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Fluid Structure Interaction and Aero Acoustic Study on Horizontal Axis Wind Turbine

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***Abstract:** Now a days conventional energy resources has decreased due to the continues use, which lead to find an alternative way that is renewable source of energy. Wind energy is one of the clean sources of renewable energy. We can harness the wind energy through wind turbines. In this study a scaled model of 3KW horizontal axis wind turbine is created on the basis of Blade Element Momentum theory. A three dimensional CFD and aero acoustic simulation has been carried out for wind velocity from 4 to 12 meter per second, keeping the tip speed ratio as 6. The various flow characteristics for different wind velocity around the turbine blades are studied.*
***Keywords:** Horizontal axis wind turbine; Blade element momentum theory; Computational fluid dynamics; Aero acoustics; Ansys fluent.*

I. INTRODUCTION

All the physical activities carried out in this world, whether by human beings or by nature is due to the cause of energy flow from one form to the other form. To do any kind of work energy is very much required. The word energy is derived from the Greek word ‘en-ergon’ which means ‘in-work’ or ‘work content’. The output of any work depends upon the amount of energy input. For the economical growth and development of a country energy is very much needed. In this world energy can be mainly of two forms. Non-renewable energy and renewable energy. Limited natural resources that cannot be remade or re-grown in a short amount of time like coal, petrol are called Non-renewable form of energy and the resources which are unlimitedly available in nature and replenished in a short period of time are called Renewable form of energy. Renewable energy is energy generated from natural resources such as sunlight, wind, rain, tides, and geothermal heat which are naturally replenished. The energy which is harnessed by the kinetic energy of the wind is called as the wind energy. Today the world is encountering a worst environmental crisis. Global warming, irregular weather patterns, the price of fossil fuels have increased, oil insecurity and care about climate change have cast a shadow over the future of oil, coal and other conventional forms of energy. To overcome this problem a new energy economy is coming. This new economy obtains the energy in wind. Fossil fuel energies exhaust natural resources are responsible for the adverse environmental impacts leading to change in climatic conditions. On the other side, renewable energies in general, and wind energy in particular, produce considerable less environmental effects than conventional energies. To meet the energy requirements of India in balanced level wind energy is considered as a key resource. A power capacity of 30GW is installed which utilizes wind energy up to December 2017. The Indian government incited the wind program in the year 1983 under this program 34 locations were selected with the average speed of 13 km per hour. The first grid connection of 40 KW was set up at Gujarat in 1985 under the both ownership of local government and private company. Later on with the same ownership structure more wind form was started in Mandvi, Gujarat.[2]

Sriramkrishnan [1] has made a study on a small horizontal axis wind turbine. Modelled based on Blade Element Momentum theory and conducted the CFD simulation for various wind velocities. In this present study a 3WK horizontal axis wind turbine is modelled using the Blade Element Momentum theory with the use of NACA 4418 aerofoil, simulations are carried out in Ansys Fluent and Aero Acoustics characteristics of various flow around the wind turbine blade is studied.

II. METHODOLOGY

The basic steps in designing a wind turbine includes the selection of the power output, appropriate aerofoil, rotor diameter, pitch angle of the blades, number of blades. The power output of a horizontal axis wind turbine is given by equation (1)

$$P = C_p \frac{1}{2} \rho V^3 \pi R^2 \qquad (1)$$

Where
C_p is Power co efficient

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ρ is density of the air (1.2kg/m^3)
R is the radius of the rotor
V is the free wind velocity
By using the above equation we can get the radius of the
Wind turbine as substituting the power output as 3KW and power co efficient as 0.35 considering the electrical loses and Betz limits. The ratio of power absorbed by the wind turbine to the wind power is called the power co efficient. After simplification the radius comes out to be 2.9 meters. For the convenience of the study the model is scaled down to 1:13. This comes out to be 0.225 meters.
Tip speed ratio is the ratio of tip speed to the free wind velocity. It is given by equation (2)

$$TSR \quad (\lambda) = \Omega \frac{R}{V} \qquad (2)$$

Where V is the free wind velocity, R is the radius of the rotor, λ is selected as 6 for the optimum condition for power generation. Ω can be calculated for various wind velocities.
According to the literature review the blade is been divided into eleven equal parts of 20 millimetre. Based on the BEM, chord length and angle of twist for each element is given in below table (1)

Table 1: Dimensions of the blade.

Sl. No.	Radius (r) (mm)	Chord length (c) (mm)	Twist angle (θ)°
1	25	35.872	31.232
2	45	32.852	20.229
3	65	27.13	13.680
4	85	22.452	9.5624
5	105	18.942	6.7943
6	125	16.299	4.8246
7	145	14.267	3.3586
8	165	12.666	2.2280
9	185	11.377	1.3310
10	205	10.321	0.6027
11	225	9.4400	0

The optimum rotor is considered with wake rotation. Angle of rotation is kept constant (6.5°) throughout the blade length to obtain the maximum C_L/C_D ratio.

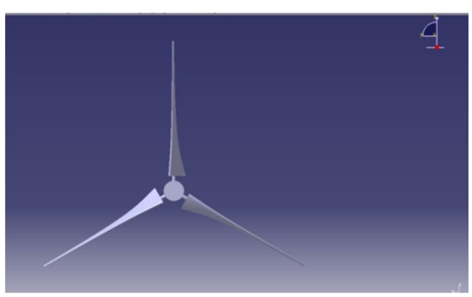

Figure 1: Model assembly of rotor blade assembly done in CATIA.

A. CFD Modelling and Aero Acoustic Analysis

The aerofoil with respective radius, chord length and twist angle are imported to the catia and then joined together to form a blade. Connecting rod and hub were created separately and assembled. Figure (1) shows the rotor assembly modelled in catia. In order to perform the CFD simulations the model is imported to Ansys. Two different domains are created to carry out Moving Reference Frame (MRF), outer domain is stationary and inner domain is the rotating.

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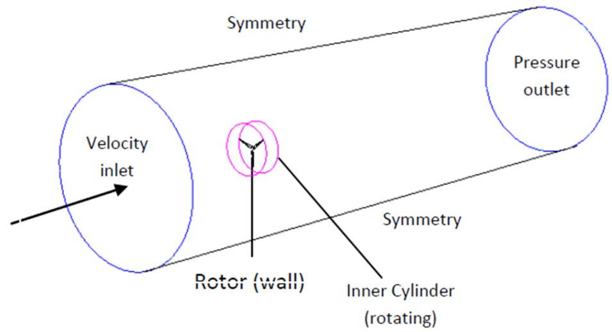

Figure 2: Rotor with stationary and rotating domain.[1]

The dimensions of the rotating domain are given by 1.5d diameter, 0.5d length. Stationary domain is given by 5d diameter and 20d length. 5d of length in upstream and 15d of length in downstream. As shown in figure (2) Where d is the diameter of the rotor. Fine meshing is created near the rotor and coarse meshing is created in stationary domain, since we are concentrating only on the flow characteristics near the rotor blades. As this is an external flow condition the rotor blade assembly is suppressed, it is defined as wall with no slip condition and the surface of the rotor body is meshed with 1millimeter triangular element. 0.84 Million elements are present in overall body. The inner domain face is mentioned as interface between both the domains.

The upstream and downstream faces are defined as velocity inlet and pressure outlet boundary conditions respectively. The curved surface of the stationary domain is given as symmetry boundary condition. To obtain the good results pressure based solution is selected. Hydraulic diameter is selected of the outer diameter and for the fully development of the turbulence intensity is chosen as 5%. K-omega shear stress transport turbulence model is selected has it works well for the larger separated flow field then k-epsilon model. Acoustics model is enabled, Broadband nose source is selected with $4e^{-10}$ reference acoustic power for air.

III. RESULTS AND DISCUSSION

The solution is obtained until the steady state convergence. The normal force and the aero acoustics results are obtained. Considering the rotating domain area as characteristic area and integrating the pressure along the same face normal force is calculated. The plots of normal force for various wind velocity is shown in the figure 3

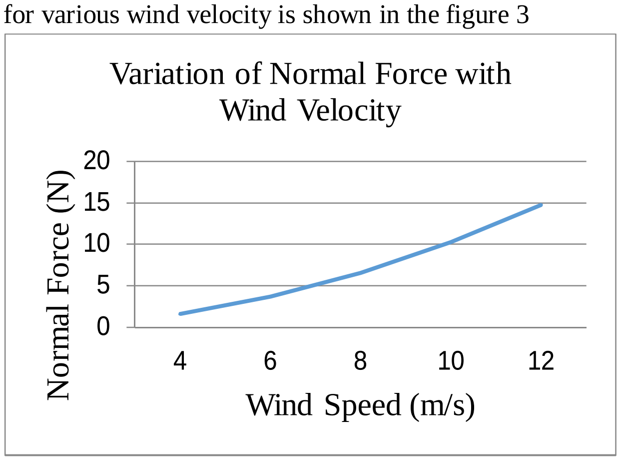

Figure 3: Variation of the normal force with the wind velocity.

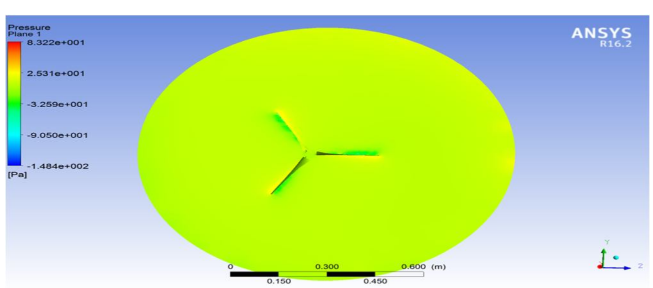

Figure 4(a): Pressure Contour for 4m/s Wind Velocity

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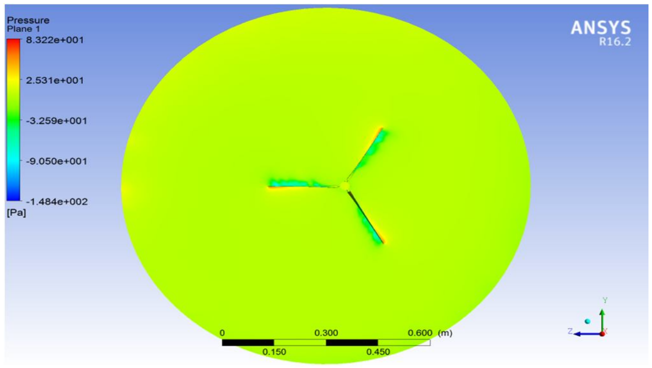

Figure 4(b): Pressure Contour for 6m/s Wind Velocity

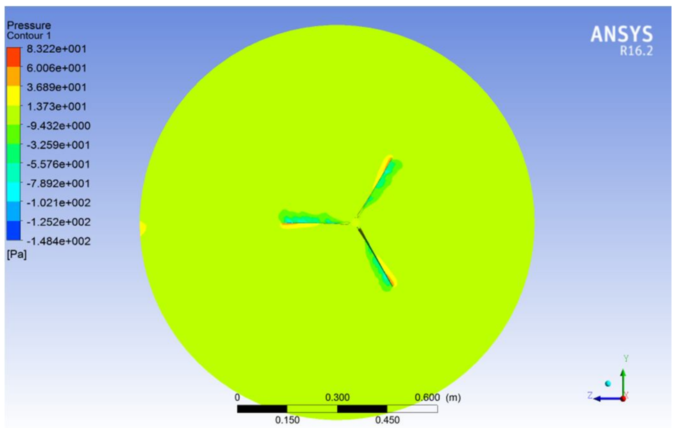

Figure 4(c): Pressure Contour for 8m/s Wind Velocity

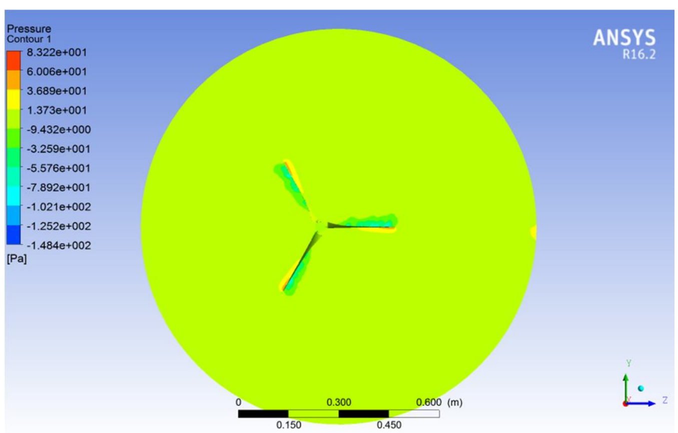

Figure 4(d): Pressure Contour for 10m/s Wind Velocity

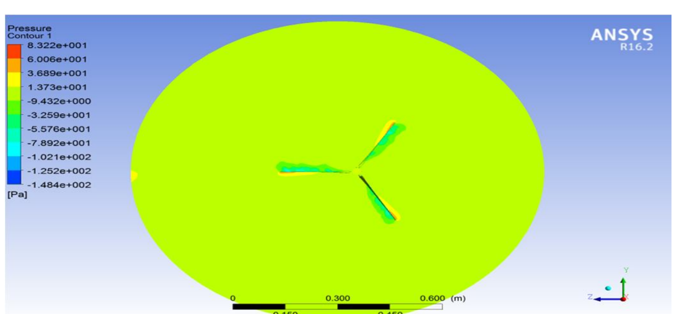

Figure 4(e): Pressure Contour for 12m/s Wind Velocity

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In model, Ffowcs Williams-Hawkings analogy is used as acoustics model and reference acoustic power is considered as $4e^{-10}$ for the atmospheric air.[3] Simulations are carried up to the convergence of solution for the wind velocity range from 4m/s to 12m/s. Figure 5 (a), (b), (c), (d) and (e) shows the noise level induced for wind velocity 4m/s, 6m/s, 8m/s, 10m/s and 12m/s respectively.

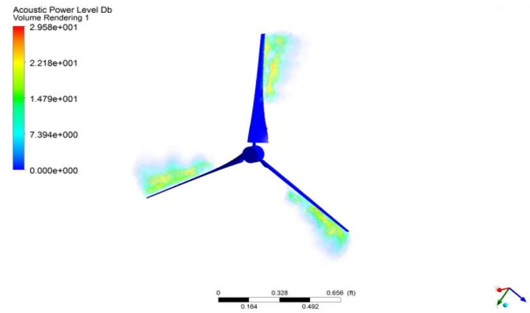

Figure 5(a) Aero Acoustics contour for 4m/s

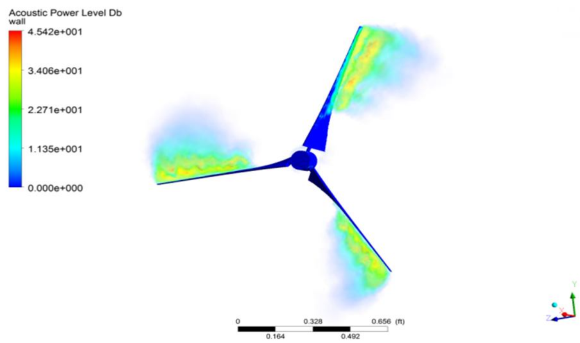

Figure 5(b) Aero Acoustics contour for 6m/s

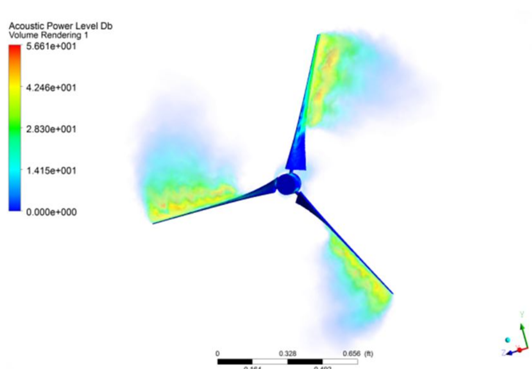

Figure 5(c) Aero Acoustics contour for 8m/s

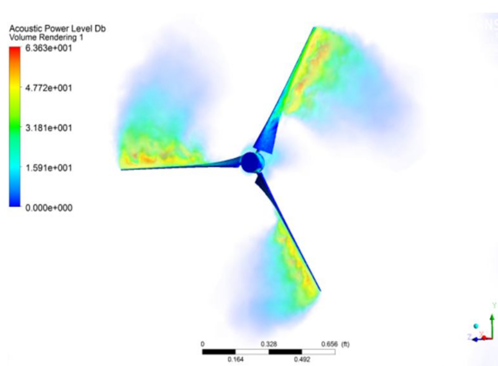

Figure 5(d) Aero Acoustics contour for 10m/s

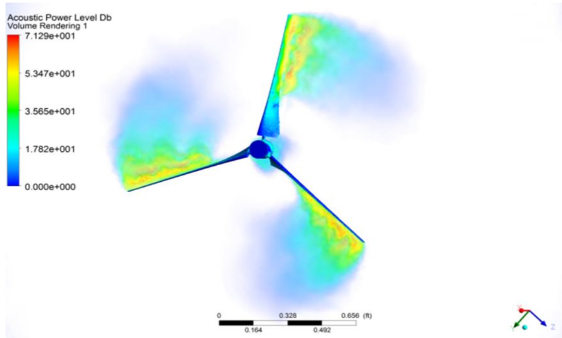

Figure 5(e) Aero Acoustics contour for 12m/s

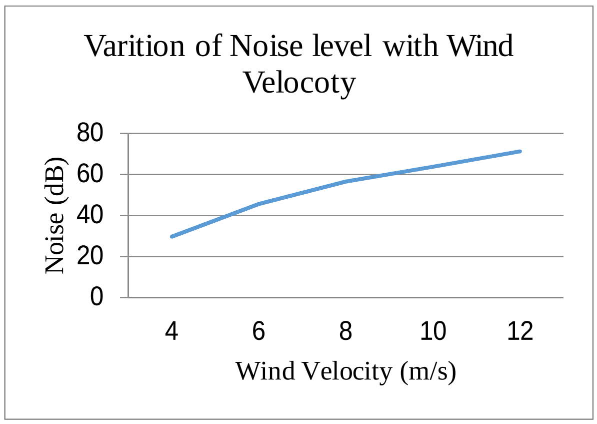

Figure 6 Variation of Noise Level with Wind Velocity

IV. CONCLUSIONS

In this study BEM theory is been used to obtain the blades of a 3KW horizontal axis wind turbine. NACA 4418 aerofoil with varying chord length and twist angle is used for the blade surface. The wind turbine blade assembly is modelled with the help of CATIA V5. Commercial Ansys Fluent 15 is used to carry out the computational fluid dynamic analysis and aero acoustics. The simulations are conducted by keeping constant tip speed ratio for moving reference frame technique. Variation of pressure, normal force and noise level is studied for wind velocity range from 4m/s to 12m/s.

A. It is observed that the pressure exerting on the blades by wind increases with increases in velocity of wind.
B. Maximum pressure exerted on a wind turbine blade is near the tip end of the blade.
C. Normal force increases with wind velocity, Variation of normal force for various wind velocity is plotted.
D. Aero acoustic simulations are carried out to study the noise level induced.
E. Noise level induced due to the fluid structural interaction increases with the wind velocity.
F. The way which noise propagates is obtained and studied.
G. The maximum noise level induced is 71.29 dB, which lies below the threshold noise which is not harmful to human beings, so this wind turbine can be used in urban areas and on top of the buildings which helps in generating the electricity for daily needs.

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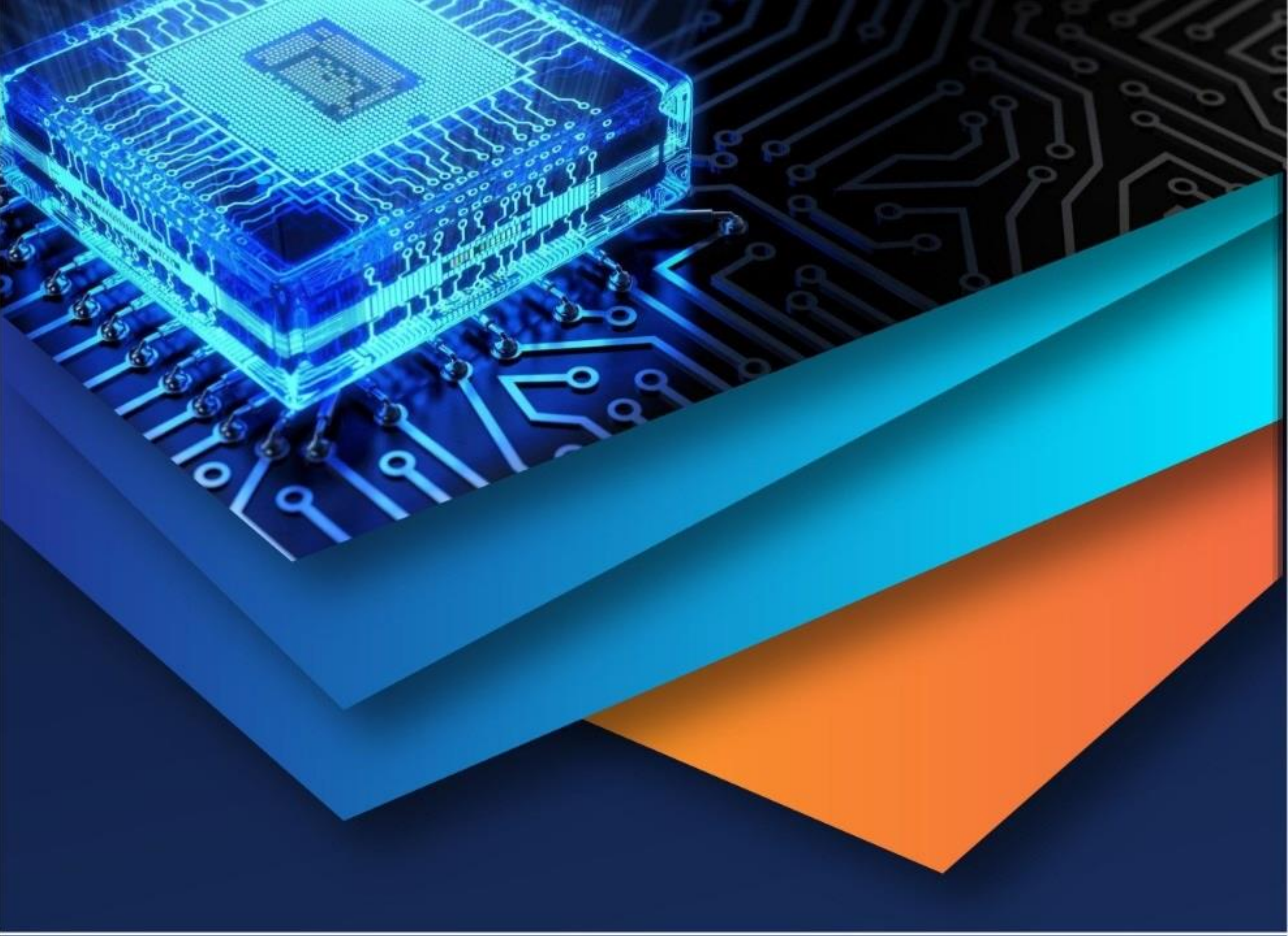

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