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Aerodynamics of Reverse Delta Wing

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Abstract: Delta wings are mostly used in supersonic jets and fighter aircrafts. A delta wing is naturally stable and produces vortex lift, so the flow separation can be made into increasing lift. This augmented lift comes at an expense of high drag. A reverse delta wing is nothing but an inverted delta wing, the forward swept wings were inspired from this design. It has low drag coefficient and was used in ground effect vehicle. This paper aims to bring out all the possible studies and research work done on a reverse delta wing. The study was mainly inspired by the works of Alexander Lippisch and his design for the X-112 WIG (wing-in-ground effect).This paper will provide comparative flow patterns around a reverse delta wing and a normal wing with simulations and ways to optimize it to get a better efficiency.

I. INTRODUCTION

Vortex flow plays an important role in all modern aerodynamic applications. The vortices created by an aircraft are a major consequence of the lift production. The wake-vortex provides a bigger threat to the aircraft during it's take off and landing, mainly because of the maximum tip vortex circulation. This restricts the spacing of aircrafts between Akhil Nair, Hindustan Institute of Technology and Sciences the landing and take-off. The reverse delta wing can be very useful in vortex alleviation. They can be also used in the enhancement of forward swept wings.

II. STUDIES ON REVERSE DELTA WING

Early investigations on the reverse delta wing and its aerodynamics were carried out way back in 1947 by the NACA. The reverse delta wing has some beneficial characteristics that can be manipulated for supersonic flight. Gerhardt studied the flow over the reverse delta wing at high Mach numbers and noted that there were many differences in the flow compared to a normal delta wing. The surface pressure counters are expected to have a regular shift in pressure than a normal delta wing and there are chances of strong pressure gradients near the trailing edge regions.

A supersonic transport jet was designed by a group of Northrop Grumman designers in 1999, it consisted of a very different kind of reverse delta wing which was said to have additional lifts at low speeds with minimal power requirements and noise. Recent investigations were carried out by Elsayed et al which showed favorable vortex characteristics. There results showed that reverse delta wings are devices which can contribute to wake alleviation, this may excite stable or unstable wave phase or by modifying the vortex roll up process as a result of interaction with turbulent phase, further leading to fast diffusion of vorticity. Hence enhancing the wake vortex decay which gives rise to wake vortex alleviation. Many research work have been carried out on the development of vortex flow and wake vortex alleviation on the reverse delta wing.

III. REVERSE DELTA WING DESIGN AS GROUND EFFECT VEHICLES

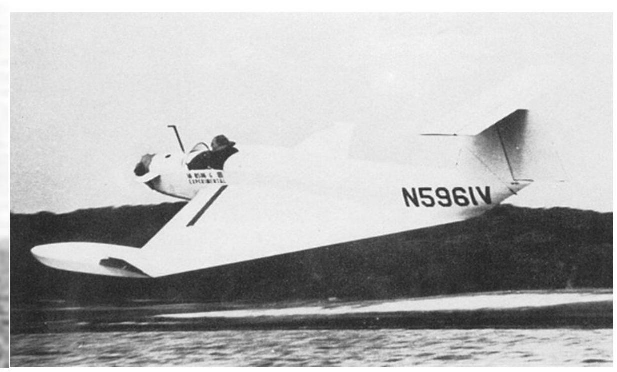


Fig 1: The Rhein-Flugzeugbau X-114 in flight   Fig 2: Collins X-112

In 1963 Lippisch developed the X-112, an innovative design with reversed delta wing and T-tail. It was designed like an aerofoil boat with its main purpose of use being use over water It was a stable and efficient design in ground effect, even after its successful test, the project was stopped and the patents were sold to a German company Rhein Flugzeugbau (RFB), which further developed the inverse delta concept into the X-113 and the six seat X-114 which utilised fibre glass and was capable of surveillance duties, flying at greater heights.

A. Flow over the Reverse Delta Wing of X-114

They are mainly used for ground-effect craft. The main idea is to have positive angle of attack, a tapered wing and a trailing edge with constant, low distance from the ground. The wing would behave just like a normal forward swept, low aspect ratio wing. It would have a small lift curve slope and a lousy stall behaviour, because the low tip chord will make the tips stall first, causing the whole wing to roll. Unfortunately, the low leading edge sweep will prevent vortex lift, which is a typical feature of regular delta wings, to develop, so the stall angle will be only little higher than that of a straight wing with the same aspect ratio.

IV. SIMULATION

A. Aircraft Specifications

The design parameters of a 120-170 seater passenger configuration aircraft is given below:

1) External Diameter

Length - 42.5 m
Wingspan – 41.6m
Wing area – 137.2m^2
Max Fuselage Diameter – 4.10m

2) Wing

Aspect Ratio – 12.18
Wing Aerofoil- NASA 0710
AoA – 6.65 rad^{-1}
Root chord length – 7.6m
Mean geometrical chpord – 3.76m
Taper Ratio – 0.15
Dihedral angle – 5.6^o
Average T/C – 10
Wing setting amgle – 3.1
Wing Twist - -3.5^o (linear geometrical)
Chord – 7600mm
Z offset - -1880
Chord Thickness(%) – 0.1
Root apex Distance – 15600mm

3) Horizontal Tail

Aspect Ratio – 5.2
Span – 12.8m
Area – 31.5m^2
Wing Aerofoil – NACA 2410
AoA – 6.6 rad^{-1}
Root chord length – 3.9m
Taper Ratio – 0.286
Wing setting angle - - 1.8^o
Dihedral angle – 5.2^o

4) Vertical Tail

Aspect Ratio – 2.13
Height – 7.2m
Area – 24.3m^2
Tail Aerofoil – NACA 0010 symmetrical
AoA – 7.16 rad^{-1}
Tail root chord – 5.2m
Taper Ratio – 0.3

B. CAD Model of Conventional Aircraft

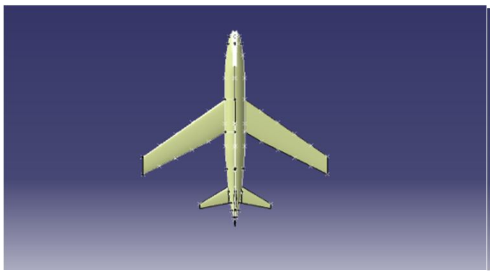


Fig 3: Top view

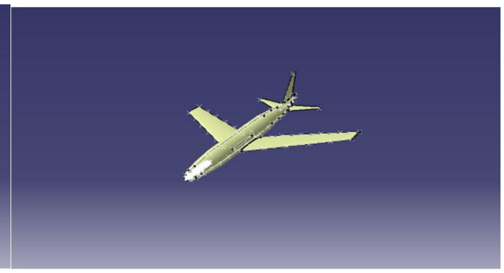


Fig 4: isometric view

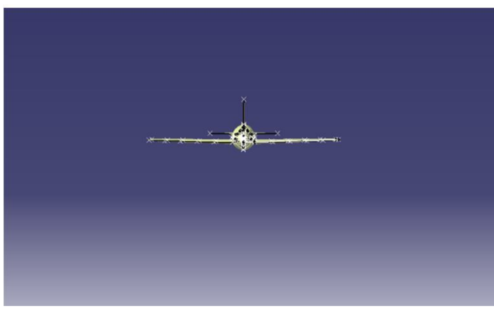


Fig 5: Front view

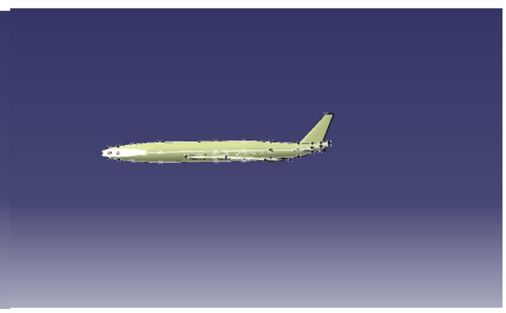


Fig 6: Side view

C. CAD Model of Reverse Delta Wing aircraft

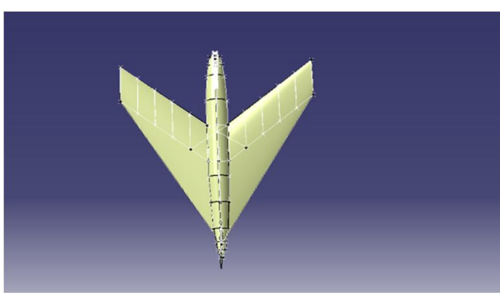


Fig 7: Top view

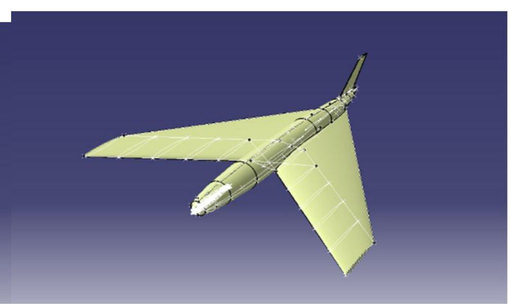


Fig 8: isometric view

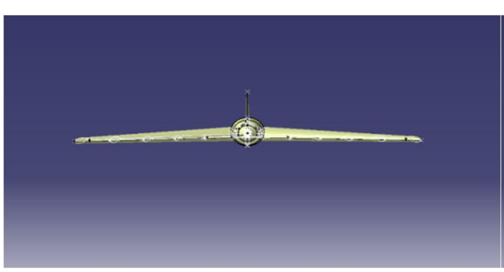


Fig 9: Front view

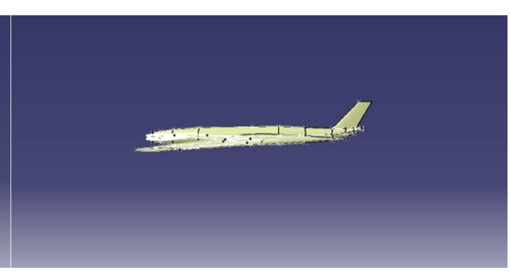


Fig 10: Side view

V. RESULTS

The following results were obtained from the simulation of the two designs:

1) Conventional aircraft
2) Reverse Delta wing aircraft

Four simulations were performed using the two designs at two different altitudes to compare the results and performance are as follows:

a) *Simulation 1:* Conventional aircraft at 1000m altitude.
b) *Simulation 2:* Reverse Delta wing aircraft at 1000m altitude.
c) *Simulation 3:* Convectional aircraft at 4000m altitude.
d) *Simulation 4:* Reverse Delta wing aircraft at 4000m altitude.

Fig 11: Graph representing Coefficient of drag and lift of Simulation 1:

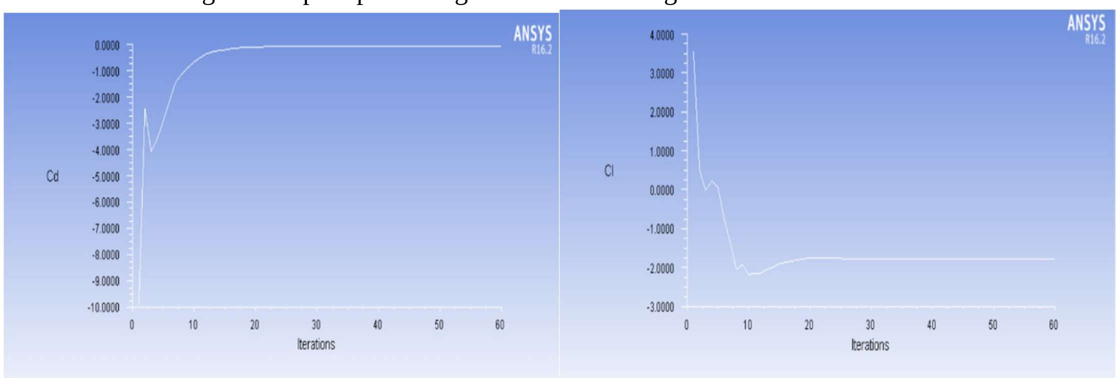


Fig 12: Graph representing Coefficient of drag and lift of Simulation 2:

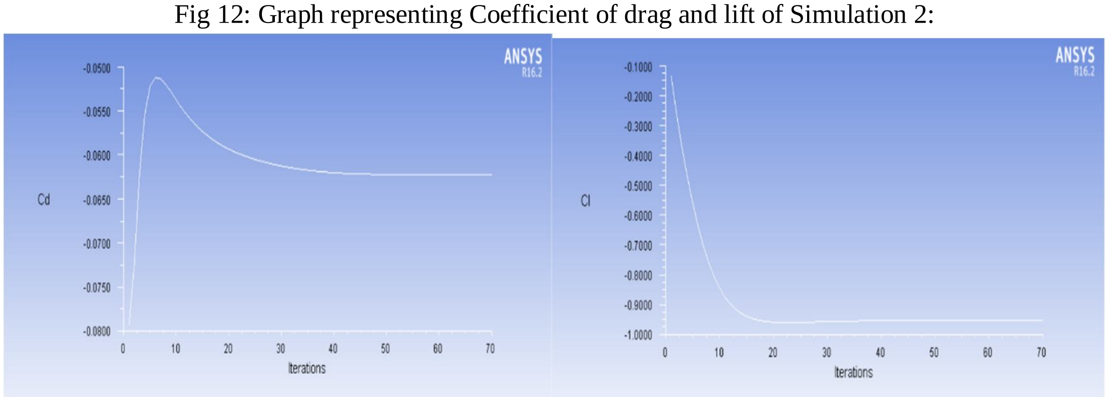


Fig 13: Graph representing Coefficient of drag and lift of Simulation 3:

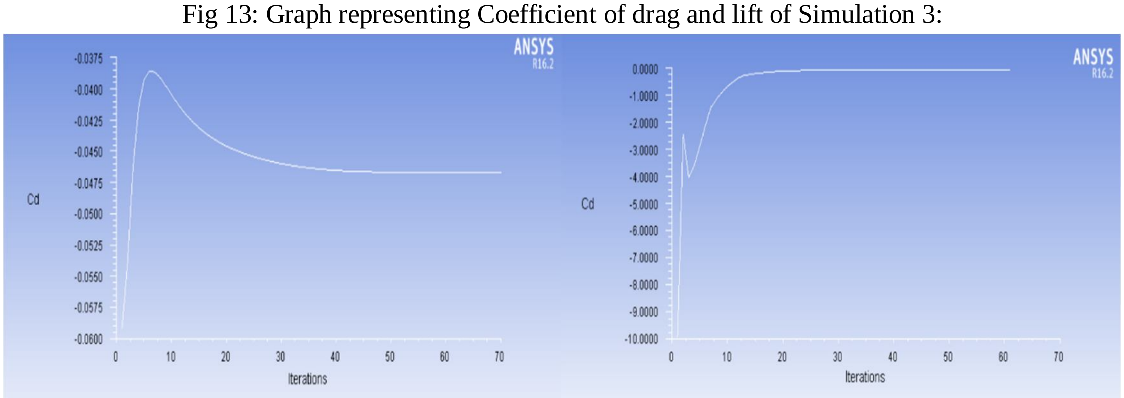
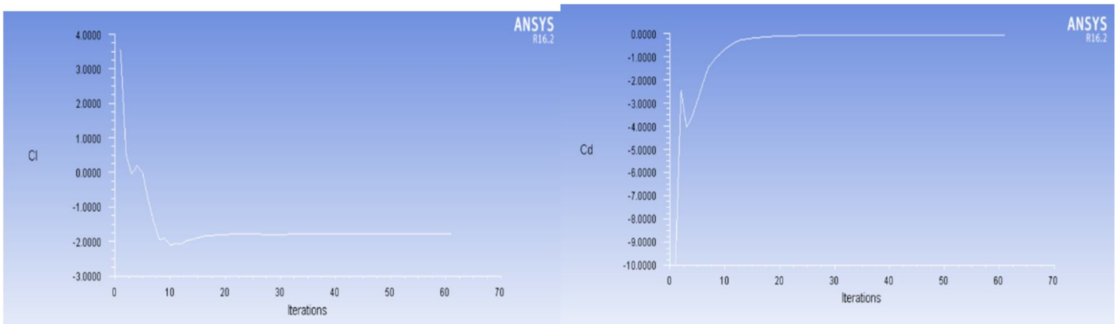
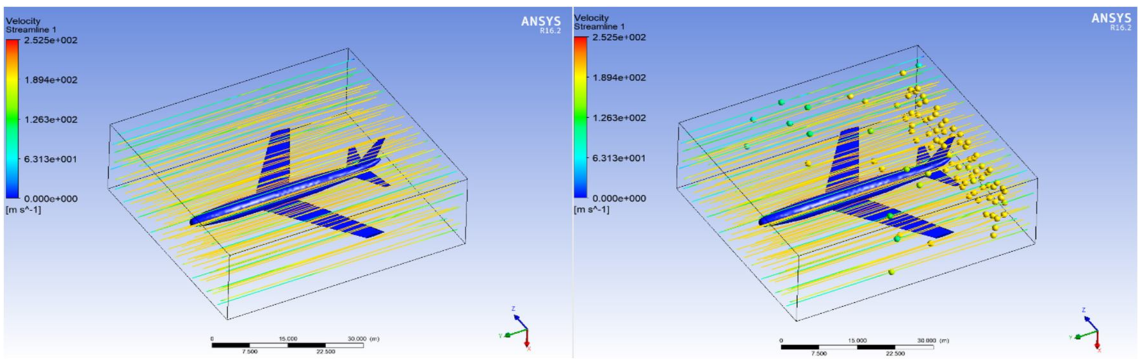


Fig 14: Graph representing Coefficient of lift and drag of Simulation4:



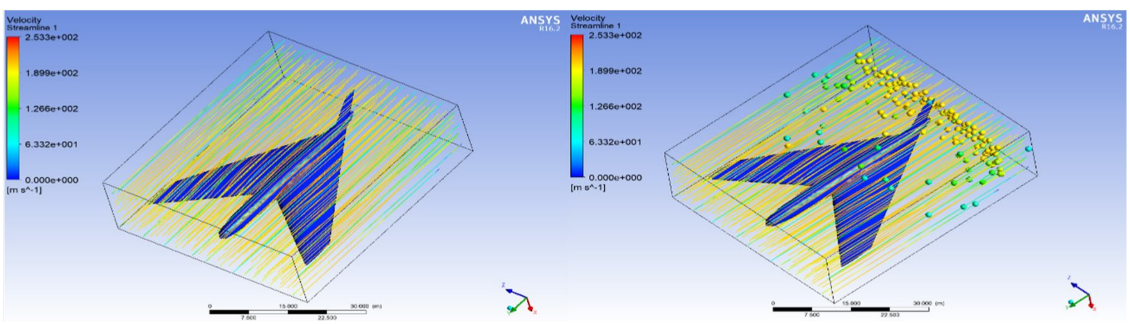
A. Simulation 1

Lift/ Drag ratio = 12.287



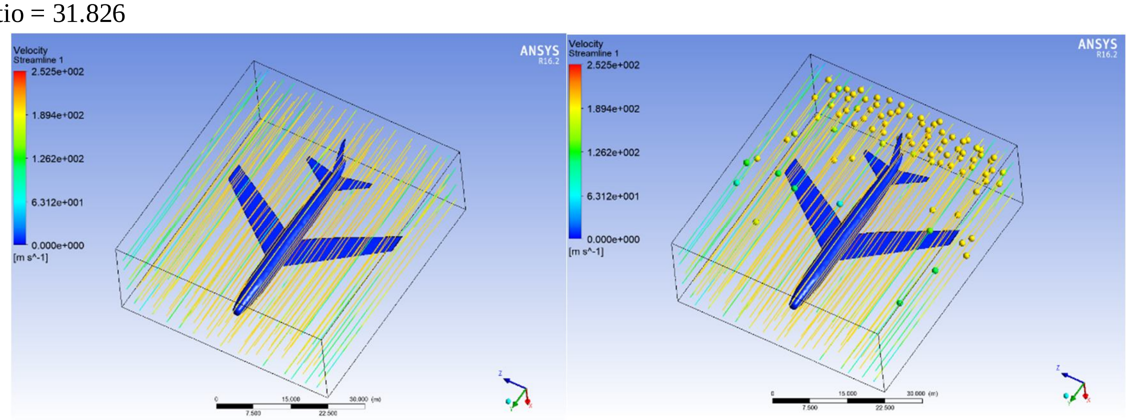
B. Simulation 2

Lift/ Drag ratio = 22.799



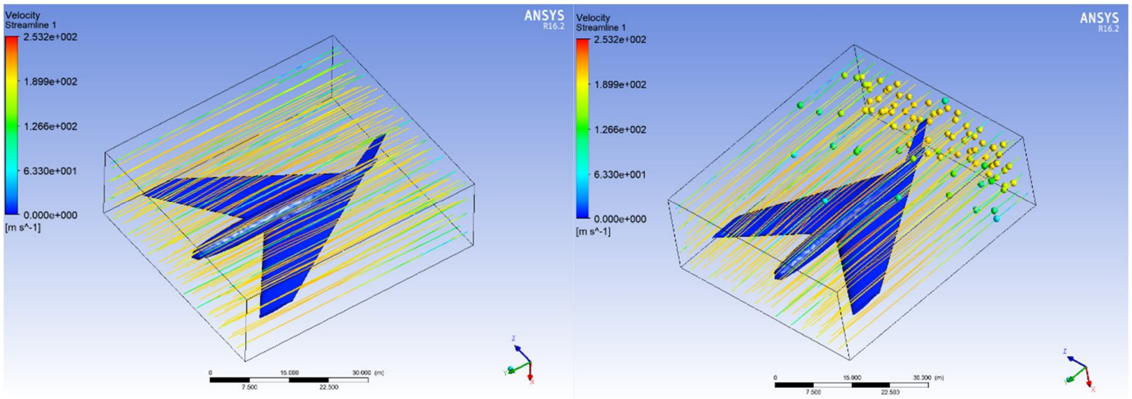
C. Simulation 3

Lift/ Drag ratio = 31.826



D. Simulation 4

Lift/ Drag ratio = 22.108



It can be seen from simulation 1 and 2 that when the altitude is kept at 1000m, the reverse delta wing performs better than the conventional aircraft because of the vortex alleviation by the reverse delta wing. But as the altitude is increased to 4000m , it can be seen that the conventional wing design has higher L/D ratio than the reverse delta wing design . This lower lift induced drag of the RDW design as compared to the generic aircraft design improves its fuel efficiency and up to a point, its speed. The reverse delta wing at a particular angle of attack, exhibited a low value of tangential velocity, circulation and vorticity than the regular delta wing. The reverse delta wing was also found to have a lower lift and drag coefficient than a delta wing, however, the lowered drag coefficient resulted in a higher lift-to-drag ratio compared to the delta wing.

VI. CONCLUSION

These types of aircrafts are best suited as ground effect vehicles. Further improvement in design can optimize the reverse delta wing to bring out even better efficiencies. Due its lack of applicability and popularity , the aerodynamics and the vortex flow field are not given much of an interest and are extensively not well researched. A reverse delta wing can produce a greater lift at lower speeds, it reduces the power required for operation and generates lesser noise. By implementing an anhedral wing to the aircraft , can create a high pressure region below the wing which could contribute to lift addition.

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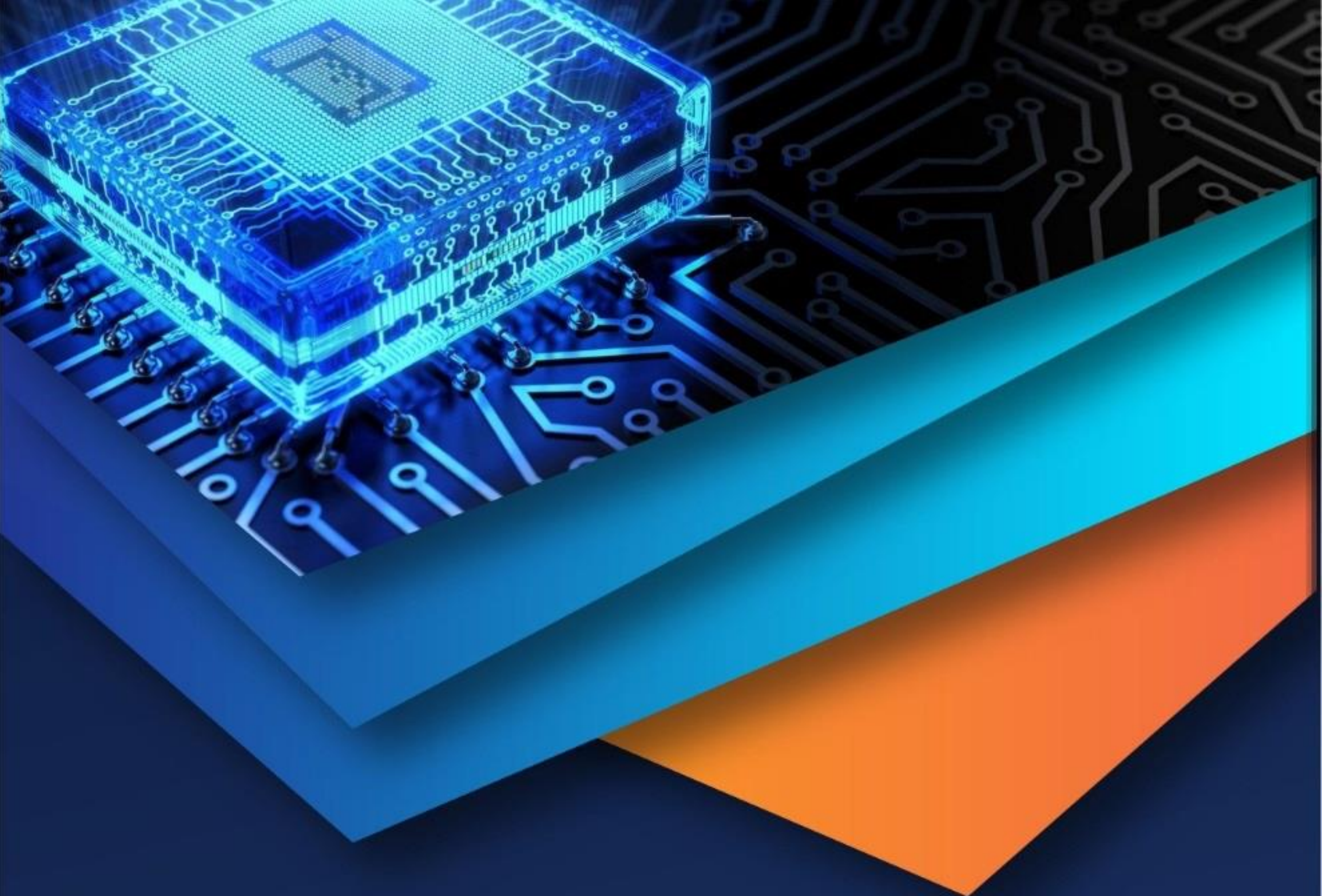

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