Optimizing Aerodynamic Performance of Selig S3014 Airfoil through Dimensional Parametric Analysis

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Optimizing Aerodynamic Performance of Selig S3014 Airfoil through Dimensional Parametric Analysis

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Abstract: *Investigation of the effect of the modified design parameters on the performance characteristics of the Selig S3014 airfoil. The goal is to increase the lift coefficient, reduce drag, and maximize the lift-drag ratio by optimizing the wing form. Using the XFLR5 software, a parametric optimization approach was used. Also, six observations were made by changing certain design parameters. According to the results, this modification has a considerable influence on airfoil performance, including lift, drag, and stall behavior. For improving lift characteristics Observation 2 which calls for increasing camber by 5% of the chord length, would be a better choice. On the other side, Observation 4, which calls for a smaller trailing edge gap, would be favored for lowering drag. This study develops our understanding of airfoil design optimization used in a variety of applications, like aircraft wings, wind turbine blades, and hydrofoils. In the aerospace industry, improving design parameters also increases wing performance and efficiency, which is emphasized in this research.*

Keywords: Airfoil design optimization, XFLR5 software, Lift coefficient, Drag coefficient, Parametric optimization approach

1. INTRODUCTION

The base airfoil used for this analysis is Selig S3014. The Selig S3014 in Figure 1 is a symmetric airfoil designed by Michael Selig, a renowned aerospace engineer, for low-speed applications in aviation [1]. The thickness to chord ratio of it is 14% with the length of the chord 1 meter. It is used in low-speed aircraft like gliders and small planes. A special feature of Selig S3014 is it has a high lift coefficient which leads to creating a high amount of lift in an aircraft. It reduces fuel consumption and enhances efficiency due to the low drag coefficient. Moreover, the Selig S3014 airfoil has a smooth and well-defined pressure distribution, which ensures stable and predictable flight characteristics.

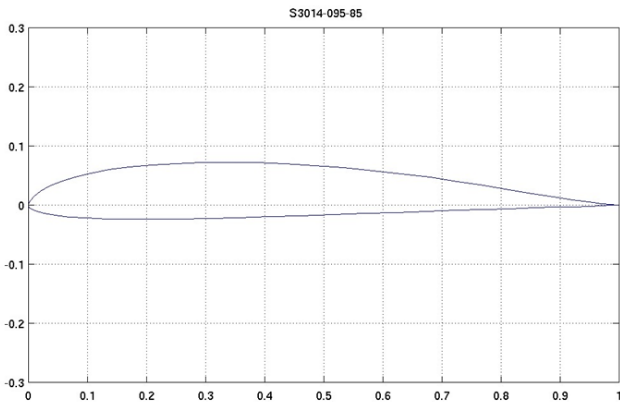

Figure 1. 2D of Selig S3014 [2]

The Selig S3014 airfoil has been extensively tested and validated using experimental methods and computational fluid dynamics simulations. Its performance has been found comparatively better than many other airfoils in its class, which also makes it a popular choice for various low-speed applications in aviation.

The properties listed in Table 1 provide necessary information about the airfoil's shape and performance characteristics. The chord length is a significant property of airfoil that affects lift and drag. The distance between the leading edge and trailing edge of the airfoil is called the chord length. The curvature of an airfoil shape is indicated by maximum thickness and maximum camber. And these are related to lift and drag coefficients for different angles of attack.

Table 1: Properties of Selig S3014 [1]

Property	Value
Chord length	0.2 m
Max thickness	14.4%
Max camber	4.2%
Angle of attack for maximum C_l	14°
Lift coefficient at 0° angle of attack	0
Lift coefficient at 10° angle of attack	1.2
Lift coefficient at 20° angle of attack	2.5
Drag coefficient at 0° angle of attack	0.007
Drag coefficient at 10° angle of attack	0.034
Drag coefficient at 20° angle of attack	0.105

The lift coefficients at 0°, 10°, and 20° angles of attack give an idea about how the airfoil will behave at different flight conditions. The information about the airfoil's resistance to forward motion through the air is provided by the drag coefficients at these same angles of attack.
Overall, understanding these properties is essential for designing and optimizing air- craft wing shapes for efficient and effective flight.

1.1 XFLR5: Aerodynamic tool

Several computational aerodynamic tools can be used to investigate the aerodynamic performance of the Selig S3014 airfoil.
For the construction and analysis of airfoils, Analytical Methods Inc. created the commercial software program XLFR. The Selig S3014 airfoil's aerodynamic performance is predicted using a mix of panel methods and boundary layer analysis [8]. Although XLFR is an effective instrument for designing and analyzing airfoils,

it is not a CFD tool. XLFR employs streamlined mathematical models to forecast the aerodynamic performance of the airfoil, in contrast to CFD tools that solve the Navier-Stokes equations to simulate the fluid flow around an airfoil [9]. In light of this, XLFR may not produce findings that are as precise as CFD simulations, especially under complex flow conditions or at high Reynolds numbers. However, XLFR can be an effective instrument for preliminary airfoil design and analysis, and it can shed light on how the Selig S3014 airfoil performs in particular operating scenarios. It can also be applied in conjunction with CFD simulations to verify and improve the airfoil shape.

2. LITERATURE REVIEW

The purpose of airfoils is to increase lift and decrease drag when traveling through a fluid medium like air. Airfoils come in many different varieties, each with unique properties and use in aerodynamics and aviation. Symmetrical, NACA, Supercritical, and Selig airfoils are a few examples of common types of airfoils. Depending on how the aircraft or item is going to be used, each type of airfoil is designed to meet a specific set of needs, such as lift generation, drag reduction, stability, or maneuverability [3]

Michael Selig and his colleagues at the University of Illinois created a collection of airfoil forms known as the Selig airfoil series. The design of airplanes and aerodynamic research both frequently use these airfoils [4]. Frequently used in flight, especially in the creation of unmanned aerial vehicles, is the Selig S3014 airfoil. (UAVs).

2.1 Airfoil Properties

These are a few of its main characteristics [5]:

The top and bottom surfaces of the S3014 are identically shaped because it is an airfoil with a symmetrical structure.

The airfoil can be as thick as 14% of the section length.

The airfoil has a camber of 1.5% of the chord length, which indicates that the center of the airfoil has a small curvature or arch.

The S3014 performs efficiently in terms of aerodynamics thanks to its comparatively low drag coefficient. It has a comparatively low lift coefficient, so it might not be the best option for applications requiring high lift, like those found in large aircraft.

It has high pitching moment coefficient, the S3014 is stable in pitch and has the propensity to withstand changes in the angle of attack.

Being a flexible airfoil, the Selig S3014 is well adapted for various applications, especially in UAV design where efficiency and stability are crucial factors.

2.2 XFLR and Methodology

XFLR5 is a tool for analyzing airfoils, wings, and aircraft with low Reynolds Numbers. It has capabilities for both direct and inverse analysis of foils, as well as for designing and analyzing wings using the Lifting Line Theory, the Vortex Lattice Method, and the 3D Panel Method. The purpose of XFLR is to investigate stability and control dynamics. This evolution has benefited the research of aerodynamics as well as the dynamic modelling of the aircraft. With the aid of XFLR, a piece of stability analysis software, it is simple to create an aero plane model based on physical measurements and conduct an aerodynamic analysis to gather the necessary aerodynamic data for the assessment of stability derivatives. It is a tool used to perform different Reynolds number operations on a wing, airfoil, or entire aero plane [6]. It is also readily available for download and works with Windows and LINUX. For XFLR, the original FORTRAN code for XFoil has been converted to C/C++. The stability analysis of the planes is a new feature of the software. For XFoil, it also provides inverse and direct analysis capabilities [7]. The modelling of a wing, aircraft, or other lifting surface is the first step in performing analysis in XFLR. The wing/airfoil design is analyzed using the 3D panel method, the vortex lattice method (VLM), and lifting line theory (LLT), in addition to doing other studies. XFoil also has the ability to perform inverse and direct analysis [8]. Analysis of the two-dimensional viscous findings from the XFoil subsonic airfoil development system and the time-independent incompressible flow solution from the Laplace equation is another use of the XFLR software [9]. XFLR can be used to approximate inertia utilizing geometry and mass distribution data, such as fuselage structure, wing mass, and the locations and masses of servo-actuator, battery, nose lead, and receiver [10].

2.4 Application

The Selig S3014 airfoil is a popular choice for a range of applications due to its favorable aerodynamic properties. The airfoil's design features a moderately thick profile with a slightly curved upper surface and a flat lower surface, which results in low drag and high lift [11]. This makes it suitable for use in a variety of aircraft, like small UAVs, gliders, and general aviation planes, where aerodynamic efficiency is critical. Along with its use in aviation, the Selig S3014 airfoil is also used in wind turbines due to its ability to generate high lift at low angles of attack. It is also commonly used in academic and research settings to test and validate new aerodynamic simulation tools and techniques. Overall, the Selig S3014 airfoil's combination of low drag and high lift makes it a versatile and popular choice for a variety of applications in the aviation and renewable energy industries, as well as in academic research.

3. DESIGN ANALYSIS

Table 2 shows the parametric changes made to the Selig S3014 airfoil, along with the corresponding values. These changes were made for various observation numbers, as listed in the first column. The design criteria were changed based on random assumption in following observations. The specific changes made for each observation number are given in the second column, and the corresponding values resulting from the changes are given in the third column.

4. RESULTS AND DISCUSSION

Each observation in Table 2 represents a modification made to the Selig S3014 airfoil by changing one or more design parameters. These modifications require investigating the effects of the modified parameters on the wing performance characteristics such as lift, drag and stall behavior.

Table 2: Parametric Change of Selig S3014

Obs. No	Parametric Change	Values
1	Leading Edge Gap	15% Chord
2	Camber	5% Chord
3	Camber	1% Chord
4	Trailing Edge Gap	-1% Chord
5	Camber	0.50% Chord
	Thickness	5.40% Chord
6	Leading Edge Gap	New/old Ratio: 5 Blending Distance from LE: 20%chord

Observation 1 shows that increasing the leading-edge gap by 15% of the chord length may improve the performance of the airfoil at high angles of attack, but may also increase drag. Observation 2 includes an increase in camber by 5% of the chord length, which may improve the lift characteristics of the airfoil, but may increase drag. Observation 3 increases camber by 1% chord. This may improve the lift characteristics of the airfoil but may increase drag. Observation 4 includes a chord reduction of 1% in the trailing edge gap, which may reduce drag but may adversely affect lift. Observation 5 included increases in both camber (0.50% of chord) and thickness (5.40% of chord), which may improve both lift and drag characteristics, but not stability. It also affects other performance indicators such as control and control, and affects structural requirements. Observation 6 involves the variation of the leading-edge gap based on two parameters.

The old/new ratio is 5, and the fade distance from the leading edge is 20% of the chord length. This modification may improve the wing's performance at high angles of attack by slowing stall and stall, but it may also increase drag. Gradual mixing helps reduce the negative lift and drag effects caused by increasing gap size. Analyzing these observations, it is seen how changes in specific parameters of the wing design affect the performance characteristics of the wing. These pieces of information can be used to reform future wing designs for various applications like airplane wings, wind turbine blades, and hydrofoils.

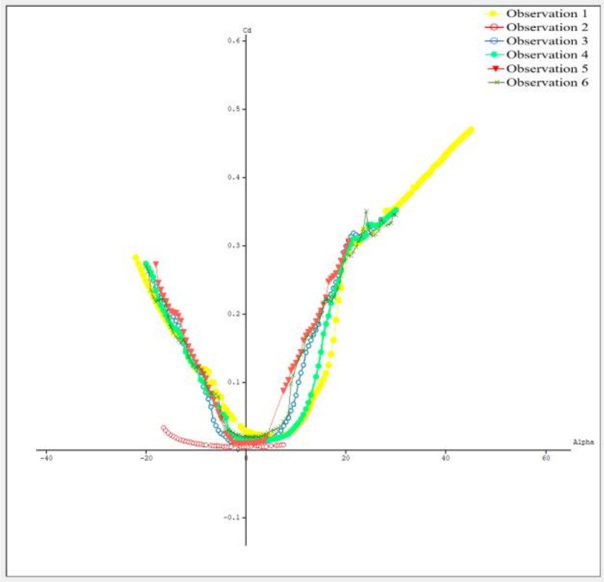

Figure 2: Coefficient of Drag (C_d) VS Angle of Attack (α)

Change of aerodynamic properties shows the change of Coefficient of drag (Cd) with angle of attack in figure 2. Least drag is obtained in observation 2 with change is angle of attack.

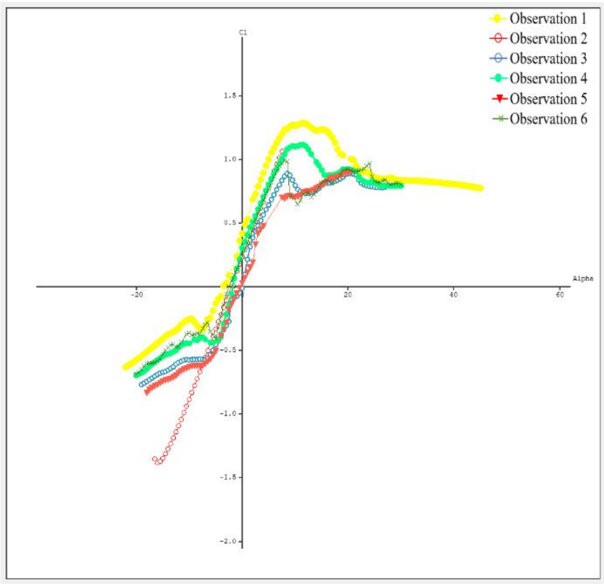

Figure 3: Coefficient of Lift (C_l) VS Angle of Attack (α)

Obtaining higher lift is the fundamental need of an airfoil. Lift coefficient change with angle of attack is shown in figure 3. At a certain positive angle of attack observation 1 has obtained highest lift coefficient and followed by observation 4.

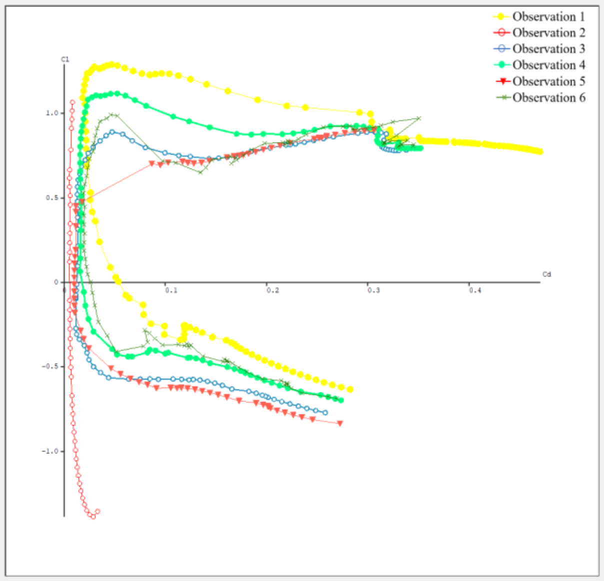

Figure 4: Coefficient of Lift (C_l) VS Coefficient of Drag (C_d)

Also, from the Cl vs Cd graph in figure 4 shows the change of lift coefficient with drag. Less lift force is considered with increase in drag by observation 1.

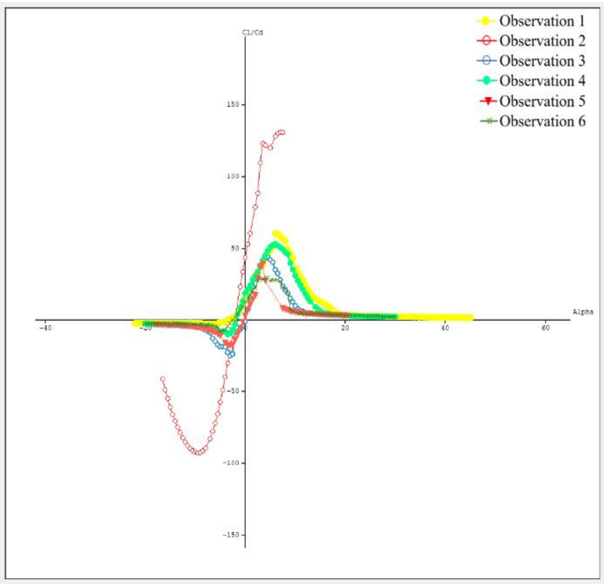

Figure 5: C_l/C_d VS Angle of Attack (α)

Cl/Cd change with angle of attack is shown in figure 5. Cl/Cd is fluctuating much in observation 2. With a small change in angle of attack shows much changes in drag and lift of the airfoil in observation 2.

5. CONCLUDING REMARKS

In conclusion, the observations in Table 2 provides valuable insights into how specific design parameter changes affect the performance characteristics of the Selig S3014 airfoil. These findings will be instrumental in improving future wing designs for various applications, including airplanes, wind turbines, and hydrofoils.

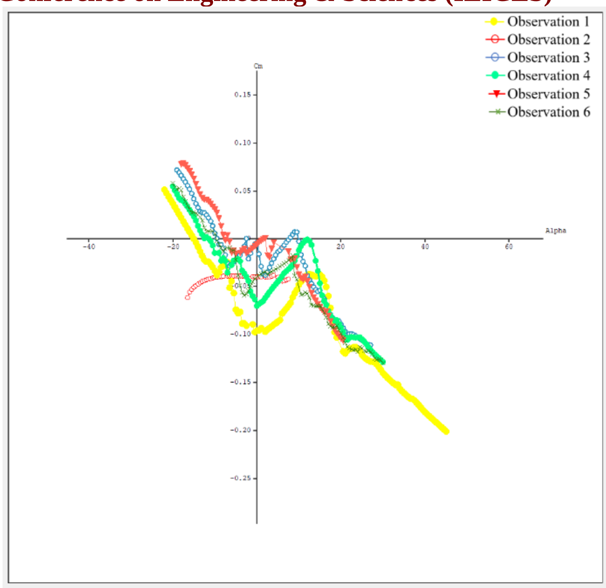

Figure 6: Moment coefficient (C_m) VS Angle of Attack (α)s

Moment coefficient vs Angle of attack in the figure 6 shows there is not much deviation on every observation except the observation 1.

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