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UNIVERSITAT POLITÈCNICA DE CATALUNYA

TREBALL DE FI DE CARRERA

TÍTOL DEL TFC: Study of electric energy production with small scale wind turbines in Viladecans (Delta del Llobregat)

TITULACIÓ: Enginyeria Tècnica Aeronàutica, especiatitat Aeronavegació

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DATA: June, 5th 2013

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Resum

L'objectiu d'aquest projecte és determinar quin dels dos aerogeneradors proposats (IT-PE-100 i HP-600) és el més apropiat per les condicions de vent a Viladecans (Delta del Llobregat).

Primerament, es va dur a terme un estudi del vent, amb l'objectiu d'obtenir la distribució de velocitats fent servir la funció de densitat de probabilitat de Weibull. Aquesta distribució va resultar en una mitja ponderada de velocitats de 1.46 m/s.

Es va decidir que la millor manera d'escollir una de les dues turbines seria fer servir el software de simulació Fast & Aerodyn, fent servir com a inputs la distribució de probabilitat del vent prèviament calculada, juntament amb arxius de caracterització dels aerogeneradors, amb tal d'obtenir la corba de potència per cada cas.

Pel model IT-PE-100 es van fer servir arxius de Fast & Aerodyn ja generats, extrets d'altres projectes fets a la Universitat Politècnica de Catalunya (UPC). Per tal d'adequar els resultats a l'àrea de Viladecans, només es van haver de modificar els arxius relatius al vent. Amb aquests inputs, el software va reportar una producció energètica anual de 99.6kWh.

Amb el cas de l'aerogenerador HP-600, els arxius de Fast & Aerodyn van haver de ser creats de forma íntegra. Degut a que només teníem a la nostra disposició una de les pales de la turbina, es va decidir fer una digitalització en 3D d'aquesta. Aquest procés ens va donar el núvol de punts de la pala, que va ser convertit a un arxiu de tipus CAD mitjançant el software d'enginyeria inversa Rapidform. Important l'arxiu de CAD a SolidWorks, va ser possible fer una simulació de flux al voltant de la pala, que ens va permetre obtenir tots els paràmetres aerodinàmics necessaris per la creació dels inputs demanats per Fast & Aerodyn. Aquests arxius, juntament amb la distribució de vents que va ser calculada prèviament, ens van reportar una producció energètica anual inferior de 66.3kWh.

Per tant, es va concloure que la millor opció per l'àrea de Viladecans era fer servir l'aerogenerador IT-PE-100.

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Overview

The objective of this project was to determine which of the two small scale wind turbines presented (IT-PE-100 and HP-600) was the most appropriate for the wind conditions of Viladecans (Delta del Llobregat).

Firstly, a wind study was conducted in order to obtain the speed distribution, using Weibull probability density function, and showed a weighted average speed of 1.46 m/s.

It was decided that the best way to choose one of the two turbines would be using Fast & Aerodyn simulation software, using the previously calculated wind speed distribution, to obtain the generator power curve for each case.

For the IT-PE-100 model, we used already calculated Fast & Aerodyn files from other projects conducted at Universitat Politècnica de Catalunya (UPC), and only changed the wind files, to adequate the outputs to the Viladecans area. With that wind speed distribution, the software submitted a yearly income of 99.6kWh.

For the HP-600, the Fast & Aerodyn files were had to be made from scratch. Since only one of the turbine blades was available for our study, it was decided to perform a 3D digitalization. That gave us a point cloud of the blade, which was converted into a CAD file using Rapidform, a reverse engineering software.
With the CAD file we were able to perform a flow simulation along the blade, using SolidWorks, in order to obtain all the necessary aerodynamic parameters needed for the creation of the Fast & Aerodyn files. These files, along with the previously calculated wind speed distribution, were used as inputs in Fast & Aerodyn, which gave us a yearly income of 66kWh, which was to be expected, since this wind turbine model is thought to work at higher wind speeds.

Therefore, it was concluded that the best option for the Viladecans area was the IT-PE-100 small scale wind turbine.

ÍNDEX

INTRODUCTION

We were presented with two low-scale wind turbines, IT-PE-100 and HP-600, which offered 100W and 600W when working at their rated wind speeds, respectively. Our task consisted in determining which one was the most appropriate for the wind speed conditions of Viladecans (Delta del Llobregat).

The first step was to analyze our area of study. “L’Institut Català de Meteorologia” provided us with the wind data of the last 19 years, consisting in wind speed and wind direction. With that data, we had to obtain the wind speed distribution. We assumed the time of our turbines aligning themselves to the wind as negligible, thus simplifying the process.

Upon research, it was decided that the best way to treat wind data was to obtain the Weibull probability density function. Using a Matlab code, we obtained the shape and scale factor of the wind in Viladecans (essential parameters when obtaining a Weibull distribution), and we were able to plot a graph showing the probability for the wind to reach a certain speed value.

Once the wind speed distribution was completed, the next step was to use the simulation software pack “Fast & Aerodyn” to obtain the generator power for our wind turbines. This software, besides the wind data, requires several input files that were to be obtained.

For the IT-PE-100, we were able to use already calculated input files from other projects conducted at Universitat Politècnica de Catalunya (UPC). With them and the previously calculated wind speed distribution, we were able to obtain the power curve, along with the yearly energy income, which was 99.6kWh.

For the HP-600 turbine, the files were had to be made from scratch. Since the manufacturer couldn’t provide us with enough information, we had to make a reverse engineering process to obtain all the data that Fast & Aerodyn required. We contacted a company, Asorcad, to digitalize one of the blades of the turbine, in order to have a CAD file. That file was a scale representation of the blade, and it allowed us to conduct several flow simulations using SolidWorks, in order to determine most of the aerodynamic parameters needed, such as the lift and drag coefficients for a given angle of attack.

With those parameters we were able to complete the Fast & Aerodyn files for the HP-600 wind turbine, and thus we were able to obtain its power curve and the yearly energy income, which was 66.3kWh.

Once we were able to obtain the power curves, we compared them along with other relevant data, such as the annual estimated benefit of the wind turbines or the power coefficient.

We determined that the most appropriate was the IT-PE-100, since it produced more power at the low-speed regions and had a better performance overall.

The distribution of this project follows the process described. The first chapter serves as an explanation of the type of wind that Viladecans has, along with theory backing the decisions that were made. It also serves as an example of how to obtain the Weibull distribution of a given wind data, with the Matlab code that was used attached as an annex.

In the following chapter we can find the core of the project. Here we explain the main features of the simulation software Fast & Aerodyn, describing each file that was relevant to the simulations. We also elaborate on how the digitalization of the HP-600 blade was made, and what process was followed in order to obtain the aerodynamic parameters using Flow Simulation.

The third chapter consists in comparing the power curves, power coefficients and other parameters obtained in the second chapter.

In the conclusions we expose all the data that has previously been compared, and justify the decision of choosing the IT-PE-100 over the HP-600 wind turbine.

CHAPTER 1. WIND RESOURCES

1.1. Introduction

As stated before, the main goal of this project is to study two low profile wind turbines, and to compare them with the purpose of determining which one fits best in the agricultural area of Viladecans.

In order to do so, we must start from the very beginning: Analyzing and understanding the wind in the area where the wind turbines are going to be located. Therefore, this chapter is aimed to provide all the necessary knowledge regarding what kind of wind does Viladecans have, how is it going to be treated from a statistical point of view, as well as explaining why certain statistical distributions are more useful than others when representing a massive amount of wind data.

1.2. The wind

The amount of energy provided by a moving mass of air in its circulation on the lowest layers of the atmosphere represents a relatively high energy potential, especially under determined local and temporal conditions. Therefore it is justified the effort of transforming the wind into useful energy, and its exploitation taking into account both efficiency and profitability.

The wind is formed because of the expansion and convection of the air induced because of different solar energy absorptions on the Earth. In a global scale, these thermal effects combine with dynamic effects due to Earth’s rotation, thus resulting in the atmospheric general circulation. In addition to this large-scale situation, there are important local and temporal variations due to geographic and climatologic factors. [4]

Therefore, the wind, when being considered as an energetic resource, has its own specific characteristics: A source with substantial temporal variations, both in small and large time scale, and spatial, both in surface and height. At the same time, we must take into account that the available wind energy per area unit is proportional to the cube of the speed, and therefore small variations in the wind speed will result in noticeable variations on the supplied energy.

1.2.1. The origin of the wind

The wind is produced due to the movement of the air mass in the troposphere, the lowest layer in the atmosphere. Inside of it, the most important winds from an energetic point of view will be the ones that are produced on the Earth’s surface.

The movement of the masses of air must be found in the pressure gradients, which are due to different thermal gradients originated because of the solar radiation perceived on Earth. That means, the layers of hot air ascend leaving free space for the cold air ones, thus originating the movement between air layers.

That way, when this process occurs, air from the warmer zone will move to the colder zone, equilibrating its temperatures and making the pressure stable within that area, as shown below (see Fig. 1.1) [3]

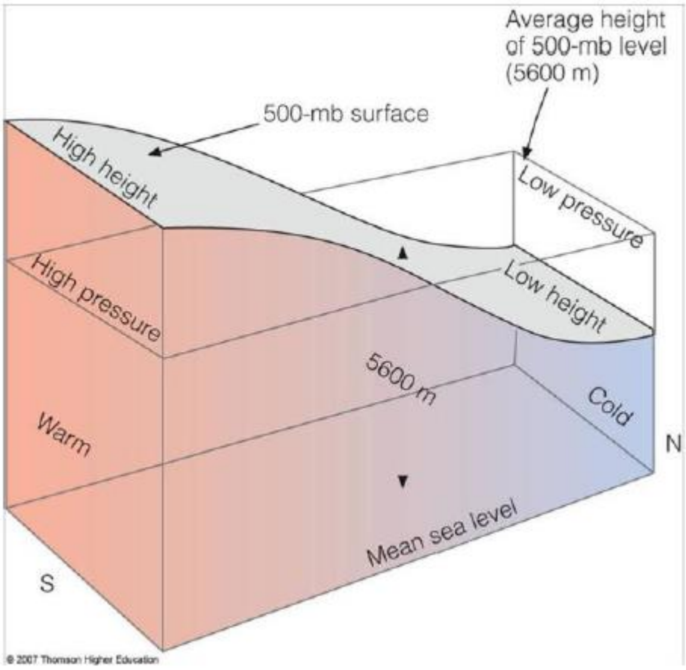


Fig 1.1 Wind originated due to different pressure values.

1.2.2. Ground influence

At a great height over ground level, approximately at 1 kilometer, the influence of earth's surface on the wind is almost zero. However, on the lower layers of the atmosphere, wind speeds are affected by the friction with the ground. We can measure this friction with a parameter, named roughness length.

The roughness of a surface is determined by the size and the distribution of the roughness elements that are contained within it. The roughness length, *z0*, gives us the height at which the average speed is zero when the wind has a logarithmic variation with height: [4]

$$Z0=0.5*S*h/Ah \quad \textbf{(1.1)}$$

Where h, S and Ah being height, section of the roughness elements facing the wind, and horizontal area of each obstacle, respectively.

In the next image we can appreciate how the ground obstacles affect the wind profile (see Fig. 1.2):

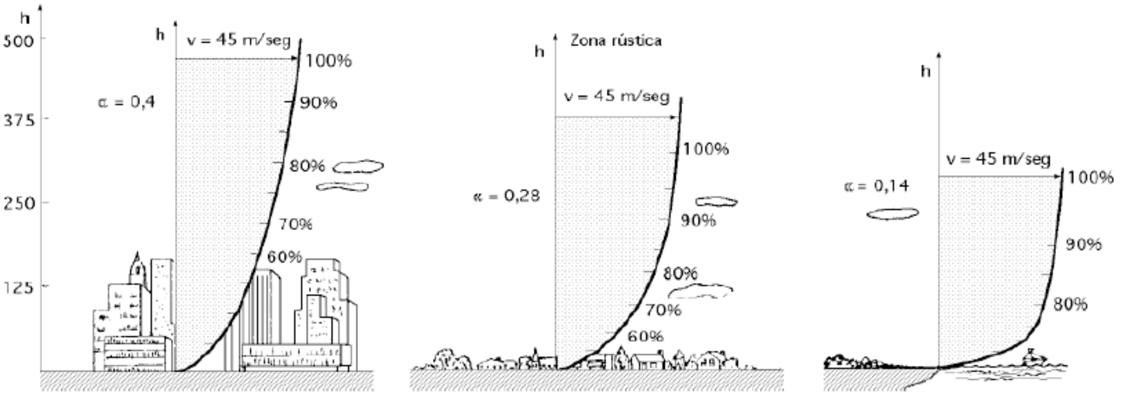


Fig 1.2 Differences in roughness length affects wind spreading.

Generally, the greater the length roughness, the higher will be the deceleration experimented by the wind. Therefore, areas like cities and forests will have a higher slowdown, whereas, for example, an airport runway will have a much lesser effect on the wind.

In the following table we can appreciate different landscape features and their roughness length value.

Table 1.1 Different roughness values according to landscape features.

Class		Roughness length	Landscape Features
Nº	name		
1	Sea	0.0002	Open water
2	Smooth	0.005	Featureless land, ice
3	Open	0.03	Flat terrain with grass, airport runway
4	Roughly open	0.10	Cultivated area, low crops
5	Rough	0.25	Open landscape, scattered shelter belts
6	Very rough	0.5	Landscape with bushes, young forest
7	Closed	1	Low-rise build area, mature forest
8	Chaotic	Over 2	City centre

1.2.3. Wind direction

The wind direction depends directly on the pressure distribution, since the wind blows from the higher pressure zone to the lower pressure one. It is usually represented using a compass rose, where there are represented the four main cardinal points, and up to 32 intermediate points between them. Although the most used compass rose is the one pictured below (Fig 1.3):

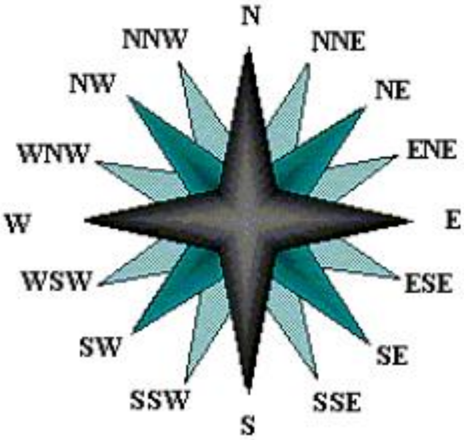


Fig 1.3 Compass rose with 16 cardinal points.

1.2.4. Distribution of wind speed

Apart from the average strength of wind over a period of time, its distribution is also a critical factor in wind resource assessment. Wind turbines installed at two places with the same average wind speed may yield entirely different energy output due to differences in the velocity distribution. For example, consider two sites with a given daily wind pattern. For the first location, the wind velocity is 15 m/s throughout the day. At the second site, velocity is 30 m/s for the first 12 hours and 0 for the rest of the day. In both the cases, the daily average wind velocity is 15 m/s.

When the turbine is put to work at the first site, as the wind velocity is 15 m/s throughout the day, the system will efficiently work at its rated capacity for all the time. However, in the second case, the turbine will idle throughout the day as the velocity is 30 m/s in the first half (which is well above its cut-off speed) and 0 in the second half. This shows that, along with the mean wind velocity, the distribution of velocity within the regime is also an important factor in the wind energy analysis. [5]

1.2.4.1 Statistical model for wind speed distribution

One of the analytic expressions used more often when treating low wind speeds is the so called Weibull distribution. It is a special case of Pierson class III distribution, and is characterized by two functions: The probability density function and the cumulative distribution function, being the former the one chosen for our study, since it indicates the fraction of probability for which the wind is, at a given velocity V:

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} e^{-\left(V/c\right)^{k}} \tag{1.2}$$

Being k the shape factor and C the scale factor. The figure below (Fig 1.4) represents the typical shape of a Weibull distribution.

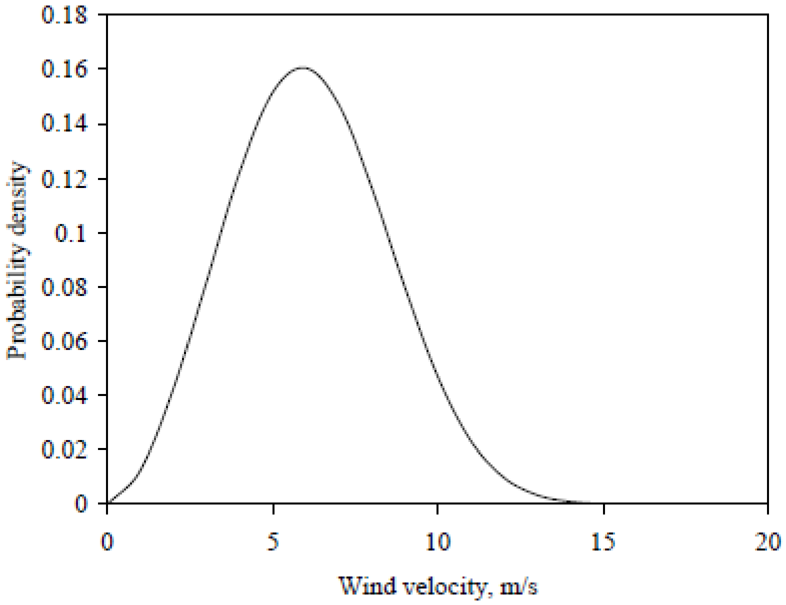


Fig 1.4 Weibull probability density distribution

In order to obtain the Weibull distribution of a certain wind data, both the scale and shape factor for this specific data must be acquired.

There are different methods to calculate them, one of the most used being the lineal regression [1]. Although it is considered to be adequately precise, in this project it was decided to use the “Levenberg – Marquardt least squares regression”, provided by the mathematical software Matlab, which gives a 95% confidence interval for the parameter estimates.

The following figure (see Fig. 1.5) illustrates the shape differences when the *k* factor is modified.

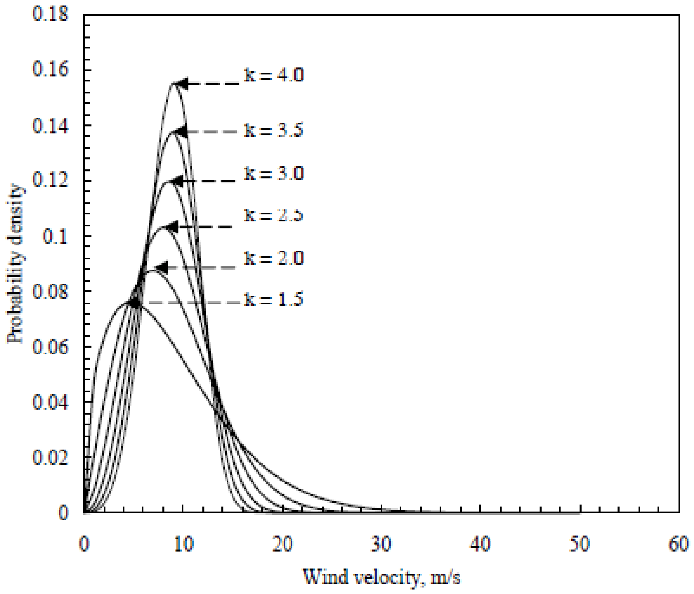


Fig 1.5 Difference between Weibull distribution for different shape factors.

1.3. Viladecans wind data

Once all the theory regarding wind treatment has been exposed, we can present our case study:

The wind turbines were thought to be mounted in Agropolis, an agricultural area located in Viladecans, property of the UPC. Therefore, “Servei Meteorològic de Catalunya” provided us with wind data from that area, which consisted in the wind speed and direction of every hour for the last 19 years, measured at 2 meters.

The first step towards analyzing the data is modifying this wind values so that they are located at 10 meters instead of the 2 meters from which they were measured. Thus, assuming a neutral atmosphere, and estimating the roughness length at 0.1 (See table 1.1) we can apply the vertical wind variation formula to obtain the values at 10 meters:

$$V_H = V_{2m} \cdot \frac{\ln(H/z_0)}{\ln(2/z_0)} \qquad \textbf{(1.3)}$$

Being Vh the desired speed, V2m the speed at 2 meters, H our desired height (10m) and z0 the roughness length, 0.1. [2]

Note that this process does not affect the wind direction. We can also plot a compass rose (see Fig 1.6) to know where most of the wind will be coming from: [3]

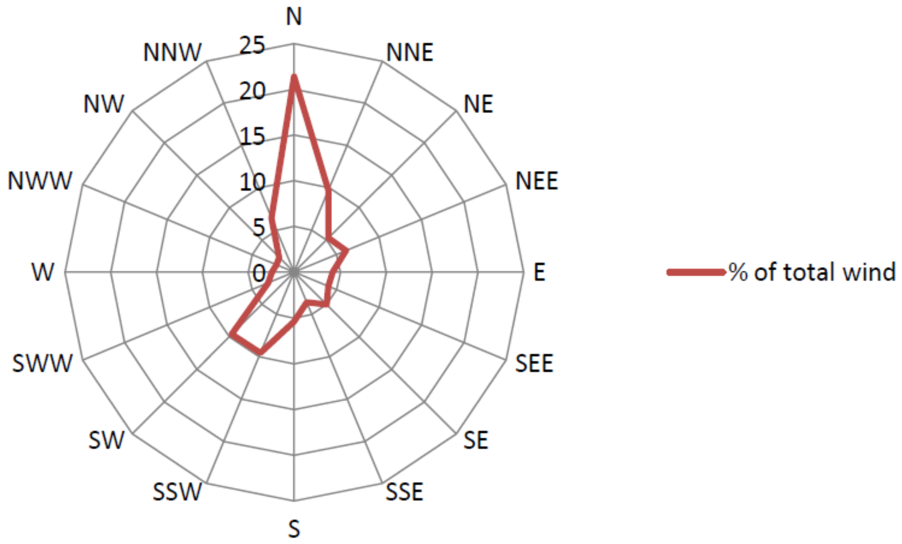


Fig 1.6 Compass rose for Viladecans wind direction.

Since both IT-PE-100 and HP-600 have a rotational gear that allows them to face the wind, it was decided that it would not be taken into consideration any loss due to different wind directions, and that the time that the turbines need to fully orient themselves to the wind is negligible.

Our next step is creating the wind distribution using the Weibull probability density function. In order to do so, we created a Matlab code that arranged all the wind speed values (which were previously converted from 2 to 10 meters) into 0.5m/s intervals. By doing that we are able to know how many times will the wind reach a certain speed value during the year, as illustrated in the following image (see Fig 1.7)

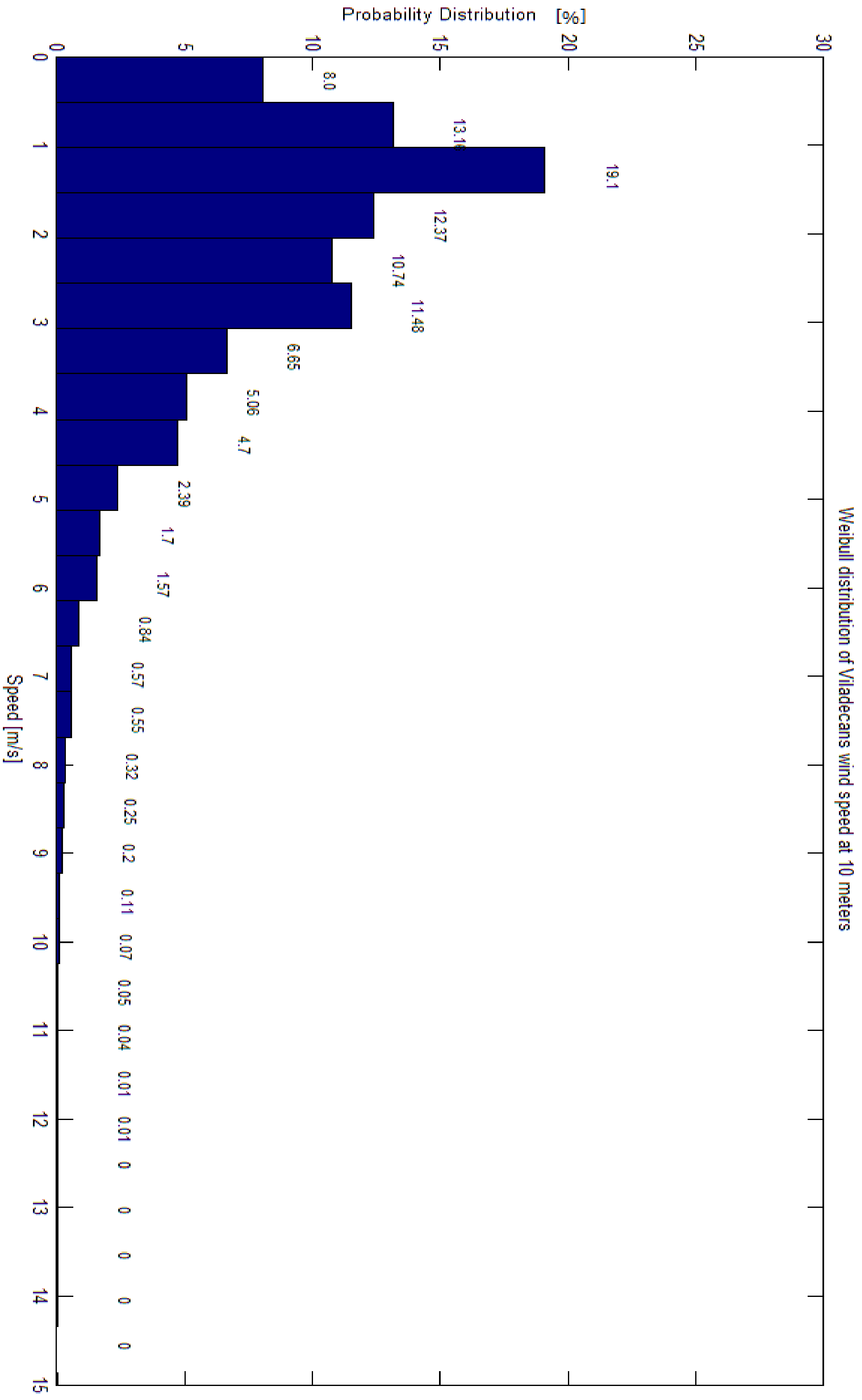


Fig 1.7 Weibull-shaped histogram of Viladecans wind speed.

Once this histogram has been made, we can now use the *wblfit* function to determine what are the scale and shape factors and thus, plotting the Weibull distribution, as shown below (Fig 1.8)

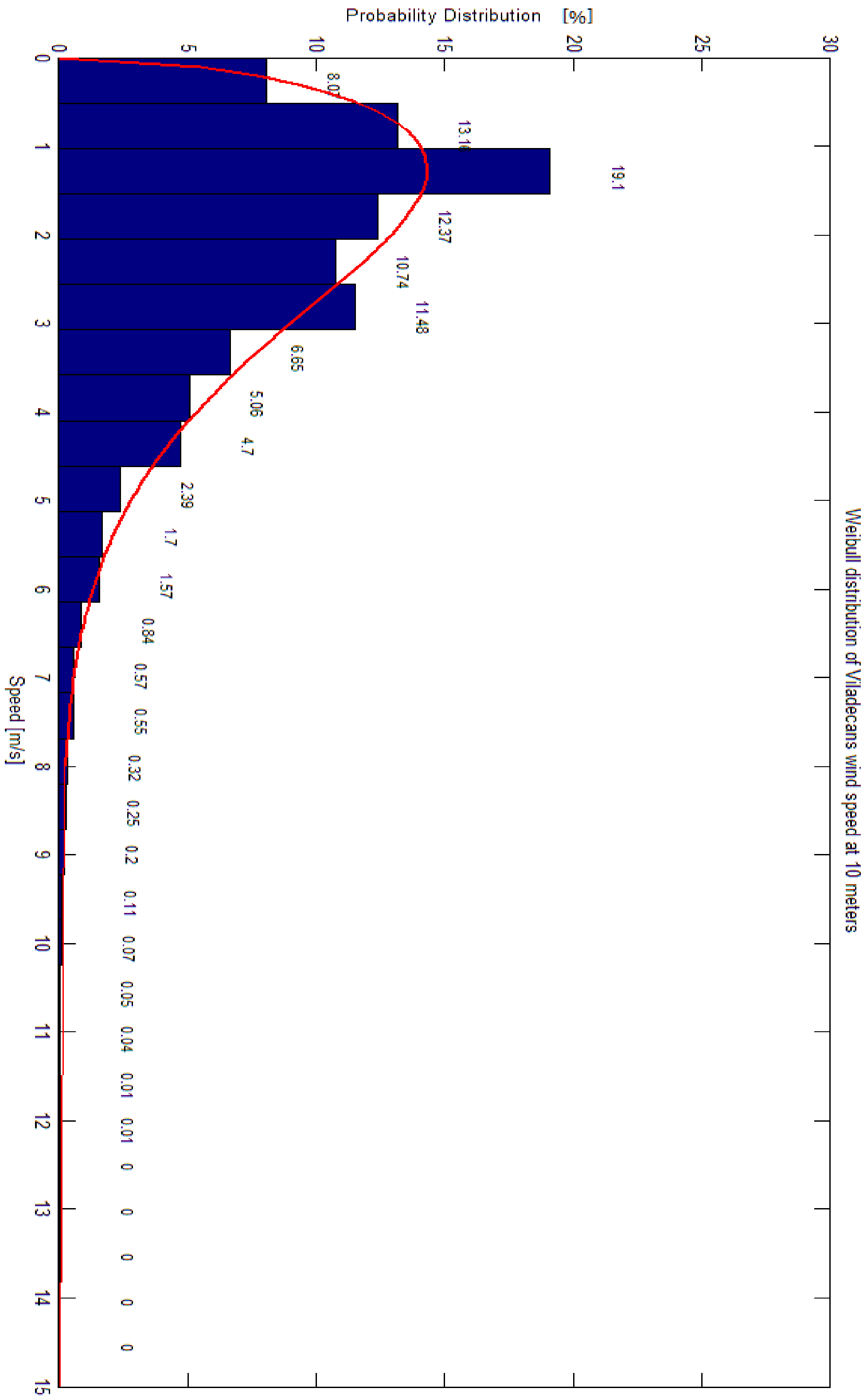


Fig 1.8 Weibull distribution and histogram of Viladecans wind speed at 10 meters.

Alternatively, we can plot the Weibull distribution of the sea breeze hours (7am-7pm), so that we can appreciate an increase in the wind speed. As shown in Fig 1.9:

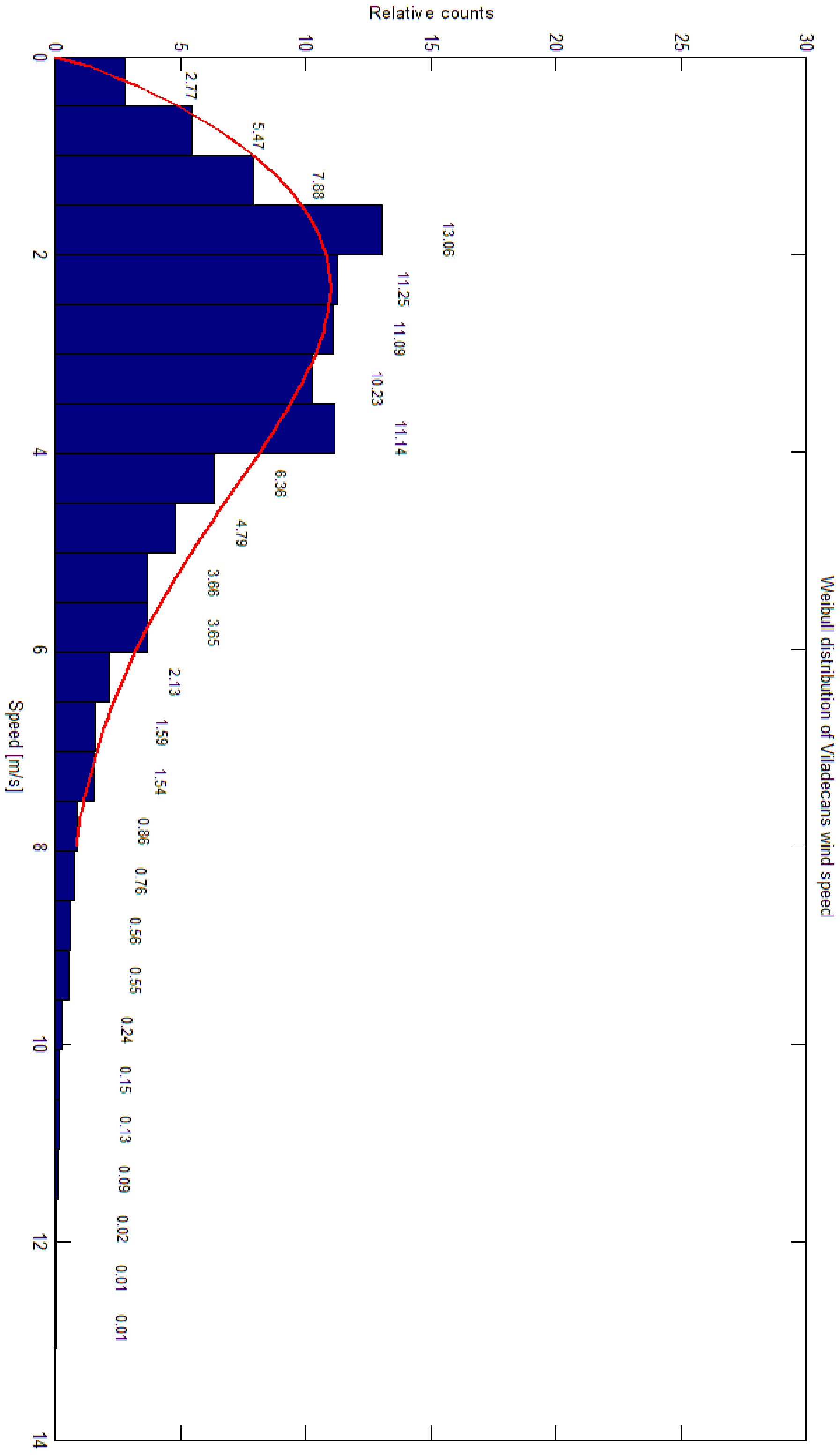


Fig 1.9 Weibull distribution of Viladecans at sea breeze hours and 10 meters

The sea breeze is a particular case of thermal winds. It appears in coastal areas and it is formed due to the temperature difference between the earth and the sea surfaces.

Occurs because the sea has a greater heat capacity than the land, and therefore its surface heats up more slowly. This difference in temperature originates a pressure gradient that, like we have seen before, will result in a wind current from the land to the sea.

We can appreciate that the peak of the Weibull probability density function has displaced towards a wind speed value of 2.75 m/s approximately, whereas for the total wind distribution that peak is located at 1.25 m/s.

CHAPTER 2. MODELLING AND SIMULATION

2.1. IT-PE-100 Wind Turbine

2.1.1. Introduction

The IT-PE-100 is a low power wind turbine, designed to take advantage and to produce electricity from a wide range of wind speeds, from slow breezes to strong winds, and manufactured through simple processes. In its design it has been considered the resistance under adverse weather (such as corrosion) and its effects on the production, taking into account practical considerations for easy operation and maintenance.

These turbines start to work from very low speed (3 m/s) and have a generating curve up to speeds about 12 m/s. For higher speeds, these machines have a mechanism of protection (both mechanical and aerodynamic), which allows them to trickle out of the wind direction, turning sideways.

2.1.2. General description

The IT-PE-100 was developed by the company *Soluciones Prácticas* - ITDG for installation in remote rural areas of Peru, where its implementation is a reality today. It is a simple generator with a simple structure and an affordable manufacturing process. All aspects were designed for trouble-free installation and long life in developing and remote areas.

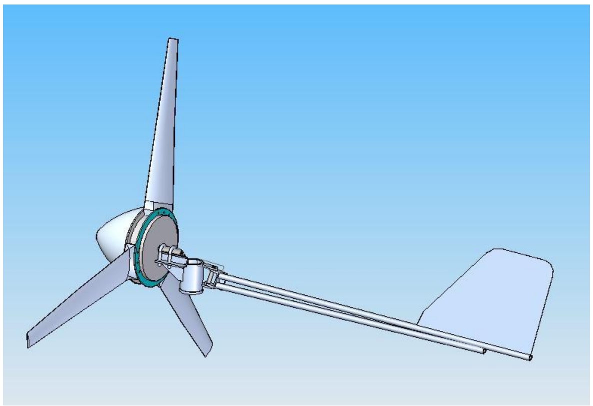


Fig 2.1 IT-PE-100 CAD model.

The IT-PE-100 is an upwind horizontal axis rotor. The rotor is composed of three small blades attached to a hub, with an overall diameter of 1.7 m. The blades are not uniform along the span, but are characterized by one airfoil type only, the NACA 4412. The majority of the components of the rotor are made of fiberglass. This gives them a very low weight with good structural properties.

The nature of the rotor and the short and light blade involves high operating speeds, at least 100 rpm. In turn, this feature makes it possible to connect the rotor shaft to the shaft of the generator directly, that is both turn together. This is a great advantage because it makes it unnecessary to have a heavy transmission system. Should the rotor work at lower speeds, a transmission wheel would be indispensable.

The generator-rotor is firmly attached to the nacelle, a cylindrical piece of structural reinforced steel, inserted into the upper end of the tower. The nacelle allows free rotation of the rotor-generator set around its vertical axis, i.e., the yaw angle has a range of 360°, which facilitates alignment of the assembly with the incoming wind whatever its direction.

Fig. 2.2 shows a three-dimensional representation of the nacelle:

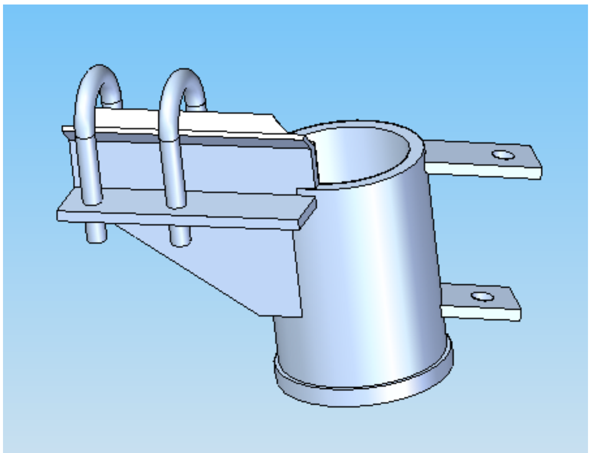


Fig 2.2 CAD representation of the nacelle.

Moreover, the nacelle structure holds the tail, which has rotational freedom to align with the wind (See Fig. 2.3):

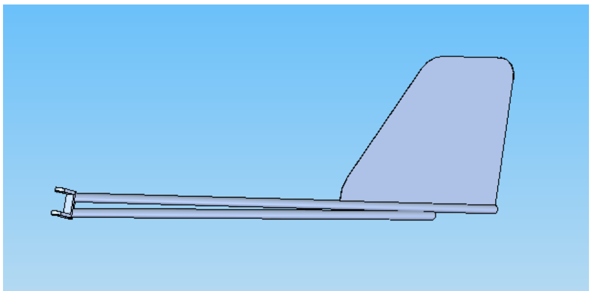


Fig 2.3 CAD representation of the tail.

Finally, the structure consists of a cylindrical steel tower of eight meters height that will hold the turbine to this height. The structure is firmly held in its location by a number of bracing wires to prevent excessive swinging.

The company that developed the turbine took into account the characteristics of the wind speeds in Peru. Existing conditions invited to create a wind turbine capable of operating at low wind speeds. For this purpose, the IT-PE-100 uses a permanent magnet (PM) generator made of neodymium. In Fig 2.4 can be seen a schematic representation of the electric system.

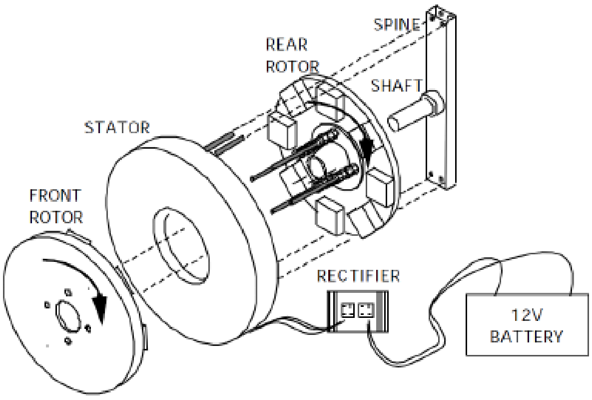


Fig 2.4 Electric system

With this structure, the IT-PE-100 offers a nominal power of around 100W, enough to take a first step in the electrification in rural areas.

Fig. 2.5 shows the complete power curve of this model.

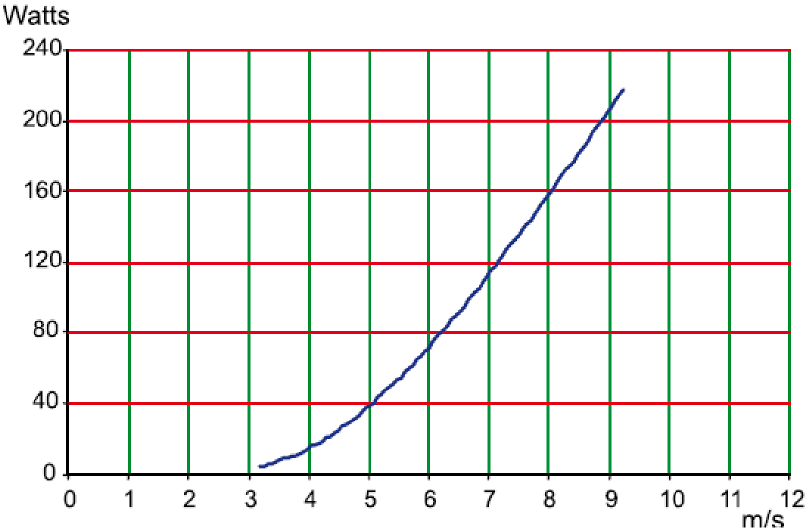


Fig 2.5 Power curve for IT-PE-100

For a complete list of the technical specifications of the IT-PE-100 wind turbine, see Annex B.

2.2. Hopeful HP-600 Wind Turbine

2.2.1. Introduction

The HP-600 is a small scale wind turbine designed by *Hopeful Energy*, a manufacturer specialized in low-wind speed generators. It has been designed to work at higher speeds than the previous model, the IT-PE-100. It features a light and compact size, making it smaller than most low-wind speed turbines.

Unlike the IT-PE-100 model, it cannot be built at home, and it is only available as a boxed product through the manufacturer. As a result, it is difficult to find technical information regarding this wind turbine, other than the presented at the *Hopeful Energy* website.

2.2.2. General description

As stated before, it is substantially smaller than similar small scale wind turbines, with a blade length of 0.68 m and a rotor diameter of 1.5 m. It features a 3 bladed upwind rotor, as Fig. 2.6 shows.

Fig 2.6 HP-600 Wind turbine.

The blades are made of nylon and glass fiber, and specially coated to prevent corrosion, high temperatures, water and sand.

It has a start up wind speed of 3m/s, and a nominal output power of 600W at 12m/s. As the IT-PE-100, the HP-600 has a 3 phases PM generator.

It works at higher rpms than the previous turbine, up to 920 rpm, where it provides 750W.

The following graph (see Fig 2.7), provided by the manufacturer, shows the power in Watts against the wind speed in m/s:

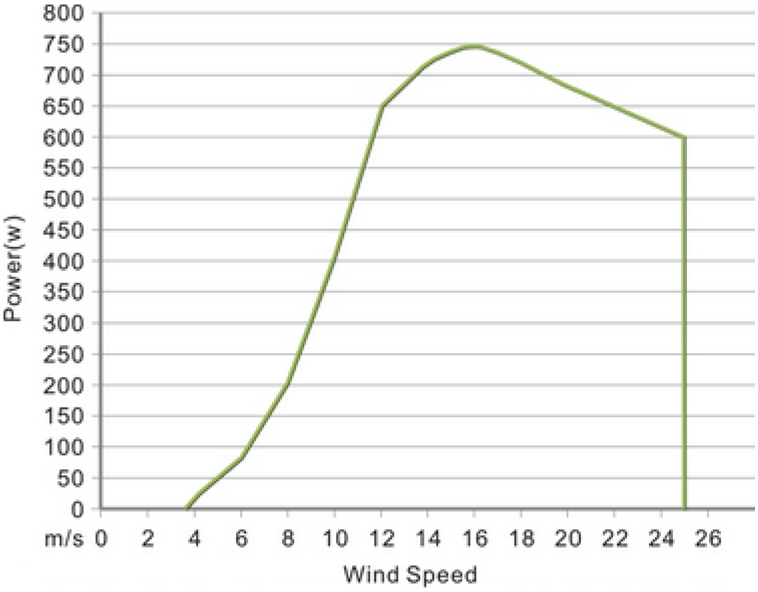


Fig 2.7 HP-600 Power curve given by the manufacturer.

2.3. Fast & Aerodyn

2.3.1. Introduction

To obtain the power production of the turbines studied in this project, we have used a pair of simulation tools called FAST and AeroDyn which work together as one. This chapter contains a quick reference of these tools including basic definitions of both of them, as well as general features like modes of operation, turbine control options, basic recommendations, limitations, and finally, an example of files and the relation between them.

2.3.2. Fast

The FAST (Fatigue, Aerodynamics, Structures, and Turbulence) code is a comprehensive aeroelastic simulator capable of predicting both the extreme and fatigue loads of two and three-bladed horizontal-axis wind turbines (HAWTs).

FAST has been developed by NREL (National Renewable Energy Laboratory), a U.S. laboratory, in collaboration with the University of Oregon, and has been validated by Germanischer Lloyd for the certification of wind turbines.

Using the FAST code the following can be calculated for a HAWT:

- Total loads on the various components.
- Distributed loads on the main components.
- Aerodynamic parameters.
- Power curves.
- Component movements.
- Deflections.
- Noise estimation.

Model description:

The FAST code can model a three-bladed HAWT with 24 degrees of freedom (DOFs)

- 6 DOFs originate from the translational (surge, sway, and heave) and rotational (roll, pitch, and yaw) motions of the support platform relative to the inertia frame.
- 4 DOFs account for tower motion; two are longitudinal modes, and two are lateral modes.
- 1 DOF provided by yawing motion of the nacelle.
- 1 DOF for the generator azimuth angle.
- 1 DOF is the compliance in the drivetrain between the generator and hub/rotor.
- 3 DOFs for the blade flapwise tip motion for the first mode.
- 3 DOFs for the tip displacement for each blade for the second flapwise mode.
- 3 DOFs for the blade edgewise tip displacement for the first edgewise mode.
- 2 DOFs for rotor- and tail-furl.

The DOFs and features most applicable to a given analysis are dictated by the configuration of the wind turbine to be analyzed.

It is important to note the following:

- The more degrees of freedom activated, the more realistic the result.
- The more degrees of freedom activated, the greater the computation time and the more difficult to detect errors.

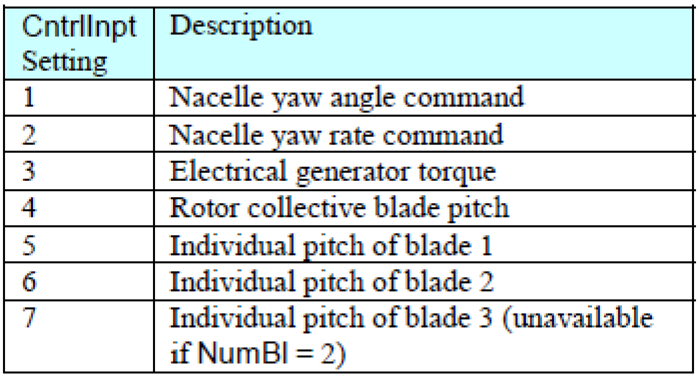
- It is self-defeating the use of DOFs if there is no detailed structural information. When not knowing the distribution of mass and stiffness of the blades, calculated deformations can be farther from reality than calculations with the simple model (no DOFs).

Taking that into account, it is recommended to disable all DOFs (in the FAST main input file) and activate them progressively. A first level of complexity would be activating the rotor and tower first modes. A more realistic model can be accomplished activating the first and second *flapwise* rotor mode, the *edgewise* rotor mode and one mode for each direction for the tower.

Controls:

During time-marching analysis, FAST makes it possible to control your turbine and model specific conditions in many ways. Five basic methods of control are available: blade pitching, controlling the generator torque, applying the HSS brake, deploying tip brakes, and yawing the nacelle. The simpler turbine control methods require nothing more than setting some of the appropriate input parameters in the Turbine Control section of the primary input file.

More complicated control methods require to either elaborate customary routines, compile them, and link them with the rest of the program or implement customary routines in a Simulink model with which FAST can be interfaced to. (See Fig 2.8)



CntrlInpt Setting	Description
1	Nacelle yaw angle command
2	Nacelle yaw rate command
3	Electrical generator torque
4	Rotor collective blade pitch
5	Individual pitch of blade 1
6	Individual pitch of blade 2
7	Individual pitch of blade 3 (unavailable if NumBl = 2)

Fig 2.8 Control input settings

Advanced operating modes:

FAST has the capability of extracting “equivalent” ADAMS (Automatic Dynamic Analysis of Mechanical Systems) wind turbine datasets from the turbine properties specified in the FAST input files. This means that FAST can be used as a preprocessor to create an ADAMS model.

The FAST to ADAMS preprocessor provides a natural progression from the medium-complexity FAST wind turbine models to the highly complex models

possible using ADAMS. Once a working FAST model has been developed, little additional effort is required to create the more advanced ADAMS model.
Several characteristics not implemented in the FAST model are incorporated into the extracted ADAMS model. Some of these characteristics are torsional and extensional DOFs for the blades and tower, flap/twist coupling in the blades, precurved and preswept blades, mass and elastic offsets for the blades, mass offsets for the tower, actuator dynamics for the blade pitch controls, and graphical output capabilities.

(Fig 2.9) shows schematically the complete operating mode between FAST and AeroDyn (using FAST as preprocessor to create ADAMS model)

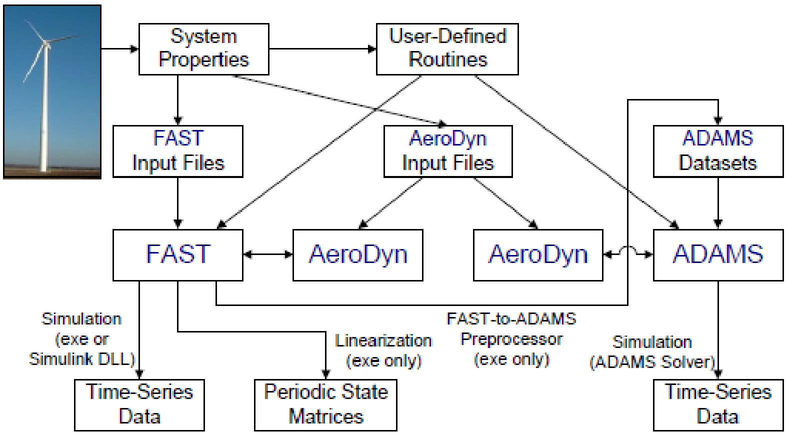


Fig 2.9 Fast & Aerodyn operating mode.

For the study covered in this project it has been used a simplified model which is shown in (Fig 2.10)

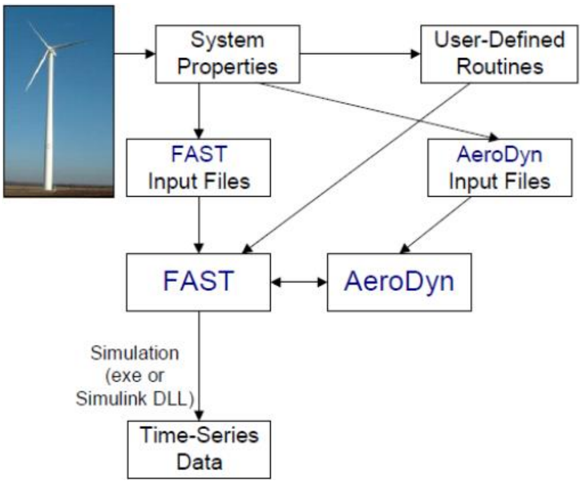


Fig 2.10 Simplified Fast & Aerodyn model

Basic Limitations:

For reasons of stability calculation, it is possible that the values obtained in the first seconds of the simulation are not correct. Therefore, the results of the first 4 or 5 turns of rotor should be dismissed.

For the simulations with large yaw angle or working in the stall region, the calculation results show more uncertainty. These results must be taken with some caution.

At very low wind speeds (between 2 and 5 m/s) the uncertainty of the results is large. The causes of this uncertainty at low speeds are:

- The effects of inertia. They are much more important in the starting and stopping of the rotor, such that the model may not be adequate to evaluate these operating states (boot and shutdown).

- GDW model instability. This model and the BEM model are used in aerodynamic calculations. It has shown some uncertainty in the results at low speeds. It is always useful to represent the results in graphical form, in order to observe possible changes or discontinuities in the calculations.

- For high angles of attack, 3D corrections based on semi-empirical data have not been evaluated for that range of speeds.

2.3.3. Aerodyn

AeroDyn is a set of routines used in conjunction with an aeroelastic simulation code to predict the aerodynamics of horizontal axis wind turbines.

AeroDyn contains two models for calculating the effect of wind turbine wakes: the blade element momentum theory (BEM) and the generalized dynamic-wake theory (GDW). Blade element momentum theory is the classical standard used by many wind turbine designers and generalized dynamic wake theory is a more recent model useful for modeling skewed and unsteady wake dynamics.

When using the blade element momentum theory, various corrections are available, such as incorporating the aerodynamic effects of tip losses, hub losses, and skewed wakes. With the generalized dynamic wake, all of these effects are automatically included.

Both of these methods are used to calculate the axial induced velocities from the wake in the rotor plane and the rotational induced velocity. In addition, AeroDyn contains an important model for dynamic stall based on the semi-empirical Beddoes-Leishman model. This model is particularly important for yawed wind turbines.

Another aerodynamic model in AeroDyn is a tower shadow model based on potential flow around a cylinder and an expanding wake. Finally, AeroDyn has the ability to read several different formats of wind input, including single-point hub-height wind files or multiple-point turbulent winds. [5]

2.3.4. Input Files

Fig 2.4 shows the files involved in the simulations and the relations to FAST and AeroDyn (Fig 2.11)

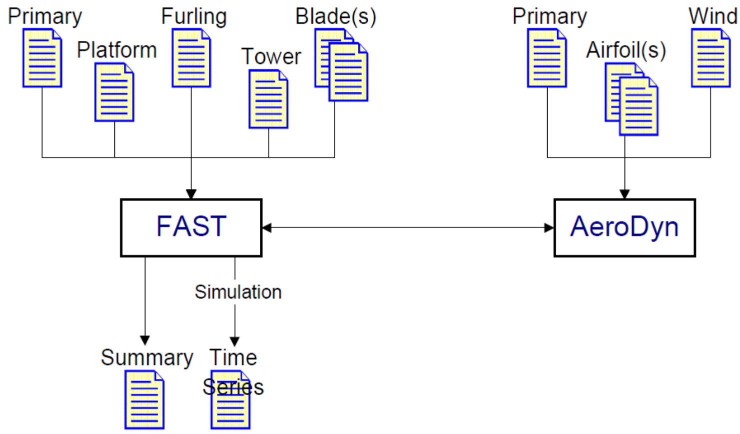


Fig 2.11 Fast & Aerodyn input files

The FAST archive provides a sample set of 17 models, including all pertinent input files. The next table provides a general description of these sample models.

Test Name	Turbine Name	No. Blades (-)	Rotor Diameter (m)	Rated Power (kW)	Test Description
Test01	AWT-27CR2	2	27	175	Flexible, fixed yaw error, steady wind
Test02	AWT-27CR2	2	27	175	Flexible, start-up, HSS brake shut-down, steady wind
Test03	AWT-27CR2	2	27	175	Flexible, free yaw, steady wind
Test04	AWT-27CR2	2	27	175	Flexible, free yaw, turbulence
Test05	AWT-27CR2	2	27	175	Flexible, generator start-up, tip-brake shutdown, steady wind
Test06	AOC-15/50	3	15	50	Flexible, generator start-up, tip-brake shutdown, steady wind
Test07	AOC-15/50	3	15	50	Flexible, free yaw, turbulence
Test08	AOC-15/50	3	15	50	Flexible, fixed yaw error, steady wind
Test09	UAE VI downwind	2	10	20	Flexible, yaw ramp, steady wind
Test10	UAE VI upwind	2	10	20	Rigid, power curve, ramp wind
Test11	WP 1.5 MW	3	70	1500	Flexible, variable speed & pitch control, pitch failure, turbulence
Test12	WP 1.5 MW	3	70	1500	Flexible, variable speed & pitch control, ECD event
Test13	WP 1.5 MW	3	70	1500	Flexible, variable speed & pitch control, turbulence
Test14	WP 1.5 MW	3	70	1500	Flexible, stationary linearization, vacuum
Test15	SWRT	3	5.8	10	Flexible, variable speed control, free yaw, tail-furl, EOG01 event
Test16	SWRT	3	5.8	10	Flexible, variable speed control, free yaw, tail-furl, EDC01 event
Test17	SWRT	3	5.8	10	Flexible, variable speed control, free yaw, tail-furl, turbulence

Fig 2.12 Different sample models.

For the study covered in this project we chose Test 17, whose files are created to simulate Small Research Wind Turbines (SWRT). The wind turbine studied in this project can be considered a SWRT.

2.3.4.1. Fast Input Files

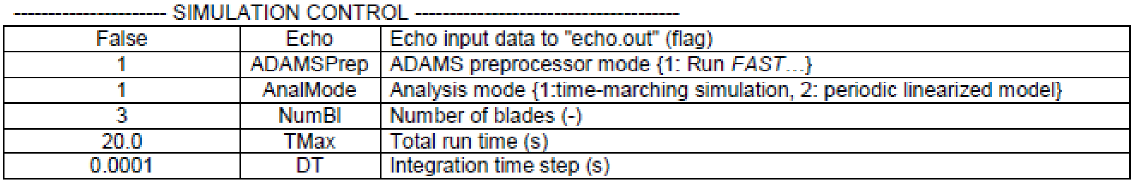
Primary input file:

FAST uses a primary input file to describe the wind turbine operating parameters and basic geometry.
However, the blade, tower, furling, and aerodynamic parameters and wind-time histories are read from separate files.

The parameter input files have a simple text format that can be read and modified by any text editor. Most lines in the input file are divided into three sections: value(s), variable name(s), and description.

The Variable-Name section contains the variable name used internally by the program and in references for other parameters. The Description section of the line contains a brief description of the parameter as a reminder to the user of its purpose. This section also contains the physical units of the numerical value, where appropriate.

The primary FAST input file has a list of output parameters at the end of the file that can be as long as you like. Some parameters do not apply to two-bladed turbines, and others do not apply to three-bladed turbines. FAST treats these as comments.



---------------------- SIMULATION CONTROL --------------------------------------

False	Echo	Echo input data to "echo.out" (flag)
1	ADAMSPrep	ADAMS preprocessor mode {1: Run *FAST*…}
1	AnalMode	Analysis mode {1:time-marching simulation, 2: periodic linearized model}
3	NumBl	Number of blades (-)
20.0	TMax	Total run time (s)
0.0001	DT	Integration time step (s)

---------------------- TURBINE CONTROL ---

0	YCMode	Yaw control mode {0: none, 1: user-defined from routine UserYawCont}
9999.9	TYCOn	Time to enable active yaw control (s) [unused when YCMode=0]
0	PCMode	Pitch control mode {0: none, 1: user-defined from routine PitchCntrl} (switch)
9999.9	TPCOn	Time to enable active pitch control (s) [unused when PCMode=0]
2	VSContrl	Variable-speed control mode { 2: user-defined from routine UserVSCont}
9999.9	VS_RtGnSp	Rated generator speed for simple variable-speed generator control (rpm)
9999.9	VS_RtTq	Rated generator torque/constant ... simple variable-speed generator control
9999.9	VS_Rgn2K	Generator torque constant ... simple variable-speed generator (N-m/rpm^2)
9999.9	VS_SlPc	Rated generator slip ...simple variable-speed generator control (%)
1	GenModel	Generator model {1: simple, 3: user-defined from routine UserGen}
True	GenTiStr	Method to start the generator
True	GenTiStp	Method to stop the generator
9999.9	SpdGenOn	Generator speed to turn on the generator for a startup (HSS speed) (rpm)
0.0	TimGenOn	Time to turn on the generator for a startup (s) [used only when GenTiStr=True]
9999.9	TimGenOf	Time to turn off the generator (s) [used only when GenTiStp=True]
1	HSSBrMode	HSS brake model {1: simple, 2: user-defined from routine UserHSSBr} (switch)
9999.9	THSSBrDp	time to initiate deployment of the HSS BRAKE (S)
9999.9	TiDynBrk	Time to initiate deployment of the dynamic generator brake
9999.9	TTpBrDp(1)	Time to initiate deployment of tip brake 1 (s)
9999.9	TTpBrDp(2)	Time to initiate deployment of tip brake 2 (s)
9999.9	TTpBrDp(3)	Time to initiate deployment of tip brake 3 (s) [unused for 2 blades]
9999.9	TBDeplSp(1)	Deployment-initiation speed for the tip brake on blade 1 (rpm)
9999.9	TBDeplSp(2)	Deployment-initiation speed for the tip brake on blade 2 (rpm)
9999.9	TBDeplSp(3)	Deployment-initiation speed for the tip brake on blade 3 (rpm)
9999.9	TYawManS	time to start override YAW maneuver AND end standard YAW CONTROL (S)
9999.9	TYawManE	time at which override YAW maneuver reaches final YAW angle (S)
0.0	NacYawF	final YAW angle for YAW maneuvers (degrees)
9999.9	TPitManS(1)	Time to start pitch maneuver for blade 1 and end standard pitch control (s)
9999.9	TPitManS(2)	Time to start pitch maneuver for blade 2 and end standard pitch control (s)
9999.9	TPitManS(3)	Time to start pitch maneuver for blade 3 and end standard pitch control (s)
9999.9	TPitManE(1)	Time at which override pitch maneuver for blade 1 reaches final pitch (s)
9999.9	TPitManE(2)	Time at which override pitch maneuver for blade 2 reaches final pitch (s)
9999.9	TPitManE(3)	Time at which override pitch maneuver for blade 3 reaches final pitch (s)
0.0	BlPitch(1)	Blade 1 initial pitch (degrees)
0.0	BlPitch(2)	Blade 2 initial pitch (degrees)
0.0	BlPitch(3)	Blade 3 initial pitch (degrees) [unused for 2 blades]
0.0	BlPitchF(1)	Blade 1 final pitch for pitch maneuvers (degrees)
0.0	BlPitchF(2)	Blade 2 final pitch for pitch maneuvers (degrees)
0.0	BlPitchF(3)	Blade 3 final pitch for pitch maneuvers (degrees) [unused for 2 blades]

---------------------- FEATURE FLAGS --

True	FlapDOF1	First flapwise BLADE mode DOF (flag)
True	FlapDOF2	Second flapwise BLADE mode DOF (flag)
True	EdgeDOF	First edgewise BLADE mode DOF (flag)
False	TeetDOF	Rotor-teeter DOF (flag) [unused for 3 blades]
False	DrTrDOF	DRIVETRAIN rotational-flexibility DOF (flag)
True	GenDOF	GENERATOR DOF (flag)
false	YawDOF	YAW DOF (flag)
False	TwFADOF1	First fore-aft TOWER bending-mode DOF (flag)
False	TwFADOF2	Second fore-aft TOWER bending-mode DOF (flag)
False	TwSSDOF1	First side-to-side TOWER bending-mode DOF (flag)
False	TwSSDOF2	Second side-to-side TOWER bending-mode DOF (flag)
True	CompAero	Compute *Aerodynamic* forces (flag)
False	CompNoise	Compute *Aerodynamic* NOISE (flag)

---------------------- INITIAL CONDITIONS --------------------------------------

CURRENTLY IGNORED	

---------------------- TURBINE CONFIGURATION -----------------------------------

0.9	TipRad	The distance from the rotor apex to the blade tip (meters)
0.15	HubRad	The distance from the rotor apex to the blade root (meters)
1	PSpnElN	Innermost blade element which is still part of the pitchable portion of the blade
0.0	UndSling	Undersling length [distance from teeter pin to the rotor apex] (meters)
0.1324	HubCM	Distance from rotor apex to hub mass [positive downwind] (meters)
-0.170	OverHang	Distance from yaw axis to rotor apex [3 blades] or teeter pin [2 blades] (meters)
0.183	NacCMxn	Downwind distance from the tower-top to the nacelle CM (meters)
0.0	NacCMyn	Lateral distance from the tower-top to the nacelle CM (meters)
0.0405	NacCMzn	Vertical distance from the tower-top to the nacelle CM (meters)
8.0	TowerHt	Height of tower above ground level [onshore] or MSL [offshore] (meters)
0.155	Twr2Shft	Vertical distance from the tower-top to the rotor shaft (meters)
0.0	TwrRBHt	Tower rigid base height (meters)
0.0	ShftTilt	Rotor shaft tilt angle (degrees). Negative for an upwind rotor.
0.0	Delta3	Delta-3 angle for teetering rotors (degrees) [unused for 3 blades]
5.5	PreCone(1)	Blade 1 cone angle (degrees)
5.5	PreCone(2)	Blade 2 cone angle (degrees)
5.5	PreCone(3)	Blade 3 cone angle (degrees) [unused for 2 blades]
0.0	AzimB1Up	Azimuth value to use for I/O when blade 1 points up (degrees)

---------------------- MASS AND INERTIA ---

0.0	YawBrMass	Yaw bearing mass (kg)
1.49	NacMass	Nacelle mass (kg)
0.46	HubMass	Hub mass (kg)
0.0	TipMass(1)	Tip-brake mass, blade 1 (kg)
0.0	TipMass(2)	Tip-brake mass, blade 2 (kg)
0.0	TipMass(3)	Tip-brake mass, blade 3 (kg) [unused for 2 blades]
0.05	NacYIner	Nacelle inertia about yaw axis (kg m^2)
0.0	GenIner	Generator inertia about HSS (kg m^2)
0.0	HubIner	Hub inertia about rotor axis [3 blades] or teeter axis [2 blades] (kg m^2)

---------------------- DRIVETRAIN ---

CURRENTLY IGNORED

---------------------- SIMPLE INDUCTION GENERATOR ------------------------------

CURRENTLY IGNORED

---------------------- THEVENIN-EQUIVALENT INDUCTION GENERATOR ----------------

CURRENTLY IGNORED

---------------------- PLATFORM --

CURRENTLY IGNORED

---------------------- TOWER ---

10	TwrNodes	Number of tower nodes used for analysis (-)
"SWRT_Tower.dat"	TwrFile	Name of file containing tower properties (quoted string)

---------------------- NACELLE-YAW ---

0.0	YawSpr	Nacelle-yaw spring constant (N-m/rad)
0.0	YawDamp	Nacelle-yaw damping constant (N-m/(rad/s))
0.0	YawNeut	Neutral yaw position--yaw spring force is zero at this yaw (degrees)

---------------------- FURLING ---

True	Furling	Read in additional model properties for furling turbine (flag)
SWRT_Furl.dat	FurlFile	Name of file containing furling properties (quoted string)

---------------------- ROTOR-TEETER --

CURRENTLY IGNORED

---------------------- TIP-BRAKE ---

CURRENTLY IGNORED

---------------------- BLADE ---

"SWRT_Blade.dat"	BldFile(1)	Name of file containing properties for blade 1 (quoted string)
"SWRT_Blade.dat"	BldFile(2)	Name of file containing properties for blade 2 (quoted string)
"SWRT_Blade.dat"	BldFile(3)	Name of file containing properties for blade 3 (quoted string)

---------------------- *AERODYN* ---

Test17_AD.ipt	ADFile	Name of file containing *Aerodyn* input parameters (quoted string)

---------------------- NOISE ---

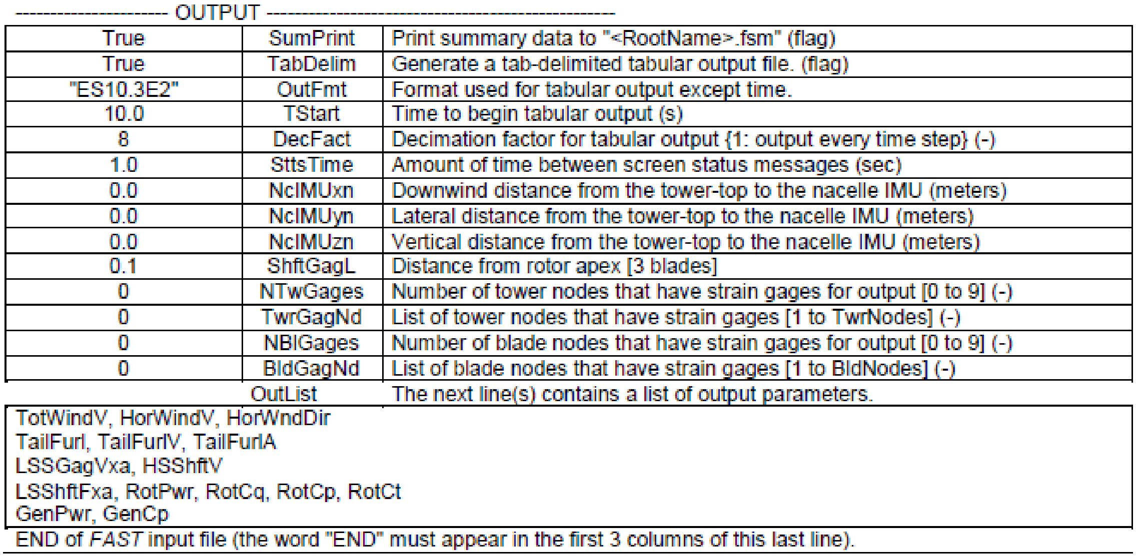
CURRENTLY IGNORED

---------------------- ADAMS ---

CURRENTLY IGNORED

---------------------- LINEARIZATION CONTROL -----------------------------------

CURRENTLY IGNORED



---------------------- OUTPUT --

True	SumPrint	Print summary data to "<RootName>.fsm" (flag)
True	TabDelim	Generate a tab-delimited tabular output file. (flag)
"ES10.3E2"	OutFmt	Format used for tabular output except time.
10.0	TStart	Time to begin tabular output (s)
8	DecFact	Decimation factor for tabular output {1: output every time step} (-)
1.0	SttsTime	Amount of time between screen status messages (sec)
0.0	NcIMUxn	Downwind distance from the tower-top to the nacelle IMU (meters)
0.0	NcIMUyn	Lateral distance from the tower-top to the nacelle IMU (meters)
0.0	NcIMUzn	Vertical distance from the tower-top to the nacelle IMU (meters)
0.1	ShftGagL	Distance from rotor apex [3 blades]
0	NTwGages	Number of tower nodes that have strain gages for output [0 to 9] (-)
0	TwrGagNd	List of tower nodes that have strain gages [1 to TwrNodes] (-)
0	NBlGages	Number of blade nodes that have strain gages for output [0 to 9] (-)
0	BldGagNd	List of blade nodes that have strain gages [1 to BldNodes] (-)
	OutList	The next line(s) contains a list of output parameters.

TotWindV, HorWindV, HorWndDir
TailFurl, TailFurlV, TailFurlA
LSSGagVxa, HSShftV
LSShftFxa, RotPwr, RotCq, RotCp, RotCt
GenPwr, GenCp

END of *FAST* input file (the word "END" must appear in the first 3 columns of this last line).

Fig 2.13 Fast primary input file.

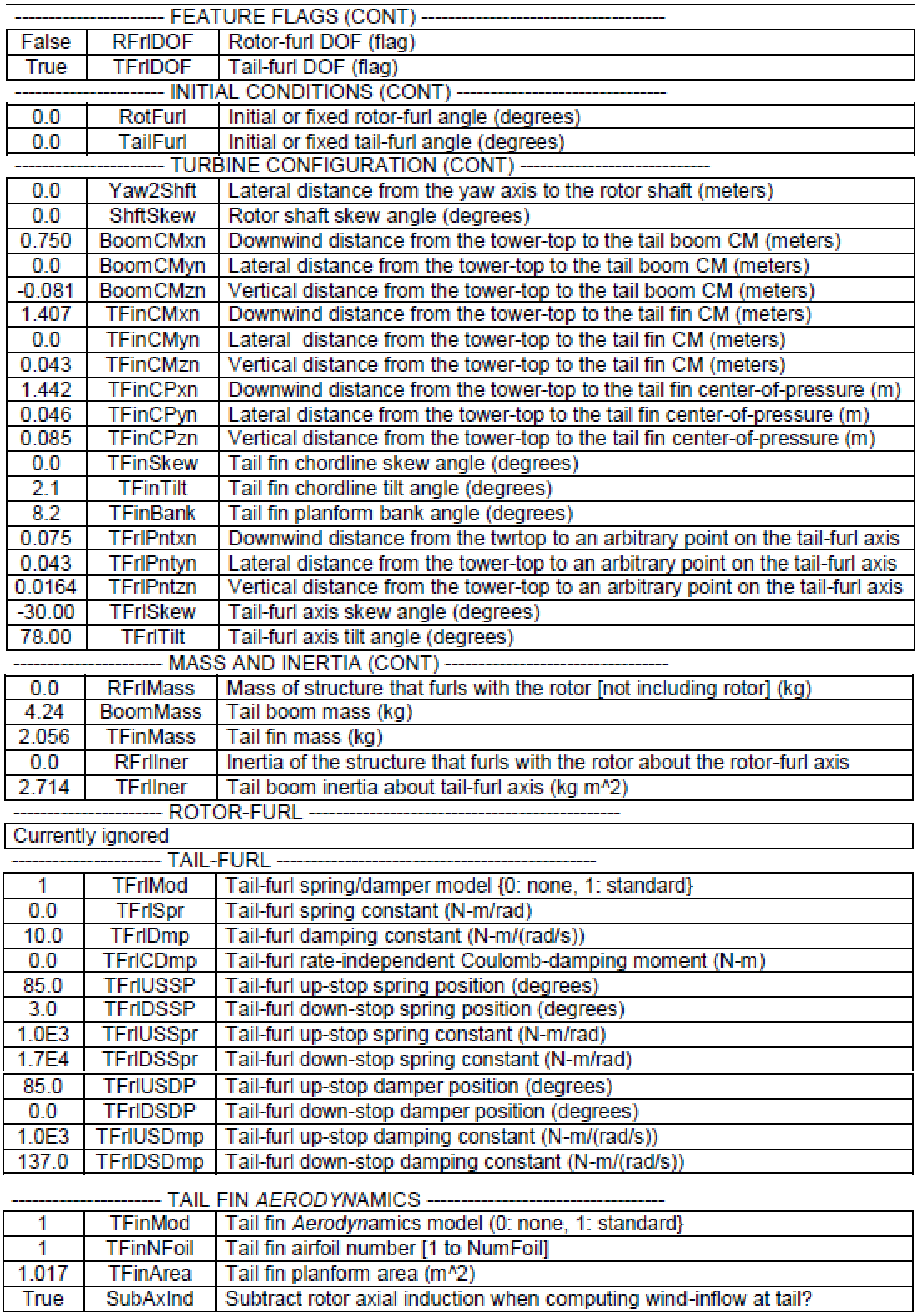
The file structure can be divided in three main sections (see gaps indicated by red lines). In the first section we find the controls for the simulation, the performances of the turbine and to external conditions also trigger flags degrees of freedom and the initial conditions. In the second section we dealt with the structural characteristics of the turbine itself, such as distances between components and angles, mass and inertia characteristics.

The last section includes secondary files paths for tower, furling, blades and AeroDyn entry. After determining the logical addresses of these secondary files defining characteristics of the outputs of the simulation.

Furling Input File:

The inputs available in the furling input file define the core configuration of the turbine, just like those available in the primary input file. These parameters are separated because the parameters available in the furling input are unique to small wind turbines. The challenge in defining the unique configurations of small wind turbines relative to the configurations of conventional machines is clearly demonstrated by the contents of the furling input file. The furling input file is organized into sections similar to those available in the primary input file. This supports the notion that the furling file is simply a continuation and expansion of the core configuration definition designations available in the primary file. FAST only reads the furling input file if the model is designated as a furling machine (when Furling is set to True).

The inputs pertain to the lateral offset and skew angle of the rotor shaft, rotor-furling, tail-furling, and tail inertia and aerodynamics. The furling file must be assembled even if your turbine does not “furl” in the common sense of the word.



---------------------- FEATURE FLAGS (CONT) ----------------------------------

False	RFrlDOF	Rotor-furl DOF (flag)
True	TFrlDOF	Tail-furl DOF (flag)

---------------------- INITIAL CONDITIONS (CONT) ------------------------------

0.0	RotFurl	Initial or fixed rotor-furl angle (degrees)
0.0	TailFurl	Initial or fixed tail-furl angle (degrees)

---------------------- TURBINE CONFIGURATION (CONT) ---------------------------

0.0	Yaw2Shft	Lateral distance from the yaw axis to the rotor shaft (meters)
0.0	ShftSkew	Rotor shaft skew angle (degrees)
0.750	BoomCMxn	Downwind distance from the tower-top to the tail boom CM (meters)
0.0	BoomCMyn	Lateral distance from the tower-top to the tail boom CM (meters)
-0.081	BoomCMzn	Vertical distance from the tower-top to the tail boom CM (meters)
1.407	TFinCMxn	Downwind distance from the tower-top to the tail fin CM (meters)
0.0	TFinCMyn	Lateral distance from the tower-top to the tail fin CM (meters)
0.043	TFinCMzn	Vertical distance from the tower-top to the tail fin CM (meters)
1.442	TFinCPxn	Downwind distance from the tower-top to the tail fin center-of-pressure (m)
0.046	TFinCPyn	Lateral distance from the tower-top to the tail fin center-of-pressure (m)
0.085	TFinCPzn	Vertical distance from the tower-top to the tail fin center-of-pressure (m)
0.0	TFinSkew	Tail fin chordline skew angle (degrees)
2.1	TFinTilt	Tail fin chordline tilt angle (degrees)
8.2	TFinBank	Tail fin planform bank angle (degrees)
0.075	TFrlPntxn	Downwind distance from the twrtop to an arbitrary point on the tail-furl axis
0.043	TFrlPntyn	Lateral distance from the tower-top to an arbitrary point on the tail-furl axis
0.0164	TFrlPntzn	Vertical distance from the tower-top to an arbitrary point on the tail-furl axis
-30.00	TFrlSkew	Tail-furl axis skew angle (degrees)
78.00	TFrlTilt	Tail-furl axis tilt angle (degrees)

---------------------- MASS AND INERTIA (CONT) --------------------------------

0.0	RFrlMass	Mass of structure that furls with the rotor [not including rotor] (kg)
4.24	BoomMass	Tail boom mass (kg)
2.056	TFinMass	Tail fin mass (kg)
0.0	RFrlIner	Inertia of the structure that furls with the rotor about the rotor-furl axis
2.714	TFrlIner	Tail boom inertia about tail-furl axis (kg m^2)

---------------------- ROTOR-FURL ---

Currently ignored

---------------------- TAIL-FURL --

1	TFrlMod	Tail-furl spring/damper model {0: none, 1: standard}
0.0	TFrlSpr	Tail-furl spring constant (N-m/rad)
10.0	TFrlDmp	Tail-furl damping constant (N-m/(rad/s))
0.0	TFrlCDmp	Tail-furl rate-independent Coulomb-damping moment (N-m)
85.0	TFrlUSSP	Tail-furl up-stop spring position (degrees)
3.0	TFrlDSSP	Tail-furl down-stop spring position (degrees)
1.0E3	TFrlUSSpr	Tail-furl up-stop spring constant (N-m/rad)
1.7E4	TFrlDSSpr	Tail-furl down-stop spring constant (N-m/rad)
85.0	TFrlUSDP	Tail-furl up-stop damper position (degrees)
0.0	TFrlDSDP	Tail-furl down-stop damper position (degrees)
1.0E3	TFrlUSDmp	Tail-furl up-stop damping constant (N-m/(rad/s))
137.0	TFrlDSDmp	Tail-furl down-stop damping constant (N-m/(rad/s))

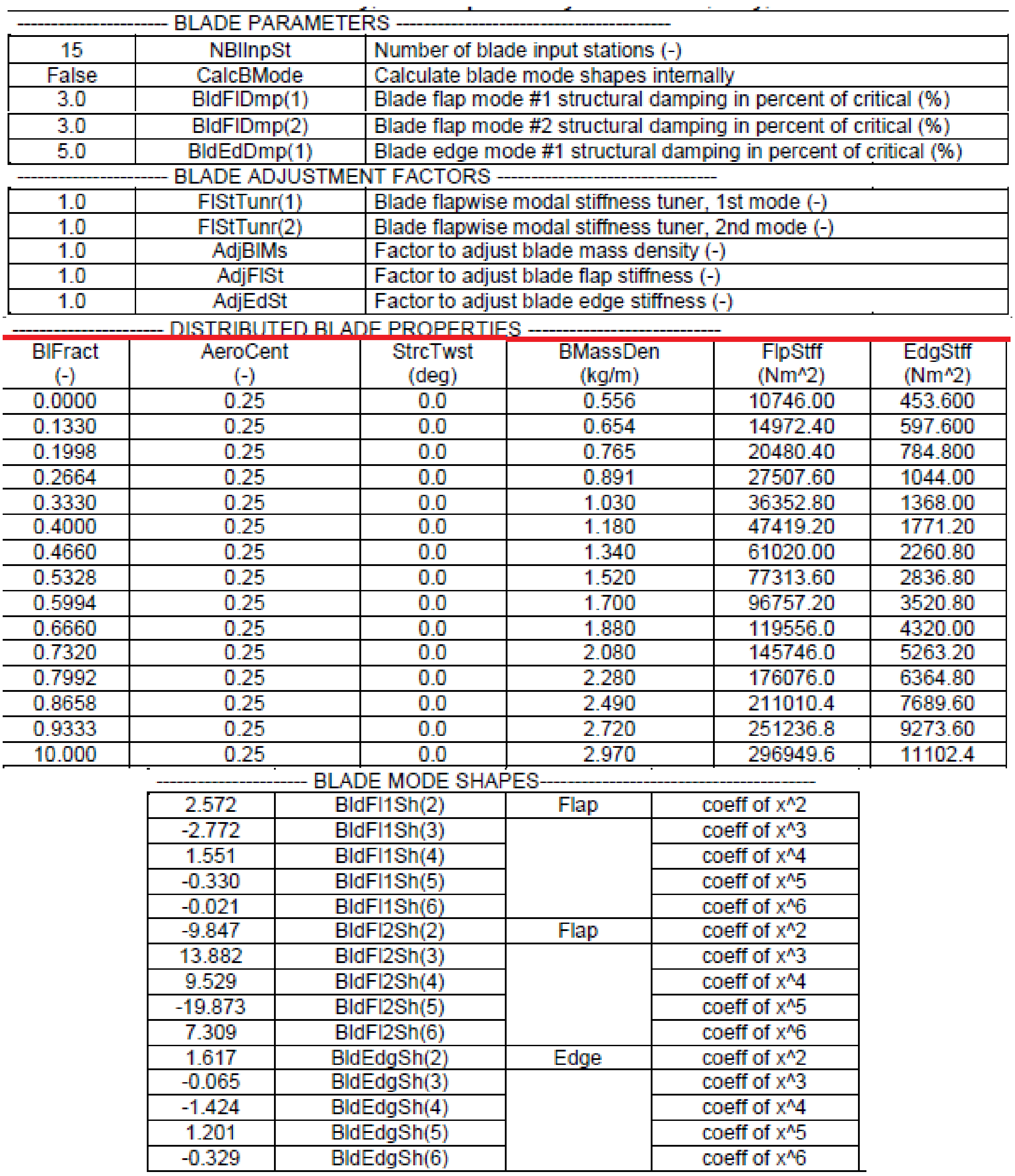
---------------------- TAIL FIN *AERODYNAMICS* ---------------------------------

1	TFinMod	Tail fin *Aerodyn*amics model (0: none, 1: standard}
1	TFinNFoil	Tail fin airfoil number [1 to NumFoil]
1.017	TFinArea	Tail fin planform area (m^2)
True	SubAxInd	Subtract rotor axial induction when computing wind-inflow at tail?

Fig 2.14 Furling input file.

Blade Input File:

In the blade input files, there are tables of blade characteristics. There are several columns of data in the Distributed Blade Properties section, but only the first six columns are used to characterize the FAST model. The last 11 columns are used only for creating ADAMS datasets using the FAST-to-ADAMS preprocessor feature of FAST. You need to enter only one line if the blade is uniform. You must specify a zero for the location of this single station. If you model non-uniform blades, you must specify at least two stations; the first must be at the zero location and the last must have a location of 1 (for 100% span). FAST will linearly interpolate these data to the analysis nodes specified in the AeroDyn input file. FAST reads this file even if you requested no blade DOFs.



---------------------- BLADE PARAMETERS --

15	NBlInpSt	Number of blade input stations (-)
False	CalcBMode	Calculate blade mode shapes internally
3.0	BldFlDmp(1)	Blade flap mode #1 structural damping in percent of critical (%)
3.0	BldFlDmp(2)	Blade flap mode #2 structural damping in percent of critical (%)
5.0	BldEdDmp(1)	Blade edge mode #1 structural damping in percent of critical (%)

---------------------- BLADE ADJUSTMENT FACTORS ------------------------------

1.0	FlStTunr(1)	Blade flapwise modal stiffness tuner, 1st mode (-)
1.0	FlStTunr(2)	Blade flapwise modal stiffness tuner, 2nd mode (-)
1.0	AdjBlMs	Factor to adjust blade mass density (-)
1.0	AdjFlSt	Factor to adjust blade flap stiffness (-)
1.0	AdjEdSt	Factor to adjust blade edge stiffness (-)

---------------------- DISTRIBUTED BLADE PROPERTIES ----------------------------

BlFract (-)	AeroCent (-)	StrcTwst (deg)	BMassDen (kg/m)	FlpStff (Nm^2)	EdgStff (Nm^2)
0.0000	0.25	0.0	0.556	10746.00	453.600
0.1330	0.25	0.0	0.654	14972.40	597.600
0.1998	0.25	0.0	0.765	20480.40	784.800
0.2664	0.25	0.0	0.891	27507.60	1044.00
0.3330	0.25	0.0	1.030	36352.80	1368.00
0.4000	0.25	0.0	1.180	47419.20	1771.20
0.4660	0.25	0.0	1.340	61020.00	2260.80
0.5328	0.25	0.0	1.520	77313.60	2836.80
0.5994	0.25	0.0	1.700	96757.20	3520.80
0.6660	0.25	0.0	1.880	119556.0	4320.00
0.7320	0.25	0.0	2.080	145746.0	5263.20
0.7992	0.25	0.0	2.280	176076.0	6364.80
0.8658	0.25	0.0	2.490	211010.4	7689.60
0.9333	0.25	0.0	2.720	251236.8	9273.60
10.000	0.25	0.0	2.970	296949.6	11102.4

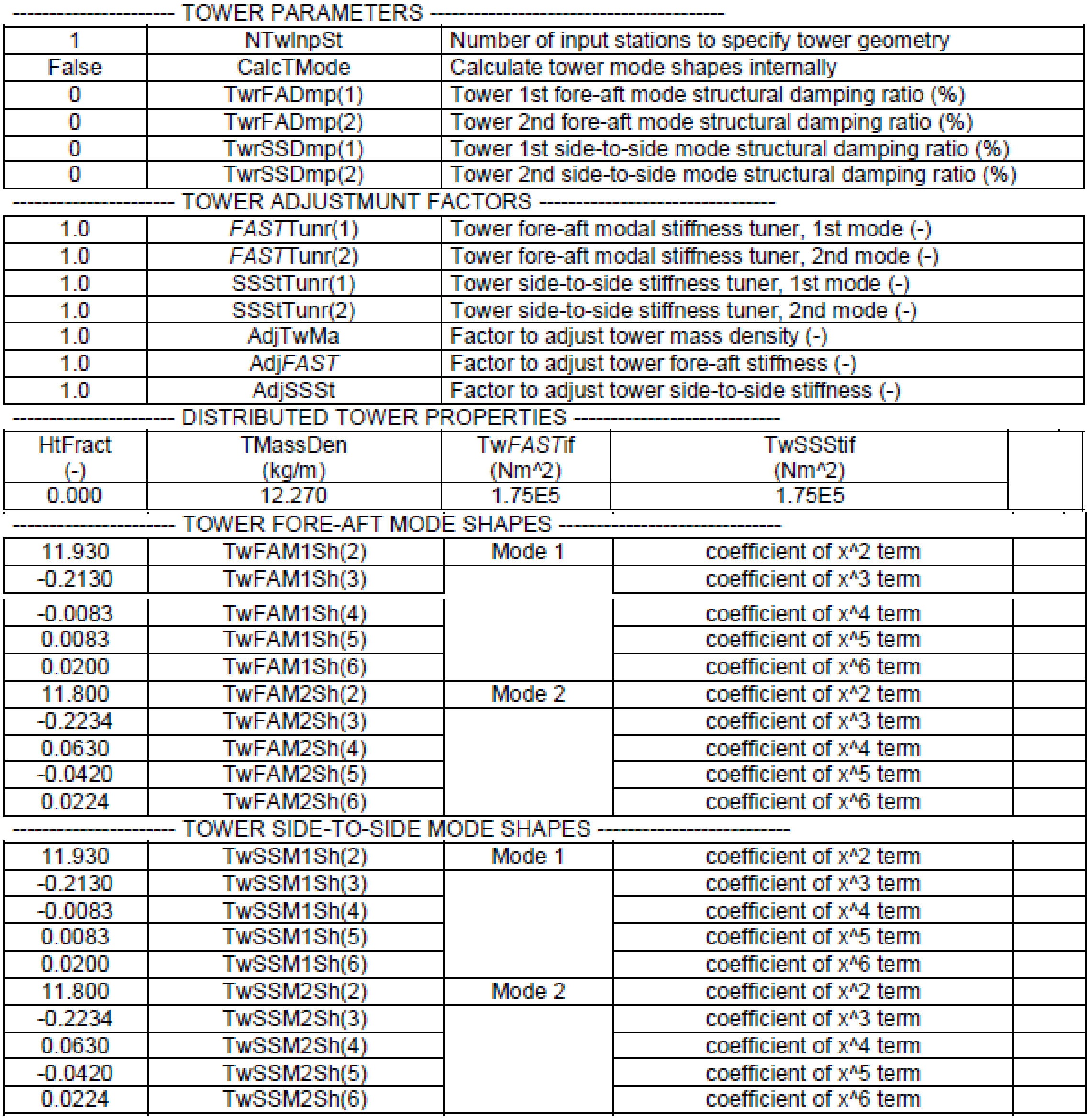
---------------------- BLADE MODE SHAPES --

2.572	BldFl1Sh(2)	Flap	coeff of x^2
-2.772	BldFl1Sh(3)		coeff of x^3
1.551	BldFl1Sh(4)		coeff of x^4
-0.330	BldFl1Sh(5)		coeff of x^5
-0.021	BldFl1Sh(6)		coeff of x^6
-9.847	BldFl2Sh(2)	Flap	coeff of x^2
13.882	BldFl2Sh(3)		coeff of x^3
9.529	BldFl2Sh(4)		coeff of x^4
-19.873	BldFl2Sh(5)		coeff of x^5
7.309	BldFl2Sh(6)		coeff of x^6
1.617	BldEdgSh(2)	Edge	coeff of x^2
-0.065	BldEdgSh(3)		coeff of x^3
-1.424	BldEdgSh(4)		coeff of x^4
1.201	BldEdgSh(5)		coeff of x^5
-0.329	BldEdgSh(6)		coeff of x^6

Fig 2.15 Blade input file

Tower Input File:

In the tower file, there is a table for the tower characteristics, which requires several columns of data in the Distributed Tower Properties section of the input file. Only the first four columns are used to characterize the FAST model. The last six columns are used only for creating ADAMS datasets using the FAST-to-ADAMS preprocessor feature of FAST. You need to enter only one line if the tower is uniform. If you model a non-uniform tower, you must specify at least two stations; the first must be at the 0 location and the last must have a location of 1. FAST will linearly interpolate these data to the centers of the equally spaced segments, which are the analysis nodes. FAST reads this file even if you requested no tower DOFs.



---------------------- TOWER PARAMETERS --

1	NTwInpSt	Number of input stations to specify tower geometry
False	CalcTMode	Calculate tower mode shapes internally
0	TwrFADmp(1)	Tower 1st fore-aft mode structural damping ratio (%)
0	TwrFADmp(2)	Tower 2nd fore-aft mode structural damping ratio (%)
0	TwrSSDmp(1)	Tower 1st side-to-side mode structural damping ratio (%)
0	TwrSSDmp(2)	Tower 2nd side-to-side mode structural damping ratio (%)

---------------------- TOWER ADJUSTMUNT FACTORS --------------------------------

1.0	*FAST*Tunr(1)	Tower fore-aft modal stiffness tuner, 1st mode (-)
1.0	*FAST*Tunr(2)	Tower fore-aft modal stiffness tuner, 2nd mode (-)
1.0	SSStTunr(1)	Tower side-to-side stiffness tuner, 1st mode (-)
1.0	SSStTunr(2)	Tower side-to-side stiffness tuner, 2nd mode (-)
1.0	AdjTwMa	Factor to adjust tower mass density (-)
1.0	Adj*FAST*	Factor to adjust tower fore-aft stiffness (-)
1.0	AdjSSSt	Factor to adjust tower side-to-side stiffness (-)

---------------------- DISTRIBUTED TOWER PROPERTIES ---------------------------

HtFract (-)	TMassDen (kg/m)	Tw*FAST*if (Nm^2)	TwSSStif (Nm^2)	
0.000	12.270	1.75E5	1.75E5	

---------------------- TOWER FORE-AFT MODE SHAPES -----------------------------

11.930	TwFAM1Sh(2)	Mode 1	coefficient of x^2 term	
-0.2130	TwFAM1Sh(3)		coefficient of x^3 term	
-0.0083	TwFAM1Sh(4)		coefficient of x^4 term	
0.0083	TwFAM1Sh(5)		coefficient of x^5 term	
0.0200	TwFAM1Sh(6)		coefficient of x^6 term	
11.800	TwFAM2Sh(2)	Mode 2	coefficient of x^2 term	
-0.2234	TwFAM2Sh(3)		coefficient of x^3 term	
0.0630	TwFAM2Sh(4)		coefficient of x^4 term	
-0.0420	TwFAM2Sh(5)		coefficient of x^5 term	
0.0224	TwFAM2Sh(6)		coefficient of x^6 term	

---------------------- TOWER SIDE-TO-SIDE MODE SHAPES -------------------------

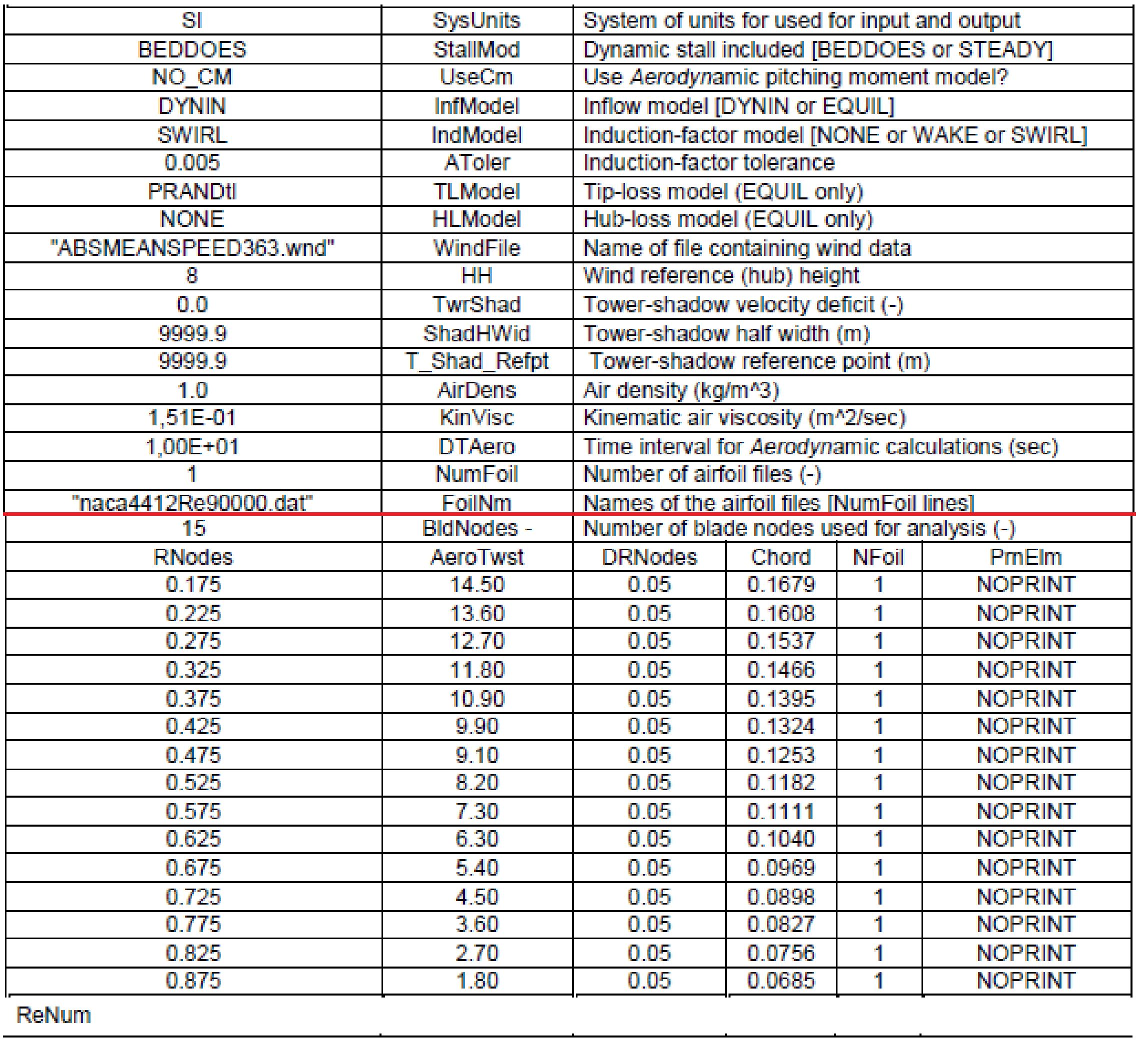
11.930	TwSSM1Sh(2)	Mode 1	coefficient of x^2 term	
-0.2130	TwSSM1Sh(3)		coefficient of x^3 term	
-0.0083	TwSSM1Sh(4)		coefficient of x^4 term	
0.0083	TwSSM1Sh(5)		coefficient of x^5 term	
0.0200	TwSSM1Sh(6)		coefficient of x^6 term	
11.800	TwSSM2Sh(2)	Mode 2	coefficient of x^2 term	
-0.2234	TwSSM2Sh(3)		coefficient of x^3 term	
0.0630	TwSSM2Sh(4)		coefficient of x^4 term	
-0.0420	TwSSM2Sh(5)		coefficient of x^5 term	
0.0224	TwSSM2Sh(6)		coefficient of x^6 term	

Fig 2.16 Tower input file.

2.3.4.2. AeroDyn Input Files

AeroDyn Main File:

The main aerodynamic data file can be distinguished from the rest by its extension. "Ipt". This file has two distinct parts: a section with simulation control parameters, and another with the aerodynamic characteristics of the blade. (See Fig 2.17).



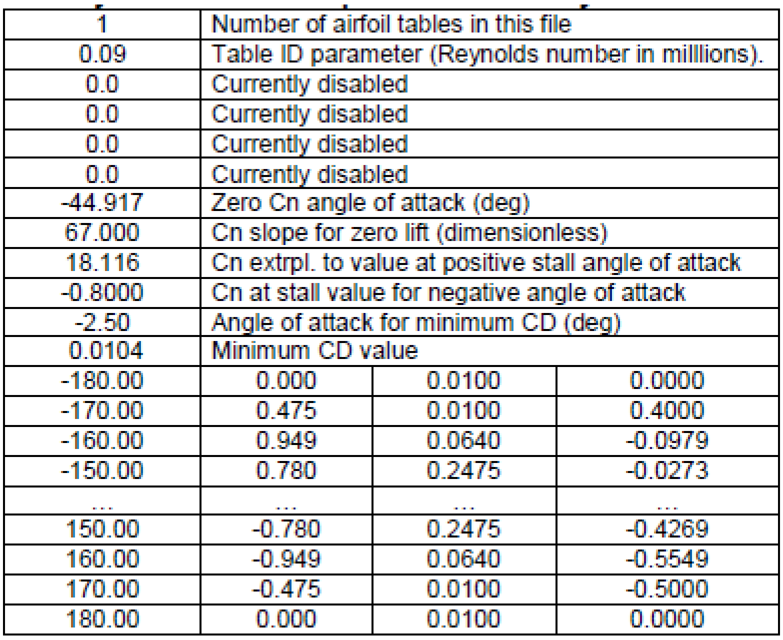
SI	SysUnits	System of units for used for input and output
BEDDOES	StallMod	Dynamic stall included [BEDDOES or STEADY]
NO_CM	UseCm	Use *Aerodyn*amic pitching moment model?
DYNIN	InfModel	Inflow model [DYNIN or EQUIL]
SWIRL	IndModel	Induction-factor model [NONE or WAKE or SWIRL]
0.005	AToler	Induction-factor tolerance
PRANDtl	TLModel	Tip-loss model (EQUIL only)
NONE	HLModel	Hub-loss model (EQUIL only)
"ABSMEANSPEED363.wnd"	WindFile	Name of file containing wind data
8	HH	Wind reference (hub) height
0.0	TwrShad	Tower-shadow velocity deficit (-)
9999.9	ShadHWid	Tower-shadow half width (m)
9999.9	T_Shad_Refpt	Tower-shadow reference point (m)
1.0	AirDens	Air density (kg/m^3)
1,51E-01	KinVisc	Kinematic air viscosity (m^2/sec)
1,00E+01	DTAero	Time interval for *Aerodyn*amic calculations (sec)
1	NumFoil	Number of airfoil files (-)
"naca4412Re90000.dat"	FoilNm	Names of the airfoil files [NumFoil lines]
15	BldNodes -	Number of blade nodes used for analysis (-)

RNodes	AeroTwst	DRNodes	Chord	NFoil	PrnElm
0.175	14.50	0.05	0.1679	1	NOPRINT
0.225	13.60	0.05	0.1608	1	NOPRINT
0.275	12.70	0.05	0.1537	1	NOPRINT
0.325	11.80	0.05	0.1466	1	NOPRINT
0.375	10.90	0.05	0.1395	1	NOPRINT
0.425	9.90	0.05	0.1324	1	NOPRINT
0.475	9.10	0.05	0.1253	1	NOPRINT
0.525	8.20	0.05	0.1182	1	NOPRINT
0.575	7.30	0.05	0.1111	1	NOPRINT
0.625	6.30	0.05	0.1040	1	NOPRINT
0.675	5.40	0.05	0.0969	1	NOPRINT
0.725	4.50	0.05	0.0898	1	NOPRINT
0.775	3.60	0.05	0.0827	1	NOPRINT
0.825	2.70	0.05	0.0756	1	NOPRINT
0.875	1.80	0.05	0.0685	1	NOPRINT
ReNum					

Fig 2.17 Aerodyn main input file.

Airfoil Input File:

The Airfoil File is the one used by AeroDyn for the aerodynamic calculations of the blade. (Fig 2.18) shows the configuration of this file.

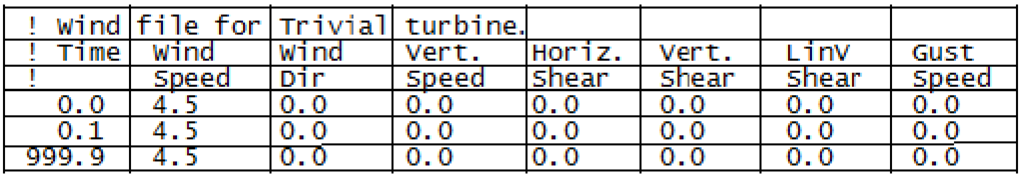


1	Number of airfoil tables in this file		
0.09	Table ID parameter (Reynolds number in milllions).		
0.0	Currently disabled		
0.0	Currently disabled		
0.0	Currently disabled		
0.0	Currently disabled		
-44.917	Zero Cn angle of attack (deg)		
67.000	Cn slope for zero lift (dimensionless)		
18.116	Cn extrpl. to value at positive stall angle of attack		
-0.8000	Cn at stall value for negative angle of attack		
-2.50	Angle of attack for minimum CD (deg)		
0.0104	Minimum CD value		
-180.00	0.000	0.0100	0.0000
-170.00	0.475	0.0100	0.4000
-160.00	0.949	0.0640	-0.0979
-150.00	0.780	0.2475	-0.0273
...	...	...	...
150.00	-0.780	0.2475	-0.4269
160.00	-0.949	0.0640	-0.5549
170.00	-0.475	0.0100	-0.5000
180.00	0.000	0.0100	0.0000

Fig 2.18 Airfoil input file.

Wind Input File:

The last file needed for aerodynamic calculations is the Wind Input File which defines the wind approaching the rotor blades. Wind files can be of two types, *Hub Height* wind files or *Full Field* wind files. Hub Height wind files, the simpler ones, give the characteristics of the wind at the turbine hub height. It contains tabulated values of speed, wind direction, vertical speed, wind shear and wind gusts intensity with time. The second file type, Full Field wind file, can only be built using software like *Turbsim*. In this study we decided to use Hub Height wind files.



! Wind	file for	Trivial	turbine.				
! Time	Wind	Wind	Vert.	Horiz.	Vert.	LinV	Gust
!	Speed	Dir	Speed	Shear	Shear	Shear	Speed
0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0
0.1	4.5	0.0	0.0	0.0	0.0	0.0	0.0
999.9	4.5	0.0	0.0	0.0	0.0	0.0	0.0

Fig 2.19 Wind input file.

For a complete description of all files used in the simulations for each wind turbine, see annex A and C.

2.4. Digitalization of the blades of the HP-600

Since *Hopeful Energy* does not provide more of the information necessary to build the Fast & Aerodyn files, such as the airfoil of the blades, or the aerodynamic coefficients, it was decided to digitalize one of the blades.

Digitalizing is a reverse engineering process that consists in scanning a 3D object in order to obtain a simulation of its 3D shape in a computer. This process usually provides as output a cloud of points of the object, known as *.STL File*. This file must then be converted into a *CAD* file in order to be treated on conventional 3D editing programs, such as SolidWorks.

We contacted *AsorCAD*, a reverse-engineering company especialized in 3D digitalizations and commissioned them with the digitalization of one of the HP-600 blades. Using the *Gama HANDYscan 3D* portable scanner, they were able to generate an *STL* file containing over 370.000 points. (see Fig 2.19)

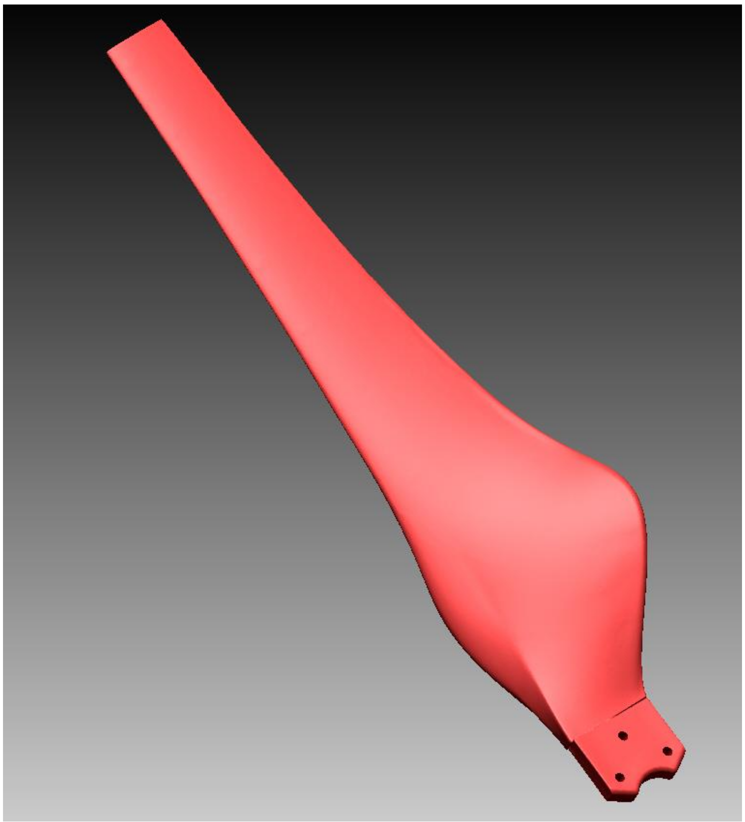


Fig 2.19 STL File generated by AsorCAD.

But, as we explained earlier, this file is just a number of points associated with their respective coordinates in a 3D environment. In order to convert these points into surfaces that a CAD program can recognize, another program must be used. Typically, the most useful for "*CAD to STL"* functions is *Rapidform XOV*. Due to our inexperience with this software, *AsorCAD* offered to do this task and sent us the CAD model of the blade (see Fig 2.20).

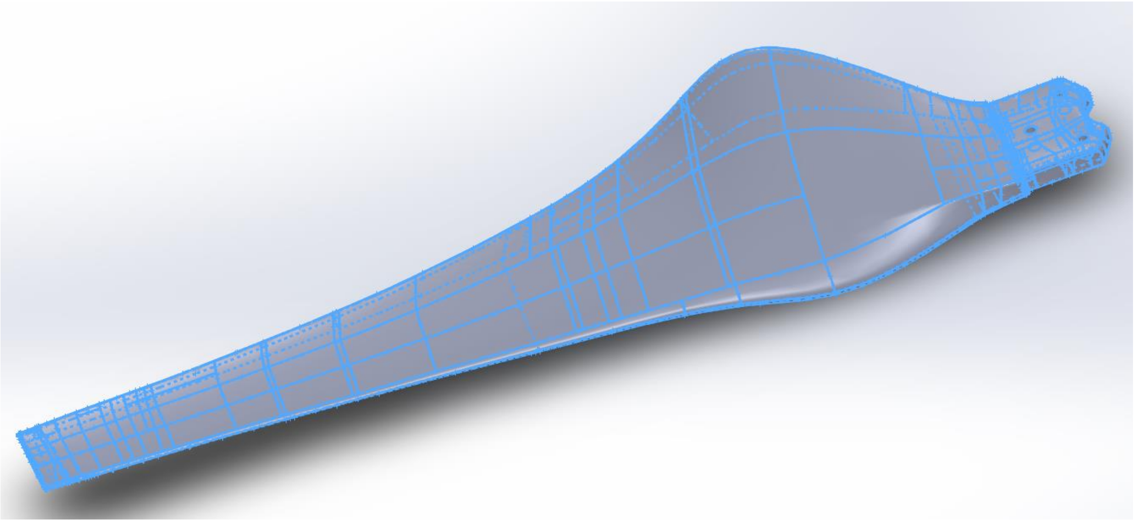


Fig 2.20 CAD model of the HP-600 blade in SolidWorks.

We can appreciate in Fig. 2.20 that SolidWorks recognizes the blade as the sum of smaller surfaces. Once we had the CAD file, we were ready to extract all the necessary information for the Fast & Aerodyn input files.

A significant amount of those files required a further step, using *Flow Simulation*, a built-in application of SolidWorks. This will be explained in the following sub-chapter.

The information that did not require *Flow Simulation* was the lower section of Fig. 2.17. We had to first divide our blade into a given number of sections (19, for our case) and, for each section, we specified the twist, the chord length and the type of airfoil.

Using SolidWorks, we created a draft that divided the blade into the mentioned equispaced slices (see Fig 2.21):

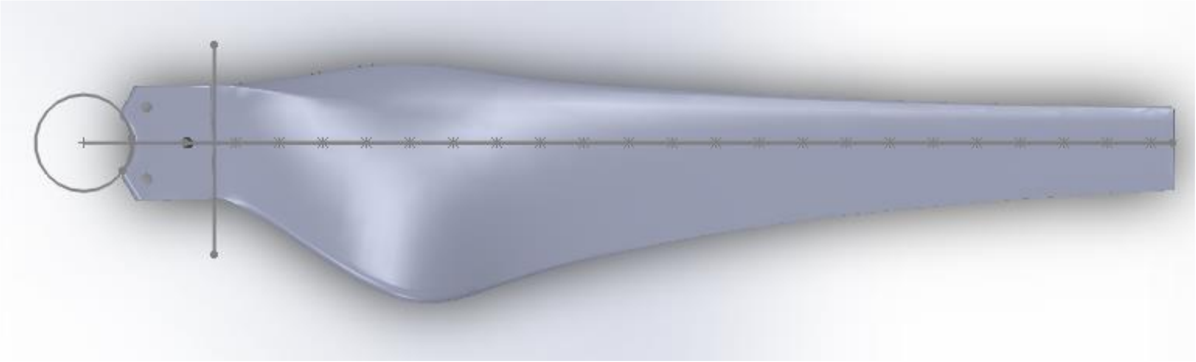


Fig 2.21 Each dot in the image shows the center of a section.

For each slice, we eliminated the rest of the blade, and analyzed its properties (see Fig. 2.22), e.g., we measured the chord and the twist (98.77 mm and 9.59º respectively, in the example shown in Fig. 2.22).

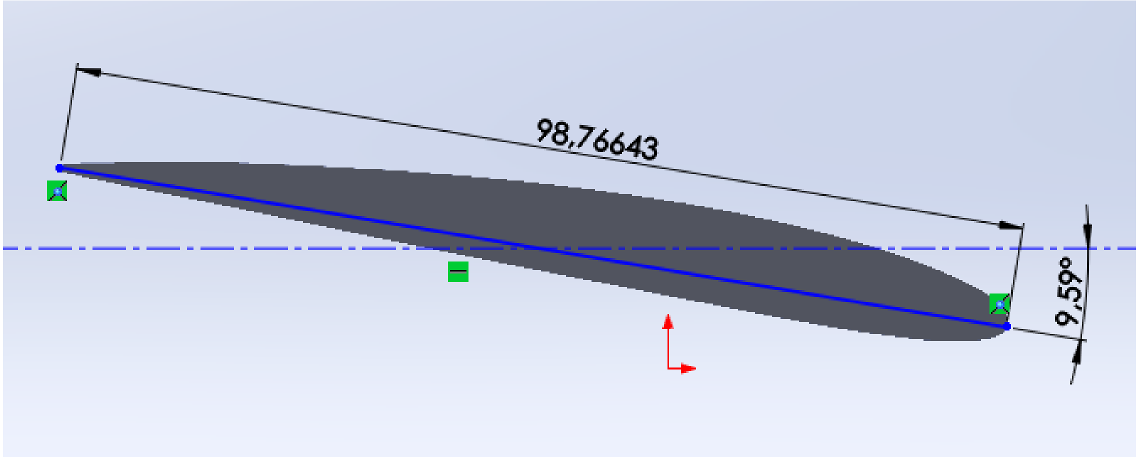


Fig 2.22 Example of section cut. (Section 12)

As per the type of airfoil, we analized all the sections, looking for similarities. It was decided that there were two kinds of airfoils in our blade, and the most representatives sections of each airfoil were Section 7 and Section 13 (see Fig. 2.23)

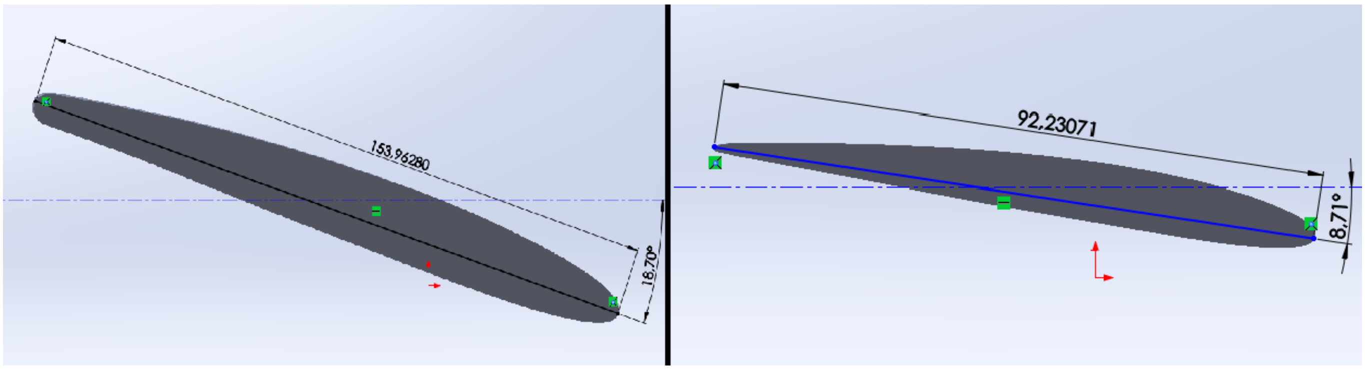


Fig 2.23 Section 7 (left) and Section 13 (right)

We then marked the airfoils from sections 1 to 9 as #1, and airfoils from 10 to 19 as #2, finishing that part of the Aerodyn main file.

2.4.1. Obtaining aerodynamic parameters using Flow Simulation (FS)

Like we stated before, there are several parameters that we needed to obtain from the blade, but which we could not find without more complex simulations. Particularly, we wanted to create the Aerodyn Airfoil File (see Fig. 2.18). In order to do that, we needed to calculate the lift and drag coefficients for every airfoil type previously selected. Like it has been stated before (see Fig. 2.22), the airfoils chosen were Section 7 and Section 13. Lift and Drag are calculated as follows:

$$L = \tfrac{1}{2}\rho v^2 A C_L \tag{2.1}$$

$$\mathrm{D} = \tfrac{1}{2}\rho v^2 A C_d \tag{2.2}$$

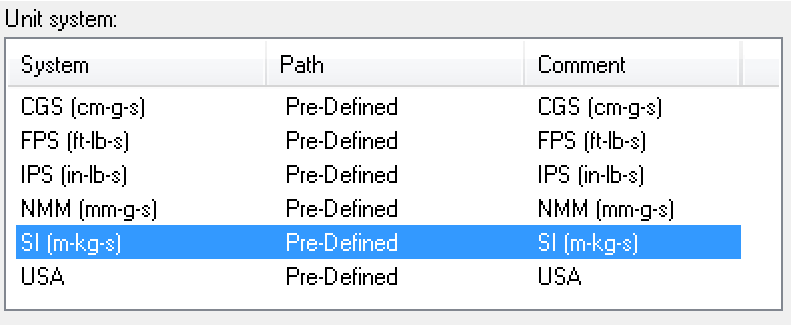
Being *L* the lift force, *D* the drag force, *ρ* the air density, *v* is the air speed and *A* the planform area.

Aerodyn required us to calculate the lift and drag coefficients for a range of angles of attack: in steps of 2 degrees from -20º to 10º, and in steps of 10º from 10 to 180 degrees, and from -20 to -180 degrees. For now, focus is placed on the first range, from -20 to 10 degrees.

We can consider that the air density is constant, 1.225kg/m^3. Supposing that our blade has angle of attack of 0º, the air speed is the vectorial sum of the wind speed and the speed of the blade spinning, which was 14.2m/s.

In order to obtain the lift, drag, and their respective coefficients, we must set up the *Flow Simulation* tool inside SolidWorks, which will allow us to recreate the conditions that our blade would experience in real service life.

First, we open the Flow Simulation Wizard, and select SI as our unit system (see Fig. 2.23)

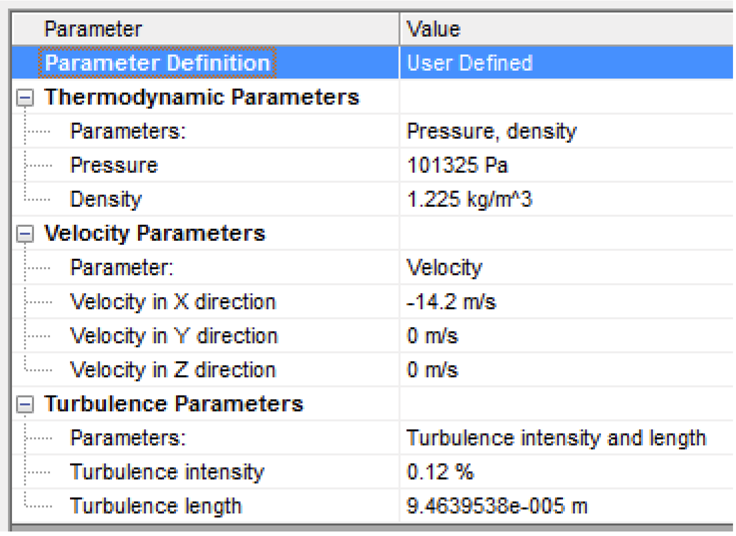


Unit system:

System	Path	Comment
CGS (cm-g-s)	Pre-Defined	CGS (cm-g-s)
FPS (ft-lb-s)	Pre-Defined	FPS (ft-lb-s)
IPS (in-lb-s)	Pre-Defined	IPS (in-lb-s)
NMM (mm-g-s)	Pre-Defined	NMM (mm-g-s)
SI (m-kg-s)	Pre-Defined	SI (m-kg-s)
USA	Pre-Defined	USA

Fig 2.23 Selecting SI as unit system.

We click next, and introduce the values of pressure, density and speed on their corresponding boxes. Note that the speed appears as negative to adequate to the axis of the blade (see Fig. 2.24)



Parameter	Value
Parameter Definition	User Defined
⊟ **Thermodynamic Parameters**	
Parameters:	Pressure, density
Pressure	101325 Pa
Density	1.225 kg/m^3
⊟ **Velocity Parameters**	
Parameter:	Velocity
Velocity in X direction	-14.2 m/s
Velocity in Y direction	0 m/s
Velocity in Z direction	0 m/s
⊟ **Turbulence Parameters**	
Parameters:	Turbulence intensity and length
Turbulence intensity	0.12 %
Turbulence length	9.4639538e-005 m

Fig 2.24 Introducing parameters.

Now we have to determine the computational domain, which is the area that SolidWorks will analyze and obtain its results from. It is composed by cells, whose size determines the precision of the results.

As we can appreciate in Fig 2.25, it was decided to use a computational domain with variable cell size, being finer in the vicinity of the airfoil.

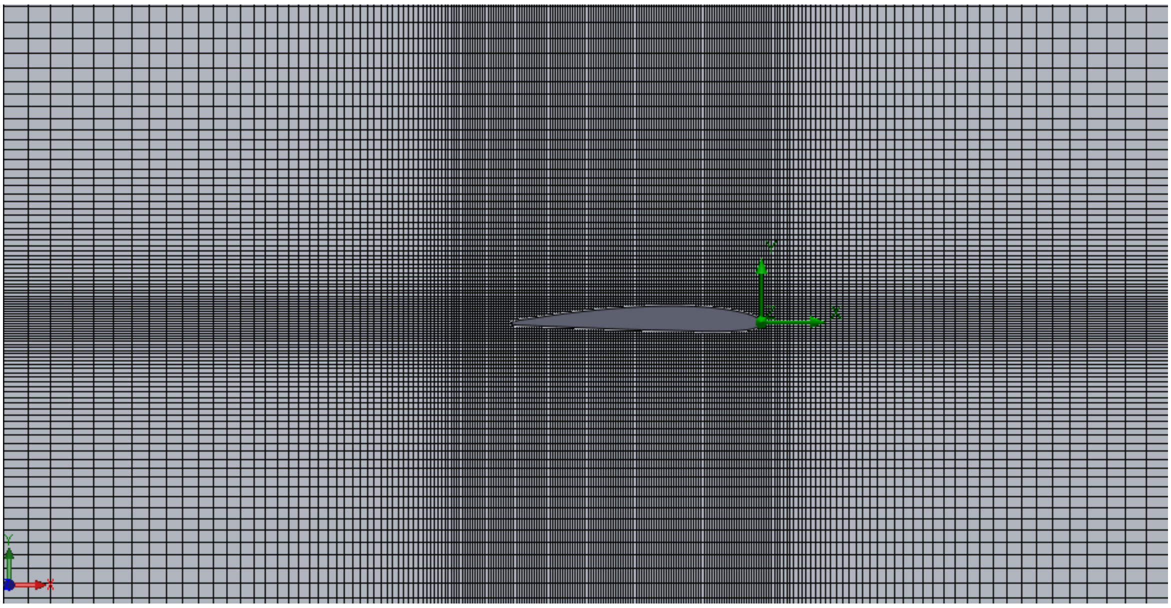


Fig 2.25 Computational domain for Section 13.

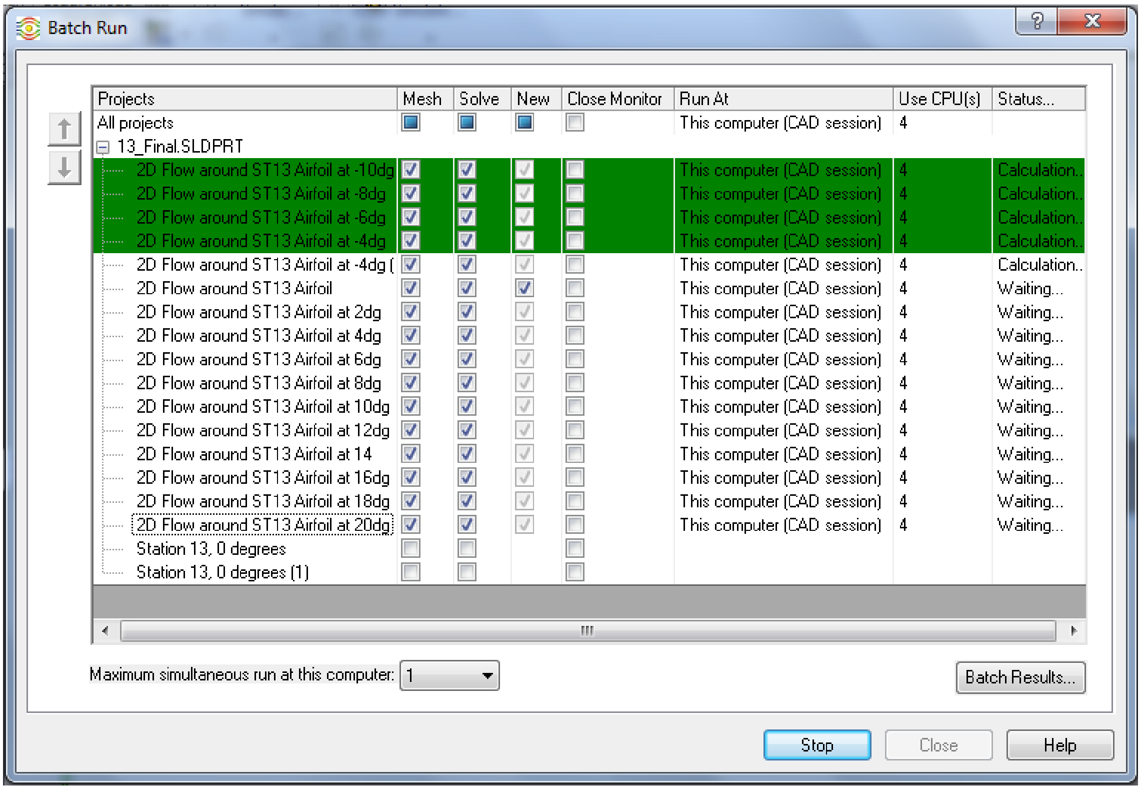
With the computational domain properly defined, we can now enter the goals of the simulations. That is, the outputs we want to extract from *Flow Simulation*.

We isolated both C_L and C_D from equations 2.1 and 2.2, and entered them as goals, being A (planform area) calculated as the chord multiplied by the width of the computational domain, which was 2 mm. [8]

The simulation for Section 13 at 0º angle of attack would be now ready. But in order to speed up the process, we can enable *Batch Runs* (see Fig. 2.26), a SolidWorks feature that allows us to simulate the same object at various conditions, for instance, with different angles of attack.

Different angles of attack are introduced in SolidWorks by varying the X and Y components of the wind speed, instead of modifying the current object. We can compute those components multiplying the wind speed used at 0º angle of attack either by the sine of the new angle to obtain the Y speed, or by the cosine to obtain the X component of the speed.

We introduced these values for an angle of attack from -20º to 10º, in steps of 2º. Once all the speeds were introduced, we were able to start the simulations.



Projects	Mesh	Solve	New	Close Monitor	Run At	Use CPU(s)	Status...
All projects	■	■	■	☐	This computer (CAD session)	4	
13_Final.SLDPRT							
2D Flow around ST13 Airfoil at -10dg	☑	☑	☑	☐	This computer (CAD session)	4	Calculation..
2D Flow around ST13 Airfoil at -8dg	☑	☑	☑	☐	This computer (CAD session)	4	Calculation..
2D Flow around ST13 Airfoil at -6dg	☑	☑	☑	☐	This computer (CAD session)	4	Calculation..
2D Flow around ST13 Airfoil at -4dg	☑	☑	☑	☐	This computer (CAD session)	4	Calculation..
2D Flow around ST13 Airfoil at -4dg (	☑	☑	☑	☐	This computer (CAD session)	4	Calculation..
2D Flow around ST13 Airfoil	☑	☑	☑	☐	This computer (CAD session)	4	Waiting...
2D Flow around ST13 Airfoil at 2dg	☑	☑	☑	☐	This computer (CAD session)	4	Waiting...
2D Flow around ST13 Airfoil at 4dg	☑	☑	☑	☐	This computer (CAD session)	4	Waiting...
2D Flow around ST13 Airfoil at 6dg	☑	☑	☑	☐	This computer (CAD session)	4	Waiting...
2D Flow around ST13 Airfoil at 8dg	☑	☑	☑	☐	This computer (CAD session)	4	Waiting...
2D Flow around ST13 Airfoil at 10dg	☑	☑	☑	☐	This computer (CAD session)	4	Waiting...
2D Flow around ST13 Airfoil at 12dg	☑	☑	☑	☐	This computer (CAD session)	4	Waiting...
2D Flow around ST13 Airfoil at 14	☑	☑	☑	☐	This computer (CAD session)	4	Waiting...
2D Flow around ST13 Airfoil at 16dg	☑	☑	☑	☐	This computer (CAD session)	4	Waiting...
2D Flow around ST13 Airfoil at 18dg	☑	☑	☑	☐	This computer (CAD session)	4	Waiting...
2D Flow around ST13 Airfoil at 20dg	☑	☑	☑	☐	This computer (CAD session)	4	Waiting...
Station 13, 0 degrees	☐	☐		☐			
Station 13, 0 degrees (1)	☐	☐		☐			

Maximum simultaneous run at this computer: 1

Fig 2.26 Batch run with the simulations for Section 13.

With the results obtained from these simulations, we were able to complete the values for the -20º to 10º range, but the Aerodyn Airfoil File requires to provide the coefficients for an angle of attack ranging from -180º to 180º. To obtain these values, as well as other required inputs such as the "*Cn slope for zero lift*" (complete list is shown at Fig. 2.18), to build a file suitable for Aerodyn, we used an *Excel* file, provided by *INTA* (Instituto Nacional de Técnica Aeroespacial).

That *Excel* file, named “*Airfoil_prep_v2p2*” requires as input the range of coefficients that was previously calculated, and through a series of internal interpolations, it is able to output us the whole Aerodyn Airfoil Input File. [4]

This process was repeated for Section 7 of our wind turbine blade.

For a complete list of the other Input Files required to simulate in Fast & Aerodyn, see Annex C.

CHAPTER 3. RESULTS AND DISCUSSION

3.1. Introduction

In the previous chapter we explained in-depth the inputs that Fast & Aerodyn simulation software needs, and how to calculate them from scratch, to obtain outputs such as the revolutions per minute (rpm) of the generator, or the associated generator power. As we have stated earlier, the results for the desired outputs are given by Fast & Aerodyn in "*.OUT*" files that can be opened with a word processor such as Windows' notepad.

The aim of this chapter is to present all the data obtained previously in a more intuitive manner, such as figures and tables for each wind turbine, and to compare the results to identify differences in performance.

3.2. Generator Power

One of the most important parameters that we want to study is the generator power. It tells us how much wind kinetic energy will our turbine be able to convert into electric energy and, as a consequence, how much power is available to us.

The most common graph is to plot the generator power against the wind speed. This gives us a relatively good concept of how our wind turbine works, but it can be misleading as well, since the probability of a power value occurring during the year should also be taken into consideration.

This means that it is possible to know the amount of power that a wind turbine will produce at a given wind speed value. But, is it possible to know the probability distribution of that amount of power?

There are several methods to obtain the probability distribution of the generator power: the static method, the semi static method and the quasi dynamic method, being the static method the simpler, and the quasi dynamic the most complex.

Static method: It is obtained analytically or graphically from the probability distribution of the wind in the corresponding area, and the power curve of the wind turbine. The wind speed probability curve represents the probability of occurrence, or the estimated percentage of time in which every speed interval occurs. The power curve of the wind turbine represents the power produced for every speed interval. From their superposition, the probability curve of occurrence for every power value is obtained.

The advantage that this method presents is its simplicity, although this simplicity also ignores non-stationary effects, losses due to changes in wind direction, and maintenance periods.

Semi static method: A series of temporal wind values is compared with the power curve of the wind turbine, to obtain a temporal series of the provided wind power. Integrating over time, the energy production is obtained.

The advantage is that it is possible to introduce information about controlled starts and stops, and the orientation of the wind turbine. The main disadvantage is that it is based in the ideal power curve of the generator.

Quasi dynamic method: It is based on a series of temporal wind data as inputs for a numerical model that represents the performance of the generator. Using this method we can obtain in a more precise manner the energy produced, the performance towards the orientation and controlled starts and stops.

The Static method was used due to both its simplicity and the fact that we decided to neglect the losses due to the wind changing its direction, and the static method does not account for this factor. [1]

The static method is based on the principle that the probability density function of the generator power follows a Weibull curve with the same scale and shape factors as the Weibull curve of the wind speed distribution the power originated from. That is to say that the probability density function of the wind speed is the same as for the generator power. [1]

Thus, the best way to represent the generator power is to include also in the plot the probability density function, so as to serve as an indicator of the chance of a certain power value to occur during the year.

3.2.1. Power curve of IT-PE-100

The following image (Fig 3.1) plots the power curve of the IT-PE-100 wind turbine using the Static method, described previously.

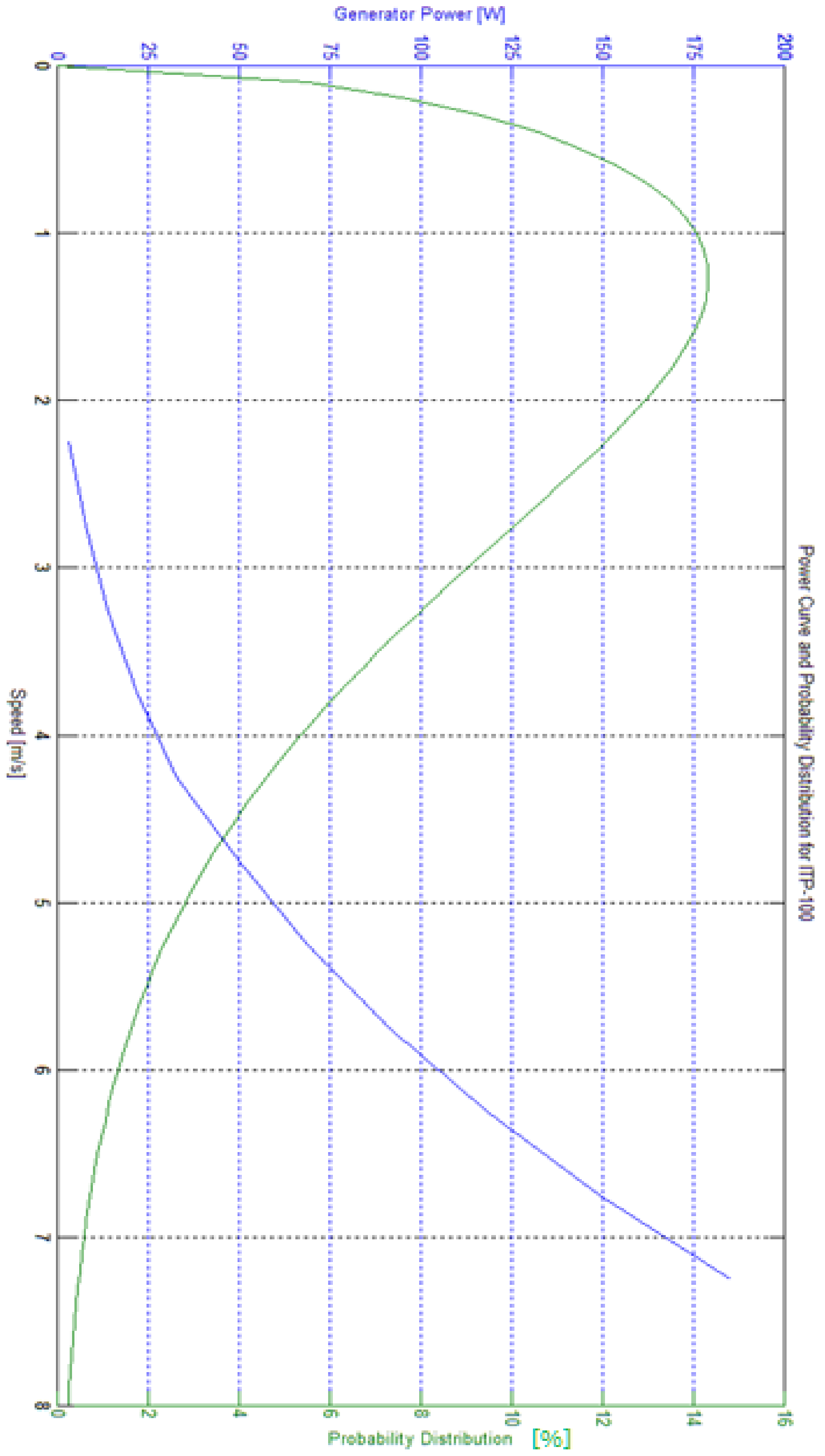


Fig 3.1 Power curve for IT-PE-100 (in blue) and probability distribution of wind in Viladecans (green).

We can appreciate in blue the power curve and, in green, the Weibull probability density function. Note that the supposed start up wind speed (the wind speed that will turn an unloaded rotor) is at around 2.2m/s, while the manufacturer states that it is at 3m/s. This is due to the fact that the inputs introduced to Fast & Aerodyn are not perfectly precise, thus making the simulation slightly inaccurate.

For a better understanding of how the plot works, suppose we want to know the power the generator will give at 3.5 m/s. As shown in Fig. 3.2.

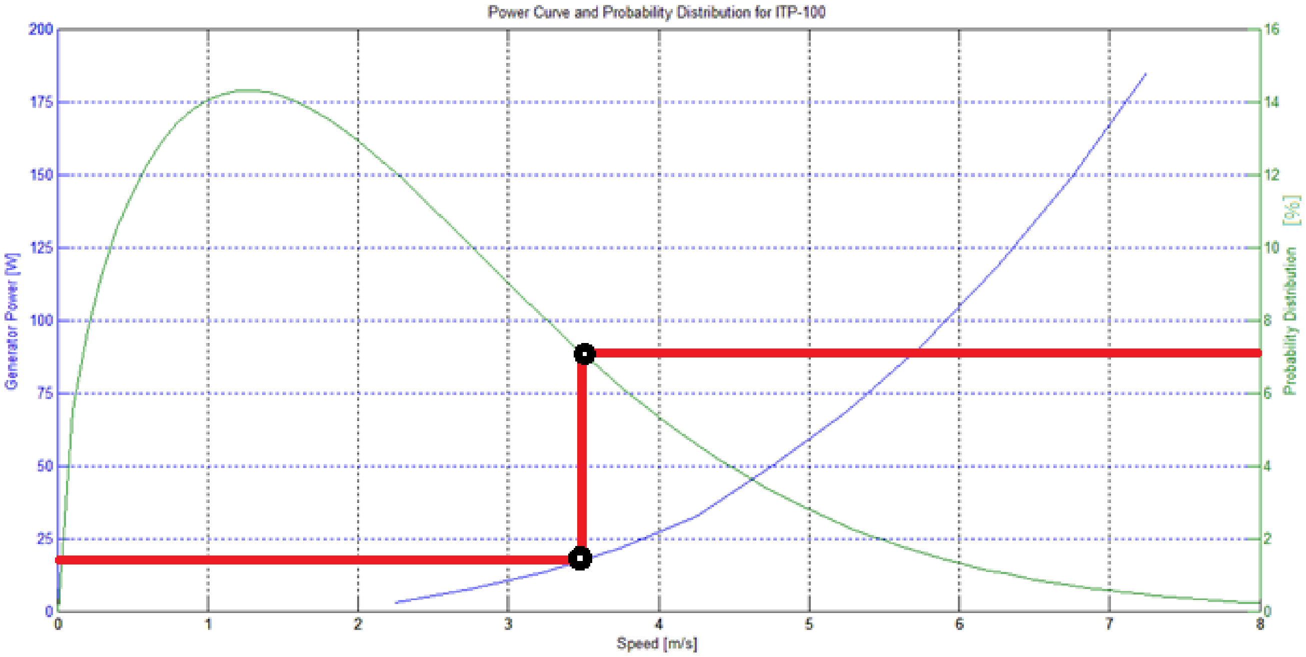


Fig 3.2 Power curve of IT-PE-100 (in blue) and probability distribution of wind in Viladecans (in green). A red mark showing power and probability at 3.5 m/s.

We draw a vertical line at 3.5m/s, and mark the intersection points with the graphs. The one in blue (The generator power curve) is at 20 W, while the green plot (Weibull probability distribution) is at 7%. This means that the probability of the generator giving an output of 20W at any point in the year is 7%. Note that this 7% also means the probability of the wind reaching 3.5m/s, as stated above.

We can now obtain the percentage of time during the year in which our IT-PE-100 will not provide any power. Supposing the start up wind speed provided by the manufacturer (3 m/s), that percentage is the sum of the probability of wind for every wind speed, from 0 m/s to 3 m/s. From the data at Fig. 1.8, the IT-PE-100 will not work for 74.92% of the time.

Alternatively, the simulation of our wind turbine stops working at 7 m/s. Therefore we can obtain the percentage of time in which our generator will work. The range of 3 m/s to 7 m/s represents a 23.48% of the year.

Also, we can compare the power curve obtained through the Fast & Aerodyn software with the power curve provided by the manufacturer. (see Fig. 3.3)

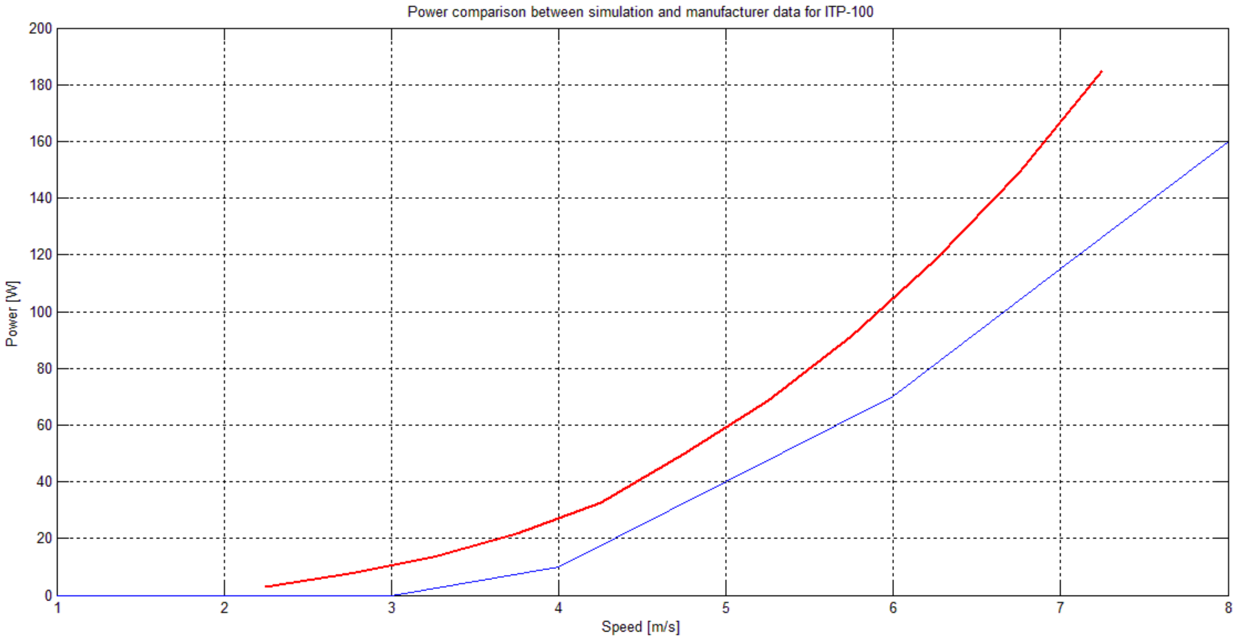


Fig 3.3 Comparison between the power curve obtained from the simulations (red) and provided by the manufacturer (blue) for IT-PE-100.

We can appreciate the differences between the simulations and the manufacturer data. Like we have stated before, these differences are due to the fact that the inputs entered into Fast & Aerodyn are not perfectly accurate. Using Matlab, an error rate of 43% between the manufacturer and our simulations was obtained. This is due to the fact that Fast & Aerodyn is fairly inaccurate in the range of 2 to 5 m/s.

3.2.2. Power curve of HP-600

Using the same method for the HP-600 wind turbine, we can plot its power curve graph (Fig. 3.3):

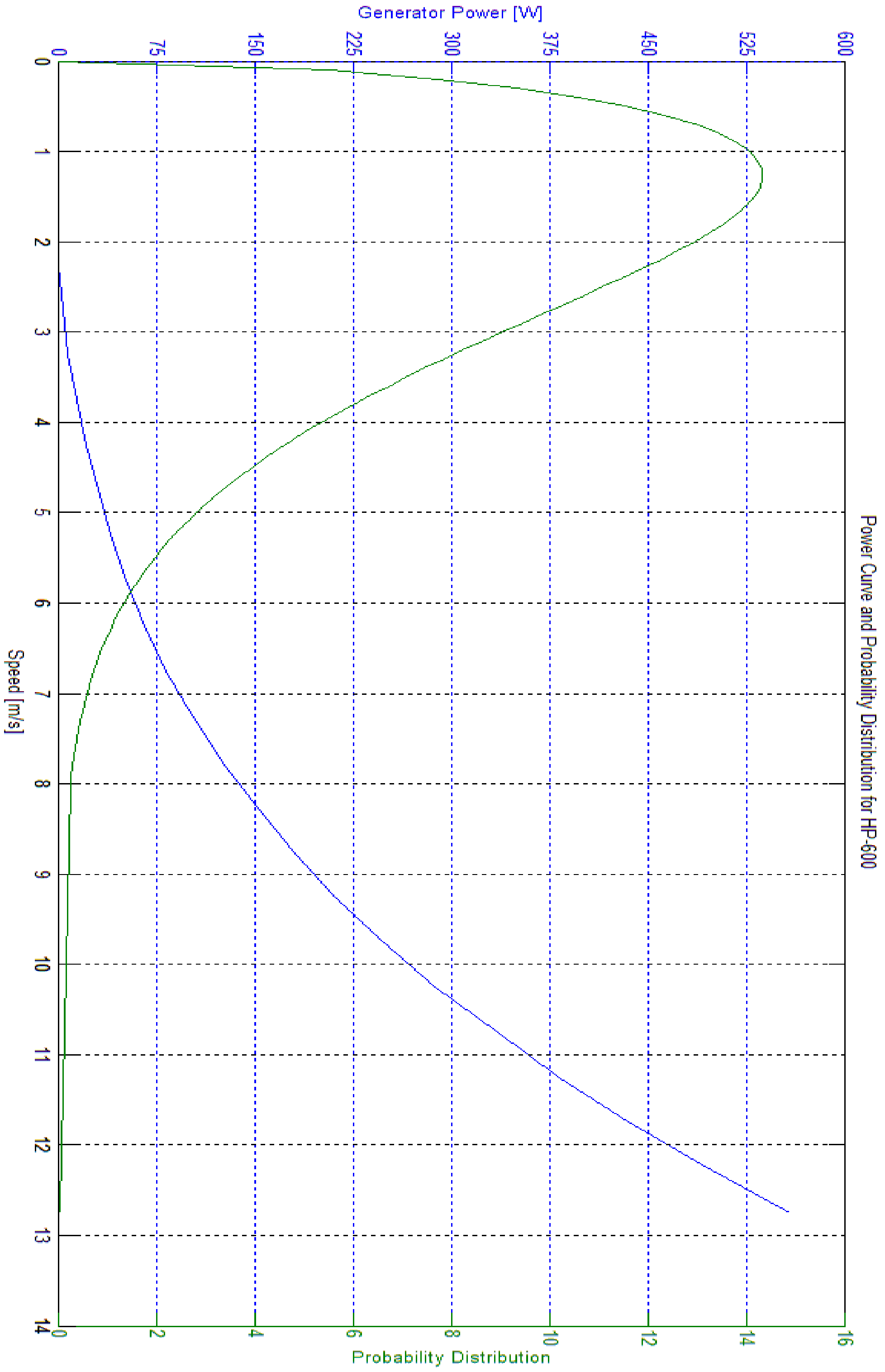


Fig 3.4 Power curve for HP-600 (in blue) and probability distribution of wind in Viladecans.

We can appreciate that the generator starts producing power at about 2.5m/s, while the manufacturer states that its start up wind speed is at 3m/s. The reason behind this is the same as for the IT-PE-100 (see above).

As with the IT-PE-100 model, we can obtain the percentage of time in which our turbine will not work. Since the start up wind speed is the same for both generators, that percentage will also be the same, 74.92%. The working range for the HP-600 is greater, from 3 m/s up to 25 m/s. This means that it will be working 25.08% of a year.

The following graph (Fig. 3.5) plots the power curves for the Fast & Aerodyn simulation and the manufacturer data.

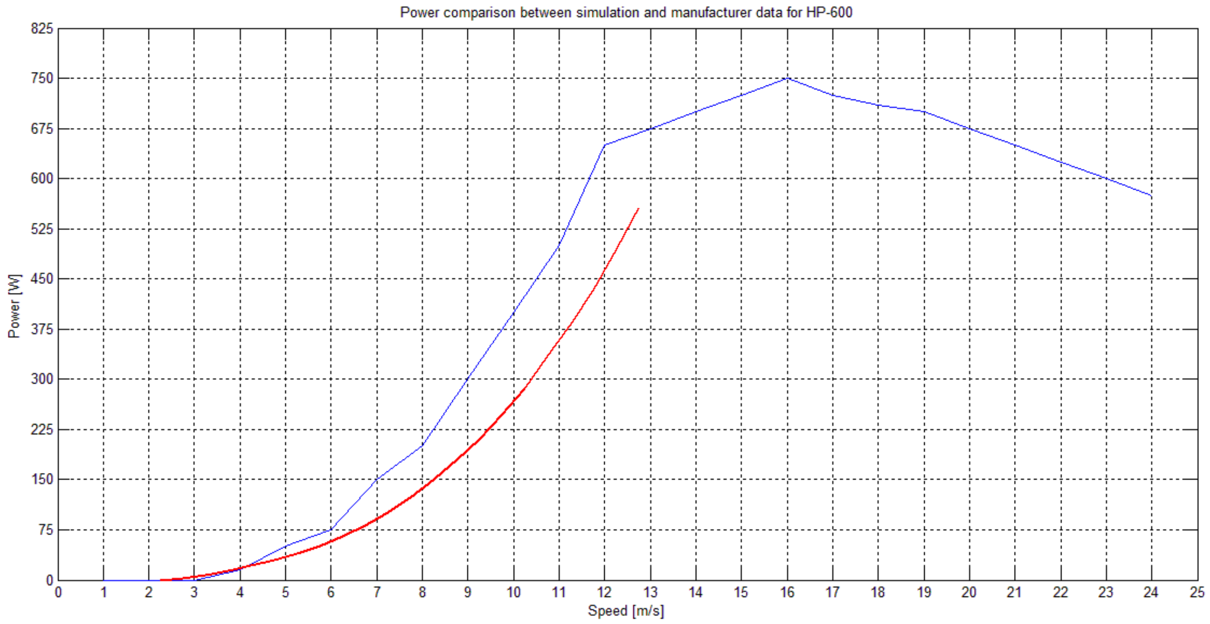


Fig 3.5 Comparison between the power curve obtained from the simulations (red) and provided by the manufacturer (blue) for HP-600

The differences between graphs are originated due to differences between the real turbine and its inputs in Fast & Aerodyn simulation software. We can also appreciate that the simulation graph stops at 12.75 m/s, while the manufacturer data states that the wind turbine will provide power up to 24 m/s. This is due to the fact that our Viladecans wind data never reached speeds past 13 m/s.

Using Matlab, an error rate of 28% between the manufacturer and our analysis was obtained. We can appreciate that it is lower than the IT-PE-100 model (which was 43%)

3.2.3. Yearly energy income

Another useful criterion when trying to determine which wind turbine is the best option, is to compare the yearly energy income in Viladecans. In order to do that we must take into account that the probability of a certain power value to occur during the year depends on the wind distribution. [1]

Therefore, the yearly energy income is calculated as follows:

$$E = \sum(p_i \cdot P_i) \cdot 8760\ [Wh] \quad \textbf{(3.1)}$$

Where E is the energy income, p_i is the probability of a certain power value given a wind speed range (taken in a 0.5 m/s interval), P_i is the power corresponding to that wind speed range, and 8760 being the number of hours contained in a year.

To obtain more accurate results, it was taken into account the start up wind speed specified by the manufacturer for both IT-PE-100 and HP-600.

That calculation gave us 99.6kWh for the IT-PE-100 wind turbine, and 66.3kWh for the HP-600. We will look into those values in the comparison section (3.4) but, as a reference, an average house requires around 20 kWh on a daily basis.

3.3. Power Coefficient

While the yearly energy income is one of the most important parameters that should be taken into account, since it gives us the amount of energy at our disposal, another parameter worth noting is the Power Coefficient. It is defined as the fraction of power contained in the incident wind that is captured by the wind turbine. It is a measure of efficiency:

$$C_p = \frac{Pobtained}{P\ available} \quad \textbf{(3.2)}$$

$P_{obtained}$ are the values calculated previously using Fast & Aerodyn (see section 3.2), and $P_{available}$ is the power which can be theoretically extracted from the wind:

$$P_{available} = \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \quad \textbf{(3.3)}$$

Being ρ the wind's density, A the area exposed to the incident wind, and v its speed. [3]

According to the Betz Law, this value cannot exceed 0.5925. [4]

The following figure (Fig. 3.6) represents the typical shape of a Power Coefficient graph:

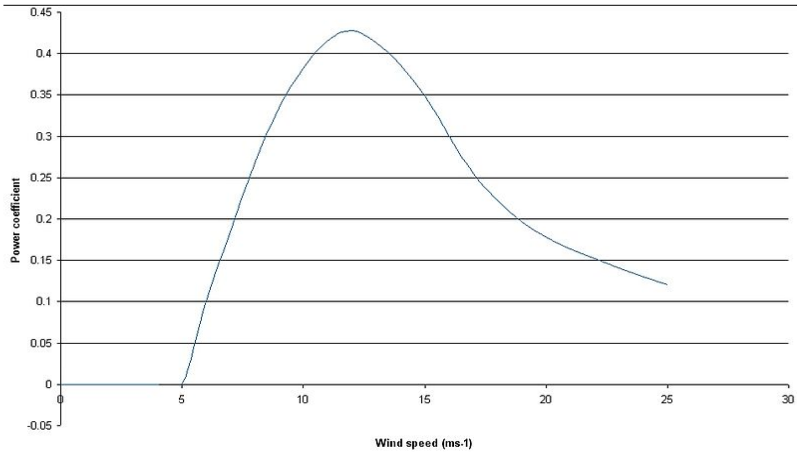


Fig 3.6. Typical shape of a Power Coefficient graph.

We can appreciate a peak in efficiency at around 12 m/s, which represents the rated speed of the wind turbine, and a drop in efficiency after that point. This is because the generator is not working at its optimum conditions.

3.3.1. Cp for IT-PE-100

If we apply the 3.2 formula, we can obtain the power coefficient for the IT-PE-100 wind turbine, as shown in the graph below (Fig. 3.7)

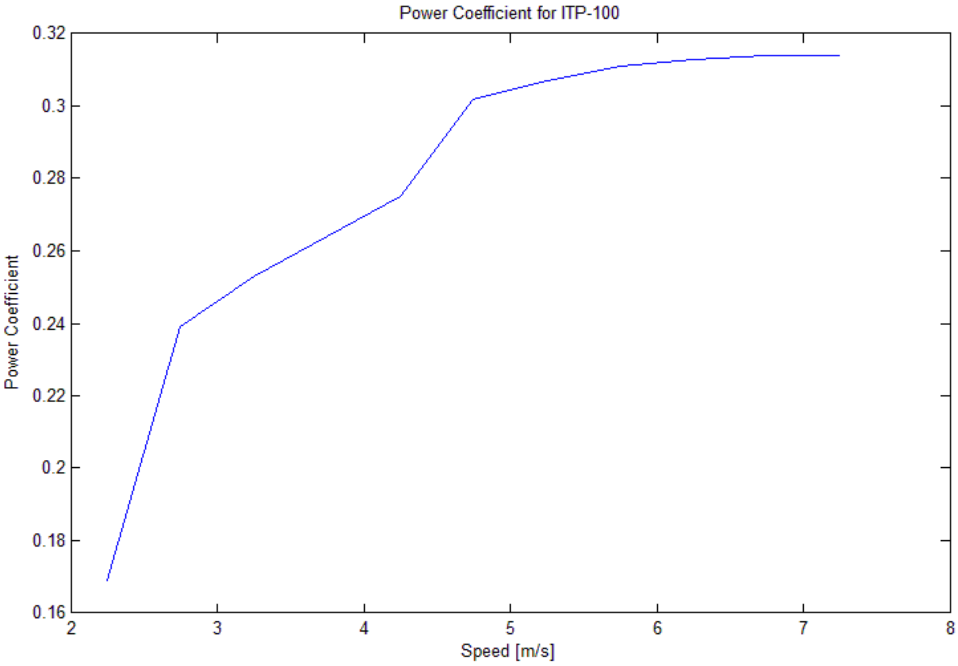


Fig 3.7 Power coefficient for IT-PE-100.

We can appreciate a constant increase in efficiency up to the working limits of the turbine (around 7 m/s). If we compare this graph with the typical shape of a power coefficient (Fig 3.4), we can notice the IT-PE-100 doesn't have a fall in efficiency after its peak. This is due to the fact that our turbine stops working past this point.

3.3.2. Cp for HP-600

The graph for the power coefficient of the HP-600 wind turbine can also be plotted (Fig 3.8):

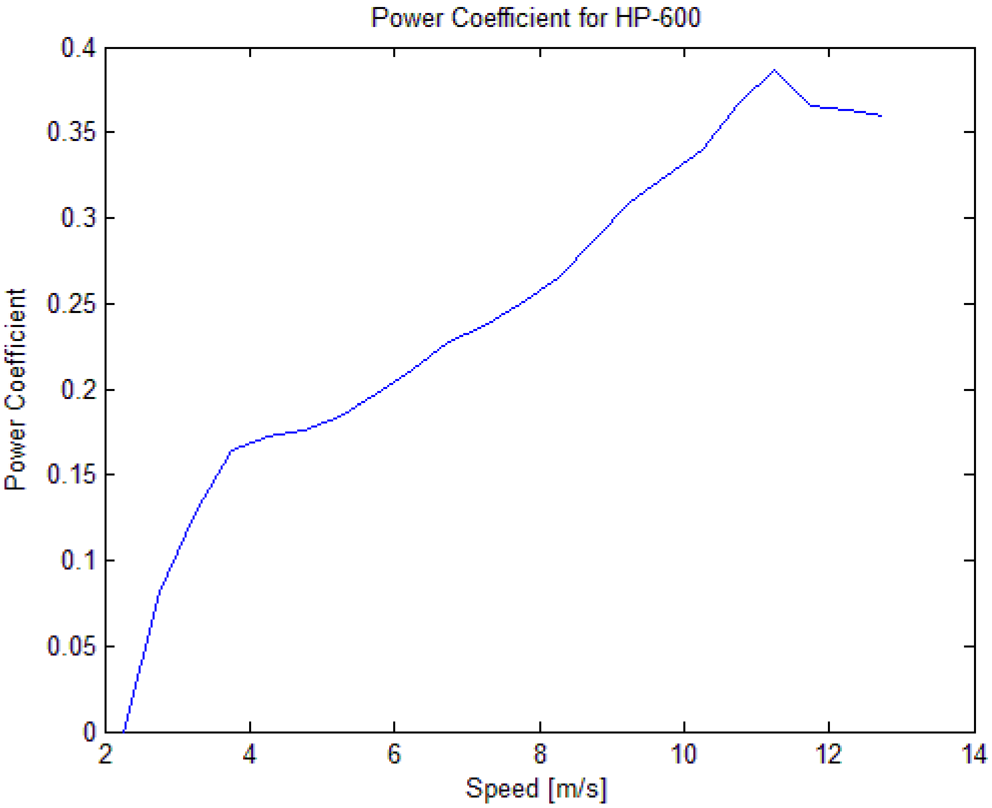


Fig 3.8 Power coefficient for HP-600.

In this graph we can appreciate a peak in efficiency at around 11.5 m/s, and a drop that extends up to 13 m/s. This is due to the fact that the wind in Viladecans does not get past that speed value. If we compare this plot with the one shown previously at Fig 3.4, we can notice that the gradient is slower for the HP-600.

3.4. Comparison

3.4.1. Power curve and Cp comparison

Plotting the power curve of our wind turbines gives us a better understanding of the differences between them (see Fig 3.9):

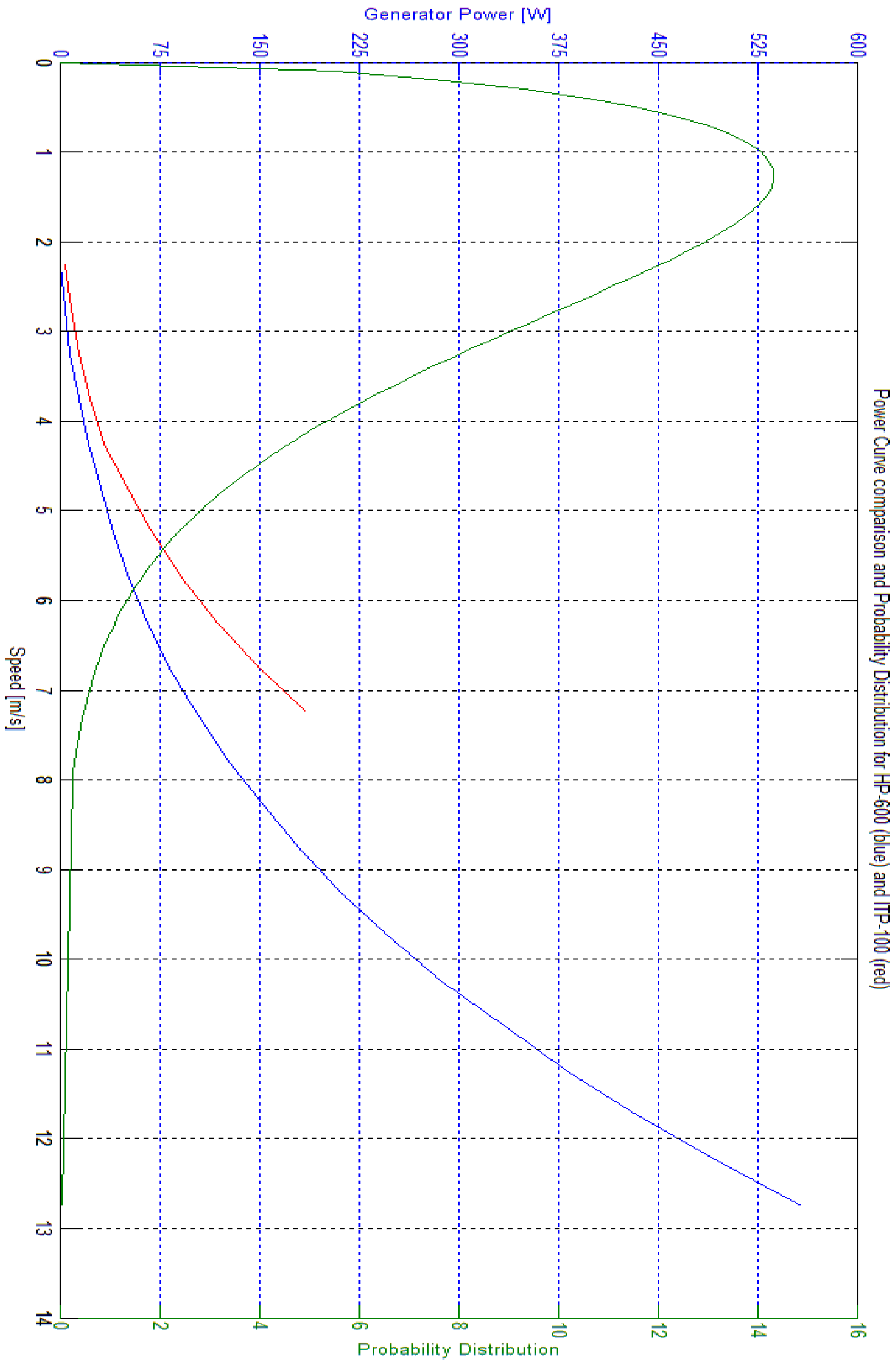


Fig 3.9 Power curve comparison and probability density function.

We can appreciate that the IT-PE-100 gives us a greater power at low wind speeds, but stops at about 7m/s, while the HP-600 seems to work better at higher values. This indicates us that, while the HP-600 gives a good amount of power in a wider range of speeds, the IT-PE-100 is the best option for the wind in the Viladecans area, since past the 7m/s mark (when the IT-PE-100 stops working) the probability of the wind is lesser than 1%.

A power coefficient graph representing both wind turbines can also be plotted, as shown in Fig. 3.10.

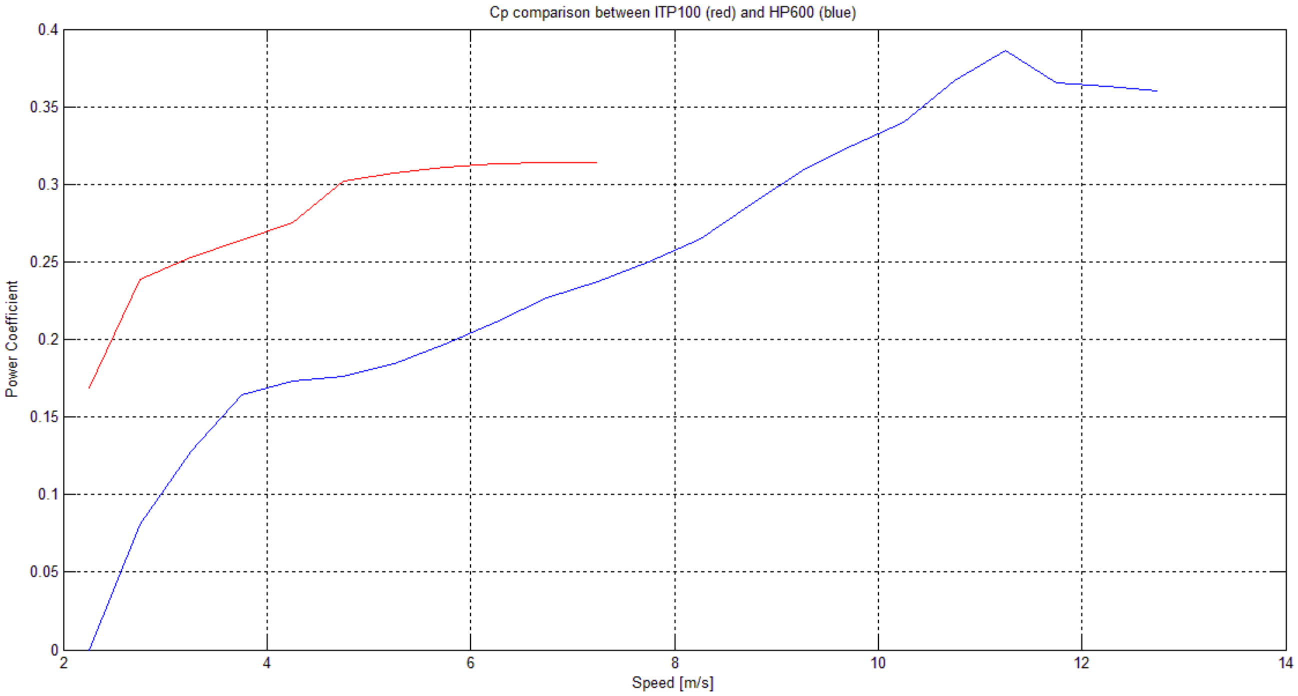


Fig 3.10 Power coefficient comparison between IT-PE-100 (red) and HP-600 (blue)

The conclusions we can draw from Fig. 3.10 are similar as of the previous graph: While the HP-600 achieves overall higher values of efficiency at greater speeds, IT-PE-100 works better at the low wind speed regions.

3.4.1 Economic interest

Another interesting parameter is the kilowatt-hour that was previously calculated (see Section 3.2.3). As expected from the corresponding power coefficients and the low wind speeds in Viladecans, the IT-PE-100 gives more energy than the HP-600 (99.6kWh against 66.3kWh) in the studied time period (i.e., a reference year).

For putting in perspective these values, we can compute the amount of time we could light a street lamp with our wind turbines.

It was decided to use a 50W LED from V-Tac (see Fig 3.11), which gives a lumen value close to the current high-pressure sodium vapor street lamps, while requiring significantly less power. [5]

Fig 3.11 50W LED Street lamp from V-Tac

Now, we apply the following formula to obtain *h*, the amount of hours that the street lamp must be working to reach either 99.6kWh for the IT-PE-100 or 66.3kWh for the HP600:

$$h = \frac{\text{Yearly energy income [Wh]}}{\text{Lamp Power consumption [W]}} \qquad \textbf{(3.4)}$$

That gives us 82 days for the IT-PE-100, and 55 days for the HP-600. This means that if our wind turbines were working for a whole year in Viladecans, supported by batteries, we then would be able to feed the street lamp for the stated amount of time. But, in reality, street lamps are not lighted 24 hours a day. If we estimate that a lamp is lit 8 hours a day, our wind turbines would be able to power the lamp 246 days for the IT-PE-100, and 166 days for the HP-600.

We can now calculate the income in euros of our wind turbines. The Spanish Ministry of Energy rates the kWh at 0.17€. If we multiply this value for our yearly energy income, we obtain 17.13€ for the IT-PE-100 and 11.40€ for the HP-600. [6]

With those values we can now calculate how much time do we need to amortize the costs of both turbines, based solely on their energy income. The price of the IT-PE-100 is 550€, so it would be covered in 32 years. The HP-600 cost is approximately 800€, and therefore it would be covered in 70 years. [8]

Although these values seem to render the wind turbines as not worthy of installing in the Viladecans area, it must be noted that they are designed to work in the low wind speed region, and to produce low power outputs.

3.4.2. Ecologic interest

It is also possible to calculate the amount of emitted CO_2 equivalent to the energy produced by our generators, in order to know how much CO_2 emissions we are saving.

Depending on the source of the energy, a different quantity of CO_2 will be emitted. The following table (Table 3.1) shows the most usual sources of energy and their respective emissions.

Table 3.1. CO_2 emissions for the most used energy sources. [9]

Energy source	**CO2 emission [g/kWh]**
Coal	1050
Natural gas	430
Hydroelectric	4
Wood	1500

We now multiply these values for our yearly energy income (99.6 kWh for IT-PE-100 and 66.3 kWh for HP-600) to obtain the amount of CO_2 grams that would be reduced yearly using our wind turbines, for every energy source (see Table 3.2).

Table 3.2. Amount of CO_2 emissions equivalent to the energy produced by our generators.

Energy source	**Using IT-PE-100 income**	**Using HP-600 income**
Coal	104.6 kg of CO_2	69.6 kg of CO_2
Natural gas	32.8 kg of CO_2	28.5 kg of CO_2
Hydroelectric	398.4 g of CO_2	265 g of CO_2
Wood	149 kg of CO_2	99.5 kg of CO_2

This means that if all the energy came from, for example, Coal burning, we would save 104.6 kg of CO_2 using the IT-PE-100 and 69.6 kg of CO_2, using the HP-600.

CHAPTER 4. CONCLUSIONS

The aim of this project was to analyze two low-scale wind turbines to determine which one constitutes the best option to be installed in Viladecans (Delta del Llobregat), in view of the power produced. A secondary objective is to validate Fast and AeroDyn for the simulation of small scale wind turbines operating in low-wind speed conditions. In order to fulfill the objectives, we followed these steps:

- Determination of the probability density function of the wind velocity in the Viladecans area, based on data recorded for the last 19 years.
- Simulation of the power curve for the IT-PE-100, using the previous wind velocity probability density function, and files extracted from previous TFCs conducted at EETAC-UPC.
- Digitalization of the blade of HP-600, preparation of the Fast & Aerodyn files needed for the HP-600 simulation, using the previous wind velocity probability density function.

Once the simulations were finished, we were able to plot both power curves (see Fig. 3.6) and analyze them. As stated before, the IT-PE-100 outputs higher electric power values for the low wind region.

The HP-600 starts producing more power for wind speeds around 9m/s. But from Fig. 1.7, we can appreciate that the probability for wind speeds of 9m/s and higher, is 0% in Viladecans. In fact, taking a closer look at the wind data, during 19 years that wind speed was achieved only once in a 1 hour interval.

The same applies for the power coefficient shown on Fig. 3.7. The HP-600 starts to work more efficiently than the IT-PE-100 at wind speeds higher than 9m/s.

Therefore, it is reasonable to conclude that the IT-PE-100 wind turbine is the best option for the Viladecans area.

As per the economic figures, the IT-PE-100 produces an estimate of 99.6kWh per year that, once stored, could be used to light a street lamp for 82 days a year, or 249 days considering that the street lamp is lit 8 hours a day.

This project also served to test the performance of Fast & Aerodyn operating in low-wind speed conditions. Comparing our results with the data provided by each manufacturer, an error of 43% was estimated for the power curve of the IT-PE-100 model, whereas a 28% was obtained for the HP-600. Therefore, we can conclude that, for low wind speeds, this software may not be as precise as desired, although it gives a good approximation of the real values.

One proposal for future work could be to study the feasibility of installing several wind turbines in the same area, in order to extract more energy from the wind. That would suppose the ability to light not one, but several street lamps during the whole year, thus creating a low-scale wind farm in Viladecans.

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ANNEXOS

TÍTOL DEL TFC: Study of electric energy production with small scale wind turbines in Viladecans (Delta del Llobregat)

TITULACIÓ: Enginyeria Tècnica Aeronàutica, especiatitat Aeronavegació

AUTORS: Jordi Jou
Aaron Valle

DIRECTOR: José I. Rojas Gregorio

CODIRECTOR: Jordi Mazón Bueso

DATA: June, 5th 2013

ANNEX A. IT-PE-100 INPUT FILES

PRIMARY INPUT FILE IT-PE100

------- FAST INPUT FILE --
FAST certification Test #17: FAST model of a SWRT 3-bladed upwind turbine. Note- SWRT rotates in CCW direction- some inputs will be mirror image of the actual turbine.
Model properties from "SWRTv1p2.adm" and SWRT "AdamsWT_MakeBladeDat_v12.xls". JEM Jan., 2004. Updated by J. Jonkman, NREL, Feb, 2004. Compatible with FAST v7.00.00.

--------------------- SIMULATION CONTROL -------------------------------------

False	Echo - Echo input data to "echo.out" (flag)
1	ADAMSPrep - ADAMS preprocessor mode {1: Run FAST, 2: use FAST as a preprocessor to create an ADAMS model, 3: do both} (switch)
1	AnalMode - Analysis mode {1: Run a time-marching simulation, 2: create a periodic linearized model} (switch)
3	NumBl - Number of blades (-)
20.0	TMax - Total run time (s)
0.0001	DT - Integration time step (s)

--------------------- TURBINE CONTROL --

0	YCMode - Yaw control mode {0: none, 1: user-defined from routine UserYawCont, 2: user-defined from Simulink} (switch)
9999.9	TYCOn - Time to enable active yaw control (s) [unused when YCMode=0]
0	PCMode - Pitch control mode {0: none, 1: user-defined from routine PitchCntrl, 2: user-defined from Simulink} (switch)
9999.9	TPCOn - Time to enable active pitch control (s) [unused when PCMode=0]
2	VSContrl - Variable-speed control mode {0: none, 1: simple VS, 2: user-defined from routine UserVSCont, 3: user-defined from Simulink} (switch)
9999.9	VS_RtGnSp - Rated generator speed for simple variable-speed generator control (HSS side) (rpm) [used only when VSContrl=1]
9999.9	VS_RtTq - Rated generator torque/constant generator torque in Region 3 for simple variable-speed generator control (HSS side) (N-m) [used only when VSContrl=1]
9999.9	VS_Rgn2K - Generator torque constant in Region 2 for simple variable-speed generator control (HSS side) (N-m/rpm^2) [used only when VSContrl=1]
9999.9	VS_SlPc - Rated generator slip percentage in Region 2 1/2 for simple variable-speed generator control (%) [used only when VSContrl=1]
1	GenModel - Generator model {1: simple, 2: Thevenin, 3: user-defined from routine UserGen} (switch) [used only when VSContrl=0]
True	GenTiStr - Method to start the generator {T: timed using TimGenOn, F: generator speed using SpdGenOn} (flag)
True	GenTiStp - Method to stop the generator {T: timed using TimGenOf, F: when generator power = 0} (flag)
9999.9	SpdGenOn - Generator speed to turn on the generator for a startup (HSS speed) (rpm) [used only when GenTiStr=False]
0.0	TimGenOn - Time to turn on the generator for a startup (s) [used only when GenTiStr=True]
9999.9	TimGenOf - Time to turn off the generator (s) [used only when GenTiStp=True]
1	HSSBrMode - HSS brake model {1: simple, 2: user-defined from routine UserHSSBr} (switch)
9999.9	THSSBrDp - Time to initiate deployment of the HSS brake (s)
9999.9	TiDynBrk - Time to initiate deployment of the dynamic generator brake [CURRENTLY IGNORED] (s)
9999.9	TTpBrDp(1) - Time to initiate deployment of tip brake 1 (s)
9999.9	TTpBrDp(2) - Time to initiate deployment of tip brake 2 (s)
9999.9	TTpBrDp(3) - Time to initiate deployment of tip brake 3 (s) [unused for 2 blades]
9999.9	TBDepISp(1) - Deployment-initiation speed for the tip brake on blade 1 (rpm)

9999.9	TBDepISp(2) - Deployment-initiation speed for the tip brake on blade 2 (rpm)
9999.9	TBDepISp(3) - Deployment-initiation speed for the tip brake on blade 3 (rpm) [unused for 2 blades]
9999.9	TYawManS - Time to start override yaw maneuver and end standard yaw control (s)
9999.9	TYawManE - Time at which override yaw maneuver reaches final yaw angle (s)
0.0	NacYawF - Final yaw angle for yaw maneuvers (degrees)
9999.9	TPitManS(1) - Time to start override pitch maneuver for blade 1 and end standard pitch control (s)
9999.9	TPitManS(2) - Time to start override pitch maneuver for blade 2 and end standard pitch control (s)
9999.9	TPitManS(3) - Time to start override pitch maneuver for blade 3 and end standard pitch control (s) [unused for 2 blades]
9999.9	TPitManE(1) - Time at which override pitch maneuver for blade 1 reaches final pitch (s)
9999.9	TPitManE(2) - Time at which override pitch maneuver for blade 2 reaches final pitch (s)
9999.9	TPitManE(3) - Time at which override pitch maneuver for blade 3 reaches final pitch (s) [unused for 2 blades]
0.0	BlPitch(1) - Blade 1 initial pitch (degrees)
0.0	BlPitch(2) - Blade 2 initial pitch (degrees)
0.0	BlPitch(3) - Blade 3 initial pitch (degrees) [unused for 2 blades]
0.0	BlPitchF(1) - Blade 1 final pitch for pitch maneuvers (degrees)
0.0	BlPitchF(2) - Blade 2 final pitch for pitch maneuvers (degrees)
0.0	BlPitchF(3) - Blade 3 final pitch for pitch maneuvers (degrees) [unused for 2 blades]

---------------------- ENVIRONMENTAL CONDITIONS -------------------------------

9.81	Gravity - Gravitational acceleration (m/s^2)

---------------------- FEATURE FLAGS ---

True	FlapDOF1 - First flapwise blade mode DOF (flag)
True	FlapDOF2 - Second flapwise blade mode DOF (flag)
True	EdgeDOF - First edgewise blade mode DOF (flag)
False	TeetDOF - Rotor-teeter DOF (flag) [unused for 3 blades]
False	DrTrDOF - Drivetrain rotational-flexibility DOF (flag)
True	GenDOF - Generator DOF (flag)
false	YawDOF - Yaw DOF (flag)
True	TwFADOF1 - First fore-aft tower bending-mode DOF (flag)
True	TwFADOF2 - Second fore-aft tower bending-mode DOF (flag)
True	TwSSDOF1 - First side-to-side tower bending-mode DOF (flag)
True	TwSSDOF2 - Second side-to-side tower bending-mode DOF (flag)
True	CompAero - Compute aerodynamic forces (flag)
False	CompNoise - Compute aerodynamic noise (flag)

---------------------- INITIAL CONDITIONS ------------------------------------

0.0	OoPDefl - Initial out-of-plane blade-tip displacement (meters)
0.0	IPDefl - Initial in-plane blade-tip deflection (meters)
0.0	TeetDefl - Initial or fixed teeter angle (degrees) [unused for 3 blades]
0.0	Azimuth - Initial azimuth angle for blade 1 (degrees)
230	RotSpeed - Initial or fixed rotor speed (rpm)
0.0	NacYaw - Initial or fixed nacelle-yaw angle (degrees)
0.0	TTDspFA - Initial fore-aft tower-top displacement (meters)
0.0	TTDspSS - Initial side-to-side tower-top displacement (meters)

---------------------- TURBINE CONFIGURATION ---------------------------------

0.9	TipRad - The distance from the rotor apex to the blade tip (meters)
0.15	HubRad - The distance from the rotor apex to the blade root (meters)
1	PSpnElN - Number of the innermost blade element which is still part of the pitchable portion of the blade for partial-span pitch control [1 to BldNodes] [CURRENTLY IGNORED] (-)
0.0	UndSling - Undersling length [distance from teeter pin to the rotor apex] (meters) [unused for 3 blades]

0.1324	HubCM - Distance from rotor apex to hub mass [positive downwind] (meters)
-0.170	OverHang - Distance from yaw axis to rotor apex [3 blades] or teeter pin [2 blades] (meters)
0.183	NacCMxn - Downwind distance from the tower-top to the nacelle CM (meters)
0.0	NacCMyn - Lateral distance from the tower-top to the nacelle CM (meters)
0.0405	NacCMzn - Vertical distance from the tower-top to the nacelle CM (meters)
10.0	TowerHt - Height of tower above ground level [onshore] or MSL [offshore] (meters)
0.155	Twr2Shft - Vertical distance from the tower-top to the rotor shaft (meters)
0.0	TwrRBHt - Tower rigid base height (meters)
0.0	ShftTilt - Rotor shaft tilt angle (degrees). Negative for an upwind rotor.
0.0	Delta3 - Delta-3 angle for teetering rotors (degrees) [unused for 3 blades]
5.5	PreCone(1) - Blade 1 cone angle (degrees)
5.5	PreCone(2) - Blade 2 cone angle (degrees)
5.5	PreCone(3) - Blade 3 cone angle (degrees) [unused for 2 blades]
0.0	AzimB1Up - Azimuth value to use for I/O when blade 1 points up (degrees)

--------------------- MASS AND INERTIA ---------------------------------------

0.0	YawBrMass - Yaw bearing mass (kg)
1.49	NacMass - Nacelle mass (kg)
0.46	HubMass - Hub mass (kg)
0.0	TipMass(1) - Tip-brake mass, blade 1 (kg)
0.0	TipMass(2) - Tip-brake mass, blade 2 (kg)
0.0	TipMass(3) - Tip-brake mass, blade 3 (kg) [unused for 2 blades]
0.05	NacYIner - Nacelle inertia about yaw axis (kg m^2)
0.0	GenIner - Generator inertia about HSS (kg m^2)
0.0	HubIner - Hub inertia about rotor axis [3 blades] or teeter axis [2 blades] (kg m^2)

--------------------- DRIVETRAIN --

100.0	GBoxEff - Gearbox efficiency (%)
66.0	GenEff - Generator efficiency [ignored by the Thevenin and user-defined generator models] (%)
1.0	GBRatio - Gearbox ratio (-)
False	GBRevers - Gearbox reversal {T: if rotor and generator rotate in opposite directions} (flag)
9999.9	HSSBrTqF - Fully deployed HSS-brake torque (N-m)
9999.9	HSSBrDT - Time for HSS-brake to reach full deployment once initiated (sec) [used only when HSSBrMode=1]
""	DynBrkFi - File containing a mech-gen-torque vs HSS-speed curve for a dynamic brake [CURRENTLY IGNORED] (quoted string)
9999.9	DTTorSpr - Drivetrain torsional spring (N-m/rad)
9999.9	DTTorDmp - Drivetrain torsional damper (N-m/(rad/s))

--------------------- SIMPLE INDUCTION GENERATOR -----------------------------

9999.9	SIG_SlPc - Rated generator slip percentage (%) [used only when VSContrl=0 and GenModel=1]
9999.9	SIG_SySp - Synchronous (zero-torque) generator speed (rpm) [used only when VSContrl=0 and GenModel=1]
9999.9	SIG_RtTq - Rated torque (N-m) [used only when VSContrl=0 and GenModel=1]
9999.9	SIG_PORt - Pull-out ratio (Tpullout/Trated) (-) [used only when VSContrl=0 and GenModel=1]

--------------------- THEVENIN-EQUIVALENT INDUCTION GENERATOR -----------------

9999.9	TEC_Freq - Line frequency [50 or 60] (Hz) [used only when VSContrl=0 and GenModel=2]
9998	TEC_NPol - Number of poles [even integer > 0] (-) [used only when VSContrl=0 and GenModel=2]
9999.9	TEC_SRes - Stator resistance (ohms) [used only when VSContrl=0 and GenModel=2]

9999.9	TEC_RRes - Rotor resistance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9	TEC_VLL - Line-to-line RMS voltage (volts) [used only when VSContrl=0 and GenModel=2]
9999.9	TEC_SLR - Stator leakage reactance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9	TEC_RLR - Rotor leakage reactance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9	TEC_MR - Magnetizing reactance (ohms) [used only when VSContrl=0 and GenModel=2]

--------------------- PLATFORM --

0	PtfmModel - Platform model {0: none, 1: onshore, 2: fixed bottom offshore, 3: floating offshore} (switch)
""	PtfmFile - Name of file containing platform properties (quoted string) [unused when PtfmModel=0]

--------------------- TOWER ---

10	TwrNodes - Number of tower nodes used for analysis (-)
"SWRT_Tower.dat"	TwrFile - Name of file containing tower properties (quoted string)

--------------------- NACELLE-YAW ---

0.0	YawSpr - Nacelle-yaw spring constant (N-m/rad)
0.0	YawDamp - Nacelle-yaw damping constant (N-m/(rad/s))
0.0	YawNeut - Neutral yaw position--yaw spring force is zero at this yaw (degrees)

--------------------- FURLING ---

True	Furling - Read in additional model properties for furling turbine (flag)
"SWRT_Furl.dat"	FurlFile - Name of file containing furling properties (quoted string) [unused when Furling=False]

--------------------- ROTOR-TEETER --

0	TeetMod - Rotor-teeter spring/damper model {0: none, 1: standard, 2: user-defined from routine UserTeet} (switch) [unused for 3 blades]
0.0	TeetDmpP - Rotor-teeter damper position (degrees) [used only for 2 blades and when TeetMod=1]
0.0	TeetDmp - Rotor-teeter damping constant (N-m/(rad/s)) [used only for 2 blades and when TeetMod=1]
0.0	TeetCDmp - Rotor-teeter rate-independent Coulomb-damping moment (N-m) [used only for 2 blades and when TeetMod=1]
0.0	TeetSStP - Rotor-teeter soft-stop position (degrees) [used only for 2 blades and when TeetMod=1]
0.0	TeetHStP - Rotor-teeter hard-stop position (degrees) [used only for 2 blades and when TeetMod=1]
0.0	TeetSSSp - Rotor-teeter soft-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]
0.0	TeetHSSp - Rotor-teeter hard-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]

--------------------- TIP-BRAKE ---

0.0	TBDrConN - Tip-brake drag constant during normal operation, Cd*Area (m^2)
0.0	TBDrConD - Tip-brake drag constant during fully-deployed operation, Cd*Area (m^2)
0.0	TpBrDT - Time for tip-brake to reach full deployment once released (sec)

--------------------- BLADE ---

"SWRT_Blade.dat"	BldFile(1) - Name of file containing properties for blade 1 (quoted string)
"SWRT_Blade.dat"	BldFile(2) - Name of file containing properties for blade 2 (quoted string)
"SWRT_Blade.dat"	BldFile(3) - Name of file containing properties for blade 3 (quoted string) [unused for 2 blades]

--------------------- AERODYN ---

"Test17_AD.ipt"	ADFile - Name of file containing AeroDyn input parameters (quoted string)

--------------------- NOISE ---

""	NoiseFile - Name of file containing aerodynamic noise input parameters (quoted string) [used only when CompNoise=True]

--------------------- ADAMS --

"SWRT_ADAMS.dat"	ADAMSFile - Name of file containing ADAMS-specific input parameters (quoted string) [unused when ADAMSPrep=1]

--------------------- LINEARIZATION CONTROL ----------------------------------

"SWRT_Linear.dat"	LinFile - Name of file containing FAST linearization parameters (quoted string) [unused when AnalMode=1]

--------------------- OUTPUT --

True	SumPrint - Print summary data to "<RootName>.fsm" (flag)
True	TabDelim - Generate a tab-delimited tabular output file. (flag)
"ES10.3E2"	OutFmt - Format used for tabular output except time. Resulting field should be 10 characters. (quoted string) [not checked for validity!]
10.0	TStart - Time to begin tabular output (s)
8	DecFact - Decimation factor for tabular output {1: output every time step} (-)
1.0	SttsTime - Amount of time between screen status messages (sec)
0.0	NcIMUxn - Downwind distance from the tower-top to the nacelle IMU (meters)
0.0	NcIMUyn - Lateral distance from the tower-top to the nacelle IMU (meters)
0.0	NcIMUzn - Vertical distance from the tower-top to the nacelle IMU (meters)
0.1	ShftGagL - Distance from rotor apex [3 blades] or teeter pin [2 blades] to shaft strain gages [positive for upwind rotors] (meters)
0	NTwGages - Number of tower nodes that have strain gages for output [0 to 9] (-)
0	TwrGagNd - List of tower nodes that have strain gages [1 to TwrNodes] (-) [unused if NTwGages=0]
0	NBlGages - Number of blade nodes that have strain gages for output [0 to 9] (-)
0	BldGagNd - List of blade nodes that have strain gages [1 to BldNodes] (-) [unused if NBlGages=0]
OutList - The next line(s) contains a list of output parameters. See OutList.txt for a listing of available output channels, (-)	
"TotWindV, HorWindV, HorWndDir"	
"LSSGagVxa, TipSpdRat"	
"LSShftFxa, LSShftMxa, HSShftV, RotPwr, RotCq, RotCp, RotCt"	
"GenPwr, GenCp , GenTq"	
END of FAST input file (the word "END" must appear in the first 3 columns of this last line).	

AERODYN INPUT FILE ITP-E100

SWRT rotor aerodynamic parameters for FAST certification test #17.	
SI	SysUnits - System of units for used for input and output [must be SI for FAST] (unquoted string)
BEDDOES	StallMod - Dynamic stall included [BEDDOES or STEADY] (unquoted string)
NO_CM	UseCm - Use aerodynamic pitching moment model? [USE_CM or NO_CM] (unquoted string)
DYNIN	InfModel - Inflow model [DYNIN or EQUIL] (unquoted string)
SWIRL	IndModel - Induction-factor model [NONE or WAKE or SWIRL] (unquoted string)
0.005	AToler - Induction-factor tolerance (convergence criteria) (-)
PRANDtl	TLModel - Tip-loss model (EQUIL only) [PRANDtl, GTECH, or NONE] (unquoted string)
NONE	HLModel - Hub-loss model (EQUIL only) [PRANdtl or NONE] (unquoted string)
"MEANMAXSPEED744.wnd"	WindFile - Name of file containing wind data (quoted string)
10	HH - Wind reference (hub) height [TowerHt+Twr2Shft+OverHang*SIN(ShftTilt)] (m)
0.0	TwrShad - Tower-shadow velocity deficit (-)
9999.9	ShadHWid - Tower-shadow half width (m)
9999.9	T_Shad_Refpt - Tower-shadow reference point (m)

1.225	AirDens - Air density (kg/m^3)
1.5100E-05	KinVisc - Kinematic air viscosity (m^2/sec)
1.0000E-03	DTAero - Time interval for aerodynamic calculations (sec)
1	NumFoil - Number of airfoil files (-)
"naca4412Re90000.dat"	FoilNm - Names of the airfoil files [NumFoil lines] (quoted strings)
15	BldNodes - Number of blade nodes used for analysis (-)

RNodes	AeroTwst	DRNodes	Chord	NFoil	PrnElm
0.175	14.50	0.05	0.1679	1	NOPRINT
0.225	13.60	0.05	0.1608	1	NOPRINT
0.275	12.70	0.05	0.1537	1	NOPRINT
0.325	11.80	0.05	0.1466	1	NOPRINT
0.375	10.90	0.05	0.1395	1	NOPRINT
0.425	9.90	0.05	0.1324	1	NOPRINT
0.475	9.10	0.05	0.1253	1	NOPRINT
0.525	8.20	0.05	0.1182	1	NOPRINT
0.575	7.30	0.05	0.1111	1	NOPRINT
0.625	6.30	0.05	0.1040	1	NOPRINT
0.675	5.40	0.05	0.0969	1	NOPRINT
0.725	4.50	0.05	0.0898	1	NOPRINT
0.775	3.60	0.05	0.0827	1	NOPRINT
0.825	2.70	0.05	0.0756	1	NOPRINT
0.875	1.80	0.05	0.0685	1	NOPRINT
ReNum					

AIRFOIL FILE IT-PE100

AeroDyn airfoil file. Compatible with AeroDyn v13.0.	
Perfil NACA4412, Re=.09 Million. El perfil de l'IT-100	
1	Number of airfoil tables in this file
0.09	Table ID parameter (Reynolds number in milllions). For efficiency, make very large if only one table.
0.0	
0.0	
0.0	
0.0	
-4.4917	Zero Cn angle of attack (deg)
6.7000	Cn slope for zero lift (dimensionless)
1.8116	Cn extrapolated to value at positive stall angle of attack
-0.8000	Cn at stall value for negative angle of attack
-2.50	Angle of attack for minimum CD (deg)
0.0104	Minimum CD value

-180.00	0.000	0.0100	0.0000
-170.00	0.475	0.0100	0.4000
-160.00	0.949	0.0640	-0.0979
-150.00	0.780	0.2475	-0.0273
-140.00	0.687	0.4736	0.0154
-130.00	0.593	0.7158	0.0586
-120.00	0.475	0.9460	0.1054
-110.00	0.330	1.1377	0.1525
-100.00	0.166	1.2692	0.1948
-90.00	0.000	1.3260	0.2265
-80.00	-0.166	1.2692	0.2346
-70.00	-0.330	1.1377	0.2284
-60.00	-0.475	0.9460	0.2130
-50.00	-0.593	0.7158	0.1962
-40.00	-0.687	0.4736	0.1900

-30.00	-0.780	0.2475	0.2169
-20.00	-0.949	0.0640	-0.1060
-19.50	-1.763	0.0557	-0.1060
-19.00	-1.706	0.0532	-0.1060
-18.50	-1.650	0.0509	-0.1060
-18.00	-1.593	0.0485	-0.1060
-17.50	-1.536	0.0462	-0.1060
-17.00	-1.479	0.0429	-0.1060
-16.50	-1.422	0.0409	-0.1050
-16.00	-1.364	0.0389	-0.1050
-15.50	-1.307	0.0370	-0.1050
-15.00	-1.249	0.0353	-0.1050
-14.50	-1.191	0.0335	-0.1050
-14.00	-1.133	0.0319	-0.1050
-13.50	-1.075	0.0297	-0.1050
-13.00	-1.016	0.0282	-0.1050
-12.50	-0.958	0.0268	-0.1050
-12.00	-0.899	0.0256	-0.1050
-11.50	-0.840	0.0244	-0.1050
-11.00	-0.782	0.0228	-0.1050
-10.50	-0.723	0.0217	-0.1050
-10.00	-0.664	0.0208	-0.1050
-9.50	-0.604	0.0196	-0.1050
-9.00	-0.545	0.0187	-0.1050
-8.50	-0.486	0.0180	-0.1050
-8.00	-0.427	0.0170	-0.1050
-7.50	-0.367	0.0164	-0.1050
-7.00	-0.308	0.0156	-0.1050
-6.50	-0.248	0.0149	-0.1050
-6.00	-0.188	0.0142	-0.1050
-5.50	-0.129	0.0134	-0.1050
-5.00	-0.069	0.0130	-0.1050
-4.50	-0.009	0.0122	-0.1050
-4.00	0.050	0.0118	-0.1050
-3.50	0.110	0.0113	-0.1050
-3.00	0.170	0.0108	-0.1050
-2.50	0.230	0.0104	-0.1050
-2.00	0.290	0.0104	-0.1050
-1.50	0.349	0.0105	-0.1050
-1.00	0.409	0.0107	-0.1050
-0.50	0.469	0.0107	-0.1050
0.00	0.529	0.0108	-0.1060
0.50	0.588	0.0109	-0.1060
1.00	0.648	0.0111	-0.1060
1.50	0.708	0.0114	-0.1060
2.00	0.767	0.0116	-0.1060
2.50	0.827	0.0120	-0.1060
3.00	0.886	0.0123	-0.1060
3.50	0.937	0.0126	-0.1060
4.00	0.985	0.0131	-0.1070
4.50	1.030	0.0138	-0.1070
5.00	1.073	0.0142	-0.1070
5.50	1.114	0.0149	-0.1070
6.00	1.153	0.0157	-0.1070
6.50	1.190	0.0161	-0.1080
7.00	1.224	0.0171	-0.1080
7.50	1.256	0.0178	-0.1080
8.00	1.286	0.0188	-0.1080

8.50	1.314	0.0194	-0.1080
9.00	1.339	0.0208	-0.1090
9.50	1.363	0.0214	-0.1090
10.00	1.384	0.0229	-0.1090
10.50	1.403	0.0238	-0.1090
11.00	1.420	0.0254	-0.1090
11.50	1.435	0.0265	-0.1100
12.00	1.448	0.0288	-0.1100
12.50	1.459	0.0300	-0.1100
13.00	1.468	0.0312	-0.1100
13.50	1.475	0.0332	-0.1110
14.00	1.479	0.0356	-0.1110
14.50	1.481	0.0372	-0.1110
15.00	1.482	0.0399	-0.1120
15.50	1.480	0.0417	-0.1120
16.00	1.475	0.0435	-0.1120
16.50	1.469	0.0455	-0.1120
17.00	1.460	0.0487	-0.1130
17.50	1.449	0.0508	-0.1130
18.00	1.436	0.0530	-0.1130
18.50	1.420	0.0552	-0.1140
19.00	1.401	0.0575	-0.1140
19.50	1.380	0.0615	-0.1140
20.00	1.356	0.0640	-0.1150
30.00	1.114	0.2475	-0.2109
40.00	0.982	0.4736	-0.2581
50.00	0.847	0.7158	-0.2974
60.00	0.678	0.9460	-0.3356
70.00	0.471	1.1377	-0.3731
80.00	0.238	1.2692	-0.4077
90.00	0.000	1.3260	-0.4365
100.00	-0.166	1.2692	-0.4446
110.00	-0.330	1.1377	-0.4384
120.00	-0.475	0.9460	-0.4230
130.00	-0.593	0.7158	-0.4062
140.00	-0.687	0.4736	-0.4000
150.00	-0.780	0.2475	-0.4269
160.00	-0.949	0.0640	-0.5549
170.00	-0.475	0.0100	-0.5000
180.00	0.000	0.0100	0.0000

WIND FILE

! Wind file for Trivial turbine.							
! Time	Wind	Wind	Vert.	Horiz.	Vert.	LinV	Gust
!	Speed	Dir	Speed	Shear	Shear	Shear	Speed
0	4.25	0	0	0	0	0	0
20	4.25	0	0	0	0	0	0

SPEED VS TORQUE ITPE100

RPM and Torque (Nm) for IT	100 rotor mod by CS April 10, 2011
0	0
10	0
20	0
30	0

40	0
50	0
60	0
70	0
80	0
90	0
100	0
110	0
120	0
130	0
140	0
150	0
160	0
170	0
180	0
190	0
200	0
210	0
220	0
230	0
240	0
250	0
260	0
270	0
280	0
290	0
300	3,6
310	5,806451613
320	8,4375
330	10,90909091
340	12,70588235
350	15,42857143
360	16,66666667
370	18,64864865
380	20,52631579
390	21,69230769
400	24
410	25,6097561
420	27,14285714
430	27,90697674
440	0
450	0

BLADE INPUT FILE

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--------------------- FAST INDIVIDUAL BLADE FILE -----------------------------	
SWRT blade. Windward Engineering. January, 2004. Updated by J. Jonkman, NREL, Feb, 2004.	
--------------------- BLADE PARAMETERS ---------------------------------------	
4	NBlInpSt - Number of blade input stations (-)
False	CalcBMode - Calculate blade mode shapes internally {T: ignore mode shapes from below, F: use mode shapes from below} [CURRENTLY IGNORED] (flag)
3.0	BldFlDmp(1) - Blade flap mode #1 structural damping in percent of critical (%)
3.0	BldFlDmp(2) - Blade flap mode #2 structural damping in percent of critical (%)
5.0	BldEdDmp(1) - Blade edge mode #1 structural damping in percent of critical (%)

---------------------- BLADE ADJUSTMENT FACTORS --------------------------------	
1.0	FlStTunr(1) - Blade flapwise modal stiffness tuner, 1st mode (-)
1.0	FlStTunr(2) - Blade flapwise modal stiffness tuner, 2nd mode (-)
1.0	AdjBlMs - Factor to adjust blade mass density (-)
1.0	AdjFlSt - Factor to adjust blade flap stiffness (-)
1.0	AdjEdSt - Factor to adjust blade edge stiffness (-)
---------------------- DISTRIBUTED BLADE PROPERTIES ----------------------------	
BlFract AeroCent StrcTwst BMassDen FlpStff EdgStff GJStff EAStff Alpha FlpIner EdgIner PrecrvRef PreswpRef FlpcgOf EdgcgOf FlpEAOf EdgEAOf	
(-) (-) (deg) (kg/m) (Nm^2) (Nm^2) (Nm^2) (N) (-) (kg m) (kg m) (m) (m) (m) (m) (m) (m)	
0.00 0.25 0.0 4.192 4.53E+03 1.99E+05 4.48E+03 2.04E+06 0.0 0.005890117 0.021739021 0.0 0.0 0.0 0.0 0.0 0.0	
0.90 0.25 0.0 4.192 4.53E+03 1.99E+05 4.48E+03 2.04E+06 0.0 0.005890117 0.021739021 0.0 0.0 0.0 0.0 0.0 0.0	
0.95 0.25 0.0 4.020 4.53E+03 1.99E+05 4.48E+03 2.04E+06 0.0 0.005648443 0.020847058 0.0 0.0 0.0 0.0 0.0 0.0	
1.00 0.25 0.0 3.848 4.53E+03 1.99E+05 4.48E+03 2.04E+06 0.0 0.005406768 0.019955094 0.0 0.0 0.0 0.0 0.0 0.0	
---------------------- BLADE MODE SHAPES---------------------------------------	
2.572	BldFl1Sh(2) - Flap , coeff of x^2
-2.772	BldFl1Sh(3) - , coeff of x^3
1.551	BldFl1Sh(4) - , coeff of x^4
-0.330	BldFl1Sh(5) - , coeff of x^5
-0.021	BldFl1Sh(6) - , coeff of x^6
-9.847	BldFl2Sh(2) - Flap , coeff of x^2
13.882	BldFl2Sh(3) - , coeff of x^3
9.529	BldFl2Sh(4) - , coeff of x^4
-19.873	BldFl2Sh(5) - , coeff of x^5
7.309	BldFl2Sh(6) - , coeff of x^6
1.617	BldEdgSh(2) - Edge , coeff of x^2
-0.065	BldEdgSh(3) - , coeff of x^3
-1.424	BldEdgSh(4) - , coeff of x^4
1.201	BldEdgSh(5) - , coeff of x^5
-0.329	BldEdgSh(6) - , coeff of x^6

TOWER FILE

---------------------- FAST TOWER FILE ---
RIGID TOWER- none of this information is correct but, it does not matter for a rigid tower.

---------------------- TOWER PARAMETERS ---------------------------------------

1	NTwInpSt - Number of input stations to specify tower geometry
False	CalcTMode - Calculate tower mode shapes internally {T: ignore mode shapes from below, F: use mode shapes from below} [CURRENTLY IGNORED] (flag)
3.435	TwrFADmp(1) - Tower 1st fore-aft mode structural damping ratio (%)
3.435	TwrFADmp(2) - Tower 2nd fore-aft mode structural damping ratio (%)
3.435	TwrSSDmp(1) - Tower 1st side-to-side mode structural damping ratio (%)
3.435	TwrSSDmp(2) - Tower 2nd side-to-side mode structural damping ratio (%)

---------------------- TOWER ADJUSTMUNT FACTORS -------------------------------

1.0	FAStTunr(1) - Tower fore-aft modal stiffness tuner, 1st mode (-)
1.0	FAStTunr(2) - Tower fore-aft modal stiffness tuner, 2nd mode (-)
1.0	SSStTunr(1) - Tower side-to-side stiffness tuner, 1st mode (-)

1.0	SSStTunr(2) - Tower side-to-side stiffness tuner, 2nd mode (-)
1.0	AdjTwMa - Factor to adjust tower mass density (-)
1.0	AdjFASt - Factor to adjust tower fore-aft stiffness (-)
1.0	AdjSSSt - Factor to adjust tower side-to-side stiffness (-)

---------------------- DISTRIBUTED TOWER PROPERTIES ----------------------------

HtFract	TMassDen	TwFAStif	TwSSStif	TwGJStif	TwEAStif	TwFAIner	TwSSIner	TwFAcgOf	TwSScgOf
(-)	(kg/m)	(Nm^2)	(Nm^2)	(Nm^2)	(N)	(kg m)	(kg m)	(m)	(m)
0.000	879.16	1.564E10	1.564E10	3.0E10	2.02E9	0.0	0.0	0.0	0.0

---------------------- TOWER FORE-AFT MODE SHAPES ------------------------------

1.6400	TwFAM1Sh(2) - Mode 1, coefficient of x^2 term
-0.6510	TwFAM1Sh(3) - , coefficient of x^3 term
-0.0460	TwFAM1Sh(4) - , coefficient of x^4 term
0.0520	TwFAM1Sh(5) - , coefficient of x^5 term
0.0050	TwFAM1Sh(6) - , coefficient of x^6 term
-17.9490	TwFAM2Sh(2) - Mode 2, coefficient of x^2 term
22.8840	TwFAM2Sh(3) - , coefficient of x^3 term
14.1730	TwFAM2Sh(4) - , coefficient of x^4 term
-27.1580	TwFAM2Sh(5) - , coefficient of x^5 term
9.0500	TwFAM2Sh(6) - , coefficient of x^6 term

---------------------- TOWER SIDE-TO-SIDE MODE SHAPES --------------------------

1.6400	TwSSM1Sh(2) - Mode 1, coefficient of x^2 term
-0.6510	TwSSM1Sh(3) - , coefficient of x^3 term
-0.0460	TwSSM1Sh(4) - , coefficient of x^4 term
0.0520	TwSSM1Sh(5) - , coefficient of x^5 term
0.0050	TwSSM1Sh(6) - , coefficient of x^6 term
-17.9490	TwSSM2Sh(2) - Mode 2, coefficient of x^2 term
22.8840	TwSSM2Sh(3) - , coefficient of x^3 term
14.1730	TwSSM2Sh(4) - , coefficient of x^4 term
-27.1580	TwSSM2Sh(5) - , coefficient of x^5 term
9.0500	TwSSM2Sh(6) - , coefficient of x^6 term

FURLING FILE

---------------------- FAST FURLING FILE ---------------------------------------

SWRT input properties. Windward Engineering. January, 2004. Updated by J. Jonkman, NREL, Feb, 2004.

--------------------- FEATURE FLAGS (CONT) -----------------------------------

False	RFrlDOF - Rotor-furl DOF (flag)
True	TFrlDOF - Tail-furl DOF (flag)

--------------------- INITIAL CONDITIONS (CONT) ------------------------------

0.0	RotFurl - Initial or fixed rotor-furl angle (degrees)
0.0	TailFurl - Initial or fixed tail-furl angle (degrees)

--------------------- TURBINE CONFIGURATION (CONT) ---------------------------

0.106	Yaw2Shft - Lateral distance from the yaw axis to the rotor shaft (meters)
0.0	ShftSkew - Rotor shaft skew angle (degrees)
0.0	RFrlCMxn - Downwind distance from the tower-top to the CM of the structure that furls with the rotor [not including rotor] (meters)
0.0	RFrlCMyn - Lateral distance from the tower-top to the CM of the structure that furls with the rotor [not including rotor] (meters)
0.0	RFrlCMzn - Vertical distance from the tower-top to the CM of the structure that furls with the rotor [not including rotor] (meters)
1.7667	BoomCMxn - Downwind distance from the tower-top to the tail boom CM (meters)
0.106	BoomCMyn - Lateral distance from the tower-top to the tail boom CM (meters)
0.2668	BoomCMzn - Vertical distance from the tower-top to the tail boom CM (meters)
0.0	TFinCMxn - Downwind distance from the tower-top to the tail fin CM (meters)
0.0	TFinCMyn - Lateral distance from the tower-top to the tail fin CM (meters)
0.0	TFinCMzn - Vertical distance from the tower-top to the tail fin CM (meters)
2.7674	TFinCPxn - Downwind distance from the tower-top to the tail fin center-of-pressure (m)
0.106	TFinCPyn - Lateral distance from the tower-top to the tail fin center-of-pressure (m)
0.1262	TFinCPzn - Vertical distance from the tower-top to the tail fin center-of-pressure (m)
0.0	TFinSkew - Tail fin chordline skew angle (degrees)
-8.0	TFinTilt - Tail fin chordline tilt angle (degrees)
8.0	TFinBank - Tail fin planform bank angle (degrees)
0.0	RFrlPntxn - Downwind distance from the tower-top to an arbitrary point on the rotor-furl axis (meters)
0.0	RFrlPntyn - Lateral distance from the tower-top to an arbitrary point on the rotor-furl axis (meters)
0.0	RFrlPntzn - Vertical distance from the tower-top to an arbitrary point on the rotor-furl axis (meters)
0.0	RFrlSkew - Rotor-furl axis skew angle (degrees)
0.0	RFrlTilt - Rotor-furl axis tilt angle (degrees)
0.318	TFrlPntxn - Downwind distance from the tower-top to an arbitrary point on the tail-furl axis (meters)
0.106	TFrlPntyn - Lateral distance from the tower-top to an arbitrary point on the tail-furl axis (meters)
0.470	TFrlPntzn - Vertical distance from the tower-top to an arbitrary point on the tail-furl axis (meters)
-45.2802	TFrlSkew - Tail-furl axis skew angle (degrees)
78.7047	TFrlTilt - Tail-furl axis tilt angle (degrees)

--------------------- MASS AND INERTIA (CONT) --------------------------------

0.0	RFrlMass - Mass of structure that furls with the rotor [not including rotor] (kg)
86.8	BoomMass - Tail boom mass (kg)
0.0	TFinMass - Tail fin mass (kg)
0.0	RFrlIner - Inertia of the structure that furls with the rotor about the rotor-furl axis (kg m^2) [not including rotor]
264.7	TFrlIner - Tail boom inertia about tail-furl axis (kg m^2)

--------------------- ROTOR-FURL --

0	RFrlMod - Rotor-furl spring/damper model {0: none, 1: standard, 2: user-defined from routine UserRFrl} (switch)
0.0	RFrlSpr - Rotor-furl spring constant (N-m/rad) [used only when RFrlMod=1]
0.0	RFrlDmp - Rotor-furl damping constant (N-m/(rad/s)) [used only when RFrlMod=1]
0.0	RFrlCDmp - Rotor-furl rate-independent Coulomb-damping moment (N-m) [used only when RFrlMod=1]
0.0	RFrlUSSP - Rotor-furl up-stop spring position (degrees) [used only when RFrlMod=1]
0.0	RFrlDSSP - Rotor-furl down-stop spring position (degrees) [used only when RFrlMod=1]
0.0	RFrlUSSpr - Rotor-furl up-stop spring constant (N-m/rad) [used only when RFrlMod=1]
0.0	RFrlDSSpr - Rotor-furl down-stop spring constant (N-m/rad) [used only when RFrlMod=1]
0.0	RFrlUSDP - Rotor-furl up-stop damper position (degrees) [used only when RFrlMod=1]
0.0	RFrlDSDP - Rotor-furl down-stop damper position (degrees) [used only when RFrlMod=1]
0.0	RFrlUSDmp - Rotor-furl up-stop damping constant (N-m/(rad/s)) [used only when RFrlMod=1]
0.0	RFrlDSDmp - Rotor-furl down-stop damping constant (N-m/(rad/s)) [used only when RFrlMod=1]

--------------------- TAIL-FURL ---

1	TFrlMod - Tail-furl spring/damper model {0: none, 1: standard, 2: user-defined from routine UserTFrl} (switch)
0.0	TFrlSpr - Tail-furl spring constant (N-m/rad) [used only when TFrlMod=1]
10.0	TFrlDmp - Tail-furl damping constant (N-m/(rad/s)) [used only when TFrlMod=1]
0.0	TFrlCDmp - Tail-furl rate-independent Coulomb-damping moment (N-m) [used only when TFrlMod=1]
85.0	TFrlUSSP - Tail-furl up-stop spring position (degrees) [used only when TFrlMod=1]
3.0	TFrlDSSP - Tail-furl down-stop spring position (degrees) [used only when TFrlMod=1]
1.0E3	TFrlUSSpr - Tail-furl up-stop spring constant (N-m/rad) [used only when TFrlMod=1]
1.7E4	TFrlDSSpr - Tail-furl down-stop spring constant (N-m/rad) [used only when TFrlMod=1]
85.0	TFrlUSDP - Tail-furl up-stop damper position (degrees) [used only when TFrlMod=1]
0.0	TFrlDSDP - Tail-furl down-stop damper position (degrees) [used only when TFrlMod=1]
1.0E3	TFrlUSDmp - Tail-furl up-stop damping constant (N-m/(rad/s)) [used only when TFrlMod=1]
137.0	TFrlDSDmp - Tail-furl down-stop damping constant (N-m/(rad/s)) [used only when TFrlMod=1]

--------------------- TAIL FIN AERODYNAMICS ----------------------------------

1	TFinMod - Tail fin aerodynamics model (0: none, 1: standard, 2: user-defined from routine UserTFin) (switch)
1	TFinNFoil - Tail fin airfoil number [1 to NumFoil] [used only when TFinMod=1]
1.017	TFinArea - Tail fin planform area (m^2) [used only when TFinMod=1]
True	SubAxInd - Subtract average rotor axial induction when computing relative wind-inflow at tail fin? (flag) [used only when TFinMod=1]

LINEARIZATION FILE

---------------------- FAST LINEARIZATION CONTROL FILE -------------------------	
SWRT linearization input properties.	
--------------------- PERIODIC STEADY STATE SOLUTION --------------------------	
True	CalcStdy - Calculate periodic steady state condition {False: linearize about initial conditions} (flag)
2	TrimCase - Trim case {1: find nacelle yaw, 2: find generator torque, 3: find collective blade pitch} (switch) [used only when CalcStdy=True and GenDOF=True]
0.0001	DispTol - Convergence tolerance for the 2-norm of displacements in the periodic steady state calculation (rad) [used only when CalcStdy=True]
0.0010	VelTol - Convergence tolerance for the 2-norm of velocities in the periodic steady state calculation (rad/s) [used only when CalcStdy=True]

---------------------- MODEL LINEARIZATION -------------------------------------

36	NAzimStep - Number of equally-spaced azimuth steps in periodic linearized model (-)
1	MdlOrder - Order of output linearized model {1: 1st order A, B, Bd, C, D, Dd; 2: 2nd order M, C, K, F, Fd, VelC, DspC, D, Dd} (switch)

--------------------- INPUTS AND DISTURBANCES --------------------------------

0	NInputs - Number of control inputs [0 (none) or 1 to 4+NumBl] (-)
	CntrlInpt - List of control inputs [1 to NInputs] {1: nacelle yaw angle, 2: nacelle yaw rate, 3: generator torque, 4: collective blade pitch, 5: individual pitch of blade 1, 6: individual pitch of blade 2, 7: individual pitch of blade 3 [unavailable for 2-bladed turbines]} (-) [unused if NInputs=0]
0	NDisturbs - Number of wind disturbances [0 (none) or 1 to 7] (-)
	Disturbnc - List of input wind disturbances [1 to NDisturbs] {1: horizontal hub-height wind speed, 2: horizontal wind direction, 3: vertical wind speed, 4: horizontal wind shear, 5: vertical power law wind shear, 6: linear vertical wind shear, 7: horizontal hub-height wind gust} (-) [unused if NDisturbs=0]

ADAMS FILE

---------------------- FAST 2 ADAMS PREPROCESSOR, ADAMS-SPECIFIC DATA FILE -----	
SWRT ADAMS-specific input properties.	

---------------------- FEATURE FLAGS --

False	SaveGrphcs - Save GRAPHICS output (flag)
False	MakeLINacf - Make an ADAMS/LINEAR control / command file (flag)

---------------------- DAMPING PARAMETERS -------------------------------------

0.01	CRatioTGJ - Ratio of damping to stiffness for the tower torsion deflection (-)
0.01	CRatioTEA - Ratio of damping to stiffness for the tower extensional deflection (-)
0.01	CRatioBGJ - Ratio of damping to stiffness for the blade torsion deflections (-)
0.01	CRatioBEA - Ratio of damping to stiffness for the blade extensional deflections (-)

--------------------- BLADE PITCH ACTUATOR PARAMETERS ------------------------

1.0E12	BPActrSpr - Blade pitch actuator spring stiffness constant (N-m/rad)
1.0E11	BPActrDmp - Blade pitch actuator damping constant (N-m/(rad/s))

--------------------- GRAPHICS PARAMETERS -----------------------------------

12	NSides - Number of sides used in GRAPHICS CYLINDER and FRUSTUM statements (-)
0.711	TwrBaseRad - Tower base radius used for linearly tapered tower GRAPHICS CYLINDERs (m)
0.17775	TwrTopRad - Tower top radius used for linearly tapered tower GRAPHICS CYLINDERs (m)
0.0	NacLength - Length of nacelle used for the nacelle GRAPHICS (m)
0.0	NacRadBot - Bottom (opposite rotor) radius of nacelle FRUSTUM used for the nacelle GRAPHICS (m)
0.0	NacRadTop - Top (rotor end) radius of nacelle FRUSTUM used for the

	nacelle GRAPHICS (m)
0.0	GBoxLength - Length, width, and height of the gearbox BOX for gearbox GRAPHICS (m)
0.0	GenLength - Length of the generator CYLINDER used for generator GRAPHICS (m)
0.69021	HSSLength - Length of the high-speed shaft CYLINDER used for HSS GRAPHICS (m) !NOTE: This is used to represent the yaw-to-generator connecting structure
0.3756	LSSLength - Length of the low-speed shaft CYLINDER used for LSS GRAPHICS (m) !NOTE: This is used to represent the hub and generator housing
0.0	GenRad - Radius of the generator CYLINDER used for generator GRAPHICS (m)
0.0583	HSSRad - Radius of the high-speed shaft CYLINDER used for HSS GRAPHICS (m) !NOTE: This is used to represent the yaw-to-generator connecting structure
0.2921	LSSRad - Radius of the low -speed shaft CYLINDER used for LSS GRAPHICS (m) !NOTE: This is used to represent the hub and generator housing
0.0	HubCylRad - Radius of hub CYLINDER used for hub GRAPHICS (m)
0.1	ThkOvrChrd - Ratio of blade thickness to blade chord used for blade element BOX GRAPHICS (-)
0.0375	BoomRad - Radius of the tail boom CYLINDER used for tail boom GRAPHICS (m)

Some files listed above have been used in the simulations of the two wind turbines, without any modification. This is the case of the Tower file, because both wind turbines are planned to be used in the same tower, or the Furling file due to the fact that the HP-600 tail’s structural properties were not available and these features are more similar to IT-PE-100 than to generic Test 17 (SWRT). ADAMS and Linearization files listed above are also the same for both wind turbines because they are not used in the simulation but they are a software requirement to run.

ANNEX B. IT-PE-100 TECHNICAL SPECIFICATIONS

Wind rotor

- Three blades aerodynamic NACA 4412 profile, made of fiberglass and resin.
- Rated speed of 420 rpm at a wind speed of 6.5 m / s.
- 1.70 m. of diameter
- Direct coupling with the generator.

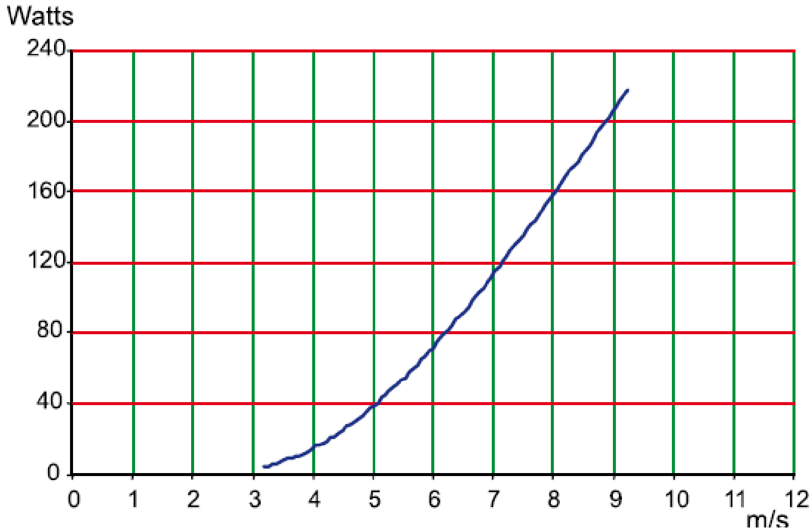

Fig B.1 Wind speed vs power

Generator

- Three-phase permanent magnet ferrite or neodymium.
- 12 Volt DC.
- Eight pairs of poles, double star connection.
- Rated power of 330 W.
- Rated speed of 420 rpm.
- Efficiency: 70%.

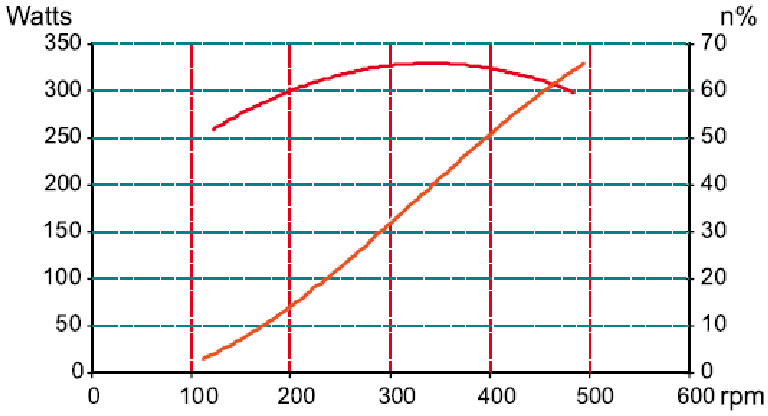

Fig B.2 RPM vs power

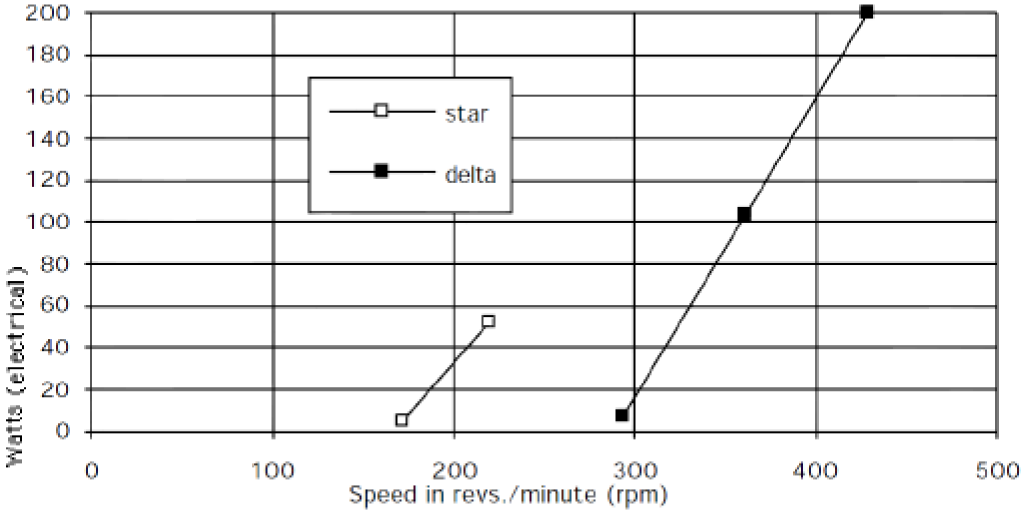

Fig B.3 Different IT-PE-100 configurations

To use the same PMG for both low and high speeds, it is possible to change the connections. There are two ways to connect the stator wires to the rectifier. They can be connected 'star' or 'delta'. See Section 7 for a detailed description of the star and delta connections. See diagram 3 for the graph of power vs. speed. Star begins to work at low speed (170 rpm). Delta gives more power, but only at higher speed. Star is good in very low windspeeds, and delta is better in higher winds. A bigger version of this PMG would be able to give higher power at lower speed.

ANNEX C. HP-600 INPUT FILES

FAST PRIMARY INPUT FILE HP600

------- FAST INPUT FILE ---
FAST certification Test #17: FAST model of a SWRT 3-bladed upwind turbine. Note- SWRT rotates in CCW direction- some inputs will be mirror image of the actual turbine.
Model properties from "SWRTv1p2.adm" and SWRT "AdamsWT_MakeBladeDat_v12.xls". JEM Jan., 2004. Updated by J. Jonkman, NREL, Feb, 2004. Compatible with FAST v7.00.00.

--------------------- SIMULATION CONTROL -------------------------------------

False	Echo - Echo input data to "echo.out" (flag)
1	ADAMSPrep - ADAMS preprocessor mode {1: Run FAST, 2: use FAST as a preprocessor to create an ADAMS model, 3: do both} (switch)
1	AnalMode - Analysis mode {1: Run a time-marching simulation, 2: create a periodic linearized model} (switch)
3	NumBl - Number of blades (-)
20.0	TMax - Total run time (s)
0.0001	DT - Integration time step (s)

--------------------- TURBINE CONTROL ---------------------------------------

0	YCMode - Yaw control mode {0: none, 1: user-defined from routine UserYawCont, 2: user-defined from Simulink} (switch)
9999.9	TYCOn - Time to enable active yaw control (s) [unused when YCMode=0]
0	PCMode - Pitch control mode {0: none, 1: user-defined from routine PitchCntrl, 2: user-defined from Simulink} (switch)
9999.9	TPCOn - Time to enable active pitch control (s) [unused when PCMode=0]
2	VSContrl - Variable-speed control mode {0: none, 1: simple VS, 2: user-defined from routine UserVSCont, 3: user-defined from Simulink} (switch)
9999.9	VS_RtGnSp - Rated generator speed for simple variable-speed generator control (HSS side) (rpm) [used only when VSContrl=1]
9999.9	VS_RtTq - Rated generator torque/constant generator torque in Region 3 for simple variable-speed generator control (HSS side) (N-m) [used only when VSContrl=1]
9999.9	VS_Rgn2K - Generator torque constant in Region 2 for simple variable-speed generator control (HSS side) (N-m/rpm^2) [used only when VSContrl=1]
9999.9	VS_SlPc - Rated generator slip percentage in Region 2 1/2 for simple variable-speed generator control (%) [used only when VSContrl=1]
1	GenModel - Generator model {1: simple, 2: Thevenin, 3: user-defined from routine UserGen} (switch) [used only when VSContrl=0]
True	GenTiStr - Method to start the generator {T: timed using TimGenOn, F: generator speed using SpdGenOn} (flag)
True	GenTiStp - Method to stop the generator {T: timed using TimGenOf, F: when generator power = 0} (flag)
9999.9	SpdGenOn - Generator speed to turn on the generator for a startup (HSS speed) (rpm) [used only when GenTiStr=False]
0.0	TimGenOn - Time to turn on the generator for a startup (s) [used only when GenTiStr=True]
9999.9	TimGenOf - Time to turn off the generator (s) [used only when GenTiStp=True]
1	HSSBrMode - HSS brake model {1: simple, 2: user-defined from routine UserHSSBr} (switch)
9999.9	THSSBrDp - Time to initiate deployment of the HSS brake (s)
9999.9	TiDynBrk - Time to initiate deployment of the dynamic generator brake [CURRENTLY IGNORED] (s)
9999.9	TTpBrDp(1) - Time to initiate deployment of tip brake 1 (s)

9999.9	TTpBrDp(2) - Time to initiate deployment of tip brake 2 (s)
9999.9	TTpBrDp(3) - Time to initiate deployment of tip brake 3 (s) [unused for 2 blades]
9999.9	TBDepISp(1) - Deployment-initiation speed for the tip brake on blade 1 (rpm)
9999.9	TBDepISp(2) - Deployment-initiation speed for the tip brake on blade 2 (rpm)
9999.9	TBDepISp(3) - Deployment-initiation speed for the tip brake on blade 3 (rpm) [unused for 2 blades]
9999.9	TYawManS - Time to start override yaw maneuver and end standard yaw control (s)
9999.9	TYawManE - Time at which override yaw maneuver reaches final yaw angle (s)
0.0	NacYawF - Final yaw angle for yaw maneuvers (degrees)
9999.9	TPitManS(1) - Time to start override pitch maneuver for blade 1 and end standard pitch control (s)
9999.9	TPitManS(2) - Time to start override pitch maneuver for blade 2 and end standard pitch control (s)
9999.9	TPitManS(3) - Time to start override pitch maneuver for blade 3 and end standard pitch control (s) [unused for 2 blades]
9999.9	TPitManE(1) - Time at which override pitch maneuver for blade 1 reaches final pitch (s)
9999.9	TPitManE(2) - Time at which override pitch maneuver for blade 2 reaches final pitch (s)
9999.9	TPitManE(3) - Time at which override pitch maneuver for blade 3 reaches final pitch (s) [unused for 2 blades]
0.0	BlPitch(1) - Blade 1 initial pitch (degrees)
0.0	BlPitch(2) - Blade 2 initial pitch (degrees)
0.0	BlPitch(3) - Blade 3 initial pitch (degrees) [unused for 2 blades]
0.0	BlPitchF(1) - Blade 1 final pitch for pitch maneuvers (degrees)
0.0	BlPitchF(2) - Blade 2 final pitch for pitch maneuvers (degrees)
0.0	BlPitchF(3) - Blade 3 final pitch for pitch maneuvers (degrees) [unused for 2 blades]

---------------------- ENVIRONMENTAL CONDITIONS -------------------------------

9.81	Gravity - Gravitational acceleration (m/s^2)

---------------------- FEATURE FLAGS ---

True	FlapDOF1 - First flapwise blade mode DOF (flag)
True	FlapDOF2 - Second flapwise blade mode DOF (flag)
True	EdgeDOF - First edgewise blade mode DOF (flag)
False	TeetDOF - Rotor-teeter DOF (flag) [unused for 3 blades]
False	DrTrDOF - Drivetrain rotational-flexibility DOF (flag)
True	GenDOF - Generator DOF (flag)
false	YawDOF - Yaw DOF (flag)
True	TwFADOF1 - First fore-aft tower bending-mode DOF (flag)
True	TwFADOF2 - Second fore-aft tower bending-mode DOF (flag)
True	TwSSDOF1 - First side-to-side tower bending-mode DOF (flag)
True	TwSSDOF2 - Second side-to-side tower bending-mode DOF (flag)
True	CompAero - Compute aerodynamic forces (flag)
False	CompNoise - Compute aerodynamic noise (flag)

---------------------- INITIAL CONDITIONS --------------------------------------

0.0	OoPDefl - Initial out-of-plane blade-tip displacement (meters)
0.0	IPDefl - Initial in-plane blade-tip deflection (meters)
0.0	TeetDefl - Initial or fixed teeter angle (degrees) [unused for 3 blades]
0.0	Azimuth - Initial azimuth angle for blade 1 (degrees)
230	RotSpeed - Initial or fixed rotor speed (rpm)
0.0	NacYaw - Initial or fixed nacelle-yaw angle (degrees)
0.0	TTDspFA - Initial fore-aft tower-top displacement (meters)
0.0	TTDspSS - Initial side-to-side tower-top displacement (meters)

---------------------- TURBINE CONFIGURATION ----------------------------------

0.75	TipRad - The distance from the rotor apex to the blade tip (meters)
0.18	HubRad - The distance from the rotor apex to the blade root (meters)
1	PSpnElN - Number of the innermost blade element which is still part of the pitchable portion of the blade for partial-span pitch control [1 to BldNodes]

	[CURRENTLY IGNORED] (-)
0.0	UndSling - Undersling length [distance from teeter pin to the rotor apex] (meters) [unused for 3 blades]
0.1324	HubCM - Distance from rotor apex to hub mass [positive downwind] (meters)
- 0.170	OverHang - Distance from yaw axis to rotor apex [3 blades] or teeter pin [2 blades] (meters)
0.183	NacCMxn - Downwind distance from the tower-top to the nacelle CM (meters)
0.0	NacCMyn - Lateral distance from the tower-top to the nacelle CM (meters)
0.0405	NacCMzn - Vertical distance from the tower-top to the nacelle CM (meters)
10.0	TowerHt - Height of tower above ground level [onshore] or MSL [offshore] (meters)
0.155	Twr2Shft - Vertical distance from the tower-top to the rotor shaft (meters)
0.0	TwrRBHt - Tower rigid base height (meters)
0.0	ShftTilt - Rotor shaft tilt angle (degrees). Negative for an upwind rotor.
0.0	Delta3 - Delta-3 angle for teetering rotors (degrees) [unused for 3 blades]
5.5	PreCone(1) - Blade 1 cone angle (degrees)
5.5	PreCone(2) - Blade 2 cone angle (degrees)
5.5	PreCone(3) - Blade 3 cone angle (degrees) [unused for 2 blades]
0.0	AzimB1Up - Azimuth value to use for I/O when blade 1 points up (degrees)

--------------------- MASS AND INERTIA ---------------------------------------

0.0	YawBrMass - Yaw bearing mass (kg)
1.49	NacMass - Nacelle mass (kg)
0.46	HubMass - Hub mass (kg)
0.0	TipMass(1) - Tip-brake mass, blade 1 (kg)
0.0	TipMass(2) - Tip-brake mass, blade 2 (kg)
0.0	TipMass(3) - Tip-brake mass, blade 3 (kg) [unused for 2 blades]
0.05	NacYIner - Nacelle inertia about yaw axis (kg m^2)
0.0	GenIner - Generator inertia about HSS (kg m^2)
0.0	HubIner - Hub inertia about rotor axis [3 blades] or teeter axis [2 blades] (kg m^2)

--------------------- DRIVETRAIN ---

100.0	GBoxEff - Gearbox efficiency (%)
70.0	GenEff - Generator efficiency [ignored by the Thevenin and user-defined generator models] (%)
1.0	GBRatio - Gearbox ratio (-)
False	GBRevers - Gearbox reversal {T: if rotor and generator rotate in opposite directions} (flag)
9999.9	HSSBrTqF - Fully deployed HSS-brake torque (N-m)
9999.9	HSSBrDT - Time for HSS-brake to reach full deployment once initiated (sec) [used only when HSSBrMode=1]
""	DynBrkFi - File containing a mech-gen-torque vs HSS-speed curve for a dynamic brake [CURRENTLY IGNORED] (quoted string)
9999.9	DTTorSpr - Drivetrain torsional spring (N-m/rad)
9999.9	DTTorDmp - Drivetrain torsional damper (N-m/(rad/s))

--------------------- SIMPLE INDUCTION GENERATOR -----------------------------

9999.9	SIG_SlPc - Rated generator slip percentage (%) [used only when VSContrl=0 and GenModel=1]
9999.9	SIG_SySp - Synchronous (zero-torque) generator speed (rpm) [used only when VSContrl=0 and GenModel=1]
9999.9	SIG_RtTq - Rated torque (N-m) [used only when VSContrl=0 and GenModel=1]
9999.9	SIG_PORt - Pull-out ratio (Tpullout/Trated) (-) [used only when VSContrl=0 and GenModel=1]

--------------------- THEVENIN-EQUIVALENT INDUCTION GENERATOR -----------------

9999.9	TEC_Freq - Line frequency [50 or 60] (Hz) [used only when VSContrl=0 and GenModel=2]
9998	TEC_NPol - Number of poles [even integer > 0] (-) [used only when VSContrl=0 and

	GenModel=2]
9999.9	TEC_SRes - Stator resistance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9	TEC_RRes - Rotor resistance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9	TEC_VLL - Line-to-line RMS voltage (volts) [used only when VSContrl=0 and GenModel=2]
9999.9	TEC_SLR - Stator leakage reactance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9	TEC_RLR - Rotor leakage reactance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9	TEC_MR - Magnetizing reactance (ohms) [used only when VSContrl=0 and GenModel=2]

---------------------- PLATFORM ---

0	PtfmModel - Platform model {0: none, 1: onshore, 2: fixed bottom offshore, 3: floating offshore} (switch)
""	PtfmFile - Name of file containing platform properties (quoted string) [unused when PtfmModel=0]

---------------------- TOWER --

10	TwrNodes - Number of tower nodes used for analysis (-)
"SWRT_Tower.dat"	TwrFile - Name of file containing tower properties (quoted string)

---------------------- NACELLE-YAW --

0.0	YawSpr - Nacelle-yaw spring constant (N-m/rad)
0.0	YawDamp - Nacelle-yaw damping constant (N-m/(rad/s))
0.0	YawNeut - Neutral yaw position--yaw spring force is zero at this yaw (degrees)

---------------------- FURLING --

True	Furling - Read in additional model properties for furling turbine (flag)
"SWRT_Furl.dat"	FurlFile - Name of file containing furling properties (quoted string) [unused when Furling=False]

---------------------- ROTOR-TEETER ---

0	TeetMod - Rotor-teeter spring/damper model {0: none, 1: standard, 2: user-defined from routine UserTeet} (switch) [unused for 3 blades]
0.0	TeetDmpP - Rotor-teeter damper position (degrees) [used only for 2 blades and when TeetMod=1]
0.0	TeetDmp - Rotor-teeter damping constant (N-m/(rad/s)) [used only for 2 blades and when TeetMod=1]
0.0	TeetCDmp - Rotor-teeter rate-independent Coulomb-damping moment (N-m) [used only for 2 blades and when TeetMod=1]
0.0	TeetSStP - Rotor-teeter soft-stop position (degrees) [used only for 2 blades and when TeetMod=1]
0.0	TeetHStP - Rotor-teeter hard-stop position (degrees) [used only for 2 blades and when TeetMod=1]
0.0	TeetSSSp - Rotor-teeter soft-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]
0.0	TeetHSSp - Rotor-teeter hard-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]

---------------------- TIP-BRAKE --

0.0	TBDrConN - Tip-brake drag constant during normal operation, Cd*Area (m^2)
0.0	TBDrConD - Tip-brake drag constant during fully-deployed operation, Cd*Area (m^2)
0.0	TpBrDT - Time for tip-brake to reach full deployment once released (sec)

---------------------- BLADE --

"SWRT_Blade_H600.dat"	BldFile(1) - Name of file containing properties for blade 1 (quoted string)
"SWRT_Blade_H600.dat"	BldFile(2) - Name of file containing properties for blade 2 (quoted string)
"SWRT_Blade_H600.dat"	BldFile(3) - Name of file containing properties for blade 3 (quoted string) [unused for 2 blades]

--------------------- AERODYN --

"Test17_AD_H600.ipt"	ADFile - Name of file containing AeroDyn input parameters (quoted string)

--------------------- NOISE --

""	NoiseFile - Name of file containing aerodynamic noise input parameters (quoted string) [used only when CompNoise=True]

--------------------- ADAMS --

"SWRT_ADAMS.dat"	ADAMSFile - Name of file containing ADAMS-specific input parameters (quoted string) [unused when ADAMSPrep=1]

--------------------- LINEARIZATION CONTROL ---------------------------------

"SWRT_Linear.dat"	LinFile - Name of file containing FAST linearization parameters (quoted string) [unused when AnalMode=1]

--------------------- OUTPUT ---

True	SumPrint - Print summary data to "<RootName>.fsm" (flag)
True	TabDelim - Generate a tab-delimited tabular output file. (flag)
"ES10.3E2"	OutFmt - Format used for tabular output except time. Resulting field should be 10 characters. (quoted string) [not checked for validity!]
10.0	TStart - Time to begin tabular output (s)
8	DecFact - Decimation factor for tabular output {1: output every time step} (-)
1.0	SttsTime - Amount of time between screen status messages (sec)
0.0	NcIMUxn - Downwind distance from the tower-top to the nacelle IMU (meters)
0.0	NcIMUyn - Lateral distance from the tower-top to the nacelle IMU (meters)
0.0	NcIMUzn - Vertical distance from the tower-top to the nacelle IMU (meters)
0.1	ShftGagL - Distance from rotor apex [3 blades] or teeter pin [2 blades] to shaft strain gages [positive for upwind rotors] (meters)
0	NTwGages - Number of tower nodes that have strain gages for output [0 to 9] (-)
0	TwrGagNd - List of tower nodes that have strain gages [1 to TwrNodes] (-) [unused if NTwGages=0]
0	NBlGages - Number of blade nodes that have strain gages for output [0 to 9] (-)
0	BldGagNd - List of blade nodes that have strain gages [1 to BldNodes] (-) [unused if NBlGages=0]

OutList - The next line(s) contains a list of output parameters. See OutList.txt for a listing of available output channels, (-)
"TotWindV, HorWindV, HorWndDir"
"LSSGagVxa, TipSpdRat"
"LSShftFxa, LSShftMxa, HSShftV, RotCq, RotCt, RotCp, RotPwr"
"GenPwr, GenCp"
END of FAST input file (the word "END" must appear in the first 3 columns of this last line).

AERODYN PRIMARY FILE HP600

SWRT rotor aerodynamic parameters for FAST certification test #17.	
SI	SysUnits - System of units for used for input and output [must be SI for FAST] (unquoted string)
BEDDOES	StallMod - Dynamic stall included [BEDDOES or STEADY] (unquoted string)
NO_CM	UseCm - Use aerodynamic pitching moment model? [USE_CM or NO_CM] (unquoted string)
DYNIN	InfModel - Inflow model [DYNIN or EQUIL] (unquoted string)
SWIRL	IndModel - Induction-factor model [NONE or WAKE or SWIRL] (unquoted string)
0.005	AToler - Induction-factor tolerance (convergence criteria) (-)
PRANDtl	TLModel - Tip-loss model (EQUIL only) [PRANDtl, GTECH, or NONE] (unquoted string)
NONE	HLModel - Hub-loss model (EQUIL only) [PRANdtl or NONE] (unquoted string)
"MEANMAXSPEED744.wnd"	WindFile - Name of file containing wind data (quoted string)
10	HH - Wind reference (hub) height [TowerHt+Twr2Shft+OverHang*SIN(ShftTilt)] (m)

0.0	TwrShad - Tower-shadow velocity deficit (-)
9999.9	ShadHWid - Tower-shadow half width (m)
9999.9	T_Shad_Refpt - Tower-shadow reference point (m)
1.225	AirDens - Air density (kg/m^3)
1.47E-05	KinVisc - Kinematic air viscosity (m^2/sec)
1.0000E-03	DTAero - Time interval for aerodynamic calculations (sec)
2	NumFoil - Number of airfoil files (-)
"perfil7.dat"	FoilNm - Names of the airfoil files [NumFoil lines] (quoted strings)
"perfil13.dat"	FoilNm - Names of the airfoil files [NumFoil lines] (quoted strings)
19	BldNodes - Number of blade nodes used for analysis (-)
RNodes AeroTwst DRNodes Chord NFoil PrnElm	
0.195 27.87 0.03 0.1694 1 NOPRINT	
0.225 26.56 0.03 0.1819 1 NOPRINT	
0.255 23.36 0.03 0.1737 1 NOPRINT	
0.285 18.70 0.03 0.1539 1 NOPRINT	
0.315 15.27 0.03 0.1371 1 NOPRINT	
0.345 12.73 0.03 0.1243 1 NOPRINT	
0.375 11.30 0.03 0.1147 2 NOPRINT	
0.405 10.64 0.03 0.1063 2 NOPRINT	
0.435 9.59 0.03 0.0988 2 NOPRINT	
0.465 8.71 0.03 0.0923 2 NOPRINT	
0.495 7.52 0.03 0.0861 2 NOPRINT	
0.525 6.99 0.03 0.0811 2 NOPRINT	
0.555 6.46 0.03 0.0765 2 NOPRINT	
0.585 5.78 0.03 0.0726 2 NOPRINT	
0.615 5.54 0.03 0.0688 2 NOPRINT	
0.645 4.95 0.03 0.0656 2 NOPRINT	
0.675 4.71 0.03 0.0634 2 NOPRINT	
0.705 4.63 0.03 0.0612 2 NOPRINT	
0.735 4.22 0.03 0.0587 2 NOPRINT	
ReNum	

AIRFOIL FILE HP600 ST13

AeroDyn airfoil file. Compatible with AeroDyn v13.0.		
Perfil st13, Re=.073 Million. El perfil del H600		
1	Number of airfoil tables in this file	
0.073	Table ID parameter (Reynolds number in milllions). For efficiency, make very large if only one table.	
0.0		
0.0		
0.0		
0.0		
0.678	Zero Cn angle of attack (deg)	
3.831	Cn slope for zero lift (dimensionless)	
1.292	Cn extrapolated to value at positive stall angle of attack	
-0.75	Cn at stall value for negative angle of attack	
-4	Angle of attack for minimum CD (deg)	
0,0108	Minimum CD value	
-180	0.0000	0.0000
-170	0.3555	0.0627
-160	0.7109	0.2588
-150	0.6354	0.3669
-140	0.5934	0.4979
-130	0.5325	0.6346
-120	0.4380	0.7587
-110	0.3105	0.8531

-100	0.1594	0.9041
-90	0.0000	0.9030
-80	-0.1594	0.9041
-70	-0.3105	0.8531
-60	-0.4380	0.7587
-50	-0.5325	0.6346
-40	-0.5934	0.4979
-30	-0.6354	0.3669
-20	-0.7109	0.2588
-10	-0.3497	0.1058
-8	-0.1954	0.1035
-6	-0.2441	0.0635
-4	-0.3111	0.0110
-2	-0.1976	0.0117
0	-0.0315	0.0157
2	0.1164	0.0176
4	0.1974	0.0215
6	0.3498	0.0168
8	0.4217	0.0144
10	0.4811	0.0108
12	0.5732	0.0256
14	0.6750	0.0302
16	0.8733	0.0586
18	0.8757	0.0437
20	1.0156	0.3696
30	0.9078	0.5241
40	0.8477	0.7113
50	0.7608	0.9066
60	0.6258	1.0839
70	0.4436	1.2187
80	0.2277	1.2915
90	0.0000	1.2900
100	-0.1594	1.0800
110	-0.3105	0.8531
120	-0.4380	0.7587
130	-0.5325	0.6346
140	-0.5934	0.4979
150	-0.6354	0.3669
160	-0.7109	0.2588
170	-0.3555	0.0627
180	0.0000	0.0000

AIRFOIL FILE HP600 ST7

AeroDyn airfoil file. Compatible with AeroDyn v13.0.	
Perfil st7, Re=.075 Million. El perfil del H600	
1	Number of airfoil tables in this file
0.075	Table ID parameter (Reynolds number in milllions). For efficiency, make very large if only one table.
0.0	
0.0	
0.0	
0.0	
-0.648	Zero Cn angle of attack (deg)
3.325	Cn slope for zero lift (dimensionless)
1.198	Cn extrapolated to value at positive stall angle of attack
-0.914	Cn at stall value for negative angle of attack

-2.00	Angle of attack for minimum CD (deg)	
0.01	Minimum CD value	
-180	0.0000	0.0000
-170	0.4293	0.0757
-160	0.8586	0.3125
-150	0.7212	0.4164
-140	0.6456	0.5417
-130	0.5634	0.6714
-120	0.4546	0.7873
-110	0.3176	0.8727
-100	0.1612	0.9140
-90	0.0000	0.9030
-80	-0.1612	0.9140
-70	-0.3176	0.8727
-60	-0.4546	0.7873
-50	-0.5634	0.6714
-40	-0.6456	0.5417
-30	-0.7212	0.4164
-20	-0.8586	0.3125
-10	-0.5768	0.1963
-8	-0.4576	0.1683
-6	-0.3312	0.1107
-4	-0.2015	0.0302
-2	-0.0735	0.0100
0	0.0340	0.0216
2	0.1465	0.0229
4	0.2745	0.0200
6	0.3908	0.0171
8	0.5149	0.0200
10	0.6368	0.0353
12	0.7588	0.0582
14	0.8753	0.0747
16	0.9991	0.1082
18	1.1090	0.1039
20	1.2265	0.4464
30	1.0303	0.5949
40	0.9223	0.7739
50	0.8048	0.9591
60	0.6494	1.1247
70	0.4537	1.2467
80	0.2302	1.3057
90	0.0000	1.2900
100	-0.1612	1.0800
110	-0.3176	0.8727
120	-0.4546	0.7873
130	-0.5634	0.6714
140	-0.6456	0.5417
150	-0.7212	0.4164
160	-0.8586	0.3125
170	-0.4293	0.0757
180	0.0000	0.0000

SPEED VS TORQUE HP600

RPM and Torque (Nm) for H600	
0	0
10	0
20	0
30	0
40	0
50	0
60	0
70	0
80	0
90	0
100	0
110	0
120	0
130	0
140	0
150	0
160	0
170	0
180	0
190	0
200	0
210	0
220	0
230	0
240	0.227442437
250	0.454884873
260	0.68232731
270	0.909769746
280	1.12638159
290	1.342993434
300	1.559605278
310	1.776217123
320	1.992828967
330	2.209440811
340	2.426052655
350	2.442900243
360	2.459747831
370	2.476595419
380	2.493443006
390	2.510290594
400	2.527138182
410	2.785009425
420	3.042880668
430	3.300751911
440	3.558623155
450	3.816494398
460	4.074365641
470	4.332236884
480	4.435385381
490	4.538533879
500	4.641682376
510	4.744830873
520	4.84797937
530	4.951127868
540	5.054276365

550	5.294956192
560	5.535636019
570	5.776315846
580	6.016995672
590	6.257675499
600	6.498355326
610	6.739035153
620	6.963669658
630	7.188304163
640	7.412938668
650	7.637573173
660	7.862207678
670	8.086842183
680	8.323146013
690	8.559449843
700	8.795753673
710	9.032057504
720	9.268361334
730	9.504665164
740	9.740968994
750	9.913820869
760	10.08667274
770	10.25952462
780	10.43237649
790	10.60522837
800	10.77808024
810	10.95093212
820	10.91643943
830	10.88194673
840	10.84745404
850	10.81296134
860	10.77846865
870	10.83081852
880	10.8831684
890	10.93551827
900	10.98786814
910	10.93829643
920	11.13677857
930	10.80132957
940	0