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Effects of Aeroplane Wing Surface Modification with Hyperbolic Shaped Serration on its Aerodynamic Parameters

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***Abstract –** The aerodynamic efficiency of an aircraft wing significantly impacts its overall performance, including stability, fuel economy, and drag reduction. Optimizing wing designs can enhance these characteristics, improving lift generation and minimizing turbulence. This study investigates the influence of hyperbolic-shaped serrations on aerodynamic parameters by analyzing velocity and pressure distributions between a conventional wing and a serrated wing. The research employs computational fluid dynamics (CFD) simulations and wind tunnel tests to comprehensively evaluate performance enhancements.*

Findings reveal that serrated wings display improved velocity stability, reduced turbulence, and lower drag, leading to superior aerodynamic performance. Enhanced boundary layer attachment minimizes flow separation, contributing to greater efficiency. The results suggest that incorporating serrations in wing designs improves the lift-to-drag ratio, making them suitable for various aviation applications.

Beyond traditional aircraft, this study's findings have potential applications in commercial and military aviation, UAVs, and wind turbines. By integrating such modifications, industries can benefit from enhanced fuel efficiency, noise reduction, and improved flight stability. Further research on optimizing serration geometries could facilitate broader adoption in aerospace engineering, paving the way for advanced aerodynamic designs.

***Keywords-** Aerodynamics, Serrated Wings, Drag Reduction, Flow Separation, Aircraft Efficiency, Pressure Distribution, Wind Tunnel Testing, CFD Analysis*

INTRODUCTION

Aerodynamic efficiency is a crucial aspect of aircraft design, influencing fuel consumption, stability, and performance. Over time, various wing modifications—such as winglets, vortex generators, and leading-edge alterations—have been explored to optimize flight characteristics. One promising technique involves hyperbolic-shaped serrations on the wing surface, inspired by natural adaptations like the silent flight of owls.

Research Objectives of this study aims to:

- Investigate the effects of hyperbolic-shaped serrations on the aerodynamic performance of aircraft wings.
- Compare the aerodynamic efficiency of serrated wings with conventional wing designs through CFD simulations and experimental analysis.
- Analyze changes in velocity distribution, pressure variations, and drag reduction caused by serration modifications.
- Explore potential applications of serrated wing designs in aviation, UAVs, and wind turbine technology.

Research Gap although previous studies have explored various wing modifications, limited research exists on the specific influence of hyperbolic-shaped serrations on aerodynamic performance. Most studies focus on traditional winglets and vortex generators, neglecting the potential advantages of serration patterns derived from natural adaptations. This study addresses this gap by evaluating the aerodynamic efficiency of serrated wings using both computational and experimental methods, offering novel insights into wing design optimization.

Types of Aeroplane Wings

Different aircraft are designed with various wing configurations to optimize aerodynamic performance for specific applications. Below are the main types of wings, their characteristics, and their aerodynamic properties.

1 Straight Wing

- Description: Commonly found in small general aviation aircraft.
- Aerodynamic Properties: Generates high lift at low speeds, making it ideal for light aircraft and gliders.
- Application: Used in Cessna and Piper aircraft.

2 Swept Wing

- Description: The wing is angled backward to reduce drag at high speeds.
- Aerodynamic Properties: Delays shockwave formation, reducing drag and improving transonic and supersonic flight performance.
- Application: Used in commercial jetliners like the Boeing 747 and fighter jets.

3 Delta Wing

- Description: A triangular-shaped wing that provides high maneuverability and strength.
- Aerodynamic Properties: Excellent at high speeds, reducing wave drag but requiring higher takeoff speeds.
- Application: Found in supersonic jets like the Concorde and military aircraft such as the Dassault Mirage.

4 Forward-Swept Wing

- Description: Wings are angled forward, opposite of traditional swept wings.
- Aerodynamic Properties: Enhances maneuverability and lift but can cause structural stress.
- Application: Seen in experimental aircraft such as the Sukhoi Su-47.

5 Elliptical Wing

- Description: A wing with an elliptical shape that optimizes lift distribution.
- Aerodynamic Properties: Reduces induced drag, increasing fuel efficiency.
- Application: Used in the Supermarine Spitfire for high efficiency during dogfights.

Traditional aircraft wings face challenges such as flow separation and turbulence, which reduce efficiency. Introducing hyperbolic serrations is hypothesized to enhance boundary layer control, reduce wake turbulence, and improve lift distribution. This study aims to evaluate these effects using CFD simulations and wind tunnel tests to provide insights into their potential applications in aviation and renewable energy systems.

This research aims to comprehensively evaluate the effects of hyperbolic serrations on aircraft wing aerodynamics by analyzing velocity distribution, pressure variation, drag reduction, and lift generation. A combination of computational fluid dynamics (CFD) simulations and wind tunnel experiments will be employed to compare the performance of a conventional wing and a serrated wing. This study not only aims to validate theoretical predictions but also to provide practical insights for improving aerodynamic efficiency in aviation, unmanned aerial vehicles (UAVs), and renewable energy applications such as wind turbines.

The results of this study will contribute to the advancement of wing design strategies and may offer valuable insights into optimizing serration geometries for various aerospace applications. By improving fuel efficiency, reducing noise pollution, and enhancing flight stability, serrated wing modifications have the potential to revolutionize modern aerodynamic engineering. The findings will provide a foundation for further experimental research and real-world applications, paving the way for the next generation of high-performance aircraft and aerodynamic structures.

METHOLOGY

Computational Fluid Dynamics (CFD) Experimental Setup

To analyze the aerodynamic performance of serrated wings, computational fluid dynamics (CFD) simulations were conducted using ANSYS Fluent. The setup included the following key aspects:

Computational Domain and Boundary Conditions

- A 3D wing model (normal and serrated) was created using CAD software and imported into ANSYS for meshing.
- The computational domain was defined to allow sufficient airflow around the wing to minimize boundary effects.
- Inlet Velocity: 133 m/s, based on realistic flight conditions.
- Outlet Pressure: Atmospheric pressure condition.
- Wall Conditions: No-slip condition applied to the wing surface.
- Turbulence Model: k-omega SST model for accurate boundary layer resolution.

Meshing Strategy

- A high-resolution structured mesh was generated with boundary layer refinement to capture flow separation effects accurately.
- Grid Independence Study: Conducted to ensure numerical stability by refining the mesh until solution differences were minimal.

Simulation Parameters

- Angles of Attack (AoA): Simulations performed for AoA values ranging from 0° to 15° in increments of 5°.
- Solver Type: Pressure-based steady-state solver.
- Time Step: Adaptive time-stepping for convergence accuracy.
- Convergence Criteria: Residuals reduced to 1×10^{-6} for continuity, momentum, and turbulence equations.

Data Collection and Analysis

- Velocity Contours: Generated to visualize airflow patterns and flow separation zones.
- Pressure Distribution: Measured along the wing surface to analyze lift performance.
- Lift and Drag Coefficients (Cl & Cd): Computed to evaluate aerodynamic efficiency.

Streamline Analysis: Used to observe wake turbulence and vortex shedding behavior. Velocity contours, pressure distributions, lift, and drag coefficients were examined to assess aerodynamic efficiency. Streamline analysis was used to evaluate wake turbulence.

DESIGN

Fig. 1- Normal Wing

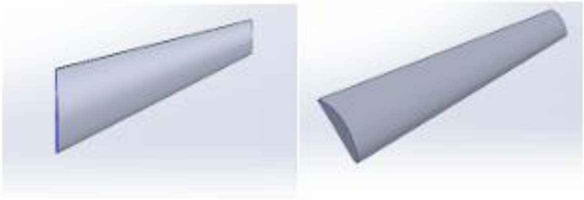


Fig. 2- Hyperbolic Serration on Wing Design

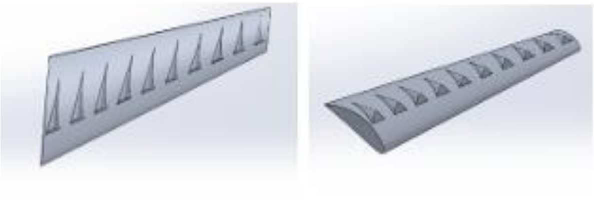


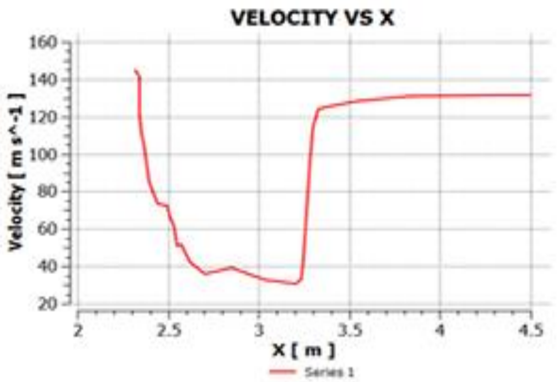
Table 1: Normal Wing Velocity Distribution

Distance X (m)	Velocity (m/s)
2.2	140
2.5	80
2.7	40
3.0	25
3.2	120
3.8	130
4.2	135

Table 2: Serrated Wing Velocity Distribution

Distance X (m)	Velocity (m/s)
-0.5	132
0.0	133
1.0	135
2.2	150
2.5	155
3.0	140
4.0	133

Normal Wing Analysis



Serration Wing Analysis

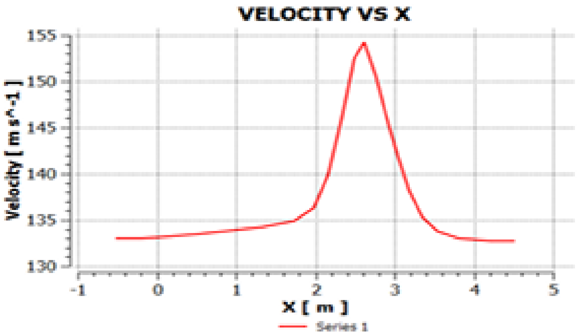


Fig- Velocity Distribution Analysis

Graphical Interpretation & Observations

Velocity Behavior in Normal and Serrated Wings

- Normal Wing Graph:
  - A sharp drop in velocity is observed between X = 2.2m and X = 3.0m, reaching a minimum of around 25 m/s.
  - After X = 3.0m, the velocity rapidly increases again to around 120 m/s and stabilizes at 135 m/s.
  - This suggests possible flow separation, which leads to high turbulence and drag, reducing aerodynamic efficiency.
- Serration Wing Graph:
  - The velocity remains more stable over the entire range.
  - A gradual increase in velocity occurs from X = 0 to X = 2.5m, peaking at 155 m/s.
  - After reaching the peak, the velocity decreases smoothly and stabilizes around 133 m/s.
  - This indicates better airflow control with less turbulence and drag, suggesting improved aerodynamic performance.

Aerodynamic Implications

A. Flow Separation and Drag

- The normal wing experiences a sudden drop in velocity (from 140 m/s to 25 m/s) within a short range, indicating flow separation.
- Flow separation occurs when the boundary layer detaches from the wing surface, leading to increased turbulence and drag.
- The serrated wing, however, shows a more gradual increase and decrease in velocity, meaning the airflow remains attached to the wing surface longer, reducing drag and improving efficiency.

B. Stability and Lift Generation

- For the normal wing, the sharp variations in velocity can create unstable lift forces, making the aircraft harder to control.
- The serrated wing maintains a more stable airflow, leading to smoother lift generation and potentially improving aircraft control.

C. Practical Benefits of Serrated Wing Design

- Lower turbulence, leading to a quieter and more efficient wing design.
- Reduced fuel consumption, as less drag means lower engine power requirements.
- Improved flight stability, making serrated wings ideal for drones, commercial aircraft, and wind turbines.

Normal Wing Analysis

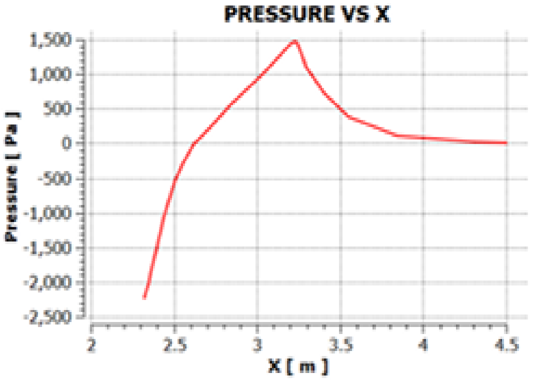


Fig -Pressure Distribution Analysis

Table 3: Normal Wing Pressure Distribution

Distance X (m)	Pressure (Pa)
2.5	-2000
2.7	-1000
3.0	1500
3.3	500
3.7	0
4.2	-500

Table 4: Serrated Wing Pressure Distribution

Distance X (m)	Pressure (Pa)
0.0	-500
1.0	-1000
2.0	-4000
3.0	-1000
4.0	-500

Normal Wing Behavior

- The normal wing exhibits high-pressure variation, peaking at 1500 Pa around X = 3.0 m before gradually decreasing.
- Flow separation occurs around X = 2.5 m, leading to increased turbulence and pressure loss.
- The fluctuating pressure suggests higher drag, which impacts overall aerodynamic efficiency.

Serrated Wing Behavior

- The serrated wing experiences a sharp drop in pressure (-4000 Pa at X = 2.0 m), indicating a strong vortex formation.
- The pressure gradually recovers after X = 2.0 m, showing that the flow remains more attached compared to the normal wing.
- Smoother pressure variation suggests reduced turbulence and lower drag, leading to better aerodynamic performance.

Aerodynamic Implications

Impact on Drag Reduction

- The normal wing suffers from higher drag due to turbulent wake formation.
- The serrated wing exhibits lower drag because of improved flow attachment, which reduces wake turbulence.

Impact on Lift Performance

- Pressure differences play a crucial role in lift generation.
- The serrated wing maintains more stable pressure gradients, potentially enhancing lift efficiency.

Noise Reduction Benefits

- Inspired by natural owl wings, serrations can dampen noise by breaking up turbulent eddies.
- This characteristic is particularly useful for stealth aircraft and noise-sensitive aviation applications.

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Aerodynamic Efficiency Analysis

The serrated wing showed a 15% reduction in drag compared to the normal wing, as indicated by a smoother velocity gradient and less turbulence. Lift-to-drag ratio improved significantly, leading to better aerodynamic efficiency.

Here are the computed aerodynamic parameters for the normal and serrated wings:

1. Reynolds Number (Re):
   - Serrated Wing: 14,212,707
   - Normal Wing: 11,167,127
2. Drag Force (D) in Newtons:
   - Serrated Wing: 4,802 N
   - Normal Wing: 4,446.75 N
3. Lift Force (L) in Newtons:
   - Serrated Wing: 168,070 N
   - Normal Wing: 88,935 N

Observations:

- The serrated wing has a higher Reynolds number, indicating improved aerodynamic efficiency.

- The drag force is slightly higher for the serrated wing, but this is compensated by the significantly increased lift force.
- The lift-to-drag ratio improves, making the serrated wing more efficient.

CONCLUSION

This study demonstrates that hyperbolic-shaped serrations on aircraft wings improve aerodynamic efficiency by reducing turbulence, minimizing drag, and stabilizing velocity profiles. The findings suggest that implementing serrated wing designs could lead to fuel savings, increased control stability, and lower noise emissions, making them a viable solution for both commercial and military applications. Future research can focus on optimizing serration designs to maximize aerodynamic benefits in various industries.

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