International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Analysis of Wind Turbine Blade

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Accepted 10 January 2014, Available online 01 February 2014, **Special Issue-2, (February 2014)**

Abstract

Blades are the most critical component of a wind turbine which is responsible for conversion of wind energy into kinetic energy. Aerodynamics is a science and study of physical laws of the behavior of objects in airflow and the forces that are produced by airflows. In the early stage, the research on wind turbine blade design was limited on theoretical study, field testing and wind tunnel testing which need a lot of efforts and resources. Due to the development of computer aided design codes, they provide another way to design and analyzed the wind turbine blades. Aerodynamic performance of wind turbine blades can be analyzed using computational fluid dynamics (CFD), which is one of the branches of fluid mechanics. In this paper an effort is made to study the Lift and Drag forces in a wind turbine blade at numerous sections and the effect of angle of attack on these forces. In this paper airfoil profile is considered for analysis of wind turbine blade. The wind turbine blade is modeled and several sections are produced from root to tip. The Lift and Drag forces are calculated at different sections for different angle of attack (AoA) for varied Reynolds numbers. The pressure and velocity distributions are also conspired. The cross sectional of blade is analyzed based on computational fluid dynamics to identify its suitability for its application on wind turbine blades and good agreement is made between conclusions.

Keywords: *blade, airflow, aerofoil, pressure distribution, velocity distribution.*

1. Introduction

Wind turbine blades are shaped to generate the maximum power from the wind at the minimum cost. Primarily the design is driven by the aerodynamic requirements, but economics mean that the blade shape is a compromise to keep the cost of construction reasonable. In particular, the blade tends to be thicker than the aerodynamic optimum close to the root, where the stresses due to bending are greatest (Bhargav Patel *et al* 2012). Wind turbine was invented by engineers in order to extract energy from the wind. Because the energy in the wind is converted to electric energy, the machine is also called wind generator. Locally, wind velocities are significantly reduced by obstacles such as trees or buildings (Thumthae *et al* 2006). A renewable energy source will be ideally suited to comply these energy needs. The sources available easily are wind, solar, biogas, etc. out of which wind energy is studied in length in this paper.

The blade design process starts with a "best guess" compromise between aerodynamic and structural efficiency. The choice of materials and manufacturing process will also have an influence on how thin (hence aerodynamically ideal) the blade can be built. For instance, prepreg carbon fibre is stiffer and stronger than infused glass fibre. The chosen aerodynamic shape gives rise to loads, which are fed into the structural design. Problems identified at this stage can then be used to modify the shape if necessary and recalculate the aerodynamic performance. A wind turbine consists of several main parts, i.e. the rotor, generator, driven chain, control system and so on. The rotor is driven by the wind and rotates at predefined speed in terms of the wind speed, so that the generator can produce electric energy output under the regulation of the control system. In order to extract the maximum kinetic energy from wind, researchers put much effort on the design of effective blade geometry.

1.1 How Blade Capture Wind Power

Just like an aeroplane wing, wind turbine blades work by generating lift due to their shape. The more curved side generates low air pressures while high pressure air pushes on the other side of the aerofoil. The net result is a lift force perpendicular to the direction of flow of the air.

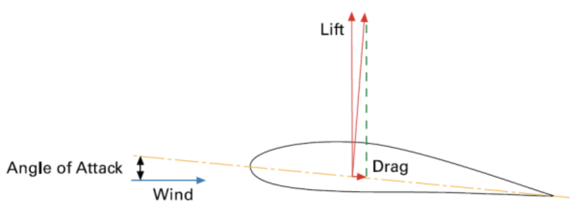

Fig.1 Lift and Drag Vectors

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The lift force increases as the blade is turned to present itself at a greater angle to the wind. This is called the angle of attack. At very large angles of attack the blade "stalls" and the lift decreases again. So there is an optimum angle of attack to generate the maximum lift. There is, unfortunately, also a retarding force on the blade: the drag. This is the force parallel to the wind flow, and also increases with angle of attack. If the aerofoil shape is good, the lift force is much bigger than the drag, but at very high angles of attack, especially when the blade stalls.

1.2 Number of blades

The limitation on the available power in the wind means that the more blades there are the less power each can extract. A consequence of this is that each blade must also be narrower to maintain aerodynamic efficiency. The total blade area as a fraction of the total swept disc area is called the solidity, and aerodynamically there is an optimum solidity for a given tip speed; the higher the number of blades, the narrower each one must be. In practice the optimum solidity is low (only a few percent) which means that even with only three blades, each one must be very narrow. To slip through the air easily the blades must be thin relative to their width, so the limited solidity also limits the thickness of the blades. Furthermore, it becomes difficult to build the blades strong enough if they are too thin or the cost per blade increases significantly as more expensive materials are required.

For this reason, most large machines do not have more than three blades. The other factor influencing the number of blades is aesthetics: it is generally accepted that three-bladed turbines are less visually disturbing than one- or two-bladed designs.

2. Methodology

The aerofoil is chosen for blade modeling as shown in fig.4. Profiles are obtained from Design Foil Workshop for various chords (Abbott *et al* Report No.824). The modeling is done with GAMBIT. The blade is modeled for the Nomenclature given in Table.1

Table 1 Aerofoil Nomenclature

S.No.	Nomenclature	Blade Data
1.	Root chord length 1651 mm	1638mm
2.	Tip Chord Length	614mm
3.	Length of Blade	98100mm
4.	Hub diameter	247.2mm
5.	Hub Length	1296mm
6.	Hub to blade	1485mm

Aerodynamic studies are quite mature for flows with Reynolds number greater than 10^6. However, there are not many analytical or numerical or experimental studies available for flows at very low Reynolds numbers. Consideration of 2D geometries, i.e., airfoils, for such studies seems to be a good starting point to improve our understanding of low Reynolds number flows. Some experimental studies are reported in(Schmitz et al 1967), (Sunada *et al* 1997), (Sunada et al 2002). Numerical studies, for analysis as well as for design and experimental validations of airfoils at ultralow Reynolds number are presented in (Kroo *et al* 2000), (Kunz *et al* 2000). The lift and drag forces are calculated by the following formula and the lift to drag ratio (L/D ratio) is also found out from equ.(1,2).

$$\text{Lift} = (1/2)\,X\rho X\,CLXcXLXV_{rel}^{2} \quad (1)$$
$$\text{Drag} = (1/2)\,X\rho X\,CDXcXLXV_{rel}^{2} \quad (2)$$

Where ρ – density of air, c – Chord length in meter, L – Length of the blade element, V_{rel} – relative velocity of air in m/s = $((V_o)^2 + (r\omega)^2)^{0.5}$, The values of C_L and C_D were found out for various angles of attack (AoA).

The drag increases dramatically. So at an angle slightly less than the maximum lift angle, the blade reaches its maximum lift/drag ratio. The best operating point will be between these two angles.

The Lift and Drag forces are calculated for the different angle of attack The Lift/Drag ratio is calculated for different angle of attack ranges from 0^o to 12^o for the velocity ranges. The lift/drag ratio for different angle of attack is shown in bar Chart 1.

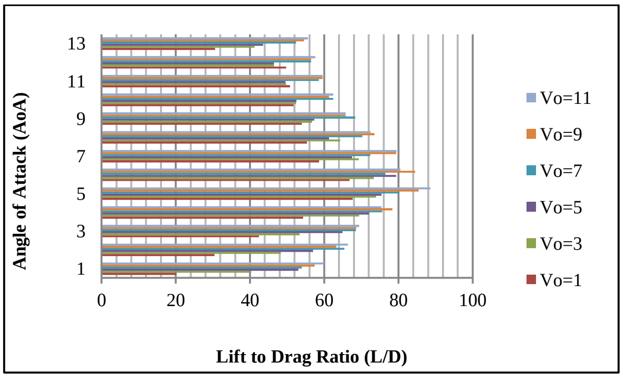

Chart 1.Lift to Drag ratio Vs Angle of Attack (AoA)

The L/D ratio for the different angle of attack and different velocities. The cross sections of the blade are created at different sections from root to tip. At this sections lift and drag forces are determined.

The lift and drag forces at different distance from hub are calculated for various angles of attack shown in Fig. 2 and Chart 2. Increase in lift and drag forces for various angles of attack also calculated. The coefficient of lift is calculated at the upper and lower surface is calculated shown in Fig.3.

3. Numerical Simulation

The numerical method utilized for the simulation had a density based solver with implicit formulation, 2-D domain geometry, absolute velocity formulation, and superficial velocity for porous formulation. For this test, a simple solver and an external compressible flow model for the turbulence was utilized.

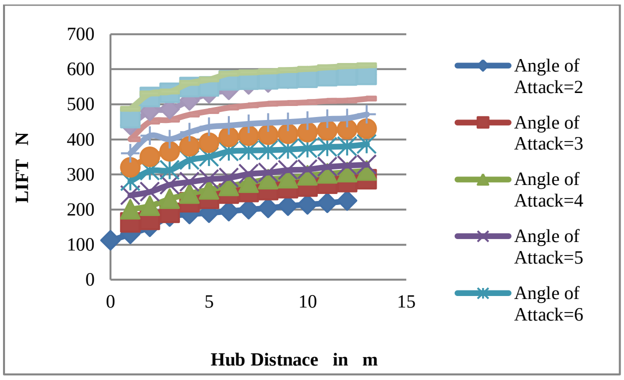

Fig 2: Lift force Vs Hub Distance

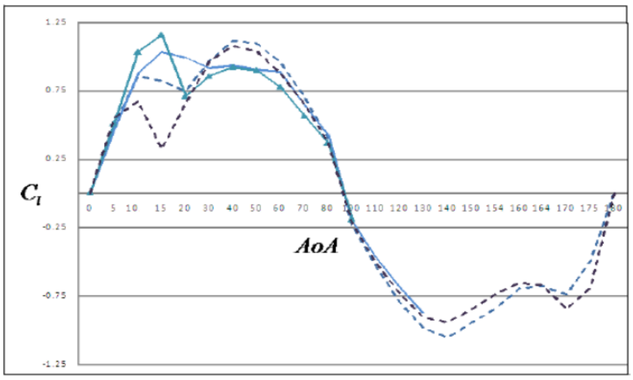

Fig 3. Coefficient of Lift Vs Angle of Attack

The green-gauss cell based was used for the gradient option. There are different equations used for flow, turbulence, species, and energy (Abbott *et al* report.no.824). A simple method was used for the pressure-velocity coupling.

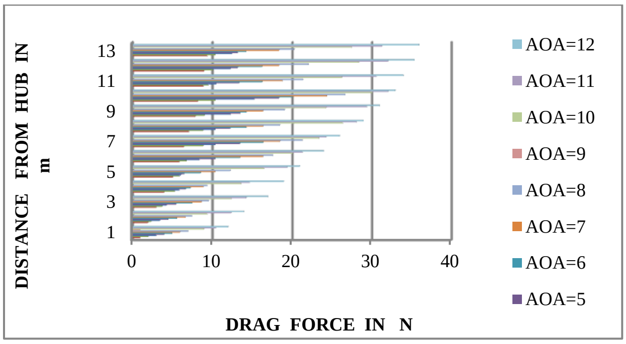

Chart 2. Hub Distance Vs Drag force

For the discretization, a standard pressure was used, and density, momentum and turbulent kinetic energy were set to second order upwind.

3.1 Geometry creation, Mesh and Boundary Conditions

Inlet velocity for the experiments and simulations is 10m/sec and turbulence viscosity ratio is 10. A fully turbulent flow solution was used in FLUENT & GAMBIT, where Spalart – Allmaras (S-A) equation was used for turbulent viscosity.

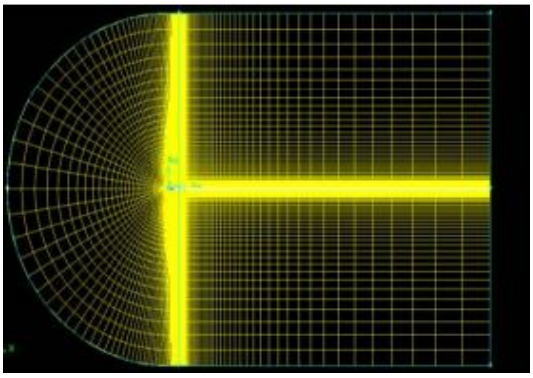

Fig 4. Aerofoil Geometry Mesh in Gambit

A simple solver was utilized and the operating pressure was set to zero. Calculations were done for the "linear" region, i.e. for angles of attack 5 degrees, due to greater reliability of both experimental and computed values in this region (Wagh *et al* 2012). The airfoil profile and boundary conditions are all created. The airfoil consists of 71 vertices and two edges (upper and lower edge) as shown in Fig.4.

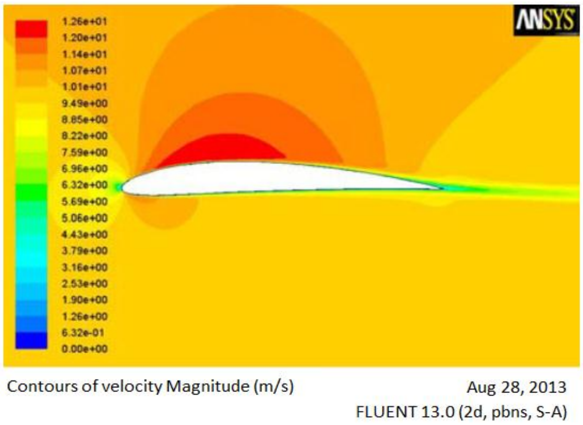

Fig.5. Velocity Magnitude Contour at 1^0 AoA

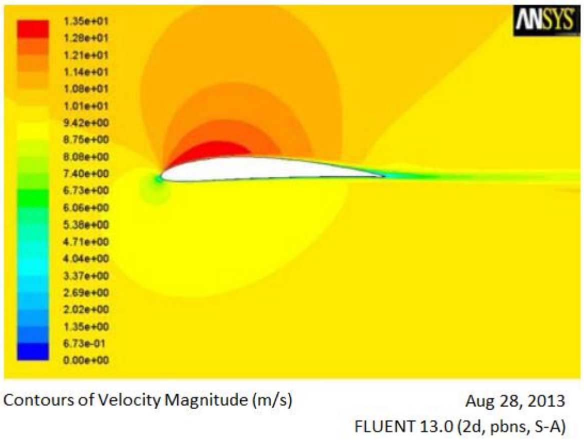

Fig.6. Velocity Magnitude Contour at 3^0 AoA

The Computational Fluid Dynamic analysis also carried out using FLUENT & GAMBIT software. The velocity and pressure distribution at various angles of attack of the blade is shown in Fig. 5-11. These results are coinciding with the wind tunnel Experimental values. Hence the results are validated with the experimental work.

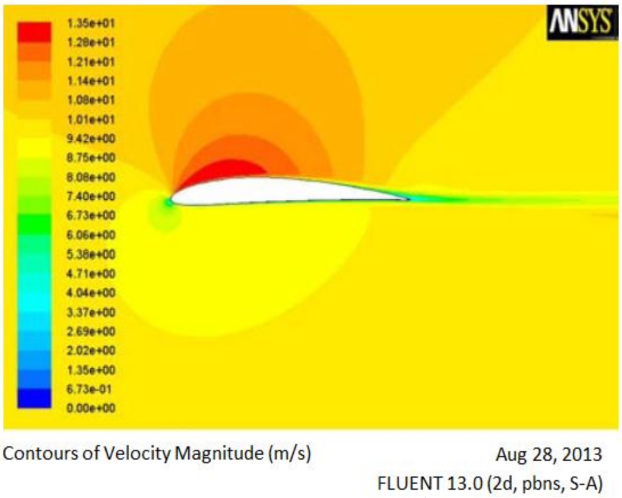

Fig.7. Velocity Magnitude Contour at 6^0 AoA

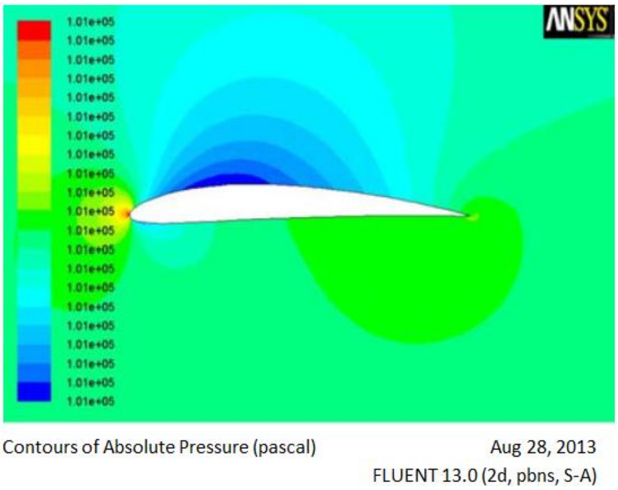

Fig.8. Velocity Magnitude Contour at 1^0 AoA

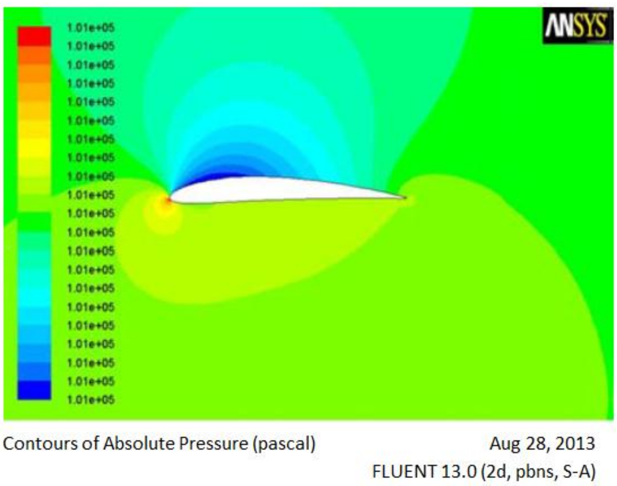

Fig.9. Absolute Pressure Contour at 1^0 AoA

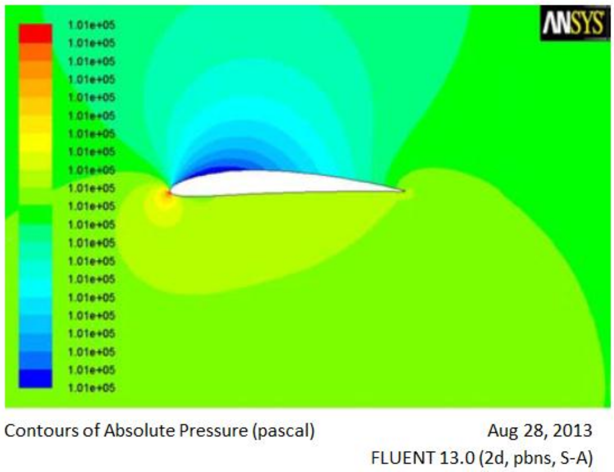

Fig.10. Absolute Pressure Contour at 3^0 AoA

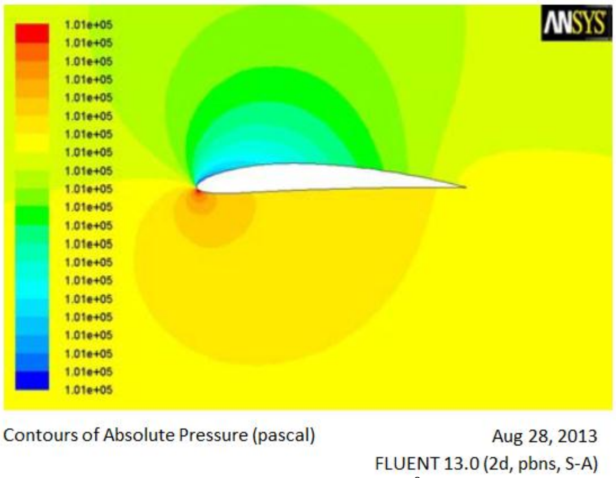

Fig.11. Absolute Pressure Contour at 6^0 AoA .

Conclusions

1) The coefficient of Lift and drag is calculated for wind turbine blade for the different angle of attack 0° to 6°. The coefficient of Lift increases with increase in Angle of attack up to 14^o.
2) The aerofoil blade has an aerodynamic profile in cross section to create lift and rotate the turbine. The results demonstrate the pressure distribution over the airfoil. It could be observed that the upper surface on the aerofoil experiences a higher velocity compared to the lower surface.
3) By increasing the velocity at higher Mach numbers there would be a shock wave on the upper surface that could cause discontinuity. The pressure on the lower surface of the airfoil is greater than that of the incoming flow stream and as a result of that it effectively pushes the airfoil upward, normal to the incoming flow stream.
4) The drag force begin of dominate beyond this angle of attack. The rate of increase in lift is more for angle of attack from 0^o to 6^o and between 0^o to 6^o the rise in lift force is less.
5) The maximum L/D ratio is achieved at 5° of angle of attack, for the average velocity. It is found that blade with 5° angle of attack has the maximum L/D ratio.

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