Interface for the Modeling and Simulation of a Airfoil of Turbine of Wind

Ricardo Alvarez Cervera, Raúl Lesso Arroyo, Ramón Rodríguez Castro
Instituto Tecnológico de Celaya, Tel. 52-461-611 75 75, Ext. 207, Fax. 52-461-611 79 79, Celaya, Gto, México, e-mail: rless@itc.mx, ramonr@itc.mx

Victor Lopez Garza
Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Mich, México, Tel. 01 (443) 3 16 72 07, e-mail: nepesh@hotmail.com

Abstract
This paper shows software that makes the aerodynamic design of blades of a wind turbine. This software acts like interface using a program of simulation by finite element (ANSYS), which makes the aerodynamic airfoil analysis, applying the conditions of border and displaying the results in a stage of the post processing of the simulator. The interface also models the wind turbine blade, in order to make a 3D analysis to simulate the behaviour of the blade, to obtain: fluid-structural analysis, modal simulation and fluids analysis. The software considerably reduces the time destined to the aerodynamic design, modelled and airfoil analysis of blades. In addition it offers the opportunity to choose among a series of airfoils profiles that are commonly used in the design of blades of wind turbines. The obtained results were validated using numerical analysis; which showed satisfactory results. Software besides to be designed of tutorial form has a structure opened for future analysis of the structural type or fluids.

Fig 1. Wind turbine blade

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>Air density .</td>
</tr>
<tr>
<td>$A$</td>
<td>Sweep area of wind turbine.</td>
</tr>
<tr>
<td>$V$</td>
<td>Wind speed</td>
</tr>
<tr>
<td>$U$</td>
<td>Tangential velocity.</td>
</tr>
<tr>
<td>$W$</td>
<td>Relative velocity.</td>
</tr>
<tr>
<td>$L$</td>
<td>Lift.</td>
</tr>
<tr>
<td>$D$</td>
<td>Drag .</td>
</tr>
<tr>
<td>$C_l$</td>
<td>Lift coefficient.</td>
</tr>
<tr>
<td>$C_d$</td>
<td>Drag coefficient</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Speed ratio.</td>
</tr>
<tr>
<td>$P_0$</td>
<td>Power of free air stream</td>
</tr>
<tr>
<td>$P_{\text{max}}$</td>
<td>Maximum Power.</td>
</tr>
<tr>
<td>$R$</td>
<td>Outer Blade radius</td>
</tr>
<tr>
<td>$F_l$</td>
<td>Lift Force</td>
</tr>
<tr>
<td>$F_D$</td>
<td>Drag Force</td>
</tr>
<tr>
<td>$c$</td>
<td>Airfoil chord</td>
</tr>
<tr>
<td>$B$</td>
<td>Number of blades</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Angle of attack.</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Pitch angle.</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Angle of relative velocity.</td>
</tr>
<tr>
<td>$C_p$</td>
<td>Power coefficient</td>
</tr>
<tr>
<td>$r$</td>
<td>Wind turbine radius</td>
</tr>
<tr>
<td>$\eta_{\text{mech}}$</td>
<td>Mechanical efficient</td>
</tr>
<tr>
<td>$\eta_{\text{elec}}$</td>
<td>Electrical coefficient</td>
</tr>
</tbody>
</table>
Introduction

Wind is air in motion. It is produced by the uneven heating of the earth’s surface by the sun. Since the earth’s surface is made of various land and water formations, it absorbs the sun’s radiation unevenly. When the sun is shining during the day, the air over landmasses heats more quickly than the air over water. The warm air over the land expands and rises, and the heavier, cooler air over water moves in to take its place, creating local winds. At night, the winds are reversed because the air cools more rapidly over land than over water. Similarly, the large atmospheric winds that circle the earth are created because the surface air near the equator is warmed more by the sun than the air over the North and South Poles. Wind is called a renewable energy source because wind will continually be produced as long as the sun shines on the earth. [12].

In the 1970s, oil shortages pushed the development of alternative energy sources. In the 1990s, the push came from a renewed concern for the environment in response to scientific studies indicating potential changes to the global climate if the use of fossil fuels continues to increase. Wind energy offers a viable, economical alternative to conventional power plants in many areas of the country. Wind is a clean fuel; wind farms produce no air or water pollution because no fuel is burned [12].

The most serious environmental drawbacks to wind machines may be their negative effect on wild bird populations and the visual impact on the landscape. To some, the glistening blades of windmills on the horizon are an eyesore; to others, they’re a beautiful alternative to conventional power plants. Recent technology advances have reduced risk to migratory birds by increasing the size and visibility of the blades, slowing the speed of rotation and using tubular towers with internal ladders and underground wiring to eliminate roosting and nesting sites on the structure itself [12].

The main interesting we have about wind energy at present, is the electricity production in order to substitute the expensive fossil fuels. To produce electric energy using the wind it is required an Aeolian-Generator, which is supported with the same principles of windmills. It is consisted by a wind turbine basically composed by blades, a cube or base and the electric generator.
Wind Energy

In a practical point of view we are interested in taking advantage of wind energy. The energetic contained in wind depends on the density and air velocity. The density, as any other gas, changes in agreement to the temperature and pressure which varies with the high level of the sea. The energy of a mass of air which displaces is determined by the cube law [6]:

\[ P_0 = \frac{1}{2} \rho A V^3 \]  

(1)

The conversion mechanism of energy in wind turbines is achieved by the deceleration of free wind stream. This phenomenon happens by the next way; the wind deceleration forehead the wind turbine increase of static pressure, once the wind cross the wind turbine, the static pressure drops into a lower pressure than the atmospheric pressure. As the air follows its trajectory, it takes its atmospheric value again, inducing an extra wind deceleration. By this way, in a distance between up stream water (forehead the turbine) and down stream water (behind the turbine), faraway the generated wake, there is no changes in static pressure, but there is a reduction in kinetics energy. To study this conversion it is considered the Betz law, who formulated the global theory for an horizontal axis aeolian-machine, and it is defined by [8]:

\[ P_{Max} = \frac{8}{27} \rho A V^3 \]  

(2)

Aerodynamics of Wind Turbines

The wind turbine power depends on the interaction between the rotor and the wind. The mission of the rotor in a wind turbine is transforming the kinetic energy of wind in mechanical energy. The rotor airfoils have a certain shape on its cross section which permits taking advantage of at maximum the wind energy. These shapes are named airfoils. There are a lot of airfoil families that have been developed thanks to analytic and experimental works, through which it is obtained the better aerodynamics performance. Most of this analytic and experimental work has been reached by the National Advisory Committee for Aeronautics (NACA) who is the predecessor of the National Aeronautics and Space Administration (NASA) [5].

A wind turbine blade is composed by many of airfoils a long its cross section in order to give it an optimum aerodynamic behavior. The figure 2 shows the axial distribution of airfoils in a wind turbine blades [7].

[Image: Fig2. Airfoil distribution in a wind turbine blade]
Properties developed by an airfoil during the wind turbine rotation are shown in figure 3, where: $\Omega$ angular speed, $W$ relative speed, $U$ wind speed, $\phi$ angle of relative wind, $\alpha$ angle of attack and $\beta$ pitch angle [2].

![Fig3. Speed performance in an airfoil of wind turbine blade.]

**Blades design**

To start the blade design is necessary to section all along its wingspread (Figure 2) to specify in each sectioned point the airfoils cord longitude and the pitch angle $\beta$, this angle is formed by the rotation plane and the airfoils cord [5].

**Speed ratio.** This design parameter is chosen by the designer and it represent a relation between the tangential velocity and the wind velocity [2].

$$\lambda = \frac{U}{V}$$

**Fundamental blade theory.** The acting forces over the blade can be determined by figure 4:

![Fig4. Result aerodynamic force and its components]

$$L^2 + D^2 = F^2$$

that can be represented by:

$$C_L^2 + C_D^2 = C_F^2$$

$C_L$ and $C_D$ are calculated by:

$$C_L = \frac{F_L}{\frac{1}{2} \rho V^2 A} \quad C_D = \frac{F_D}{\frac{1}{2} \rho V^2 A}$$
In the design process, the angle of attack $\alpha$ is a very important parameter to have in mind, it directly controls the airfoil lift and the drag. As low $C_D$ more efficient is the blade. The angle of attack is defined by the angle of relative wind $\phi$ and the section pitch angle. From figure 3, the angle of attack is defined by [2]:

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

The angle $\phi$ is defined by:

$$\phi = \tan^{-1}\left(\frac{2R}{3\lambda R}\right)$$

The calculus of the cord in each point of the sectioned blade is defined by the next expression [2]:

$$C_i \lambda = \frac{16}{9} \frac{R}{\lambda} \sqrt{\frac{2}{R^2 \lambda^2 + \frac{4}{9}}}$$

The theoretical calculus of power coefficient is obtained using the Wilson Linssman empiric equation; which involves the number of wind turbine blades and the airfoil real properties. The expressions establish [5]:

$$C_p = 0.593 \frac{\lambda^{0.85} - 1.92 \lambda^3 B \left( \frac{D}{L} \right)}{\psi + 2 \lambda B \left( \frac{D}{L} \right)}$$

$$\psi = 1.48 + \left( B^{0.85} - 0.004 \right) \lambda + 0.0025 \lambda^2$$

Finally the power delivered is in function of mechanical and electrical efficiency and it is calculated by [2]:

$$P = \frac{1}{2} \eta_m \eta_e C_p \lambda \rho AV^3$$

**Wind velocity.** The wind velocity $V$ to design a blade use to have mediums values of the wind velocity measured in the place where the aeloian-generator will be installed. All wind turbine needs a minimum wind velocity to start up and another to keep it working, this is the one considerated to design the wind turbine blade. To get the velocity to design, it is necessary to make statistics measurements of the location during a certain period of time to get reliable [5].

**Power required to produce electric energy.** The power required is function of the energetic quantity that is demanded by the system which electrical energy will be supplied [5].
Software *TIMEO*

1. *TIMEO* software is opened:

![Software Interface](image1)

2. To start a new project: In this part, the operator introduce the name of the project and design parameters like the power he needs, number of blades to be used, the number of parts the blade will be divided and the speed ratio.

![New Project Dialog](image2)
3. Air properties: The next step is introduced the air density and air velocity, according with the air characteristics of the location where the wind turbine will be installed.

4. Efficiency: Aeolian generators has mechanical and electrical losses, and it's important to consider them to design wind turbine blades. In this step, the operator previously has to analyze what is the efficiency of the equipment he will use (Rotor and electric generator).

5. Design options: TIMEO count with two theories for designing wind turbines blades and two methods to divide the blade. Both theories and divide options has been defined before.
6. Airfoil selection: *TIMEO* count with a database of twenty-five airfoils, in order to offer to the operator a variety of options to choose the one he thinks is the better one for his needs.

![Airfoil Selection](image)

7. Design: The last step, the operator makes a click on *design* and *TIMEO* processes all data to design the blade.

![Design](image)

As soon as button design has been clicked, in the display is shown the curve $c/R - r/R$ which defines the blade shape.

![Aerodynamic Design](image)
8. Results: Finally, the design data shown in the next table:

Furthermore, TIMEO is able to show many interesting graphs useful to understand more the design that has been realized:

- **Angles**
- **Flow Factor**
- **Aerodynamic Design**
**TIMEO – ANSYS interface**

Once the design has been done, TIMEO create many text archives (macros) with ANSYS commands, they contain information to model the blade and to do the wind turbine airfoils analysis.

**Blade Model**

With the macros obtained by TIMEO, the blade model is created by ANSYS following the next sequence:

<table>
<thead>
<tr>
<th>Process</th>
<th>ANSYS Commands</th>
<th>Finite Element Plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Start functions</td>
<td>GRA,POWER</td>
<td></td>
</tr>
<tr>
<td></td>
<td>/GST,ON</td>
<td></td>
</tr>
<tr>
<td></td>
<td>/PREP7</td>
<td></td>
</tr>
<tr>
<td>b) Keypoints and lines generation</td>
<td>K, LSTR</td>
<td></td>
</tr>
<tr>
<td>c) Areas and volume generation</td>
<td>FLST, FITEM, VA</td>
<td></td>
</tr>
</tbody>
</table>
## Airfoils Analysis

When the wind turbine is rotating, the airfoils which are part of the blade develop different aerodynamic characteristics each one that is because of the blade twist and the different cords they have. The reason to do an airfoils analysis, is to obtain a pressure and velocity distributions for each airfoil of the blade. Once obtained the airfoil analysis, is possible to know the aerodynamic behaviour.

<table>
<thead>
<tr>
<th>Process</th>
<th><strong>ANSYS Commands</strong></th>
<th>Finite Element Plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Start functions</td>
<td>GRA,POWER /GST,ON /PREP7</td>
<td></td>
</tr>
<tr>
<td>b) Keypoints, lines and surface generation for the airfoil model</td>
<td>( K ) ( LSTR ) ( L,1,3 ) ( AL,4,7,3,1,10,5 ) ( ASBW,1 ) ( ASBW,2 )</td>
<td><img src="image1.png" alt="Finite Element Plot" /></td>
</tr>
<tr>
<td>c) Meshed</td>
<td>( LSEL,S,..,1 ) ( LESIZE,ALL,..,40,..,1 ) ( ESIZE,\ 0.0047,0 ) ( AMAP,1,8,7,2,123 )</td>
<td><img src="image2.png" alt="Finite Element Plot" /></td>
</tr>
<tr>
<td>d) Fluid boundary Conditions</td>
<td>/SOL ( LSEL,A,.., ) ( DL,ALL,VX,0,1 ) ( LSEL,S, ..,7,8,1 ) ( DL,ALL,VX,1.87,1 ) /COM,,Steady State,0 FLDATA2,ITER,,100</td>
<td><img src="image3.png" alt="Finite Element Plot" /></td>
</tr>
<tr>
<td>e) Solution</td>
<td>!SOLUCION SOLVE FINISH</td>
<td><img src="image4.png" alt="Finite Element Plot" /></td>
</tr>
</tbody>
</table>
This process is repeated as many of blade divisions had been chosen by the operator. The reason to do these airfoils analysis is to simulate the aerodynamic behaviour of the blade.

The information obtained in this analysis is important to start a 3D analysis of the complete blade in order to do a fluid-structural analysis.
Conclusions

Nowadays, the using of software to technologic development for any country is fundamental. Software technology is increasing every day and global world economy is growing in the direction of software development. In Mexico, this type of technology has not been explored, because our country is big consumer of international market.

In Mexico exists a big Aeolian source which has been wasteful and the using of this type of renewable energy could helps to develop alternative sources energy which offers an indigenous source and clean energy where the fossil oils that damage the environment are excluded.

The development of this software (TIMEO), represents a new technological tool to support the renewable energy development in our country, and its main function is to reduce the time used for wind turbines blades design and its interface with ANSYS offers a simulation of the blade behaviour in order to prove the well operation of the blade designed. ANSYS is an excellent Finite Element software which offers the opportunity through its commands to make an interface with the TIMEO to study and analyse wind turbines with fluids, modal and fluid-structural results.

Bibliography