OPTIMIZATION OF AIRFOIL SHAPES TO USE IN WIND BLADES

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ABSTRACT

In the present work, the XFLR5 software is used to analyze the flow behavior over different airfoils, which can be applied to the profile of a wind turbine blades. First, the essential parameters for calculating the Reynolds number (Re) are defined, such as the kinematic viscosity of the air at the turbine installation site, the estimated average wind speed, and the mean chord. After determining the Re, a two-dimensional analysis is performed using the XFLR5 software. Then, 20 airfoil profiles available in the free Airfoil Tools database are selected. A comparative analysis of the lift, efficiency, and drag coefficients is carried out, leading to the selection of four profiles: CH10SM, EPPLER423, EPPLER420, and S1210. As a result, the CH10SM airfoil proved to be the most suitable, especially due to its ability to generate lift efficiently while minimizing the adverse effects of wingtip vortices and reducing drag. In conclusion, a trapezoidal wing with a CH10SM airfoil was designed, highlighting both aerodynamic and structural details.

Keywords: Flow over airfoil; Pannel Method; Potential flow; Wind turbine blade.

INTRODUCTION

The blades used in Horizontal-Axis Wind Turbines (HAWT) operate by utilizing the vector sum of the wind velocities, which are in the axial direction, and the turbine's rotational speed, which is in the tangential direction, generating the so-called relative velocity. Thus, the movement of air relative to a turbine blade generates forces and moments on it. The force in the direction of the relative velocity is defined as drag, while the force perpendicular to the relative velocity is defined as lift [1] and [2]. In Fig. 1 [3], these forces are presented in relation to the aerodynamic profile of the wind turbine blade.

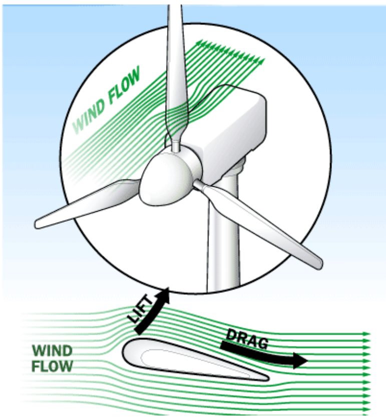

Figure 1. Direction of aerodynamic forces on a plane that intersects a wind turbine blade. Adapted from [3].

The lift force is responsible for producing the rotational motion and, consequently, the torque on the turbine's shaft [2]. On the other hand, the drag force acts in the direction of pushing the blade backward, which reduces torque and causes structural flexion, impairing the conversion of wind kinetic energy into available mechanical energy. Therefore, it is necessary to achieve the highest lift force and the lowest drag force. However, whenever an increase in lift force is achieved, the drag force also increases. Specific aerodynamic profiles, or airfoils, are used to obtain the highest ratio between lift and drag forces.

In the present article, the free and open-source software XFLR5, which utilizes Potential Flow Theory [4], is employed to generate lift and drag curves for various airfoils available in the free database [5]. From this set of simulations, the most optimized airfoil is defined, aiming at maximizing the conversion of wind energy into mechanical energy.

METHOD

In the present work, the XFLR5 software is used, a free and open-source CFD tool that employs the Panel Method (PM)[4], which is based on Potential Flow Theory, to calculate the aerodynamic forces on airfoils. The choice of this software is justified by its ability to approximate numerical results to those obtained experimentally in wind tunnels, demonstrating its value in predicting aerodynamic behaviors and optimizing designs for efficiency and performance.

Initially, to determine the Reynolds number, it is imperative to define the kinematic viscosity of the air, which must align with the local atmospheric conditions. To ensure data accuracy, a free calculation tool available on the website [5] was used. Additionally, the wind speed is another preliminary parameter, estimated at 17 m/s [6].

After defining the chord, the Reynolds number [1,2] can be calculated according to Eq. (1):

$$Re = \frac{V \cdot c}{v}. \qquad \text{Eq. (1)}$$

where V is the wind speed, in m/s, c is the blade chord, in m, and v is the kinematic viscosity, in m^2/s.

Twenty aerodynamic profiles from the [5] database were selected. For the analysis of these profiles, XFLR5 software version 6.58 is used to determine the lift and drag forces, expressed in coefficients nondimensionalized [1,2], given in Eq. (2):

$$C_{L,D} = \frac{2F_{L,D}}{\rho V^2 A_p}, \qquad \text{Eq. (2)}$$

where $F_{L,D}$ is the lift or drag force, V is the free stream velocity and A_p is the planar area of the blade given by $A_p = c \cdot b$, where c is the chord and b is the blade span and $C_{L,D}$ is the Lift or Drag coefficient.

The analyses will be supported by the use of a data spreadsheet, which will streamline the process through dynamic tables based on the coefficients obtained from the XFLR5 simulations [4].

In this context, the profiles that exhibit the highest lift coefficient ($Cl\ x\ \alpha$) and the best lift-to-drag ratio ($Cl\ x\ Cd$) will first be selected based on the XFLR5 software graphs. Subsequently, among these selected profiles, a final analysis will be conducted, considering each airfoil's efficiency ($Cl/Cd\ x\ \alpha$), culminating in the selection of four profiles with the best aerodynamic performance.

RESULTS AND DISCUSSION

The software XFLR5 is used to perform a flow simulations over 20 wind turbine airfoils, using $c = 0.40$ m, $b = 2.1$ m, $V = 17.0$ m/s and $\nu = 1.4E(-6)$ m²/s, resulting in a Reynolds number of 5.0E(+5) to compare with the reference [6]. The results of coefficient forces and coefficient ratio are presented in **Table 1**.

Table 1. Results of coefficient forces and coefficient ratio.

Airfoil	$(Cl)_{máx}$	(α)	$(Cd)_{min}$	$(Cl/Cd)_{máx}$
A18	1,115	5,5	0,0079	108,707
AH 6 40 7	1,426	8,0	0,0100	99,871
CH10SM	2,028	10,5	0,0116	132,545
DAE-31	1,671	16,5	0,0100	138,915
E385	1,510	11,5	0,0084	133,915
E387	1,220	9,0	0,0064	105,979
E392	1,339	14,5	0,0068	122,475
E591	1,971	16,0	0,0103	108,995
EPPLER 420	2,169	14,0	0,0133	104,508
EPPLER 421	2,036	14,0	0,0123	105,783
EPPLER 422	1,895	14,5	0,0114	105,935
EPPLER 423	2,038	13,0	0,0124	122,537
FX73 CL3 152	2,120	16,0	0,0126	99,536
FX74 CL5 140	2,295	12,5	0,0200	102,909
GOE 14	1,766	18,5	0,0286	100,660
GOE 233	1,628	9,5	0,0101	112,346
NACA M20	1,276	12,0	0,0260	90,111
NACA M23	1,194	8,5	0,0248	95,573
S1210	2,007	12,0	0,0110	122,537
S1223	2,287	12,5	0,0143	98,395

Thus, using the results of **Table 1** it is possible to transfer the necessary data to a spreadsheet, enabling the evaluation and selection of the most suitable aerodynamic profiles. It is observed that the parameter $(Cl/Cd)máx$ is paramount due to its importance in evaluations. Thus, profiles with high Cl/Cd ratios demonstrate that lift significantly outweighs drag across various ranges of the angle of attack, *i.e.*, the angle between flow direction and airfoil chord. Conversely, the minimum drag $(Cd)min$ offered by each airfoil is also examined, as one of the essential goals in aerodynamic design projects is to minimize drag to ensure lift efficiency.

In the analysis conducted, four profiles stood out according to the data in **Table 1**, as they exhibited the most satisfactory results for the considered parameters. The CH10SM profile is notable for its excellent lift-to-drag ratio $(Cl/Cd)máx$, also registering one of the lowest minimum drag values $(Cd)min$ and a high lift coefficient $(Cl)máx$. The S1210 profile, on the other hand, shows a positive relationship between the lift and drag coefficients, standing out for having the lowest minimum drag value among all the examined airfoils. Additionally, the EPPLER 423 and EPPLER 420 profiles were notable for their robust lift coefficients.

CONCLUSION

The CH10SM aerodynamic profile distinguished itself as superior to the other analyzed profiles based on criteria such as chord length and Reynolds numbers, and an efficient trailing edge geometry. This profile not only met performance requirements but also demonstrated greater efficiency and the ability to generate higher lift.

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