MAE 339

Lift and Drag on an airfoil in a Wind Tunnel

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I. Abstract:

The first part of the wind tunnel experiment included putting an airfoil in a running wind tunnel and measuring the angle of attacks, the dynamic pressure, the Lift forces over time and the Drag forces over time. These quantities were measured because the coefficient of Lift could be calculated using them, and the results present a relationship which has been proven to exist, the relationship between the coefficient of Lift and the Angle of Attack. Their relationship is one of proportionality, that is until high angle of attacks cause stall leading to a decrease in Lift, and since Lift is also proportional to coefficient of Lift, that leads to a decrease in Coefficient of Lift. The way the first part of the wind tunnel experiment was executed was by using a wind tunnel, a computer with LabVIEW to monitor data, a pitot static tube, a set screw, a ruler, and a force balance. The results compiled include the freestream Velocity, the Reynolds Number, the dynamic pressure, the average Lift over time, the average Drag over time, the Lift per unit span, the Drag per unit span, the coefficient of Lift, the uncorrected drag coefficient, the solid blockage, the wake blockage, the total blockage, and the corrected drag coefficient. The insights presented are that the coefficient of Lift does act proportional to the angle of attack until stall, and blockage is a significant change to the coefficient of Drag.

The second part of the wind tunnel experiment involved running the wind tunnel with an airfoil in it at different angles of attack while connected to a manometer bank. The measurements that were required were those of the height at each of the 9 pressure taps along the chord of the airfoil, the height of the atmospheric pressure tap, the angles of attack, and the dynamic pressure. These variables were quantified because a coefficient of Lift could be extrapolated from them. The coefficient of Lift is important to the results because it shows its behavior with respect to the angle of attack and allows for other coefficient of lift to angle of attack relationship comparisons. This is true for comparison with the theoretical coefficient of Lift, the NACA coefficient of lift results and the coefficient of lift from the first part of the experiment. The execution of this part of the experiment involved using the wind tunnel, the pressure taps of the manometer bank, the pitot static probe, and a protractor. The Results presented include the dynamic pressure, the Reynolds number, the freestream velocity, the coefficient of pressures for each angle of attack, and each of the 9 pressure taps. They also include for each angle of attack the coefficient of force, the coefficient of the moment about the leading edge, the coefficient of lift, and the center of pressure. Plots are made for the lower and upper coefficients of pressure versus the fractional distance along the chord, one for each angle of attack. Finally, the results include plots for the calculated coefficients of lift for part 1 and part 2 of this experiment, the theoretical coefficients of lift, the NACA coefficients of lift, the coefficient of the moment about the leading edge, and the center of pressure, all of them against the angle of attack. The insights revealed include the comparison of all the coefficient of lifts against the angle of Attack, they somewhat vary, that the Pressure on the lower surface is greater than the Pressure on the upper surface indicating positive lift, that the airfoil is stable because of the negative coefficient of the moment about the leading edge, and that the aerodynamic center should be around the quarter chord just like a thin airfoil because of the center of pressure plot moving toward that quarter chord.

II. Theory/Procedure:

In the force balance experiment measurements were taken of the dynamic pressure, the angle of attack, the Lift forces over time, and the Drag Forces over time. These quantities are being measured in order to calculate the velocity of the flow, the Reynolds Number, the average Lift over time, the average Drag over time, the Lift per unit span, the Drag per unit span, the coefficient of lift, the uncorrected coefficient of drag, the solid blockage, the wake blockage, the total blockage, and the corrected coefficient of drag. Other groups have experimented with airfoils and have done similar tests in wind tunnels. They found that there is a proportional relationship between the angle of attack, and the coefficient of Lift. They also found that blockage significantly contribute to the coefficient of Drag. There are equations below used to calculate the desired quantities.

This equation below is to calculate the freestream velocity of the flow. It required the dynamic pressure measurement.

$$U_\infty=(q_\infty*2/\rho_\infty)^{\wedge}0.5$$

U_∞=freestream velocity

q_∞=Dynamic Pressure

ρ_∞=freestream density

The equation below is used to calculate the Reynolds number. It required the freestream velocity.

$$Re=\frac{\rho_\infty U_\infty c}{\mu_\infty}=\frac{U_\infty c}{\nu_\infty}$$

Re=Reynolds Number

c=chord length=10.16 cm

μ_∞=freestream dynamic viscosity

ν_∞=freestream kinematic viscosity

Then the Lift per unit span is found using the equation below. It requires the measurement of Lift over time.

$$L' = L/b$$

L'=Lift per unit span

L=Lift

b=airfoil model span

Then the Drag per unit span is found using the equation below. It requires the measurement of Drag over time.

$$D' = D/b$$

D'=Drag per unit span

D=Drag

After the Lift per unit span and dynamic pressure are used to find the coefficient of Lift in the equation below.

$$c_l = \frac{L'}{q_\infty c}$$

c_l=coefficient of lift

Then the Drag per unit span and dynamic pressure are used to find the coefficient of uncorrected Drag in the equation below.

$$c_{du} = \frac{D'}{q_\infty c}.$$

c_{du}=coefficient of uncorrected Drag

We then calculate the solid blockage using the equation below. It is the first step to calculate the corrected drag coefficient.

$$\varepsilon_{sb} = \frac{K_1}{A^{3/2}}$$

Esb=solid blockage

K_1=model volume= 0.00026429 m^3

A=test section area=1ft × 1ft

Then the wake blockage is calculated using the calculated uncorrected coefficient of drag. The equation for this is shown below.

$$\varepsilon_{wb} = \frac{c}{2h} c_{du}$$

Ewb=wake blockage

h=height of the test section=1 ft

Then the total blockage is calculated using the solid and wake blockage. This is shown in the equation below.

$$\varepsilon_b = \varepsilon_{sb} + \varepsilon_{wb}$$

Eb=Total blockage

Finally, the corrected drag coefficient is calculated using the quantities uncorrected coefficient of drag, the solid blockage, and total blockage using the equation shown below.

$$c_d = c_{du} \frac{1 - \varepsilon_{sb}}{(1 + \varepsilon_b)^2}$$

Cd=corrected coefficient of Drag

These results gave insight into the amount of blockage that contributes to the coefficient of Drag, and to the proven proportional relationship between the angle of attack and the coefficient of Lift.

In the pressure survey lab, the angle of attack, height of 9 pressure taps, height of the atmospheric pressure tap, and the dynamic pressure were measured. These properties were quantified in order to compute the freestream velocity, the Reynolds Number, the coefficient of pressure at each angle of attack and each of the 9 pressure taps. Other properties calculated, this time for each angle of attack are the coefficient of Force, the coefficient of the Moment about the Leading edge, the coefficient of lift and the center of pressure. Then using the calculated quantities plots are made to demonstrate trends, some plots made are the upper and lower coefficients of pressure versus the fractional distance for each angle of attack. Other plots are made for the lift coefficient, the leading edge moment coefficient, and the center of pressure all versing the angle of attack. Also the aerodynamic center is calculated. Other groups of people have experimented with airfoils in wind tunnels and published results for the coefficient of Lift versus angle of Attack. There is a theory already documented for a thin airfoil for the relationship between the angle of Attack and the lift coefficient. Equations used to obtain the desired results are shown below.
This equation below is to calculate the freestream velocity of the flow. It required the dynamic pressure measurement.

$$U_\infty=(q_\infty*2/\rho_\infty)\text{^}0.5$$

U_∞=freestream velocity

q_∞=Dynamic Pressure

ρ_∞=freestream density

The equation below is used to calculate the Reynolds number. It required the freestream velocity.

$$Re = \frac{\rho_\infty U_\infty c}{\mu_\infty} = \frac{U_\infty c}{\nu_\infty}$$

Re=Reynolds Number

c=chord length=10.16 cm

$\mu\infty$=freestream dynamic viscosity

ν_∞=freestream kinematic viscosity

After the coefficient of pressures are calculated for each of the 9 pressure taps and each angle of attack. The coefficient pf pressures are calculated for the lower and upper pressures using the equation below.

$$\frac{P_l - P_u}{q_\infty} = \frac{P_l - P_\infty}{q_\infty} - \frac{P_u - P_\infty}{q_\infty} \equiv C_{P,l} - C_{P,u}$$

$C_{P,l}$=Coefficient of Pressure for the lower surface

$C_{P,u}$=Coefficient of Pressure for the upper surface

Pl=lower pressure

Pu=upper pressure

P_∞ =atmospheric Pressure

The difference between the lower and upper pressures and the atmospheric pressure is calculated using the change in height of the manometer and the atmospheric manometer. This can be used to calculate the coefficients of Pressure. The equations are shown below.

$Cp=(P- P_\infty)/\ q_\infty=(\rho_\infty * g*(hatm-hpt))/\ q_\infty$

Cp=coefficient of pressure

P=Pressure

G=gravitational constant=9.81 m/s^2

After all the coefficient of pressures are calculated, the coefficient of force is calculated for each angle of attack using the computed coefficient of upper and lower pressure. The equation for this coefficient is shown below.

$$C_F = \int_0^c \frac{P_l - P_u}{q_\infty} d\left(\frac{x}{c}\right) = \int_0^1 (C_{P,l} - C_{P,u}) d\xi$$

C_F=Coefficient of Force

ξ=x/c=fractional distance along chord

x=location from the leading edge

After the coefficient of the moment about the leading edge is computed using the calculated coefficients of pressure for the upper and lower surface, for each angle of attack. The equation for this is shown below.

$$C_{m,LE} = -\int_0^c \left(\frac{x}{c}\right) \frac{P_l - P_u}{q_\infty} d\left(\frac{x}{c}\right) = -\int_0^1 \xi (C_{P,l} - C_{P,u}) d\xi$$

$C_{m,LE}$=Coefficient of moment about leading edge

The coefficient of lift for each angle of attack is then obtained by using the calculated coefficient of force and the measured angle of attack. The equation for this is below.

$$C_L = \frac{L}{q_\infty c} = C_F \cos \alpha$$

CL=coefficient of lift

L=Lift

α =angle of attack

The second to last calculation is the center of pressure for each angle of attack, and its computed by using the calculated force and leading edge moment coefficients. The equation for this is below.

$$C_{m,LE} = -\xi_{CP} C_F$$

$$\therefore \xi_{CP} = -\frac{C_{m,LE}}{C_F}$$

ξ_{CP}=center of pressure

All of the calculations are used to create plots to compare the relationships between the calculated coefficient and the angle of attack, except for the coefficient of lower and upper pressures which are plotted against the fractional distance along the chord to show their respective relationship. These plots bring goals in terms of determining relationships and stability of the airfoil.

Lastly the aerodynamic center is calculated using the center of pressure and coefficient of force calculations. The equation for this is shown below.

$$\xi_{CP} = \xi_{AC} - \frac{C_{m,AC}}{C_F}$$

ξ_{AC}=aerodynamic center

$C_{m,AC}$=moment coefficient about the aerodynamic center

The last plot is the center of pressure versus the angle of attack made possible by the equations used. It leads to seeing where the aerodynamic center should coincide with the center of pressure.

III. Setup/Equipment/Execution

For the force balance part of the lab the equipment employed to take data included a ruler, a static pitot probe, a computer with LabVIEW on it, a force balance and a wind tunnel with an airfoil in it. Safety concerns included sealing the airfoil in the wind tunnel tightly so the flow would stay in the wind tunnel. Sources of human error anticipated for were the errors in perception of angle, and the solution was a ruler. The force balance was calibrated to reduce error, their knobs were used to set the Lift and Drag to before running the wind tunnel. For the Force Lab experiment, Steven set up the wind tunnel, while I recorded results, and Emanuel set the force balance. Emanuel set the Pitot static tube far ahead of the airfoil, while Steven set the angle of attack to 0 for the airfoil using the set screw and protractor, and I opened up the LabVIEW program to measure dynamic pressure. Emanuel zeroed the Lift and Drag readings on the force balance machine by using the knobs. Then Steven, after tightly sealing up the wind tunnel turned it on, I ran the pressure analog program to get the dynamic pressure. I recorded the dynamic pressure, closed the program and then opened up the wind tunnel program to record the Lift and Drag forces over time. I clicked the run button and input 100 for the number of samples and sampling rate. Then I waited 2 minutes before recording 10 seconds of data. We turned off the wind tunnel, set the pitot static probe back to its initial condition and repeated the process for 2,4,6,8,9,10,11,12,13,14, and 15 degrees for the angle of Attack. At first it took us a few times to correctly record the data, but eventually we got it. I sent all the recordings to each of us by email.

We moved on the pressure survey part of the lab. The equipment we employed involved the wind tunnel, a protractor, the airfoil, a manometer bank with 9 pressure taps, and an atmospheric pressure tap. Safety concerns again included sealing the wind tunnel with the airfoil inside it tightly, and now making sure not to knock over the pressure taps with the fluid inside them. Sources of error again would be due to human perception in the angle of attack and now a protractor was used for the solution. There was no calibration to be done this time. The pressure taps were connected to the upper surface, and we all played roles in the experiment. We did not have to take the dynamic pressure again since we did it in the force balance part. Steven set up the wind tunnel again, I recorded results again while Emanuel read off the height measurements from the manometer bank. Steven set the angle of attack to 3 degrees, sealed the tunnel tightly, and then turned on the wind tunnel. Emanuel read the height off the atmospheric pressure tap and the heights of the other 9 pressure taps. I recorded all of them down. We repeated this process for the angle of attack of 6,9,12 and 15 degrees. Then we moved on the negative angles of attack with the same magnitude, this was still on the upper surface, but since the angles of attack were negative it yielded the same results we would get if the angles were positive and the taps were connected to the lower surface. Sometimes Emanuel had to double check the manometer to see if there was a change, or if he read it wrong. I sent all the recorded results to our group by email, and then we helped disconnect the pressure taps from the wind tunnel. We also set the wind tunnel back to its original condition.

IV. Results/Analysis/Uncertainty/Discussion

Force Balance Lab

1)

U(m/s)	Reynolds Number	q(Pa)	p(kg/m^3)	c(m)	u(Ns/m^2)	v(m^2/s)
22.821	143232.5598	319	1.225	0.1016	1.983*10^-5	15.11*10^-6

2)

Angle of Attack(degrees)	Lift(N)	Drag(N)
0	0.058791	0.324401
2	1.014763	0.301873
4	1.632231	0.317049
6	2.27912	0.37373
8	2.687502	0.437192
9	2.892759	0.472506
10	2.815694	0.462087
11	2.845584	1.586821
12	2.742648	1.771811
13	2.526287	2.045438
14	2.42879	2.264994
15	2.32972	2.40695

3)

AoA(degrees)	L'(N/m)	D'(N/m)	cl	cdu
0	0.192885	1.064308	0.005951	0.032838
2	3.329277	0.990397	0.102722	0.030558
4	5.35509	1.040187	0.165228	0.032094
6	7.477427	1.22615	0.230711	0.037832
8	8.817263	1.434355	0.27205	0.044256
9	9.490678	1.550216	0.292828	0.047831
10	9.23784	1.516035	0.285027	0.046776
11	9.335905	5.206106	0.288053	0.160631
12	8.99819	5.813029	0.277633	0.179357
13	8.288344	6.710754	0.255731	0.207056
14	7.968472	7.431082	0.245862	0.229281
15	7.643439	7.896819	0.235833	0.243651

4)

Esb	0.009333313

AoA(degrees)	Ewb	Eb	cd
0	0.005473	0.014806	0.03159
2	0.005093	0.014426	0.029418
4	0.005349	0.014682	0.030881
6	0.006305	0.015638	0.036334
8	0.007376	0.016709	0.042414
9	0.007972	0.017305	0.045786
10	0.007796	0.017129	0.044792
11	0.026772	0.036105	0.148234
12	0.029893	0.039226	0.164523
13	0.034509	0.043842	0.188254
14	0.038213	0.047547	0.20699
15	0.040608	0.049942	0.21896

Pressure Survey Lab

1)

U(m/s)	Reynolds Number	q(Pa)	p(kg/m^3)	c(m)	u(Ns/m^2)	v(m^2/s)
22.821	143232.5598	319	1.225	0.1016	1.983*10^-5	15.11*10^-6

2)

A	cP1	cP2	cP3	cP4	Cp5	Cp6	CP7	Cp8	CP9
3	-2.84496	-2.59095	-2.38774	-2.26073	-2.13372	-2.08292	-2.00671	-1.87971	-1.7781
6	-3.81022	-3.37839	-2.61635	-2.46394	-2.33693	-2.15912	-2.05752	-1.95591	-1.85431
9	-4.52146	-3.5308	-2.79416	-2.48934	-2.28613	-2.23533	-1.95591	-1.85431	-1.7273
12	-2.46394	-2.48934	-2.48934	-2.56555	-2.59095	-2.56555	-2.51474	-2.48934	-2.46394
15	-2.33693	-2.36233	-2.36233	-2.38774	-2.41314	-2.46394	-2.54014	-2.59095	-2.59095
-3	-1.42248	-1.6765	-1.98131	-2.00671	-2.00671	-2.00671	-2.00671	-1.95591	-1.93051
-6	-1.04146	-1.52409	-1.7781	-1.85431	-1.93051	-1.93051	-1.98131	-1.95591	-1.95591
-9	-0.53343	-0.99066	-1.29547	-1.42248	-1.52409	-1.54949	-1.60029	-1.62569	-1.65109
-12	-0.71124	-1.14306	-1.42248	-1.54949	-1.65109	-1.7019	-1.7781	-1.8289	-1.90511
-15	-0.60963	-1.04146	-1.32087	-1.49869	-1.60029	-1.6765	-1.7781	-1.8289	-1.93051

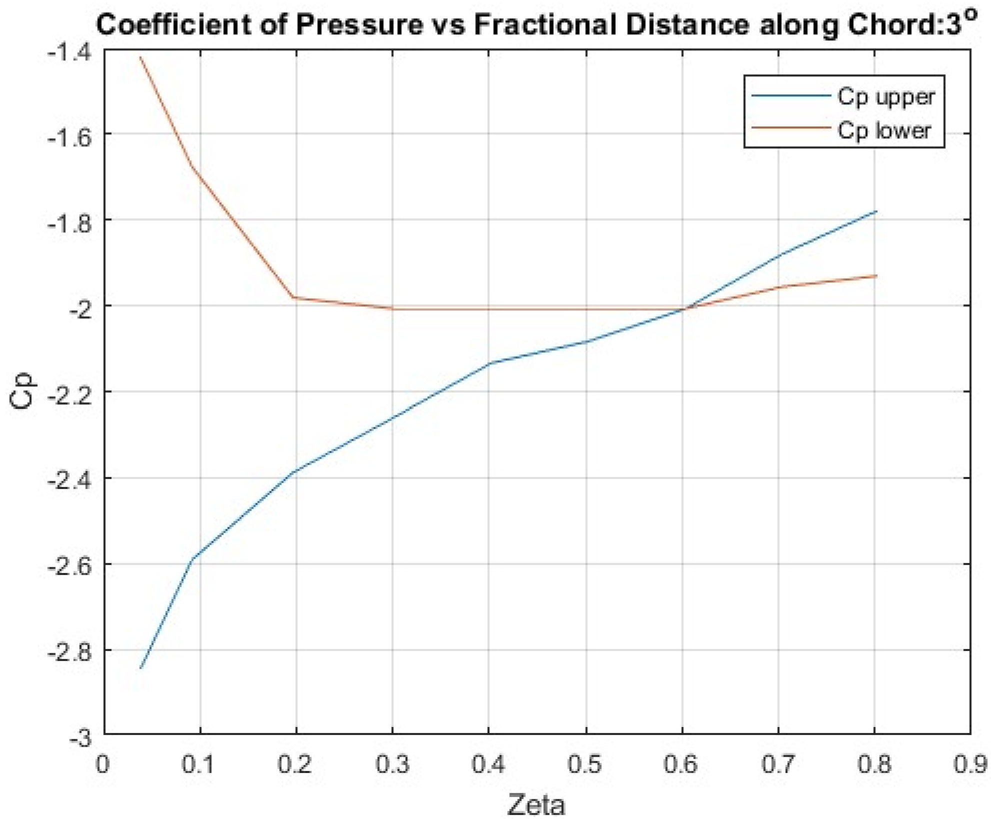
AoA(degrees)	Cf	Cmle
3	0.184	-0.0219
6	0.4371	-0.081
9	0.7814	-0.1926
12	0.7184	-0.2601
15	0.6971	-0.2591

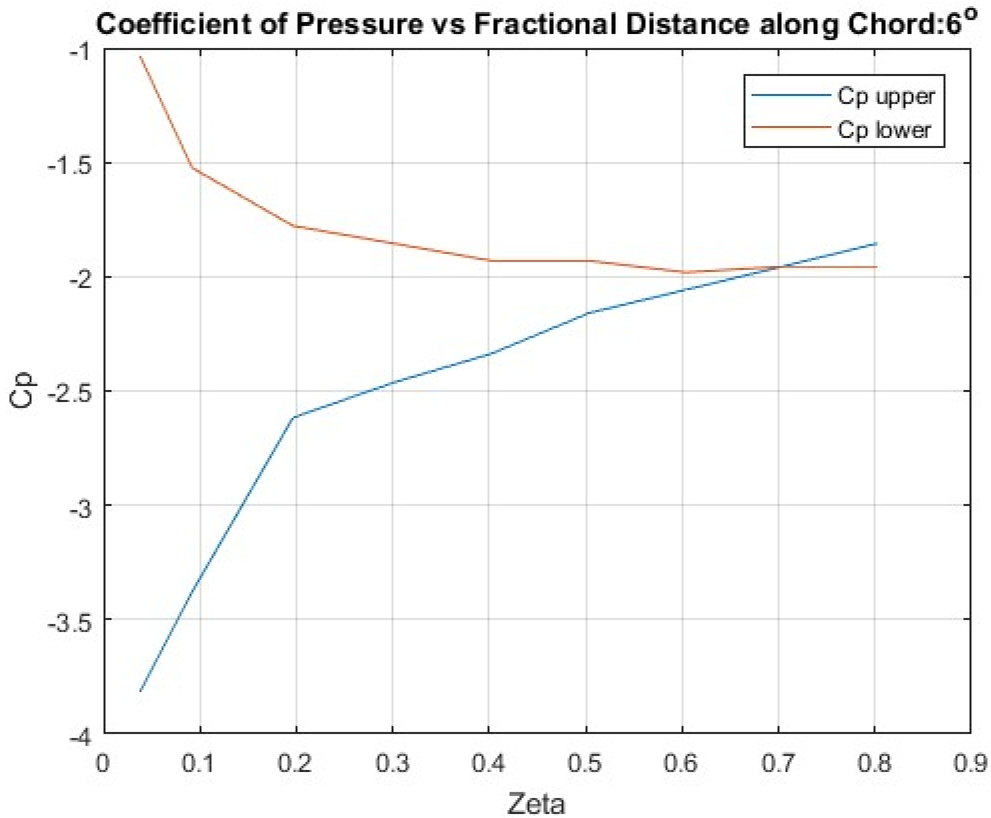
AoA(degrees)	Cl
3	0.183757
6	0.434741
9	0.77175
12	0.702689
15	0.673375

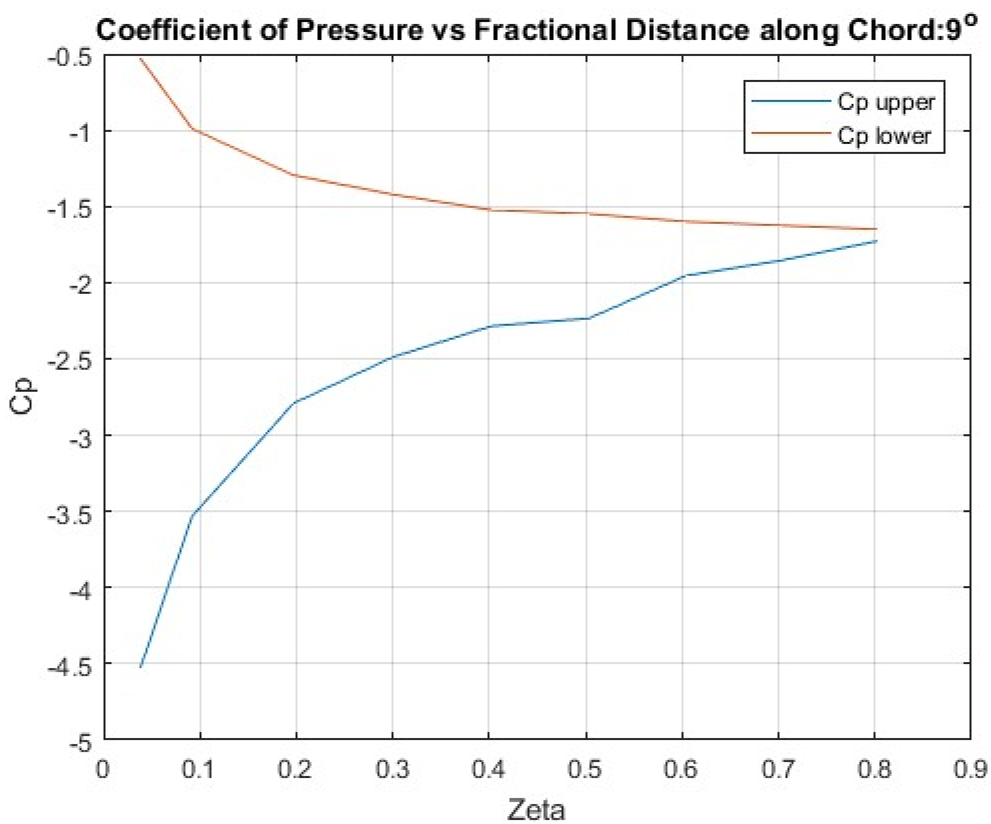
3)

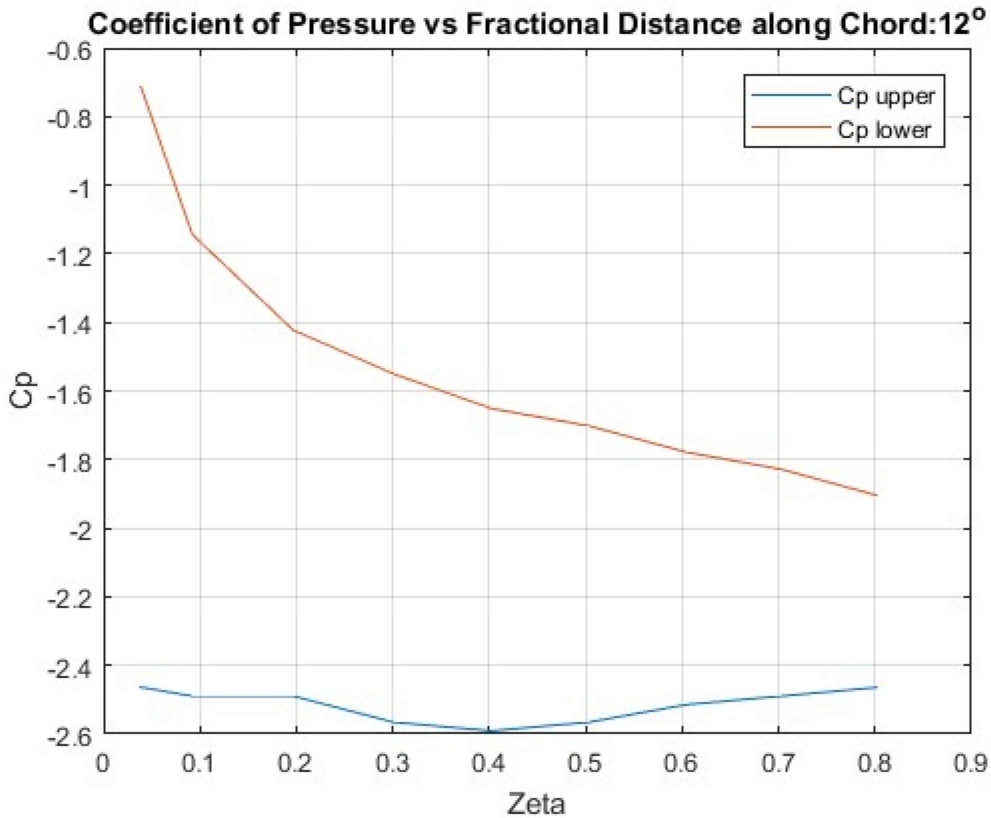
AoA(degrees)	Ecp
3	0.119017
6	0.18538
9	0.246519
12	0.362004
15	0.37161

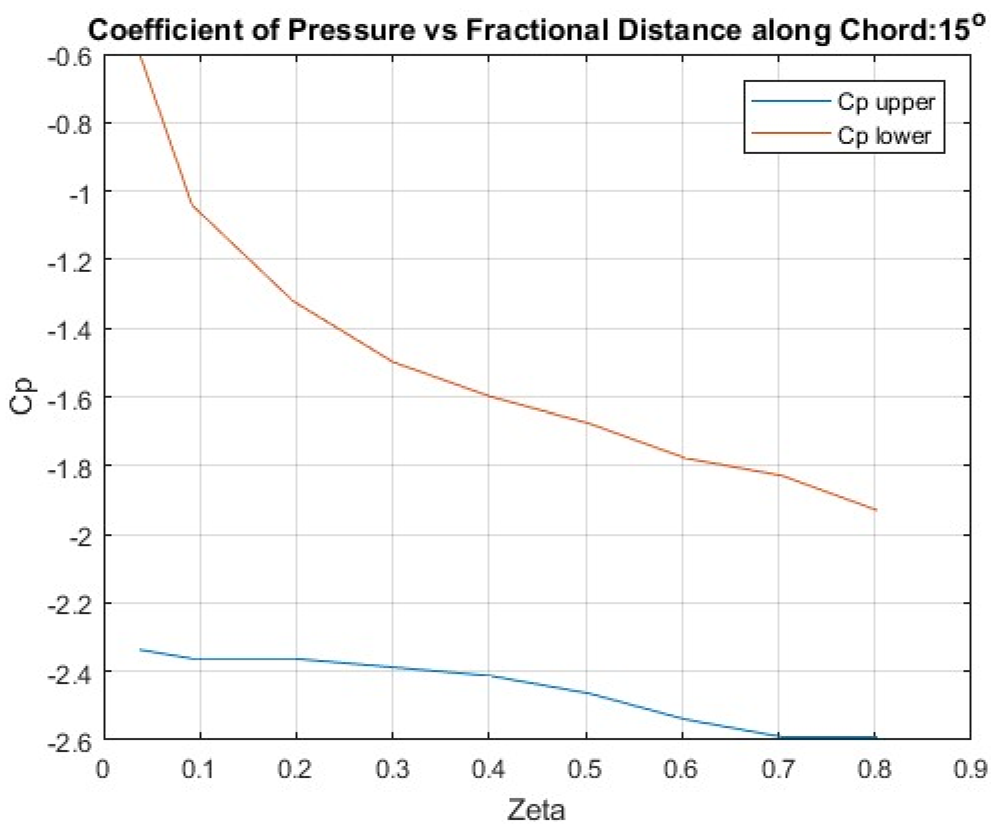
4)




Coefficient of Pressure vs Fractional Distance along Chord:6°
Cp upper
Cp lower
Cp
Zeta
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

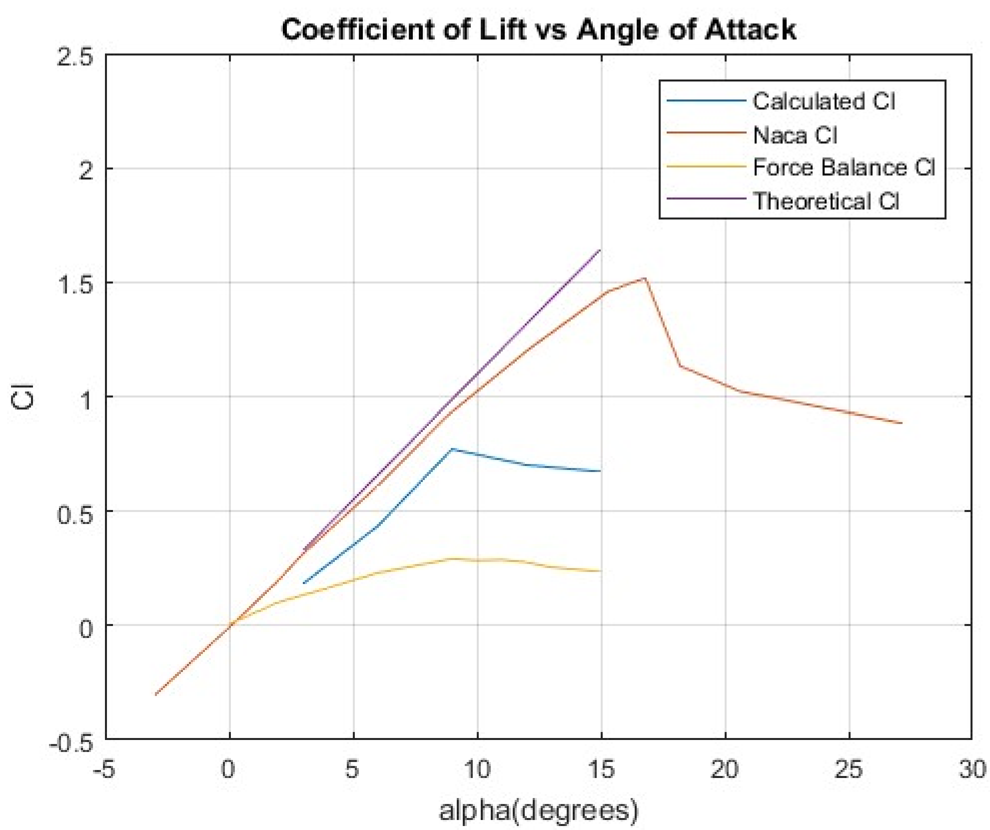

Coefficient of Pressure vs Fractional Distance along Chord:9°
Cp upper
Cp lower
Cp
Zeta
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


Coefficient of Pressure vs Fractional Distance along Chord:12°
Cp upper
Cp lower
Cp
Zeta
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
-2.6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


Coefficient of Pressure vs Fractional Distance along Chord:15°
Cp upper
Cp lower
Cp
Zeta
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
-2.6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

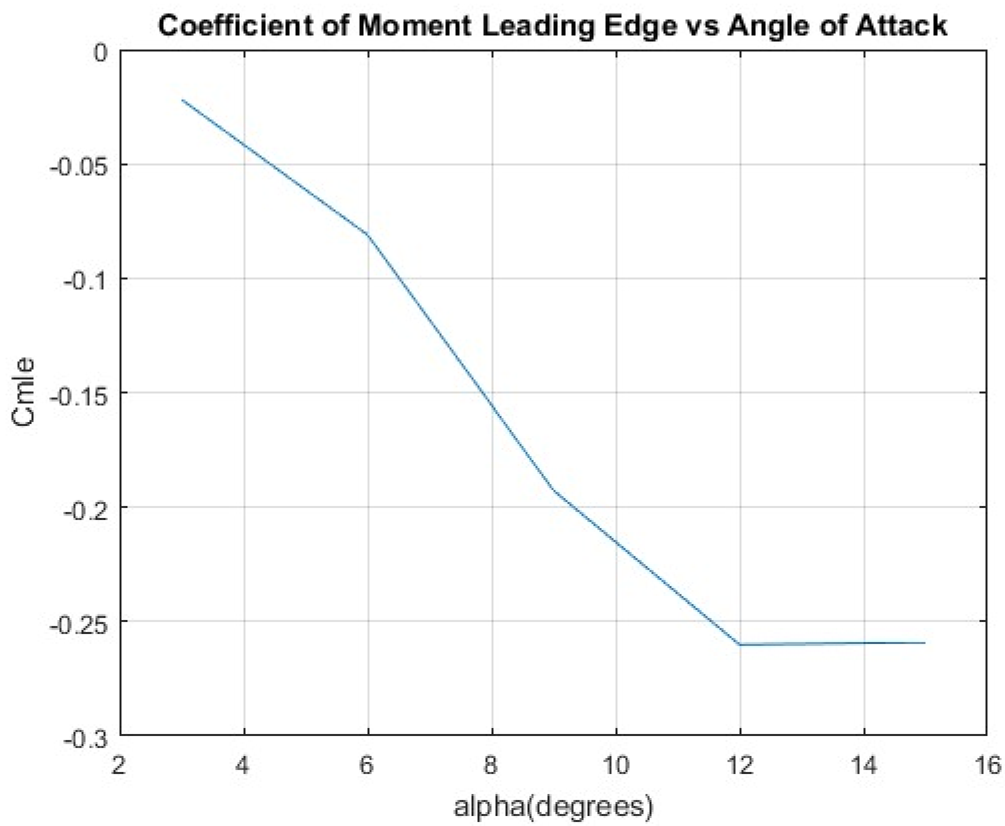
4a) Most of the plots for coefficient of lower and upper pressures versus the fractional distance along the chord have the coefficient of the lower pressure being larger than the coefficient of the upper pressure. This signifies that the Pressure on the lower surface is larger than the pressure on the upper surface which means that the coefficient of lift is positive. This makes sense for those angle of attacks for which it applies to, especially if they are lower than high angle of attacks which would cause stall and a decrease in Lift. The plots also show that the coefficient of pressures are negative which makes sense since having positive coefficient of pressures more than one would indicate going over the stagnation pressure. The reason that the pressure readings for the lower surface on a symmetrical airfoil at a positive angle of attack may be obtained from the readings of taps on the upper surface when the airfoil is at a negative angle of attack is because the force will be equal on both sides, and that's because the flow over the airfoil will act the same for either positive or negative angle of attack due to the symmetry of the airfoil. If the data was from a negative angle of attack the curves would be flipped across the x axis, so they would look the same but would now be positive.

5)



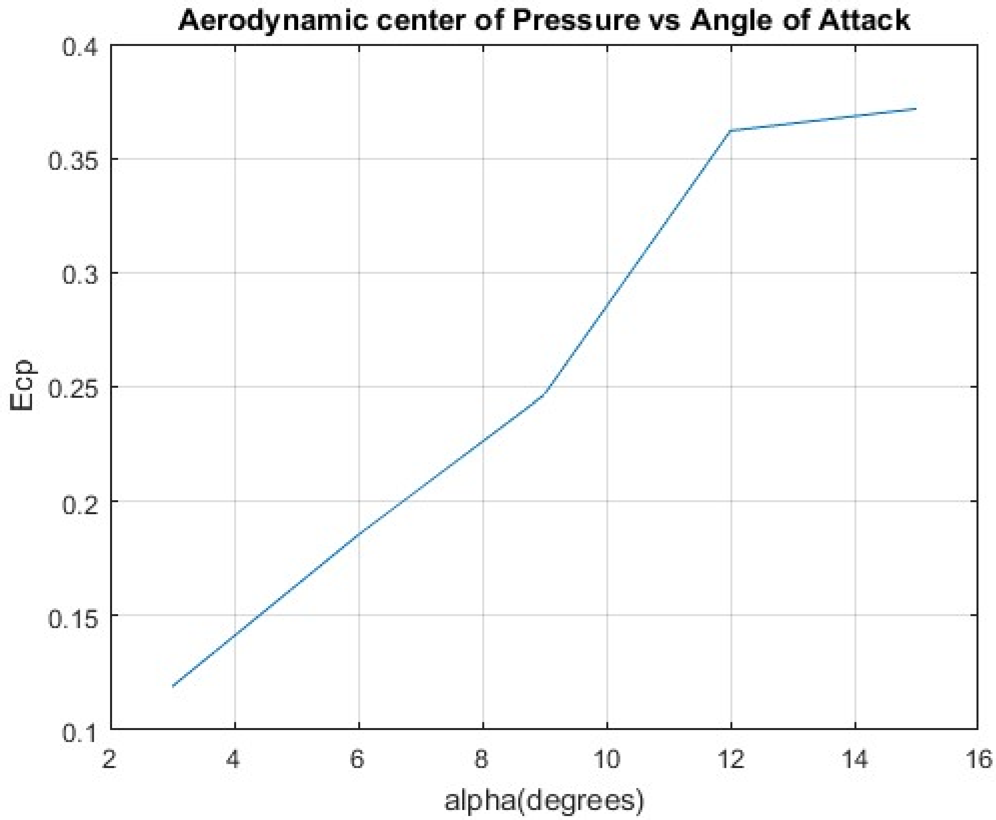
5c) The calculated coefficient of lift curves are closer to the published NACA coefficient of Lift curve than the theoretical prediction coefficient of lift. The coefficient of Lift curve for the Pressure survey lab was much closer to the published and theoretical results than the Force Balance coefficient of lift curve. All curves seem to have similar trends except for the theoretical curve. The stall seems to occur at a lower angle of attack for the pressure survey coefficient of lift and the force balance coefficient of lift compared to the published results.

6)



6a) The significance of the sign of the curves slope determines whether the airfoil is stable or not, since the sign of the coefficient of the moment about the leading edge is negative, the airfoil is stable.

7)



7a) The theoretical result of the aerodynamic center for a thin airfoil would be the quarter of the chord, the quarter of the chord would be the center of pressure for a thin airfoil, and would therefore equal the aerodynamic center. The aerodynamic center would be 0.25, since that's a quarter of the chord, there is a change in slope near the center of the pressure that is 0.25 indicating stall after that point. So the plots center of pressures do seem to agree with the fact that for a thin airfoil the aerodynamic center would be 0.25.

Appendix

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%MAE 339 Lab Airfoil Lift and Drag
%Andy Perez
Cp1=[1.422480752;0.914451912;0.406423072;0.25401442;0.12700721;0.076204326;0;-0.076204326;-
0.152408652];
Cp2=[2.768757179;1.854305266;0.838247586;0.609634608;0.406423072;0.228612978;0.076204326;0;-
0.101605768];
Cp3=[3.988026395;2.540144201;1.498685078;1.066860564;0.76204326;0.685838934;0.355620188;0.2286129
78;0.076204326];
Cp4=[1.752699498;1.346276426;1.066860564;1.01605768;0.939853354;0.863649028;0.736641818;0.6604374
92;0.558831724];
Cp5=[1.727298056;1.320874984;1.041459122;0.88905047;0.812846144;0.787444702;0.76204326;0.76204326
;0.660437492];

E=[0.0386;0.0919;0.1966;0.3002;0.4021;0.5033;0.6038;0.7036;0.8029];


Cf1=trapz(E,Cp1);
Cf2=trapz(E,Cp2);
Cf3=trapz(E,Cp3);
Cf4=trapz(E,Cp4);
Cf5=trapz(E,Cp5);


Cm1=trapz(E,-E.*Cp1);
Cm2=trapz(E,-E.*Cp2);
Cm3=trapz(E,-E.*Cp3);
Cm4=trapz(E,-E.*Cp4);
Cm5=trapz(E,-E.*Cp5);

Cl1=Cf1*cosd(3);
Cl2=Cf2*cosd(6);
Cl3=Cf3*cosd(9);
Cl4=Cf4*cosd(12);
Cl5=Cf5*cosd(15);

Ecp1=-Cm1/Cf1;
Ecp2=-Cm2/Cf2;
Ecp3=-Cm3/Cf3;
Ecp4=-Cm4/Cf4;
Ecp5=-Cm5/Cf5;

Cpu1=-[2.844961505;   2.590947085;   2.387735549;   2.260728339;   2.133721129;   2.082918245;
       2.006713918;   1.879706708;   1.77810094];
Cpu2=-[3.810216301;   3.378391787;   2.616348527;   2.463939875;   2.336932665;   2.159122571;
       2.057516803;   1.955911034;   1.854305266];
Cpu3=-[4.521456677;   3.530800439;   2.794158621;   2.489341317;   2.286129781;   2.235326897;
       1.955911034;   1.854305266;   1.727298056];
Cpu4=-[2.463939875;   2.489341317;   2.489341317;   2.565545643;   2.590947085;   2.565545643;
       2.514742759;   2.489341317;   2.463939875];
Cpu5=-[2.336932665;   2.362334107;   2.362334107;   2.387735549;   2.413136991;   2.463939875;
```

```
       2.540144201;   2.590947085;   2.590947085];
Cpl1=-[1.422480752;   1.676495172;   1.981312476;   2.006713918;   2.006713918;   2.006713918;
       2.006713918;   1.955911034;   1.930509592];
Cpl2=-[1.041459122;   1.52408652;       1.77810094;          1.854305266;      1.930509592;
       1.930509592;   1.981312476;   1.955911034;   1.955911034];
Cpl3=-[0.533430282;   0.990656238;   1.295473542;   1.422480752;   1.52408652;
1.549487962;   1.600290846;   1.625692288;   1.65109373];
Cpl4=-[0.711240376;   1.14306489;       1.422480752;      1.549487962;   1.65109373;
1.701896614;   1.77810094;       1.828903824;      1.90510815];
Cpl5=-[0.609634608;   1.041459122;   1.320874984;   1.498685078;   1.600290846;   1.676495172;
       1.77810094;       1.828903824;      1.930509592];


figure
plot(E,Cpu1,E,Cpl1)
title('Coefficient of Pressure vs Fractional Distance along Chord:3^o')
xlabel('Zeta')
ylabel('Cp')
legend('Cp upper','Cp lower')
grid on;

figure
plot(E,Cpu2,E,Cpl2)
title('Coefficient of Pressure vs Fractional Distance along Chord:6^o')
xlabel('Zeta')
ylabel('Cp')
legend('Cp upper','Cp lower')
grid on;

figure
plot(E,Cpu3,E,Cpl3)
title('Coefficient of Pressure vs Fractional Distance along Chord:9^o')
xlabel('Zeta')
ylabel('Cp')
legend('Cp upper','Cp lower')
grid on;

figure
plot(E,Cpu4,E,Cpl4)
title('Coefficient of Pressure vs Fractional Distance along Chord:12^o')
xlabel('Zeta')
ylabel('Cp')
%ylim([0.5 3])
legend('Cp upper','Cp lower')
grid on;

figure
plot(E,Cpu5,E,Cpl5)
title('Coefficient of Pressure vs Fractional Distance along Chord:15^o')
xlabel('Zeta')
ylabel('Cp')
%ylim([0.5 3])
legend('Cp upper','Cp lower')
```

```
grid on;

CL=[Cl1;Cl2;Cl3;Cl4;Cl5];
alpha=[3;6;9;12;15];
alpha2=[-2.9521;0.138;2.0496;2.9303;6.0206;8.8127;12.1;15.3;16.8;18.2;20.6;27.2];
CLtwo=[-0.3;0.00395;0.204;0.308;0.613;0.917;1.2065;1.4591;1.5187;1.1338;1.0232;0.884];
alpha3=[0;2;4;6;8;9;10;11;12;13;14;15];
CLthree=[0.005951345;0.102722476;0.165227525;0.230710742;0.272050428;0.292828178;0.285027022;0.28
8052744;0.277632787;0.255731015;0.245861589;0.235832907];
Clfour=2*pi*alpha*pi/180;

figure
plot(alpha,CL,alpha2,CLtwo,alpha3,CLthree,alpha,Clfour)
title('Coefficient of Lift vs Angle of Attack')
xlabel('alpha(degrees)')
ylabel('Cl')
ylim([-0.5 2.5])
legend('Calculated Cl','Naca Cl','Force Balance Cl','Theoretical Cl')
grid on;

Cmle=[Cm1;Cm2;Cm3;Cm4;Cm5];
figure
plot(alpha,Cmle)
title('Coefficient of Moment Leading Edge vs Angle of Attack')
xlabel('alpha(degrees)')
ylabel('Cmle')
grid on;

ECP=[Ecp1;Ecp2;Ecp3;Ecp4;Ecp5];
figure
plot(alpha,ECP)
title('Aerodynamic center of Pressure vs Angle of Attack')
xlabel('alpha(degrees)')
ylabel('Ecp')
grid on;
```

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