Develop a 3D CAD model of small power wind turbines in line with the OpenAFPM tool

Engineer assistant internship 2 th year

Mechanics and Energetics, ENSE3

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Piggott wind turbine 2m40 installed on the roof of ENSE3 by the ACE association

Contents

Abstract

French

The development of small power Piggott wind turbines is studied. This wind turbine is part of a low-tech approach, and therefore we follow a manual "The wind turbine recipe book" for each new construction. Usually only 5 wind turbines of different sizes ranging from 500W to 2kW can be built in this way. A parameterized model of the wind turbine has been developed here, making it possible to build one of any size. Wind turbines with powers greater than 2kW have also been manufactured and modeled.

In the parameterized model, there are three main types of generators according to their size: T Shape, H Shape and Star Shape. Everything is configured so that the wind turbine works as well as possible and is the easiest to build. The parameterized model is complementary to two tools developed by RurERG which give it its input parameters.

Finally, after each new parameterization, a calculation sheet with all the necessary dimensions is available. This sheet, coupled with the book "The wind turbine recipe book" allows you to build the wind turbine. In addition, the entire model is parameterized in the Freecad CAD software, which outputs all the parts to the correct dimensions. These parts can then be exported to then be manufactured by laser cutting.

This will allow future builders to have a reliable, functional and easily buildable model of wind turbine best suited to their conditions (wind speed, materials used, desired power, etc.).

English

Manufactured Piggott wind turbine development is studied. "The wind turbine recipe book" is followed for each new construction. Usually, only five wind turbines, from 500W up to 2kW are constructed that way. A parametrized model of the wind turbine that will allow any construction of any size has been developed here. Turbines with greater power (above 2kW) has also been constructed and modelized.

Three different categories of generators are presented in this model, classified by size: T Shape, H Shape, Star Shape. The paramatrization was made in order to make the construction of the wind turbine easier and allow it to work the best. This model is complementary with the design tools developed by RurERG, which give it his inputs.

After each parametrization, a spreadsheet that includes all the dimensions needed is available. Coupled with the book "The wind turbine Recipe Book", it is possible for anyone to build the turbine. Moreover, all the model is parametrized in Freecad (CAO software) which gives all the pieces of the turbine with the right dimensions. This pieces can therefore be used with a laser cut machine.

Finally, this model will allow future constructors to easily build the most suitable windturbine for their location, while being reliable.

I Context of the internship

The small Piggott wind farm and the various players

Hugh Piggott, a Scottish farmer who did not have access to the electricity grid, developed 40 years ago and after many attempts, a model of small power wind turbine. These wind turbines are part of an “OpenSource” and “Low Tech” approach (as opposed to High Tech) and can thus be built using mainly recycled elements, available everywhere and at a lower cost.

He wrote a book about it, “A wind turbine recipe book”, detailing the construction of this type of wind turbine. This book has inspired people all over the globe and for 40 years a global network has been created, continuously seeking to develop and improve this model of small wind turbine.

WindEmpowerment is a global network made up of different actors with multiple skills. One can find there research laboratories, companies, associations, NGOs and all the people who work on this model. Globally, the players in the network seek to develop and promote small-power wind power, organize training courses all over the planet, carry out market studies and R&D. In France the official network is called Tripalium and is part of WindEmpowerment.

At ENSE3 in particular, the association " **Energy Design Area** »(ACE), which is part of these 2 networks, trains dozens of engineering students each year in the creation and manufacture of this type of wind turbine, thus adding practical and manual knowledge to the concepts of electricity or mechanics. views in progress. It has spread abroad with in particular a functional wind turbine installed in a school in Morocco.

The internship takes place at **RurERG** “Rural Electrification Research Group”, a research laboratory of NTUA (National Technical University of Athens). As the name suggests, it works on off-grid electrification and has a division, headed by **Kostas Latoufis (** researcher in fluid mechanics and electricity) working on the Piggott wind farm.

The laboratory provides training in the construction of wind turbines, has built a wind turbine of greater power than the one usually built and has developed tools for sizing the generator and the rudder of the wind turbine.

Purpose of the Internship

In his book, Hugh Piggott details 6 wind turbines of different sizes, with generators ranging from 200W to 2kW. They are easy to access models, all field tested and functional. Even if all the formulas necessary for sizing are present, as soon as we move away conditions of the book, it is necessary to go through pages of calculations to resize the wind turbine, potentially with errors that could ultimately lead to the destruction of the generator.

For example the generator is sized from a certain type of magnet with a specific magnetic field. If this field is different, the whole generator must change (number of turns in the stator coils etc…). This is what happened to the ACE association in Casablanca, Morocco. In other words, if we want to size a wind turbine and its generator perfectly in relation to a given area (wind speed known with precision), or to build wind turbines more powerful than those in the book (greater than 2kW), it is also necessary to adapt the generator.

A **Parameterized model of the Piggott wind turbine** must therefore be built. The objective of this internship will therefore be to build a parameterized model in CAD (Computer Aided Design). For this we will start from the work of Fabien Pris, who for his engineering internship of 2 th year in 2017 created a CAD model of a wind turbine, and tools developed by the RurERG laboratory (MagnAFPM and the Furling Tool) which deal with electrical sizing and rudder.

From an open source perspective, the parameterized model will be made with the free CAD software: Freecad. Everyone can therefore have access to the model for free.

II Preliminary work for parameterization

Description of the wind turbine

A wind turbine is made up of 3 main parts: the mast, the nacelle with the generator and the blades. As the mast is relatively independent, it will not be configured. The blades of the wind turbine, depending on the power of the generator and the amount of wind energy that we want to capture, are not included in the parameterized model either. This can be justified by their different manufacturing method. Built by hand, a CAD model is not required. 3D scans exist for the existing models of the book but they are not yet configurable and this is not the subject of this present work.

We can however note that we can know the blade length necessary for power and wind given by the formula: $$P_{max} = \frac{16}{27} \cdot P_{cinétique} = \frac{8}{27} \cdot \rho S \cdot v^3$$.

Thus the parameterized model includes:

-**the generator,** composed of 2 rotors with permanent magnets bonded to steel discs and a stator made of coils fixed in resin.

-**Platform,** composed of different metal parts supporting the generator and a hub allowing the rotation of the rotors.

-**saffron,** allowing the wind turbine to be oriented into the wind and acting as mechanical protection (feathering) in the event of strong winds.

Below we can see an exploded view for educational purposes of the Piggott wind turbine developed by Fabien Pris.

We can observe the different parts (from left to right): first the blades, then the **first rotor (** metal disc, then resin disc - in white - then the 12 magnets), the **stator (** with the 9 coils and the resin), **the 2** nd **rotor,** then the **hub (** with the rocket) hanging on the **metallic structure.** Above we can see the **saffron.**

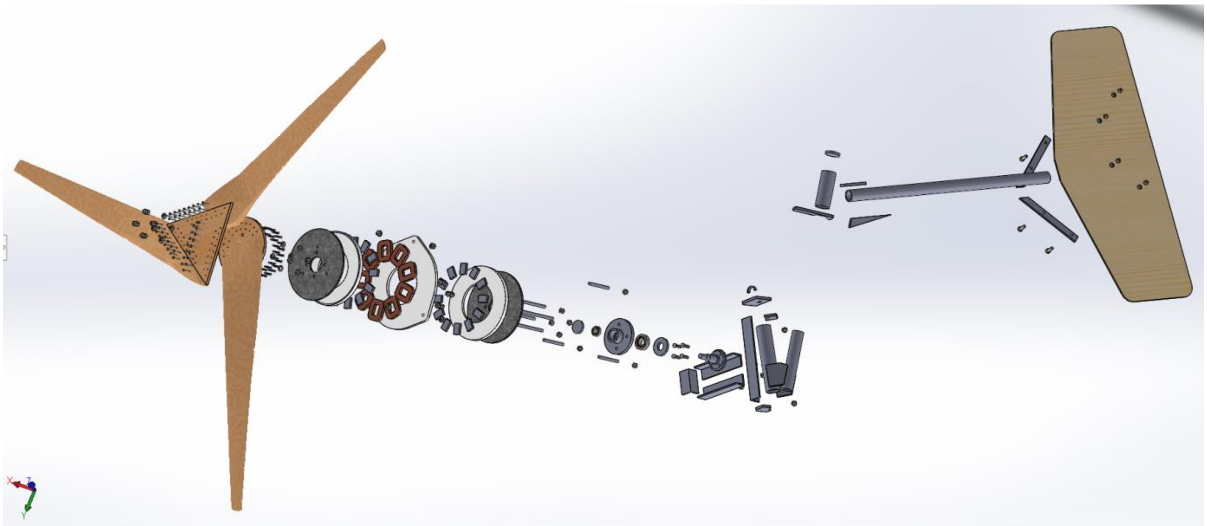


Figure 1: Exploded view of a Piggott 2m40 wind turbine under Solidworks

It can be noted that the stator is hooked to the ends of the nacelle (3 attachment points here) and that the rotors are attached to the nacelle via the hub, which allows rotation (rod bearing). The hub is itself fixed in the middle of the nacelle.

Types of wind turbines

a) From the book "a wind turbine recipe book"

Depending on the size of the generator, the general shape of the latter and of the metal structure will be modified. We can define 2 main types: **"T shape** "And" **H shape** », Names that come from the shape of the metal structure as we can see below:

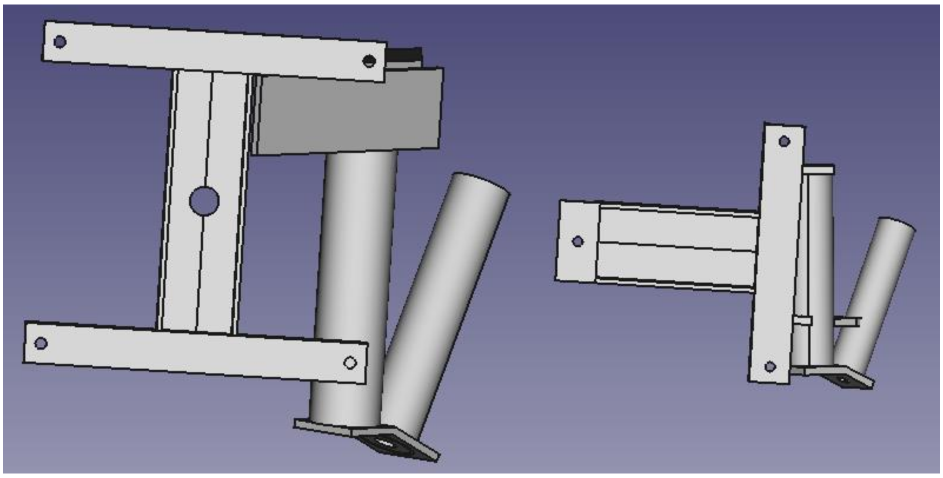


Figure 2: H Shape on the left, T Shape on the right

The "T Shape" has 3 anchor points for the stator while the "H Shape" has 4. Thus the shape
“T Shape” is for smaller wind turbines while “T Shape” is for larger ones. In his book, Hugh Piggott details the manufacture of 5 wind turbines: 2 "H Shape" (diameter traversed by the blades 3m60 and 4m20) and 3 "T Shape" (1m80, 2m40 and 3m60).

b) Other wind turbines

Members of the Windempowerment network have worked on models of larger and more powerful wind turbines. Prototypes up to powers of 5kW and blade diameters of more than 6m have emerged in Europe, the United States and Argentina. The RurERG laboratory has built a 5kW generator. These wind turbines, much more massive will give a 3 th

group that we will call " **Star Shape** ". They have 6 attachment points for the stator, to be able to support their weight.

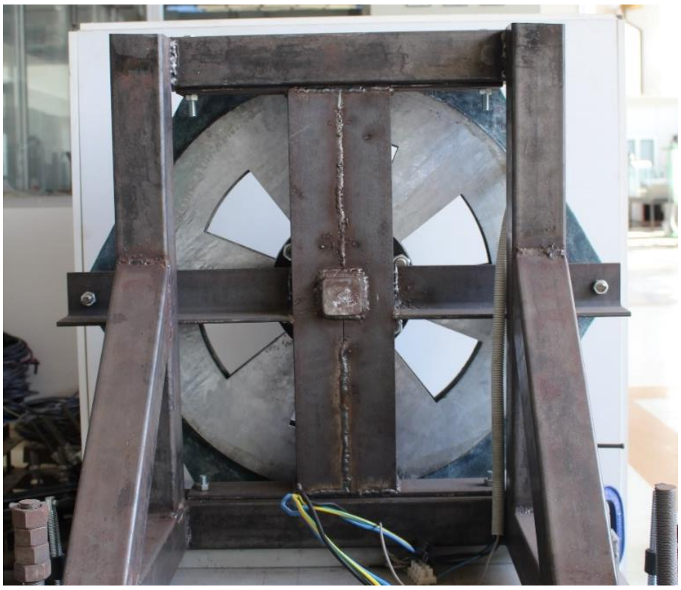


Figure 3: RurERG 5kW Star Shape generator

c) Conclusion

We therefore have 3 main types of wind turbines to model, each type must be properly configured:

- Blade diameter less than 3.30m: T Shape
- Diameter of the blades [3m30 - 4m80]: H Shape
- Diameter of the blades greater than 4m80: Star Shape

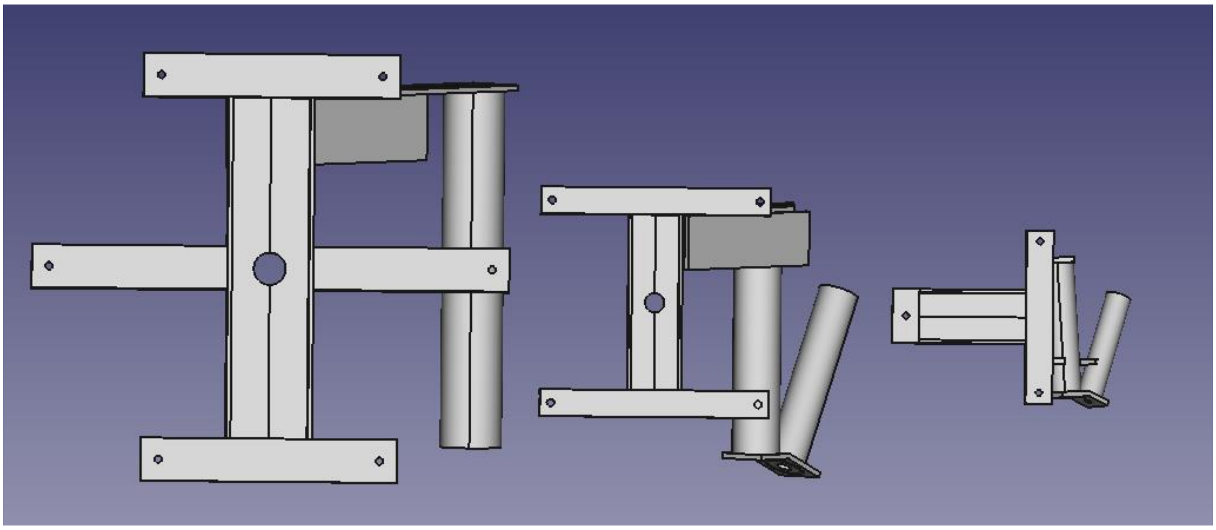


Figure 4: Freecad model of 3 types of nacelles giving their names to the 3 types of wind turbines

The tools developed by RurERG: MagnAFPM and FurlingTool

MagnAFPM is a tool that allows the user, depending on different input parameters, to configure the generator. Based on the magnets it has, the wind speed in its area, the size of its blades and the desired voltage, MagnAFPM will electrically size the entire generator: placement of the magnets, number of turns in the coils and therefore their size. MagnAFPM also calculates the necessary diameter of the rotor disc (and therefore the distance of the magnets from the center). Indeed, if the magnets are too close, the magnetic fields can overlap and cancel each other out, lowering the efficiency of the wind turbine (to have alternating current the magnets, 2 magnets in a row are of opposite pole).

Furling Tool is a tool which sizes the rudder according to the same input parameters as MagnAFPM. The rudder is not only intended to steer the wind turbine into the wind, it protects it against strong winds. The center of the generator is off-center with respect to the mast, so a torque (proportional to the wind speed) will appear when the wind turbine turns, which will tend to pull the wind turbine out of the wind.

The rudder, with a certain weight, spaced with a certain lever arm from the center, will exert a torque which will allow the wind turbine to remain facing the wind. However, for excessively high wind values, the torque exerted by the generator will be greater than that of the rudder, and the latter, in pivot connection with the nacelle, will pivot and therefore take the generator out of the wind. This is called the “feathering” of the wind turbine.

In the end, these tools will give us output values, values which will be inputs to our parameterized model.

Parameterized model inputs

A total of 30 inputs will be needed for the parameterized model: 10 from MagnAFPM, 11 from the Furling Tool and 9 user parameters. They allow the wind turbine to be fully described.

Inputs fromMagnAFPM		Inputs from FurlingTool		User	
Rotor Radius	150	Angle	20	Hub Holes Placement	50
Disk Thickness	10	BracketLength	300	Rotor Inner Circle	32.5
Magnet Length	46	BracketWidth	30	Holes	7
Magnet Width	30	BracketThickness	5	MetalLengthL	50
Magnet Thickness	10	BoomLength	1000	MetalThicknessL	6
Number Magnets	12	BoomPipeRadius	24.15	FlatMetalThickness	10
StatorThickness	13	BoomPipeThickness	5	YawPipeRadius	30.15
CoilInnerWidth1	30	VaneThickness	6	BlowjobsThickness	5
CoilInnerWidth2	30	VaneLength	1200	ResineRotorMargin	5
CoilLegWidth	22.5	VaneWidth	500		
		Offset	125		

Figure 5: Inputs of the Freecad model

One of the most important inputs is the " **Rotor Radius** », Which is the one that defines the size of the steel disc of the rotor and therefore the size of the generator. In the rest of the model, the choice of the type of wind turbine will be defined by this parameter and no longer by the diameter of the blades.

Indeed, for the same blade diameter, if we do not use neodymium magnets (default choice) but less powerful ferrites, the diameter of the “Rotor Radius” will have to be larger and the generator will therefore be larger. So it is this parameter that will be the most determining in the choice of the type of wind turbine.

The category " **User** »Corresponds to the characteristics of metal parts such as the various steel tubes, brackets and bars used. All these inputs have default values which depend on the type of wind turbine (for example the width of a metal square is 50mm for H Shape and 80mm for Star Shape, which makes it possible to better withstand the mechanical stresses due to large generator). These are standard values of metal parts, found everywhere. However, the user has the possibility during the sizing process to change these values by those of the material available.

Important points to observe

In the parameterization, if certain choices will be arbitrary or without importance on the final rendering, others can have much more important impacts.
To have an optimal output at the level of the generator, it is necessary that the magnets pass exactly in the middle of the coils. The stator shape must be able to include all the coils (these are fixed in resin).

The generator is connected in 2 places to the nacelle by metal rods: the rotors in the center via the hub and the stator at the ends. Thus the position of the holes between the metal structure and the generator must match, as well as the position of the centers. Failure to comply with these requirements may make the wind turbine unassemblable, or cause additional vibrations due to eccentricity.

The nacelle must be able to withstand the weight, loads, torques, and sudden variations in movement of the wind turbine in the event of turbulent winds.
Finally the positioning of the generator and the rudder relative to the mast (that is to say) their lever arm) are defined to effectively protect the wind turbine.

III The Freecad model

Freecad is open source CAD software and therefore accessible to everyone. While the software is very functional for the design of more or less complex parts, it does not take global variables into account, and the assembly workshop does not manage complicated constraints. Despite a few bugs, the project has come to an end, and tutorials have been written to understand how it works, or to debug if necessary.

Parameterization based on calculation sheets

The wind turbine has a large number of parts which are divided by **categories.** We can count :

- The part **rotor** which features the metal disc, magnets, resin and molds The part **stator** which includes the coils, resin
- and molds The part **carrycot** which comprises different metal parts which will support the generator (3 to 6), 1 tube
- connected to the mast, a tube connected to the rudder and 2 parts which define the lever arm between the generator and the mast

- The part **saffron** comprising the wooden plate, 1 tube acting as a lever arm, another allowing the connection to the nacelle, various parts to hold everything and 2 stops to limit the rotation of the rudder on its axis
- The part **winder (** tool to make the coils to the right dimensions)

Each room has its own **spreadsheet** »And all the CAD dimensions (length, angle, number of elements, etc.) are referenced in the calculation sheet.

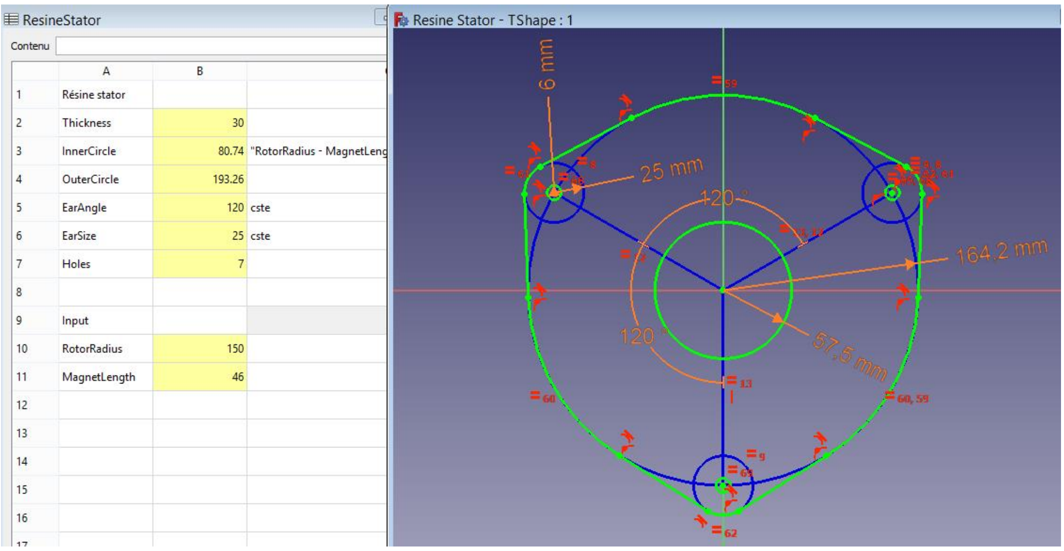


Figure 6: Calculation sheet linked to the drawing; stator resin - T shape

By category (Rotor, Stator etc ..) one can find a calculation sheet named "Master *categoryname* Which controls the calculation sheets for each part. Finally, a general calculation sheet, called “Master of All”, controls all the Master sheets a bit like the single ring that governs all the others.

This use of successive calculation sheets makes it possible to override the fact that Freecad does not accept global variables. Or rather it is a method to simulate global variables.

Below is a tree structure showing how it works. The master files are in red, the blue boxes correspond to the parts that are part of the installed wind turbine and the white boxes are the parts allowing the construction of certain parts of the wind turbine.

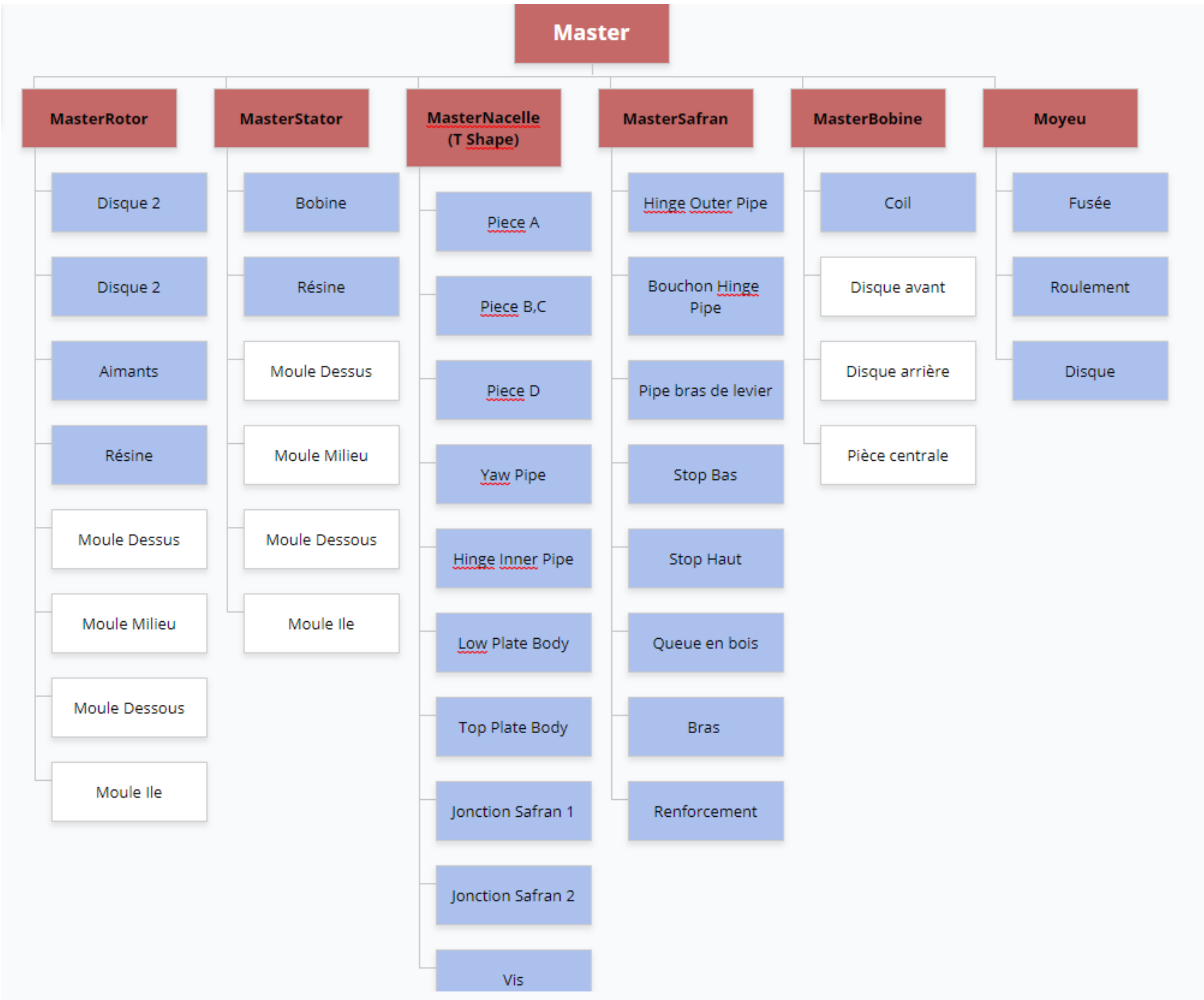


Figure 7: Tree structure for checking the various parts using the calculation sheets

Type 1: T Shape

For this first form, the starting point was the work of Fabien Pris. As seen in figure 1, he had to draw and create all the parts for a wind turbine of 2m40 in diameter. Each dimension of each part of his work was then related by functions to the input parameters. In this way, whatever the size of wind turbines, the model will follow the changes in a logical way and the important points raised in the previous part will be respected.

It would be too long and unnecessary to detail each dimension parameterized in the model, but let's take a few important examples.

a) Parametrization of the stator and magnets facing the coils

To keep the coils between them, we will cast them in resin. For this we use molds which will give their shape to the stator. The 2 most important parts of the mold are the wooden island and the middle part of the mold because they are what will give the shape of the stator.

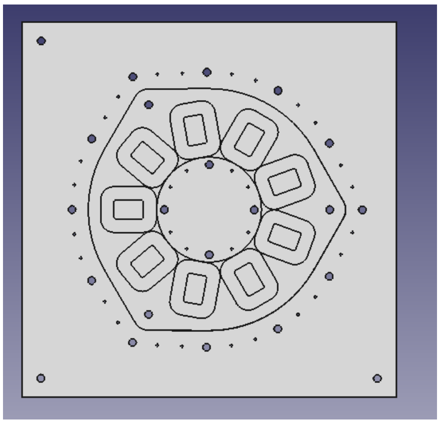


Figure 8: stator mold

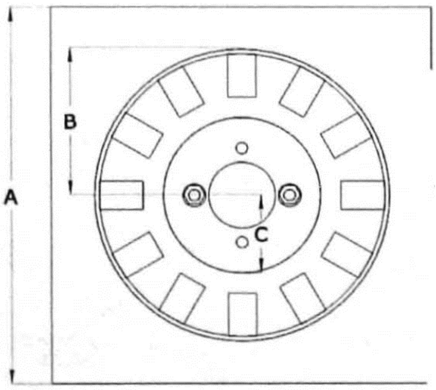


Figure 9 Rotor with magnets

Island in the center

Resin of the stator with the 9 coils

Mold around the stator

Magnets located at the end of the rotor disc

The coils 'touch' the central island of the stator so the radius of the island will be equal to:
Rotor radius - (Magnet length + Coil thickness)

If we assemble the generator, we can see that the magnets pass through the middle of the coils. (The magnet is in green in the images)

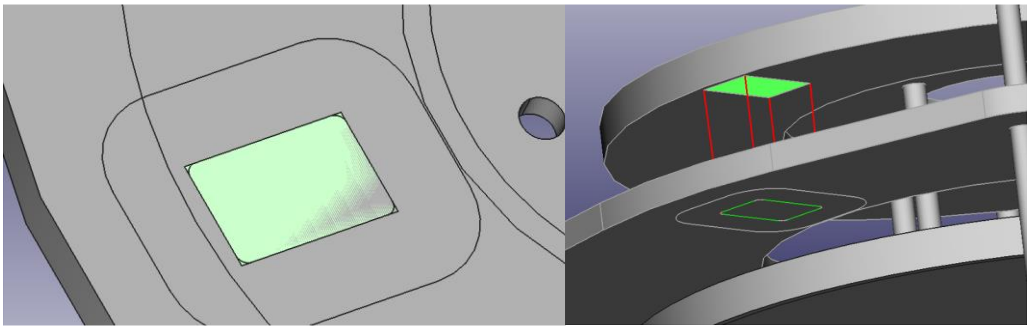
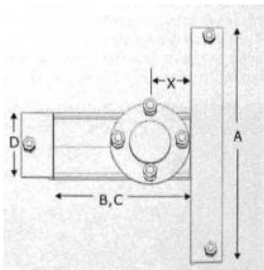


Figure 10: Magnets assembly opposite the coils

b) Metal structure and position of holes in the generator



To be able to assemble the generator correctly with the basket, it must be large enough and the fixing holes well placed. The T shape has 4 different pieces of metal (A, BC and D) like this:

The input parameter will be *StatorHolesRadius* which corresponds to the circle on which the stator holes are placed. Then the position of the center of the circle is important (distance X), it is part of the lever arm between the generator and the mast as seen previously. From there, simple geometry with right triangles gives us the distances A, B and D and the position of the holes.

c) Use of functions from the literature

In some cases, values or parameters cannot be defined from combinations of input or geometry. In these specific cases, we will use the book “the windturbine recipe book”. A function (linear or quadratic) will be deduced from the values of the book according to the input *RotorRadius.*

Example in the nacelle: the 2 parts making the junction between the metal part supporting the generator and the pipe attached to the mast.

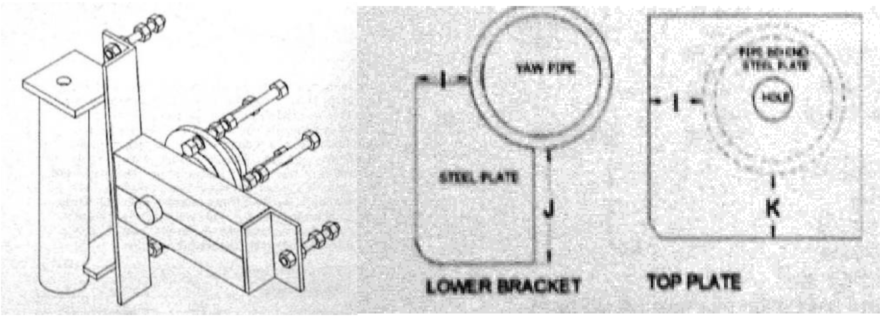


Figure 11: I, J and K

These 2 parts have a role in the mast lever arm (distance I) but also guarantee an angle of 4 ° between the generator and the pipe. In this way we can express K as a function of J and the angle.

Finally I and J are defined as functions of *RotorRadius* based on the results of the book.

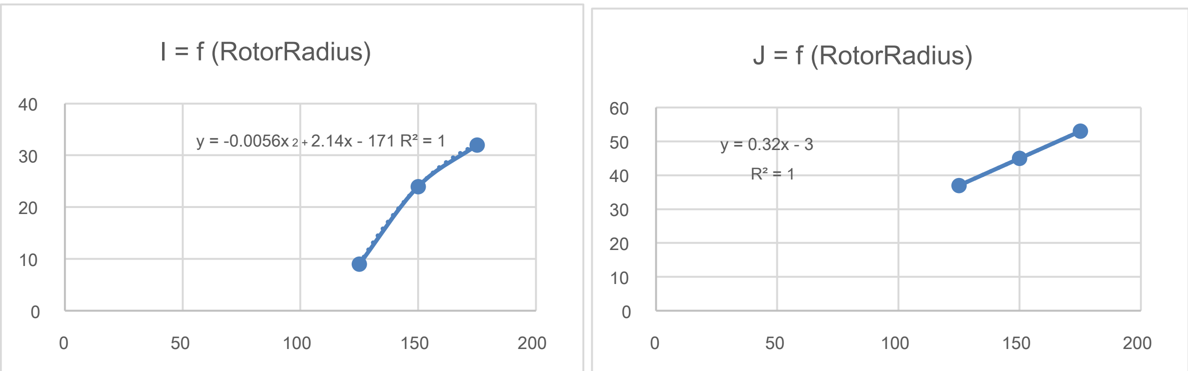


Figure 12: I and J = f (RotorRadius)

d) Assemblies and results

After each part has been individually set up, an assembly was created to verify the correct layout in the space. As seen previously, the correct positioning of the holes, magnets and coils has been verified. In addition, assemblies with the data of the 3 wind turbines in the book were made. This allows comparison with real prototypes.

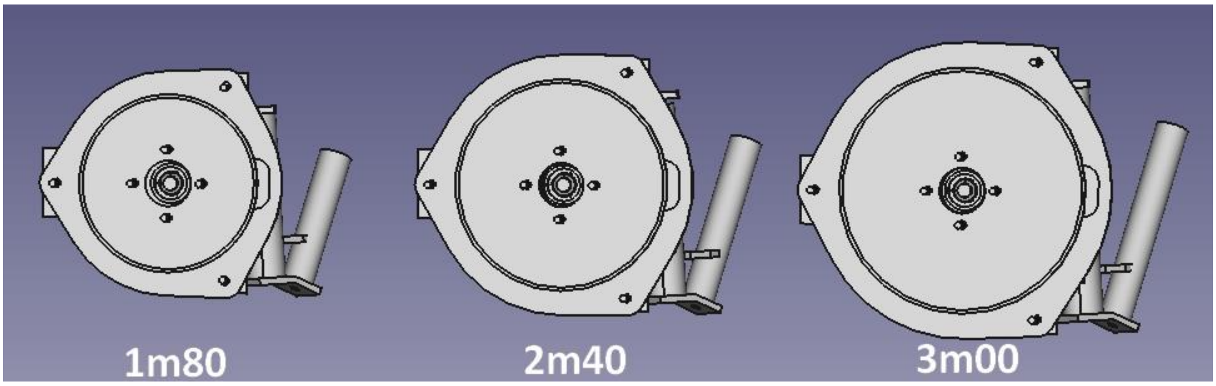


Figure 13: T Shape assemblies

The quantities, distances and positioning are well respected for the 3 models. The parameterized model sticks to reality and works well for this whole range of wind turbines.

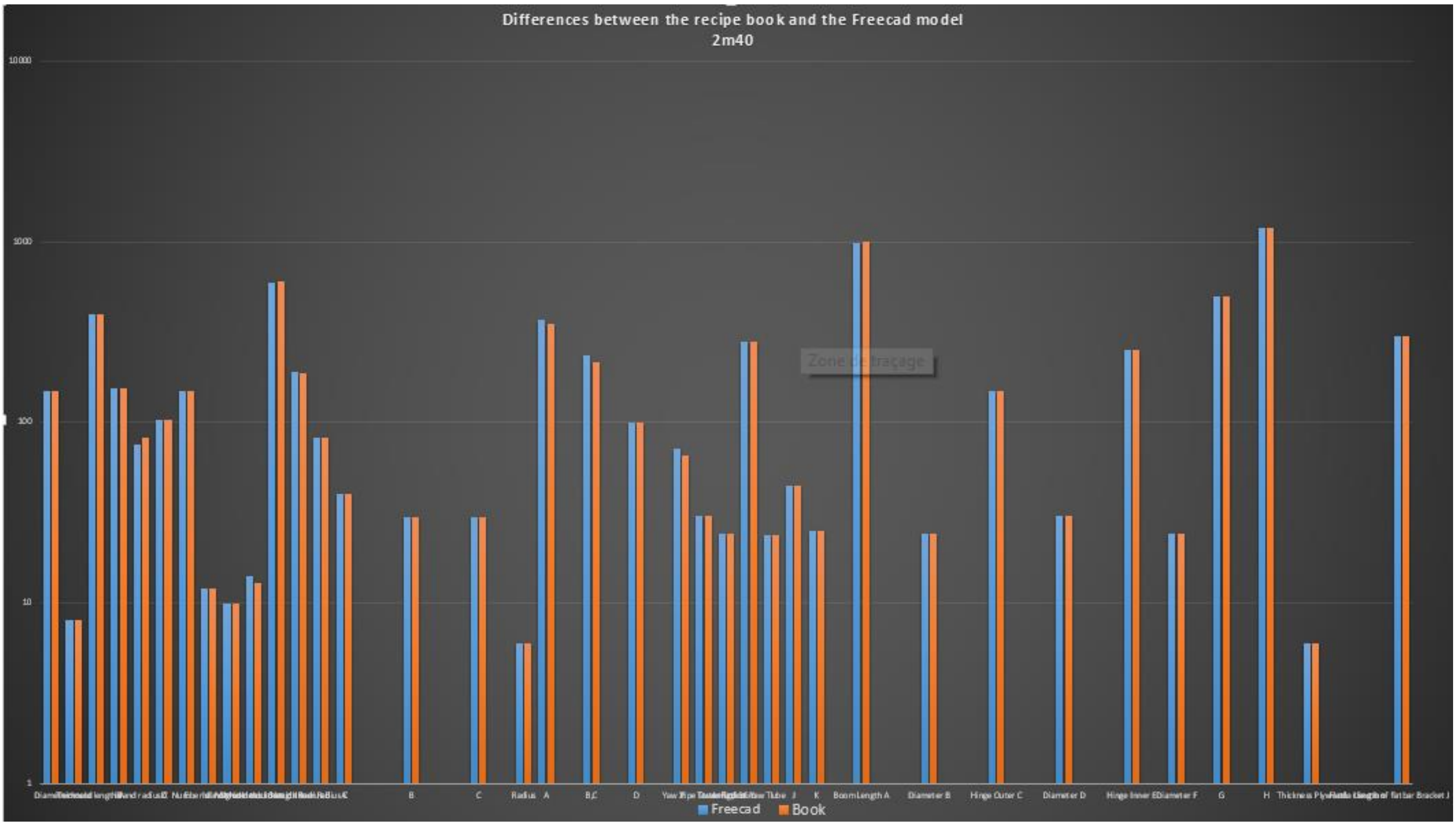


Figure 14: Differences between the Freecad model and the book for a 2m40 wind turbine

The defined parameterized model is very close to the real model. The small differences come from the way the model was set up.

Type 2: H Shape

H Shape corresponds to wind turbines of greater size and power. Compared to the T Shape, the stator and the nacelle are modified. Indeed the stator, more imposing needs 4 anchor points, the shape of the nacelle follows. The hub is larger and the rotors have 5 fixing points instead of 4. In this case, the parts were first created before being parameterized.

a) New Parts

The major differences with the T Shape can be seen below. In FIG. 15 we can observe the new form of stator in its mold, which now makes it possible to contain 12 coils against 9 previously. The size of the mold is set so that the coils always fit inside. On the right, we can see the H-shape, which defines a square-shaped surface. The hole in the middle allows part of the hub to pass (which will be welded on).

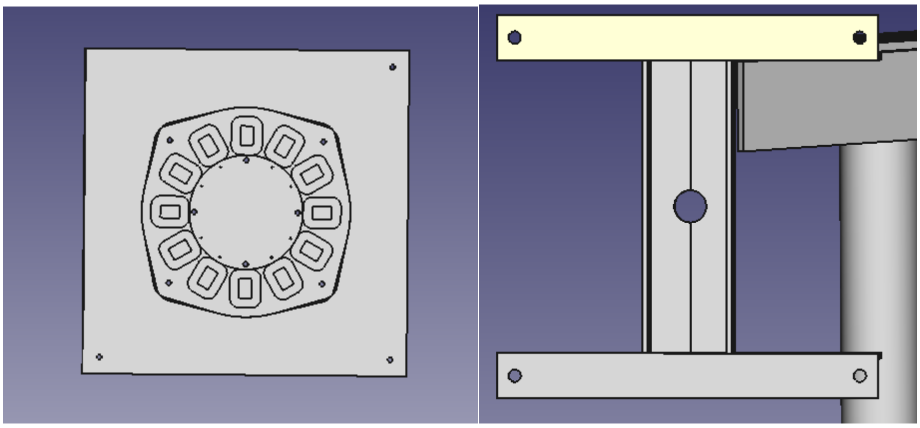


Figure 15: Stator on the left, nacelle on the right - H Shape

Below we can observe that the connection between the H part and the tube which will be fixed on the mast is different from the T Shape. Indeed, the wind turbine becoming larger, its blades also, we will therefore try to move them away from the mast so that they do not touch it in the event of a strong wind. There is therefore a larger lever arm (which will have to be compensated by the rudder), hence the 2 new parts allowing the junction.

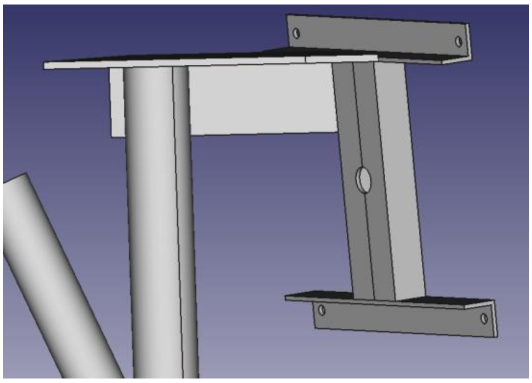


Figure 17: H Shape / Yaw Pipe

b) Parametrization

The parameterization is appreciably similar to that seen previously. All the same considerations were taken for the generator. The shape of the "H" is defined by trigonometry.

c) Assembly and results

To observe the correct operation, we also carried out an assembly with the values corresponding to the 2 examples of the book "the windturbine recipe book". Everything matches and the wind turbine is functional throughout this range of operation.

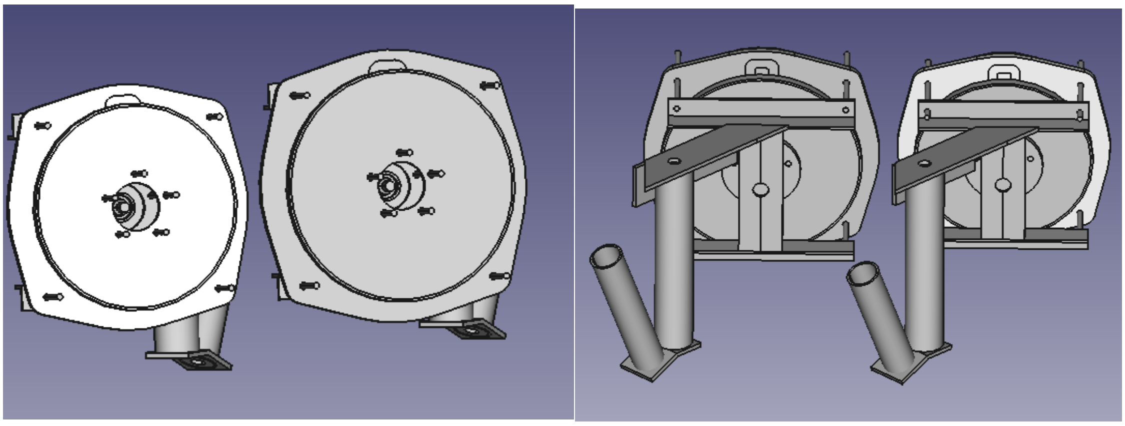


Figure 18: H Shape - 3m60 on the left, 4m20 on the right

Type 3: Star Shape

The **Star Shape** corresponds to the larger Piggott wind turbines. They are not part of the book "The windturbine recipe book" but several have been built all over the planet by various actors of the Windempowerment network. So each is unique and can have a different design (the largest to date is 7m in diameter). This model is based on a number of real wind turbines (and therefore of test) much less substantial than the other 2, even if a good part of the feedback has been taken into account. The basic model for the parametrization is that developed by the RurERG laboratory, of 5kW with 6m blades (not yet built).

Figure 19: RurERG big windturbine on its test bench

a) News

The **stator** has a new shape and a new mold. It has 6 fixing points on the nacelle which therefore has a "star" shape. To be able to withstand the mechanical constraints imposed by a much heavier and more imposing generator, the size of the metal parts making up the nacelle has increased (8mm thick instead of 6mm and 80mm wide instead of 50mm). These are recommended parameters and set by default but the user is free to change them according to the equipment he owns (as seen in the “inputs” part). The **rotors** are connected to a much larger hub and 6 fixing points. To limit the weight of the rotor discs, openings have been drilled in them.

b) Parametrization

The parameterization was done in a manner substantially similar to the previous ones. The " **RotorRadius** »Will define the placement of the coils and therefore the size and shape of the stator. The location of the stator holes is thus defined. With the location of the holes, combined with simple trigonometry, the length and arrangement of the metal parts that make up the "star" are determined. Finally, the size of the openings in the rotors is defined as half of the area traveled but this value can be easily reduced in the parameters. We end up with:

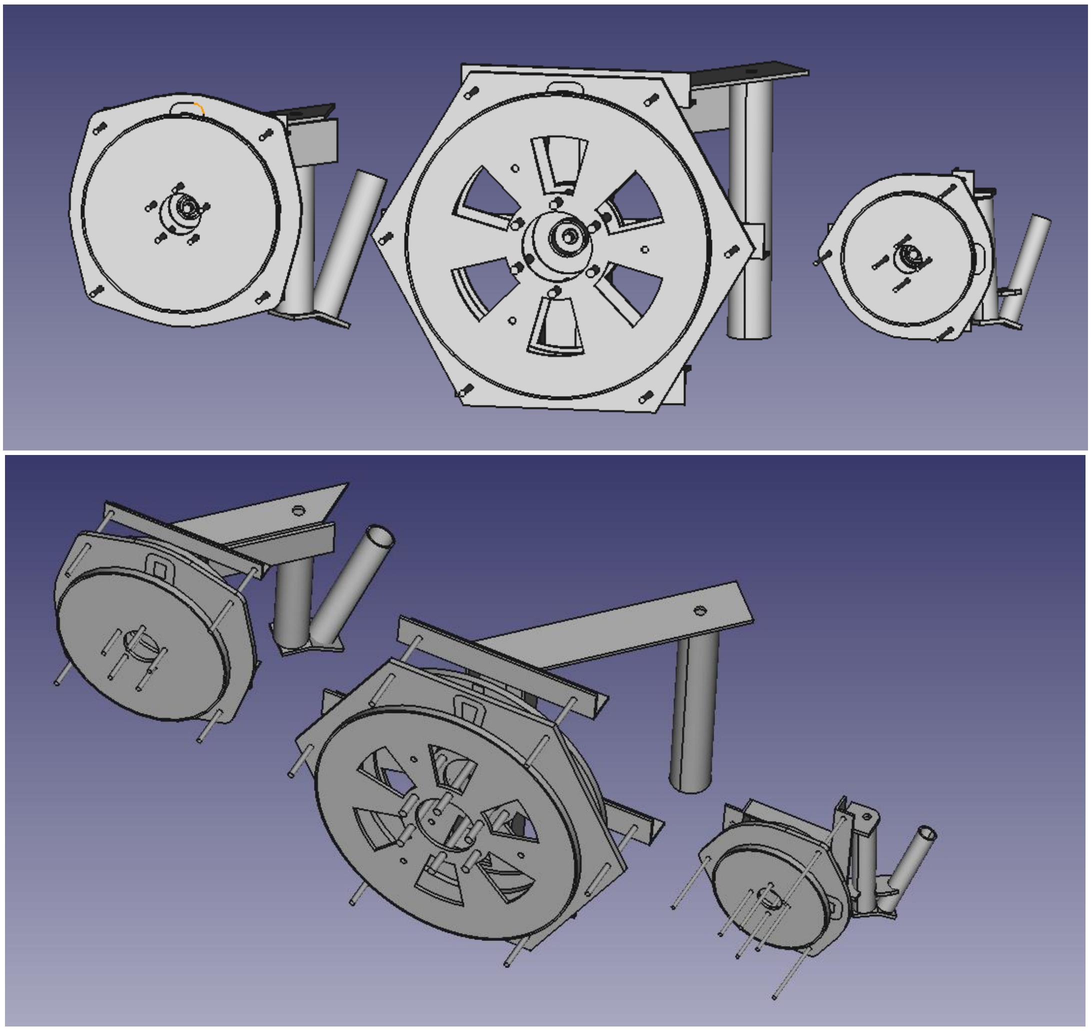


Figure 20: Freecad assembly of the 3 types of wind turbines

Winders and coil types

Initially the user has the choice to use **3 kinds of coil shapes** different: shape **rectangular,** form **key (** or trapezoid) and shape **triangular.** In some cases, for higher powers, the coils can take up too much space and do not fit into the stator while remaining in front of the magnets. In this case we can increase the thickness of the coils but there is a limit (if it increases too much, the magnets of the opposite discs risk being too far from each other and we will have a drop in efficiency). The other option is to change the shape.

The winder has the shape below and is composed of 2 wooden discs, one piece in the middle separating them, 4 nails holding the whole thing and a metal rod allowing the rotation. The most important room is the middle room. It is this which will define the shape of the coils as well as their thickness. This part is entirely defined by the inputs and depends on the type of coil and the size of the magnets.

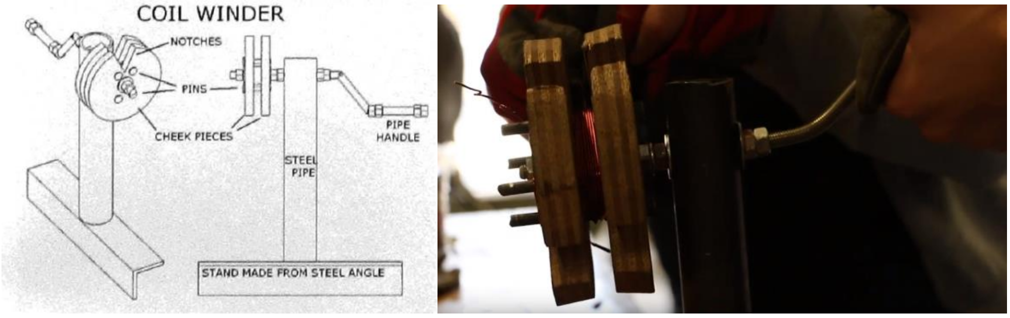


Figure 21: The winder

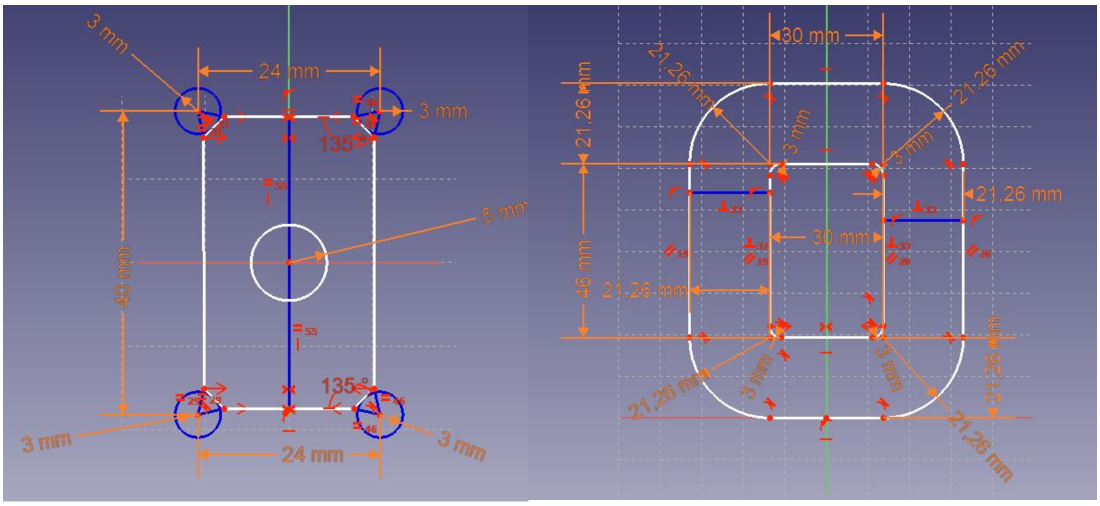


Figure 22: Rectangular middle part winder

On the left the drawing of the middle part of the winder. The blue circles correspond to the nails that hold the winder. We see that the positioning of the nails will give the shape of the right coil and that the central part will perfectly match the size of the magnets.

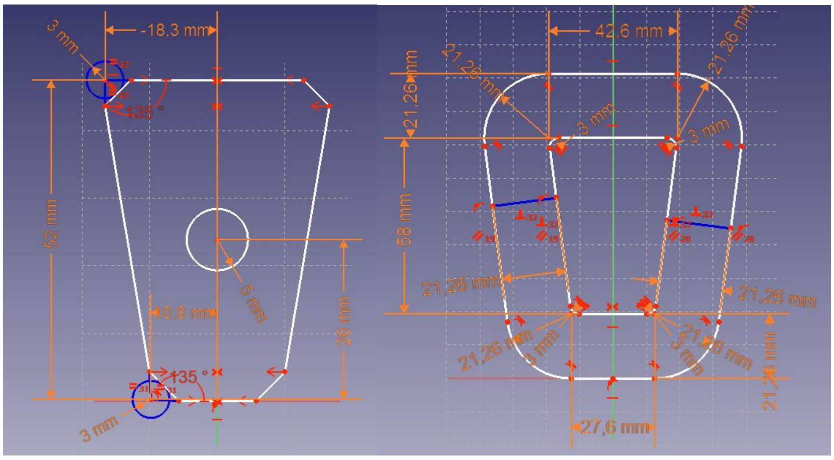


Figure 23: Mid-trapezoidal part winder

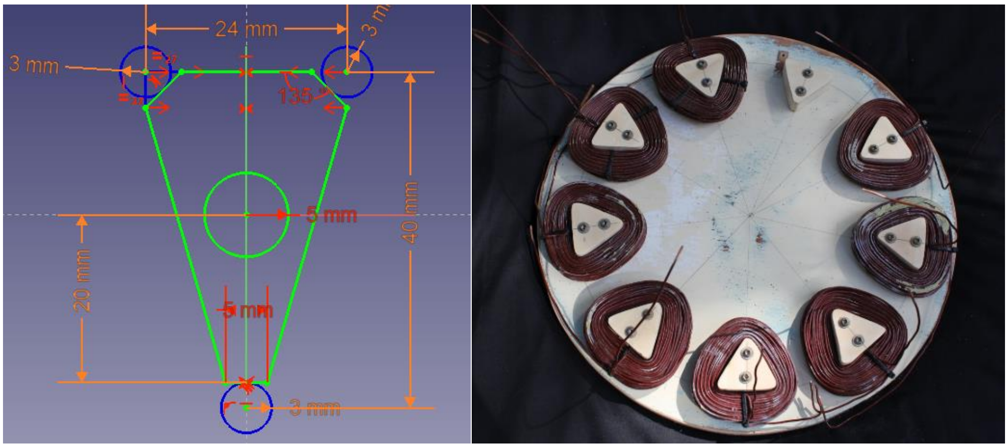


Figure 24: Mid-triangle part winder

Saffron

For the rudder part, the parameterized model is the same for the 3 types of wind turbines. As seen at the beginning it is defined by the inputs which come from the tool " **the Furling Tool** ". In general, it has this form:

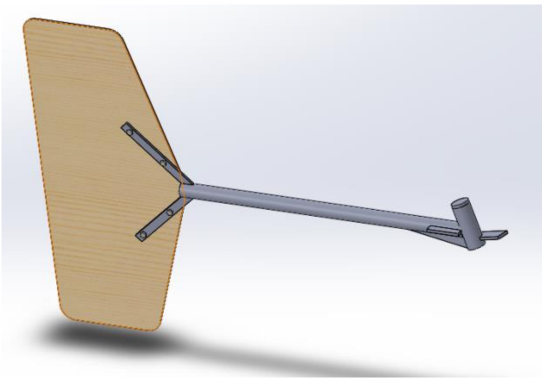


Figure 25: Saffron

For larger wind turbines (Star Shape) a second pipe is needed to support the wooden part. Indeed in these cases, the lengths can reach several meters.

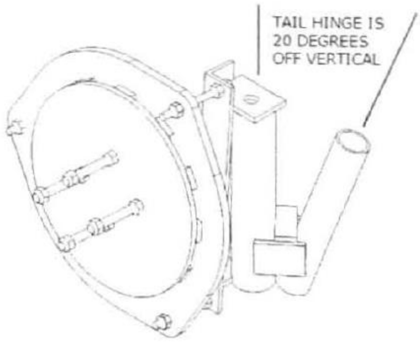


Figure 26: Angle of the rudder from vertical

Finally this **20 ° angle** must be taken into account in the creation and assembly. It is an input (it is therefore variable) and it will influence the mechanical brake exerted by the rudder. Generally, for a generator with neodymium magnets, it will be 20 °. With ferrite magnets, it is more about 13 °, which tends to reduce the torque of the rudder.

III Applications of the parameterized model

The configured model is composed of different freecad files and spreadsheets, all grouped together in a zip file. A **tutorial** explaining the layout of the folder to the user is present. A 2nd tutorial presenting the logic of the parameterization and how to make a new one is also available (available in *Annex 1),* as well as a last tutorial on the assembly part.

Calculation note

The conventional construction of this type of wind turbine requires at least 3 experienced people for 2 days or ten people for 3 to 5 days as part of a training. In all cases, the values and dimensions from Hugh Piggott's “The windturbine recipe book” are used throughout the construction as a “reference”. We can find the different dimensions of the discs, the sizes of the molds, the lengths of the metal parts etc ...

For parameterized wind turbines, based on all the inputs, a calculation sheet " **Spreadsheet Recipe** Gives all the values necessary for the construction, following a diagram similar to the book by Hugh Pigott. Thus, this book (which gives the explanations, the way to build) coupled with the "Spreadsheet Recipe" worksheet allows you to build any wind turbine of any size. An example is available in *Annex2.*

Laser cutting

In a classic construction scheme for this type of wind turbine, everything is built "by hand". For the sake of precision and time saving, the **laser cutting** to get our different parts. Indeed all the wooden and metal parts can be pre-cut with a laser. Using laser cutting, despite a higher price, allows the construction time of the wind turbine to be halved.

After performing a new parameterization, all you have to do is export all the parts in DXF format and then group them into a single file as shown below:

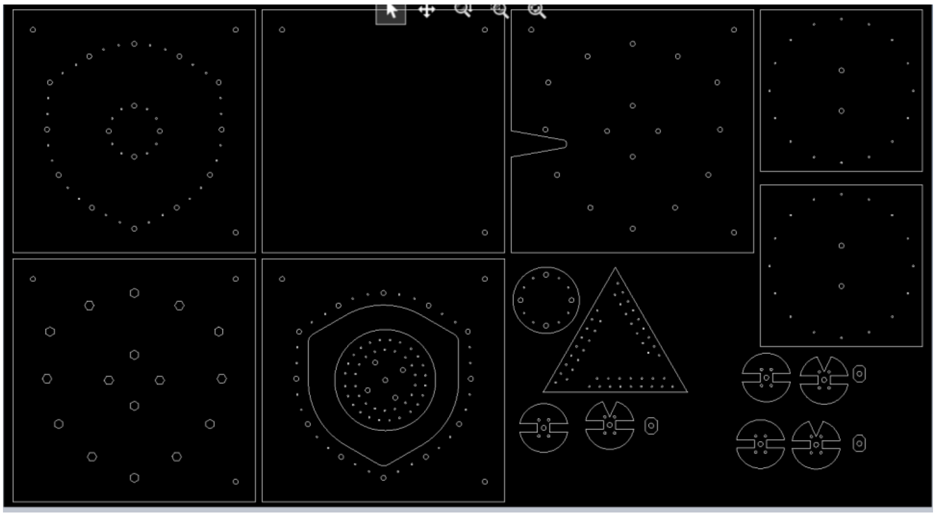


Figure 27: DXF file example for laser cutting (Fabien Pris)

Implementation with tools developed by RurERG

The initial goal of the parameterized model is to be used as a continuation of the tools developed by RurEGR, namely “MagnAFPM” and “The furling Tool”. In this context, the user will enter his initial parameters corresponding to the desired wind turbine (wind speed, generator power, etc.).

The 2 tools will be launched with these parameters and will output a .csv file which can be read by Freecad. This csv file corresponds to the input of the parameterized Freecad model. At this level, requests will be made to the user to know if he wants to use the standard values for the metal parts or to put his own (as seen in the part *II - Inputs). Model csv file in Annex 3.*

The Freecad model with these values is then launched and the user gets all the parts with the correct dimensions.

All the logic diagram being done, the link between the Freecad model and the 2 tools will be concretely coded in Python in September 2018 by a computer scientist from the NTUA. The tool will thus be complete.

Conclusion

The configured Freecad model is functional and optimized. It fits into a larger scheme and is included with other tools designed by the RurERG lab. In the world of the small Piggott wind turbine it is now possible to quickly and easily build a wind turbine of any size optimized for each site.

However, for reasons of mechanical strength of the materials, the model is limited to wind turbines smaller than 10 m in diameter (diameter of the surface swept by the blades). For larger sizes, a different design should be considered. Likewise, the blades are not taken into account in the model. These are two possible avenues for development in the future.

Personally, this gave me a mastery in CAD software, more particularly Freecad and to a lesser extent Solidworks. This allowed me to complete my technical knowledge in wind power, because it is essential to understand how the wind turbine works in order to be able to configure it. Finally, I was able to discover laboratory work, while developing my ability to work independently and to set deadlines.

References

“ **Building A Wind Turbine** ” *Tripalium Network, Hugh Piggott,* 2017

“ **A wind turbine recipe book** ” *Hugh Piggott,* 2009

“Fabien Pris internship dossier” *Fabien Taken,* 2017

“Furling wind turbine construction manual” *Hugh Piggott,* 2014

“ **MagnAFPM** ”&“ **The Furling Tool** ” *RurERG,* 2018

ANNEX

Annex 1: Tutorial

Tutorial Parametrized design of a Piggott Windturbine in Freecad

All the pieces are classified by their place in the Windturbine (Rotor, Stator, Tail, Metal Parts)
Spreadsheets guide the shape of all the pieces.
Each Piece has his own Spreadsheet.
All pieces spreadsheets from a part of the windturbine (Stator, Rotor etc...) refers to a master Spreadsheet of this part.
Finally a spreadsheet, called « Master of Puppets » controls all the master spreadsheets of the parts.
The values of Mast of Puppets come from the outputs of MagnetAFPM.

-Extract the results from MagnetAFPM in a csv file

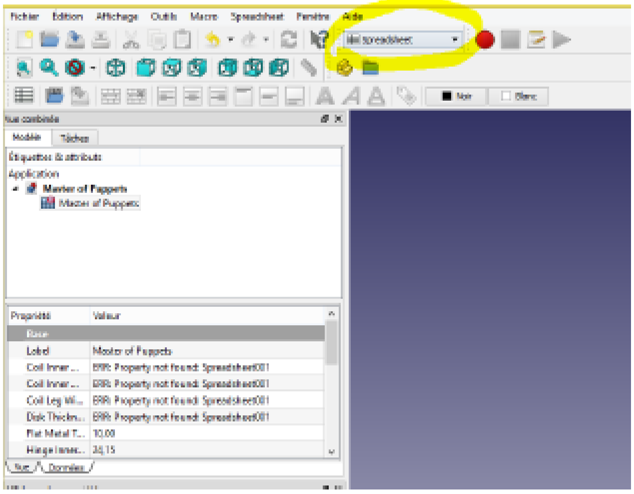
Example :

```
Inputs  Value
Holes   6
RotorRadius     150
DiskThickness   8
MagnetLength    46
MagnetWidth     30
MagnetThickness 10
NumberMagnet    12
HubHolesPlacement       50
RotorInnerCircle        32.5
StatorThickness 13
CoilLegWidth    21.26
CoilInnerWidth1 30
CoilInnerWidth2 30
```

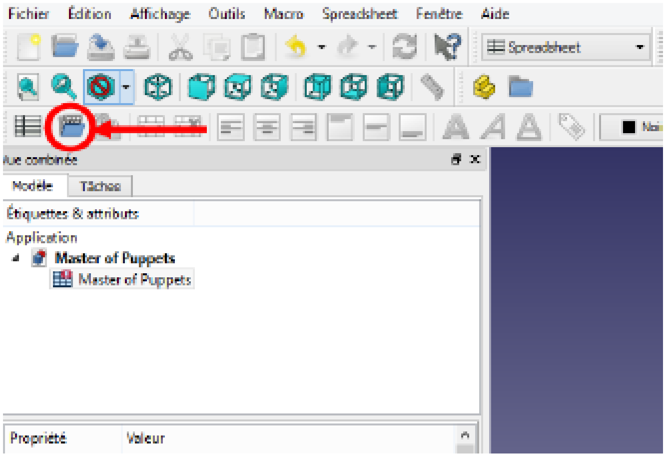
-Open Freecad

- Open Master_of_Puppet.FCSTD   (File -> Open)

-Go into the Spreadsheet Workshop



-Import the csv file (the results of MagnetAFPM)



-Recompute (F5)

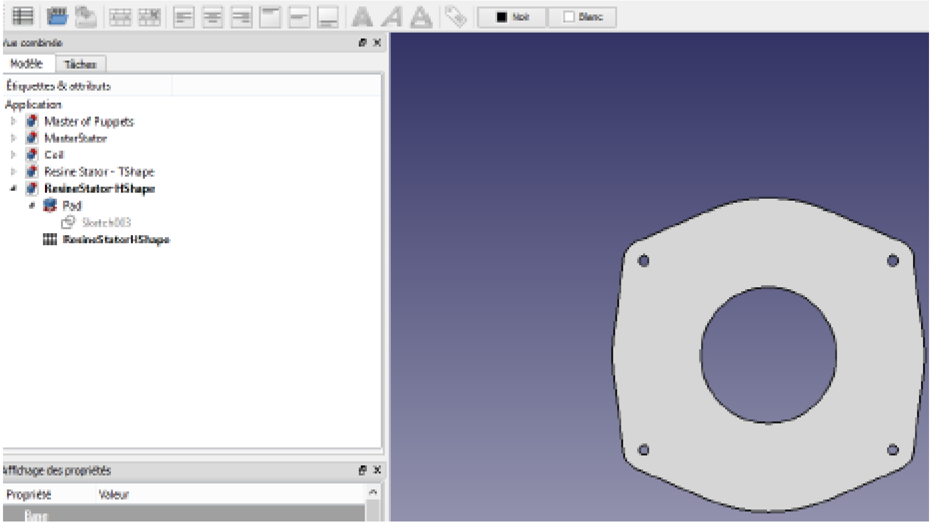
If there are still some errors, don't worry. Just go into « Master of Puppets » spreadsheet, write anything in an empty cell and push « enter ». That should actualize.

-Open the MasterFile of the part of the windturbine you want to see.

For example, for the stator, open the file « **MasterStator** »

-Then Open all the file you need for the stator

(Here, the files « Coil », « ResineStator T-Shape » and « ResineStatorHShape » has been open)



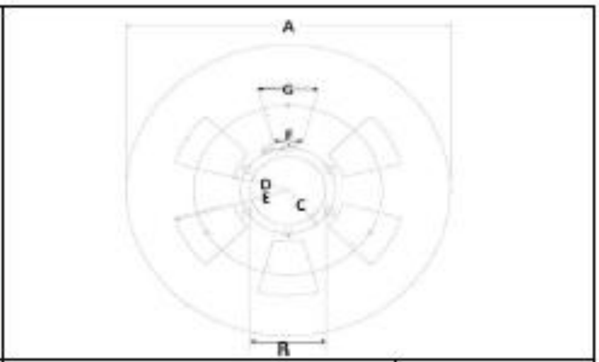
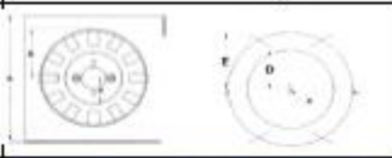
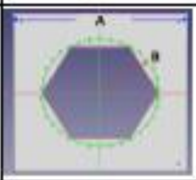
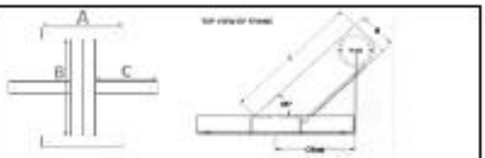
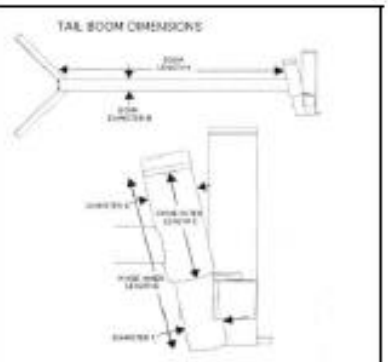
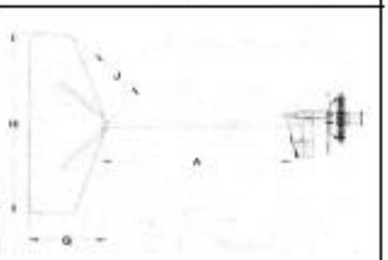
When opened, the file should be with the good new dimensions. But sometimes, it does not work, we then need to recompute ourselves :

-Click right on the file, and choose « **Mark to recompute** »

-F5 for recompute

NB : Noticed that for the Star Shape, there is only one masterfile « Master BigWindturbine » for all the categories.

Annex 2: Example Spreadsheet Recipe

Blade Diameter > 4m80			
Steel Disk Size	A	300	
	B	65	
	C	50	
	D	71	
	E	67	
	F	37,17551307	
	G	35,08111797	
	Thickness	10	
Rotor Mould	mould length A	399,9	
	B	155	
	island radius C	79	
	D	104	
	E	150	
	Number of Magnets	12	
	Island thickness	10	
Coil Winder	A	40	
	B	30	
	C	30	
Stator Mould	Thickness mould	13	
	mould length A	577,5	
	Outside Radius B	192,5	
	Inner Radius C	81,5	
Stainless Steel Studs	Radius	7	
Frame Dimensions 65*65*8	A	213,4998855	
	B	208,9416619	
	C	131,5	
	M	100	
	L	242,2819405	
	Offset	125	
Yaw Bearing Pipe Size	Yaw Pipe Outer Radius	30,15	
	Length Yaw Pipe Tube	270	
	Tower Top Stub	24,15	
Steel Pipe Dimensions for Tail	Boom Length A	1000	
	Boom Support Length	1054,187108	
	Diameter B	48,3	
	Hinge Outer C	135	
	Diameter D	30,15	
	Hinge Inner E	240	
	Diameter F	24,15	
Tail Vane And Bracket	G	500	
	H	1200	
	Thickness Plywood	6	
	Bracket Width	30	
	Bracket Thikness	5	
	Length of flatbar Bracket J	300	

Appendix 3: CSV file - Input of the Freecad model

```
Inputs   Value
MagnAFPM
RotorDiskRadius 349
DiskThickness    10
MagnetLength     58
MagnetWidth      30
MagnetThickness 10
NumberMagnet     12
StatorThickness 13
CoilLegWidth     23.26
CoilInnerWidth1 30
CoilInnerWidth2 30
FurlingTool
Angle    20
BracketLength    300
BracketWidth     30
BracketThickness        5
BoomLength       1000
BoomPipeRadius   24.15
BoomPipeThickness       5
VaneThickness    6
VaneLength       1200
VaneWidth        500
Offset   400
User
HubHolesPlacement       81.5
RotorInnerCircle        102.5
Holes    7
MetalLengthL     80
MetalThicknessL 8
FlatMetalThickness      10
YawPipeRadius    58.15
PipeThickness    6
ResineRotorMargin       5
HubHoles         10
```