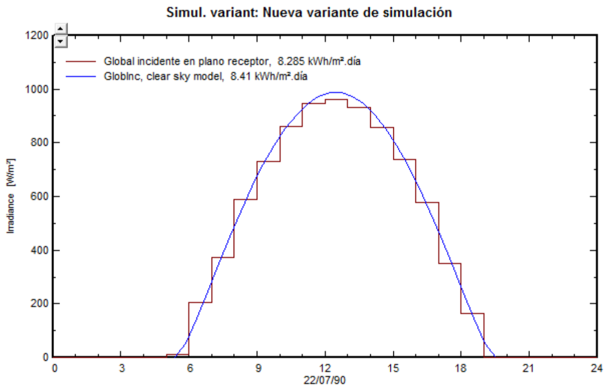
Average of hours of sunlight: $\overline{x} = \frac{9.4 + 14}{2} = 11.7\ hours\ of\ sunlight$

$$4.95 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.7\ hours\ of\ sunlight} = 0.42 \frac{Kwh}{m^2\ hour}$$

$$0.42 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 15 min = 0.0793 Kwh$$

Point 5 of the graph/ Position 4 of the solar cells:





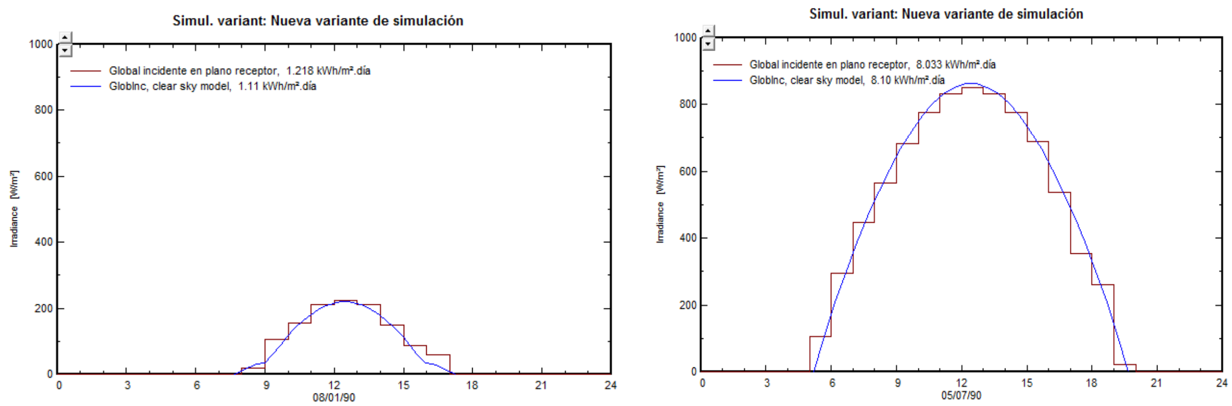
Average of global incident in collector plane: $\overline{x} = \frac{1.672 + 8.285}{2} = 4.98 \frac{Kwh}{m^2 day}$

Average of hours of sunlight: $\overline{x} = \frac{9.2 + 15.2}{2} = 12.2\ hours\ of\ sunlight$

$$4.98 \frac{Kwh}{m^2 day} \times \frac{1 day}{12.2\ hours\ of\ sunlight} = 0.408 \frac{Kwh}{m^2\ hour}$$

$$0.408 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times 2 cells \times \frac{1 hour}{60\ min} \times 15 min = 0.153 Kwh$$

Point 5 of the graph/ Position 5 of the solar cells:



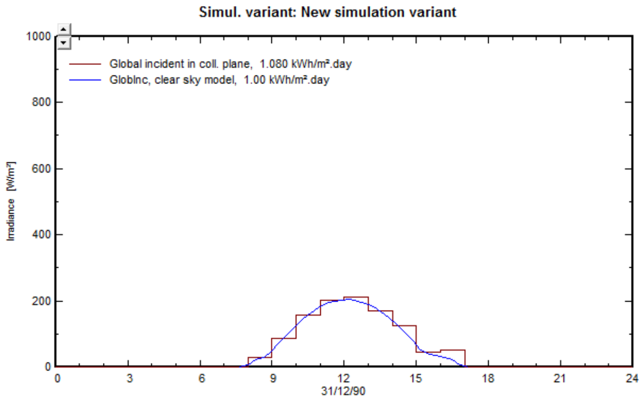
Average of global incident in collector plane: $\overline{x} = \frac{1.218 + 8.033}{2} = 4.63 \frac{Kwh}{m^2 day}$

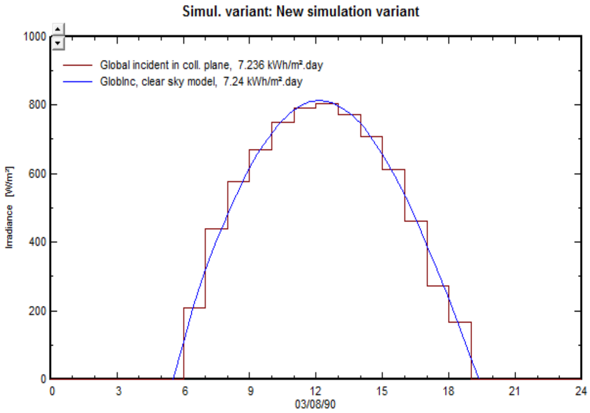
Average of hours of sunlight: $\overline{x} = \frac{9.2 + 14}{2} = 11.6\ hours\ of\ sunlight$

$$4.63 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.6\ hours\ of\ sunlight} = 0.399 \frac{Kwh}{m^2\ hour}$$

$$0.399 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 15 min = 0.0748 Kwh$$

Point 5 of the graph / Position 6 of the solar cell:





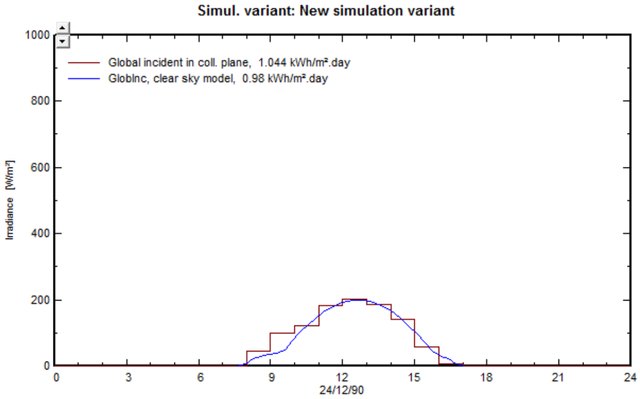
Average of global incident in collector plane: $\bar{x} = \frac{1.080 + 7.236}{2} = 4.16 \frac{Kwh}{m^2 day}$

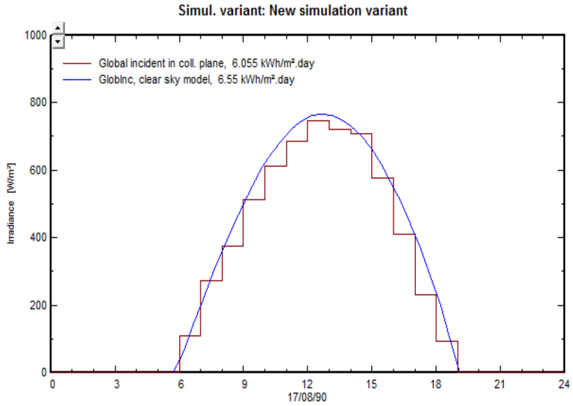
Average of hours of sunlight: $\bar{x} = \frac{9 + 14.5}{2} = 11.75\ hours\ of\ sunlight$

$$4.16 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.75\ hours\ of\ sunlight} = 0.354 \frac{Kwh}{m^2\ hour}$$

$$0.354 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 15 min = 0.0663 Kwh$$

Point 6 of the graph/ Position 7 of the solar cell:





Average of global incident in collector plane: $\bar{x} = \frac{1.044 + 6.055}{2} = 3.55 \frac{Kwh}{m^2 day}$

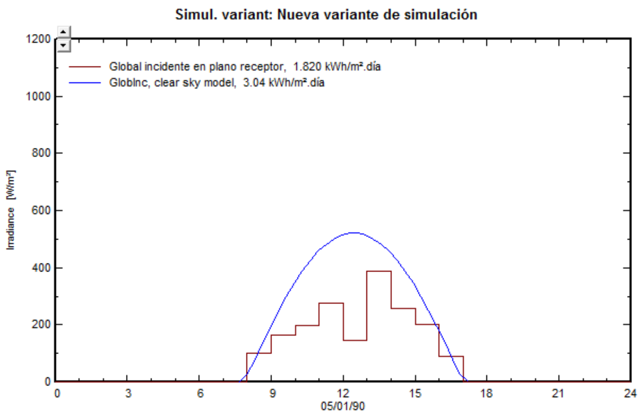
Average of hours of sunlight: $\bar{x} = \frac{9 + 14.5}{2} = 11.75\ hours\ of\ sunlight$

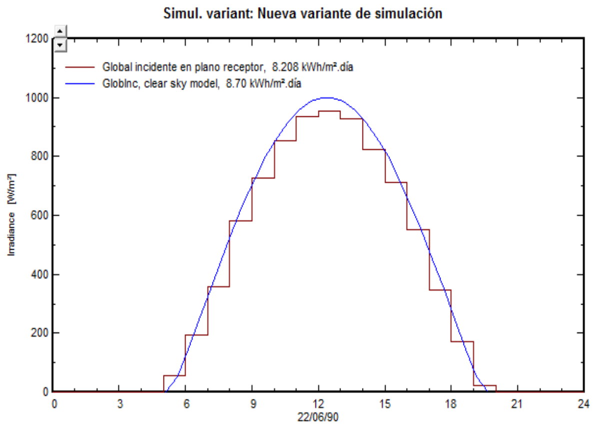
$$3.55 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.75\ hours\ of\ sunlight} = 0.302 \frac{Kwh}{m^2\ hour}$$

$$0.302 \frac{Kwh}{m^2\ hour} \times \frac{0.75m^2}{1\ cell} \times \frac{1hour}{60\ min} \times 15min = 0.0566Kwh$$

Total energy available from the Point 5 to the point 6 of the graph = 0.6727 Kwh

Point 6 of the graph/ Position 1 of the solar cells:





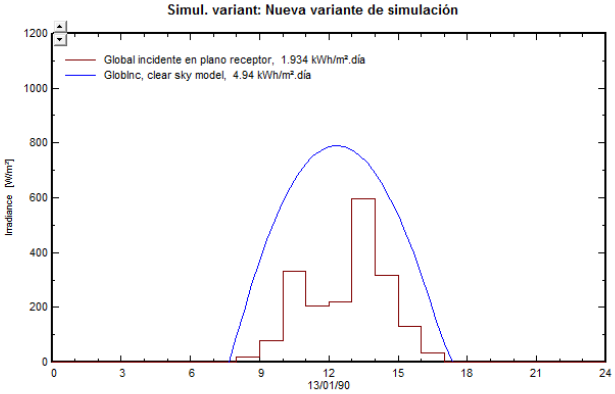
Average of global incident in collector plane: $\bar{x} = \frac{1.820 + 8.208}{2} = 5.014 \frac{Kwh}{m^2 day}$

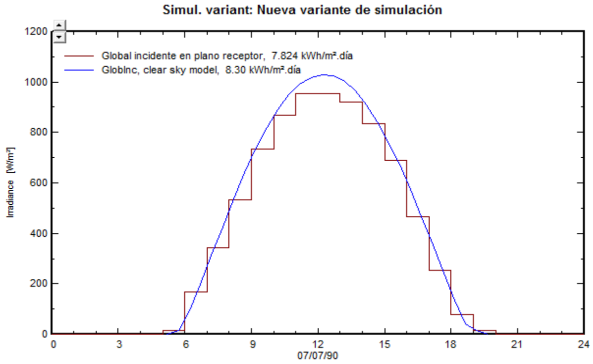
Average of hours of sunlight: $\bar{x} = \frac{9.6 + 14}{2} = 11.8\ hours\ of\ sunlight$

$$5.014 \frac{Kwh}{m^2 day} \times \frac{1day}{11.8\ hours\ of\ sunlight} = 0.4249 \frac{Kwh}{m^2\ hour}$$

$$0.4249 \frac{Kwh}{m^2\ hour} \times \frac{0.75m^2}{1\ cell} \times 2cells \times \frac{1hour}{60\ min} \times 2.5min = 0.0265Kwh$$

Point 6 of the graph/ Position 2 of the solar cell:





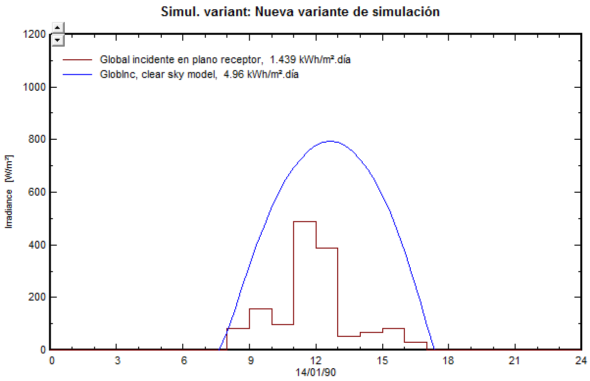
Average of global incident in collector plane: $\overline{x} = \frac{1.934 + 7.824}{2} = 4.879 \frac{Kwh}{m^2 day}$

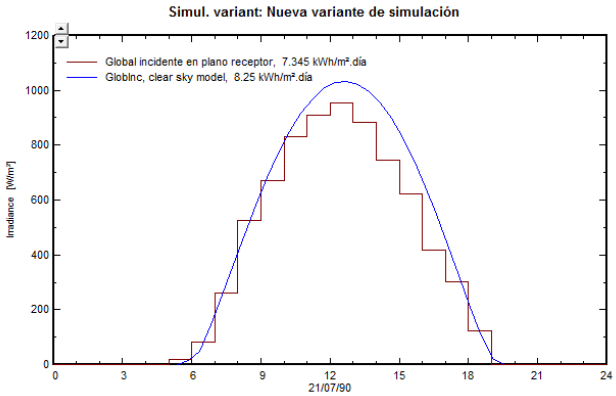
Average of hours of sunlight: $\overline{x} = \frac{9.5 + 14}{2} = 11.75 \text{ hours of sunlight}$

$$4.879 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.75 \text{ hours of sunlight}} = 0.415 \frac{Kwh}{m^2\ hour}$$

$$0.415 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 2.5 min = 0.0129\ Kwh$$

Point 6 of the graphs/ Position 3 of the solar cells:





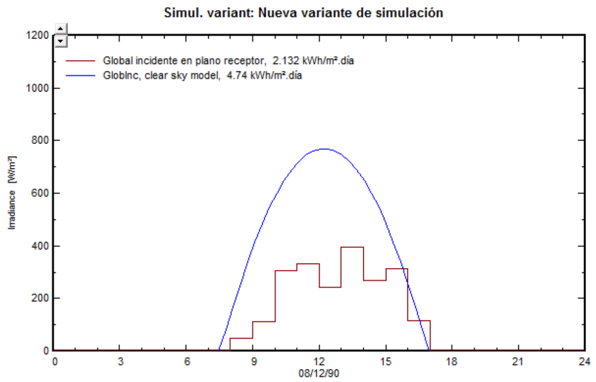
Average of global incident in collector plane: $\overline{x} = \frac{1.439 + 7.345}{2} = 4.392 \frac{Kwh}{m^2 day}$

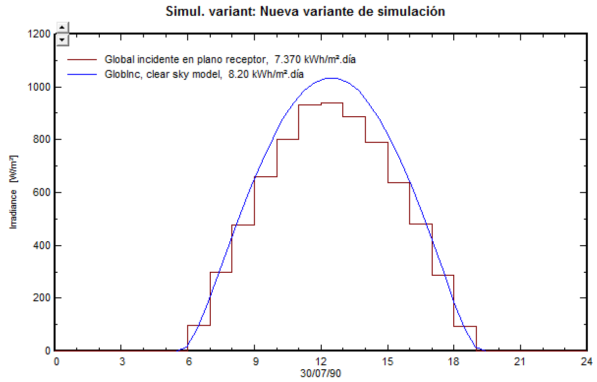
Average of hours of sunlight: $\overline{x} = \frac{10 + 14}{2} = 12 \text{ hours of sunlight}$

$$4.392 \frac{Kwh}{m^2 day} \times \frac{1 day}{12 \text{ hours of sunlight}} = 0.366 \frac{Kwh}{m^2\ hour}$$

$$0.366\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times\frac{1hour}{60\ min}\times 2.5min = 0.0114Kwh$$

Point 6 of the graph /Position 4 of the solar cells:





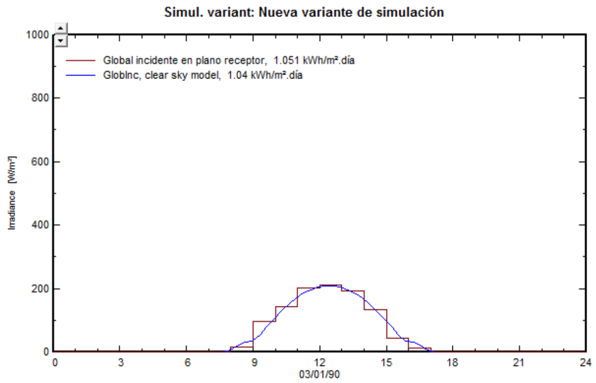
Average of global incident in collector plane: $\overline{x} = \frac{2.132+7.370}{2} = 4.75\ \frac{Kwh}{m^2 day}$

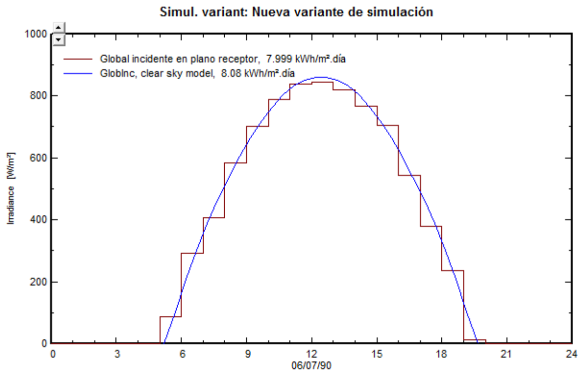
Average of hours of sunlight: $\overline{x} = \frac{9.5+13.4}{2} = 11.45\ hours\ of\ sunlight$

$$4.75\frac{Kwh}{m^2 day}\times\frac{1day}{11.45\ hours\ of\ sunlight} = 0.41\frac{Kwh}{m^2\ hour}$$

$$0.41\frac{Kwh}{m^2\ hour}\times\frac{0.75m^2}{1\ cell}\times 2cells\times\frac{1hour}{60\ min}\times 2.5min = 0.0256\ Kwh$$

Point 6 of the graph/ Position 5 of the solar cell:





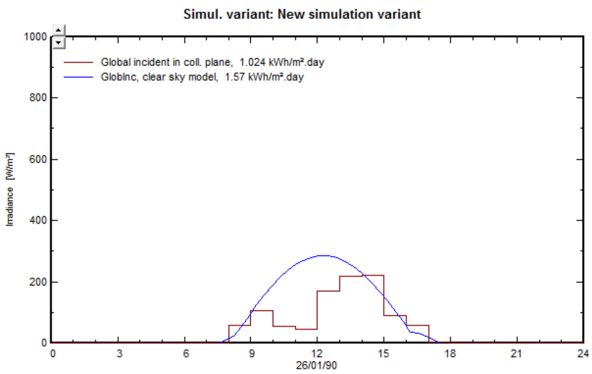
Average of global incident in collector plane: $\bar{x} = \frac{1.051 + 7.999}{2} = 4.525\,\frac{Kwh}{m^2 day}$

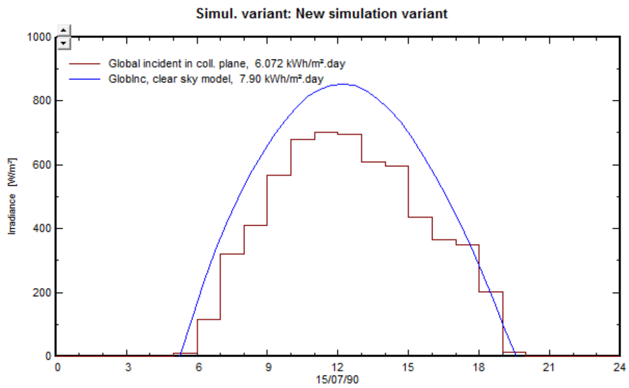
Average of hours of sunlight: $\bar{x} = \frac{9. + 15}{2} = 12\ hours\ of\ sunlight$

$$4.525\frac{Kwh}{m^2 day} \times \frac{1 day}{12\ hours\ of\ sunlight} = 0.377\frac{Kwh}{m^2\ hour}$$

$$0.377\frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 2.5 min = 0.0117 Kwh$$

Point 6 of the graph/ Position 6 of the solar cell:





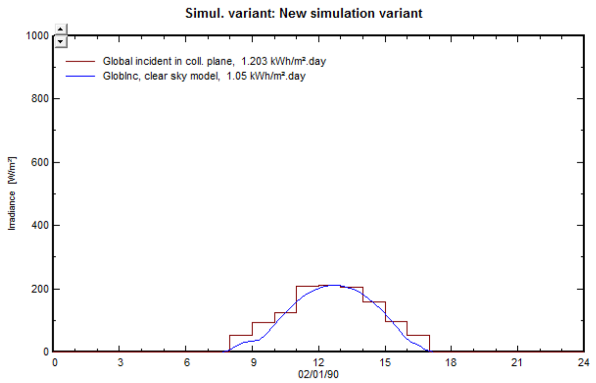
Average of global incident in collector plane: $\bar{x} = \frac{1.024 + 6.072}{2} = 3.656\frac{Kwh}{m^2 day}$

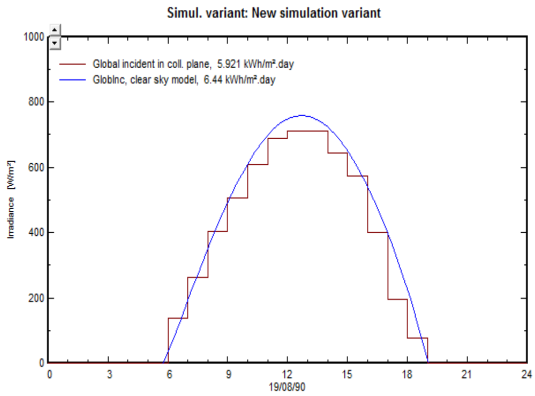
Average of hours of sunlight: $\bar{x} = \frac{9.4 + 15.75}{2} = 12.57\ hours\ of\ sunlight$

$$3.66\frac{Kwh}{m^2 day} \times \frac{1 day}{12.57 hours\ of\ sunlight} = 0.29\frac{Kwh}{m^2\ hour}$$

$$0.29\frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 2.5 min = 9.0625 * 10^{-3} Kwh$$

Point 6 of the graph/ Position 7 of the solar cell:





Average of global incident in collector plane: $\overline{x} = \frac{1.203 + 5.921}{2} = 3.562 \frac{Kwh}{m^2 day}$

Average of hours of sunlight: $\overline{x} = \frac{9 + 14}{2} = 11.5\ hours\ of\ sunlight$

$$3.56 \frac{Kwh}{m^2 day} \times \frac{1 day}{11.5 hours\ of\ sunlight} = 0.31 \frac{Kwh}{m^2\ hour}$$

$$0.31 \frac{Kwh}{m^2\ hour} \times \frac{0.75 m^2}{1\ cell} \times \frac{1 hour}{60\ min} \times 2.5 min = 9.67 * 10^{-3} Kwh$$

Total energy available from the Point 6 to the Point 7 of the graph = 0.102 Kwh

TOTAL ENERGY AVAILABLE DURING THE ONE-WAY FLIGHT= 1.103 Kwh.

5.4) CFD Software

5.4.1) Simulations in CFD Software

Here are shown the drawings of the flow trajectory of the blimp.

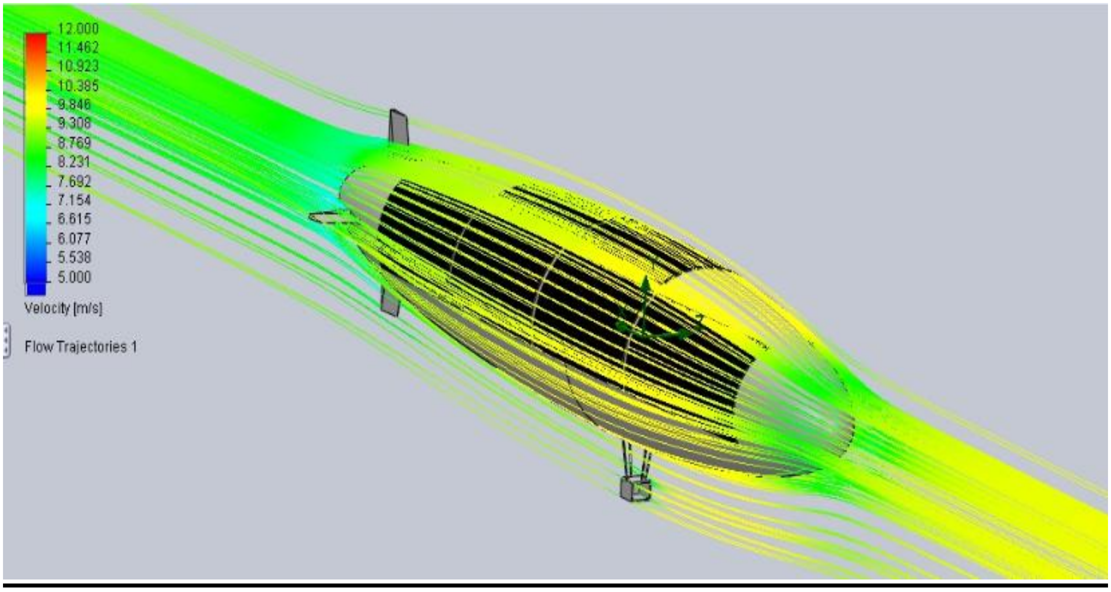


Figure 50.CFD Screen shot1

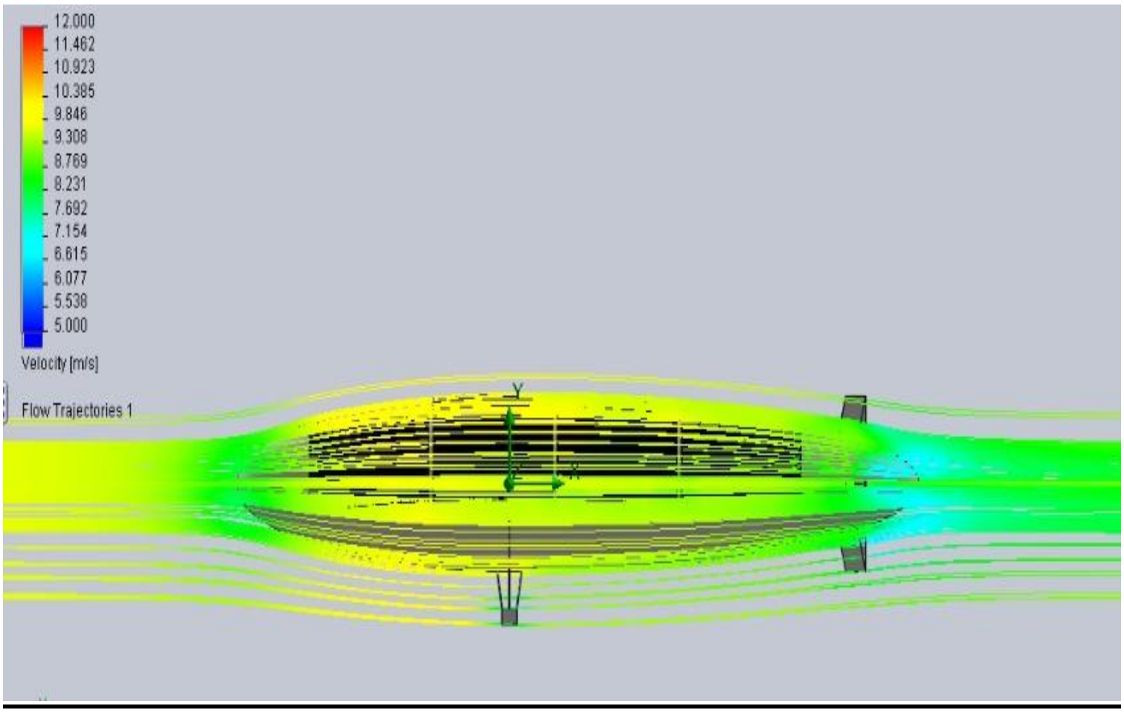


Figure 51.CFD Screen shot2

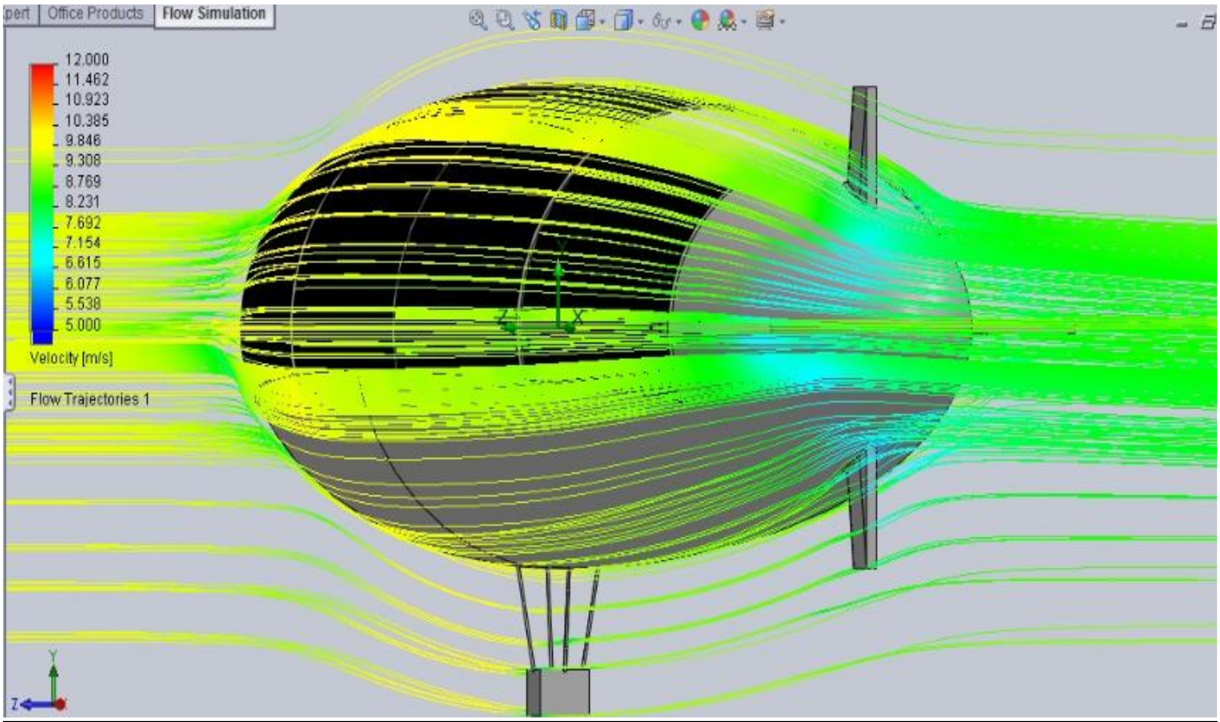


Figure 52.CFD Screen shot3

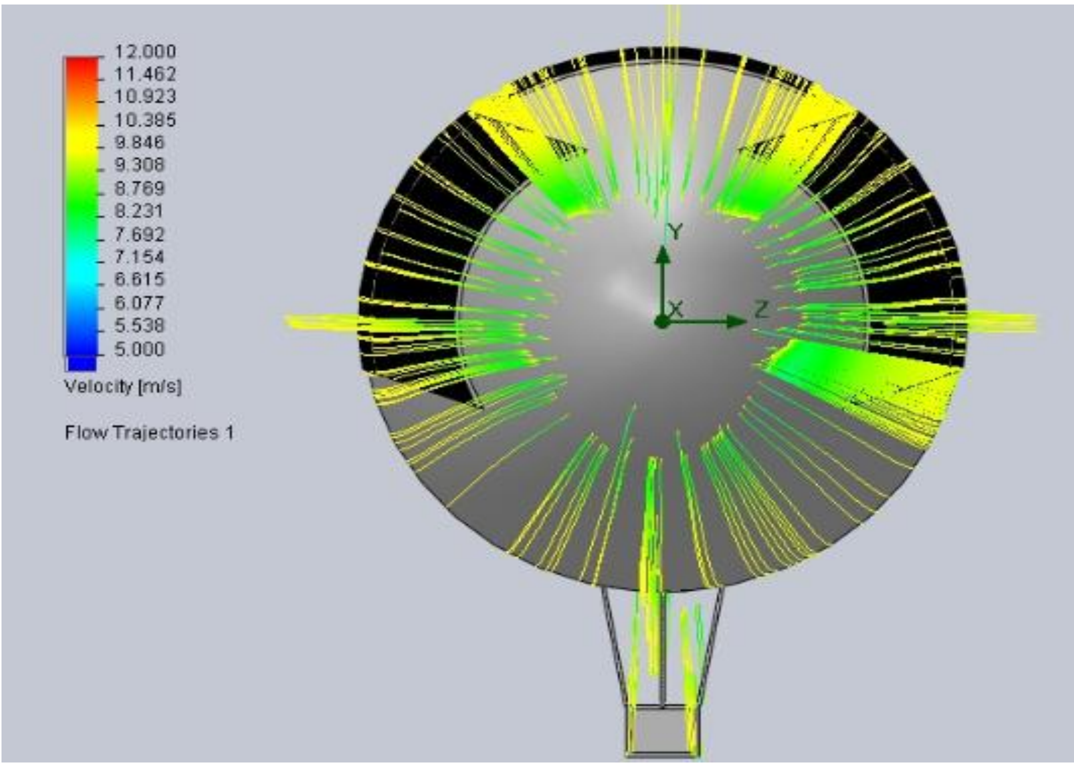


Figure 53.CFD Screen shot4

5.4.2) Power required

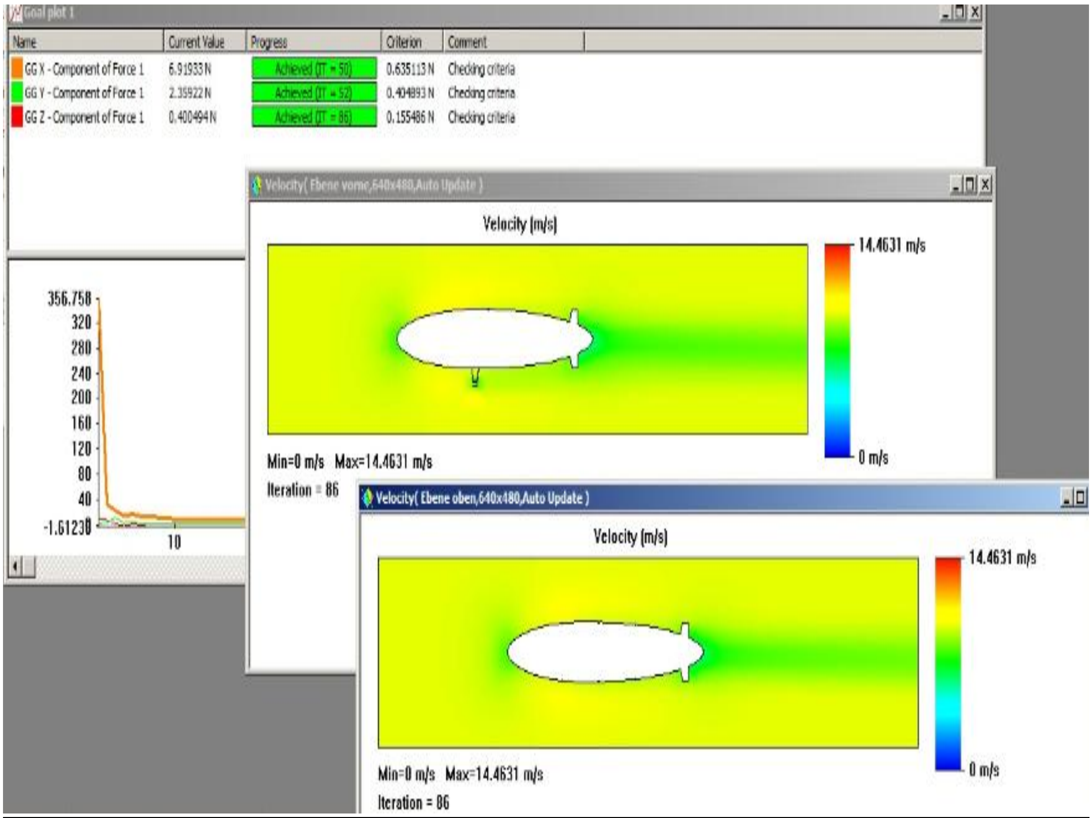


Figure 54. Force graph

$Power = Force \times Speed$

The force provided by the *CFD Software* is 6.9 Newton

For a speed of 9.72 m/s→ Power= 6.9 N * 9.72 m/s =67.1 Watts

6.CONCLUSIONS

6.1) Conclusion about the weight.

	TOTAL MASS (kg)
Pay load	1.5 Kg
Mass of helium	5.49 m^3 *0.13 Kg/m^3 = 0.7137 Kg
Mass of the membrane	21.17 * 0.15 Kg/m^3 = 3.1 Kg
Total	5.31

Table7.Weight analysis

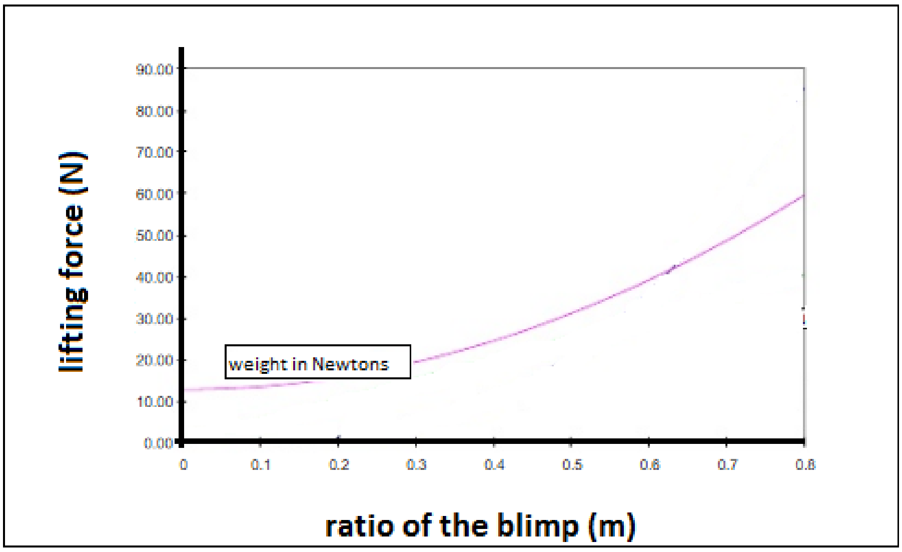


Figure 55.Graph ratio-lifting force

Taking the values from the last table, the total mass of the prototype (payload included) is 5.31 Kg. That means a total weight of:

$$5.31 \text{ Kg} * 9.8 \text{ m}/s^2 = 52.03 \text{ N}$$

The previous graph showed has a correlation between ratio and the lifting force and it was specific for the prototype of this project. According to this graph, for an approximated ratio of 0.62m, the lifting force is expected to be about 47.5 Newton.

In comparison to the actual result (52.03 N), it seems to be a slight difference between both results. Even then, it was assumed that the method used for the design was suitable.

As it was explained before, in the design of the blimp, the solar energy was not taken into account. In spite of that, it was analyzed how the blimp was affected by this phenomenon.

In the definitive design there were 10 solar cells, so:

$$10 \text{ } solar \text{ } cells \times \frac{13.2 \text{ } Kg}{1 \text{ } solar \text{ } cell} = 132Kg$$

Now the total weight is: $132Kg + 5.31 \text{ } Kg = 137.31Kg$

Total weight: $137.31*9.8 \text{ } ^{m}/_{s^2}$ =1345.64 N

Going back to the graph again, it is easy to appreciate that the lifting force of 1345.64 N does not match with any ratio showed in the horizontal axis. To support such weight, the blimp would have been designed for quite bigger dimensions.

So it is obvious to say that the blimp did not pass the weight viability.

It is necessary to say that the weight of the rest of the components of the installation (batteries, inverter…), were not be taken into account. Consequently, it would have made bigger the value of the lifting resistance distancing from the suitable ratio of the blimp.

6.2) Conclusions about the position of solar cells.

As it was assumed before, the optimal tilt angle was 32º and the optimal azimuth angle was 1º.

Basing on that conclusion, the pv module which might register highest levels of energy would be such that combine the tilt and azimuth angles close to the optimal values (32º/1º).

As it was expected the solar cells with the Position 1 (Tilt= 20º and Azimuth = 0º) registered the highest levels of energy in comparison with the other positions of the solar cells.

Here there is a table that collects all the results obtained before.

		Point 1-2	Point 2-3	Point 3-4	Point 4-5	Point 5-6	Point 6-7
Position	Tilt /Azimuth	Energy available Kwh	Energy available Kwh	Energy available Kwh	Energy available Kwh	Energy available Kwh	Energy available Kwh
1 (2cells)	20º / 0º	0.026875	0.026	0.1716	0.1647	0.165	0.0265
2	20º / -8 º	0.0129	0.0119	0.0768	0.091	0.081	0.0129
3	20º / 8º	0.0128	0.0119	0.0705	0.0845	0.0793	0.0114
4 (2cells)	90º / 0º	0.02625	0.0227	0.1710	0.1637	0.153	0.0256
5 (2cells)	20º /180 º	0.2375	0.0246	0.1525	0.0768	0.0748	0.0117
6	20º / -172º	0.118	0.0113	0.0546	0.0709	0.0663	9.0625$1 * 10^{-3}$
7	20º / 172ª	0.118	0.0119	0.0118	0.0568	0.0566	9.67*10^{-3}

Table 8. Results

Putting in order the positions of the solar cells in terms of energy (from the highest to the lowest values) it was established that:

The best position was the position 1(Tilt= 20 º / Azimuth =0º), followed by the position 2(Tilt=20º/Azimuth:-8º) and 3(Tilt=20º / Azimuth8º) with values close to the results obtained for the position 1. However, the position 4 (tilt= 90º /Azimuth 0º), registered less amount of energy, due to the tilt was far away from the optimal angle of 32º.

Logically the solar cells allocated in the back side of the blimp, with values of azimuth like 172º, 180º and -172º, experienced lower values of irradiance because these solar cells took advantage of the diffuse light.

It is necessary to remark, that it was only analyzed the one-way flight, assuming that for the return, the blimp will take the same amount of energy.

However, the current front side of the blimp will become the back side of the blimp and vice. And now the part of the blimp with lowest levels of energy will become the side exposed to the sun strongly.

In addition, the success of the definitive design (third design) is shown by the fact of distribution 4 solar cells along the front(positions with highest energy levels).

6.3) How the drag affects the blimp

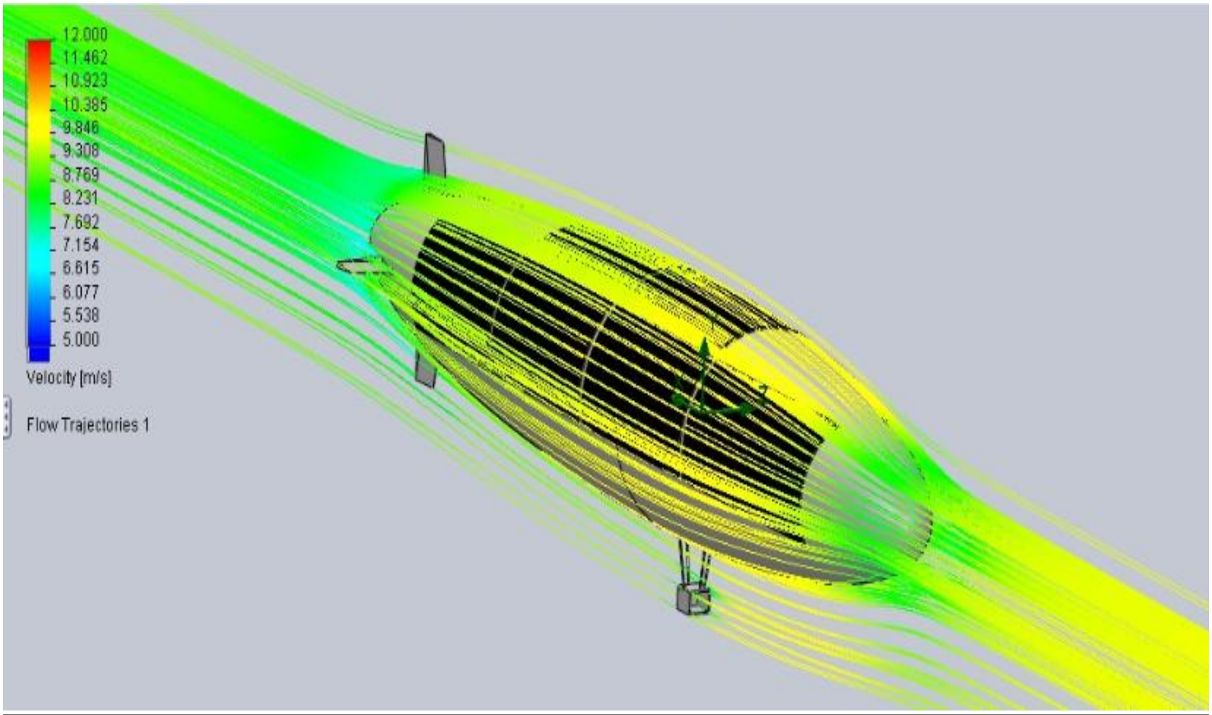


Figure 56. CFD side screen shot

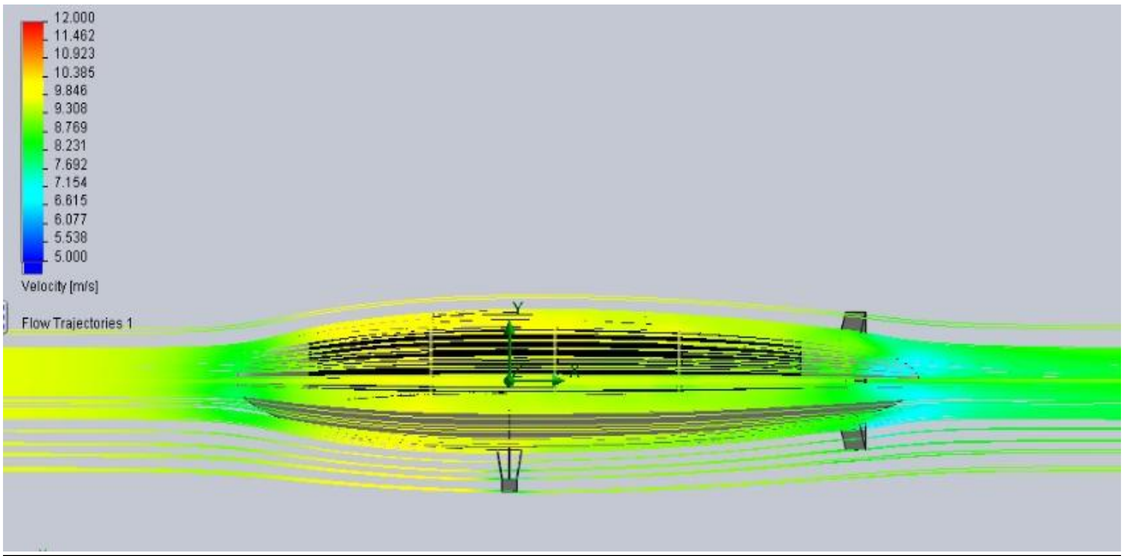


Figure 57. CFDScreen shot

As it is shown in the legend, blue color corresponds to low values of speed and that means drag.

The part most affected by drag is in the back part of the blimp which the dirigible seemed to be almost stopped.

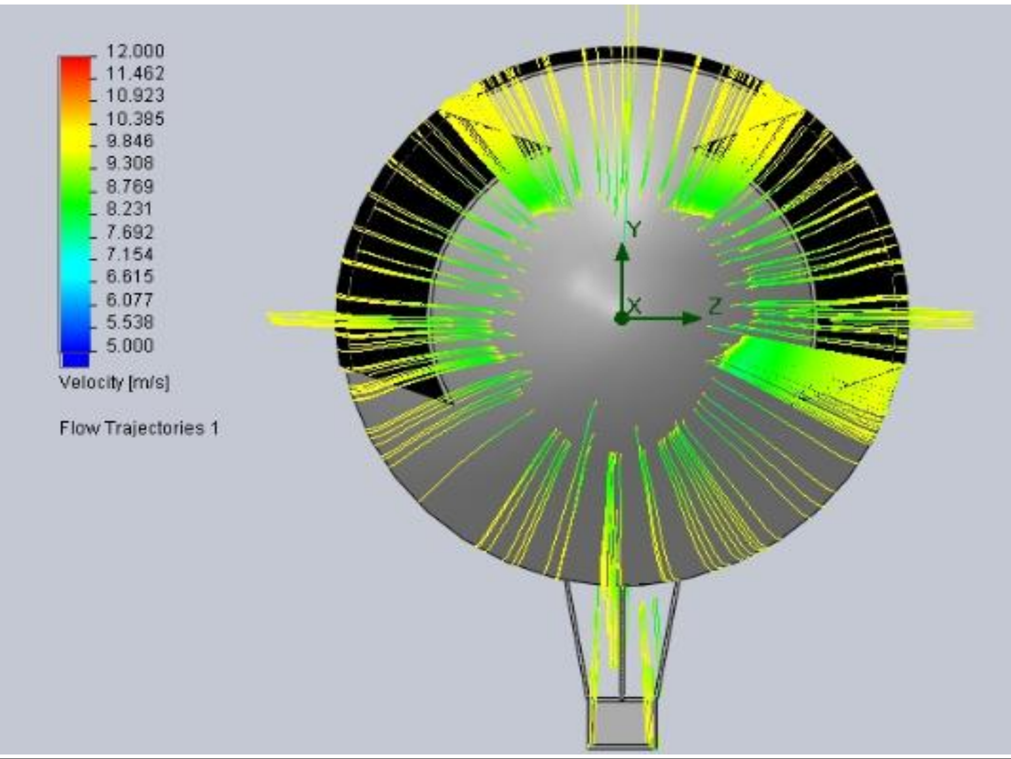


Figure 58. CFD Bottom screen shot

However, the front part of the blimp had to deal with bigger values of speed and therefore it had to support bigger reactions. That was the efforts supported by this part were analyzed in the section 4.3 of this project.

6.4) Feasibility in terms of energy

The power needed by the solar blimp is 67.1 Watts.

Energy needed for the one-way flight (40 minutes =0.66):

67.1 Watts * 0.66 hour =44.29 Wh

The power collected by the solar cells= 1.103 Kwh= 1103Wh

As 1103 Wh> 44.29 Wh, it was determinate that in terms of enerby the solar blimp was feasible.

7. RECOMMENDATIONS

Although this project was tried to be developed basing on some aeromechanical reliable concepts it was reached the conclusion that the ellipsoid shape suggested was not the perfect shape.

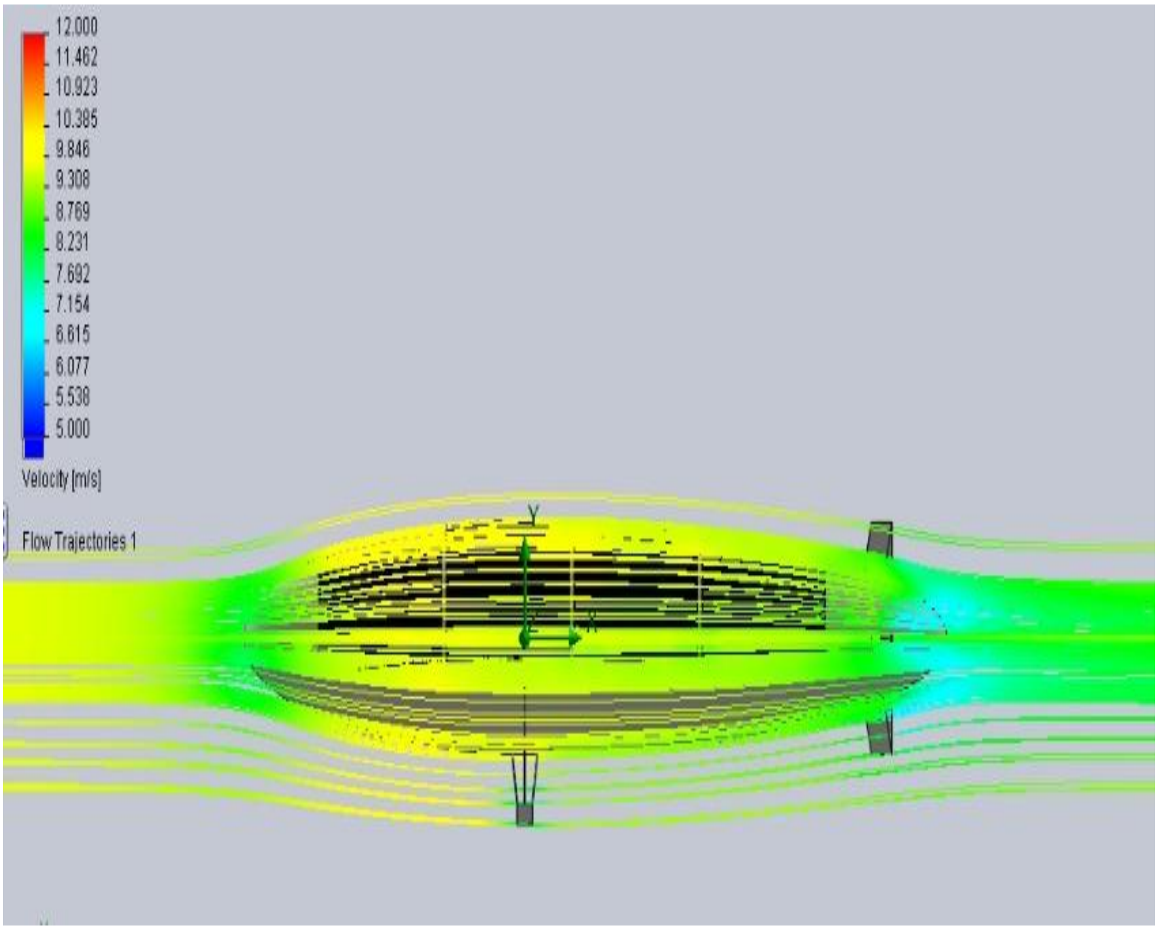


Figure 58. CFD location of drag.

Well, there is no doubt that `the perfect shape´ for a vehicle does not exist in terms of friction force. But there are some designs for the front part of the airships that resemble to a long tail which finishes in a perfect tip. The airships designed according to this design experienced low values of drag.

Figure 51.Concord plane

The front part of the blimp would have experimented less drag, if the design of the blimp had looked like similar to the plane showed in the photo [37]. It would be a good alternative to suggest a more resistant material for this part of the blimp.

In the back part of the blimp, where there was more drag registered it should have been necessary to assume a sharp ending instead the rounded shape taken.

Another recommendation concerned the platform of the camera equipment. Although this model was taken from a competent Spanish company, it would be better if it had an aerodynamic shape.

There were not thought more alternatives and aspects to change, but the author of this project will be pleased and ready to accept new suggestions and critics.

`It is enough to grow up, accept and don’t be scared of committing mistakes´. *By Paulo Coelho.*

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9. ANNEX

9.1) ANNEX 1

Q.SMART UF 75-95

DOWNLOADS Q.SMART UF G1.3

AREAS OF USE

THE NEW Q.CELLS GENERATION

- World's best efficiencies up to 13.4 %: **Highest yields per installed area.**
- Anti PID Technology (APT)1: **No power loss caused by potential induced degradation.**
- Outstanding diffuse and low-light behaviour for 360° Efficiency (TDE): **High yields even in challenging roof expositions - north, west, south, east.**
- Additional Power Boost (APB) with up to 15 % additional output due to positive sorting (+5 / -0W) and light soaking effect: **More power for your money.**
- Frameless Design: **Ideal for roof-parallel installations on flat roofs.**
- Full black surface: **Excellent visual appearance.**
- 10 years product warranty, 25 years linear performance warranty, even for installations < 30 kWp2: **Secure investment.**

[1] APT test conditions: Cells at -600 V relative to support, wet module surface, 25 °C, 300 h

[2] Performance warranty: min. 100 % of nominal power in the first 3 years; max. 0.7 % degradation per year from year 4; min. 85 % of nominal power after 25 years. Full product and performance warranties in accordance with the valid regional warranty terms.

TECHNICAL SPECS

Nominal power	75 - 95 Wp
Nominal efficiency	10.0 % - 12.7%
Positive sorting	+5 / -0 Wp
Format	1,190 mm × 630 mm × 7.3 mm
Area	0.75 m²
Weight	13.2 kg