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Simultaneous Solutions of Three Dimensional MHD Rotating Flow of Non-Newtonian Fluid over an Elongated Surface

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***Abstract:** Magnetohydrodynamic 3D flow of non-Newtonian fluid past a rotating extending surface in with thermophoresis and Brownian moment is investigated theoretically. The governing partial differential equations are transformed as ordinary differential equations with the help of suitable similarities and solved numerically using the bvp4c Matlab package. Simulataneous solutions are presented for Casson and regular fluid cases. From the solution, it is perceived that the flowis affected by sundry physical quantities like Brownian moment and thermophoresis. The influence of various parameters on the flow, temperature and concentration fields are studied with the help of graphical and tabular results. From the results we infer that the rotation decreases the flow field and encourages the thermal field.*
***Keywords:** MHD, Heat transfer, Mass transfer, Thermophoresis and Brownian moment, Rotation.*

I. INTRODUCTION

The study of MHD is the relation between electric and magnetic properties. It has extensive applications in the manufacturing fields like bearing, MHD generators, pumps, flow meter, etc. MHD boundary layer is noticed bymany technical systems retaining plasma flow and liquid metal opposite to the magnetic fields. This type of force is called resistive force. Now, many researchers illustrated the stydu of MHD flows past a stretching surface [1-5]. The study of non-Newtonian fluids have multiple applications in industry and engineering. In particular separation of crude oil from petroleum products. Casson fluid is also consider as a non-Newtonian fluid. In 1859 Casson introduced the Casson fluid.It reveal the yield stress. When shear stress is small it acts like a solid otherwise it is a liquid. Tomato sauce, Jelly, Paint, vigorous fruit and soup are Casson fluid example. The heat transfer flow over a stretching sheet with radiation was illustrated by Pramanik [6] and observed that rising values of Casson parameter enhances the surface stress. The MHD heat transfer Casson fluid past a stretching sheet in the presence of magnetic field analysed by Hayat et al. [7] and Nadeem et al. [8]. Sulochana and Sandeep [9] discussed the convective MHD flow towards a stretching sheet with the slip effects. They concluded that rising values of magnetic field parameter depreciate Nusselt number and skin friction. The researchers [10-12] analysed the convective heat transfer in MHD flows. Abdul Hakeem et al. [13] presented the influence of inclined Lorentz force on Casson fluid towards a stretching surface. The numerical solution of entrophy generation towards the radiation of MHD Careau fluid flow over a stretching surface eas explained by Bhatti et al. [14]. Sathish Kumar et al. [15] explained the MHD flow on heat and mass transfer over a stretching surface with a suction/injection effect. The study of MHD heat and mass transfer on Casson fluid towards a stretching surface was analyzed by Nadeem et al. [16].Gireesha et al. [17] presented the numerical solution for boundary layer MHD heat and mass transfer past a stretching sheet with chemical reaction effect. Sandeep [18] studied the effect of aligned magnetic field on thin film flow of a nano fluid. Khan et al. [19] discussed the magnetic field effect on MHD flow of Careau fluid with convective boundary condition. The effect of Brownian motion and thermophoresis on heat and mass transfer of viscous fluid over a cylinder was discussed by Hayat et al. [20]. The effect of Cattaneo-Christov heat flux model on heat transfer of a Jaffrey fluid past a stretching sheet was analysed by Hayat et al. [21,22] and found that for larger value of the Schmidt number depreciate the concentration field. The numerical study of heat transfer of nanofluid flow through a channel with velocity slip condition was investigated by Khan et al. [23]. The 3D MHD squeezing flow of nanofluid towards a stretching wall and plate with magnetic fields effects was investigated by Khan et al. [24-30]. In this paper, we analysed the effect of thermophoresis and Brownian moment on the MHD rotation flow of Casson fluid towards a stretching sheet withmagnetic field effect. We discussed the dualsolutions for the Newtonian fluid and non-Newtonian fluid cases. The resulting non-linear PDE were changed into the set of ODE and solved numerically using the bvp4c Matlab package. The effect of various parameters on flow, thermal and concentration fields, along with skin friction and Nusselt number are investigated through tables and graphs.

II. FORMULATION OF THE PROBLEM

3D, steady, laminar, incompressible flow of magnetohydrodynamic Casson fluid past a stretching sheet is considered. Transverse magnetic field is applied as shown in Fig 1. The flow of the rotating fluid is considered in the positive z-plane. It is considered that the sheet extends in its individual plane with the velocity commensurate to $e^{\left(x/L\right)}$. It is alos considered that the fluid is rotating about the z-axis with steady rate Ω. Here T_w is the fluid temperature near the wall.

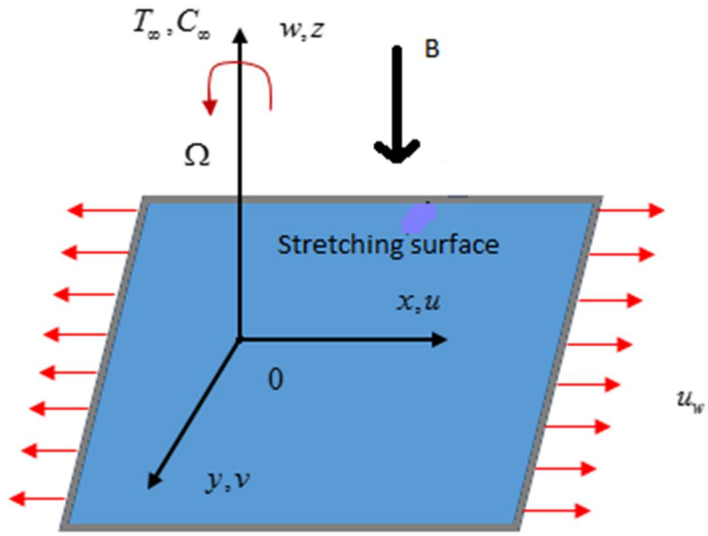

Fig.1 Flow configuration

As per the above assumptions, the governing equations can be written as

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0, \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=2\Omega v+v\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial z^2}-\frac{\sigma B_0^2}{\rho}u, \tag{2}$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-2\Omega u+v\left(1+\frac{1}{\beta}\right)\frac{\partial^2 v}{\partial z^2}-\frac{\sigma B_0^2}{\rho}v, \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha\frac{\partial^2 T}{\partial z^2}+\tau\left(D_B\frac{\partial T}{\partial z}\frac{\partial C}{\partial z}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial z}\right)^2\right), \tag{4}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}=D_B\frac{\partial^2 C}{\partial z^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial z^2}, \tag{5}$$

With the boundary conditions

$$\begin{gathered} u=u_w(x)=u_0\,\mathrm{e}^{\left(x/L\right)}, v=0, -k\frac{\partial T}{\partial z}=h\left(T_w-T\right), D_B\frac{\partial C}{\partial z}+\frac{D_T}{T_\infty}\frac{\partial T}{\partial z}=0 \;\; at \;\; z=0, \\ u\to 0, T\to T_\infty, C\to C_\infty, \qquad as \;\; z\to\infty \end{gathered} \tag{6}$$

Where Ω is rotation parameter, B_0 is the magnetic induction parameter, β is Casson parameter, ρ is the fluid density, α is the thermal diffusivity, D_m is mass diffusivity, $D_{\mathbf{B}}$ is coefficient of diffusion, T_w, T_∞ are wall temperature and free steam temperature and C_∞ is the free stream concentration.

The following similarities are used to convert the governing equations as dimensionless

$$u = u_0\, e^{(x/L)}\, f'(\eta), w = -\sqrt{\frac{\nu u_0}{2L}}\,\left(f(\eta) + \eta f'(\eta)\right),$$
$$v = v_o\, e^{(x/L)}\, g(\eta),\ \eta = \sqrt{\frac{u_0}{2\nu L}}\, e^{(x/L)z}, \theta = \frac{T - T_\infty}{T_w - T_\infty},\ \phi = \frac{C - C_\infty}{C_\infty}, \quad (7)$$

with the help of Eq. (7), Eqs. (1)-(6) can be reduced as

$$\left(1 + \frac{1}{\beta}\right) f''' + ff'' - 2f'^2 + 4\Omega g - Mf' = 0, \quad (8)$$

$$\left(1 + \frac{1}{\beta}\right) g'' + fg' - 2f'g - 4\Omega f' - Mg = 0, \quad (9)$$

$$\frac{1}{\Pr}\theta'' + f\theta' + Nt\theta'^2 + Nb\theta'\phi' = 0, \quad (10)$$

$$\phi'' + \left(\frac{Nt}{Nb}\right)\theta'' + Scf\phi' = 0, \quad (11)$$

with the transformed boundary conditions

$$f'(0) = 1,\ f(0) = 0,\ g'(0) = \lambda, \phi'(0) + \left(\frac{Nt}{Nb}\right)\theta'(0) = 0,$$
$$\theta'(0) = -\gamma(1 - \theta),\ \ f'(\infty) = g'(\infty) = \theta(\infty) = \phi(\infty) = 0, \quad (12)$$

Where the nondimensional parameters are defined as Ref [10].

$$Sc = \frac{\nu}{D_B}, M = \frac{\sigma B_0^2}{\rho u_0}, \lambda = \frac{v_0}{u_0},\ \Pr = \frac{\nu}{\alpha},\ \gamma = \frac{h}{k}\sqrt{\left(\frac{2\nu L}{u_0}\right)},\ Nt = \frac{\tau D_T(T_w - T_\infty)}{T_\infty \nu}, Nb = \frac{\tau D_B C_\infty}{\nu} \quad (13)$$

Wall friction and local Nusselt number can be defined as

$$C_{fx} = \left(1 + \frac{1}{\beta}\right)\frac{\tau_{zx}|_{z=0}}{\rho u_w^2},\ C_{fy} = \left(1 + \frac{1}{\beta}\right)\frac{\tau_{zy}|_{z=0}}{\rho u_w^2},$$
$$\mathrm{Re}_x^{1/2} C_{fx} = \left(1 + \frac{1}{\beta}\right) f''(0),\ \mathrm{Re}_y^{1/2} C_{fy} = \left(1 + \frac{1}{\beta}\right) g'(0), \quad (14)$$

Where, $\mathrm{Re}_x = \frac{u_w L}{\nu}$ - reduced Reynolds number.

$$Nu_x = \frac{x q_w}{k(T_w - T_\infty)}$$
$$\frac{L}{x}\sqrt{\frac{2}{\mathrm{Re}_x}} Nu_x = -\theta'(0) \quad (15)$$

III. RESULTS AND DISCUSSION

The system of ordinary differential equations (8)-(11) through the boundary conditions in equation (12) are numerically solved using R-K based shooting method. For numerical computations we considered the non-dimensional parameter values as Sc=0.3, β=0.5, Pr=6, Nb=0.5, Nt=0.5, m=0.1, M=1. These values are invariant unless otherwise specified in the tables and graphs. The influence of the of the different relevant parameters on the flow, temperature and concentration distributionalong with the reduced Nusselt number and wall friction is presented and discussed through tables and graphs.

Figs. 2 and 3 depict the Effect of magnetic field parameter M on velocity and temperature profiles for both Newtonian and non-Newtonian cases. We observed that an increasing values of M increases the temperature profile and depreciate the velocity profile for both cases. Generally, the transverse magnetic field produce the body force,to be exact the Lorentz force, which opposes the motion of the fluid and encourage the thermal boundary layer thickness.

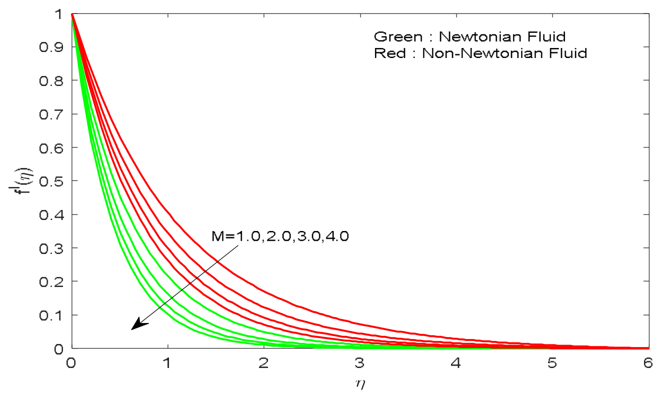

Fig. 2. Effect of M on $f'(\eta)$

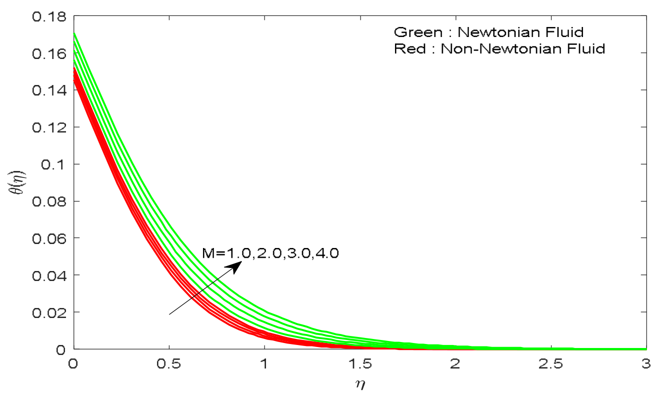

Fig. 3. Effect of M on $\theta(\eta)$

Figs. 4 and 5 depict the effect of rotation parameter Ω on velocity and temperature profiles. We observed that the increasing values of rotation parameter Ω increases the temperature field and depreciate the velocity profile. Physically, this may happen due to the nanoparticle concentration being directly proportional to the rotation parameter. Fig. 6. Shows the nature of the temperature field for increasing values of Nt. Here, we noticed that rising values of Nt enhances the temperature causing an increase in the wall temperature.

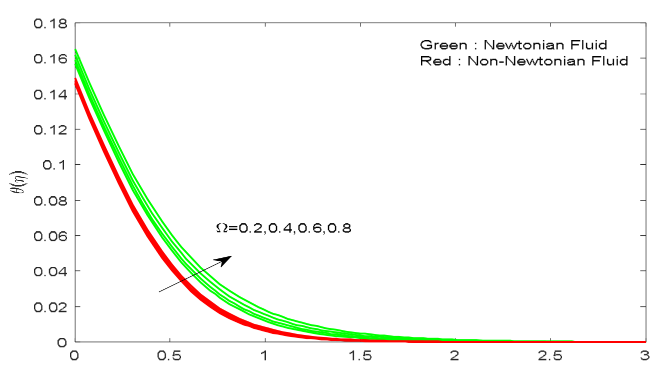

Fig. 4. Effect of Ω on $\theta(\eta)$

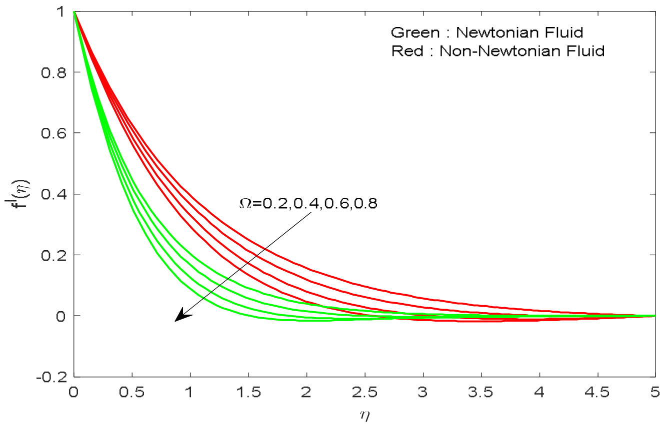

Fig. 5. Effect of Ω on $f'(\eta)$

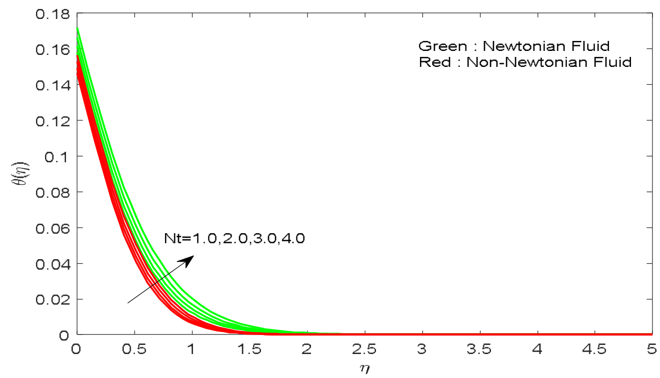

Fig. 6. Effect of Nt on $\theta(\eta)$

The effect of Sc on the temperature field is plotted in Fig. 7. It can be seen that increasing values of Sc enhances the temperature field. Fig. 8. Shows the influence of Ω on $g^1(\eta)$. It is observed that the rising values of Ω increases $g^1(\eta)$. Fig. 9. depict the effect of magnetic field parameter on $g^1(\eta)$. Here, we see that an increasing values of M enhances $g^1(\eta)$.

Table shows the effect of various pertinent parameterson the skin friction and Nusselt number. It isevident that rising values of magnetic field parameter and rottion parameter declines the heat transfer rate and friction factor for both cases.

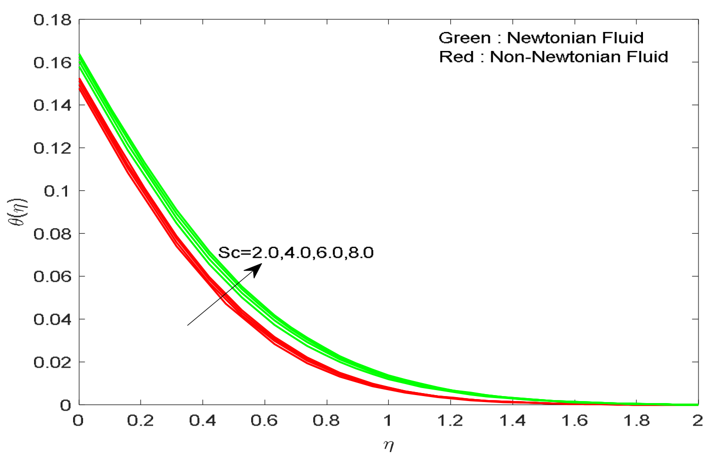

Fig. 7. Effect of Sc on $\theta(\eta)$

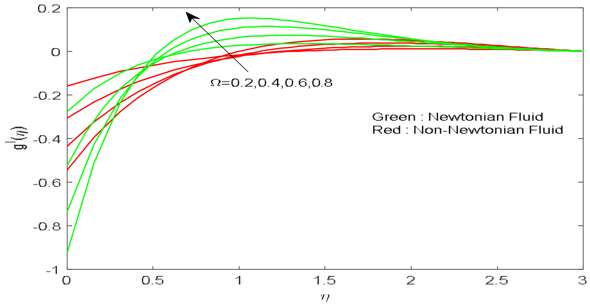

Fig. 8. Effect of Ω on $g^1(\eta)$

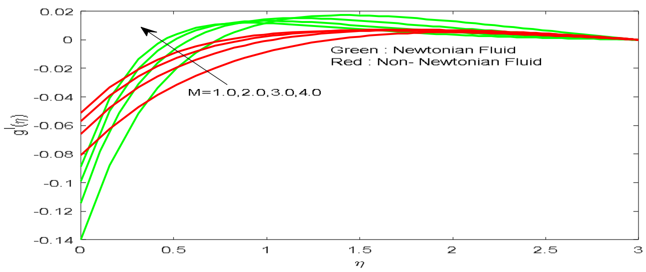

Fig. 9. Effect of M on $g^1(\eta)$

TABLE-1**:** Physical parameter values for various values of the pertinent parameters.

M	Ω	Nt	Sc	Nb	$\left(1+\frac{1}{\beta}\right)f''(0)$	$\left(1+\frac{1}{\beta}\right)g'(0)$	$-\theta'(0)$
1.0					-2.842809	-0.243288	0.256453
2.0					-3.321997	-0.197764	0.255697
3.0					-3.744197	-0.171458	0.255004
4.0					-4.124553	-0.153566	0.254359
	0.2				-2.899544	-0.480048	0.256320
	0.4				-3.005328	-0.921701	0.256080
	0.6				-3.150937	-1.304072	0.255736
	0.8				-3.309939	-1.629018	0.255343
		1.0			-2.870458	-0.242660	0.255960
		2.0			-2.870458	-0.242660	0.255048
		3.0			-2.870458	-0.242660	0.254039
		4.0			-2.870458	-0.242660	0.252913
			2.0		-3.003609	-0.230114	0.255688
			4.0		-3.003609	-0.230114	0.255087
			6.0		-3.003609	-0.230114	0.254604
			8.0		-3.003609	-0.230114	0.254203
				1.0	-2.842809	-0.243288	0.256453
				2.0	-2.842809	-0.243288	0.256453
				3.0	-2.842809	-0.243288	0.256453
				4.0	-2.842809	-0.243288	0.256453

IV. CONCLUSIONS

Brownian motion with a combination of Cross diffusion and thermophoresis has several real time industrial applications.With this influence, this paper reports on the velocity, heat and mass transfer attributes of the 3D motion of a MHD rotating flow of non-Newtonian fluid past an elongated surface. The diffusion and energy equations are constructed by the joint influence of thermophoresis, Brownian motion and Cross diffusion.

A. Increasing values of M enhances the temperature field and decreases the velocity field.
B. Rising values of rotation parameter decreases the velocity field and increases the temperature field.
C. An increase in the Schmidt number increases the temperature profile.
D. The Brownian motion and thermophoresis parameters have an affinity to decrease the Nusselt number.
E. Rotation causes regulation of the flow, thermal and concentration fields.

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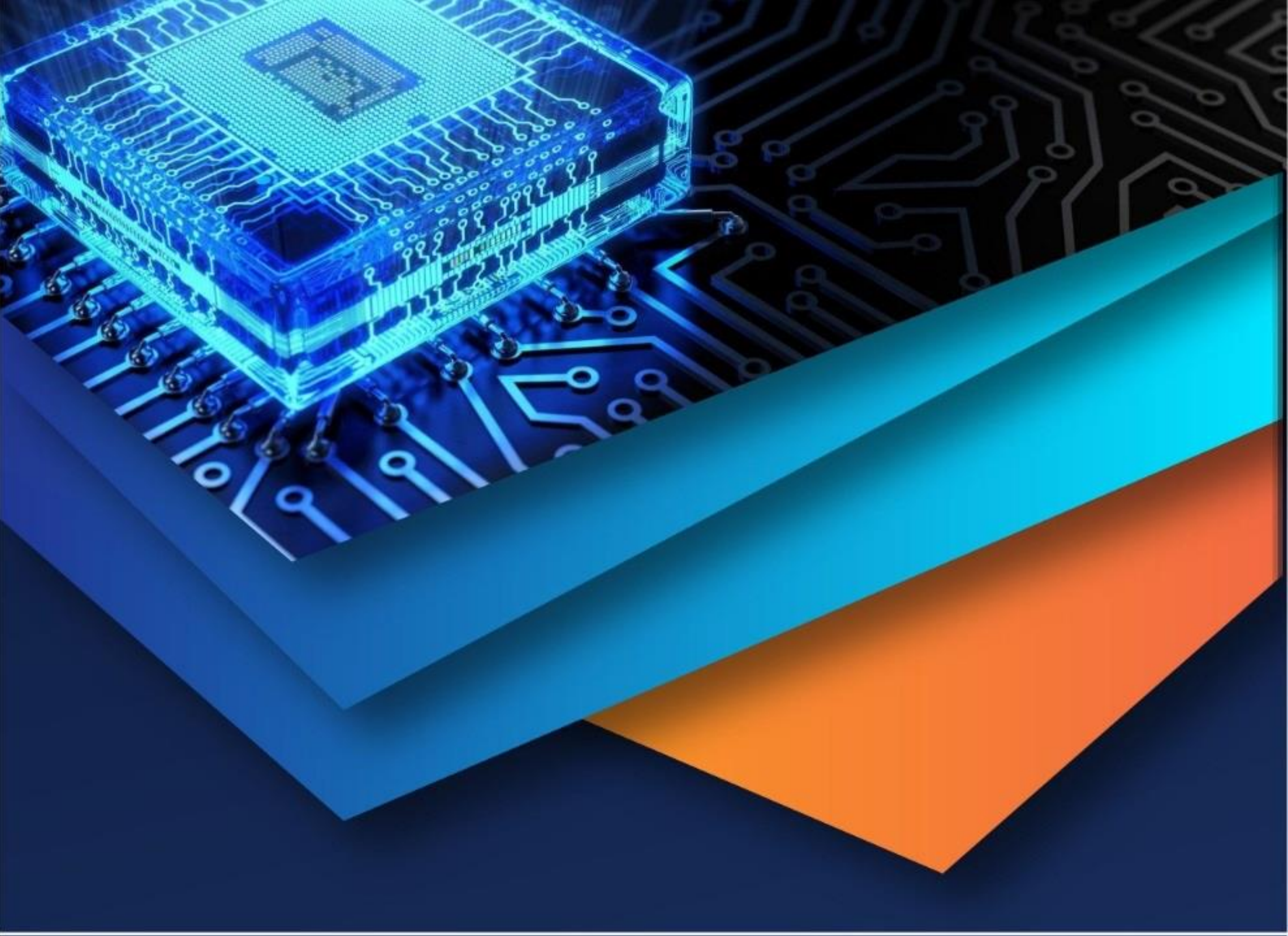

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