Wind Angle and Velocity Effects on a 2D Airfoil

Course Project

EN222: Fluid Mechanics and Heat Transfer

Energy Science and Engineering Department, IIT Bombay

Guide:
Professor Manaswita Bose

group

Name	Yash Mehta	Tarun Kurapaty
Roll Number	22B1504	22B1537

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Contents

1 OBJECTIVE

With the increasing penetration of renewables, research regarding optimisation of renewable energy technologies is of key interest. One such popular mode of renewable energy is wind energy. We want to analyse how different angles of attack and wind velocities affect the drag coefficient, lift coefficient and moment coefficient of a windmill blade giving us insights on the overall performance of the wind blade.

We initially planned to create a 3D model of a wind turbine blade in a CAD software and simulate its behavior using tools like COMSOL or ANSYS. We even developed an approximate CAD model by studying the blade's structure and dimensions. However, when we imported the CAD model and configured all the parameters, we encountered issues while creating a mesh for the external wind flow.

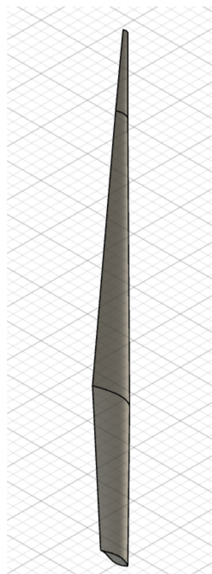

Figure 1: CAD model of the 3D blade

It became evident that the shape of the air packet around the blade couldn't be arbitrary; rather, it required careful design of the mesh, inlet, and outlet. Specifically, the mesh near the blade surface needed to be highly refined, while the rest of the mesh needed a pattern that would guide the wind flow as desired.

Given our limited expertise and time constraints, creating a suitable mesh for a 3D blade proved to be beyond our capabilities. As a result, we shifted our focus to a more fundamental objective: analyzing wind flow around a 2D airfoil. To assist us in this task, we referred to a YouTube video [1] for guidance.

We used the 2D model of NACA 4430 airfoil (which is used in that part of a windmill blade which has the largest chord length (refer figure 2)) and simulated it in ANSYS by varying velocities and angle of attacks.

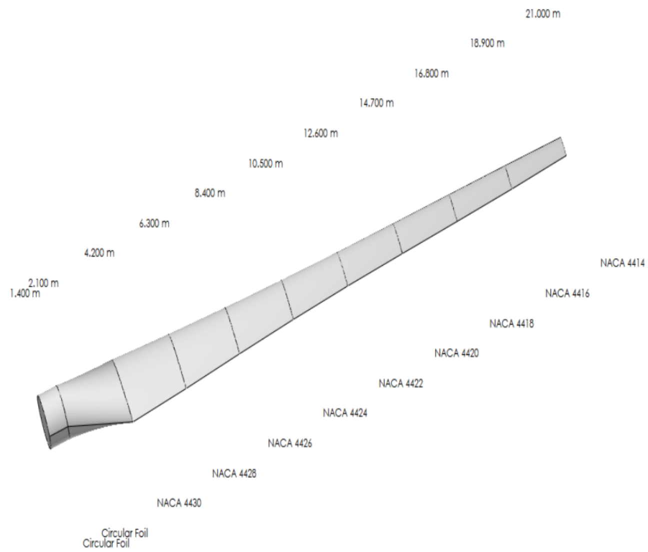

Figure 2: Various Airfoils in a Blade [2]

2 PROCESS OF SIMULATION

We used an air foil generator [3] to generate 2D coordinates of NACA 4430 which we used as input for our ANSYS file. Then we created a mesh for external flow around the air foil.

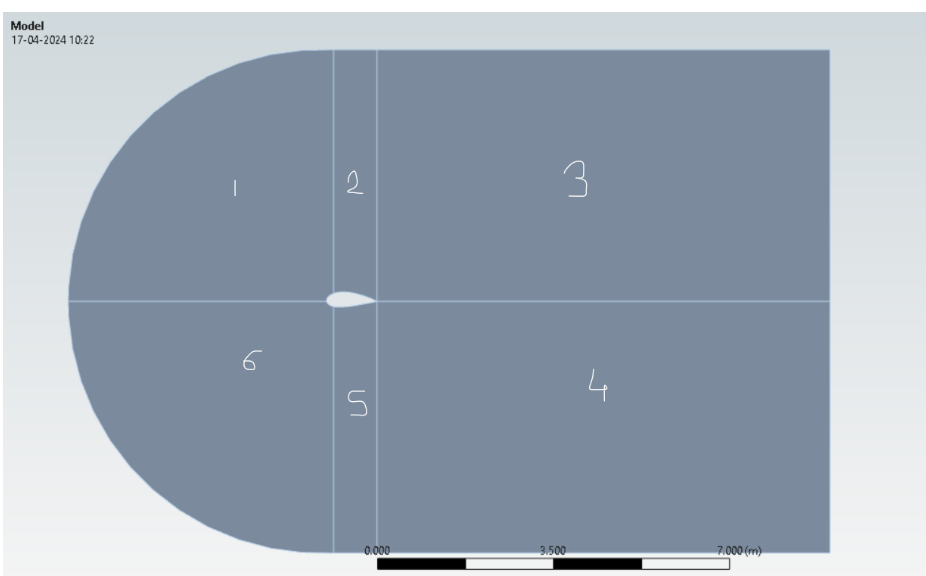

Figure 3: Various Airfoils in a Blade

The mesh was to be made of a specific shape. The figure 3 shows more about the shape. Also, the mesh was divided into 6 different parts. Hard means that the cell shape of that part of mesh won't change according to the change in the simulation environment; while the soft part of the mesh does change. The area around the airfoil was generally set to hard.

Also, bias was introduced in different parts of the mesh. The circular portion and the portion above and below the airfoil had no bias, while the rest of the portion had a bias.

The final mesh looked something like shown in figure 4.

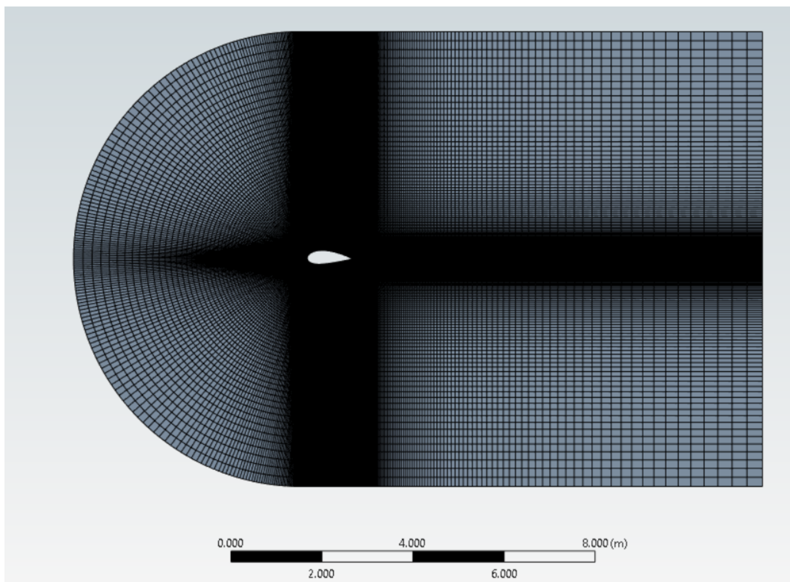

Figure 4: Mesh of the airfoil

3 RESULTS AND ANALYSIS

The following figures (5 and 6) show the trend between Coefficient of Lift, Coefficient of Drag, Moment Coefficient and Angle of Attack through different graphs.

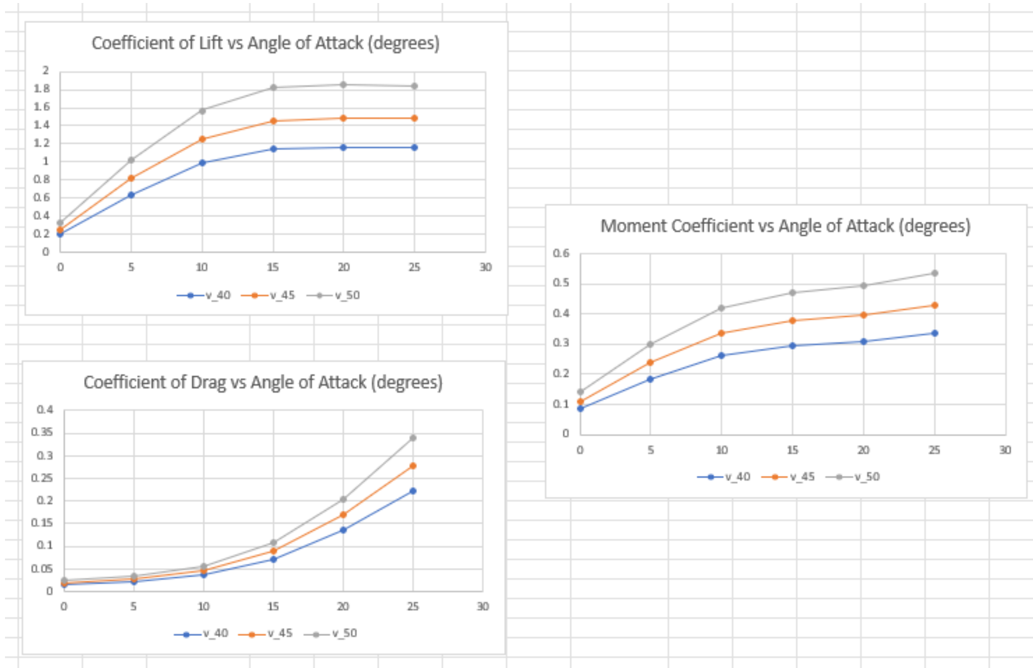

Figure 5: C_l, C_d, C_m vs Angle of Attack (degrees)

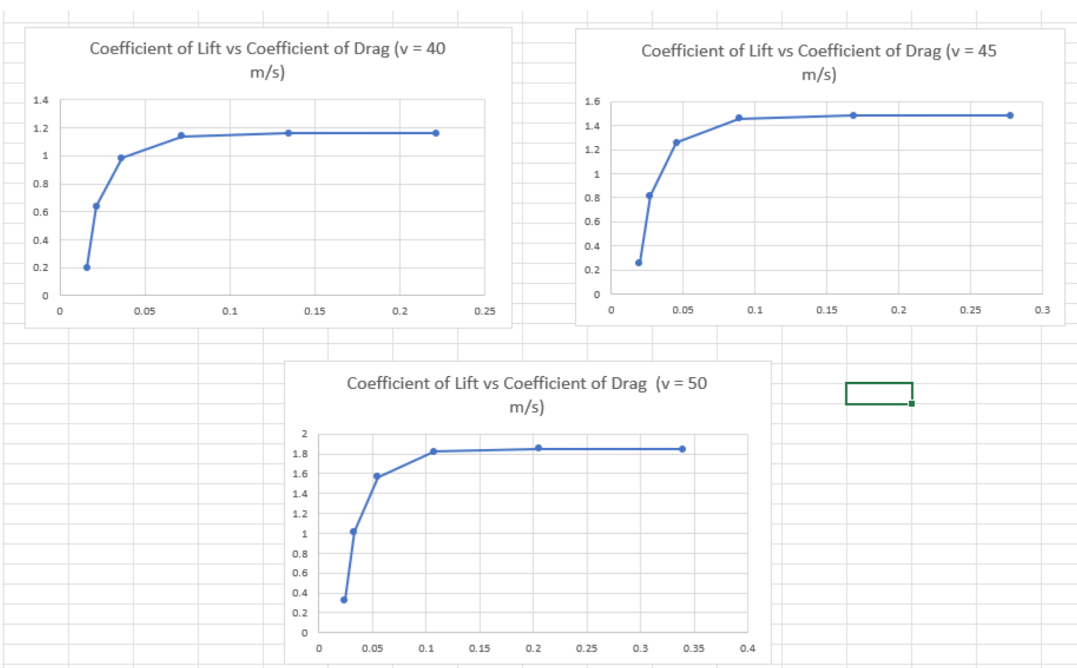

Figure 6: C_l vs C_d for different velocities of wind

3.1 Analysis of Graphs from figure 5

From figure 5, we can see that C_l, C_d and C_m increase with the angle of attack of wind. However, while the coefficient of lift and moment coefficient start converging, the coefficient of drag starts increasing with larger slopes as the angle of attack increases.

Also, the values of all the three coefficients increase with the wind velocity for a given angle of attack.

3.2 Analysis of Graphs from figure 6

It is evident from figure 6 that for any of the three wind velocities used (40 m/s, 45 m/s and 50 m/s), the value of coefficient of lift first increases with the coefficient of drag. But, after a certain value of coefficient of drag, the coefficient of lift starts to saturate to a constant value.

We can infer from this analysis that beyond that value of C_d (let's call it the **threshold $\mathbf{C_d}$**) at which C_l starts to saturate, only the drag force increases while the lift saturates. Drag force is an undesirable quantity and lift is what we desire. Hence, we need to find an optimum angle of attack at which we get maximum lift and the drag force is not that high.

Hence, the optimum angle of attack can be roughly considered to be that angle which corresponds to threshold C_d. This is because at this point, the lift is maximum and drag is also not that high. Although this is just a claim, the optimum can be found out by building an objective function in which the lift can be given a positive coefficient and drag a negative coefficient, and applying optimisation on it.

In an actual wind turbine, the power transferred in rotation depends on C_T, which is given by [4] -

$$C_t = C_l sin\phi - C_d cos\phi \tag{1}$$

Also the normal force on the axis is depends on C_A given by-

$$C_a = C_l cos\phi + C_l sin\phi \tag{2}$$

Here, phi is the relative wind angle which is the sum of angle of attack, global pitch angle and the twist angle of blade. [5]

Hence, the objective function can be C_T (after substituting phi, C_l, C_d in terms of angle of attack) and the constraint will depend on maximum normal force that the wind turbine can handle that would depend on C_A. Calculating the optimum angle of attack based on this is yet beyond the scope of expertise of group members.

3.3 For Reference

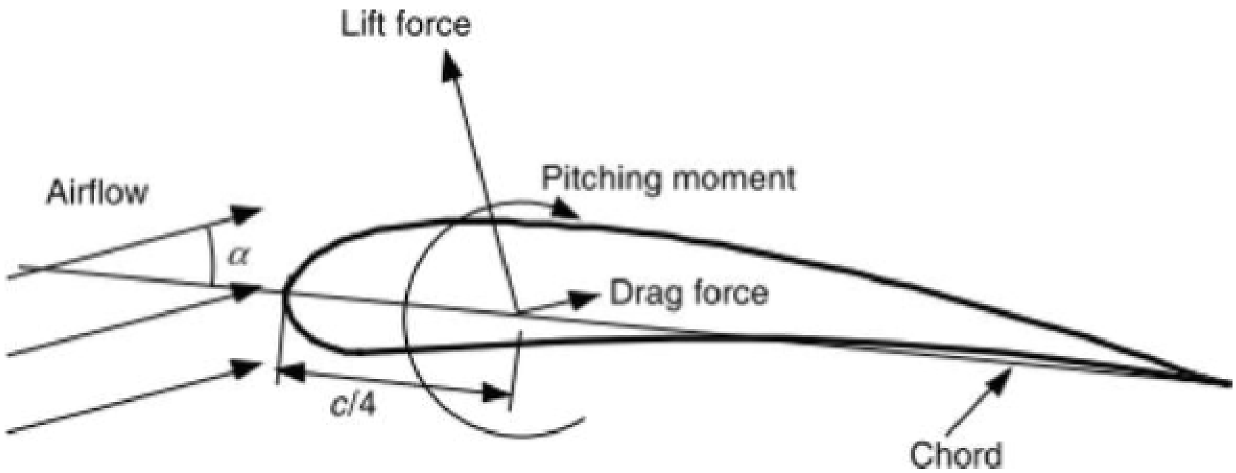

Figure 7: Forces on a Blade

The equations for lift and drag are -

$$F_{\text{drag}} = \frac{1}{2}\rho v^2 C_d A \tag{3}$$

$$F_{\text{lift}} = \frac{1}{2}\rho v^2 C_l A \tag{4}$$

Hence, the total force on the blade considering the fact that lift and drag act orthogonally is -

$$F_{\text{total}} = \frac{1}{2}\rho v^2 A \sqrt{C_l^2 + C_d^2} \tag{5}$$

4 IMAGE GALLERY

Velocity	Angle of Attack	Cd	Cl	Cm
40	0	0.0159	0.1991	0.0858
	5	0.0216	0.6363	0.1853
	10	0.0365	0.9834	0.262
	15	0.0718	1.1379	0.2943
	20	0.1349	1.1605	0.3098
	25	0.2217	1.1596	0.3382
45	0	0.0197	0.2577	0.1109
	5	0.0269	0.8146	0.238
	10	0.0453	1.2587	0.3362
	15	0.0889	1.4595	0.3765
	20	0.1683	1.485	0.3958
	25	0.2776	1.4816	0.4306
50	0	0.0239	0.3244	0.1395
	5	0.0326	1.0158	0.2975
	10	0.0549	1.5695	0.4201
	15	0.1077	1.8234	0.4707
	20	0.205	1.8519	0.4927
	25	0.3394	1.8451	0.5346

Figure 8: The excel sheet containing final results of simulation

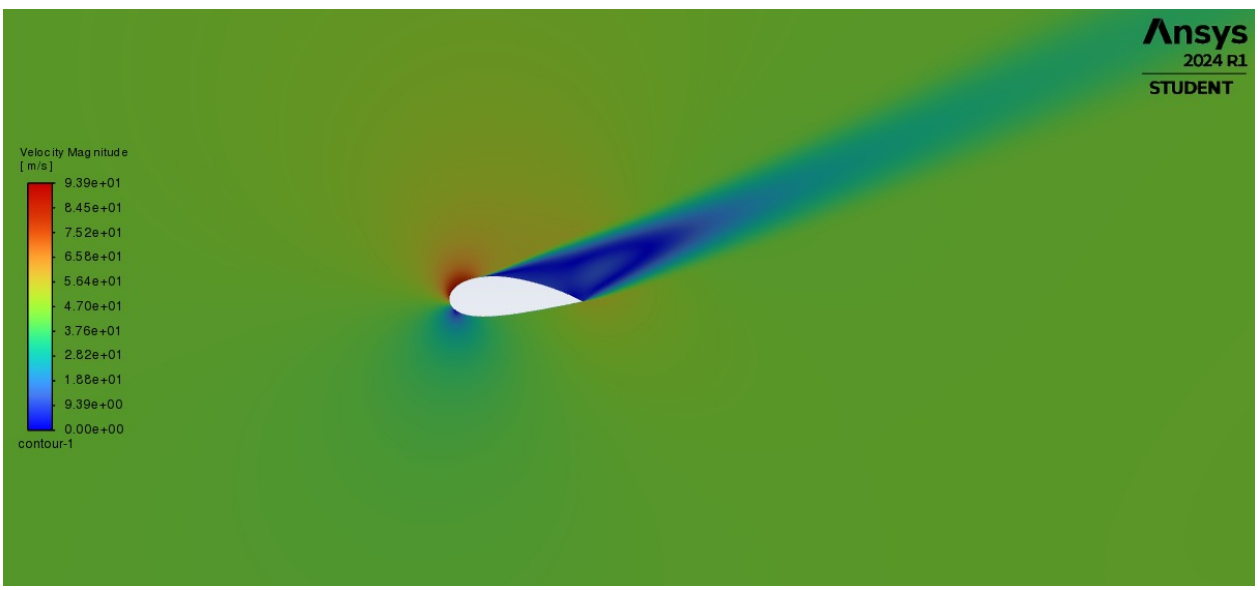

Figure 9: The velocity profile of wind for a wind velocity of 45 m/s and angle of attack of 25 degrees

We can see in figure 9 that the part of airfoil surface where the velocity of wind is maximum will have least pressure. Hence, the lift force is being generated normal to that part of the surface (the reddish part).

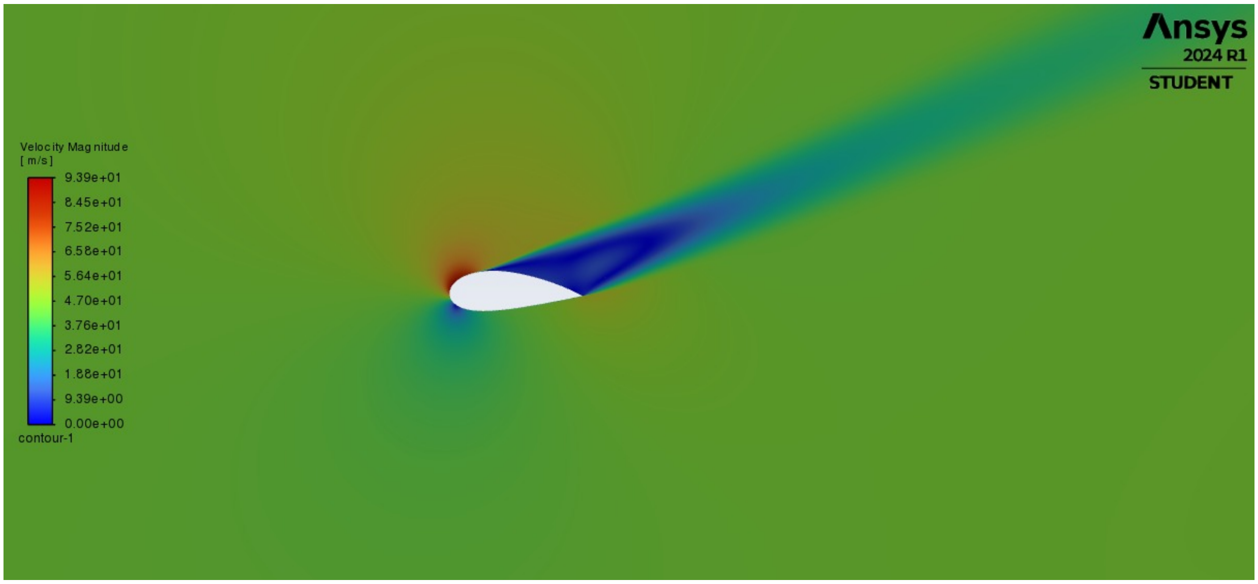

Figure 10: The velocity profile of wind for a wind velocity of 50 m/s and angle of attack of 20 degrees

5 REFERENCES

1. YouTube Video for reference -
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2. Various Airfoils in a Blade -
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5. Relative Wind Angle -
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