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Computational Analysis of Flame Holding Characteristics of Trapped Vortex Combustor

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Abstract: Computational study done on trapped Vortex combustor for different operating inlet parameters. The present investigation carried out to focus on the flame holding characteristic of cavity. The vanes and the v-gutter (bluff body) are introduced to increase the combustion efficiency. The prime requirement of the flame stabilization is maximum wake formation and the minimum loss in total pressure. The v-gutter with different apex angle of 60, 90,120 deg has been used.
Two-dimensional unsteady turbulence flow, premixed combustion has been carried out. Both cavity and v gutter efficiently generate the recirculation zone which in-turn makes air and methane to burn completely inside the combustion chamber. Velocity values are plotted along the length of combustor shows that for given flow velocity the recirculation zone length of a V-gutter with apex angle of 120 deg and 90 deg is 1.315 and 1.178 times greater than V-gutter with apex angle of 60 deg. The flow velocity** is **7.5m/s. As the speed of the inlet premixed mixture increase the length of recirculation zone and the wake width tend to increase , it infer that optimum angle of V-gutter is lies in between 90-120 deg apex angle of v-gutter.
Keywords: Trapped Vortex combustor (TVC); Guide vane; V-gutter; Recirculation zone; Turbulence Kinetic Energy.

I. INTRODUCTION

Air transportation plays a significant role in raising the overall temperature of our planet (global warming) by emitting toxic gases like nitrous oxides and carbon monoxides. In order to reduce emission of such toxic gases, requires some rigorous changes in the combustion chamber design and the whole physics of combustion itself .It has been found that reducing the maximum temperature of the combustion phenomenon will reduce the NOx emissions .To reduce the peak temperature, the combustion should occur at lean limits, which will give rise to several other troubles that may damage the combustor itself.

A steady continuous combustion process is essential in an air breathing engine at various air velocities. In an air breathing engine combustor and after burner are the only sub components that add energy to engine. The most important consideration while designing a combustor is that combustor should be able to self ignite the incoming mixture of air –fuel once ignited by igniters so that we can have stable continuous source of energy to run the compressor and accessories along with thrust produced due to expansion of the hot gases. Flame stabilization is of fundamental importance in the combustor design, the efficient performance and reliable operation of high speed propulsion system. In gas turbine and others combustion equipment, the velocities at which gases flow are much higher than the maximum flame speed. The combustor should be independent of the large excess air as the power output is regulated by the fuel mass flow rate. It is found that , the flow velocity along with burning velocity are the most important factors that flame stabilization depends on the burning velocity should be equal to the flow velocity of stationary flame front.

Flame stabilizer are any device that hold a flame at their wake to ignite an sustain combustion for entire engine operation regimes .The most common flame stabilizers are bluff body stabilizers and cavities. They create a vortex or recirculation and wakes are formed at and in downstream. The turbulent kinetic energy and the velocity fluctuations are increased substantially as a consequence of combustion. Low-velocity flows in the cavities of a combustor can aid in establishing stable flames. However, unsteady flows in and around cavities may destabilize these flames. By proper cavity design it is possible to lock (trap) the vortices spatially and, thereby, stabilize the flames. The spatially locked vortices restrict the entrainment of main air into the cavity. For obtaining good performance characteristics with a trapped-vortex combustor, a sufficient amount of fuel and air must be injected directly into the cavity[1].

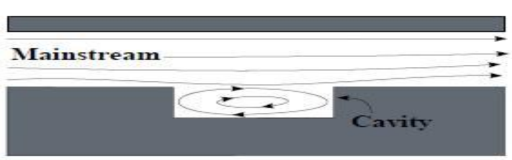


Figure 1: Flow Topology of TVC

Air force research laboratory in the year 1990s the started to develop the TVC with work of the katta et al. and HSU et al. Fig shows basic flow phenomenon of the TVC. Mainstream air flows past cavity, a vortex is trapped inside the cavity.

The TVC concept uses a recirculating rich flow trapped in a cavity to create a stable pilot flame that continuously ignites a main lean mixture passing above the cavity. Recirculating zones of hot combustion products inside the cavity and their rapid mixing with the lean main mixture provide a continuous ignition source and stabilize the flame. In order to achieve an improved mixing between cavity products and the main flow, additional flame holders can be added in the main channel.

II. BACKGROUND

The trapped vortex combustor is a new combustion chamber design proposed, its main aim to provide the flame stability by vortex in cavity, and research on flame holding characteristics of V-gutter were also studied by many researchers over past decades.

A. Adela Ben-Yakar and Ronald K. Hanson" Cavity Flame holders For Ignition and Flame Stabilization in Scramjets: Review and Experimental Study" AIAA 1998.

In this study they say about both supersonic and subsonic flow over the cavity. In low speed flow to stabilize the flame the cavity is used and in cavity there form a stationary vortex in it . The vortex will be trapped inside the cavity when the stagnation point is located at the down stream end of the cavity. In order to get better mass exchange between cavity flow and main flow . The fuel should injected directly on cavity.

B. Y. Hsu, L. P. Goss and W. M. Roquemore "Characteristic of a Trapped Vortex Combustor". Journal of Propulsion and power-1998.

In this study they investigated flame stability of TVC. The cavity is formed in between two asxisymmetric disk mounted on the tandem. The fuel and air injected directly into cavity. They found that Trapped vortex combustor has very low lean blowout limit over a operating range since cavity is shielded by annular air. It has also has the low pressure drop value which will contribute to reduction in specific fuel consumption. The flame length will decrease with increase in the air flow rate.,

C. Viswanath R. Katta and W. M. Roquemore "Study on Trapped Vortex Combustor-Effect of Injection on flow Dynamics" Journal of Propulsion and power-1998.

In this study flow of low velocity inside the cavity of combustor can establish the stable flame. In-order to get stable flow inside the cavity should design with for L/D ratio. The fuel which injected into cavity is transported along the outer core of vortex and provides the long residence time and better fuel-air mixing. The propane is used as fuel and injected into the cavity. The dynamics of cavity are studied using the time dependent, CFCD code.

The single step global chemistry model used. The steady flow inside the cavity reduces the drag coefficient.

D. Christopher Stone and Suresh Menon "Simulation of Fuel Air mixing and combustion in a Trapped Vortex Combustor" AIAA 2000.

This paper on a study of numerical investigation on fuel air mixing and combustion using Large Eddy Simulation Model. Both non reacting and reacting flow simulation has been conducted. For non reacting flow condition, is found that higher annular velocity increase the mixing rate. The higher inflow velocity increases the spatially locked vortex strength and increases the overall mixing in the cavity by reducing the characteristic mixing time.

E. Zhuoxiong Zeng , Jianxing Ren , Xiaojing Liu , Zhou Xu "The unsteady turbulence flow of cold and combustion case in different trapped vortex combustor" Journal of Applied Thermal Engineering.

This study done to increase the combustion efficiency of the trapped vortex combustor by placing a guided vane and bluff body. The numerical investigation of unsteady turbulence flow has been carried out for combustor with bluff body and without bluff body. The setting up the bluff at downstream increase the recirculation zone length and also the distribution area of turbulent kinetic energy.

F. Parammasivam. K, Subramanian. S , Sai Suganth Baskaran , Shaik Shahabaz Ahamed and Jayakumar venkatesan" Experimental Investigation of Flame Stabilization with V gutter for afterburner application" AIAA 2015.

This experiment is done to increase the flame stabilization by using the V-Gutter application. For flame to stable the there should be a minimum loss in total pressure and maximum wake formation. Both Hot and Cold flow has been carried out using V –gutter with apex angle of 60, 90,120 degrees and half V-gutter of 30,45,60 degrees in the combustor test rig. In cold flow studies recirculation zone and the wake width are accounted to find the wake formation. The optimum V-gutter apex angle with maximum wake formation and minimum total pressure loss occurs between V-gutter with apex angle 90 to 120 degree. In hot flow study lean blow out is determined by adjusting the equivalence ratio

III. COMPUTATIONAL ANALSYSIS

The Geometric characteristic of 2D dump combustor in the figure 2 designed using Catia V5. The length of the combustor is 250mm and the depth of the combustor at the inlet or exit is 50mm .The flow guided vane has 1 mm thickness. The depth of cavity is 30 mm and length of cavity is 36 mm. The V-gutter with apex angle of 60, 90,120 degree was used. It is placed at 1/3 distance from inlet. The V-gutter is used increase the flame recirculation zone.

The Navier-Stokes equation is used to simulate the combustion model and must be complemented with chemical reaction mechanism and thermodynamic model. The premixed combustion model is used. The chemical reaction mechanism describes the how the fuel and oxidiser react and what the product are formed. The thermodynamic model describes how much energy is dissipated. The governing equation for incompressible viscous flow is described by two dimensional Navier Stokes equation and turbulence modelled using standard k- □ . The boundary conditions are Velocity inlet, pressure outlet. The premixed material used in cell zone boundary condition. One step reaction rate is used for the methane premixed is used. Simple formulation is adopted.

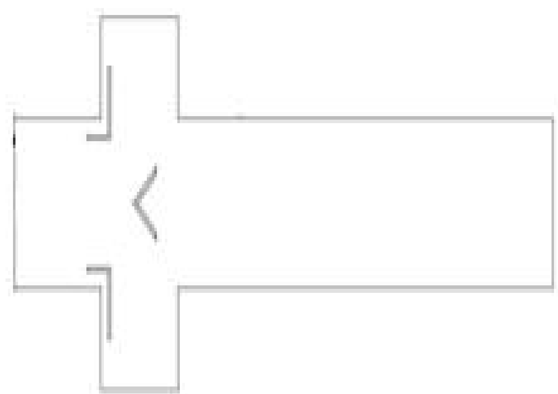


Figure 2 – Layout of combustor with 90 Degree V-Gutter (mm).

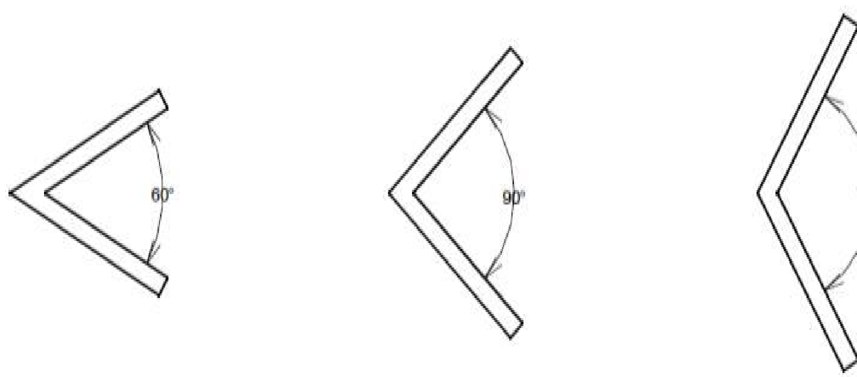


Figure 3 – Layout V-Gutter with apex angle 60, 90, 120 degrees

$$CH_4 + O_2 = CO_2 + H_2O$$

Inlet velocity is 7.5m/s air and methane equivalence ratio is 0.6 and initial temperature is 400k and pressure outlet is 101325Kpa. Numerical simulation done for different V-gutter angle is done. Non equilibrium wall function is used. Three different mesh sizes were used: coarse mesh, medium mesh and fine mesh. The both fine and the medium mesh yields similar results, so all simulation done using medium mesh is reported here.

TABLE 1: Premixed Parameters.

Parameter	Value
Mass of air (for equivalence ratio 0.6)	2*(32+3.76*28)/0.6 =457.6
Mass of 1 mole of fuel	16
Mass fraction of fuel	0.0338
Heat of combustion (j/kg)	3.84e+07
Adiabatic Temperature (K)	1950
Critical Strain Rate (1/s)	5000
Laminar Flame Speed (m/s)	0.35

IV. RESULTS AND DISCUSSIONS

The velocity stream line of the Various V-gutter Angle is shown in fig 4. The vortex formed in cavity at large range is due to the gas flows out from the cavity at larger speed due to pressure area and viscous effect near the wall. The double vortex is generated due to the effect of decalescencing in gas and decrease in swelling. Due to presence of V-gutter the main stream passes through it experiences the convergence effect, thus the flow accelerates. The effect of inverse pressure gradient behind the gutter leads to formation of the recirculation zone. The vortex shedding does not appear in the hot flow case, due to high temperature will increase the gas viscosity and temperature gradient. The strong diffusion and dissipation happens in the turbulent combustion.

It can been noted that velocity at the base of recirculation zone is low compare to near walls of combustor it is due to vortex shedding there is turbulence variation in velocity. As the angle of V-gutter increase the recirculation one formed behind it will also increases shown in fig 5.

Fig 6 shows The turbulence kinetic energy along the length of the combustor for various V-gutter apex angle It mainly concentrated near the aft-wall near cavity which strength mass and heat transfer between mainstream and gas in the cavity and low near the Inlet and exit. The turbulent kinetic energy behind v-gutter is low due to formation recirculation zone because it burning surface area and turbulent kinetic energy increase around recirculation zone and its rear area .The high temperature gas is produced in the recirculation zone which will increase the strength of the turbulent kinetic energy to strengthen heat and mass transfer behind V-gutter. The increase the velocity the intensity of turbulence kinetic energy increases.

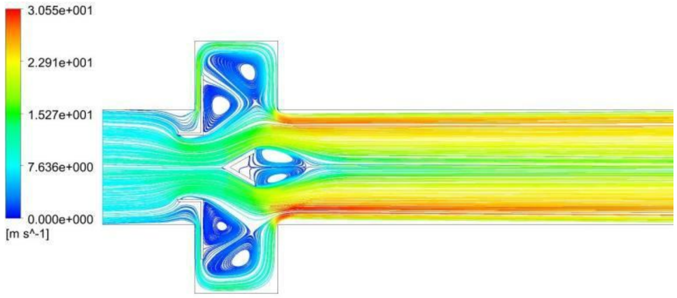
Fig 7 shows the Static temperature variation along the length of combustor. The temperature distribution of two cavities is not completely symmetrical due the effect of 3-D effect and variable distribution in chamber. The presence of the recirculation zone behind the gutter, high reaction zone formed behind it. As the velocity increase the recirculation increases due to that lean blow out occurs near downstream. The low temperature region behind the gutter gradually consumed. The highest temperature achieved is 1950k.The temperature is evenly distributed along the length of combustor due to presence of recirculation zone which makes the gas to burn completely. The area between the high and low temperature region is called transition region, the effect of the high temperature leads to increase the temperature of unburned mixture which in turn promotes combustion.

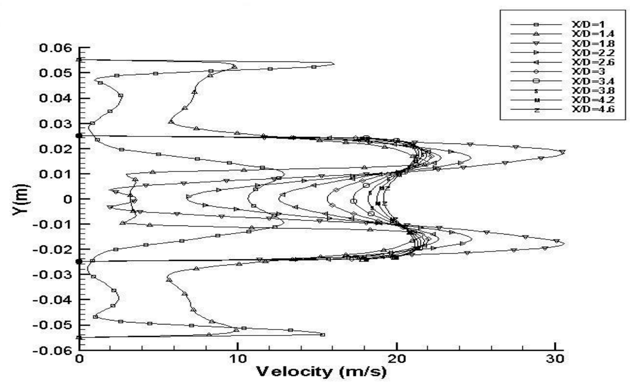
V. CONCLUSION

The trapped Vortex combustor with guided vane and V-Gutter is proposed and computational study done on it . By using guided vane double vortex structure formed inside the cavity. The V gutter increases the recirculation zone at the downstream of the Combustor. The flow passing the V gutter will experience the convergence effect due that velocity at side V-gutter will increase. This study shows that for given flow velocity the recirculation zone length of a V-gutter with apex angle of 120 deg and 90 deg is 1.315 and 1.178 times greater than V-gutter with apex angle of 60 deg.

Table 2: Recirculation Zone Variation for various angle

Angle of V-Gutter	Recirculation Length
60 degree	28.5mm
90 degree	33.2mm
120 degree	37.52mm





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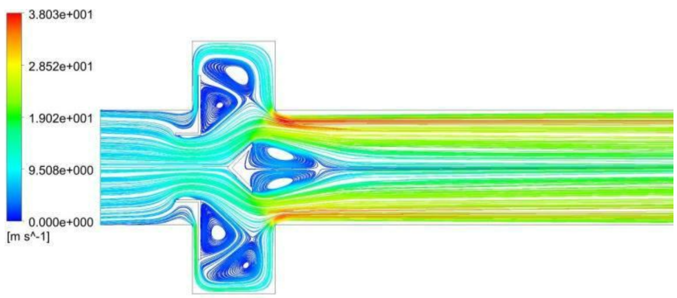
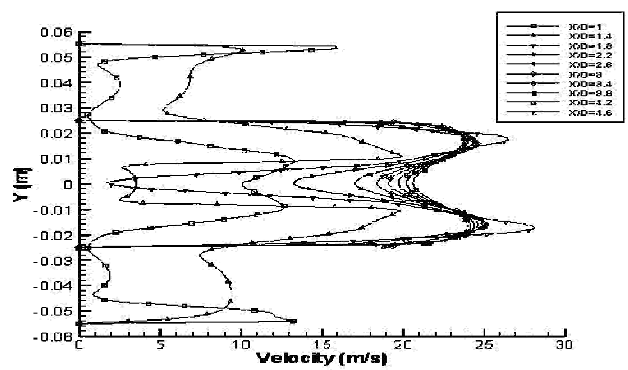
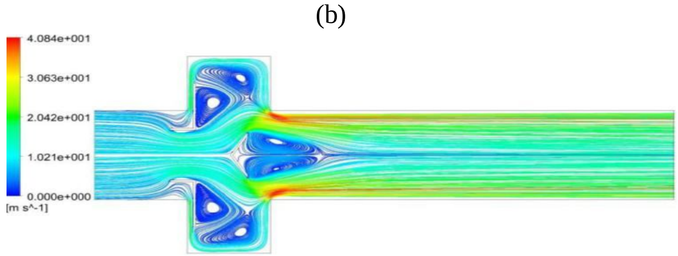
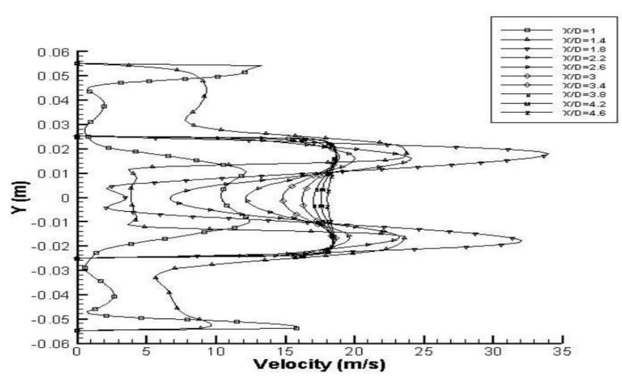




(b) (b)

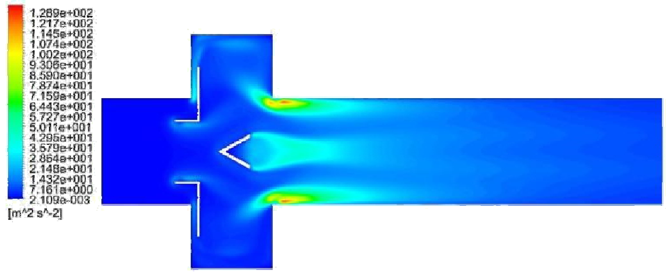




(c)

Figure 4 : Velocity Stream line Contours : (a) 60 deg; (b) 90 deg; (c)120 deg.

Figure 5 : Radial Velocity plot (a) 60 deg; (b) 90 deg; (c) 120 deg. (c)



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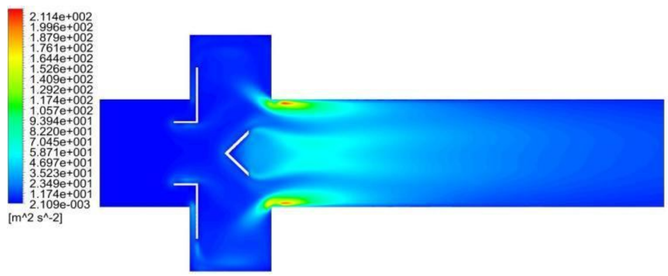

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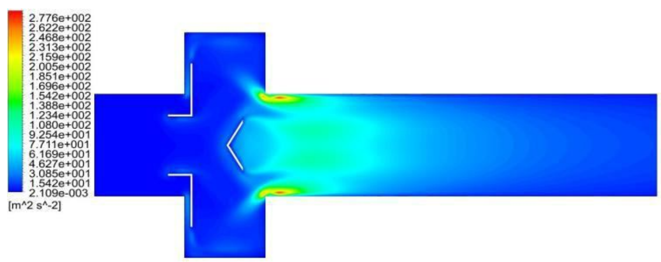
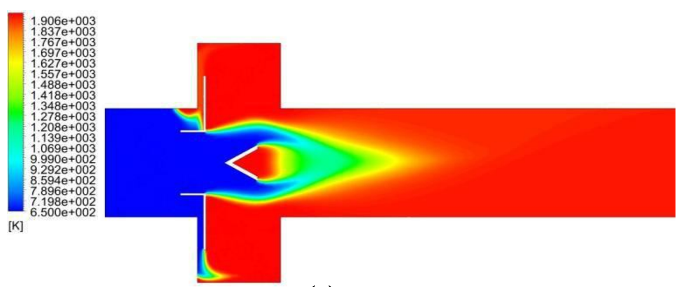


(c)

Figure 6 : Turbulence Kinetic Energy Contours : (a) 60 deg; (b) 90 deg; (c)120 deg.



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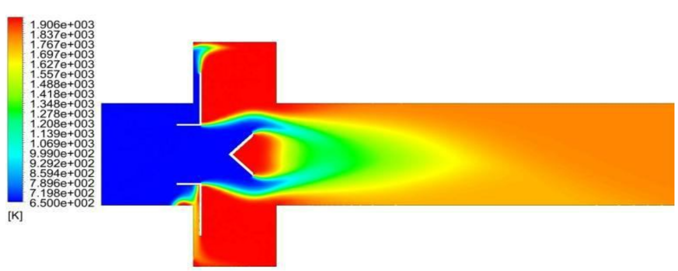

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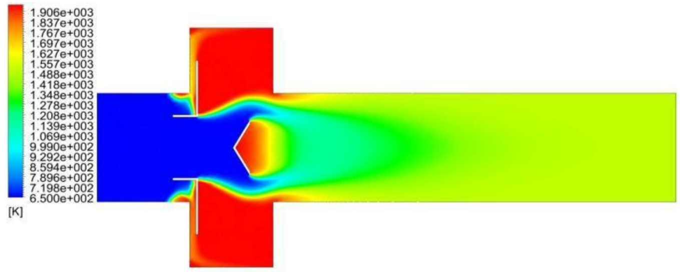

(c)

Figure 7 : Static Temperature Contours : (a) 60 deg; (b) 90 deg; (c)120 deg.

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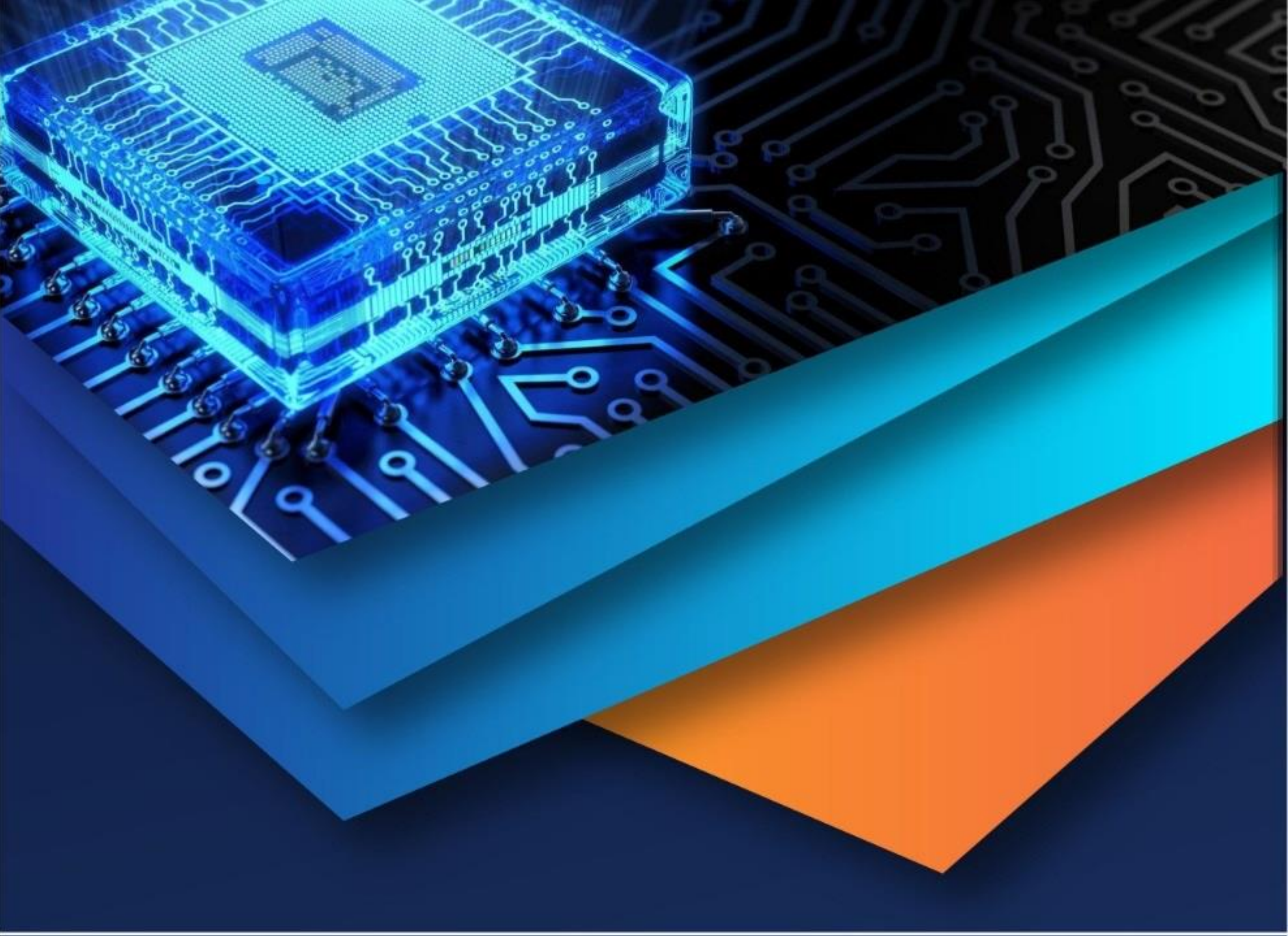

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