Engineering & Programming Challenge

Application for SGRE Position

Date: 6/04/2020

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I. INTRODUCTION AND BACKGROUND

The objective of this challenge was to write a program in MATLAB or Python to interact with and extract data from MIT's free airfoil software XFOIL. The output plots of the program will be used to compare parameters for various angles of attack and Reynolds numbers.

II. PROCEDURES

The Airfoil examined in this challenge was the NACA 63(3)-618 pictured below.

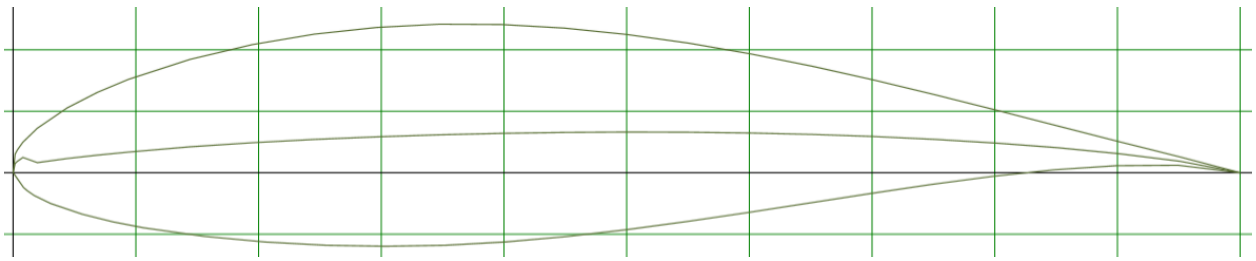

Image 1: NACA 63(3)-618 Airfoil

The program, written in Python 3.7 using Pycharm's IDE, executes by creating a text file of commands for XFOIL to follow. The Program then opens XFOIL and inputs the commands from the text file in an appropriate order to determine the airfoils response to external factors. Aerodynamic performance of this airfoil will be determined for Reynolds numbers (Re) of 3 million, 10 million, and 15 million using angles of attack (AoA) from -10 to 20 degrees. The first run through of the program will extract the aerodynamic polar coefficients for the given conditions: Lift Coefficient (C_l), Drag Coefficient (C_d), Moment Coefficient (C_m), and Lift to Drag Ratio (C_l / C_d). Second, it will extract and plot Pressure Coefficients (C_p) for angles of attack of zero, four, eight, and twelve degrees at the stated Reynolds numbers. Finally, it will determine boundary conditions at the tail end of airfoil using prescribed AoA's and Re's, namely: Displacement Thickness (δ), Moment Thickness (θ), and Shape Factor (H_k).

III. RESULTS AND ANALYSIS

The first figure shown below represents the polar coefficients of our airfoil when subject to the given AoA's at each Reynold number.

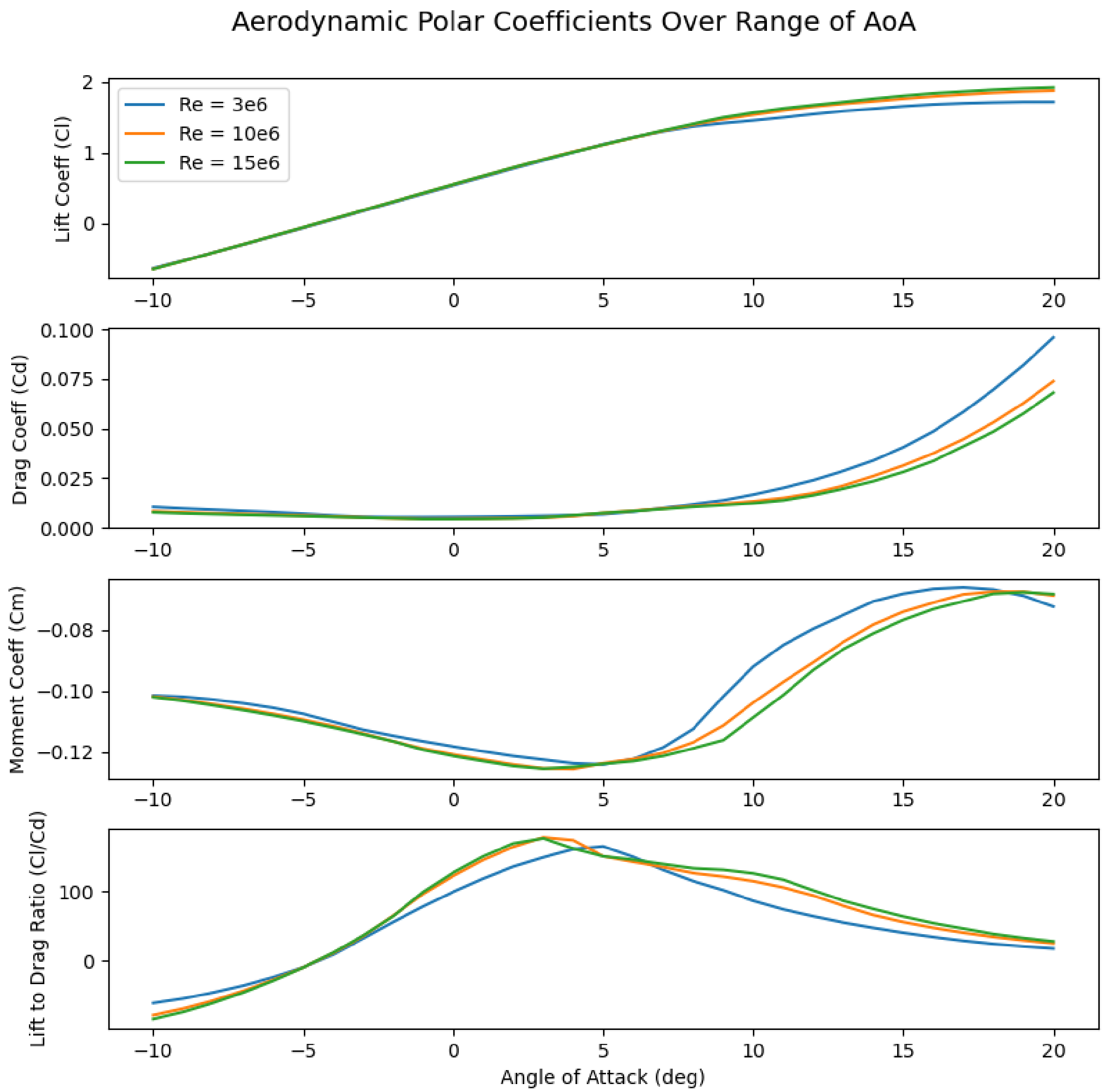

Figure 1. Aerodynamic Polar Coefficients plotted against AoA's for each Reynold number

As determined from the first subplot, the coefficient of lift increases at a slowing rate for increasing angles of attack regardless of the Reynolds number for this airfoil. It shows no signs of stall characteristics, although the values begin to level off at the higher AoA's which indicates it may be approaching a stall angle. This indicates that this is a good operating range for this airfoil, for any of these Re values. For the second subplot of each set the drag coefficient is seen to have similar characteristics for all three values of Re, reacting as expected to increase in AoA, showing no signs of stall. In addition, of the two larger Re values, we see similar drag coefficient values for this airfoil. Ideally, for the third plot, there would be little to no change in the Moment Coefficient across the operating range of AoA. In the results there are very small changes in C_m to the degree of about ±0.02 fluctuating around C_m = -0.1, but not to a significant extent. The Lift to Drag ratio is plotted in the fourth and final subplot. There is similar performance across all tested Re for this ratio. As expected, the ratio is slightly negative for AoA further into the negatives, but as AoA grows positively the airfoil performs exceptionally, with a Lift to Drag ratio over 100.

The second figure shows the pressure coefficients over the length of the airfoil for AoA's zero, four, eight, and ten.

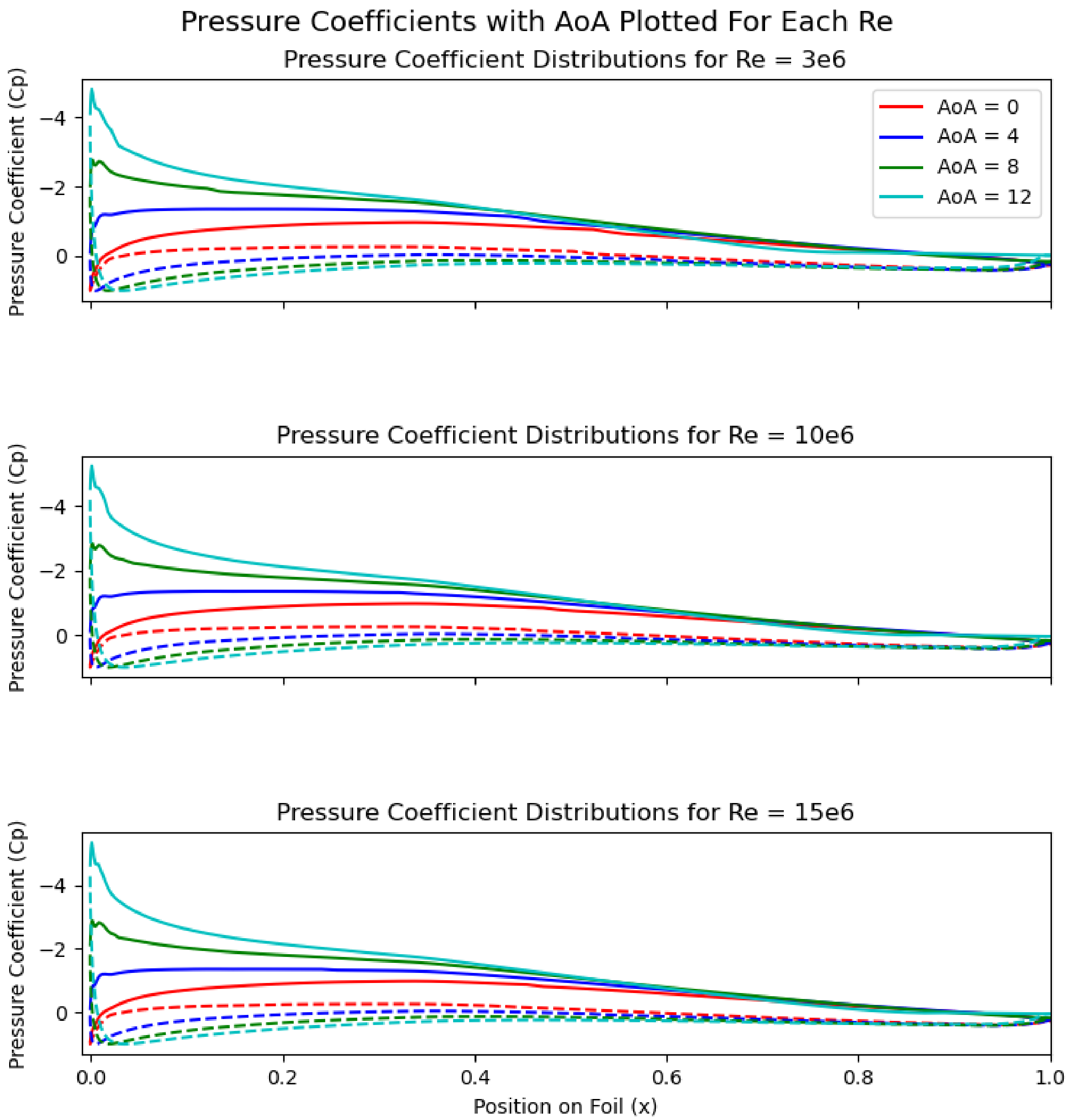

Figure 2. Pressure Coefficients plotted against position on airfoil for AoA 0, 4, 8, 12 for each Re

The pressure coefficient distributions are very similar for the same AoA's in different Re flow conditions. All C_p distributions follow logical patterns, with the highest C_p at the leading edge decreasing along the airfoil, leading to the conclusion that this airfoil is well optimized for flow in these conditions at the given AoA's.

The final figure below exhibits the boundary layer properties at the trailing edge of the airfoil for the specified range of angles of attack and Reynolds number.

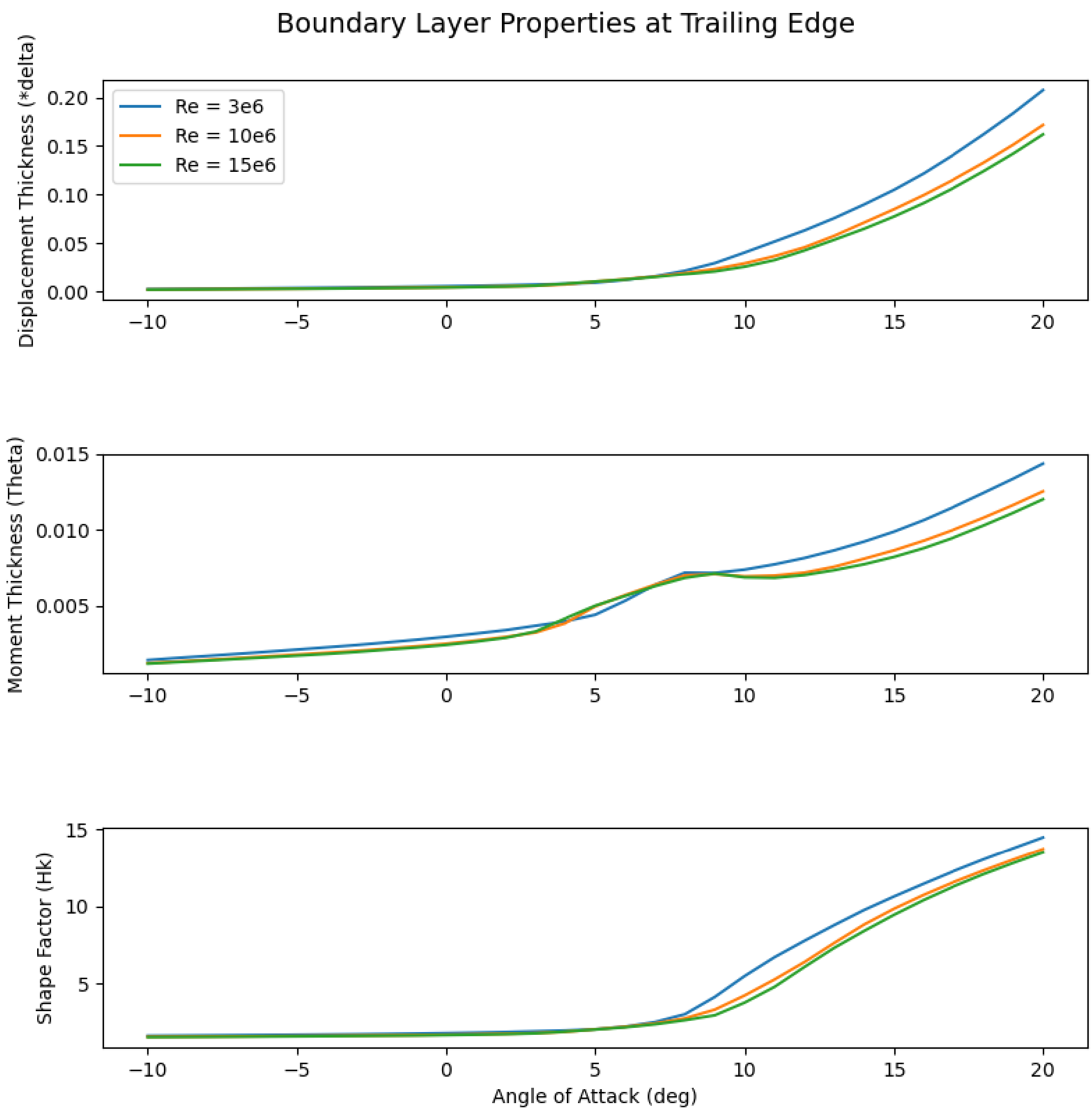

Figure 3. Trailing Edge boundary layer properties for varying AoA and Reynolds numbers

The Displacement Thickness shown in the first subplot behaves as expected. As the airfoil moves to higher AoA, the displacement thickness increases, given that we are operating in a viscous fluid, with Re of 3e6 having the most displacement due to it being the least inviscid flow of the three, and the other two values following suit. In XFOIL, at higher AoA's, the exported data for the momentum thickness would start to cut off the full length of the airfoil, thus not allowing the download for the trailing edge momentum thickness correct values. This issue would not resolve despite great efforts and searching for solutions so, as a workaround, the momentum thickness values displayed on the above graphs are extrapolated from the values of shape factor and displacement thickness in the following equation.

$$H = \frac{\delta^*}{\theta} \qquad \textbf{(Eq. 1)}$$

While not actual data, they show the same trend of the least inviscid flows having higher displacements, in this case momentum, having the highest of the three displacements for most AoA's. The final subplot shows shape factors for the given conditions. The graph shows the shape factors following similar paths for the different Re, increasing as expected as AoA is increased. These higher values of shape factor as AoA increases leads to a stronger adverse pressure gradient at these values, making them more susceptible to turbulence at lower Re values.

IV. CONCLUSION

Given the findings described above, the NACA 63(3)-318 is an ideal airfoil for operating in the conditions provided in this challenge. For angles of attack above negative five degrees the airfoil provides an excellent lift to drag ratio and steady moment coefficient, the pressure coefficient distributions are consistent and stable, and the shape factor indicates it maintains mostly laminar flows, especially at higher angles of attack. All of this makes the NACA 63(3)-618 a fantastic choice for operating within the given range of angles of attack in flow conditions with Reynolds numbers between three and fifteen million. This airfoil would make an effective wind turbine blade, as wind turbines operate in similar conditions and require similar behavior.

REFERENCES & ACKNOWLEDGEMENTS

Ge, Mingwei, et al. "Reynolds Number Effect on the Optimization of a Wind Turbine Blade for Maximum Aerodynamic Efficiency." *Journal of Energy Engineering*, vol. 142, no. 1, 2016, p. 04014056., doi:10.1061/(asce)ey.1943-7897.0000254.

http://www.joshtheengineer.com/2019/02/06/running-xfoil-from-python/ - Used as Reference for Communication Between Xfoil and Python

"The Science of Flight" – XFOIL Tutorial series
https://www.youtube.com/channel/UCQmIr2FHtLPQz9q4CrRmQTw