AIRFOIL ANALYSIS

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1 Introduction

This report reviews research done on airfoils. There are 5 areas that are covered in this research. One, it explores the effect of airfoil angle of attack on lift, drag, and moment. Two, it compares data collected by Xfoil to experimental data. Three, it explores the effect of different Reynold's numbers on airfoil polar. Four, it explores the effect of different airfoil thicknesses. And four, it explores the effect of different airfoil cambers.

2 Methods

The results of this research came from evaluating airfoils using Xfoil functions in Julia, as well as writing new functions to help in evaluating the airfoils. There were 4 functions that were used:

1. alterThicknessCamber() - this evaluated airfoils of varying thicknesses and cambers and plotted their lifts and drags together in order to compare them

2. getCoefficients() - this was a helper function that was used to calculate the coefficients of lift, drag, and moment and return them to other functions that needed those calculations done

3. alterReynolds() - this evaluated an airfoil using varying Reynold's numbers and plotted their lift, drag, and moment in order to compare them

4. autoSweep() - this calculated and plotted an airfoil's lift, drag, and moment with varying airfoil angles of attack

3 Results and Discussion

3.1 Airfoil Angle of Attack

One of the most stressed parts of this research was seeing how different airfoil angles of attack affected the lift, drag, and moment on the airfoil. In order to see those relationships, only the coefficients of drag, lift, and moment needed to evaluated, rather than the moment and the forces of lift and drag. This
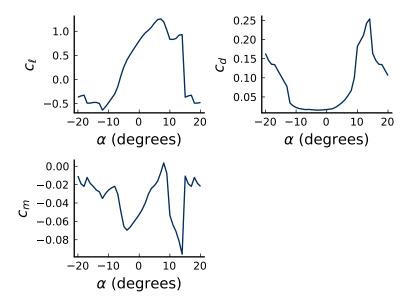
Fig. 1: *coefficients of lift, drag, and moment plotted against angle of attack for a NACA 2412 airfoil*

is because the coefficients are non-dimensional numbers. Figure 1 shows the relationships between lift, drag, and moment and α for a NACA 2412 airfoil.

The coefficients of lift (c_ℓ) and drag (c_d) both increase as angle of attack (α) increases, because as the angle increases, the pressure differential between the top and bottom of the airfoil becomes larger. This also increases coefficient of moment (c_m). It is also important to note that figure 1 establishes that lift is negative when α is less than zero, which makes sense, and that the zero-lift angle of attack is somewhere between 0 and 0.5 degrees.It appears that stall takes place at an angle of attack of about 10 degrees. This can be clearly seen on the lift and drag plots.

3.2 Airfoil Polar Comparison

The results gained from Xfoil were plotted against experimental data from a study done on the NACA 2412 airfoil (see figure 2).

It is interesting to see that the experimental lift curve looks very similar to the one obtained from Xfoil, expect shifted up. Also, the drag curves between experimental and Xfoil are very different. The reason for this is unknown, although it might be an error in Xfoil calculations.
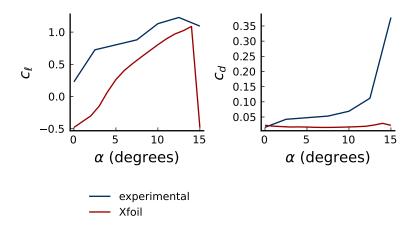
Fig. 2: *comparison of data collected experimentally to data collected from Xfoil*

3.3   Effect of Reynold's Number

The Reynold's number is an indicator of how viscous the fluid that an airfoil is traveling through is. A high Reynold's number is an indicator that fluid flow will be turbulent, where as a low Reynold's number is an indicator of laminar flow. In figure 3, the relationships between Reynold's number and the coefficients are shown.

As the Reynold's number increases, the lift curves become more steep. However, it is the opposite with drag and moment. As the Reynold's number increases, the curves of drag and moment become more leveled out; higher Reynold's numbers and therefore more turbulent flow decreases the drag and moment at more extreme angles of attack (see figure 3). It is also important to note that for greater Reynold's numbers, the stall angle becomes greater.

3.4   Effect of Airfoil Thickness and Camber

The thickness of an airfoil is the greatest distance between the upper and the lower surfaces of an airfoil. In figure 4, the relationship between airfoil thickness and the coefficients of lift, drag, and moment can be seen.

As the thickness of the airfoil increases, the ratio of lift to drag curve becomes more shallow. This is because increasing thickness leads to greater induced drag and doesn't affect the lift as much. This causes the curves to become more shallow. It is interesting to see though that no matter the thickness, the zero lift angle of attack remains the same (see figure 4).
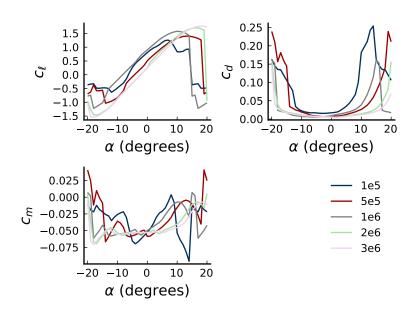
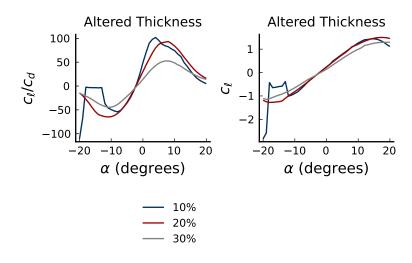Fig. 3: *plots of lift, drag, and moment for varying Reynold's numbers*

Fig. 4: *plots of ratio of lift to drag coefficients and coefficient of lift*
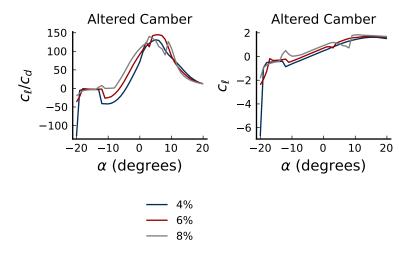
Fig. 5: *plots of ratio of lift to drag coefficients and coefficient of lift*

The camber of an airfoil is the asymmetry between the two acting surfaces of an airfoil. An airfoil with zero camber is symmetric. In figure 5, the effect of different cambers can be seen.

As the camber of the airfoil increases, the lift to drag ratio becomes higher and the whole curve is shifted upwards. This also happened with the coefficient of lift. This also means that the zero lift angle of attack became greater with increasing camber.

Appendix

- Irrotational flow: a flow in which each element of the moving fluid undergoes no net rotation with respect to a chosen coordinate axes from one instant to other

- Inviscid: having no or negligible viscosity

- Chord: a straight line from the leading edge to the trailing edge (see figure 6)

- Airfoil camber: the asymmetry between the two acting surfaces of an airfoil, with the top surface of a wing commonly being more convex. An airfoil that is not cambered is called a symmetric airfoil (see figure 6)

- Airfoil thickness: the greatest distance between the upper and the lower surfaces of an airfoil (see figure 6)
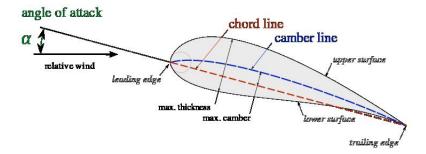
Fig. 6: *airfoil diagram showing angle of attack, airfoil camber, thickness, and chord*

- Potential flow: an idealized model of fluid flow that occurs in the case of incompressible, inviscid, and irrotational flow

- Freestream: the air far upstream of an aerodynamic body, that is, before the body has a chance to deflect, slow down or compress the air

- Angle of attack: the angle at which the chord of an aircraft's wing meets the relative wind

- Drag coefficient: equal to the drag D divided by density r times half the velocity V squared times the reference area A. It expresses the ratio of the drag force to the force produced by the dynamic pressure times the area (see equation 1)

$$c_d = \frac{2D}{\rho V^2 S} \tag{1}$$

- Lift coefficient: relates the lift generated by a lifting body to the fluid density around the body, the fluid velocity and an associated reference area (see equation 2)
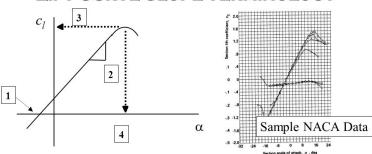
$$c_\ell = \frac{2L}{\rho V^2 S} \tag{2}$$

- Moment coefficient: pertains to the moment specifically due to the aerodynamics force (see equation 3)

$$c_m = \frac{2M}{\rho V^2 S} \tag{3}$$

- Stall: a sudden reduction in the lift generated by an aerofoil when the critical angle of attack is reached or exceeded

LIFT-CURVE SLOPE TERMINOLOGY

[1] $\alpha_{l=0}$ — Angle of attack (α) where the lift coefficient (c_l) = 0, $\therefore$ no lift is produced; $\alpha_{l=0} = 0$ for a symmetric airfoil; $\alpha_{l=0} < 0$ for a positively cambered airfoil

[2] c_{l_α} — Lift-curve slope ($dc_l/d\alpha$); 'rise' of c_l over 'run' of α for a linear portion of the plot; ≈ 0.11/deg for a thin airfoil

[3] $c_{l_{max}}$ — Maximum c_l the airfoil can produce prior to stall

[4] α_{stall} — Stall angle of attack; α at $c_{l_{max}}$; maximum α prior to stall

Fig. 7: *This diagram shows the major characteristics of a lift curve*

- Airfoil polar: represent the aerodynamic characteristics of an airfoil (figure 1 is an example of an airfoil polar)

- Reynold's number: helps predict flow patterns in different fluid flow situations. At low Reynolds numbers, flows tend to be dominated by laminar (sheet-like) flow, while at high Reynolds numbers flows tend to be turbulent. Equation 4 calculates Reynold's number using ρ(density), u(flow speed), L(characteristic linear dimension), and μ(dynamic viscosity of fluid)

$$R_e = \frac{\rho u L}{\mu} \tag{4}$$

- Mach number: ratio of the speed of a body to the speed of sound in the surrounding medium

- Lift curve slope: measure of how rapidly the wing generates lift with change in AOA (see figure 7)