SGRE Engineering Challenge

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1 Introduction

For a wind turbine to achieve high performance under normal loads, it is essential that suitable airfoils are chosen for each part of the blade. To asses the aerodynamic performance of an airfoil, an analysis can be performed to determine aerodynamic polar coefficients, pressure coefficient distributions, and boundary layer properties at the trailing edge. In this report, the program XFOIL is used to perform aerodynamic analysis of the NACA63(3)-618 airfoil. The airfoil profile used in the XFOIL program is extracted from the UIUC Applied Aerodynamic Group (2010).

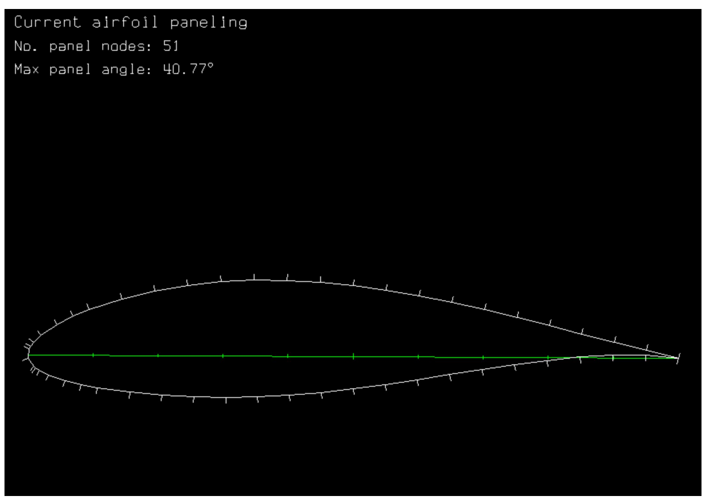
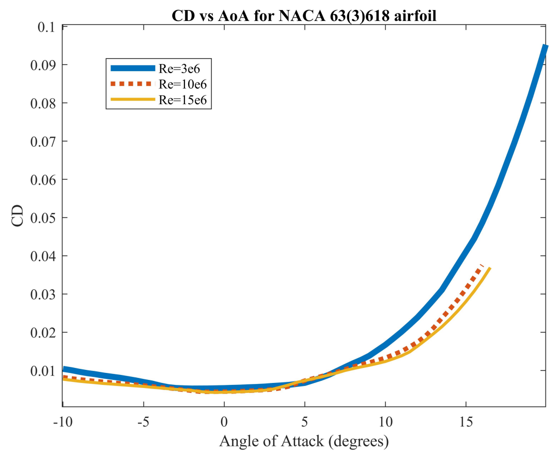


Figure 1: Profile of NACA 63(3)-618 airfoil created with XFOIL

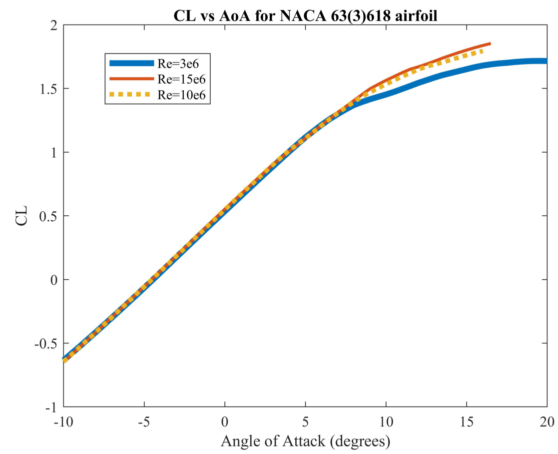
2 Aerodynamic Polar Coefficients

Significant aerodynamic properties of an airfoil can be determined by analyzing the polar coefficients: lift and drag and pitching moment. These dimensionless quantities are dependent only on the angle of attack, Reynolds number, and Mach number.

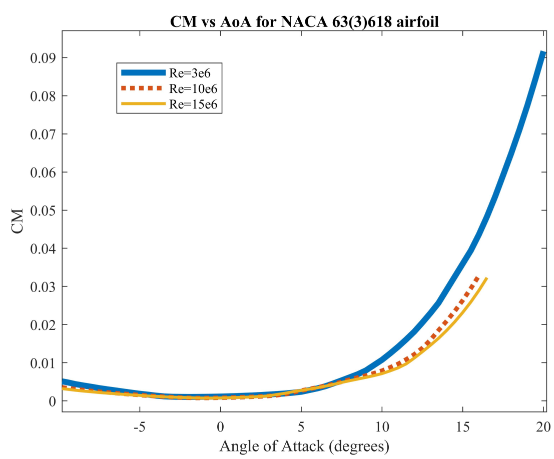
It can be seen from Figures 2a, 2b, and 2c that the drag (CD) and lift coefficients (CL) and pitching moment (CM) are the very similar over the range of Reynold's numbers for angles of attack less than eight degrees. Above eight degrees, a lower Reynold's number causes a higher drag coefficient and pitching moment and a lower lift coefficient. Turbine blades that will come in contact with faster and more turbulent airflows should be set to have a lower angle of attack.



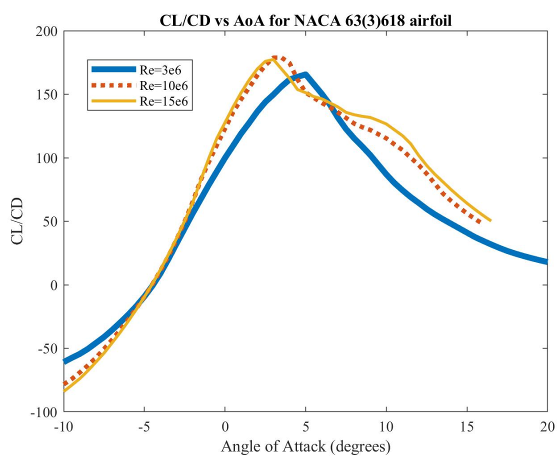
(a) Coefficient of Drag as a function of Angle of Attack for different Reynold's numbers



(b) Coefficient of Lift as a function of Angle of Attack for different Reynold's numbers.



(c) Pitching Moment as a function of Angle of Attack for different Reynold's numbers



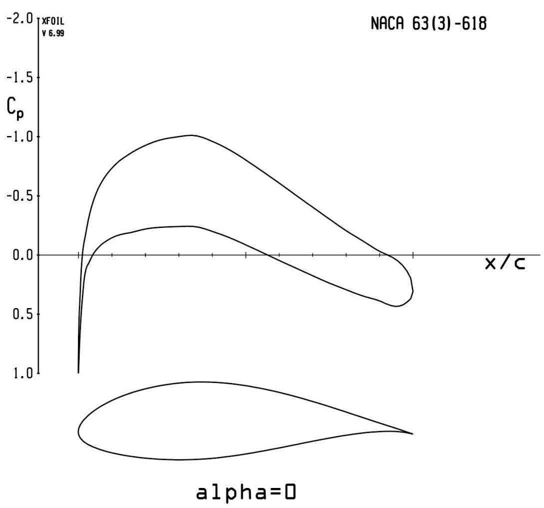
(d) Lift to Drag Ratio as a function of Angle of Attack for different Reynold's numbers

Figure 2: Aerodynamic Polar Coefficients

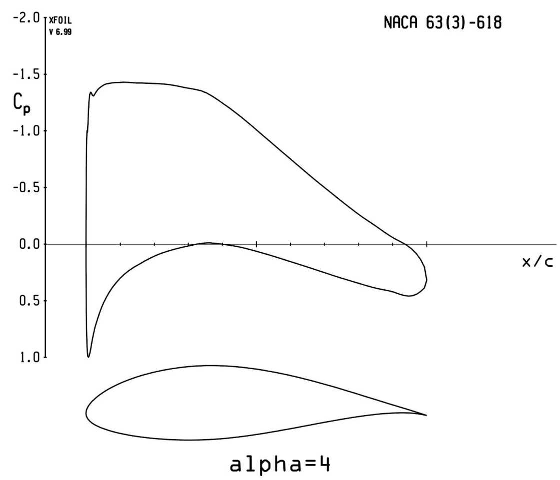
The lift to drag ratio is often described as the most important parameter in determining optimum airfoil design. It can be seen in Figure 2 that the NACA633-618 airfoil achieves maximum lift to drag ratio at higher Reynold's numbers and an angle of attack of roughly three degrees. At higher angles of attack stalling occurs, rapidly decreasing the lift force (Iliev 2016).

3 Pressure Coefficient Distributions

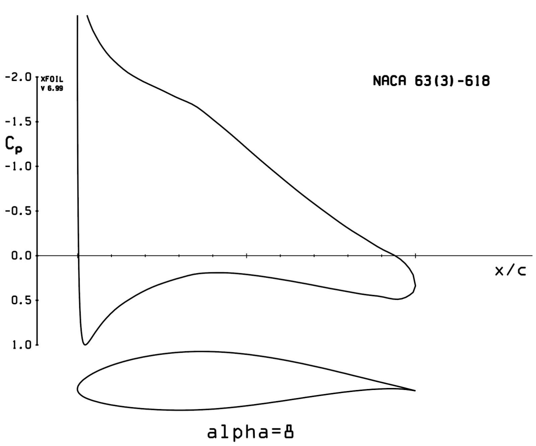
The pressure coefficient is a dimensionless quantity which describes the relative pressure in a flow field as compared to flow pressure in the free stream. Each point around the airfoil has a unique relative pressure, and the profile has a great impact on the performance of the turbine blade.



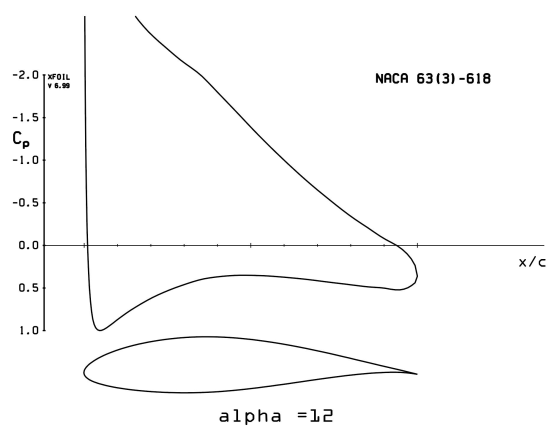
(a) Angle of attack of zero degrees



(b) Angle of attack of four degrees



(c) Angle of attack of eight degrees



(d) Angle of attack of twelve degrees

Figure 3: Pressure coefficient Distributions at a range of angles of attack.

As the angle of attack increases, the pressure coefficient distribution expands generating more extreme areas of high and low pressure at points around the airfoil. If the pressure gradient is too high, the pressure forces overcome the fluid's inertial forces, and the flow separates, greatly decreasing the lift force (Ribeiro et al. 2012). It is imperative that the angle of attack is lower than this point.

4 Boundary Layer Properties

The analysis of boundary layer properties helps to determine the inviscid characteristics of airflow around the airfoil. The boundary layer represents the distance from the wall to the point where the fluid returns to free stream velocity. The airfoil separates the flow which then merges after passing the trailing edge. If the airflow is unable to merge at the trailing edge, separation occurs which can introduce large turbulent effects (Houghton et al. 2012). Displacement thickness and Momentum thickness affect the shape factor according to Equation 1. According to Ghouila-Houri et al. (2017) for a typical airfoil as angle of attack increases, so does the shape factor, as seen in Figure 4. As the value of H increases, so does the adverse pressure gradient, which reduces the Reynold's number at which the transition to turbulence may occur (Houghton et al. 2012). So a small shape factor is desired.

δ^* =displacement thickness
$\theta =$ momentum thickness
H=shape factor

$$H = \frac{\delta^*}{\theta} \tag{1}$$

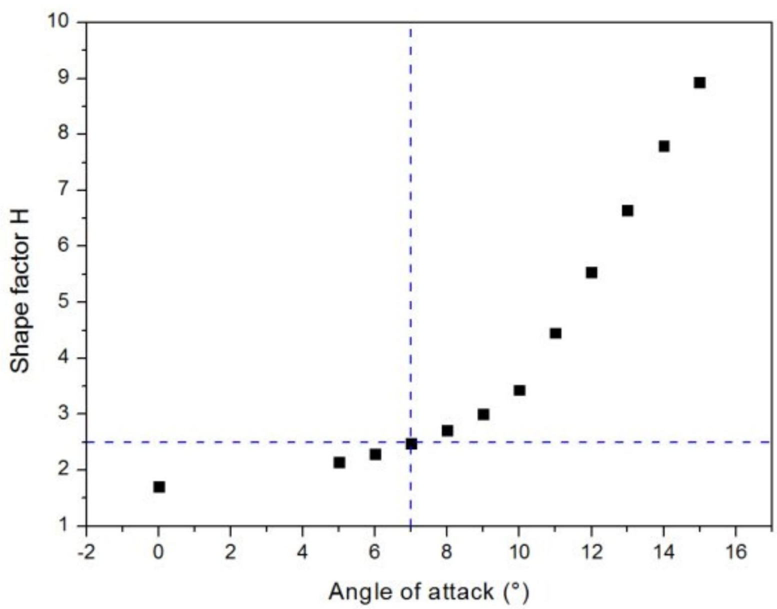


Figure 4: Shape factor vs Angle of Attack for NACA0020 airfoil, taken from Ghouila-Houri et al. (2017) showing positive relationships between H and AoA.

5 Conclusion

Using Xfoil, a thorough study can be done to analyze the aerodynamic performance of the NACA 63(3)-618 airfoil. As different aerodynamic parameters such as lift to drag ratio, pressure coefficient distribution, and shape factor are considered, the NACA 63(3)-618 airfoil is optimized at different angles of attack. Depending on which portion of the turbine blade that this airfoil is intended to be a part of, an engineer must determine which parameter is most important. By considering the Reynold's number and other environmental conditions, the airfoil can be implemented so it will produce the desired aerodynamic properties.

References

Ghouila-Houri, C., Gallas, Q. & Garnier, E. (2017), 'Wall Shear Stress Calorimetric Micro-Sensor Designed for Flow Separation Detection and Active Flow Control †'. Library Catalog: www.researchgate.net.
URL: *https://www.researchgate.net/publication/319017093*$_W$*all*$_S$*hear*$_S$*tress*$_C$*alorimetric*$_M$*icro−Sensor*$_D$*esigned*$_f$*or*$_F$*low*$_S$*eparation*$_D$*etection*$_a$*nd*$_A$*ctive*$_F$*low*$_C$*ontrol/figures?lo* = 1

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Houghton, E., Carpenter, Collicot & Valentine (2012), *Aerodynamics for Engineering Students*, 6 edn, BH.

Iliev, S. (2016), *Aerofoil Analysis using XFOIL - Practical Implementation for Preliminary Wing Design*.

Ribeiro, A. F. P., Awruch, A. M. & Gomes, H. M. (2012), 'An airfoil optimization technique for wind turbines', *Applied Mathematical Modelling* **36**(10), 4898–4907.
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