Cfd Analysis Of Wind Turbine Blade

[1]H. V. Mahawadiwar, [2]V.D. Dhopte, [3]P.S.Thakare, [4]Dr. R. D. Askhedkar
[1] M. Tech Student, K.D.K.C.E., Nagpur, India 440 009
[2,3]Asst. Professor, K.D.K.C.E., Nagpur, India 440 009
[4] Dean R & D, K.D.K.C.E, Nagpur, India 440 009

ABSTRACT:

A wind turbine is a rotary device that extracts energy from the wind. Wind energy has been shown to be one of the most viable sources of renewable energy. [1]. with current technology, the low cost of wind energy is competitive with more conventional sources of energy such as coal. Rotor blade is a key element in a wind turbine generator system to convert wind energy in to mechanical energy. [2]. Most blades available for commercial grade wind turbines incorporate airfoil shaped cross sections. These blades are found to be very efficient at lower wind speeds in comparison to the potential energy that can be extracted. Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary condition.[3] In this paper, CFD analysis of wind turbine blade, a complete drawing, and details of sub-system are carried out.

Keywords: Wind energy, Airfoils, CFD, blade geometry

1. INTRODUCTION

Computational Fluid Dynamics (CFD) has grown from a mathematical curiosity to become an essential tool in almost every branch of fluid dynamics, from aerospace propulsion to weather prediction. CFD is commonly accepted as referring to the board topic encompassing the numerical solution, by computational methods, of the governing equations which describe fluid flow, the set of the Navier-Stokes equations, continuity and any additional conservation equations, for example energy or species concentrations.[4]. As a developing science, Computational Fluid Dynamics has received extensive attention throughout the international community since the advent of the digital computer. All CFD analysis starts by defining the geometry to be used. However, for CFD, the geometry is the geometry where the air (or fluid) will flow. [5]This means that it is often necessary to define artificial boundaries for inlets, outlets, far-field conditions etc.

2. DETAILED DRAWING OF THE BLADE:

The blades are perhaps the most important part of our wind turbine. [6].These wind turbine blades have a simple airfoil shape and when finished they'll look (and work) a bit like airplane wings. The blade material is Cedar wood, strong and light weight. Fig. No. 1 shows front view of the blade with dimensions.

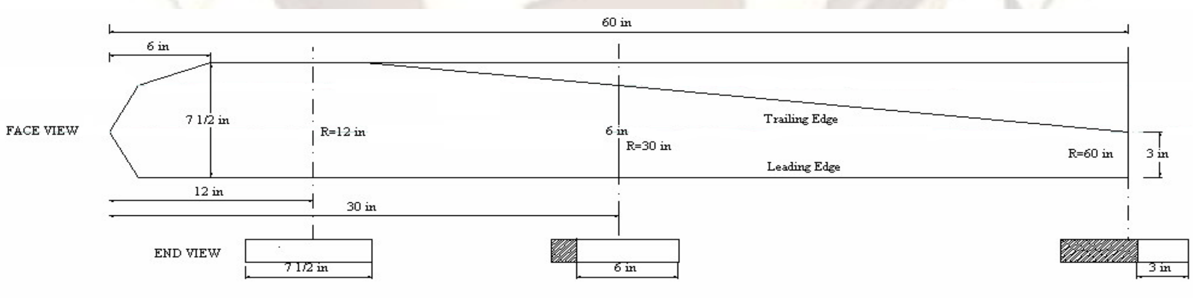

Fig. No. 1 Front View of the Blade with Dimensions

Fig. No.2 shows enlarge end - front view of the blade with angle of 120^0 at end face view.

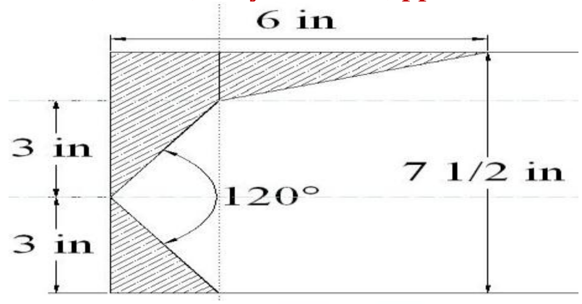

Fig. No. 2 Enlarge End – Front View of the Blade

Fig. No. 3 shows plan or top view of blade with dimensions.

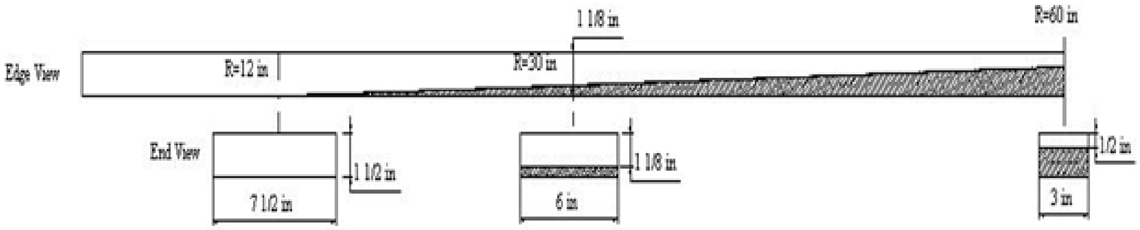

Fig. No. 3 Top View of the Blade with Dimensions

Fig. No. 4 shows end view or side view of the blade at three different cross sections at tip, middle and end of the blade.

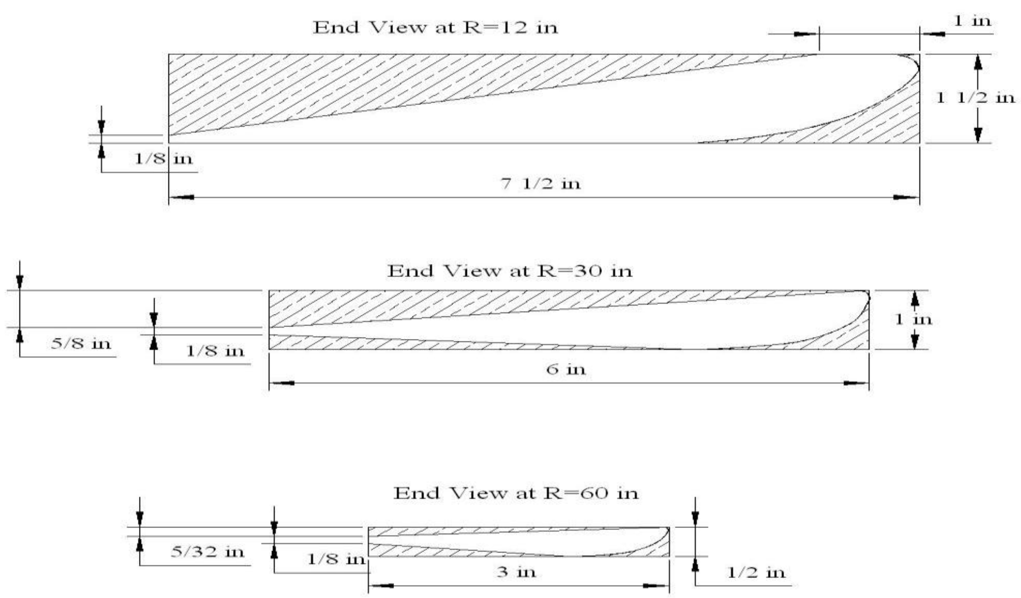

Fig. No. 4 End (Side) View of the Blade

Fig. No.5 shows the CAD Model of the Blade.

Fig. No. 5 Three Dimensional View of the Blade (F.V)

3. NOMENCLATURE:

V_0 = Inlet wind velocity; α = Angle of attack; ω = Blade angular velocity ; r = Blade radius ; V_r = Resultant wind velocity; ρ = Air density; F_L = Lift Force ; F_D = Drag Force; N= Speed of wind turbine; C_L and C_D are coefficient of lift and coefficient of drag respectively; CP= Coefficient of performance; P_N = Numerical Power; P_A = Analytical Power.

4. METHOD OF FLOW ANALYSIS:

Blade velocity triangle showing lift and drag forces on blade element are reveal in Fig. No.6 below.

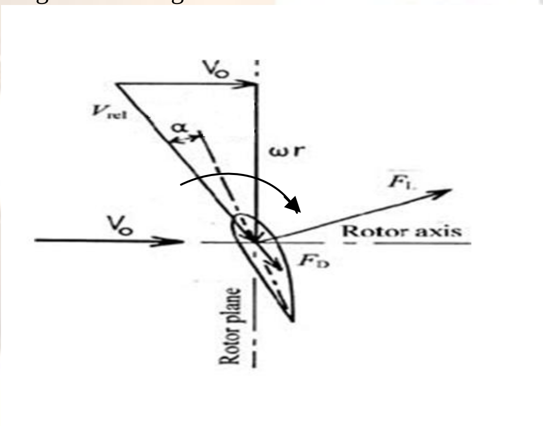

Fig. No. 6 Blade Velocity Triangle

Modeling of the blade is done in Pro-e. This blade is imported in Gambit software where meshing is done after that it is transported Into Fluent where flow analysis is carried out. Inlet wind velocity and angle of attack values are input values provided to fluent .Values C_L and C_D
are evaluated by Fluent software.

5. CFD Analysis of Wind Turbine Blade:

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary condition.[3] CFD enables scientist and engineers to perform ‘ numerical experiments, i. e. Computer simulations in a virtual flow laboratory. CFD is faster and definitely cheaper. A considerable reduction of time and costs for solving the problems as compared to traditional approaches.[8]

CFD Analysis of wind turbine blade consist of main two stages one is preprocessing and second is post processing. Preprocessing is done in Gambit and post processing is done in Fluent.

Calculations:

$\alpha = 7^0$; $V_0 = 8$ m/s ; N = 51 rpm ; r = 1.524 m ; $\rho = 1.225$ Kg/m^3

$V = r \cdot \omega = r \cdot 2 \cdot \pi \cdot N / 60$

$= 1.524 \times 2 \times \pi \times 51 / 60$

V = 8.14 m/s

$V_r = (V^2 + V_0^{\;2})^{1/2}$

$= (8.14^2 + 8^2)^{1/2}$

V_r = 11.41 m/s

From Fluent software we get values of

C_L = 0.9559

C_D = 0.00137

Therefore we get values of

Lift Force = $F_L = 0.5 \cdot \rho \cdot V_r^{\;2} \cdot C_L$

$F_L = 0.5 \times 1.225 \times (11.41)^2 \times 0.9559$

F_L = 76.22 N

Drag Force = $F_D = 0.5 \cdot \rho \cdot V_r^{\;2} \cdot C_D$

$F_D = 0.5 \times 1.225 \times (11.41)^2 \times 0.00137$

F_D = 0.1092 N

Resultant Force = $F_R = (F_D^{\;2} + F_L^{\;2})^{1/2}$

F_R = 76.22 N

Power = P_N = Torque x ω -------------- Numerical Value

$= (F_R \times r \times \omega)$

$= (F_R \times V)$

$= (76.22 \times 8.14)$

P_N = 620.43 Watts

Power = $P_A = 0.5 \times \rho \times A \times V_O^{\;3} \times$ CP--------Analytical Value

$= 0.5 \times 1.225 \times 7.296 \times 8^3 \times CP$

Therefore, **CP = 620/2288 = 0.271**

5. RESULT ANALYSIS:

1) CAD model of the blade profile using Pro-E software is created and the model drawing of the blade as shown in Fig. No 7 below.

Fig. No. 7 Three Dimensional View of the Blade (F.V)

2) For the flow analysis of the wind turbine blade mesh is created in the GAMBIT software. Fig. No. 8 shows the meshing drawing of the blade below.

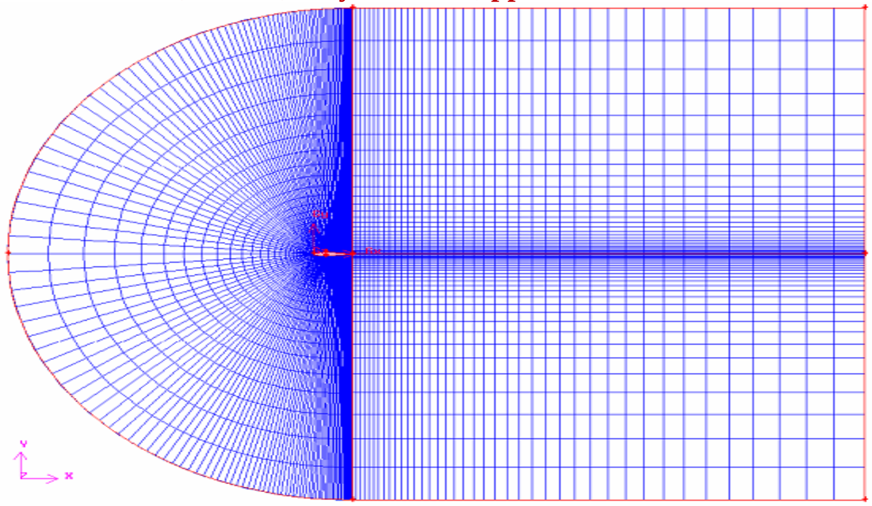

Fig. No. 8 Completed Mesh.

3) CFD analysis of the wind turbine blade is carried out in the FLUENT software, the results of numerical power is shown in table no. 1 below.

Sr. No	α	N = 19 rpm V_0 = 3m/s	N = 25 rpm V_0 = 4m/s	N = 32 rpm V_0 = 5m/s	N = 38 rpm V_0 = 6m/s	N = 44 rpm V_0 = 7m/s	N = 51 rpm V_0 = 8m/s	N = 57 rpm V_0 = 9m/s	N = 62 rpm V_0 = 10m/s	N = 70 rpm V_0 = 11m/s
		P_N (W)	P_N (W)	P_N (W)	P_N (W)	P_N (W)	P_N (W)	P_N (W)	P_N (W)	P_N (W)
1	0	15.59	40.28	106.68	195.16	284.28	558.07	808.62	1061.4	832.93
2	1	16.18	42.01	109.28	198.84	340.61	563.04	820.54	1079.81	865.96
3	2	16.70	44.3	110.67	201	345.59	559.25	831.41	1094.48	878.11
4	3	17.12	46	111.72	203.86	348.39	572.23	840.60	1104.5	905.22
5	4	17.60	48.95	113	205.37	354.4	577.94	850.87	1116.38	924.1
6	5	18.05	49.86	115.04	212.47	359.44	583.72	863.5	1131.6	951.6
7	6	18.51	52.34	118.52	215.55	362.68	604.18	867.78	1152.3	1007.1
8	7	19.42	55	121.72	219.86	368.48	620	875.65	1157	1020.3
9	8	9.97	47.03	100.97	186.91	293.33	496.54	746.78	1001.3	602.97
10	9	9.30	46	97.78	176.59	278.07	478.29	728.18	959.21	550.55

Table No. 1 Values of Numerical Power

4) The results of analytical power shown in table no. 2 below.

Sr. No	N = 19 rpm V_0 = 3m/s	N = 25 rpm V_0 = 4m/s	N = 32 rpm V_0 = 5m/s	N = 38 rpm V_0 = 6m/s	N = 44 rpm V_0 = 7m/s	N = 51 rpm V_0 = 8m/s	N = 57 rpm V_0 = 9m/s	N = 62 rpm V_0 = 10m/s	N = 70 rpm V_0 = 11m/s
	P_A (W)	P_A (W)	P_A (W)	P_A (W)	P_A (W)	P_A (W)	P_A (W)	P_A (W)	P_A (W)
1	120.63 x CP	286 x CP	558.62 x CP	965.30 x CP	1532.87 x CP	2288 x CP	3257.9 x CP	4490 x CP	5948.24 x CP

Table No. 2 Analytical Power

5) The results of coefficient of performance (CP) shown in Table No. 3 below.

Sr. No	A	N = 19 rpm V_0 = 3m/s	N = 25 rpm V_0 = 4m/s	N = 32 rpm V_0 = 5m/s	N = 38 rpm V_0 = 6m/s	N = 44 rpm V_0 = 7m/s	N = 51 rpm V_0 = 8m/s	N = 57 rpm V_0 = 9m/s	N = 62 rpm V_0 = 10m/s	N = 70 rpm V_0 = 11m/s
		CP	CP	CP	CP	CP	CP	CP	CP	CP
1	0	0.13	0.14	0.19	0.20	0.185	0.243	0.248	0.236	0.148
2	1	0.137	0.146	0.195	0.205	0.222	0.246	0.251	0.240	0.145
3	2	0.138	0.154	0.198	0.208	0.225	0.244	0.255	0.243	0.147
4	3	0.14	0.16	0.199	0.211	0.227	0.25	0.258	0.245	0.152
5	4	0.145	0.17	0.202	0.213	0.231	0.252	0.261	0.248	0.155
6	5	0.149	0.174	0.205	0.22	0.234	0.255	0.265	0.252	0.159
7	6	0.153	0.18	0.212	0.223	0.236	0.263	0.266	0.256	0.169
8	7	0.16	0.19	0.217	0.227	0.24	**0.271**	0.268	0.257	0.171
9	8	0.082	0.164	0.18	0.193	0.191	0.216	0.229	0.223	0.101
10	9	0.077	0.16	0.175	0.183	0.181	0.208	0.223	0.213	0.092

Table No. 3 Values of Coefficient of Performance (CP)

6) From the result of above table no. 3 we can plot the graph, Fig. No.9 shows the graph of Coefficient of Performance versus Velocity of air V_0

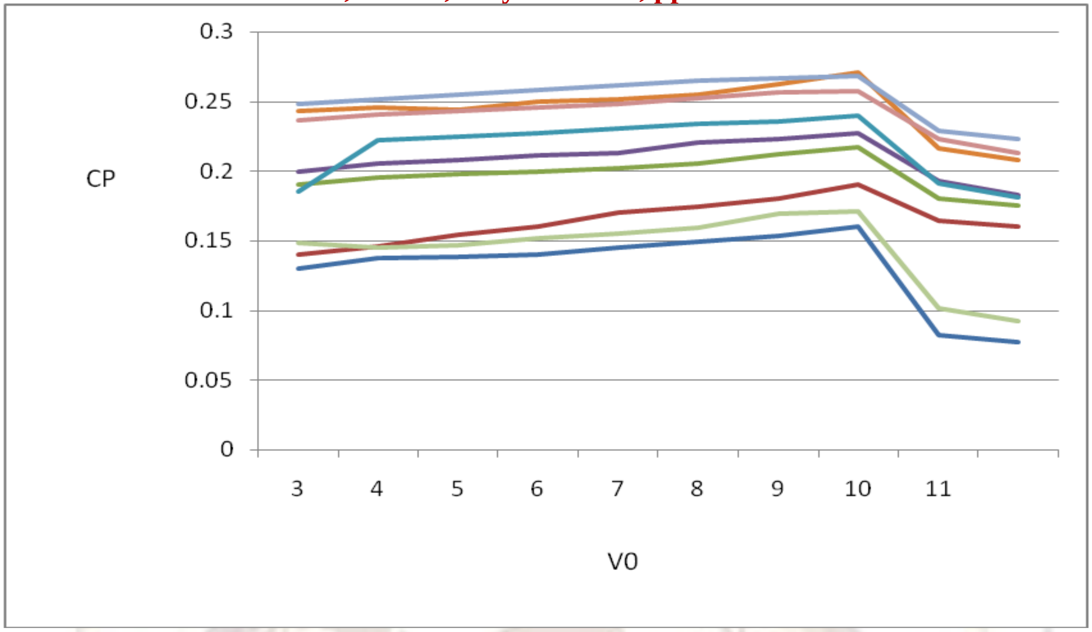

Fig. No. 9 Graph of CP versus V_0

6. CONCLUSIONS:

In this project of CFD analysis of wind turbine blade CAD drawing of the blade is drawn in Pro-E software, meshing is done in GAMBIT and blade is analyzed in FLUENT CFD software. The following conclusions emerge from this study.

1) It was observed that value of numerical power increases as angle of attack increases from 0^0 to 7^0, after 7^0 the value of numerical power reduced. Hence critical angle of attack for this blade is $7^{0.}$
2) The maximum value of coefficient of performance (CP_{max} = 0.271) was observed at angle of attack 7^0 and at velocity of air 8 m/s.
3) This blade can generate maximum power of 620 W at maximum CP, angle of attack 7^0 and velocity of air 8 m/s.
4) From the graph Fig. No. 7.1 it was observed that coefficient of performance is increases from 3 m/s to 8 m/s and after 8 m/s value of coefficient of performance reduced.

References:

[1] R.S.Amano, R.J.Malloy, “CFD Analysis on Aerodynamic Design Optimization of Wind Turbine Rotor Blade”. World Academy of Science, Engineering and Technology 2009. Pp71-75.
[2] Y. U. Sohn, Ch. H. Chun, Y. C. Kim, K. S. Han, “Blade Design of a 750 kW Direct-drive Wind Turbine Generator System” UNISON Industrial Co., LTD, 330-882, Jangsan-ri, Sooshin-myun Cheonan-si, Chung-nam, Korea R. Schmidt, M. Rees, Aerodyne Energy system GmbH, Provianthausstr. 9, D-24768 Rendsburg, Germany. pp 1-7.
[3] Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/wind_power
[4] Metin Ozen, Ashok Das, Kim Parnell, “CFD Fundamental and Applications” pp 7-8
[5] Fluent_ Tutorial/index.htm
[6] www.otherpower.com
[7] Wind Energy Handbook – 2 – Aerodynamics and Loads. pp 2
[8] Dmitri Kuzmin , “Introduction to Computational Fluid Dynamics ” , pp 1-25.