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Ornithology-Inspired Flow Analysis for Optimized Artificial Mellisuga Helenae Performance

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Abstract: ***An remarkable effectiveness of actual bird flight, this project's aim is to develop a biomimetic artificial Mellisuga Helenae featuring a semi-elliptical wing design. The aim is to develop unmanned aerial vehicles (UAVs) capable of executing various efficient tasks in areas like wildlife monitoring, ecological assessment, and emergency response by mimicking basic flight dynamics such as flapping, folding, and bending. The wing design, incorporating camber and twist, was meticulously crafted with advanced CAD software such as SolidWorks to enhance lift and maintain precise control during flight.***
Keywords: Ornithopter, UAV, CFD,

I. INTRODUCTION

The project entails creating an imitation bird's wing, evaluating its functionality using simulations, and choosing the appropriate material to achieve the best results. Unmanned aerial vehicles (UAVs), such as artificial birds, are employed in a variety of applications, including disaster relief, animal monitoring, and environ-mental monitoring. They can move and function in areas where conventional drones could find it difficult because of their biomimetic design. Flapping, folding, bending, and twisting are the main wing action sequences. A 4-bar linkage structure serves as the basis for the construction of two wing mechanisms in this paper, one specifically for artificial Mellisuga Helenae flapping motion (FM) and the other for simultaneous flapping and folding motion (FFM) during a wing stroke. The primary wings of a bird move primarily in up- and down-strokes, yet occasionally they stay still like fixed wings when gliding. The flapping, folding, bending, and twisting are the primary wing motions during wing strokes. We focus on the Flapping and Folding Motion (FFM) among them.

A. To Create an Artificial Bird's Semi elliptical Wing Structure

The technique of creating a semi elliptical wing for an artificial Mellisuga Helenaeis intricate and attempts to mimic the stable and effective flying traits of real birds. Biological wings, which are frequently designed to minimize drag and maximize lift, served as the model for this shape.

B. Semi Elliptical form Benefits

By encouraging an even distribution of lift across the span, the semi elliptical wing form reduces generated drag. Wingtip vortices, a significant source of drag in winged vehicles, have been demonstrated to be lessened in intensity by this design.

C. Aspect Ratio and Span

These factors are crucial in establishing how stable and agile the artificial Mellisuga Helenae. For an artificial Mellisuga Helenae that may need to manoeuvre through tight or natural places, a well-designed aspect ratio guarantees that the wing delivers adequate lift without compromising agility.

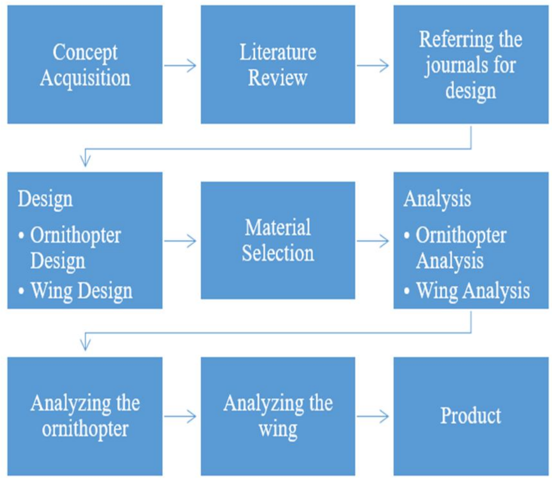
D. Wing Loading and Structural Integrity

It's critical to make sure the wing can withstand a range of flying circumstances without experiencing undue deformation or failure. The weight that the wing must support in relation to its area is taken into account during the design phase.

E. Wing Modelling

The geometry of the artificial Mellisuga Helenae wing can be created using CAD software (such as SolidWorks or CATIA) to satisfy both aerodynamic and aesthetic requirements. To increase lift while keeping control, details like twist (wingtip orientation) and camber (wing curve) are changed.

II. METHODOLOGY



A. *Objective Definition*

The goal of designing an artificial Mellisuga Helenae wing is to replicate the flight mechanics of natural birds, enabling an ornithopter to achieve sustained, energy-efficient, and controlled flight. The artificial Mellisuga Helenae wing must emulate the lift, thrust, and manoeuvrability exhibited by bird flight. This requires a deep understanding of aerodynamics, structural mechanics, and the dynamic motion of flapping wings as seen in nature.

B. *Functional Requirements*

To ensure seamless integration with an ornithopter, the wing must:

1) Generate enough lift across varying speeds.
2) Create enough thrust to overcome drag and maintain forward motion.
3) Provide precise control for flight stability and manoeuv-ring.
4) Be lightweight to reduce energy consumption during flapping while maintaining the structural strength to withstand aerodynamic and inertial forces.
5) Challenges
   a) Weight Constraints
   b) Energy Efficiency
   c) Material Fatigue

C. *Design*

Designing an artificial Mellisuga Helenae, a flapping-wing device inspired by birds, requires thorough planning to ensure structural integrity, efficient motion mechanisms, and aerodynamically optimized wings. This section provides an in-depth exploration of the essential components and processes, focusing on the structural framework, flapping mechanism, and wing design.

D. *Wing Geometry*

Low-Speed Air foils: Profiles like S1223 or Eppler E423, which provide high lift at low Reynolds numbers, are ideal for ornithopter wings.

Bio-Inspired Features: Curved leading edges and tapered trailing edges mimic natural bird wings, improving aerodynamic performance.

E. *3D Modelling and Simulation*

CAD Modelling

Internal Supports**:** Design of spars, ribs, and attachment points for structural integrity.

Aerodynamic Surfaces: Refinement of wing surfaces to ensure smooth airflow.

Aerodynamic and Dynamic Simulations

Computational Fluid Dynamics (CFD): Used to evaluate lift, drag, and flow separation during various flapping cycles.

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F. Analysis

The success of an ornithopter relies heavily on its aerodynamic and structural perfo-rmance. To achieve optimal efficiency, stability, and functionality, advanced computational tools like Computational Fluid Dynamics (CFD) and structural simulations are utilized. This section explores critical aspects of ornithopter analysis, including pressure distribution, velocity fields, streamline patterns, and wing dynamics.

Pressure distribution over the ornithopter's body and wings significantly influences its lift, drag, and structural stability.

G. Testing and Validation

Testing and validation are essential phases in the development of an ornithopter. They ensure that the prototype performs as expected under real-world conditions and meets design objectives for stability, efficiency, and endurance. The process involves fabricating a prototype, conducting controlled wind tunnel tests, performing real-world flight tests, and analysing results to refine the design iteratively.

H. Design Process of Ornithopter

There are several stages involved in designing an ornithopter in SolidWorks, including conceptual design, detailed modeling, analysis, and simulation. An ornithopter is a flying machine that flies by flapping its wings like a bird.

The picture (Fig.1) displays a thorough drawing made with the advanced computer-aided design (CAD) program SOLIDWORKS. The profile of an object is seen in this sketch, which is painstakingly delineated with several measurements marked in millimeters. For proper modeling and production, each dimension offers crucial measurements that delineate the object's exact size and shape.

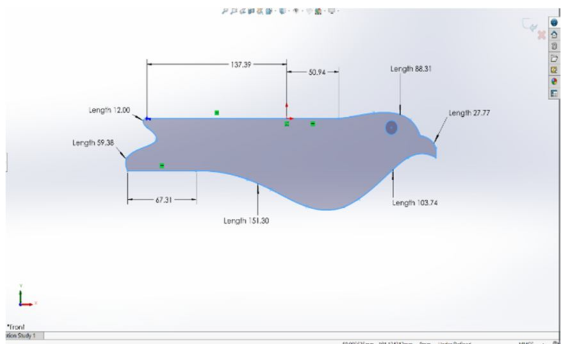

Fig. 1 Mellisuga Helenae

The dimensions transcribed from the sketch are: Lengths ranging from **12.00 mm** to **151.30 mm**,With various other specific measurements in between. Engineers and designers may make sure that every part of the thing satisfies the necessary standards by using SOLIDWORKS to design with such accuracy, which improves the final product's quality and usefulness. The picture (Fig. 2) displays a 3D model of a component created using the computer-aided design (CAD) program SOLID-WORKS. This model, which has a hole and many extrusions, looks to be a mechanical part with a distinctive bird-like design.

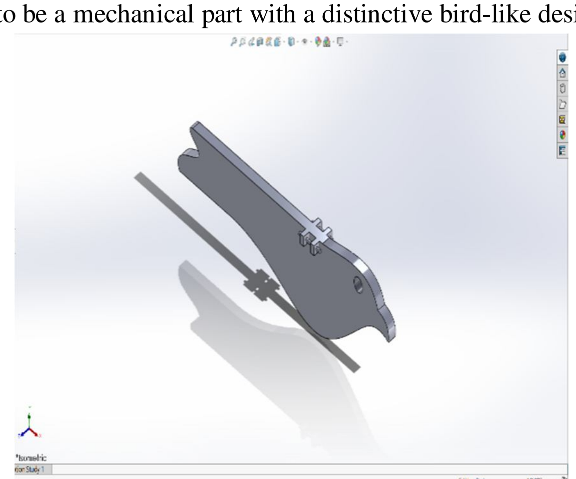

Fig. 2 3D Model Components

Labeled "Boss-Extrude1," "Boss-Extrude2," and "Boss-Extrude3" in the feature tree on the left side of the screen, the design comprises three primary extrusions. The part's size and structural characteristics are clearly visible due to its isometric depiction. The interface indicates that the model is in the "Editing Part" mode by showcasing a number of toolbars and editing choices.

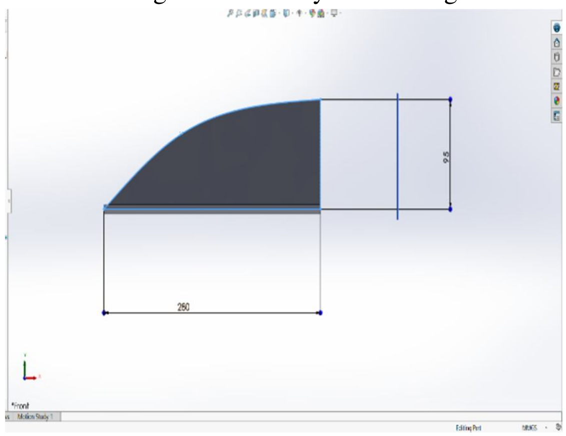

Fig. 3 Elliptical Wing

The picture (Fig. 3) displays a thorough drawing of a semi-elliptical wing created using the potent computer-aided design (CAD) program SOLIDWORKS. An accurate 2D profile with exact measu-rements that are necessary for production is shown by this sketch.

The profile includes:
A horizontal base line measuring 280 units in length.
A vertical line on the right side measuring 95 units in height.
A curved line at the top, transitioning smoothly from the left side to the right, creating a rounded profile.

Fig. 4 Isometric View

The above figure 4.4 is the isometric view of the ornithopter.

I. Analysis of the Ornithopter and its Wings

An intriguing and intricate field of aerodynamics and engineering is represented by the creation of ornithopters, or aircraft that imitate the flapping wing action of insects or birds. Ornithopters replicate the flapping action of bird wings to accomplish flight, in contrast to traditional fixed-wing or rotary-wing airc-raft, which depend on constant airflow to generate lift. Because of this, its design is very special and difficult, requiring a thorough comprehension of several mechanical, aerodynamic, and control concepts. In this regard, analysis is crucial to guaranteeing the safe, effective, and efficient operation of ornithopters. Thorough study is essential for maximizing performance and guaranteeing the durability of ornithopter designs, whether for small-scale prototypes, military reconnaissance, or possible future pass-enger aircraft.

The significance of analysis in the construction of ornithopters is examined in this article from a variety of angles, such as aerodynamics, kinematics, structural integrity, flying performance, control systems, and sustainability. It will also take into account how advanced technologies like energy analysis, finite element analysis, and computational fluid dynamics (CFD) help to improve ornithopter designs.

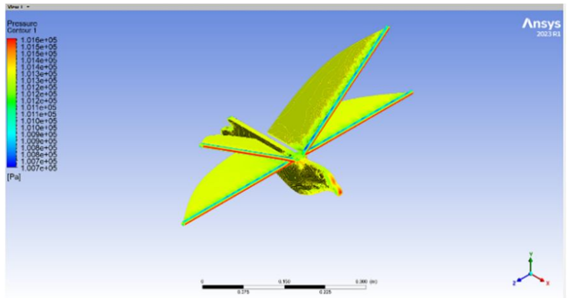

Fig. 4 Pressure Analysis

The below fig. shoes the velocity test of the ornithopter body. The dispersion of the velocity field in the surrounding fluid—in this example, air—is shown in this graphic. Different velocity values, from 0 to the maximum velocity shown in the simulation,

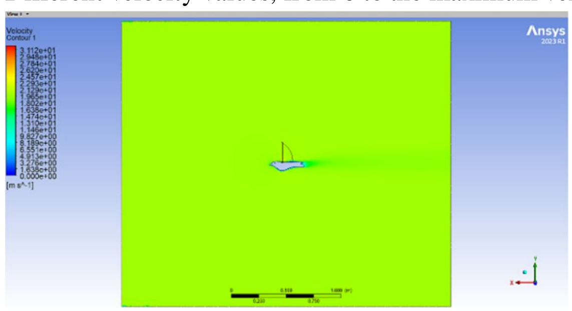

Fig. 5 Velocity Analysis

are represented by the color gradient on the left. The picture indicates a stable area as most of the surrounding air, which is colored green, has a low velocity. The blue and red hues, on the other hand, indicate regions where the velocity rises close to the ornithopter model. The ornithopter's body and wings move, creating airflow disturbances that affect these regions. In locations where the flow accelerates as a result of the ornithopter's motion, the red areas show higher velocities farther away from the body, while the blue areas show comparatively lower speeds close to the ornithopter's surface. Because it makes it easier to spot areas of high and low airflow around the model, the velocity distribution is essential for comprehending the ornithopter's aerodynamics.

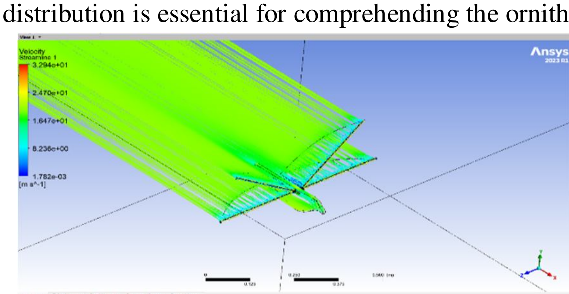

Fig. 6 Velocity Streamline

The above figure shows the velocity streamline of the ornithopter.

The below Fig shows the pressure test on the wing at 8 degree angle of attack. A pressure contour plot from an ANSYS simulation that examines fluid flow over an aerodynamic surface—likely an airfoil or wing—is shown in the image. With a scale on the left for reference, the map is color-coded to show pressure levels in Pascals, which range from around 1.005e+05 Pa to 1.016e+05 Pa. Understanding how pressure changes throughout the surface, which has a direct influence on aerodynamic performance, including lift and drag characteristics, is made possible by this simulation. The scale bar at the bottom center gives a reference for length in meters, while the coordinate system at the bottom right shows the plot's orientation in the X, Y, and Z dimensions.

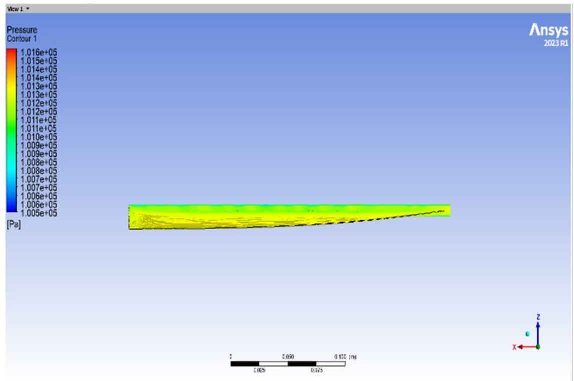

Fig. 7 Pressure Analysis at 8 deg AOA

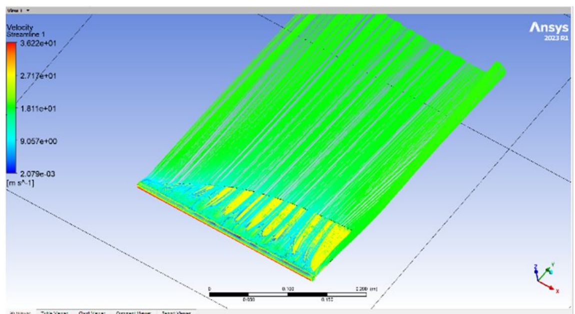

Fig. 8 Velocity Streamline at 8 deg AOA

The above fig. depicts fluid flow across a surface using a velocity streamline simulation from Ansys 2023 R1. Velocity magnitudes are shown by color-coding the streamlines, with red being the maximum velocity (20 m/s) and blue the lowest (around 2.079e-03 m/s). Understanding the fluid dynamics and velocity distribution in the simulated domain is made easier with the aid of this visualization, which offers crucial information for improving aerodynamic performance and design. To help with the accurate study of the flow characteristics, the coordinate system displays the orientation of the axes (X, Y, Z), and the scale at the bottom measures the length in meters.

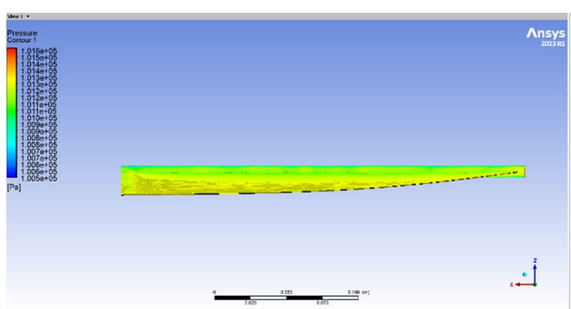

Fig. 9 Pressure Analysis at 10 deg AOA

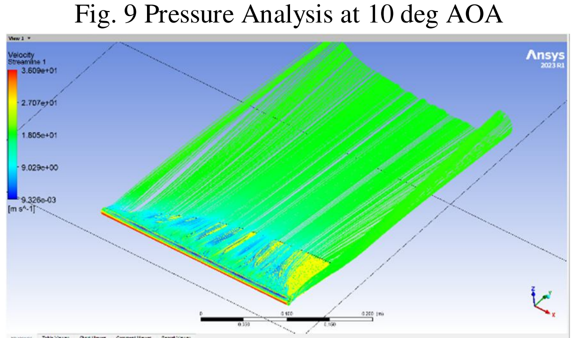

Fig. 10 Velocity Streamline at 10 deg AOA

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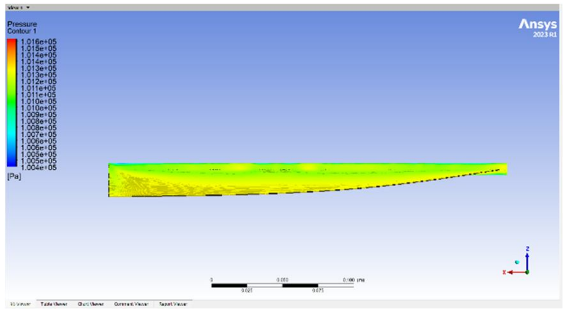


Fig. 11 Pressure Analysis at 12 deg AOA

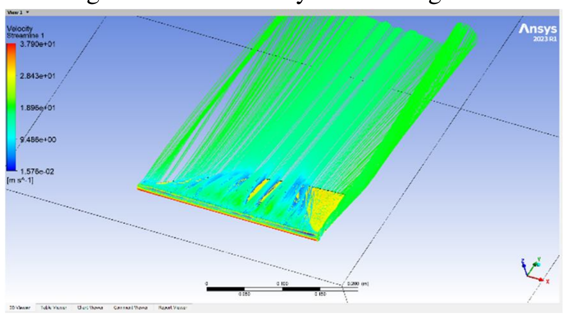
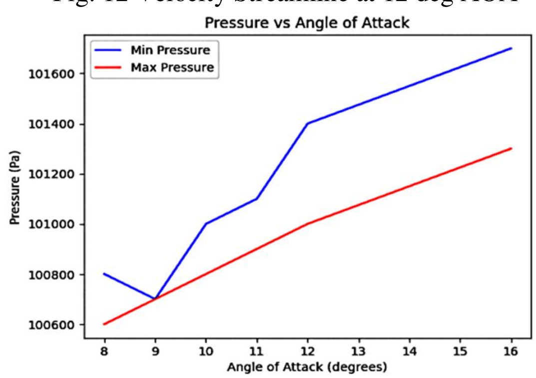


Fig. 12 Velocity Streamline at 12 deg AOA



"Pressure vs. Angle of Attack" is a graph that shows the relationship between pressure (in Pascals) on the y-axis and angle of attack (in degrees) on the x-axis. The red line indicates the highest pressure, while the blue line indicates the lowest. Higher aerodynamic forces are shown by rising minimum and maximum pressures as the angle of attack increases from 8 to 16 degrees. A key component of aerodynamic research, the graph illustrates how pressure varies as the angle of attack changes. The lowest pressure for lower angles (8 degrees) is around 100,800 Pa, while the maximum pressure is 100,600 Pa. The pressures rise continuously as the angle of attack rises. The lowest pressure drops to around 101,600 Pa while the maximum pressure rises to roughly 101,400 Pa by 16 degrees. For applications like as automotive and aircraft design, where aerodynamic performance is crucial, this constant increase in pressure indicates that higher angles of attack provide stronger aerodynamic forces acting on the surface. Designing effective airfoils and enhancing overall performance are made easier with an understanding of these dynamics.

III. CONCLUSION

With the successful conception, design, and analysis of a lightweight artificial bird with a semi-elliptical wing structure, we have made a significant advancement in the field of biomimetic design and aeronautical engineering and have taken a decisive step toward incorporating nature's flight dynamics into contemporary unmanned aerial vehicles (UAVs). This work demonstrates the potential of biomimetic solutions to address a variety of challenges, from disaster management to environmental conservation, by simulating the effectiveness, agility, and adaptability of natural flyers. This study's selection and optimization of a semi-elliptical wing design was one of its key achievements; its demonstrated aerodynamic efficiency, which is characterized by fewer wingtip vortices and an even distribution of lift, gave the artificial bird a strong basis for performance, and advanced computational fluid dynamics (CFD) simulations and material optimization ensured that the wing could withstand a variety of aerodynamic forces while maintaining a lightweight and durable structure.

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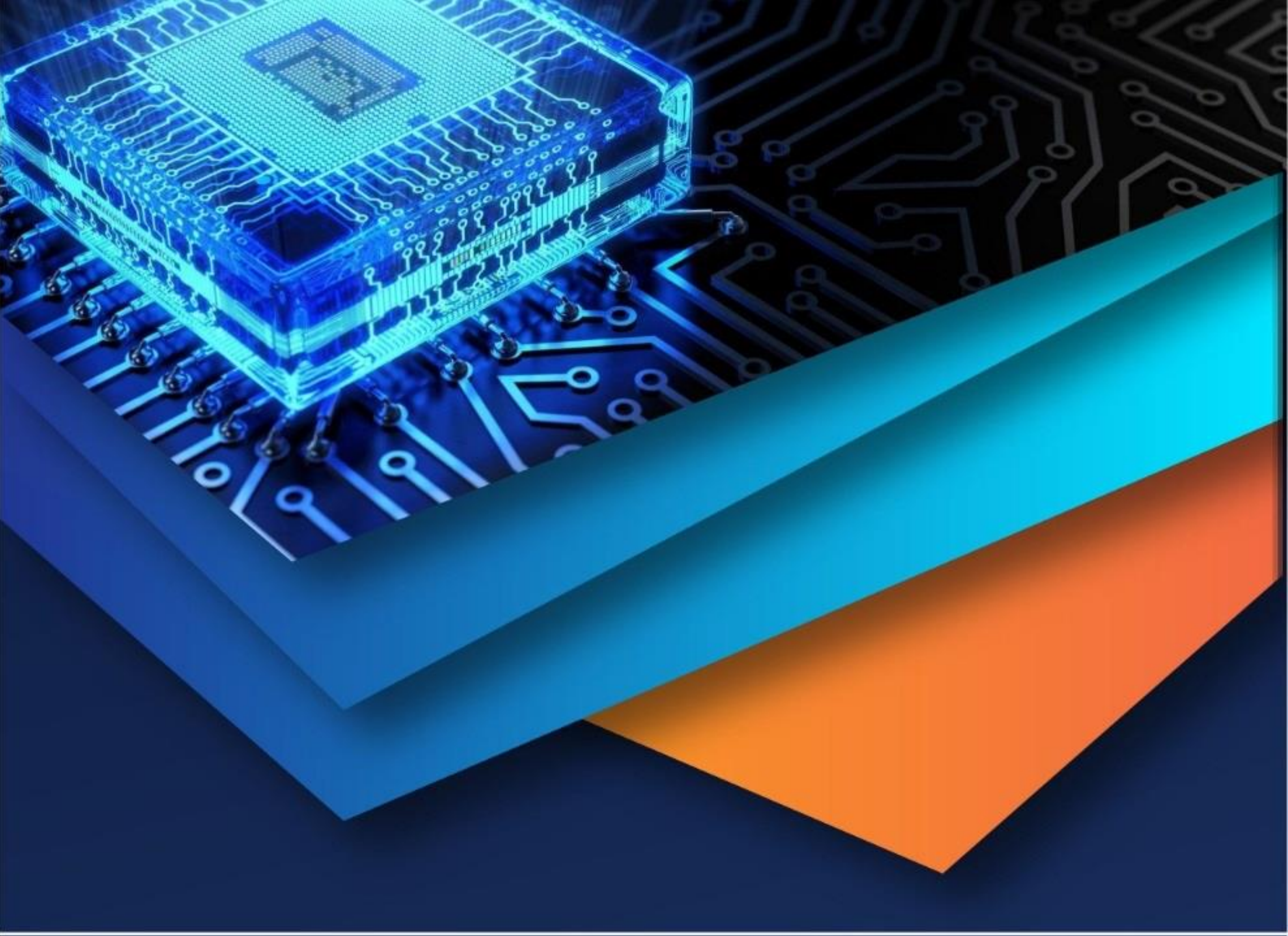

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