NUMERICAL VALIDATION OF AERODYNAMIC BEHAVIOR FOR UWA PROFILE AT LOW REYNOLDS NUMBERS

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ABSTRACT

This research presents the results of the UWA profile simulation, which is compared to profiles E387 and UMY02-T01-26 that maximizes the lift-to-drag coefficient ratio. The obtained results of the lift/drag ratio of the aerodynamic profile uniformly increase under different leading angles when compared to profiles E387 and UMY02-T01-26 in 30% ~ 40% for Re = 2 x 10^5. After comparison, it was determined that the profile created is adequate for wind turbines at low Reynolds numbers due to their better lift-to-drag ratio.

Keywords: wind energy, bezier curves, aerodynamic profile, lift coefficient, drag coefficient.

1. INTRODUCTION

The implementation of renewable energies has recently taken off all over the world due to concerns about pollution caused by fossil fuels on our planet. One of the renewable sources with the greatest growth is wind energy, partially due to the increase of research focusing on its improvement and optimization to obtain more energy [1]. Wind turbines allow for extracting kinetic energy from the wind, and turn it into electric energy through the rotation of blades or blades in a clean way. The shape of the airfoil of the blade helps it to have greater energy efficiency due to the interaction of wind with the surface of the profile, which causes the movement of the blades due to the lift profile [2]. The different techniques used for the analysis of airfoils currently employed are the CFD computer systems and shape standardization (Bezier curves). Taking into account that shape standardization does not only seek to soften the profile, but it also affects the space being studied, it is one of the key techniques for this study [3]. Limit layer separation or fluid layer separation of the surface of an aerodynamic profile with Re < 5 x 10^5 has been widely studied through analytic, experimental, and computational methods for decades [4]-[6].

In this study, the flow behavior on aerodynamic profiles that helps to noticeably increase the features of aerodynamic performance, significantly boosting the wind turbine to improve the electric energy extraction through a greater capture of kinetic wind energy [2].

2. METHODOLOGY

The design of the aerodynamic profile was carried out through Bezier curve standardization. The shape of a Bezier curve is calculated by using interpolation, an approximation method of the line pathway between each control point as shown in Figure-1. The design of the UWA profile was done with the goal to maximize the lift coefficient and minimize the drag coefficient with the XFOIL and Matlab software for the Bezier curve algorithm programming.

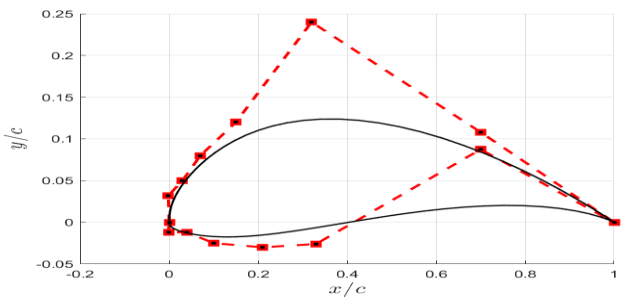


Figure-1. Control points for the design of the airfoil.

Based on the profile designed, which is shown in Figure-2, the UWA airfoil (as an homage to the indigenous people U'wa, which means intelligent people who know how to speak), is asymmetric and has a maximum thickness of 13.1% in 30.2% of the chord with a medium curve line of 6.2% in relation to the chord.

In order to assess the performance of the profile designed, it was compared to other profiles used in wind turbines. Table-1 shows the maximum lift coefficient and the minimum drag coefficient; and it is observed that the UWA profile has a similar behavior in aerodynamic coefficient, being better in some of them.

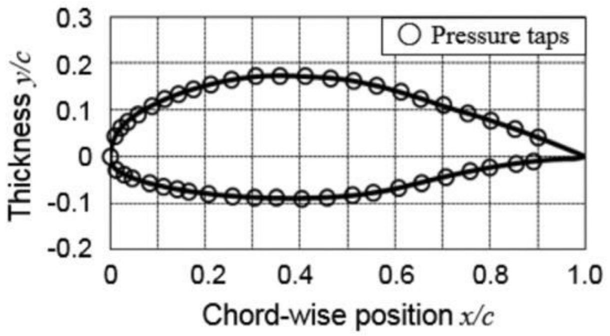
Table-1. Comparison of aerodynamic profiles used in wind turbines of low Reynolds numbers.

Airfoil	C_{Lmax}	C_{Dmin}
E387 [4]	1.25 @ α=13°	0.009 @ α=-1°
UMY02-T01-26[10]	1.70 @ α=15°	0.009 @ α=-5°
NACA 4415 [11]	1.45 @ α=15°	0.240 @ α=0°
SG6043 [12]	1.62 @ α=15°	0.0125 @ α=4°
S1223 [7]	2.28 @ α=14°	0.009 @ α=-1°
S826 [3]	1.45 @ α=14°	0.024 @ α=0°

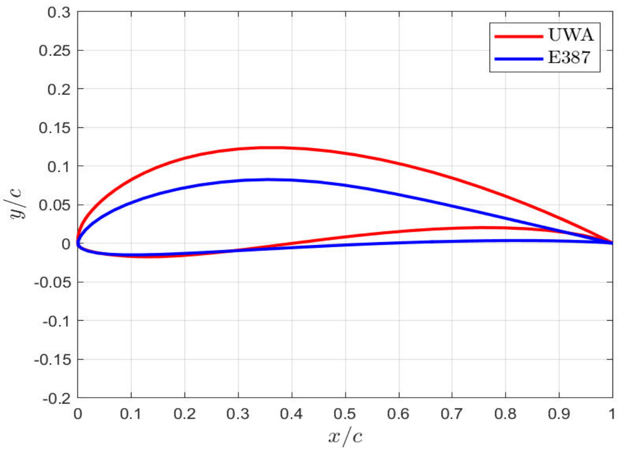
When selecting the profiles to compare to the designed profile (Table-1), it was considered that they had all or most graphics and data regarding each of the aerodynamic coefficients that were intended to be obtained and compared to, having established that the articles that have the data are [4], [7], having been able to observe in a more detailed way that these profiles had very good results to take into account compared to other studies. In spite of profile S1223 having good results regarding lift and drag coefficients, the results on aerodynamic efficiency are not very good when compared to profiles E387 and UMY02-T01-26. This was determined according to the results shown in different studies.

The aerodynamic profiles chosen as a reference to compare to the UWA profile are taken as a reference point to obtain and improve the design and study of the UWA aerodynamic profile. Obtaining the profile was achieved thanks to the different theoretical applications applied in the design and study of the profile above mentioned in this document.

In order to compare the profile designed, a comparison to aerodynamic profiles E387 and UMY02-T01-26, which show excellent lift, pressure and drag coefficient, was performed [4], [8].



a)



b)

Figure-2. Geometry of Profiles a) UMY02-T01-26 [7], b) UWA, and E387.

The airfoil used is a Type-C around the aerodynamic profile in order to avoid the undesired effects on the adjoining flow field to the aerodynamic profile. In Figure-3 the contour conditions and airfoil specifications are observed, and the ascending, descending and cross flow limits were also established at 12.5c, 12.5 c and 20 c, where c represents the chord length of the airfoil, from the aerodynamic surface, respectively. This was established according to studies [9] where minimum computational airfoil is 10c. Velocity inlet and pressure outlet boundary [12], [13], [14].

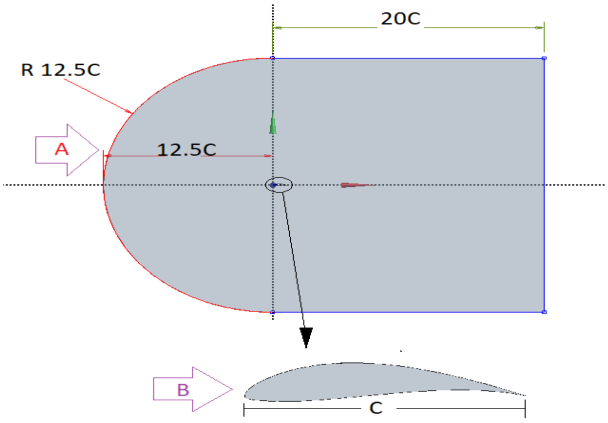


Figure-3. Computational airfoil of the simulation.

In Figure-4 the grid used for the simulation is observed, previously used by [11]. The computational airfoil was divided in several blocks to generate the grid. The Fig.4 shows the details around the aerodynamic profile (leading edge and trailing edge) to make sure that $y^+<1$. For this, the area around the aerodynamic profile was created with the Bias Factor height method. The turbulence model used was k-ω SST since it is proven to be the best option for the predictions of airfoil aerodynamics, and was applied in similar simulations by [6], [9]. The results obtained on the quality of the grid according to the quality criteria by *Skewness* and Orthogonal Quality were 0.07624 and 0.9663 respectively and the number of elements was 201134.

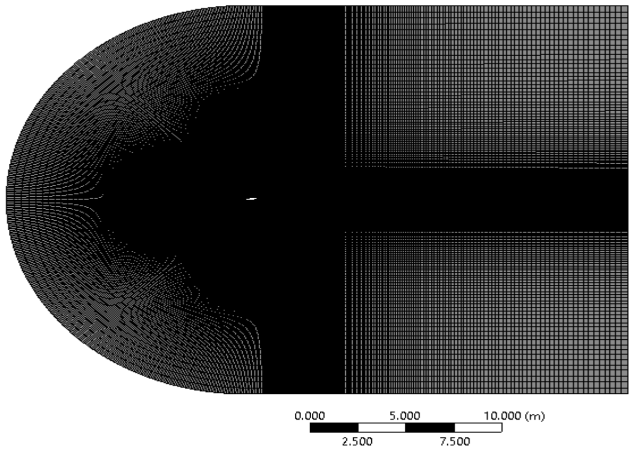


Figure-4. Grid of the UWA Profile

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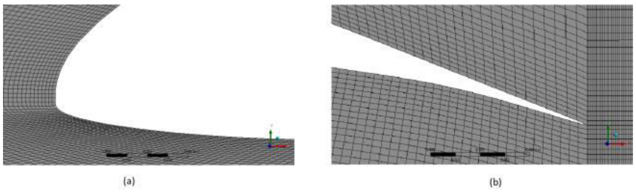

Figure-5. Details of the grid for the U'wa airfoil (a) around the leading edge (b) around the trailing edge.

During the verification of grid independence, the lift coefficient for a leading angle of α=0° was selected for low Reynolds numbers, and the time record of the lift coefficient was examined. The results of the grid done were obtained by refining the elements close to the aerodynamic profile and setting up a bias factor that allows for the coupling of the grid [4], [7].

Numerical simulations were carried out for the flow field while varying the leading angle of the flow around the UWA aerodynamic profile to a Reynolds number Re = 2 x 10^5. The data were verified by lift coefficient as shown in Table 1, the similarity in the results obtained in XFOIL when compared to the ones obtained by ANSYS was observed, presenting an error margin of 0.46% for the 0° angle compared to the calculations obtained in XFOIL, which helps to establish the grid quality [2], [4], [5].

Table-2. Validation of results.

α [DEG]	Lift Coefficient, CL		
	ANSYS	XFoil	% error
-5	0.1698	0.1742	2.6171
0	0.7980	0.7944	0.4555
5	1.3198	1.3061	1.0395
10	1.6550	1.6688	0.8355
15	1.5752	1.5830	0.4954

As it can be seen in Table 2, the lift coefficient values are very similar and the average error margin is 1.0886%, which is within the acceptable error margin for both programs, which implies that the data obtained in XFOIL as well as the simulations in ANSYS are reliable and allow for an optimal analysis result regarding the UWA profile designed and analyzed in this document. The verifications shown, the methods and the grid are appropriate for the numerical simulations.

3. RESULTS

3.1 Aerodynamic Efficiency

It measures the lift to drag ratio. The ideal is to have a greater lift combined with minimal drag, with the greatest growth as can be appreciated in the drag curves, there is not an easy lift to drag ratio. This is why this standard was defined to determine at which leading angle the maximum lift with the minimum drag possible was produced.

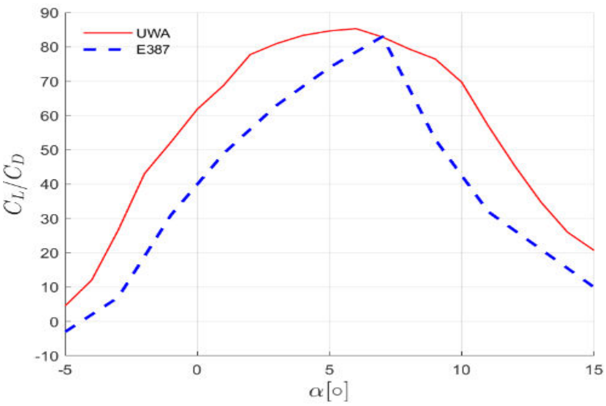

Figure-6. Lift to drag coefficient ratio.

Among the data obtained in Figure-6, the advantage in the lift to drag coefficient ratio in the UWA profile over that of E387 profile can be observed, it being greater in the whole range from - 5 until 15^0. Another important feature is that the curve is blunter in the region where the maximum ratio is obtained, which is favorable for the design of wind turbine paddles, because it makes it more stable to the variable wind conditions. From the comparison between the characteristic profiles, it was possible to determine that the aerodynamic profile created has a greater aerodynamic efficiency and lift between the angles from 0° to 15°.

3.2 Behavior of the Limit Layer

As can be observed in Figure-7, the trail of the upper limit layer adheres to the profile with minimum separation bubble generation along its surface at a leading angle of 0°. It can be seen that the trail formed by the aerodynamic profile is good and allows for the airflow to interact with the surface of the profile, turbulence intensity is lower than 1%, which helps to confirm the data in Figure-6 where high aerodynamic efficiency is observed. At this angle, lift is high and drag is high, which is why the profile tends to generate an adverse pressure gradient, which causes layer separation bubbles towards the trailing edge. This occurs in the extrados area; in the intrados area the airflow is laminar, which helps to have good aerodynamic efficiency compared to profiles E387 and UMY02-T01-26.

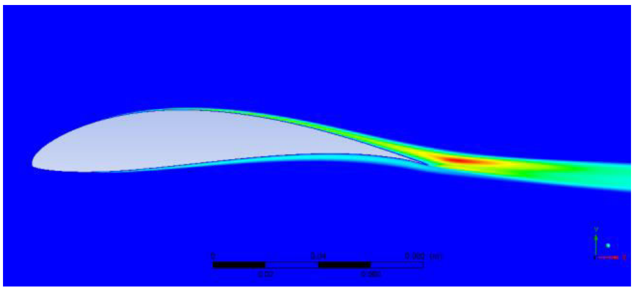

Figure-7. Behavior of the limit layer.

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As the flow goes through the aerodynamic profile in the extrados area, the pressure is low because the flow increases its velocity, Figure-7. When the flow deaccelerates, the pressure increases, Figure-8. As a consequence, the aerodynamic surface tends to spin and the pressure on the lower surface is always higher than the pressure on the upper surface. The maximum pressure area that corresponds to the leading edge can also be observed.

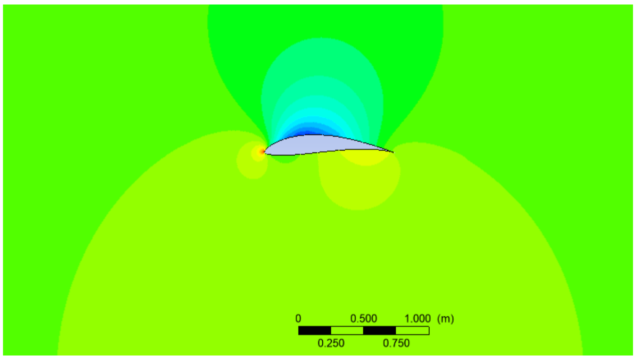

Figure-8. Distribution of Pressure at an angle α = 0°.

As the air velocity increases, the pressure coefficient becomes negative, Figure-9. In the trailing edge, the flow of the upper surface deaccelerates and merges with the flow of the lower surface.

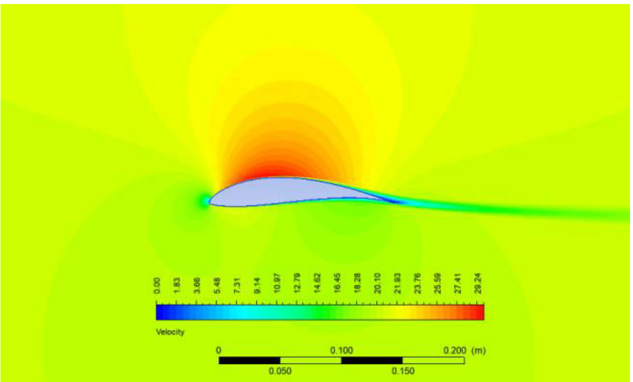

Figure-9. Distribution of the velocity magnitude at an angle α = 0°.

A visualization of the turbulent kinetic energy around the aerodynamic profile is presented in Figure-10. At α = 0° where the flow around the profile surface is shown, it can be observed that the limit layer separation occurs in the trailing edge where it separates completely around 90% of the chord. It is observed that the limit layer remains laminar along most of the aerodynamic profile.

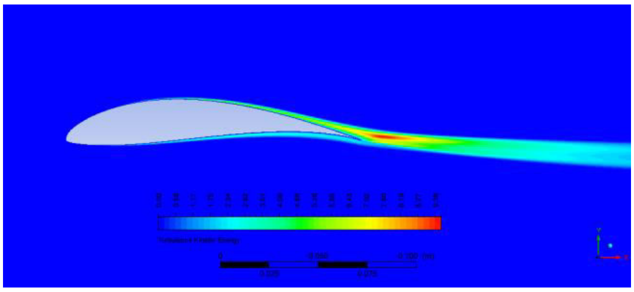

Figure-10. Turbulent kinetic energy around the aerodynamic profile at α = 0°.

4. CONCLUSIONS

An aerodynamic profile was designed through the application of the Bezier curve method. Obtaining the UWA profile was achieved through standardization of the method by means of the Matlab software, which made obtaining the profile more efficient. According to the results obtained, it is possible to affirm that through the standardization of the Bezier curve method and the use of software, it is possible to create and determine an aerodynamic profile with a greater aerodynamic efficiency in an optimal manner.

The relationship between the lift coefficient and the drag coefficient is greater than 80 for angles between 2 and 8, which makes the profile behave more stable when used in wind turbines due to the variable nature of the wind.

By the simulation through ANSYS-Fluent software, it was possible to obtain results where the interaction of the profile and the flow could be analyzed, thus being able to confirm the results obtained by the Matlab software together with the XFOIL program.

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