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Original Article

Design Optimization for SG6043 Airfoil for Using Finite Elements Analysis

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Abstract *- The importance of wind turbine blade aerodynamics cannot be emphasized enough in extending energy capture from wind. However, conventional design approaches are often challenged to balance high lift forces for efficient power generation and minimize drag forces that reduce energy losses. Thus, a more systemic methodology should be used to improve the efficiency of airfoils. In this study, an adjoint optimization solver is used to achieve both drag reduction and a high Lift-to-Drag (L/D) ratio while adhering to real-time wind conditions. The optimization procedure includes selecting the initial airfoil design and optimization algorithm, prespecifying constraints and objectives, executing the model, analyzing results, and troubleshooting and refining until the targeted reduction in drag and/or fulfillment of constraints is achieved. The developed airfoil model achieved a 9% decrease in drag and a 2% increase in the L/D ratio when the airfoil camber was expanded via a larger suction zone at the leading edge. The optimization strategy used the well-known SG6043 airfoil as an initial model widely used in wind turbine blades. The results demonstrated significant improvements in aerodynamic performance through enhanced camber and suction zone modifications at the leading edge of the airfoil, providing valuable insights for advancing airfoil designs for optimal performance across various applications.*

Keywords *- Geometry, Optimization, Aerodynamic Performance, Airfoil, Lift Coefficient, Adjoint Solver.*

1. Introduction

Wind power is becoming a promising renewable energy source. Wind turbines are crucial components of renewable energy systems. They function by converting the kinetic energy of the wind into electricity using revolving blades, which activate generators. Since it is a fundamental component of renewable energy, wind power has significant environmental benefits: it does not produce any direct emissions, decreases the impact on the environment, and ensures an infinite supply of energy. The last two decades have seen intensive theoretical, computational, and experimental studies on wind turbine aerodynamics and aeroelasticity [1]. Blade design is an essential field of research in wind turbine technology because the form of the airfoil profile affects aerodynamic efficiency. For wind turbine blade aerodynamic and structural optimization, automatic blade shape optimization processes, which have a long history in compressors [2] and turbines [3], have been applied. Classic intuitive and experience-based non-automatic optimization [4] was used. There is a considerable relationship between the aerodynamic performance of airfoils and the aerodynamic parameters of a wind turbine blade [5, 6]. Aerodynamic Shape Optimization (ASO) is crucial for aerospace and mechanical engineering advancements. The aerodynamic form parametric approach is critical to ASO [7] because it can achieve optimum results. This method shows that the CST-optimized airfoil gets increases of 11.8% and 9.6% in the lift coefficient and lift-to-drag ratio, respectively, while still getting good stability numbers for use in wind turbine blade design. These numbers help determine the total amount of aerodynamic work that can be done by new, better airfoils. So, the results that are better from an aerodynamic point of view have been given for making the NREL Phase II, Phase III, and Phase VI HAWT blades. This method shows that the airfoil made better by CST gives 11.8% and 9.6% more in the lift factor and the lift-to-drag rate, yet still gives good stability numbers for wind turbine blade design. These traits greatly boost the total aerodynamic efficiency of new, better airfoils. Thus, the aerodynamically improved results have been shared for the design of the NREL Phase II, Phase III, and Phase VI HAWT blades [8].

Based on a dataset of 7,007 different airfoils, a new method for representing airfoil geometry in Grassmann space was developed. Numerical analysis of various optimization cases demonstrated that this method is robust in both subsonic and transonic regimes. Furthermore, it overcomes the limitations of traditional parameterization methods, which rely heavily on design variable constraints. [9].

A hybrid CFD-BEM-GA optimization framework is introduced to effectively develop a more efficient small HAWT rotor that improves power output and aerodynamic performance compared to conventional designs [10].

Reviewed the simple formulas and symbols to explain the physical principles of airfoil aerodynamic lift, with particular emphasis on the significant influence of fluid viscosity. Taking the gradual development of the lift phenomenon of a flat airfoil as an example, this paper analyzes the transition from the classical inviscid annular flow theory to the viscous flow model [11].

A mathematical model based on the compact Blade Element Momentum (BEM) theory was used to design horizontal wind turbine blades. This method was used to evaluate the aerodynamic performance of wind turbine blades and ultimately improve blade geometry. Blades for the NREL Phase VI wind turbine were also optimized. The BEM theory of flow analysis and the method described by Viterna and Corrigan were used to estimate the airfoil's aerodynamic lift and drag coefficients after stall [12].

The drag and lift coefficients were estimated, and a genetic algorithm (a metaheuristic optimization technique) was employed to maximize the glide ratio while minimizing deviations from the desired design parameters. Three new airfoils were generated and compared with existing benchmark models: S823, NACA 2424, and NACA 64418. The results showed improvements of 13.8% in maximum lift and 39% in maximum glide ratio, respectively [13].

Using QBlade software, the effects of varying shell thickness, spar thickness, and spar position on the mass and modal configuration of a 5 MW wind turbine blade were investigated. The results showed that increasing shell thickness improves blade stiffness and reduces deformation, but also increases blade mass [14].

The parametric method with fewer design parameters is economical, less time-consuming during optimization, and can manage a large aerodynamic form in the design space. Previously, many aerodynamic forms were created for specific purposes and goals.

Optimizing the airfoil geometry significantly influences their outcomes, allowing a broader range of airfoil shapes with fewer parameters in the design space [8]. Aerodynamic shape parameterization methods are developed to design efficient airfoils [7], enhance wind turbine efficiency, increase energy production, and reduce costs [15, 16]. These methods fine-tune airfoil shapes using multiple approaches and algorithms to meet targeted functions and overcome existing design limitations [17, 18].

Aerodynamic optimization with computational fluid dynamics has been a well-established practice. However, the gradient-based optimization methods are widely preferred. Gradient-based optimization involves the manipulation of multiple design parameters to achieve the best aerodynamic form based on specific functions. The gradient-based optimization method uses different computational techniques, such as finite difference and adjoint optimization methods.

However, using the adjoint-based optimization method for calculating the cost function gradient is faster and more efficient than the finite difference method because it computes the gradient in just one step without using the design variables [19-21].

This study aims to determine the optimal airfoil shape to reduce drag forces while maintaining a high L/D ratio, specifically focusing on finding typical edge conditions for low-wind environments. The standardized SG6043 airfoil as a base model was used for the optimization, and the adjoint optimization solver was employed for better computational efficiency, following pre-specified constraints and objectives.

2. Methodology for Airfoil Optimization

Wind turbines have become an important source of renewable energy, and improving their design is crucial to maximizing efficiency and performance. The final airfoil shape was compared to the initial airfoil shape before optimization; the distribution of stress, lift, and drag was all considered to assess the effectiveness of the optimization process. The procedure of optimization was confined to the issues related to L/D and the dimensions of the airfoil, for example, increasing L/D, keeping the chord length constant, and maintaining a leading-edge radius of uniform size. The conditions near the ocean's surface that are associated with the optimization process are low wind speeds (10 m/s), which are used as the fluid medium, sea-level density, incompressible, and an angle of attack of 4°.

2.1. Initial Airfoil

The SG6043 airfoil is a well-known model that serves mostly as a standard model in optimization methods aiming to improve the aerodynamic performance of the airfoil of wind turbine blades. The current optimization method focuses on reducing drag while maintaining a constant L/D ratio. Some critical aspects of the SG6043 airfoil make it effective, such as a maximum thickness of 10% and 32% of the chord, a chord length of 1 meter, and a fixed leading-edge radius Figure 1. The optimization process follows the boundary conditions representative of low-wind environments.

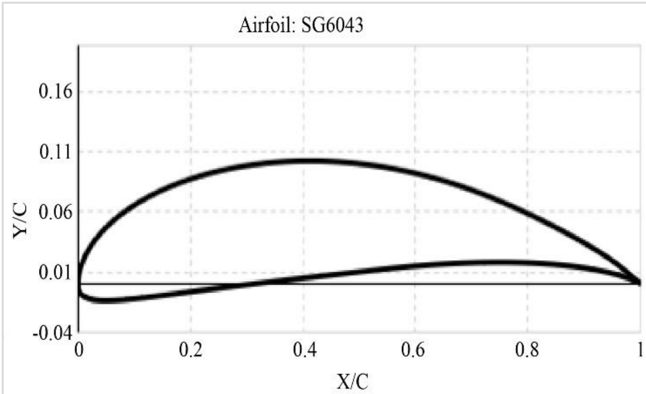


Fig. 1 Initial of Airfoil

3. Results and Discussion

3.1. Airfoil Optimization Results

The optimization process involved six steps, with a gradual decrease in drag Figure 2. Multiple iterations of the airfoils were recorded, and the final and initial airfoils were compared to track the progress Figure 3.

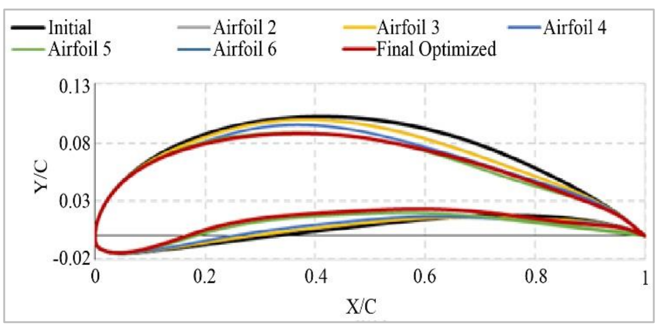


Fig. 2 Airfoil optimization history

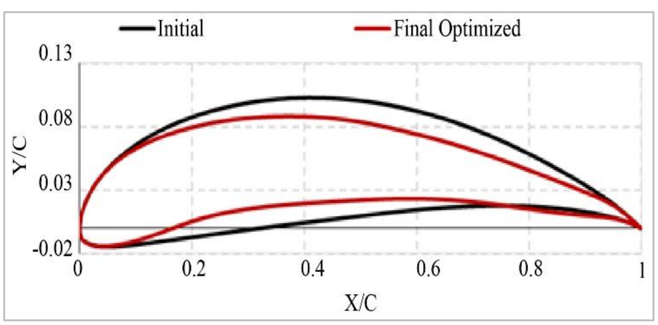


Fig. 3 Airfoil optimization comparison

The augmentation of the camber of the airfoil was a crucial strategic manoeuvre accomplished through the optimization process. The maneuver was intended to maintain a consistent L/D ratio. The optimization procedure effectively augmented the camber of the airfoil by creating a suction region at the airfoil's leading edge, a critical development for improving aerodynamic performance. A detailed analysis of the augmentation process revealed that it effectively expanded the camber of the airfoil to sustain a constant L/D ratio, primarily through the amplification of the leading-edge suction region. This augmentation in the suction region has a profound impact on the pressure distribution along the airfoil, particularly evident in the heightened pressure difference observed at the leading 25% of the airfoil's chord. This phenomenon is visually demonstrated in Figure 4, which provides a graphical representation of the pressure distribution shift.

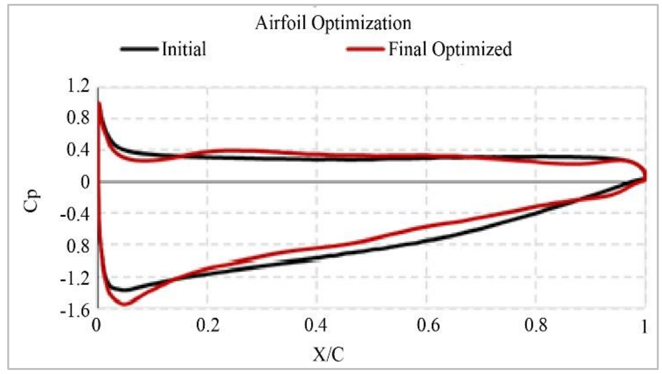
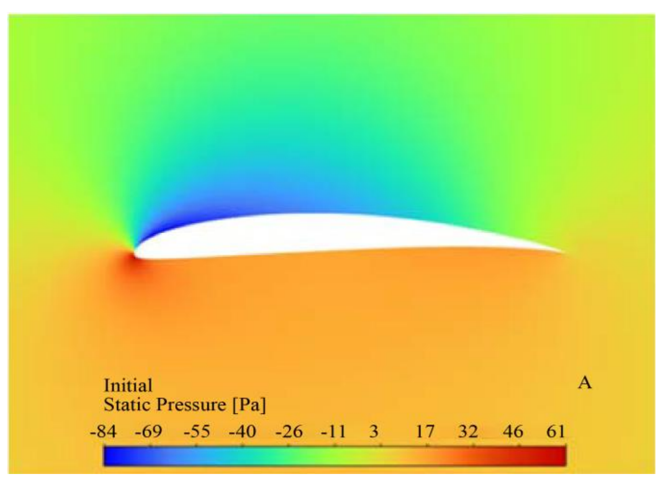


Fig. 4 Coefficient of pressure variation across the chord of the airfoil

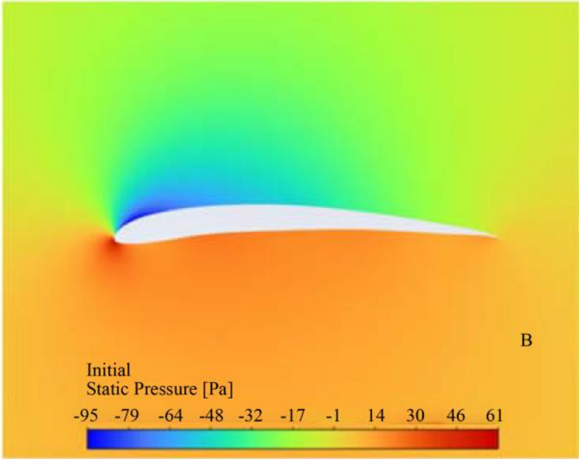
Figures 5(a) and (b) present the pressure coefficient for the two airfoil configurations, offering an in-depth understanding of their aerodynamic performance. It can be seen from the figures that the pressure distribution varies during optimization, which improves the aerodynamic performance.

3.2. Aerodynamic Performance Optimization Results

Figures 6 and 7 provide a quantitative assessment of the optimization's impact on aerodynamic efficiency. The figures show an improvement in the values of the lift-to-drag ratio during each step of optimization; also, the drag coefficient decreased, which led to enhanced airfoil geometry and improved aerodynamic performance. After six steps of optimization, the lift/ drag increased to 2%, and the drag decreased to 9%.



(a)



(b)

Fig. 5(a) Pressure contours of the initial airfoil, and (b) Pressure contours of optimized airfoil.

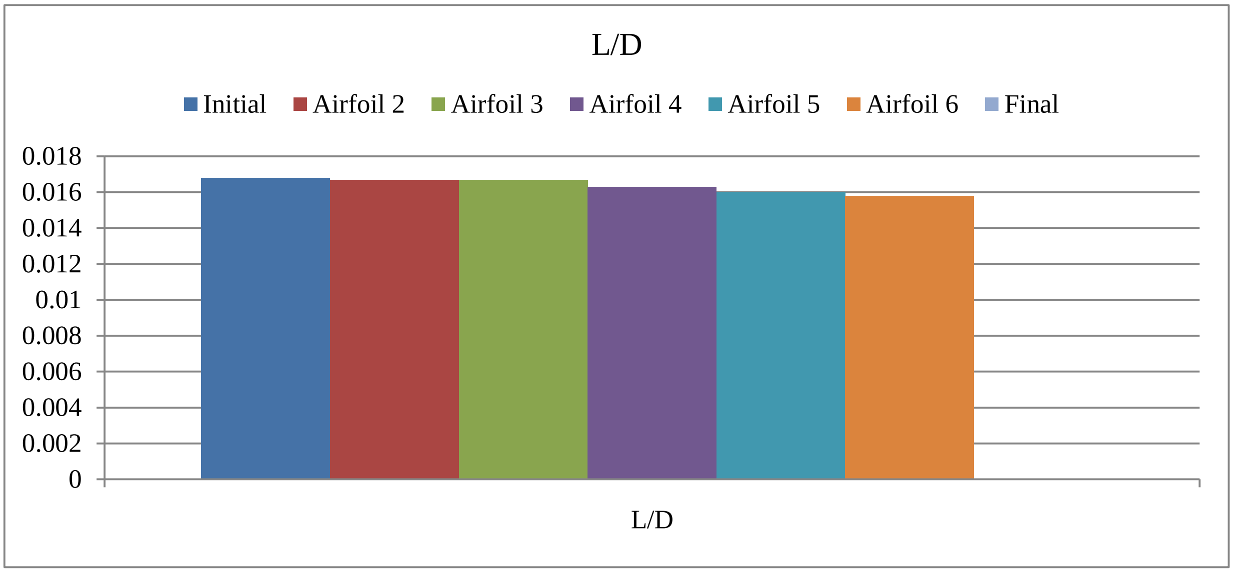


Fig. 6 Lift/drag coefficient

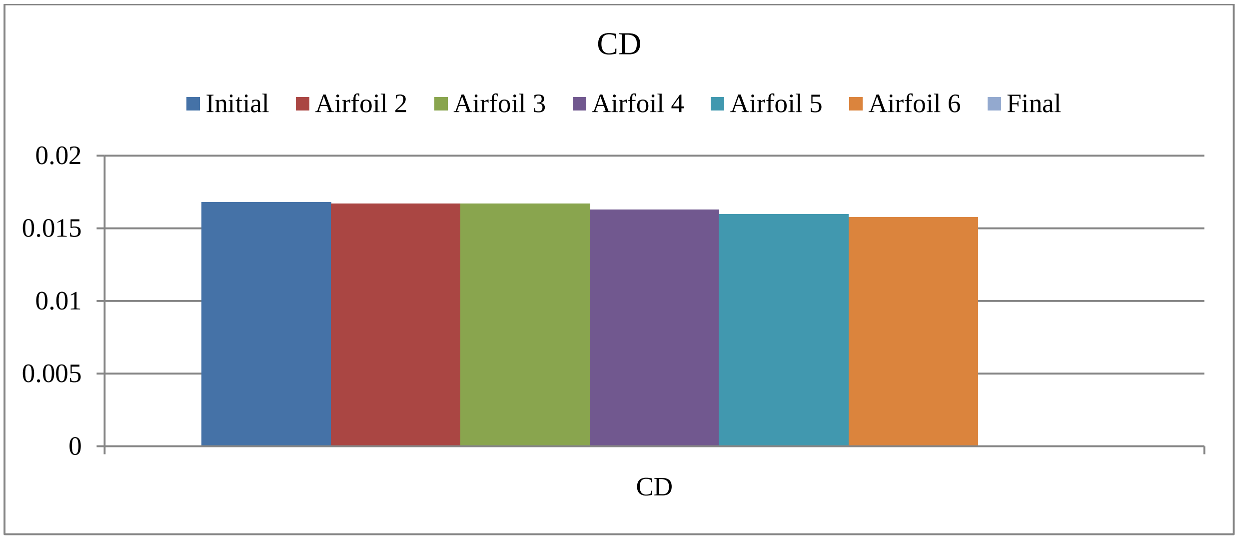


Fig. 7 Drag coefficient

4. Conclusion

During this research, a solution is employed that allows the optimization of the airfoil's shape while also increasing the aerodynamic efficiency. The alteration of the airfoil's shape led to an increase in the ratio of lift to drag, which in turn led to a decrease in the coefficient of drag. Through the alteration of the leading-edge area of suction."

Through changes to the suction zone at the leading edge." In the duration of the method of optimization, the fundamental design of the airfoil and the optimization method are selected, goals and limitations are predetermined, the model is run, the outcomes are analyzed, and any necessary troubleshooting and refinement are carried out until the desired reduction in drag and/or fulfillment of constraints is achieved. The newly constructed airfoil model was able to provide a 9% decrease in drag and a 2% rise in the L/D ratio when the camber of the airfoil was adjusted by establishing a larger suction zone at the leading edge of the airfoil. The optimization approach, which was used with a great deal of accuracy, made use of the well-known SG6043 airfoil as a starting point for its model. The SG6043 airfoil is often applied in the blades of wind turbines.

References

[1] Erich Hau, *The Wind Resource*, Wind Turbines: Fundamentals, Technologies, Application, Economics, pp. 505-547, 2013. [Google Scholar] [CrossRef] [Publisher Link]

[2] Akira Oyama, Meng-Sing Liou, and Shigeru Obayashi, “Transonic Axial-Flow Blade Optimization: Evolutionary Algorithms/Three-Dimensional Navier-Stokes Solver,” *Journal of Propulsion and Power*, vol. 20, no. 4, pp. 612-619, 2004. [CrossRef] [Google Scholar] [Publisher Link]

[3] A. Semenova et al., “Multi-Objective Shape Optimization of Runner Blade for Kaplan Turbine,” *IOP Conference Series: Earth and Environmental Science: Design and Optimization of Hydraulic Machines*, vol. 22, pp. 1-10, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[4] Chalothorn Thumthae, and Tawit Chitsomboon, “Optimal Angle of Attack for Untwisted Blade Wind Turbine,” *Renew Energy*, vol. 34, no. 5, pp. 1279-1284, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[5] J.L. Tangler, and D.M. Somers, “*NREL Airfoil Families for HAWTs*,” National Renewable Energy Lab. (NREL), Golden, pp. 1-12, 1994. [CrossRef] [Google Scholar] [Publisher Link]

[6] Jianhua Xu et al., “Design Optimization of a Multi-Megawatt Wind Turbine Blade with the NPU-MWA Airfoil Family,” *Energies*, vol. 12, no. 17, pp. 1-24, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[7] Ava Shahrokhi, and Alireza Jahangirian, “Airfoil Shape Parameterization for Optimum Navier–Stokes Design with Genetic Algorithm,” *Aerospace Science and Technology*, vol. 11, no. 6, pp. 443-450, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[8] Md. Tausif Akram, and Man-Hoe Kim, “Aerodynamic Shape Optimization of NREL S809 Airfoil for Wind Turbine Blades Using Reynolds-Averaged Navier Stokes Model—Part II,” *Applied Sciences*, vol. 11, no. 5, pp. 1-24, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[9] Yang Zhang et al., “Aerodynamic Shape Optimization with Grassmannian Shape Parameterization Method,” *Energies*, vol. 15, no. 20, pp. 1-13, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[10] Christian V. Rodriguez, and Cesar Celis, “Design Optimization Methodology of Small Horizontal Axis Wind Turbine Blades using a Hybrid CFD/BEM/GA Approach,” *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 44, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[11] Tianshu Liu, “Evolutionary Understanding of Airfoil Lift,” *Advances in Aerodynamics*, vol. 3, pp. 1-24, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[12] Y. El khchine, and M. Sriti, “Improved Blade Element Momentum theory (BEM) for Predicting the Aerodynamic Performances of Horizontal Axis Wind Turbine Blade (HAWT),” *Technische Mechanik*, vol. 38, no. 2, pp. 191-202, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[13] Jinane Radi et al., “Metaheuristic Optimization of Wind Turbine Airfoils with Maximum-Thickness and Angle-of-Attack Constraints,” *Energies*, vol. 17, no. 24, pp. 1-21, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[14] Ahmed Kadhim Zarzoor, Ahmed Adnan Shandookh, and Alaa Abdulhady Jaber, “Analysis of 5 MW NREL Wind Turbine Using Qblade Software,” *International Conference on Network, Multimedia and Information Technology*, Bengaluru, India, pp. 1-7, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[15] Vis Sripawadkul, Mattia Padulo, and Marin Guenov, “A Comparison of Airfoil Shape Parameterization Techniques for Early Design Optimization,” *13th AIAA/ISSMO Multidisciplinary Analysis Optimization Conference*, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[16] Jin Chen, and Quan Wang, *Wind Turbine Airfoils and Blades: Optimization Design Theory*, Walter de Gruyter GmbH & Co KG, vol. 3, pp. 1-392, 2017. [Google Scholar] [Publisher Link]

[17] Peter Fuglsang, and Christian Bak, “Development of the Risø Wind Turbine Airfoils,” *Wind Energy: An International Journal for Progress and Applications in Wind Power Conversion Technology*, vol. 7, no. 2, pp. 145-162, 2004. [CrossRef] [Google Scholar] [Publisher Link]

[18] Prashant Sharma et al., “Recent Advancements in Optimization Methods for Wind Turbine Airfoil Design: A Review,” *Materials Today Proceedings*, vol. 47, pp. 6556-6563, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[19] G. Carpentieri, B. Koren, and M.J. L. van Tooren, “Adjoint-Based Aerodynamic Shape Optimization on Unstructured Meshes,” *Journal of Computational Physics*, vol. 224, no. 1, pp. 267-287, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[20] Kun Wang et al., “Adjoint-Based Airfoil Optimization with Adaptive Isogeometric Discontinuous Galerkin Method,” *Computer Methods in Applied Mechanics and Engineering*, vol. 344, pp. 602-625, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[21] Pedro Gomes, and Rafael Palacios, “Aerodynamic-Driven Topology Optimization of Compliant Airfoils,” *Structural and Multidisciplinary ssOptimization*, vol. 62, pp. 2117-2130, 2020. [CrossRef] [Google Scholar] [Publisher Link]