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# Investigation into the Performance Parameters of Air-Breathing Engines

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***Abstract: When momentum is imparted to a mass of fluid in such a way that the reactive momentum builds a force determining the principle on which air-breathing engine works on. In this study, evaluation of thrust, propulsive efficiency and thermal efficiency will be carried out numerically. The study further investigates different propulsion systems and their governing equations. Furthermore, the relationship between mass of air intake Vs thrust and propulsive efficiency will be plotted graphically.***
***Keywords: air-breathing engines, gas turbine, nozzle, propulsion, thrust, thermal efficiency, etc.***

## I. INTRODUCTION

The basic principle is same as that of gas turbine engine and follows the same sequence of processes which include expansion of gas or fuel which is at high temperature and pressure t0hrough a nozzle. Derived by the second law of Newton which states that, Force is equal to the change of momentum.

F = d(mv)/dt.

Gas turbine operates on brayton cycle which includes the following processes: isentropic compression, isobaric combustion, isentropic expansion and heat rejection. The gas turbine is divided into:

1) Closed cycled and
2) Open cycle.

The gas turbine operates according on the open cycle gas turbine.

### A. *Open Cycle Gas Turbine*

Air pulled into the compressor then thrown to the combustion chamber where temperature also rises. The gases expand through the turbine as a result of fuel sprayed into the air stream as a form of energy.

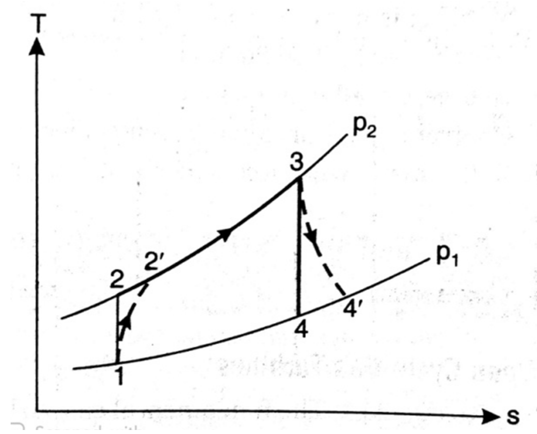


FIG: t-s diagram of open-cycle gas turbine.

1) 1-2': irreversible adiabatic compression.
2) 2'-3: constant pressure heat supply in the combustion chamber.
3) 3-4': irreversible adiabatic expansion.
4) 1-2: ideal isentropic compression.
5) 3-4: Ideal isentropic expansion.

In order to achieve net work output from the unit, the turbine must develop more gross work output that it is required to drive the compressors and to overcome mechanical losses in the drive.

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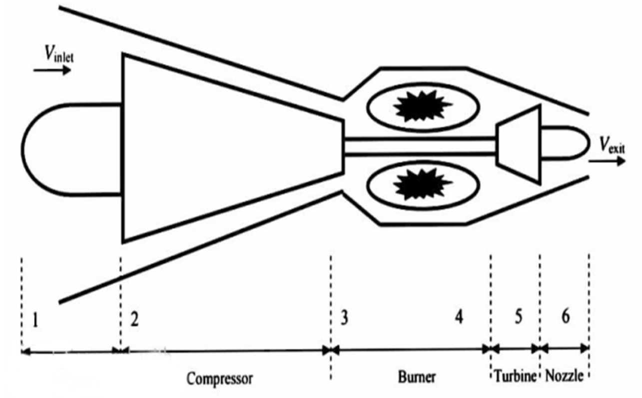
*B. Jet Propulsion*

In jet engine, discharge of fast moving jet is used to generate thrust. It is also called as reaction engine. Jet propulsion can be divided into:

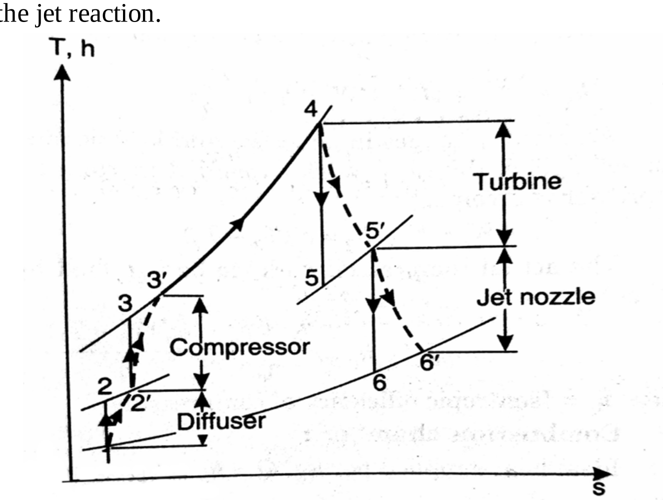
*1)* Air stream engines.
*2)* Self contained rocket engines.




*C. Turbo jet Engine*

It consists of diffuser at entrance which slows down the aur and part of the kinetic energy of the air of the air stream is converted into pressure: this type of compression is called as ram compression. The air is further compressed to a pressure of 3 to 4 bar in a rotary compressor.

The compressed air then enters the combustion chamber where fuel is added and combustion takes place. The hot gases then enter the gas turbine where partial expansion takes place. The exhaust gases from turbine are expanded in the nozzle which provides a forward motion to the aircraft by the jet reaction.




Basic cycle of turbo-jet engine

*1)* Process 1-2: isentropically air enters from the atmosphere indicating the diffuser has 100% efficiency
*2)* Process 1-$^{2'}$: the actual process of isentropic compression.
*3)* Process 2-3: isentropic compression air.
*4)* Process $2^{'}$-$3^{'}$: actual compression of air takes place.
*5)* Process 3-4: 3’-4 representing the actual addition of heat. The addtition of heat takes place during $P_3$-$P_4$.
*6)* Process 4-5: Isentropic expansion of gas in the turbine.
*7)* Process 4-5’: Actual expansion of gas in the turbine takes places.
*8)* Process 5-6: Isentropic expansion of gas in the nozzle.
*9)* Process 5’-6’: expansion of gas actually takes place.

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### *D. Turbo- prop*

The expansion gases take place in the nozzle and in the turbine to some extent, i.e 1:4 ratio. Jet produced by the nozzle and the propulsion provides forward motion to the aircraft. The pressure rises in the diffuser. To increase the overall efficiency diffuser is provided before the compressor. Incoming air is converted to kinetic energy which causes pressure rise which in turn converts into pressure energy.

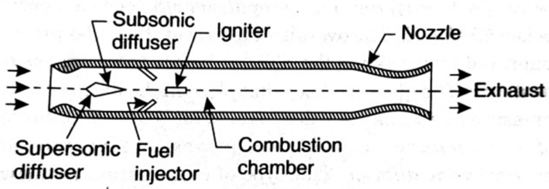
This type of compression is known as "ram effect".

Types of engines that work on the ram effect:

*1)* Ram-jet.
*2)* Pulse-jet.
*3)* Rocket engine.

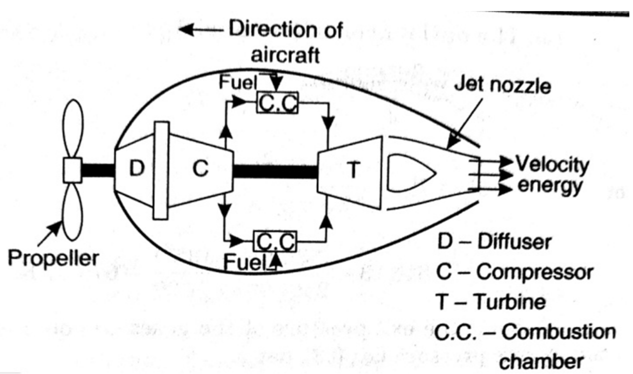
### *E. Ramjet Engine*

Consisting of a diffuser, nozzle and a combustion chamber in ram-jet air comes in with a supersonic speed. The air is then slowed down to sonic velocity. In the supersonic diffuser which suddenly the slowdown of air suddenly increases the pressure and a shockwave is formed.



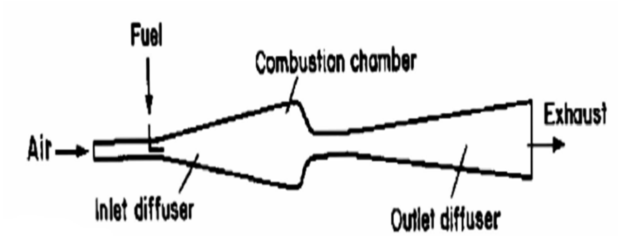

The figure shows that the fuel is injected in the combustion chamber and ignited by means of a spark plug. Entered gases and its expansion towards the diffuser is restricted by pressure barrier. The pressure energy is converted into kinetic energy.

The major shortcoming of ram-jet engine is that it cannot start on its own.




### *F. Pulse-Jet Engines*

Same as a reciprocating engine, in this combustion takes place intermittently. In the diffuse section Air is then compressed by ram effect. Fuels injectors then inject the fuel into the combustion chamber. Pressure and temperature of the combustion increases.

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## II. GOVERNING EQUATIONS

Energy equation

$C_1^2/2 + h_1 + Q_{1\text{-}2} = C_2^2/2 + h_2 + W_{1\text{-}2}$

$C_1$ = velocity of entering air from atmosphere.

$C_2$ = velocity of air leaving.

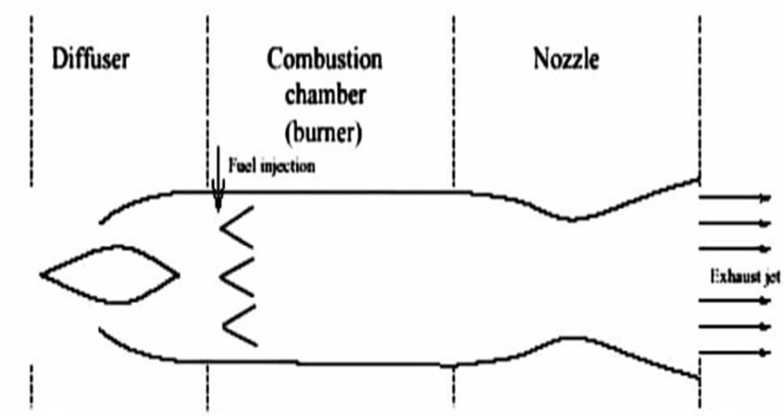
$h_1$ and $h_2$ are enthalpies.

Q and W are heat produced and Work done.

### *A. Diffuser*

Energy between states 1 and 2

1) Ideal diffuser C=0, Q=0 and W=0.
2) Enthalpy $h_2 = h_1 + C/2$ KJ/Kg.
3) $C_a^2/2 + h_1 + Q_{1\text{-}2} = C_2^2/2 + h_2 + W_{1\text{-}2.}$
4) $H = c_p.T$ , $T_2 = T_1 + C_a^2/2.c_{P.}$
5) Diffuser efficiency $\eta_d = h_2\text{-}h_1/h_2'\text{-}h_1$
6) $h_2' = h_1 + C_a^2/2.\eta_d$
7) $T'_2 = T_1 + C_a^2/2.c_p.\eta_{d.}$




### *B. Compressor*

Energy between states 2 and 3

1) $h_2 + C_2^2/2 + Q_{2\text{-}3} + W_c = h_3 + C_3^2/2.$
2) $W_c = h_3\text{-}h_2 = c_{p.}(T_3\text{-}T_2).$
3) Actual work = $h_3'\text{-}h_2 = h_3\text{-}h_2/\eta_c.$
4) $W_{act} = c_p.(T_3\text{-}T_2)/\eta_{c.}$

### *C. Combustion Chamber*

1) Ideal heat supplied per kg, $Q = h_4\text{-}h_3 = c_p.(T_4\text{-}T_3).$
2) Actual heat supplied = $(1 + m_f/m_a)\ h_4\text{-}h_3'.$
3) $Q_a = c_{pg}.(1+m_f/m_a).\ T_4 - c_{pa}.T_3'.$
4) Where $c_{pg}$ and $c_{pa}$ are specific heats of gases and air at constant pressure respectively

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### D. Turbine

1) Between the states 4 and 5
2) $h_4 + C_4^2/2 + Q_{4-5} = h_5 + C_5^2/2 + W_t$.
3) Turbine work $W_t=(h_4-h_5)+(C_4^2-C_5^2)/2$.
4) If change in kinetic energy is neglected, $W_t= (h_4-h_5) = c_p.(T_4-T_5')$.
5) Actual Turbine Work= $c_p.(T_4-T_5)*\eta_t$.
6) Turbine work = work compressor
7) $T_5'= T_4- (T_4-T_5)\eta_t = T_4- c(T_3-T_2)/\eta_c$.

### E. Jet Nozzle

1) Energy Equation between states 5 and 6
2) $h_5+C_5^2/2 =h_6+C_6^2/ 2$ ...… (Ideal case).
3) $h_5'+C_5'^2/2=h_6+C_6'^2.2$ …..(Actual case).
4) if $C_5'^2$ is very less as compared to $C_6'^2$, we have
   $h_5'=h_6'+C_6'^2/2$.
5) $C_6'=(2 \eta_n c_p (T_5' – T_6))^{1/2}$.
6) $\eta_n$ = Nozzle efficiency.
7) Thermal efficiency $\eta_{th} = (h_4-h_6')-(h_3'-h_1)/ (h_4-h_3')$.
8) $(T_4-T_6') – (T_3'-T_1) / (T_4-T_3')$.

### F. Thrust (T)

1) Ca= velocity of approach of air.
2) Cj= velocity of jet.
3) Thrust = $(1+ m_f/m_a) (C_j-Ca)$ N/kg of air/s.
4) Thrust = $(C_j-C_a)$ N/kg of air/s (neglecting mass of fuel).

### G. Thrust Power (T.P)

1) Rate at which work must be developed by the engine if the aircraft is to be kept moving a constant velocity $C_a$ against friction force or drug.
2) T.P = $[(1+ m_f/m_a)(C_j-C_a)] C_a$ W/kg of air.
3) T.P = $(C_j-C_a)C_a/1000$ kW/kg of air.

### H. Propulsive Power (P.P)

1) The energy required to change the momentum of the mass flow of gas represent the propulsive power. Expressed as,
2) P.P = $\Delta K.E = (1+ m_f/m_a)C_j^2/ 2 – C_a^2/2$ W/kg.
3) P.P = $C_j^2-C_a^2/2 * 1000$ kW/kg.

### I. Propulsive Efficiency

1) The ratio of thrust power to propulsive power is called the propulsive efficiency of the propulsive unit.
2) $\eta_{prop}$ =thrust power/ propulsive power
3) $\eta_{prop.} = 2[(1+m_f/m_a)(C_j-C_a)]C_a/[(1+m_f/m_a)C_j^2-C_a^2]$.
4) $\eta_{prop} = 2C_a/C_j+C_a$.

### J. Thermal Efficiency

1) $\eta_{th}$ = propulsive efficiency / heat released by the combustion of fuel.
2) $\eta th = (C_j^2-C_a^2)/2[m_f/m_a$ * calorific value].
3) Overall Efficiency $(\eta_o)= \eta_{th}*\eta_{prop}$
   $= (C_j-C_a)C_a/(m_f/m_a)$*C.V.
4) The jet efficiency $(\eta_{jet})$
   = (final K.E in the jet / Isentropic heat drop in the jet pipe) + Carry over from the turbine.

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## III. NUMERICAL METHODS

The following data is pertained to calculate thrust, the factors varied are the travelling speed, the inlet velocity of air, drag on the plane, the mass of fuel consumption. The nozzle convergence and divergence is varied using software and results obtained will be compared.

*1) Case 1:* Turbo – jet engine

Travelling speed = 1000 km/h

Mass of air, $m_a$ = 60.2 kg/s

Enthalpy change for nozzle, $\Delta h$ = 230 KJ/s

Velocity coefficient z = 0.96 or $M_a$

Air- fuel ratio = 70:1

Calorific value of fuel, C.V. = 420000 kJ/kg

Aircraft Velocity, $C_a$=2000*1000/60*60

= 555.55 m/s

*a)* Exit velocity of jet, $C_j$:

$C_j = z(2\ \Delta h\ 1000)^{1/2}$

= 0.96 (2*230*1000)

= 651 m/s.

*b)* Fuel flow rate :

$m_f$ = rate of air-consumption/ air-fuel ratio.

= 60.2/70 = 0.86 Kg/s.

*c)* Thrust produced = $m_f (C_j - C_a)$, neglecting mass of fuel.

= 60.2(651-555.55) = 5746.09 N

*d)* Propulsive efficiency, $\eta_{prop}$ :

= Thrust power/propulsive power = $2C_a/C_j+C_a$

= 2*555.55/651 + 555.55 = 0.92 or 92%.

*note: $M_a$= V/a , where V= local speed and C= speed of sound a= (kRT).

Varying $M_a$= 0.96, 0.8, 2, 1.5, 0.7, 0.85 respectively.

**Table 1**: Varied Aircraft performance criteria

| $m_a$(kg/s) | $m_f$(kg/s) | A:F | $C_a$(m/s) | $C_j$(m/s) | Thrust(N) | $\eta_{prop}$(%) |
|---|---|---|---|---|---|---|
| 60.2 | 0.86 | 70:1 | 555.55 | 651 | 5746.09 | 59.8 |
| 16.77 | 0.315 | 53.24:1 | 300 | 598.66 | 94.077 | 66.7 |
| 26.5 | 1.0206 | 73.1:1 | 216 | 1549.19 | 1360.65 | 24.47 |
| 9.234 | 0.0148 | 67.56:1 | 256.9 | 1341.64 | 16.054 | 32.14 |
| 15 | 0.2 | 75:1 | 155.8 | 593.96 | 87.632 | 41.55 |
| 50 | 1.069 | 46.74:1 | 456.77 | 537.58 | 86.385 | 91.87 |

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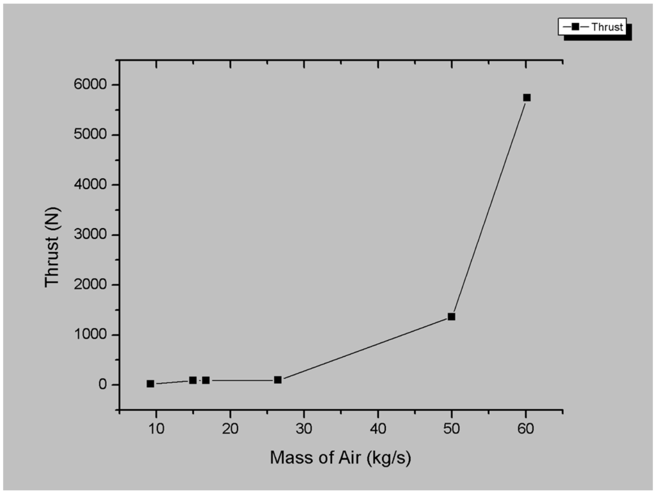
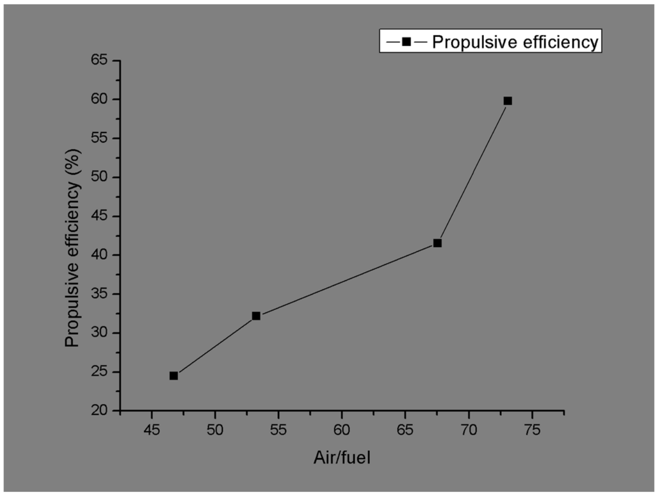
The thrust obtained by varying mass of air is shown in the graph below:




## IV. RESULTS AND DISCUSSIONS

The results obtained from the numerical methods above give and optimum thrust to achieve variable speeds. The methods further give the thrust and propulsive efficiency depending on the air: fuel ratio. The first graph depicts thrust Vs $m_a$ relation. The second graph shows a:f ratio vs. propulsive efficiency.

## V. CONCLUSION

The values obtained and graphs plotted shows that the thrust produced increases with the increase of mass of air intake. The second graph plotted shows the increase in propulsive efficiency as A: F increases.

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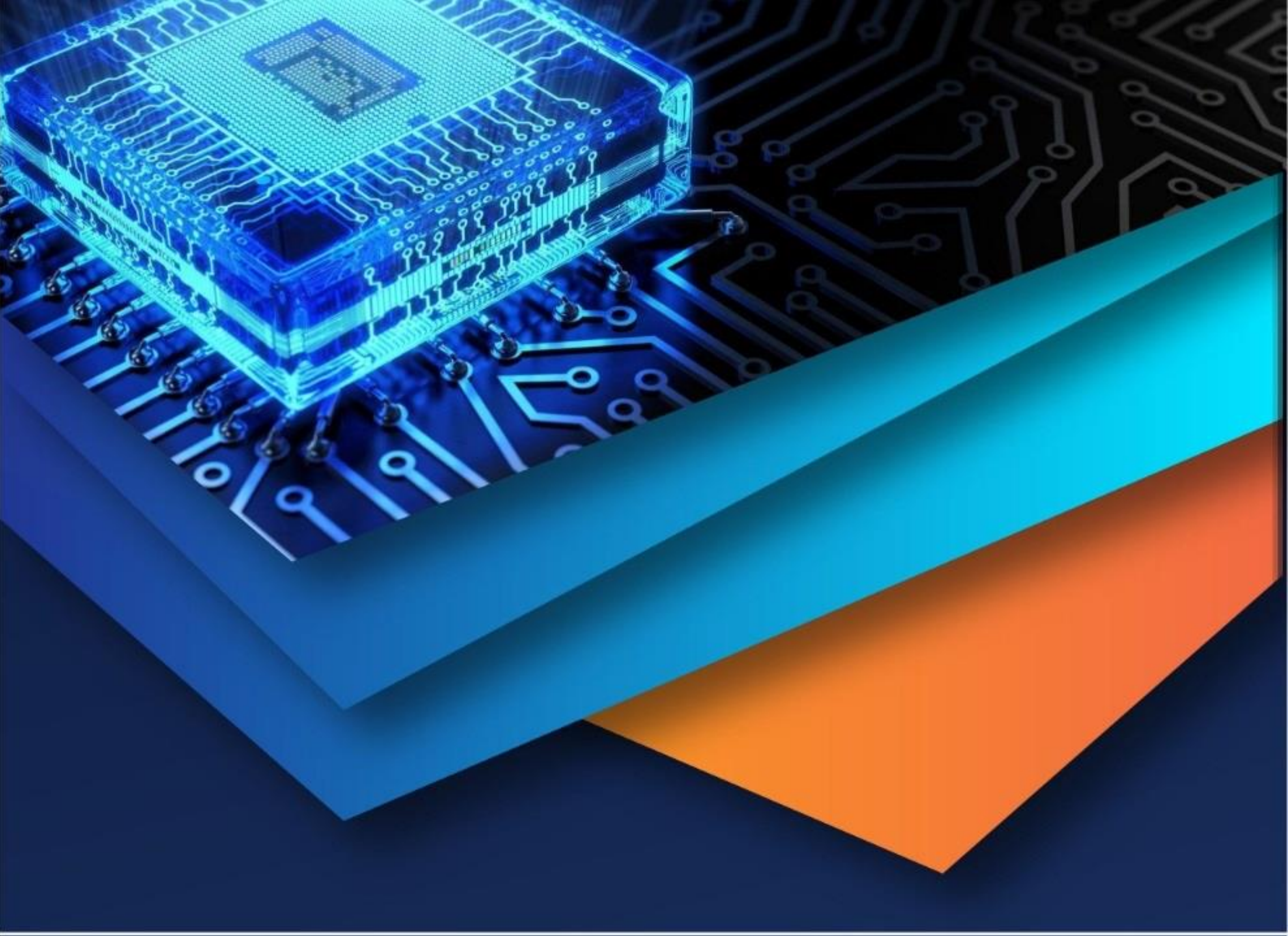


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