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Free Convection Effects on Stoke's Problem for a Vertical Plate in a Rotating Dissipative Fluid with Constant Heat Flux

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Abstract: A finite difference Analysis of Stokes problem for a vertical plate has been considered for an incompressible viscous fluid on taking into account viscous dissipative fluid with constant heat flux . ..It is observed that If 't' increase then axial velocity rise whereas transverse velocity going to fall. As rotational speed (Ek) increases there is fall in axial velocity and transverse velocity, As "Ec" increases axial skin friction decreases but transverse skin friction increases.
Key words: Rotating dissipative fluid, constant heat flux, etc.

I. INTRODUCTION

The first exact solution of the line arised Navier- Stokes equation was presented by Stokes (1851), which was concerned with the flow of a viscous fluid past an impulsively started infinite horizontal plate in a stationary mass of fluid. Stewartson (1951) studied this Stokes problem for a semi- infinite plate and presented an analytical solution and Hall(1969) presented a finite –difference solution to Stewartson's problems. Now, if the impulsive motion is given to an isothermal vertical plate surrounded by a stationary mass of fluid, how the motion takes place?. This was firstly studied by Soundalgekar (1977) who studied the effects of free-convection currents on flow near the plate and the past an accelerated infinite plate, it was studied by soundalgekar and Gupta. Then Soundalgekar and Lahurikar(1996) gives the effects of mass transfer on flow past an accelerated infinite vertical plate under constant heat flux, by using implicit finite difference technique. Now, the situation considered in all the studies is the motion of the plate in its own plate in a stationary surrounding fluid. But in many practical problem like rotating disk electrode the surrounding fluid need not be stationary. If the vertical plate is given an impulsive motion in its own plate in an infinite mass of fluid rotating about the plate, What is the effect of rotation on the motion past such a moving plate.? Was studied by Soundalgekar & Jaiswal (1999),under the condition that vertical plate is moving impulsively in its own plate in a rotating flow, where assumption is that the heat is supplied at an uniform rate to the plate when starts moving in the upward direction.

In many geophysical applications the fluid is found to be always rotating due to rotation of the earth. What is the effect of rotation and free convection currents on the motion of the fluid near an impulsively started infinite vertical plate without taking into account viscous dissipative heat?. This was studied by Lahurikar (2010) gave exact solution by Laplace transform technique.

Now it is proposed to study the free convection effect on Stoke's problem on taking into account vertical plate in a rotating dissipative fluid with constant heat flux. It can solved by using finite difference technique.

II. MATHEMATICAL ANALYSIS

Consider an unsteady motion of viscous incompressible dissipative fluid past an infinite vertical plate, The x'-axis is taken along the in the vertically upward direction and the z'-axis is taken normally to the plate y' -axis in the plate of the plate normal to both $x'z'$ −plate .Initially the fluid and the plate rotate in unison with an uniform angular velocity Ω' about the z' −axis.Relative to the rotating fluid . the plate is given an impulsive motion so that it starts moving with o velocity U_0 in its own plate along the x' −axis and heat is supplied at a consant rate q' per unit area. Under this physical situation by usual Bossiness's approximation the flow can be shown to be governed by the following system of coupled differential equations in non –dimensional form.

It can reduces to the following non dimensional form

$$\frac{\partial u}{\partial t} - 2E_K Gr\, v = \frac{\partial^2 u}{\partial z^2} + Gr\, \theta \qquad (1)$$

$$\frac{\partial v}{\partial t} + 2E_K\, Gr\, u = \frac{\partial^2 v}{\partial z^2} \qquad (2)$$

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$$Pr\frac{\partial\theta}{\partial t} = \frac{\partial^2\theta}{\partial z^2} + \text{Pr}\, E_C\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right] \qquad (3)$$

And initial boundary conditions are

$$u = 0, \quad v = 0 \quad \theta = 0, \quad for\ all\ z, t \le 0$$

$$u = 1, \quad v = 0 \quad \frac{\partial\theta}{\partial z} = -1 \quad at\ z = 0 \quad t > 0$$

$$u = 0, \quad v = 0 \quad \theta = 0 \quad as \quad z \to \infty\ , \quad t > 0 \qquad (4)$$

we now introduce the following non-dimensional quantities.

$$U = \frac{u'}{U_0}, \quad v = \frac{v'}{v_0}, \quad t = \frac{t'U_0{}^2}{v}, \quad z = \frac{z'U_0}{v}$$

$$G_r = \frac{v^2 g\beta q}{kU_0{}^4}, \theta = \frac{T' - T'\infty}{{qv}/{kU_0}}, \quad E_c = \frac{U_0{}^2}{Cp({qv}/{kU_0})}, E_K = \frac{\Omega' v}{U_0{}^2 Gr}, \quad Pr = \frac{\mu C_P}{K} \qquad (5)$$

As equation (1)-(3) are coupled nonlinear system of equations, subject to the boundary condition(4) an analytical solution is not possible so we now solved it by finite difference technique.
Then the equation reduce the following form.

$$u_{i,j+1} = u_{i,j} + \Delta t Gr\{2E_K v_{i,j} + \theta_{i,j}\} + \frac{\Delta t}{(\Delta z)^2}\{u_{i+1,j} - 2u_{i,j} + u_{i-1,j}\} \qquad (6)$$

$$v_{i,j+1} = v_{i,j} + 2\Delta t E_k Gr\, u_{i,j} + \frac{\Delta t}{(\Delta z)^2}\{v_{i+1,j} - 2v_{i,j} + v_{i+1,j}\} \qquad (7)$$

$$\theta_{i,j+1} = \theta_{i,j} + \frac{\Delta t}{Pr(\Delta z)^2}\{\theta_{i+1,j} - 2\theta_{i,j} + \theta_{i-1,j}\} + E_c\frac{\Delta t}{(\Delta z)^2}\{(u_{i+1,j} - u_{i,j})^2 + (v_{i+1,j} - v_{i,j})^2\} \qquad (8)$$

The index i refers to z and j to t .Δz is taken a 0.1 from (4) the initial conditions at z=0 take the form

$$u(0{,}0) = 1 \qquad v(0{,}0) = 0 \qquad \theta(0{,}0) = 0 \qquad (9)$$

This implies that due to the sudden velocity given to the plate , the velocity at z=0 can changes discontinuity to 1 from its value 0 at t< 0 but as the effects of the temperature at the wall only gradually and therefore $\theta(0)$ is taken as zero, the initial condition for z > 0 are

$$u(i, 0) = 0 \qquad v(i, 0) = 0 \qquad \theta(i, 0) = 0 \qquad (10)$$

From the equation (4),the boundary condition at z=0 for u, v Taken the form

$$u(0, j) = 1 \qquad v(0, j) = 0 \qquad (11)$$

We observe that θ has to be computed from (8) at i=0 also i. e. on the plate itself and will involve on the right hand side of (8) the value of θ at i=-1, i. e. at a horizontal grid point to the time axis . the second equation in (4) converted to the finite difference scam can be written in either of form,

$$\frac{\theta(1,j) - \theta(-1,j)}{2\Delta z} = -1 \ or \ \frac{\theta(0,j) - \theta(-1,j)}{\Delta z} = -1$$

Which gives the value of θat (-1,j) and the average of these is taken to be used on the right hand side of (8)

$$u(41{,}0) = 0 \quad v(41{,}0) = 0 \quad \theta(41{,}0) = 0 \quad (8)$$

Here i corresponds to z and j corresponds to t
Here infinity is taken as y=4.1, it has been observed that all goes tends to zero around y =4.
We now study the skin friction and the rate of heat transfer It is given in non-dimensional form as

$$\frac{\tau_{ax}}{\sqrt{Gr}} = -\frac{du}{dz} \mid z = 0, \qquad \frac{\tau_{tr}}{\sqrt{Gr}} = -\frac{dv}{dz} \mid z = 0$$

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The numerical values of $\frac{\tau_{ax}}{\sqrt{Gr}}$ and, $\frac{\tau_{tr}}{\sqrt{Gr}}$ evaluated by using Newton's interpolation formula for five points for the derivatives and the numerical values are entered in table I

TABLE I

t	Ek	Ec	Gr	Pr	Δt	$-\tau_{ax}$	$-\tau_{tr}$
0.2	0.1	0.05	0.2	0.71	0.00125	1.23377	0.0101
0.2	0.5	0.05	0.2	0.71	0.00125	1.23409	0.05051
0.2	1	0.05	0.2	0.71	0.00125	1.23512	0.10101
0.2	2	0.05	0.2	0.71	0.00125	1.23921	0.20188
0.4	0.1	0.05	0.2	0.71	0.00125	0.83969	0.01437
0.4	0.5	0.05	0.2	0.71	0.00125	0.84062	0.07184
0.4	0.1	0.05	0.2	0.71	0.00125	0.83969	0.01437
0.4	0.1	0.1	0.2	0.71	0.00125	0.83796	0.01438

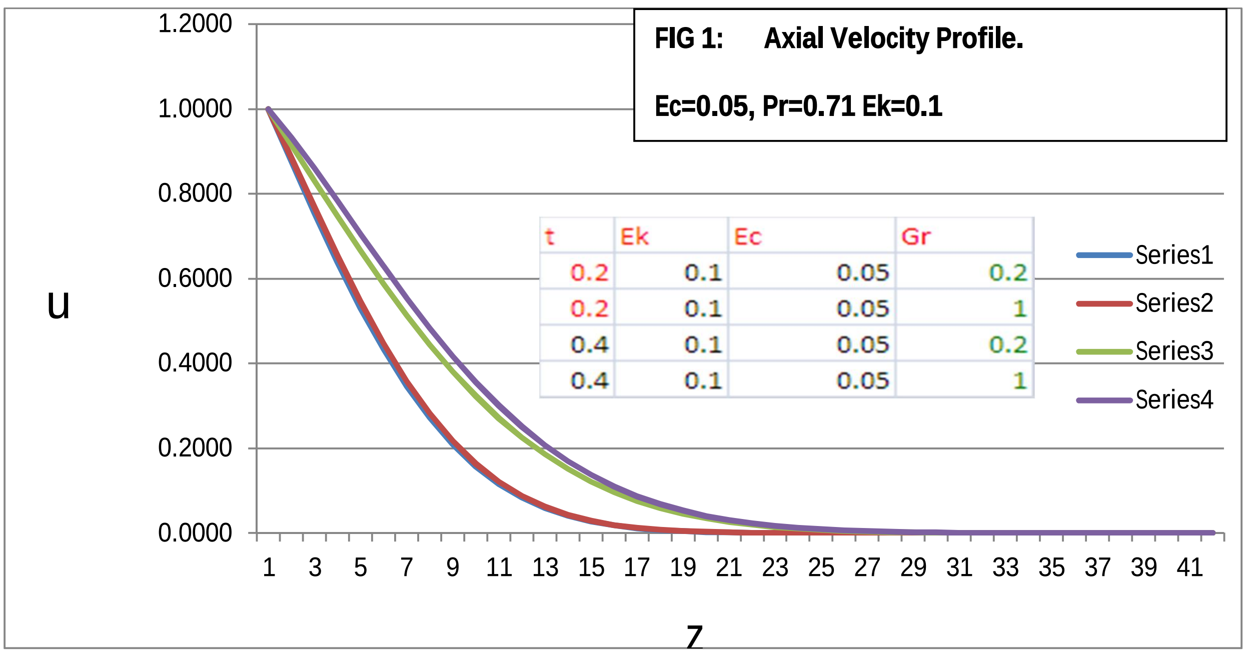

FIG 1: Axial Velocity Profile.

Ec=0.05, Pr=0.71 Ek=0.1

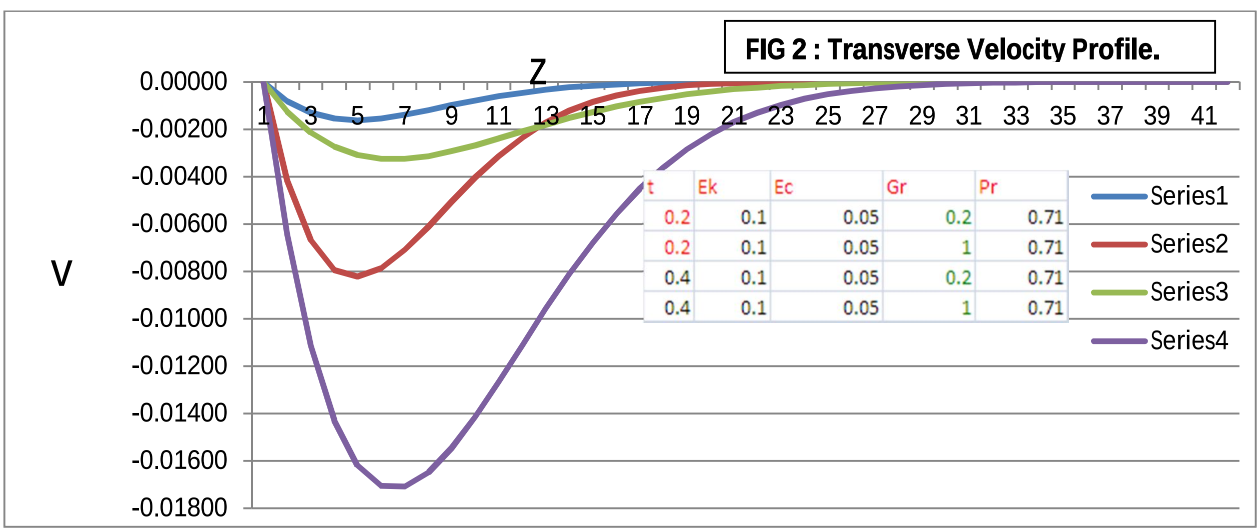

FIG 2 : Transverse Velocity Profile.

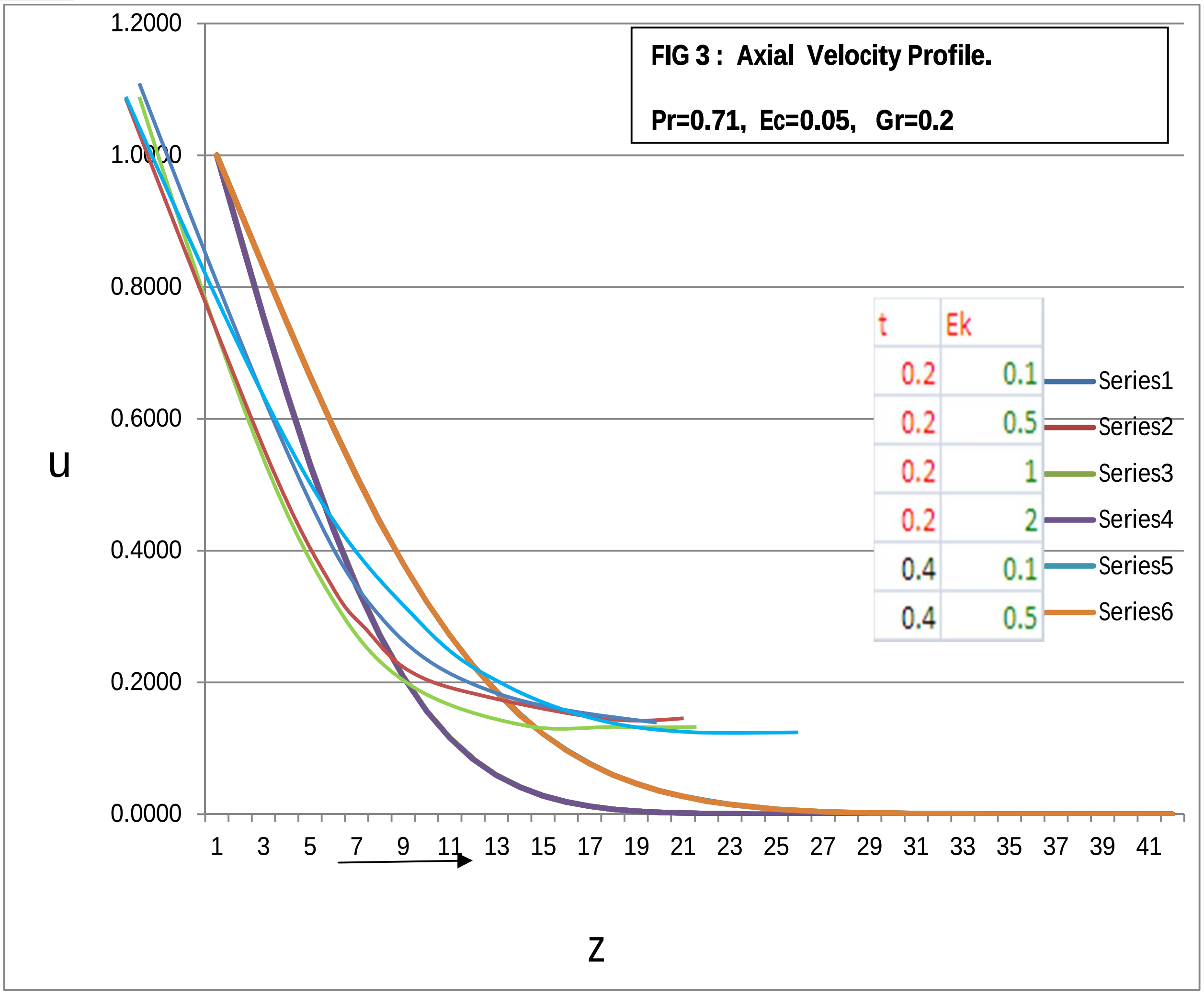

FIG 3 : Axial Velocity Profile.

Pr=0.71, Ec=0.05, Gr=0.2

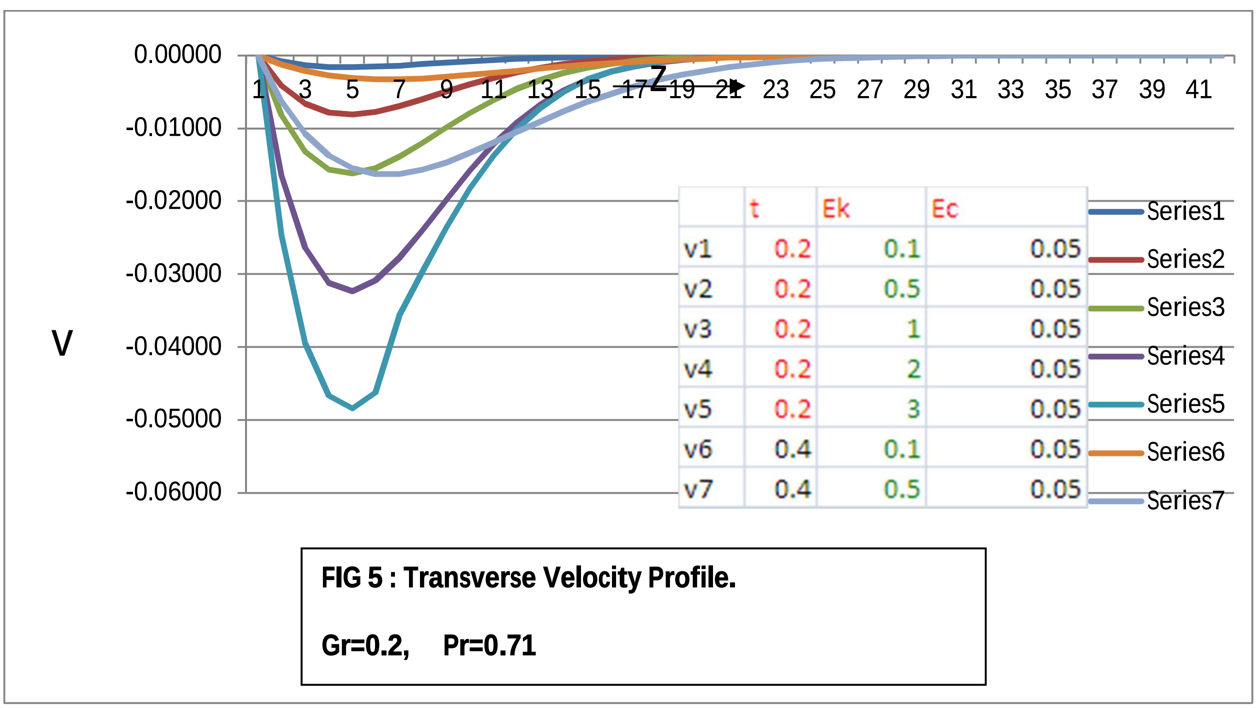

FIG 5 : Transverse Velocity Profile.

Gr=0.2, Pr=0.71

III. CONCLUSIONS

It is observed that If 't' increase then axial velocity rise whereas transverse velocity going to fall. As rotational speed (Ek) increases there is fall in axial velocity and transverse velocity, As "Ec" increases axial skin friction decreases but transverse skin friction increases.

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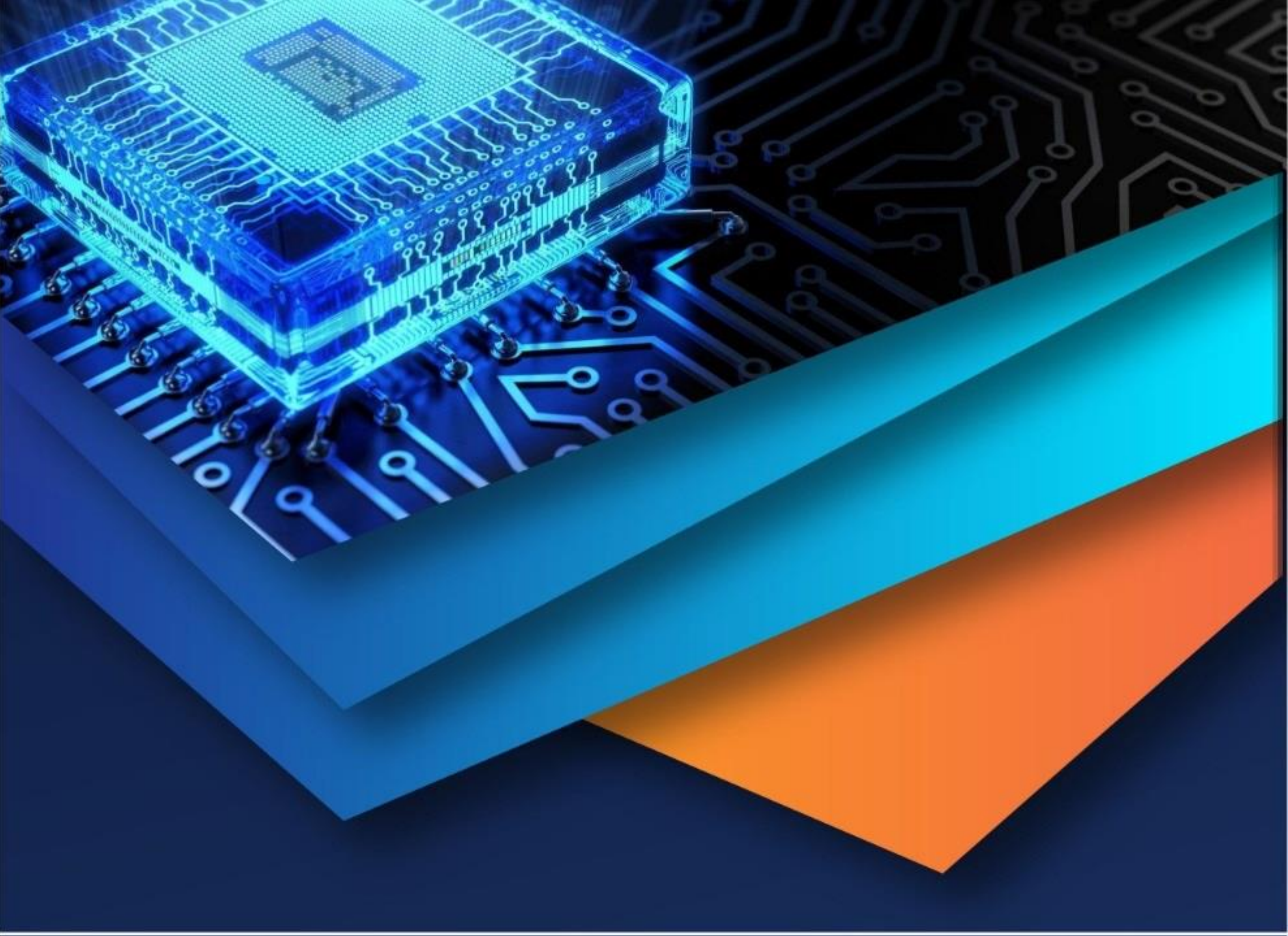

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