BYU Flow Lab Assignment 1

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1 Introduction

Many airfoil shapes exist in the world. The purpose of this research is to understand the effect of camber, airfoil thickness, and Reynolds number on the aerodynamics of an airfoil.

2 Methods

2.1 Angle Of Attack Experiment

To further understanding of airfoils. The effect of angle of attack on airfoil performance was measured. The experiment was done by creating a code in Julia that utilized Xfoil to predict the following coefficients: lift, drag, and moment. It is important to note that the particular Xfoil solver utilized accounted for viscous effects.

To accomplish this, I wrote up a function with the following inputs: airfoil data, angle of attack range, incremental angle of attack, the desired number of panels, and the number of iterations (how many times the software will iterate to match the boundary flow). The particular airfoil shape used for this experiment was a symmetric NACA16-006 airfoil. The respective coefficients were then plotted against the specific range of angle of attack values utilized. The specific range of angle of attack values was from -9 degrees to 14 degrees incrementing by 0.5 degrees. The Reynolds number was assumed to be 10000. Once the data was gathered, it was compared with plots found from Airfoiltools.com to test the accuracy of the results. It is important to note that AirfoilTools.com used a Reynolds number of 50000.

2.2 Reynolds Number Experiment

The Reynolds number experiment is very similar to the angle of attack experiment. A similar function was built in Julia with an additional input for the range of Reynolds numbers desired. Two new functions were added in which wrote the data to a CSV file and then plotted the subsequent functions and saved the files under a common folder.

For this experiment, the NACA16-006 symmetric airfoil was utilized. The range of angle of attack was from -9 to 14 degrees. It incremented by 1 degree for each data point. The range of Reynolds numbers where: 1e3, 1e4, 1e5, 1e6, and 1e7. The data points were gathered in a folder and compared with Airfoiltools.com data.

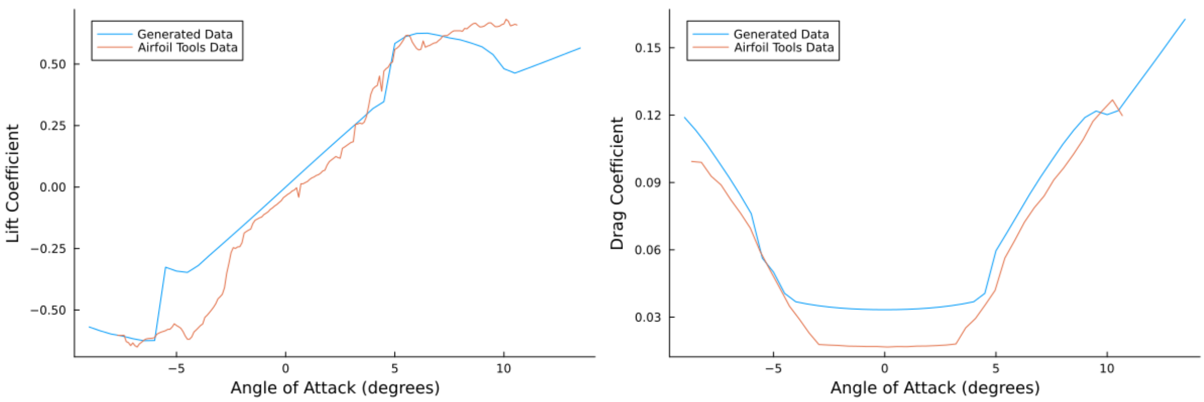
2.3 Airfoil Thickness and Camber Experiment

Similar to the last experiment, a function was called in Julia with the same inputs except for instead of a Reynolds number range it called for airfoil thickness or camber. Two programs in Julia were created with the only difference being whether airfoil thickness or camber was the input.

The results were plotted in their own respective folders. The airfoil used for this experiment was a NACA 2412. For the airfoil thickness experiment the camber was held constant at 2% (all percentages are percentages of the airfoil chord) whilst the airfoil thickness was measured at the following values: 12%, 15%, 20%, 25%, and 30%. For the camber experiment the airfoil thickness was held constant at 12%. The following camber values were tested: 2%, 4%, 5%, and 9.5%.

3 Results

3.1 Angle of Attack Experiment



(a) Lift Coefficient

(b) Drag Coefficient

Figure 1: Lift and drag coefficients for a NACA16-006 airfoil

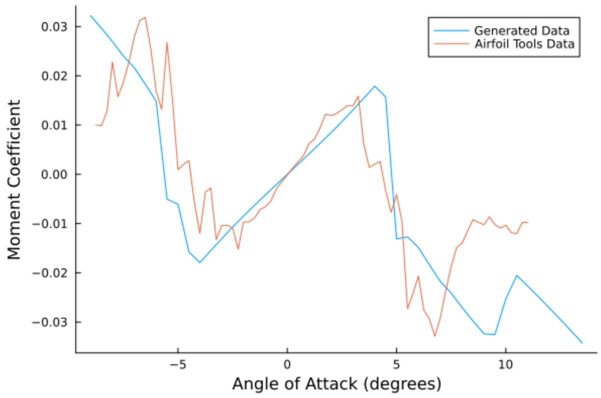


Figure 2: Moment coefficient for a NACA16-006 airfoil

3.2 Reynolds Number Experiment

Due to the abundance of data, the results are described which show some of the key differences of airfoil performance based off of a change in the Reynolds number. Another reason why the graphs are not included is because most solutions had 1 or more angle of attack solutions not converge. This led to a spike in the graph that diminished all the other data as to make any pattern not visible from the graph alone.

After looking through the CSV files, there were some notable trends in the data. As the Reynolds number increased the lift coefficients were increased, drag coefficients decreased, and moment coefficients decreased. To illustrate this, increasing the Reynolds number from 1e3 to 1e7 led to a 32% increase in the lift coefficient for an angle of attack of 2.5 degrees. The drag coefficient received a drastic reduction. It was 16.5x smaller for a Reynolds number of 1e7 than for a Reynolds number of 1e3. The moment coefficient was roughly 60% smaller by increasing the Reynolds number from 1e3 to 1e7.

This was the trend up until about 10 degrees of angle of attack. At this point things became a little unclear. Some experiments showed both the lift and moment coefficients decreased as the Reynolds number increased past 10 degrees. Whilst others would do the opposite. The drag coefficient generally followed the same trend of decreasing as Reynolds number increased. However, at these large Reynolds number there were some increases in the Reynolds number. The issue is that much of the data did not converge so it is hard to tell the overall trend.

3.3 Airfoil Thickness and Camber Experiment

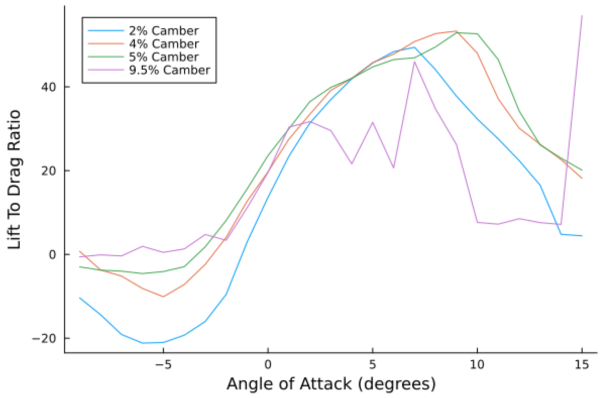


Figure 3: Lift vs drag plot for NACA2412 airfoil with adjusted camber as a percentage of the chord length. Note that 2% camber is the original NACA2412 airfoil.

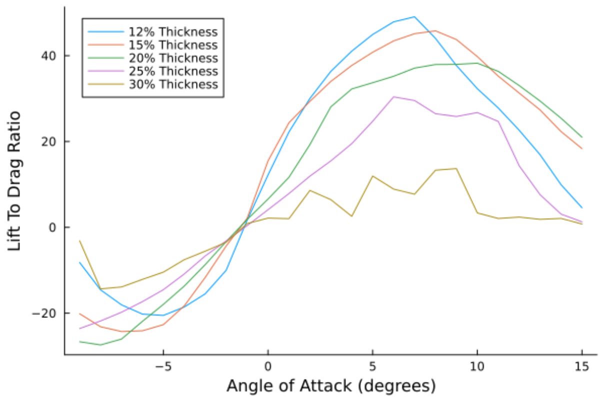


Figure 4: Lift vs drag plot for NACA2412 airfoil with adjusted airfoil thickness as a percentage of the chord length. Note that 12% thickness is the original NACA2412 airfoil.

4 Discussion

4.1 Effect of Angle of Attack on Lift, Drag, and Moment

From figure 1a, it is evident that the lift coefficient increases proportionally to the angle of attack. From roughly -3 degrees to 5 degrees the lift coefficient is linear. As the angle of attack gets greater than 5 degrees the slope starts to decrease and level off around 15 degrees.

From figure 1b, there are a few noteworthy elements to the drag coefficient. The drag coefficient follows a linear decreasing relationship with increasing angle of attack up to -3 degrees to which the curve levels off and keeps a constant value until 3 degrees. There is some disagreement between the experimental generated data and Airfoil tools data. This is likely due to the fact that the airfoil tools data involved some interpolations and regression to combine both data sets into a single plot.

From figure 2 it is evident that the moment coefficient follows a sinusoidal period that is gently decreasing overall as angle of attack increases. The mechanism behind this is unclear.

4.2 Effect of Reynolds Number on Lift and Drag

From the data there were a few noteworthy findings. Much of the convergent data showed an increase in lift with higher Reynolds number. This could be due to the fact that higher Reynolds numbers bring more turbulence which could introduce greater dynamic pressure drops. Drag coefficient also decreased substantially with higher Reynolds number which was not expected. The exact mechanism is unclear, but a reason could be that drag is fairly consistent across all Reynolds numbers and therefore the drag coefficient has to decrease to compensate for the higher Reynolds number. But that is mere speculation.

4.3 Effect of Camber and Airfoil Thickness on Lift to Drag Ratio's

Looking at figure 3 it seems that the lift to drag ratio doesn't differ that much for higher cambers up until 5 degrees angle of attack. The exception is 9.5% camber which looks to have a great deal of noise. The data trend shows that greater camber gives higher lift to drag ratios for higher angle of attacks.

For changing airfoil thickness there are some obvious trends. All airfoil thicknesses showed lift to drag ratios maxing out at around 6 or 7 degrees angle of attack. However, the slope is steeper for decreasing airfoil thickness. In addition, the height of the peak at 7 degrees angle of attack increases with decreasing airfoil thickness. It can be speculated that the trend with increases until some max efficiency value for airfoil thickness at which point the height of the peak would decrease with decreasing airfoil as the airfoil becomes flat.

References

(2024). Naca 2412 (naca2412-il). Retrieved 6 May, 2024 from http://airfoiltools.com/airfoil/details?airfoil=naca2412-il,.

Air (2024)