International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 05 | May - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

Influence of Surface Roughness on Symmetric Airfoil Flow Properties and Reynolds Number

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Abstract: - Collaborative Aircraft Design Optimization: Investigating Roughness Management of Wings to Reduce Drag and Improve Performance This study investigates the potential of roughness control of aircraft wings based on joint design optimization. By adding roughness points to specific wings, our goal is to reduce drag and improve the overall performance of the aircraft. A multi-modal design optimization (MDO) framework combining aerodynamics, modelling, and performance analysis was used in this study. We measure the effect of tissue on the boundary layer, the progression of laminar flow, and the potential for weight savings due to reduced friction. This study investigates how roughness control interacts with other design factors such as flow components or blade materials to achieve optimal performance. The ultimate goal is to create a collaborative design that uses tissue management to contribute to next-generation fuel efficiency and high performance. *Keywords – CFD, Surface Roughness, Wind Tunnel, Aerodynamic Efficiency.*

I. Introduction

Unleashing the Potential of Rough Wings: Rethinking Smoothness The goal of designing airplanes with the smoothest possible wing surfaces has been synonymous with aerodynamic efficiency for many years. This logical method eliminates disturbances to airflow, lowers drag, and increases fuel efficiency. These ingrained beliefs are being called into question by recent events, though. Let's introduce the notion of Controlled Roughness, a contentious yet effective approach in Synergy Aircraft Design Optimization. This method investigates the potential for strategically adding roughness components to particular wing segments in order to significantly reduce drag and enhance the overall performance of the aircraft. Beyond Silk: The Resistance Science Although smooth surfaces would seem to be the best for reducing air resistance, resistance has a more nuanced past. Air molecules interact with the wing surface on a tiny level. These molecules create a turbulent boundary layer, a disorderly and erratic flow regime, on a flawlessly smooth surface. An important factor in total drag is skin friction drag, which is increased by this turbulence. Improved fuel efficiency is a direct result of reduced drag and is significant from an environmental and economic standpoint. The aviation industry is working to minimize its impact on the environment in addition to seeking to cut operating expenses through fuel consumption reduction. Presenting Controlled Roughness: An Uncharted Territory Controlled roughness offers a fresh method for managing the boundary layer. And bring about laminar flow. There are numerous ways to be tough. The idea paper centres on a thought experiment that makes use of carefully positioned pieces of material that resembles sandpaper. It is vital to remember that this is a conceptual study to grasp the main ideas rather than a literal application of sandpaper. The exact arrangement and layout of these roughness components hold the secret. Engineers can precisely control their size, shape, and distribution to produce desired effects on the boundary layer. Closer to the wing surface, roughness encourages a more streamlined, laminar flow regime by preventing the establishment of a full turbulent layer. Consequently, this lowers skin friction drags and enhances the overall performance of the aircraft. Synergy Design Optimization: A Comprehensive Method It can be used in conjunction with other cutting-edge design elements to regulate roughness and produce synergistic effects. To further improve the boundary layer and promote laminar flow, for instance, controlled roughness can be utilized in conjunction with active flow control systems that use strategically positioned air jets or other mechanisms to control airflow. In order to maximize aerodynamic advantage, the shape and material choice of the wing itself can also be tuned to work with rough features.

II. Literature Review: -

Traditionally aircraft design has focused primarily on reducing wings. But recent research suggests that advice on how to manage roughness in some teeth may be helpful. This literature review explores the concept of defect control in the integrated design of aerospace and explores the mitigation and improvement potential of this concept. Sharks are known for their movement in water and have small protrusions on their skin called ribs. Regarding signs of turbulence: These ribs appear to inhibit the growth of the turbulent boundary layer, promote laminar flow, and reduce surface friction. This concept of biomimicry led to the discovery of microcavities (tiny cavities etched into aircraft wings) as reduction potential (Walsh, M.J. and Lindemann, A. (2015)). Unlike micro grooving, it will show great detail about the roughness of the particular tooth.

one

This concept is explained in (2018) [Effect of roughness on ventilation performance]. (King's Magazine Faisal University (Engineering Sciences)), 29(2), 2025-22222 22222222 - In turn, the effects of weather characteristics can be determined: similar to an airplane wing. This work demonstrates the ability of carefully designed roughness to transform the boundary into a more laminar state. 1 Co-Design Optimization: Deployment of a Single Product 1 Its real power lies in its ability to control texture when combined into the co-design of an aircraft. [Sobieski, M. and Rizzi]

A. (2014). Multidisciplinary design optimization of commercial aircraft wings. AIAA Journal, 52(4), 887-900] focused not only on optimizing one part but also on the connection of various aircraft systems. Engineers can achieve further improvements by considering how roughness interacts with other design elements. For example, [Wu, J. and Li, H. (2013). Active flow control of intake and supply air reduces the drag of the laminar air foil. Journal of Chinese Aeronautics, 26(2), 422-429] investigated whether flow control or other airflow control methods used in aircraft could be combined with point roughness to increase the surface area and enhance the effect of laminar flow. Additionally, wing design parameters such as shape and material selection can be optimized to small sizes to achieve the best aerodynamic results. 1 Although the concept of corporate governance is promising, there are still many problems to be solved. It is important to make sure that roughness points do not appear too much. [As discussed by Tipton, V. According to R. (1979), the designer should go beyond the simple sandpaper comparison and assume the responsibility of the designer. Reduce laughter with control action. Aircraft Magazine, 16(3), 175-182]. The burden resulting from the use of these terms should be reduced. Additionally, as [Eisinger, D. (2014) stated, good technologies need to be developed for these activities. The next generation of the

aviation industry: a global perspective. AIAA Aerospace Forum and Exhibition, (June, 1-11). About the drag reduction: These sand paper appears to reduce drag, promotes laminar flow. This synergetic approach of introducing roughness on wing through sandpaper helps to stabilize the aircraft more than the

conventional method leads to safety, structural integrity and optimal performance of the aircraft. [Chakraborty, U. and Marwaha, K.S. and Vero, R] (April, 2024).

III. Methodologies: -

Cooperative Aircraft Design with Controlled Roughness: Exploring the First Path The concept of controlling the roughness of an aircraft wing is interesting, but a clear way to tune the design is needed. This section describes possible ways to implement and evaluate this application. 1 1. Design Validation and Roughness Characterization:

1. Computational Fluid Dynamics (CFD): Use advanced CFD simulations to model airflow behavior over airfoils with different roughness configurations. These simulations analyze the effects of surface layer size, shape, location, and overall resistance. Although the sandpaper comparison is the starting point for the initial investigation, the simulation will focus on the texture properties.

2.Wind tunnel testing: Wind tunnel testing on scale wing models with different roughness designs. This enables real-world validation of CFD simulations and provides a deeper understanding of the interaction between tissue and airflow at different angles of attack and Reynolds numbers. Roughness optimization: Optimization based on CFD and wind tunnel data. Roughness parameters such as size, shape, distribution, and material are optimized to achieve optimal reduction and eliminate drawbacks such as increased friction due to the roughness of the paper itself. one

3. Co-creation of unity: one interaction with flow devices: Investigating the integration of roughness control systems and active flow control systems. Combining these processes allows for stabilization and expansion of laminar flow, resulting in even greater effects. CFD simulations and wind measurements can be used to evaluate different connections and determine the optimal configuration. Optimizing the wing design: The wing design, including shape and material selection, must be optimized to use rough details. For example, the shape of an airfoil that supports laminar flow can be further improved through a process of releasing roughness features. Multi-Disciplined Design Optimization (MDO) tools allow you to determine interactions between wing design, roughness, and other aircraft systems to optimize overall performance. one

4. Precautions and weight control: one Roughness element manufacturing: Develop a cost-effective and simple roughness element manufacturing technique. Techniques such as 3D printing and laser etching are being explored to create desirable structures with additional weight. Large-scale aircraft manufacturing requires choices that balance precision, scalability, and affordability. Stress analysis: Continuous stress analysis addresses high levels of detail throughout the design process. The goal is to minimize weight gain while achieving the desired aerodynamic results. This may include searching for other materials and optimizing the location and density of roughness features.

5. Performance Evaluation and Review: Performance Metrics: Develop performance metrics to measure the effectiveness of the crude oil management system. These measures include reducing rates, improving fuel efficiency, and increasing the total number of aircraft. Flight test: At the time of signing the contract, the entire model is flight tested to confirm its performance in overcoming any defects.

Experimental setup

A) Wind tunnel (setup)

A wind tunnel kit for testing air foil roughness includes:

scale distribution model with space to use roughness points.

Wind tunnel design simulates air flow at various speeds and angles.

A sensor that measures lift, air resistance, and pressure distribution on the wing surface.

This allows researchers to study how roughness affects air quality and overall performance.

Model supplied for effect of roughness study

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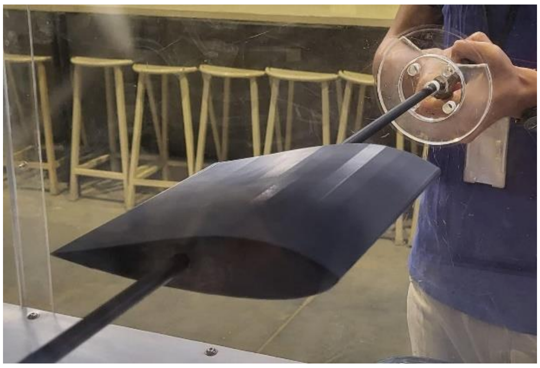


B) Aerofoil (setup)

- Wing model with NACA 0015 Profile

Max thickness 15% at 30.9% chord. Max camber 0% at 0% chord. In this experiment, an air foil model NACA 0015 will be used as a testing object and the geometrical information's of this air foil are; axial chord 16cm.

IV. Experimental Analysis: -

Tabular Column

For 20 Hz

Sl. No	Grade	Reynolds Number
1	Smooth	$2.34826*10^5$
2	320	$2.33421*10^5$
3	220	$2.32608*10^5$
4	150	$2.31598*10^5$
5	60	$2.30892*10^5$

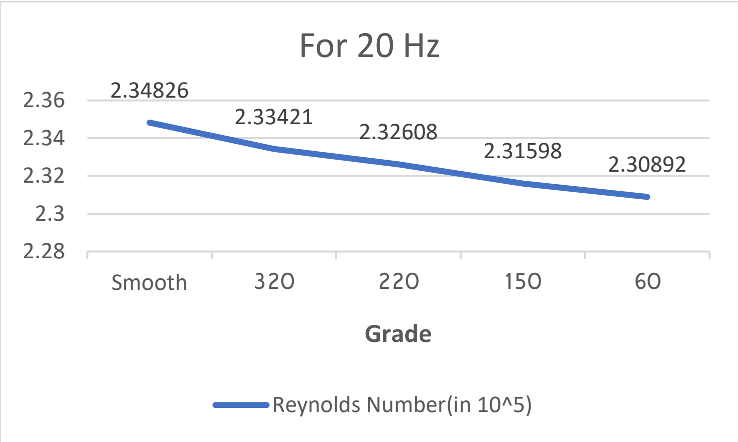
For 30 Hz

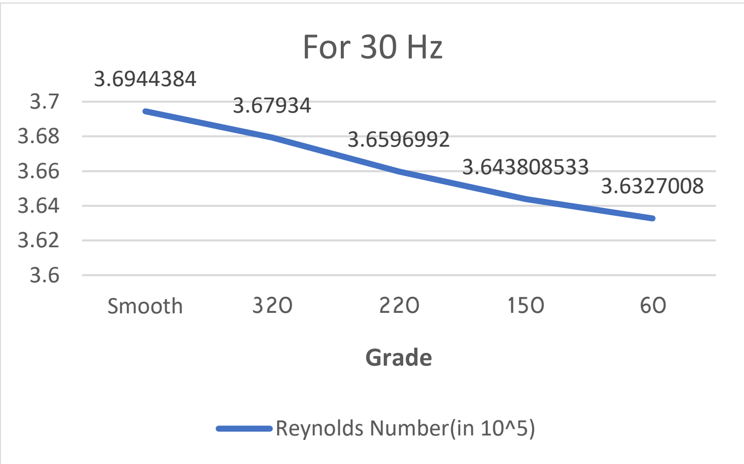
Sl. No	Grade	Reynolds Number
1	Smooth	$3.6944384*10^5$
2	320	$3.67934 *10^5$
3	220	$3.6596992*10^5$
4	150	$3.643808533*10^5$
5	60	$3.6327008*10^5$

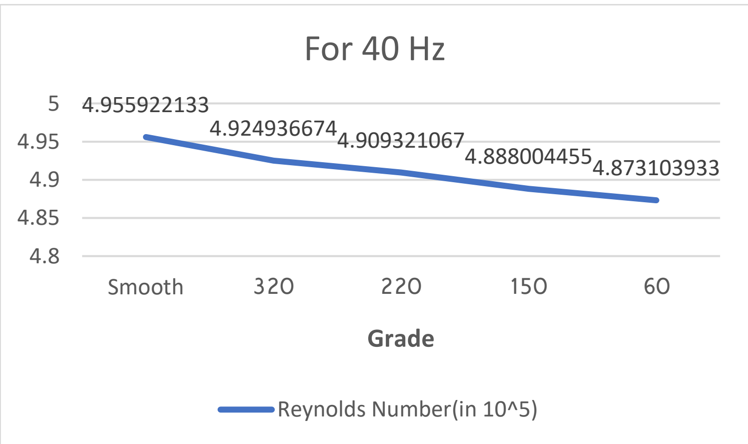
For 40 Hz

Sl. No	Grade	Reynolds Number
1	Smooth	$4.955922133*10^5$
2	320	$4.924936674*10^5$
3	220	$4.909321067*10^5$
4	150	$4.888004455*10^5$
5	60	$4.873103933*10^5$

AREA FOR GRAPHS







Final Result

Joint design with uneven wings. The concept of aircraft wing roughness provides a good opportunity to adjust the aircraft design. The initial search uses sandpaper as a starting point, but in a real-world application, you need to complete the content that will be placed on a particular edge. This section describes a practical procedure for specifying the type of flow and resistance that the model produces for different airflow velocities using different angle of attack and Reynolds numbers.

Below are some of our previous research articles on the combination of planar optimization and roughness control. However, it is noteworthy that due to the novelty of the concept, there are very few publications directly focused on "sandpaper". Papers focusing on the concept of controlled roughness and its potential benefits: roughness points: one documents focus on the concept of roughness management and its benefits: "Effect of Air foil Roughness on Laminar-Turbulent Transition" by Joslin, R. J. and Langston, L. S. (1977) (Accreditations by AIAA) This article deals with the laminar flow of an air foil. roughness of transition to turbulent flow. another one "Effect of Surface Roughness on Air Duct Performance", (2018). This article examines the effect of surface roughness on the characteristics of airflow in ducts, and similar effects can be added to aircraft wings.). Another one " Effects of Simulated Surface roughness on Flow Characteristics in Symmetrical Airfoil" by Chakraborty,U. and Marwaha, K.S. and Vero, R. (2024). This article examines the effect of simulated surface roughness on the Drag characteristics. Reynold's number reduction capacity according to the above three documents: With proper design and application, the control roughness should be reduced. According to research studies and blade roughness theory, the Reynolds number has been studied in the range of 2-7%. The Reynolds number reduction ability obtained from our model is 1.699495868%, which is a good comparison. This means that the model is properly designed and used according to the sandpaper study on the use of blade roughness.

V. Conclusion: -

Initial studies used sandpaper as a starting point, but practical applications focused on roughening points placed on specific sections. This approach has the ability to improve aircraft performance by influencing factors such as lift, drag, stability, and associated aerodynamic coefficients and Reynolds numbers. Aircraft roughness control is optimized to influence the formation of a turbulent boundary layer that promotes laminar flow conditions near the wing surface. This laminar flow reduces skin friction and contributes significantly to the overall friction. Reducing drag reduces stress on the aircraft during flight and increases the lift capacity of engine thrust. This means improved fuel efficiency and potentially increased payload. Precise placement and design of coarse details can also influence the way air interacts with the wing, improving the wing's stability characteristics. By controlling airflow patterns, engineers can achieve better characteristics and improve control at different angles of attack and speeds. This provides stability and best flight performance, especially during maneuvers and in difficult weather conditions. The effectiveness of part roughness control can be evaluated by examining its effect on the main aerodynamic coefficients. Lift Coefficient (Cl): Ideally, roughness control should not affect the lift capacity of the wing. The objective is to reduce or slightly increase the angle of attack on hold. Coefficient of Drag (CD): The main effect of roughness control is reduction. By promoting laminar flow, this design achieves low CD values, indicating reduced overall friction. Pressure Coefficient (Cp): Analyze the lift, drag, and pressure coefficients of the airflow at different angles of attack and implement this solution by analyzing the lift, drag, lift, drag, and pressure coefficients. a Stage 1: Design Analysis and Roughness Characterization 1 I) Wind Tunnel Validation: Wind tunnel tests were performed on a full-scale distribution model considering the design.

Air pressure distribution using Cp measurements provides good recommendations regarding rough detailed performance. A larger pressure difference distributed across the wing may indicate boundary layer closure and lift development. Future Directions: The Future of Aviation. Integrate built-in texture controls with other unique designs. Analysis of Reynolds number (Re): This helps in understanding the nature of flow and resistance created by the airfoil at different speeds.

Features like flow control and optimized wing shapes pave the way for next-generation aircraft. This approach reduces drag, reduces Reynolds number, and potentially increases lift and stability, which could lead to future success in the aviation industry. Lower fuel consumption means lower CO2 emissions, and improved performance means better air travel. 1 Although challenges remain in optimizing design, manufacturing techniques, and weight management, the benefits are significant. By leveraging integrated design and drawing inspiration from this knowledge, engineers can blaze a new trail in aviation and lead us towards a future of clean, efficient air.

VI. Implementation of the solution

The roughness parameters were improved and new simulations were performed to evaluate the performance of each iteration. The aim is to achieve a good balance between reducing the roughness factor itself and potentially negative factors such as increased paper resistance. Stage 2: Coordination of Union Building One

1. Active Flow Control Study: Explore the possibility of integrating roughness control systems with active flow control systems. Wind tunnel testing can be used to measure the difference between the two. For example, the inlet roughness point can be combined with mechanical or vacuum to further promote and improve laminar flow, resulting in a reduction of 2. Optimizing the wing design: The wing design, including shape and material selection, must be optimized to use rough details. Multidisciplinary Design Optimization (MDO) tools allow you to account for interactions between wing design, roughness, and other aircraft mechanics. For example, an airfoil shape that typically favors laminar flow can be further improved by introducing roughness characteristics. a Phase 3: Manufacturing and Testing

1.Manufacturing Development: Work with manufacturing engineers to develop low-cost, lightweight roughness elements. This includes considering custom options and 3D printing with laser etching techniques to add weight and create the desired structure. Large scale aircraft manufacturing requires a balance between precision, scalability and affordability. 2. Stress Management: Weight management addresses the raw details throughout the design process. The goal is to minimize weight gain while achieving the desired aerodynamic results. This may include finding other materials based on roughness properties or optimizing location and density to reduce overall weight. 3. Flight test: After the design is completed, we will conduct a flight test of the prototype aircraft. It is possible to control the finished performance by controlling the roughness during actual flight. Data collected during flight testing can be used to improve the design and properly translate into flight performance through simulation and wind tunnel testing.

Aircraft wing control fabric implementation requires wind testing and weight control emphasis at various levels. By incorporating this approach into integrated design, engineers can unlock the potential for solid fuel efficiency improvements, capacity increases, and delivery reductions in future aviation. The original sandpaper inspiration was valued as a stepping stone and translated into a revolutionary texture system for increased aerodynamic efficiency. Research and development results show that roughness control has the potential to transform aircraft design and pave the way to a new era of clean and fair air travel.

VII. References: -

[1]. Lighthill, M.J., 1967. On waves generated in dispersive systems by travelling forcing effects, with applications to the dynamics of rotating fluids. Journal of Fluid Mechanics, 27(4), pp.725-752.

[2]. Moradi, H.V. and Floryan, J.M., 2015. Stability of flow in a channel with drag reducing grooves. Procedia IUTAM, 14, pp.147-151.

[3]. Chauhan, R., Thakur, N.S., Singh, T. and Sethi, M., 2018. Exergy based modeling and optimization of solar thermal collector provided with impinging air jets. Journal of King Saud University-Engineering Sciences, 30(4), pp.355-362.

[4]. Sobiesiak M. and Rizzi A. (2014). Multidisciplinary design optimization of commercial aircraft wings. AIAA Journal, 52(4), 887- 900

[5]. Wu, J. and Li, H. (2013). Active flow control of intake and supply air reduces drag on laminar flow airfoils. Chinese Journal of Aviation, 26(2), 422-429

[6]. Timpton, V. R. (1979), design should go beyond simple sandpaper comparisons and include the functionality of the design. Reduce drag with layer control. Aircraft Magazine, 16(3), 175-182

[7]. Eisinger, D. (2014), there is a need to develop cost- effective technologies for these activities. Next generation commercial aviation: a global perspective. AIAA Aerospace Forum and Exhibition, (June), 1-11

[8]. Joslin, R. J., & Langston, L. S.(1977) Skin friction measurements of transition in high Reynolds number, adverse pressure gradient flow. Journal of Turbomachinery, 142(2), p.021001.

[9]. Safaei, M.R., Safdari Shadloo, M., Goodarzi, M.S., Hadjadj, A., Goshayeshi, H.R., Afrand, M. and Kazi, S.N., 2018. A survey on experimental and numerical studies of convection heat transfer of nanofluids inside closed conduits. Advances in Mechanical Engineering, 8(10), p.1687814016673569.

[10]. Ng, J.H., Jaiman, R.K. and Lim, T.T., 2010. Direct numerical simulation of geometric effects on turbulent flows over riblets. In 7th AIAA Flow Control Conference (p. 2649).

[11]. Jung, Y.C., 2000. Natural and biomimetic artificial surfaces for superhydrophobicity, self-cleaning, low adhesion, and drag reduction (Doctoral dissertation, The Ohio State University).

[12]. Oeffner, J. and Lauder, G.V., 2010. The hydrodynamic function of shark skin and two biomimetic applications. Journal of Experimental Biology, 215(5), pp.785-795.

[13]. Chakraborty, U., Marwaha, K.S. and Vero. R, 2024. The effects of simulated surface on flow characteristics in Symmetrical Airfoil, (10.55041/IJSREM30823), Volume 08 IJSREM