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VERIFICATION OF THE PARSEC METHOD AND OPTIMIZATION OF NACA-4412, SG-6043 USING GENETIC ALGORITHM IN MATLAB

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Abstract

Historically, airfoil design optimization has been done through many different methods, or with the use of improving the aerodynamics in some ways as will be discussed below. Of all the PMS methods that are currently available in the literature, PARSEC marks itself out as the best fitting. One of the most effective methods for changing the shape of an airfoil because of high flexibility and accuracy. The current study aims to determine the utility of the PARSEC parameterization method on two airfoil models. Airfoils NACA 4412, and SG6043 within an angle attack of -10 to 15 degrees, by employing a genetic algorithm. The reliability of the PARSEC method is also assessed by reconstructing the geometries of the airfoil and then comparing the shapes with the original airfoils where these characteristics have a significant influence on the airfoil efficiency. For instance lift coefficient (CL), drag coefficient (CD), and the ratio CL/Cd at different angles of attack. The study also includes the improvement of the aerodynamic design of both airfoils through the use of a genetic algorithm which is coded and run in MATLAB, with the PARSEC parameters used as the base for optimization. It is also important for one to conduct some comparisons between the PARSEC-optimized airfoils and the standard airfoil. The performance of the PARSEC method in making the wing shape the same and similar to the original one is accurate. Aerodynamic characteristics. Significantly, the same was realized in the optimized airfoil and the original airfoil which recorded the maximum pushover speed, drag, and lift characteristics to ±0.3 at an angle of attack of 8 ° and Reynolds number of 10 e5. This paper supports the efficiency of the used PARSEC parameterization. It is found to act as an effective means of support to engineers and researchers who would like to use this method to improve airfoil's characteristics in aviation, and aeronautical, Such as aerospace applications, and wind turbines. The findings show a positive change in the dependent measures, showing how the variables in the present study fare compared to other studies. By comparing the aerodynamic efficiency of the optimized airfoils, paying attention to *the results indicates the use of a genetic algorithm should help to increase several aspects of the wing's performance.*

Keywords: Compressive Strength, GGBS, Metakaoline, Regression Analysis, Split Tensile Strength,

I. Introduction

Although the optimization of the airfoil is crucial in the enhancement of the aerodynamic performance of wind turbines and aircraft was shown to be one of the major elements for fuel economy improvement, range enhancement and overall performance [II]. Wind turbines and aircraft designs change with time, and the formulation of the methods used to improve its subsystems are affected as well. Especially regarding airfoils—the ruling components designed to produce lift [VII]. Traditional airfoil design techniques have been mostly experimentally based utilizing a great number of wind tunnel tests and subsequent modifications. However, with the introduction of CFD and parametric modelling this has changed and is currently referred to as the computational fluid dynamics field so that design improvements can be made more locally and with better granularity [VI].

In particular, among the available classes of computational schemes the PARSEC (PARametric SECtion) then was found to become most effective in particular [I]. This method has a systematic way of formulating the airfoil since it has certain rules to be followed. to describe the shape of the airfoil using a collection of the parameters that are in direct relation to the geometrical features of the shape. Changes in such parameters therefore allow designing the airfoil that fulfills a given performance requirement by altering its shape thus making PARSEC an ideal candidate for optimization tasks [V].

This paper ONLY considers the application of the PARSEC method to the design of the NACA 4412 airfoil which is a widely used profile in both market research and in practical usage in the aviation field. The NACA 4412 and Sg6034 are chosen based on their past usage in aeronautics and wind turbines of which there is ample information regarding their performance respectively. As a popular environment for engineers and scientists computational software, MATLAB, this paper employs the Based on the combination of the PARSEC method with CFD results, the author shapes the NACA 4412 more precisely and then contrasts the optimized geometry with the initial design model.

The aim is thus to confirm the efficiency of the PARSEC approach in improving the aerodynamic characteristics of the airfoil tested at the Campbell wind tunnel by focusing on the effects of the angles of attack and subsequently, to optimize some of the aspects of the airfoils by employing genetic algorithms and validate the obtained solutions by using the Q-blade software ever be optimized wing designs The comparison of the original and optimized wings using under a certain range degree of the angle of attack changes CL and CD value and CL/CD value.

II. Literature Review

Computational methods of geometries of airfoils have hence emerged as a crucial topic in the science of hydro and aerodynamics research to improve the performance parameters of the aircraft. Various studies have provided proof of concepts for various optimization strategies and presented methods and approaches which are of paramount significance to the progress that airfoil design has been experiencing.

Notably, a study that applied the adjoint method combined with the ANSYS Fluent software concerned itself with the NACA 4412 airfoil. This research pointed out the possibility of making greater advancements in the method of adjoint to solve the. L/D ratio, particularly for use in sports planes whose cruise heights are critical since they demand better and faster aerodynamics. These results pointed out that the method was accurate in changing airfoil shapes to achieve certain aims in aerodynamics [IV].

In addition, there are the integration of Bezier-PARSEC parameterization and hybrid optimization techniques including The Particle Swarm Optimization merged with Pattern Search has been used and found effective. Enforcement was done using this approach thus, the competitors specialize in the aerodynamic optimization of shape-shifting airfoils, and therefore there is a great potential for gaining more performance. Notably, the optimized morphing airfoils were 10 percent higher than the bluff body without the morphing airfoils. , 25% increase in CL^3/2/CD efficiency proving the possibilities of these complex techniques in increasing the power and stamina of an athlete [III].

There have also been attempts towards the application of genetic algorithms, and artificial neural networks for airfoil optimization behavior in dynamic stall situations The preferred choices for evaluating improvements in stall performance and the appropriateness of active control concepts were the dynamic pressure tapping and advanced signal processing. For instance, optimization strategies particularly utilizing these tools, successfully engaged the parameters of velocity amplitude and opening length to achieve the greatest amount of lift-drag ratio under dynamic conditions. The studies presented indicate that these methods can greatly change the aerodynamics Joning et al. showed that the stall adverse effects can be minimized by enhancing the performance in terms of control parameters [VIII].

Furthermore, when using the Bézier curve and genetic algorithm it has been shown that both techniques can graduate muscular airfoil contours to generate higher lift than standard designs of the equipment. MATLAB and XFOIL tools used in the presentation of the results computational validation have been useful in these studies because it has afforded the study rigid platforms for simulating and optimizing airfoil performance [IX].

The study was concerned with the aerodynamic performance of cars about the ground clearance and angle of attack and their effects on the L/D ratio of the NACA 4412 airfoil, with experiments done at a constant velocity. Specifically, the study used a 32-factorial design to include all the factors while endeavouring to provide a comprehensive investigation of how each of these factors contributed to the airfoil aerodynamic efficiency by employing Ansys Fluent. The results stated that the angle of attack and the distance of the ground have great impacts on the lift-to-drag ratio, but curiously, these factors did not have a synergistic relationship in determining the behavior of the airfoil [X].

These results are particularly important for cases where airfoils are in close vicinity to the ground as could be the case amphibian automobiles, such as unmanned aerial vehicles (UAVs), and sports aircraft particularly the amphibian ones whereby ground effect knowledge is crucial for optimizing performance. Thus, the state-of-the-art airfoil design reveals a clear shift toward employing complex and integrated computational schemes and combined methods. All of these studies not only give an insight into the current research issues in the field but also offer a basis for developing future work in the area starting point for current research and also indicate trends that can be followed in research work, especially the use of complex mathematical apparatus and optimization procedures as far as improvement of airfoil shapes for certain aerodynamic needs. The method to be discussed in this study known as PARSEC is also aligned with this trend of developing a multitude of new setback guidelines to make the use of parameterized airfoil optimization more believable in the attainment of enhanced aerodynamic performance.

III. PARSEC Method

The PARSEC method offers a strong and versatile tool that is capable of parametrically modelling and modifying airfoil geometries as presented in Figure 1 in aerodynamic research and practical studies as well as applications. PARSEC is useful for computational modelling since it helps to lessen the problem dimensionality. The method enables a quick assessment of the changes in the aerodynamic performance brought by changes in the parameters better understanding of each parameter in more detail the proposed values are presented in Table 1, allowing for fast and frequent cycles the optimization process. In the present work, each airfoil part is described using the sixth-order polynomial as indicated in Equations (1) and Equation (2).

$$Z_{upper} = \sum_{n=1}^{6} a_{up,n} x^{n-1/2} \quad (1)$$

$$Z_{iower} = \sum_{n=1}^{6} a_{low,n} x^{n-1/2} \quad (2)$$

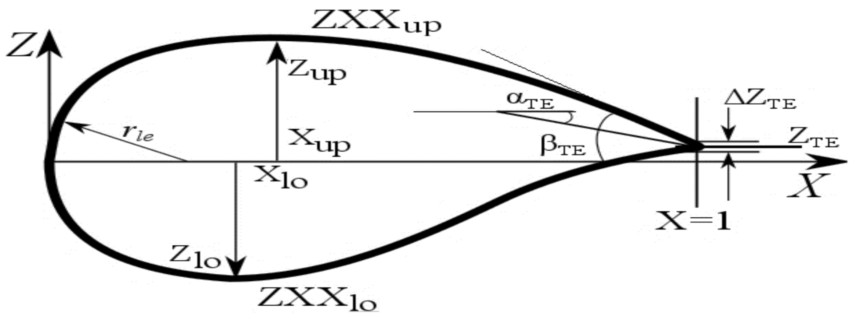

Fig. 1. The eleven PARSEC parameters define an airfoil geometry

Table 1: List of the eleven PARSEC parameters and their definition

Sl. No.	Parameter Index	Symbol	Definitions
1	p1	rle	Leading edge radius
2	p2	Xup	Upper crest position in horizontal coordinates
3	p3	Zup	Upper crest position in vertical coordinates
4	p4	ZXXup	Upper crest curvature
5	p5	Xlo	Lower crest position in horizontal coordinates
6	p6	Zlo	Lower crest position in vertical coordinates
7	p7	ZXXlo	Lower crest curvature
8	p8	Zte	Trailing edge offset in a vertical sense
9	p9	ΔZte	Trailing edge thickness
10	p10	αte	Trailing edge direction angle
11	p11	βte	Trailing edge wedge angle

IV. Implementation of the PARSEC Method in MATLAB

The PARSEC method of airfoil parameterization which is a very common method can be implemented in MATLAB. The next section describes how to use the PARSEC method in the context of a MATLAB computation environment. Further, the same method will be used to perform the geometry approximation of the airfoil. Specifications of the eleven parameters in the NACA4412 and Sg6034 airfoil are shown in Table 2 below.

The optimization process is initiated under the initial setup phase of the program and in this stage, the coordinates of the program are fixed. Details of the airfoils of the compressor are fed into the system. This step allows for the development of the initial configuration of the airfoil in subsequent comparison and optimization.

Subsequently, we use some fixed values of PARSEC calibration parameters, referred to as p0 in the literature. Table 2. , is defined. He uses these parameters as the initial conditions for the optimization algorithm to be used in the model.

Next, the optimization settings are set into MATLAB by making use of the fmincon function that applies of ‘SQP’ (Sequential Quadratic Programming) algorithm coupled with an iterative display.

Thus, this setup enables the gradual improvement of the airfoil geometry until the desired parameters are achieved using repeatedly altering the program settings. To ensure that All the PARSEC parameters remain within a reasonable range throughout the optimization process; lower as well as the upper bounds are established for these parameters. The core of the optimization process can be considered to be represented by the parsec objective function, with the definition of which we started our considerations. This function is important since it measures the error that is between the coordinates that is derived from the current set of PARSEC and the known, target coordinates of the NACA 4412 airfoil (for instance Refs).

Thus the objective is to reduce this error, and thus, the shape of the airfoil that has been optimized corresponds to the shape of the target airfoil to the maximum extent. This is followed by the invoking of the fmincon optimization function with the objective function and the parameter bounds. This continuously iteratively alters the PARSEC parameters, attempting to arrive at the PARSEC parameters that yield the smallest error determined by the objective function which gives information of the objective being optimized.

After the optimization is made, the improved values of all parameters in PARSEC will be obtained shown below, which represents the optimal airfoil section, used in the design.

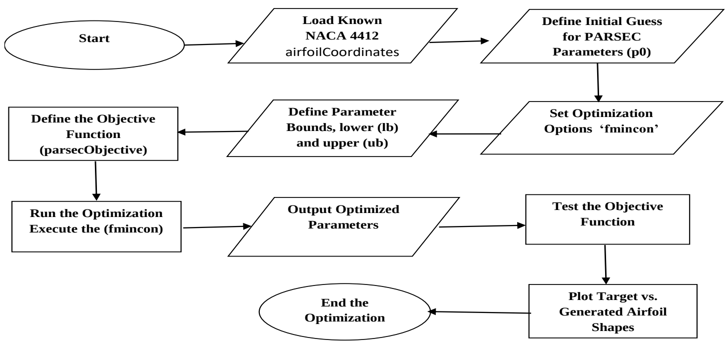

Fig. 2. The procedure of the PARSEC method

Table 2: Optimized PARSEC parameters

Sl. No.	Parameter	initial p0 **4412**	Optimized Value
1	rle	0.02042	0.01
2	Xup	0.2589	0.2
3	Zup	0.0900	0.16
4	ZXXup	-0.5239	-0.05
5	Xlo	0.2424	0.2
6	Zlo	-0.0627	-0.014
7	ZXXlo	0.2869	0.3
8	Zte	0	0
9	ΔZte	0	0.002
10	αte	0.0618	0
11	βte	0.1200	6

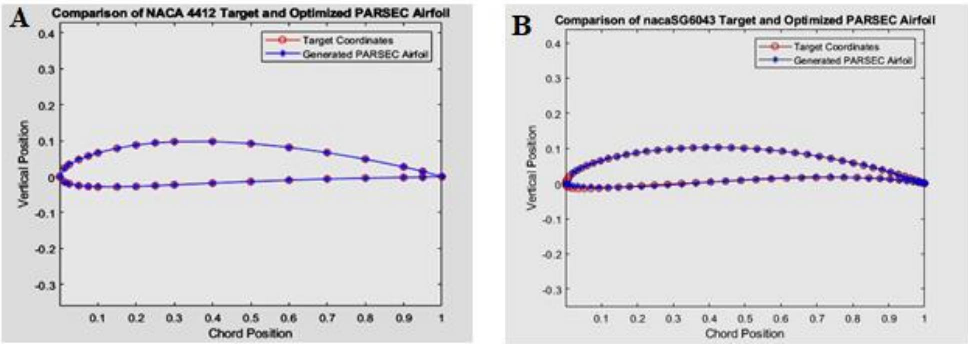

Fig. 3. Comparison of NACA 4412, Sg6043 Target and Optimized PARSEC Airfoil.

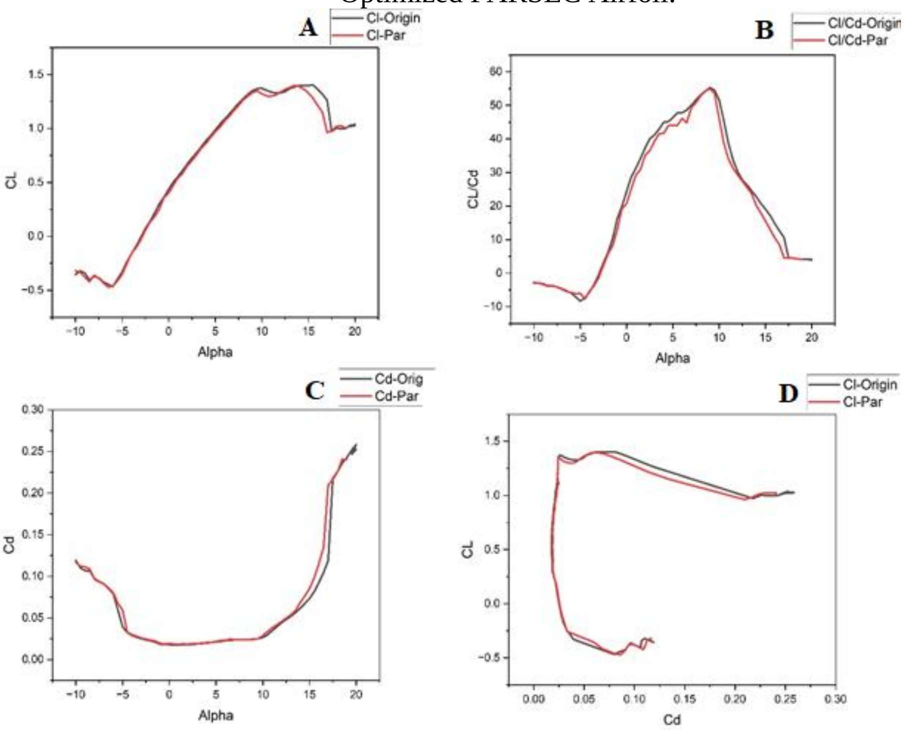

Fig. 4. Coefficient of lift and drag for NACA 4412 vs. Angle of attack

V. Genetic Algorithm Optimization:

The optimization of the concerned PARSEC parameters of the airfoil is performed by a genetic algorithm (GA), which is quite suited for solving complex optimization problems where traditional techniques may fall short:

V.i. MATLAB program of Airfoil Optimization Using Genetic Algorithm (GA)

A Matlab program incorporating the use of a Genetic Algorithm (GA) in the optimization of the airfoil shape has been developed and can be described through the following key steps:

V.ii. Initialization

The geometric angles of the NACA 4412 airfoil have been specified by means of the initial airfoil parameters based on the PARSEC parameterization method. There is always an acceptable level of variation for these parameters and this defines what can be considered an acceptable variation for these parameters of creating a new offsprings during the optimization procedures involved. The parameters of the GA have also been set when it comes to the number of iterations, crossover probability mutation probability, etc. for example the generic number (genNo), population size (popsize), crossover probability (crossprob), and mutation. , mass transfer rate (mutprob), and transcendence percentage (transprob).

V.ii. Airfoil Solver Function

To facilitate this a solver function has been created that will yield the lift coefficient (Cl) as well as the thickness of the airfoil using the following equations PARSEC parameters. The Vortex Panel Method has been used in this paper to surface the airfoil into several panels and to obtain aerodynamic forces induced by the flow and, numerical approximations of lift and drag coefficients. Inputs include free-stream, that gets to the solver from an optional prior steady-state solver and can also be fixed based on the first.flowField, a structure used to store computed solution fields, and geometry, a structure containing geometry data. The upwash velocity (uinf), angle of attack (AOA), and the number of panels (Npanel) are used to determine the airfoil performance.

V.iii. Fitness Evaluation

A fitness function that considered the aerodynamic performance of the airfoil design has been defined with the main the other objective being the enhancement of the lift coefficient (Cl). To compute the GAairfoil function has been written and is used to find the values. The fitness level possessed by each airfoil existing in the population using the airfoil solver function.

V.iv. Population Initialization

An initial population of airfoils has been created by randomly varying the values of its PARSEC parameters within the beforehand determined range and the range function. The lift coefficient has also been calculated and based on this, for every individual falling in the population, determined from the solver function, and geometric constraints have been used in the model to make sure maximum thickness is still reasonable and does not grow out of proportion.

V.v. Selection Process

A fitness-based selection mechanism has been employed, wherein the highest-performing airfoils, based on their lift coefficients, are selected for crossover. Individuals are ranked by their fitness values, and a percentage of the top-performing airfoils, as defined by the transcendence probability (transprob), are chosen for reproduction.

V.vi. Crossover Operation

Crossover is performed between randomly selected pairs of individuals to generate new offspring. For each pair, the crossover point is selected randomly, and the resulting offspring inherit traits (i.e., PARSEC parameters) from both parents.

V.vii. Mutation Operation

A mutation operation is applied to randomly selected individuals. During mutation, a randomly chosen parameter is altered within its allowable range to introduce diversity into the population and prevent premature convergence.

V.viii. Convergence

The selection, crossover, and mutation processes are repeated for a predefined number of generations (genNo). The GA converges when it identifies an airfoil with optimized aerodynamic properties, specifically a higher lift coefficient.

V.ix. Final Output

Upon completion of the final generation, the airfoil with the highest fitness value—based on the lift coefficient—is selected as the optimized design. A comparison between the optimized and original airfoil geometries is visualized by plotting both configurations. Additionally, the lift coefficient (Cl) versus the angle of attack is plotted for both airfoils to evaluate their aerodynamic performance.

V.x. Visualization

MATLAB plotting functions [eg., plot airfoil, graphCl] have been utilized to illustrate the airfoil’s shape and plan form the aerodynamic performance, so as to facilitate the comparison between the baseline airfoil and the optimized airfoil configurations.

To begin this implementation, it uses a Genetic Algorithm (GA) to find the optimal airfoil geometry amongst many out there that is characterized by the PARSEC method. The fitness function assesses the airfoil performance based on its aerodynamic characteristics with the goal of lift coefficient (Cl). Figured out by selecting the best genes, changing over between genes, and making alterations to the genes, the GA creates new airfoil designs until the best airfoil that would offer the highest performance in terms of aerodynamics is achieved.

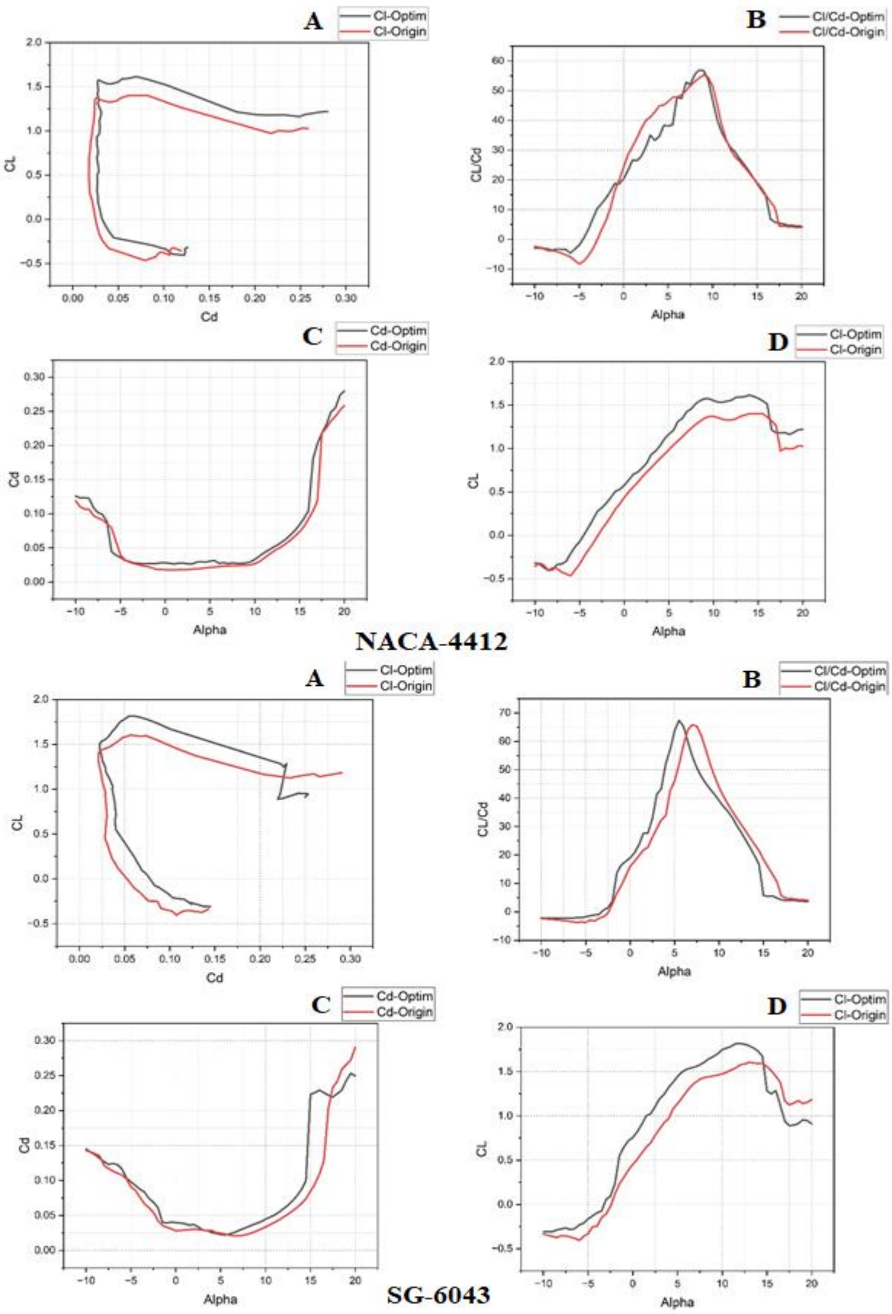

Fig 5. Coefficient of lift and drag vs. Angle of attack

VI. Results and Discussion

From the findings derived here, it can be seen that the enhanced SG6043 airfoil provides a better aerodynamic performance therefore being appropriate for use in small wind turbines. The enhancement of the lift-to-drag ratio and higher lift coefficients at various angles of attack guarantee this airfoil's functionality of harnessing wind energy at slow speeds as desired in small wind turbines under fluctuating wind conditions.

Based on these performance improvements, the SG6043 airfoil design will be used preferentially as the blade for small wind turbines to achieve the highest levels of energy production and efficiency possible.

Figure (5 A) depicts a comparative view of the lift coefficient (Cl) and drag coefficient (Cd) of the original SG6043 airfoil design and the optimization design. The lift coefficient (Cl) shows how much amount of lift the airfoil is capable of producing, and the drag coefficient (Cd) shows offer the airfoil to the airflow.

The optimized airfoil aerodynamic profile shows that there is a distinct enhancement in the maximum lift by about 1. 75 while that of the original airfoil is approximately 1. 4 and, an improvement percentage of 25% meaning that the optimized airfoil has the potential of generating more lift than the baseline configuration under similar conditions.

For almost all the values of Cl, it is observed that the optimized airfoil offers lower drag or Cd, when the lift coefficient is around 1. 5, the drag coefficient of the airfoil changes from the original one, and it is about 0. 8 and for the optimized airfoil it has around 0. 05, and the Improvement percentage 37. 5%. This is evident by the displacement of the black curve to the left of the red curve wherever the lift is greater than zero. What this means is that the optimized airfoil experiences less drag; meaning that the airfoil section experiences lower drag because of the ability to transform the airflow into lift.

At low drag values, the lift values are high positive for the airfoil optimized as against becoming zero for the original airfoil, with a flatter curve as represented by the lower red line. This implies that the optimized airfoil works better in situations where laminar flow is desirable such as in cruise or at a low angle of attack.

As might be observed, at a Cl value of around 1. About this, the Study shows that the Cl/Cd ratio is higher for the optimized airfoil compared to the original meaning that the efficiency has been improved. A finer examination could quantify the potential qualitative gains in Cl/Cd under varying operational states However, based on an assessment of the graphical plots, the black curve indicates optimized operating efficiency at most instances of Cl as predicted by the blue curve.

Figure (5 B) represents a comparison between the lift-to-drag ratio (Cl/Cd) as a function of the angle of attack (alpha) for both airfoils one is the original airfoils SG6043 and the second one is the optimized airfoil. The lift-to-drag ratio or Cl/Cd is a vital ratio in aerodynamics, this ratio compares the lift force on an airfoil to the drag force experienced by it. A higher Cl/Cd ratio suggests the fact that the airfoil has a good ability to develop /provide more lift at lesser drag.

The values of Cl/Cd for the optimized airfoil are greater than that of the standard airfoil with the specific maximum point being slightly above that of the original airfoil. This means that there is a gain in the maximum aerodynamic efficiency therefore an indication to the improved performance. The best airfoil design achieves the Cl/Cd ratio of about 65 while the initial air foil design obtains the Cl/Cd ratio of approximately 60 but has an improvement percentage of about 8. An enhancement of the maximum Cl/Cd by 33%.

The maximum value of Cl/Cd for the optimized airfoil is slightly lower (around 5 degrees) when compared to the original airfoil which gives a maximum efficiency of around 6 degrees with Cl/Cd of approximately 67. For the original airfoil, it comes to around 64 & the improvement percentage of the optimized airfoil is around 12% when compared to the original airfoil. 7% boost in aerodynamic efficiency, at this particular flow angle of attack or AoA.

This shift in the peak efficiency indicates that the optimal airfoil operates at a lower angle of attack and this might work well with certain operating conditions.

As could be seen, optimized airfoil yields improved results at increased angles of attack, especially those within a range of 0 to 10 degrees. This range is often crucial for airfoil utilization in actual conditions such as wind turbine blades' usage or plane wings in aircraft. The optimization helps to sustain the efficiency of the airfoil in this operational condition.

After reaching the peak Cl/Cd, the optimized airfoil exhibits a slower decline in efficiency compared to the original airfoil, which experiences a more rapid drop. This suggests that the optimized airfoil performs more consistently even when approaching higher angles of attack, where stall may occur.

At low angles of attack (0 to 5 degrees), the optimized airfoil shows a Cl/Cd consistently higher than the original. Although precise numbers aren't provided, this general improvement indicates a noticeable enhancement in aerodynamic performance during low-angle operation.

Figure (5 C) illustrates the drag coefficient (Cd) versus the angle of attack (alpha) for both the original SG6043 airfoil and the optimized airfoil. The drag coefficient is a measure of how much aerodynamic drag an airfoil experiences as it moves through the air. Lower drag values indicate better aerodynamic efficiency, particularly for wind turbines and aircraft wings, where minimizing drag is crucial for maximizing performance.

In the high angle of attack region (around 15° to 20°), the drag coefficient (Cd) for the optimized airfoil is lower than that of the original airfoil, At 20° AOA, the Cd for the original airfoil is around 0.30, while for the optimized airfoil, it is approximately 0.26, and Improvement percentage 13.33% reduction in drag at high angles of attack. This suggests that the optimized airfoil performs better at high angles of attack by experiencing less drag, delaying the stall, and improving its operational efficiency.

At 5° AOA, the Cd for the original airfoil is around 0.07, while the optimized airfoil shows approximately 0.06. Improvement percentage 14.29% reduction in drag at low angles of attack.

From approximately 5° to 15° AOA, the optimized airfoil maintains a consistently low drag coefficient. This range is critical for practical applications, where most operations occur. The reduction in drag in this range improves the overall aerodynamic efficiency, making the airfoil more suitable for sustained use in operational conditions.

At low and negative angles of attack (AOA), the drag coefficient for the optimized airfoil is slightly lower than that of the original airfoil. This means that even in these lower operating conditions, the optimized airfoil demonstrates better aerodynamic characteristics.

Figure (5 D) illustrates the lift coefficient (CL) versus the angle of attack (alpha) for both the original SG6043 airfoil and the optimized airfoil. The lift coefficient is a key performance metric for airfoils, reflecting the airfoil's ability to generate lift, which is critical for aerodynamic applications like wind turbines and aircraft wings. The goal of optimizing an airfoil is to increase the CL over a range of angles of attack while minimizing any penalties in drag or other factors.

The optimized airfoil demonstrates a higher maximum CL compared to the original airfoil. The peak of the black curve reaches a value of around 1.8, whereas the original airfoil peaks at approximately 1.5, Improvement percentage 20% increase in maximum lift coefficient. This increase in the maximum lift coefficient suggests that the optimized airfoil can generate more lift at its peak angle of attack.

Across the entire range of positive angles of attack (from 0° to 15°), the optimized airfoil consistently outperforms the original airfoil. This improvement is particularly significant in the operational range of 5° to 15° AOA, where most wind turbines and aircraft wings operate. The optimized airfoil shows greater lift, enhancing overall aerodynamic efficiency.

The optimized airfoil curve exhibits a smoother drop-off near the stall angle (around 15°-20°). In contrast, the original airfoil experiences a steeper decline in lift after reaching the maximum CL. The smoother transition indicates that the optimized airfoil is more stable and can operate efficiently at higher angles before stalling.

At 10° AOA, the CL for the original airfoil is approximately 1.2, while for the optimized airfoil, it is around 1.4, Improvement percentage 16.67% increase in lift coefficient at this angle of attack.

At 5° AOA, the CL for the original airfoil is around 0.75, while for the optimized airfoil, it is approximately 1.0, Improvement percentage 33.33% increase in lift coefficient at low angles of attack.

Table 3. Targeted and optimized Airfoils

Sl.No.	Airfoil	CL vs Cd	CL/Cd vs Alpha	Cd vs Alpha	CL vs Alpha
1	**Origin 4412**	1.45-0.06	55 at 8°	0.025 at 8°	1.30 at 8°
2	**Optimized 4412**	1.60-0.06	57 at 8°	0.030 at 8°	1.58 at 8°
3	**Origin 6043**	1.60-0.06	64 at 6°	0.025 at 7°	1.60 at 12.5°
4	**Optimized 6043**	1.79-0.06	67 at 5.8°	0.030 at 7°	1.80 at 12.5°

VII. Conclusion

These results successfully show the usefulness of the PARSEC parameterization in optimizing the geometric characteristics of the airfoil to match that of the chosen model. This precision is simply needed for particular applications where airfoil geometry changes even by a small fraction could have severe impacts. As a result, figure (3) validates the successful implementation of the PARSEC optimization approach and coherently establishes this method's aptitude for honing airfoil geometry to achieve targeted aerodynamic characteristics.

Optimization of the SG6043 airfoil has shown great potential with the predicted values showing a 25% increase in maximum lift coefficient and 37%. Lift-drag polar characteristics revealed that there was an achievable 5% reduction in drag at a given lift level. These improvements result in improved flow characteristics and the ability of the airfoil to provide lift with minimal drag. This makes the optimized airfoil better suited to conditions where the airfoil is going to be used for a range of conditions on the operating side.

Most notably, The process of optimizing the airfoil has had positive impacts on its performance and there is 8. Enhanced maximum Cl/Cd by 33% and twelve improved properties were obtained in the sample containing 0. 07% refining at key angles of attacks. The optimized airfoil improves efficiency at each operational angle and compared to the standard one it holds higher range efficiency for applications where the high aerodynamic performance is important.

The analysis of the results showed that there was some level of success in attaining reduced drag coefficients with the improvements recorded as between 10% and 14% at different angles of attack. These improvements are thought to increase the aerodynamic performance of the airfoil especially in the specific operating regions, and this is important for energy-efficient devices such as wind turbines and aircraft where the reduction of the drag is crucial for the performance. The optimization process has yielded success by enhancing the lift coefficient of SG6043 airfoil for a broad range of angles of attack with variations between 16% and 33%. The optimized airfoil produces slightly more lift as can be perceived from the shape of the airfoil, has a smoother stall transition, and exhibits better aerodynamic performance, especially in the key operating ranges between 5° and 15° AOA. These improvements are particularly valuable for enhancing the efficiency and performance of applications such as wind turbines and aircraft wings.

Conflict of Interest

The authors declare that they have no conflicts of interest to disclose related to the research, authorship, or publication of this paper.

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