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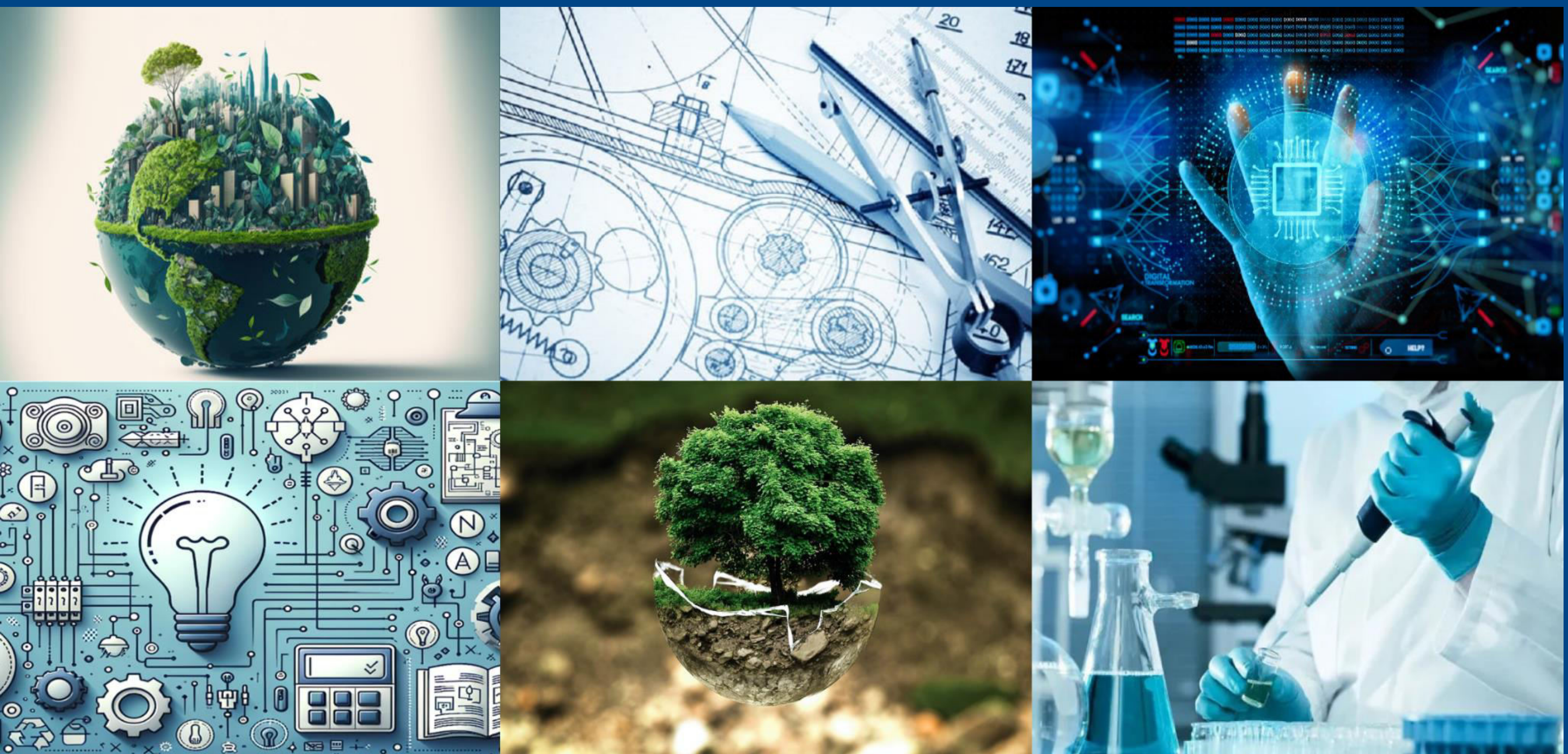

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Computational Fluid Dynamics (CFD) of Bionic Airfoil

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ABSTRACT: Efficient aerodynamic design is vital for both environmental sustainability and technological advancement. This abstract presents a comprehensive strategy for designing a prawn-inspired airfoil, addressing key objectives such as improving lift-to-drag ratios, minimizing flow separation, and enhancing aerodynamic performance. The proposed system integrates various components to streamline aerodynamic processes. The project explores the potential of prawn-inspired airfoil designs for aerodynamic applications. Using Computational Fluid Dynamics (CFD), the study aims to analyze the performance of a segmented, flexible airfoil at various angles of attack. The goal is to improve lift-to-drag ratios and minimize flow separation, with potential applications in drones and wind turbines. Innovative features such as segmentation and flexibility are incorporated to enhance the efficiency of the airfoil. By reducing drag and improving flow control, this mechanism improves overall system performance while conserving energy. Furthermore, the project integrates advanced CFD simulations to validate the design and compare it with traditional airfoil designs. These advancements highlight the importance of biomimicry in aerodynamic design. By implementing innovative technologies and design principles, the proposed prawn-inspired airfoil aims to promote cleaner environments and more efficient aerodynamic systems, contributing to overall environmental sustainability and technological progress.

KEYWORDS: Prawn-inspired Airfoil, Lift-to-Drag Ratios, Computational Fluid Dynamics (CFD).

I. INTRODUCTION

Biomimicry, the practice of drawing inspiration from nature to solve human challenges, has been widely applied in various fields, including aerodynamics. Nature has evolved efficient designs over millions of years, and these designs can be leveraged to improve human-made systems. One such example is the prawn, a marine creature known for its streamlined body and segmented exoskeleton, which allows it to move efficiently through water.

In aerodynamics, the study of airflow over surfaces such as airfoils is critical for designing efficient systems like drones, wind turbines, and aircraft. Traditional airfoil designs have been inspired by birds and fish, but prawn-inspired designs remain underexplored. Prawns' unique hydrodynamic features, such as their segmented tails and flexible exoskeletons, offer potential advantages for aerodynamic applications, particularly in reducing drag and improving flow control.

The concept of biomimicry in aerodynamics is not new. For decades, researchers have studied the flight mechanics of birds and the swimming patterns of fish to design efficient airfoils and propulsion systems. However, the application of prawn-inspired designs in aerodynamics is a relatively unexplored area. Prawns, with their segmented exoskeletons and flexible bodies, exhibit unique hydrodynamic properties that could revolutionize aerodynamic design.

This project aims to bridge the gap in research by exploring the potential of prawn-inspired airfoil designs. By studying the prawn's natural hydrodynamics, the project seeks to develop an airfoil that can improve lift-to-drag ratios, minimize flow separation, and enhance overall aerodynamic performance.

The motivation for this project stems from the need to explore innovative aerodynamic designs that can improve efficiency and performance. Traditional airfoil designs often face challenges such as flow separation and high drag, especially at varying angles of attack. By studying the prawn's natural hydrodynamics, this project aims to develop an airfoil design that can address these challenges.

The potential applications of a prawn-inspired airfoil are vast, including drones, wind turbines, and aerospace systems. Drones, for instance, require high aerodynamic efficiency to maximize flight time and payload capacity. Similarly, wind turbines can benefit from improved lift-to-drag ratios, leading to greater energy generation. By bridging the gap in research on prawn-inspired designs, this project seeks to contribute to the advancement of aerodynamic technologies. The project is also motivated by the growing demand for sustainable and energy-efficient systems. As the world moves towards cleaner energy solutions, the need for efficient aerodynamic designs becomes increasingly important. Wind turbines, for example, rely on airfoils to convert wind energy into electricity. By improving the efficiency of these airfoils, the project aims to contribute to the development of more sustainable energy systems.

II. Computational Fluid Dynamics of Bio-Inspired Airfoils

This project provides a comprehensive review of the application of Computational Fluid Dynamics (CFD) in the study of bio-inspired airfoils. The authors explore how nature-inspired designs, particularly those derived from birds, fish, and insects, have been used to improve aerodynamic performance in various engineering applications. The review highlights the growing interest in biomimicry as a means of addressing challenges such as flow separation, drag reduction, and lift enhancement in airfoil design.

The study begins by discussing the principles of biomimicry and how natural organisms have evolved to achieve optimal aerodynamic efficiency. For example, the authors examine the wing structures of birds and the fin shapes of fish, which have inspired the development of airfoils with improved lift-to-drag ratios. The paper emphasizes the importance of flexibility and segmentation in these natural designs, which allow for adaptive responses to changing airflow conditions.

III. Biomimetic Design Approach

The airfoil design draws from two key features of prawns: Segmented Exoskeleton:Mimics the flexible, overlapping segments of a prawn's tail. Aims to reduce flow separation by allowing adaptive deformation under aerodynamic loads. Streamlined Profile: Replicates the tapered, hydrodynamic shape of prawns for low drag.

Design Parameters:

Parameter	Value	Rationale
Chord Length	150 mm	Standard for small-scale aerodynamic testing.
Segment Count	5	Balances flexibility and structural integrity.
Max Thickness	12% of chord	Optimized for lift generation.
Material	Carbon Fiber (Simulated)	Lightweight and high strength-to-weight ratio.

IV. Validation Methodology

Benchmarking:Compared with NACA 0012 (conventional airfoil) under identical CFD conditions.Validated solver setup against NASA CFD data for NACA 0012 (error < 5%).

Performance Metrics:1.Lift Coefficient (C_l): Cl=Lift0.5×ρ×V2×ACl=0.5×ρ×V2×ALift 2.Drag Coefficient (Cd):3. Pressure Contours: Identified separation points.4. Streamlines: Visualized flow attachment/detachment.

Flow Separation Analysis:Flow separation is analyzed using CFD simulations. The simulations identify regions of the airfoil where airflow separates, leading to increased drag and reduced lift.

Performance Metrics:The performance of the prawn-inspired airfoil is evaluated using the following metrics:
Lift-to-Drag Ratio (L/D): A key metric for evaluating aerodynamic efficiency.

Flow Separation: The extent to which airflow separates from the airfoil surface.

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Boundary Conditions: Inlet: Velocity inlet (Turbulence intensity = 5%, Hydraulic diameter = 150 mm). Outlet: Pressure outlet (0-gauge pressure). Airfoil Surface: No-slip wall. Domain: 10 chord lengths upstream/downstream to minimize edge effects.

V. RESULT AND DISCUSSION

In the fig 1, it shows the 2D view of the Bionic Airfoil.

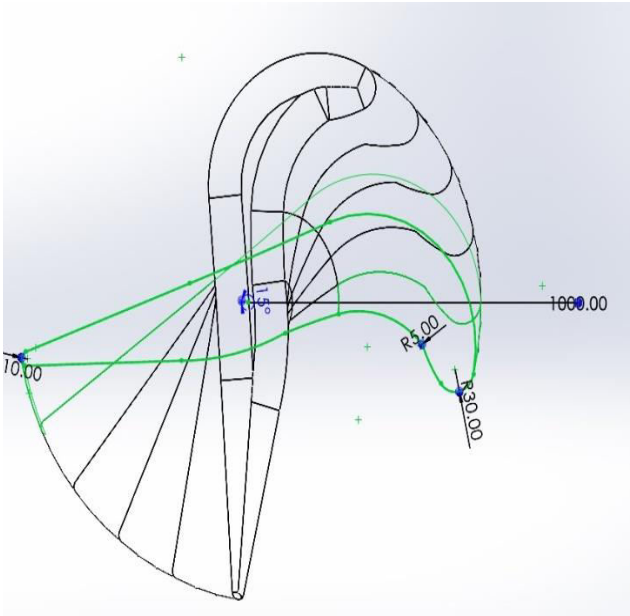

Fig. 1. 2D view of the Bionic Airfoil

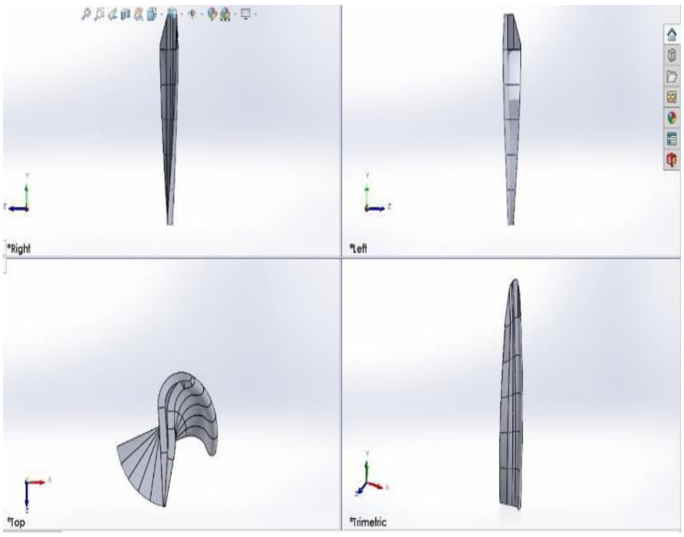

Fig. 2. 3D views of the Bionic Airfoil (Right, Left, Top, Trimetric)

In the fig 2, it shows the 3D views of the Bionic Airfoil such as right, left, top and trimetric view respectively.

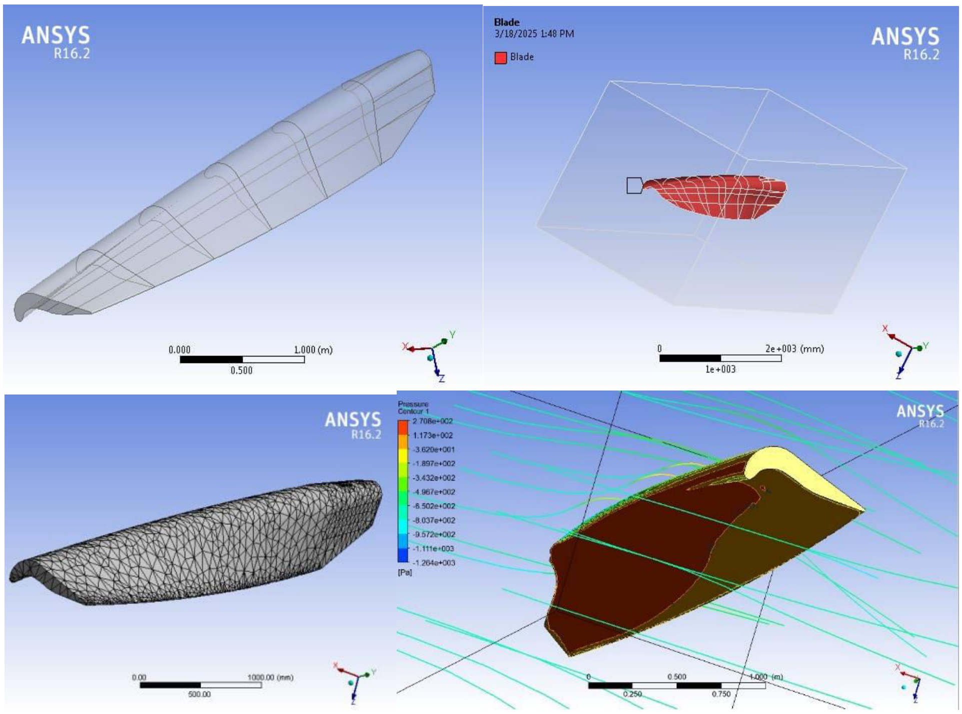

Fig. 3. Step by step process of CFD analysis

In Fig 3, It shows the step-by-step process of CFD analysis such as geometry, boundary, mesh and solution respectively.

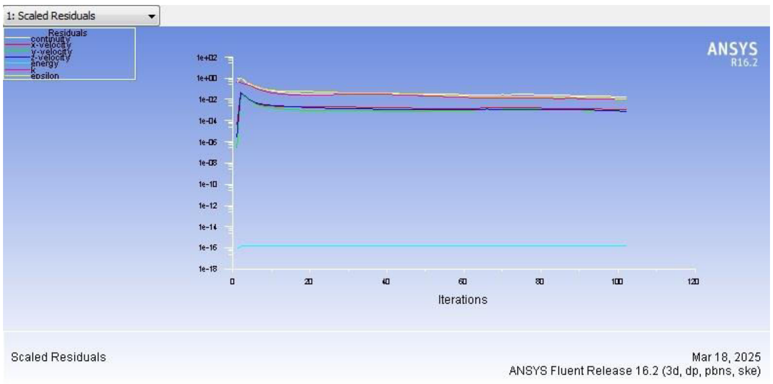

Fig. 4. Result graph

In Fig 4, It shows the end result of the analysis process

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VI. CONCLUSION

The study of prawn-inspired airfoil designs using Computational Fluid Dynamics (CFD) has demonstrated a significant improvement in aerodynamic performance compared to conventional airfoils. By leveraging the natural segmentation and flexibility of prawn exoskeletons, this research has successfully optimized lift-to-drag ratios, reduced flow separation, and enhanced stability across varying angles of attack.

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