Aerodynamic Performance of Airfoils

Thermal Fluids and Energy
Systems Lab

(ME EN 4650)

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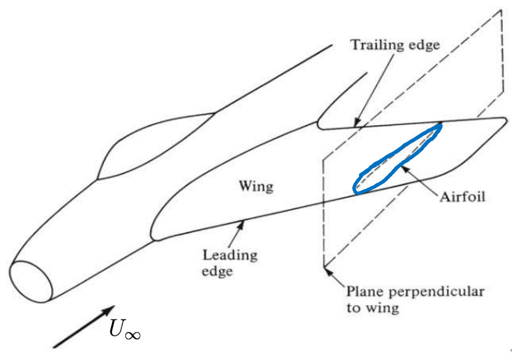
Aerodynamic Performance of Airfoils

What we want to know:

→ lift & drag coefficient vs angle of attack and Reynolds number
→ static pressure distribution vs x



What we can measure:

→ lift & drag forces (load balance)
→ pressure (pressure taps)
→ dynamic pressure (Pitot-static tube & pressure transducer)

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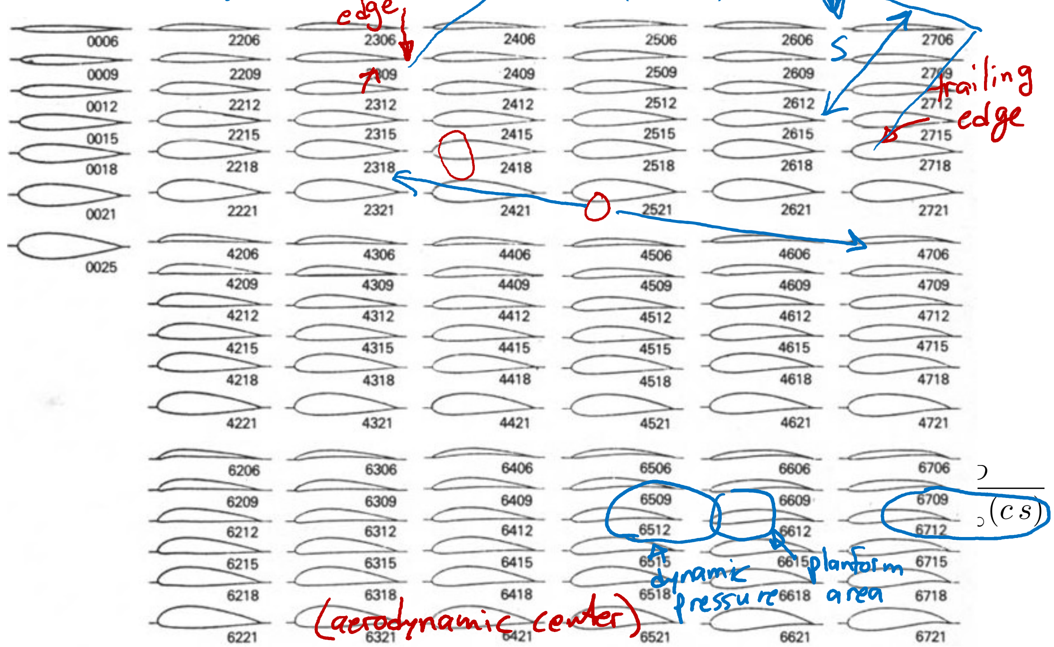
Lecture Outline

- Background (Aerodynamics)
- Experimental Setup
- Measurements and Instrumentation
- Required Figures
- Data Analysis (Coefficients & Uncertainty)

Airfoil Geometry and Terminology

National Advisory Committee for Aeronautics (NACA) Airfoils, 1920-1958



$(c\,s)$

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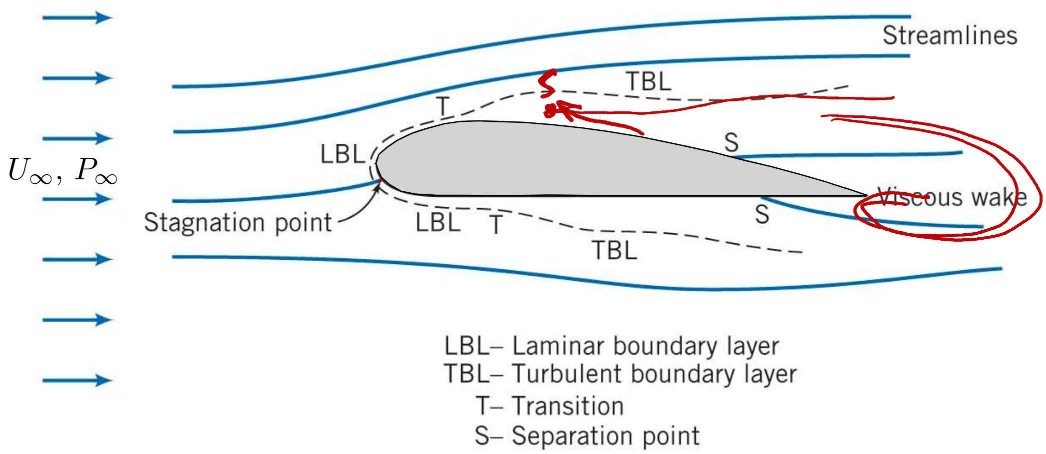
Flow around an Airfoil



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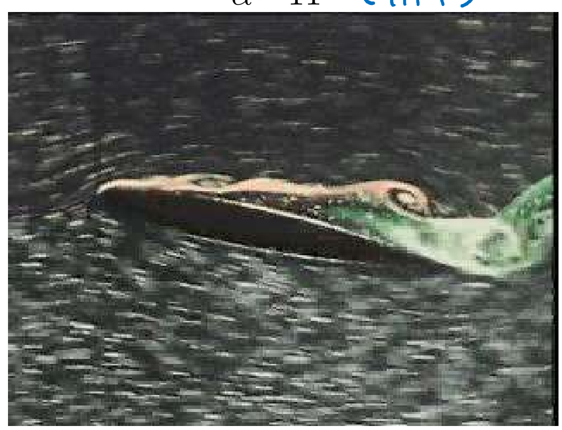
Flow Visualization

$\alpha = 0°$ (no lift)

Symmetric airfoil

$\alpha = 11°$ (max lift)



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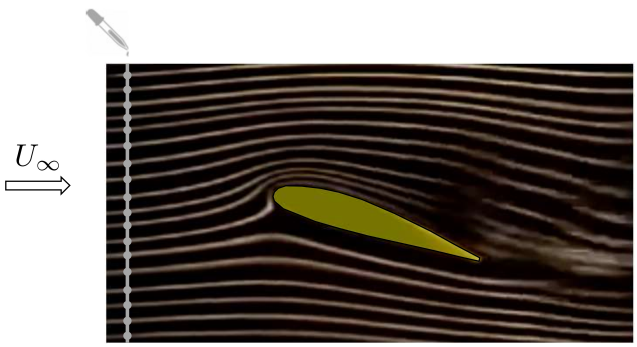
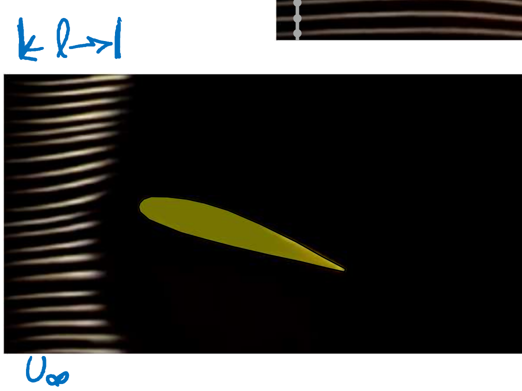
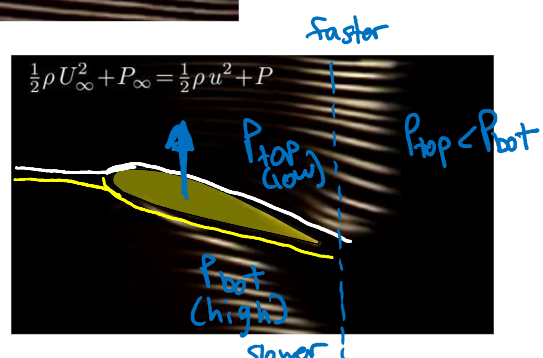
Generation of Lift







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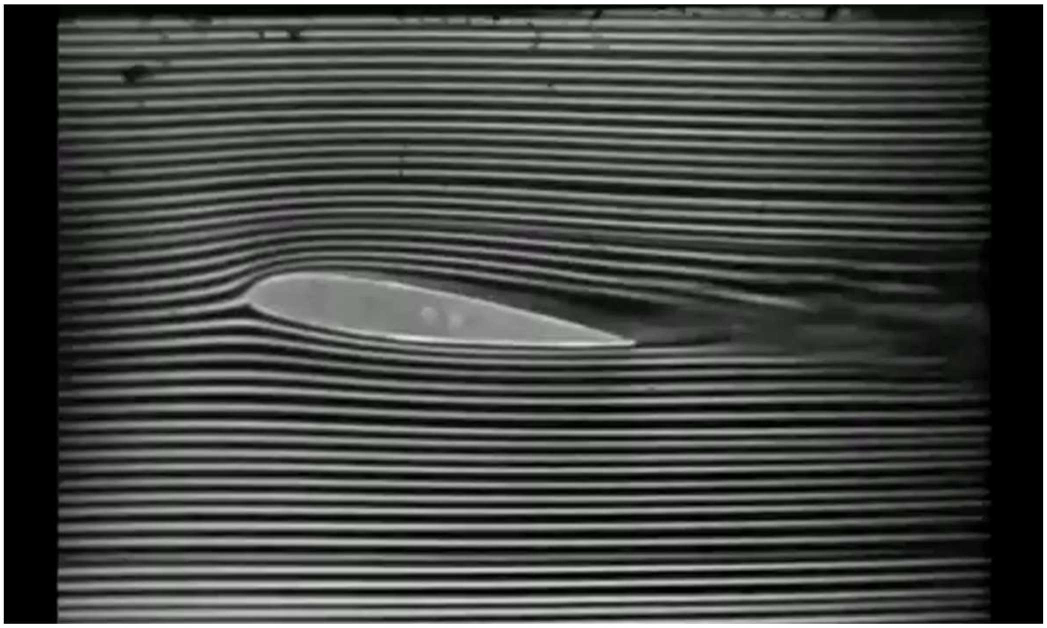
Flow Visualization: Stall



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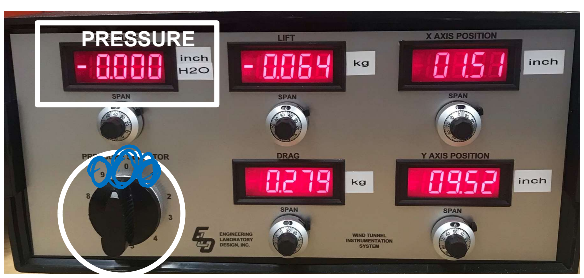
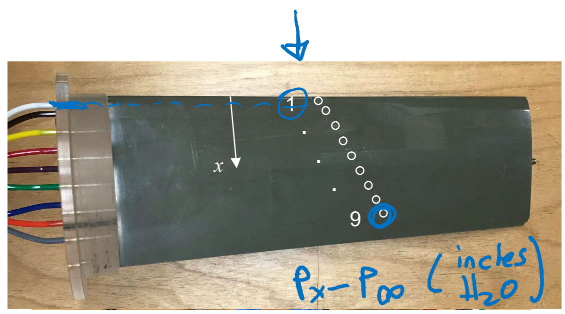
Measurements

Quantity	Symbol	Units	Instrument
Static pressure on airfoil	$P_x - P_\infty$	in H_2O	surface taps on airfoil
lift + drag forces	$F_L,\ F_D$	kg	Lift/drag balance
Freestream dynamic pressure	$\frac{1}{2}\,\rho U_\infty^2$	in H_2O	Pitot-static probe





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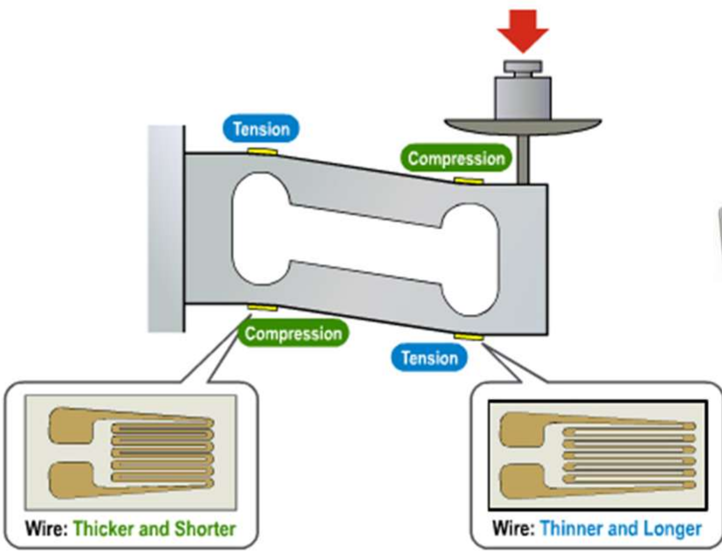
Measuring Airfoil Lift/Drag

Strain Gauge Load Cell



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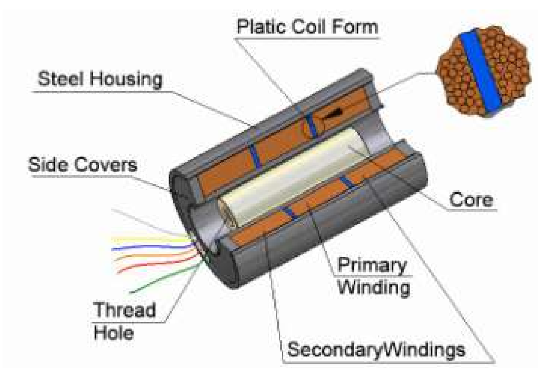
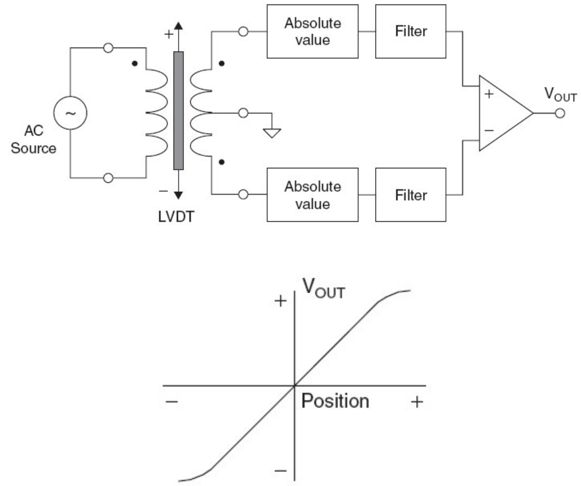
Measuring Airfoil Lift/Drag

LVDT (Linear Variable Displacement Transducer)





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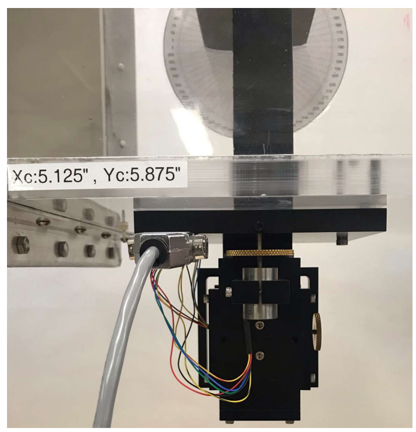
Measuring Airfoil Lift/Drag



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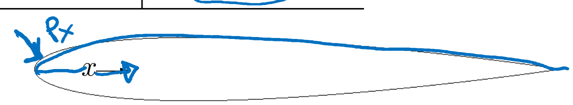
Experiments

Parameter	Symbol	Value
airfoil	—	NACA 0012
freestream velocity	U_∞	$\sim$25 m/s
chord length	c	4 in
max thickness	t	0.48 in
span length	s	12 in
chord Reynolds number	Re_c	$\sim 1.5 \times 10^5$
angle of attack	α	0°–16°

$\frac{t}{c} \simeq 12\%$

symmetric



Experiment 1:

- Measure F_D & F_L versus α

Experiment 2:

- Measure $P_x - P_\infty$ versus x (top and bottom surfaces)

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Aerodynamic Performance of Airfoils: Part II

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Quantities of Interest (Required Figures)

- C_L vs α (data w/ errorbars + $\underbrace{\text{published results}}_{1\times10^4 \leq Re_c \leq 5\times10^6}$*)

- C_D vs α (data w/ errorbars + published results*)

- i. C_p vs x at $\alpha \approx 5^\circ$ (top and bottom surfaces)
  ii. C_p vs x at $\alpha \approx 12^\circ$ (top and bottom surfaces)

*R. Sheldahl and P. Klimas, SAND80-2114 (1981)

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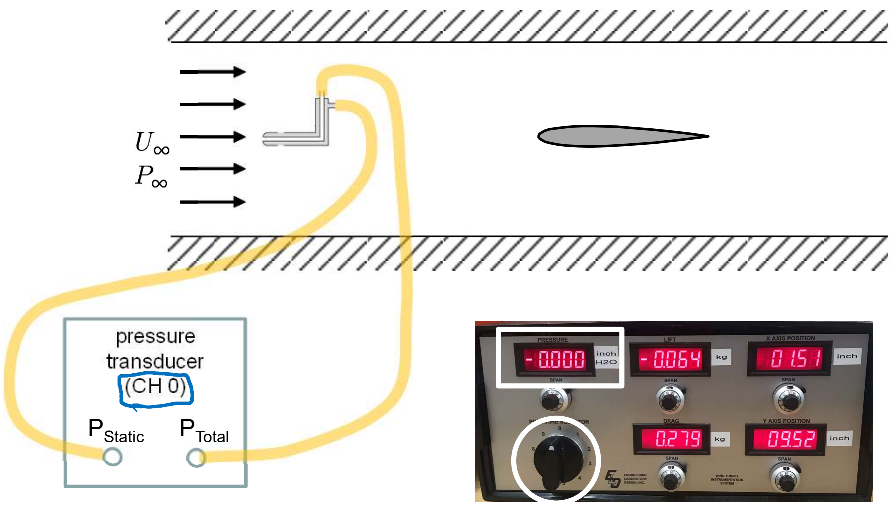
Dynamic Pressure



$$\text{output:}\ \Delta P = P_{\text{Total}} - P_{\text{Static}}$$

$$\Delta P = \underbrace{\tfrac{1}{2}\rho U_\infty^2}_{\text{dynamic pressure}}$$

dynamic pressure (in H_2O) ⇒ (Pa)

Post-Processing Raw Data:
Lift & Drag Forces

1. Read in baseline (no flow) data: take average

```
data=readtable('baseline.txt');
L_base=mean(data(:,1));
D_base=mean(data(:,2));
```

2. Create FOR-LOOP: read in lift/drag files at all angles of attack

```
for i=...
    filename=[ . . . ];
    data=readtable(filename);
    L=(data(:,1)-L_base)*g;
    D=(data(:,2)-D_base)*g;

    Lavg(i)=mean(L); Davg(i)=mean(D);
    Lerr(i)=std(L)/sqrt(n); Derr(i)=std(D)/sqrt(n);
end
```

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Post-Processing Raw Data:
Lift & Drag Forces

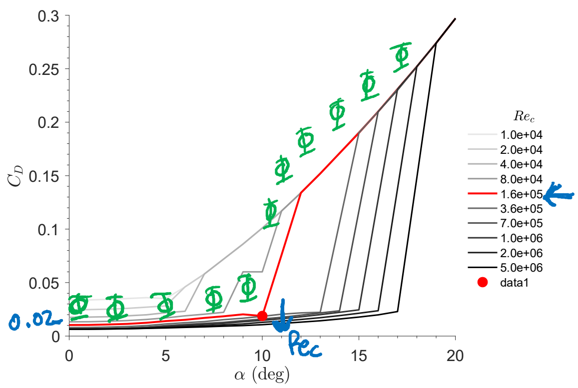
$$C_L = \frac{F_L}{\frac{1}{2}\,\rho\, U_\infty^2\,(c\,s)} \qquad C_D = \frac{F_D}{\frac{1}{2}\,\rho\, U_\infty^2\,(c\,s)}$$

3. Calculate lift and drag coefficients and standard error

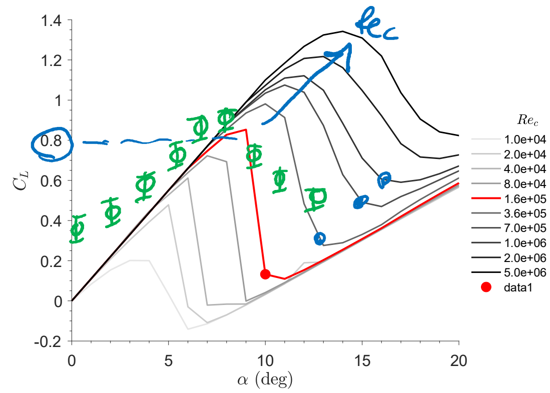
```
CL=Lavg/(Pdyn*c*s);
CD=Davg/(Pdyn*c*s);

CL_err=Lerr/(Pdyn*c*s);
CD_err=Derr/(Pdyn*c*s);
```

Figures 1a & 1b

Drag Coefficient



Lift Coefficient



aerodynamic performance: C_L/C_D

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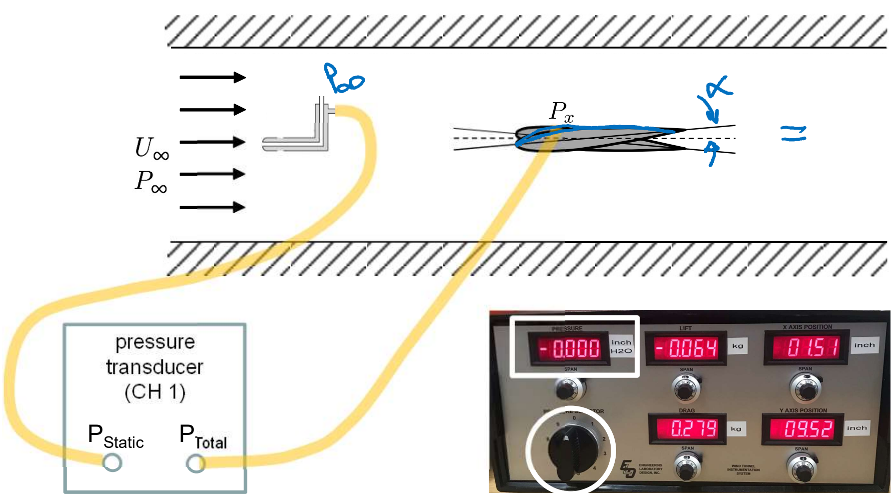
Post-Processing Raw Data:
Airfoil Relative Static Pressure



output: $\Delta P = P_{\text{Total}} - P_{\text{Static}}$

$\Delta P = P_x - P_\infty$

in H_2O → Pa

Coefficient of pressure: $C_p = \dfrac{P_x - P_\infty}{\frac{1}{2}\,\rho\,U_\infty^2}$

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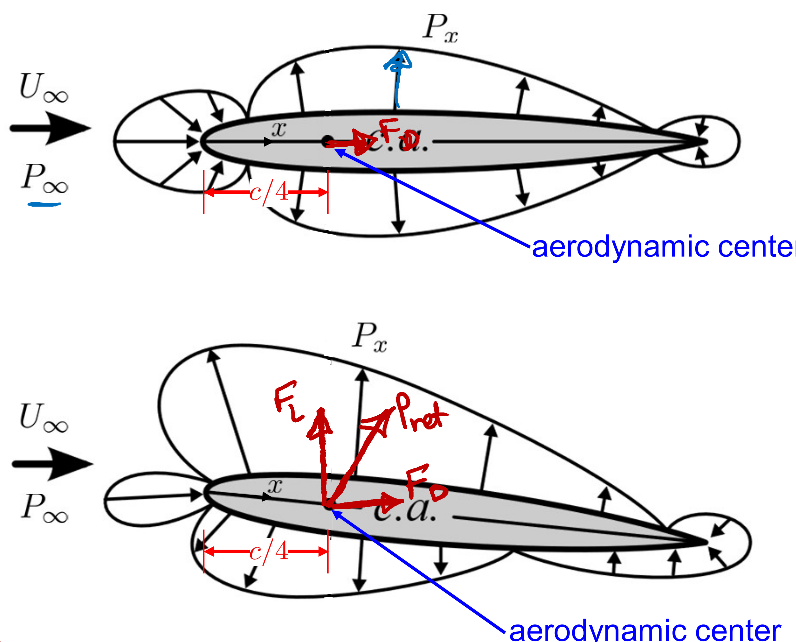
Pressure Distribution Relative to P_∞



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Coefficient of Pressure

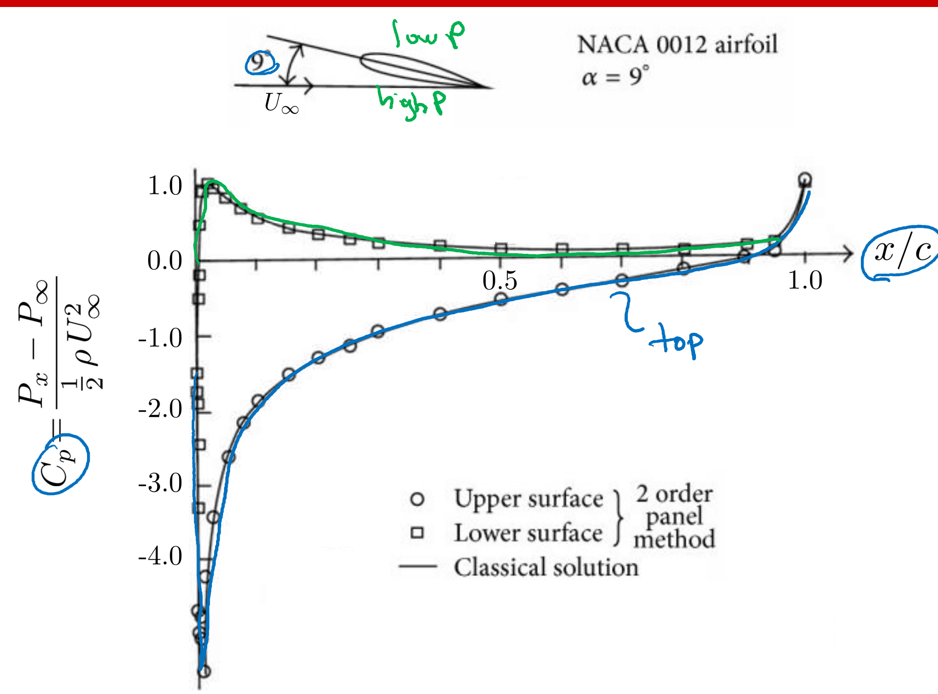
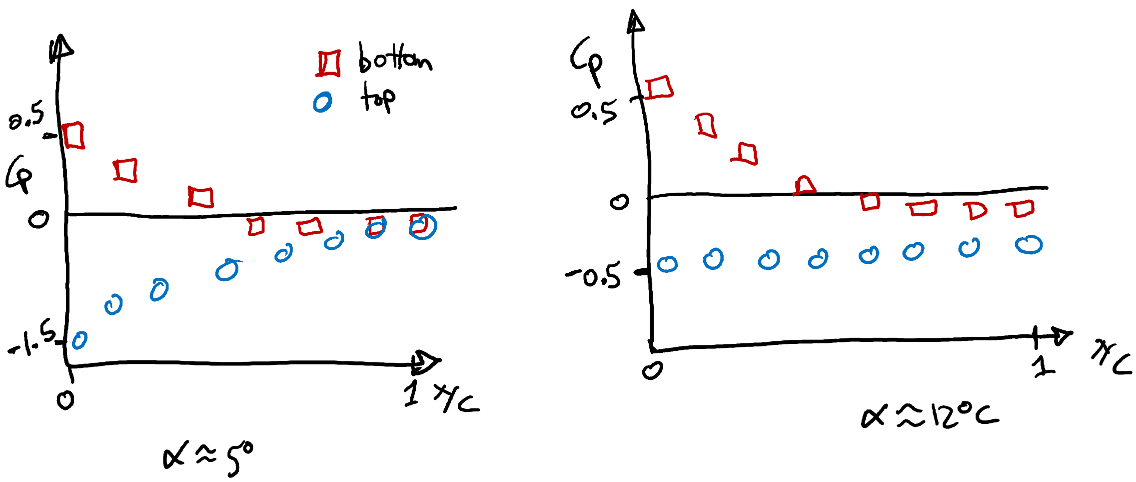


Figure 1c



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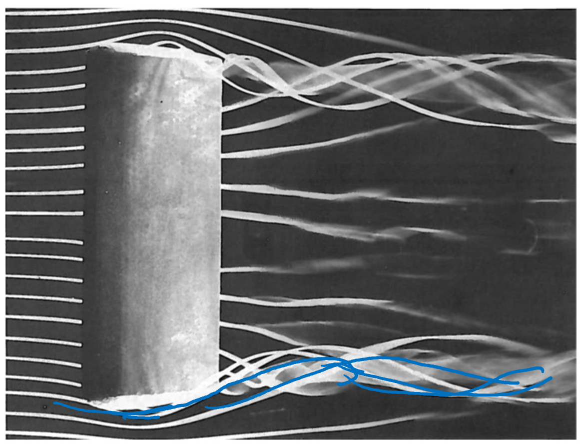
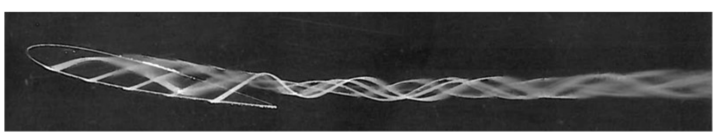
End Effects (3D Airfoils)





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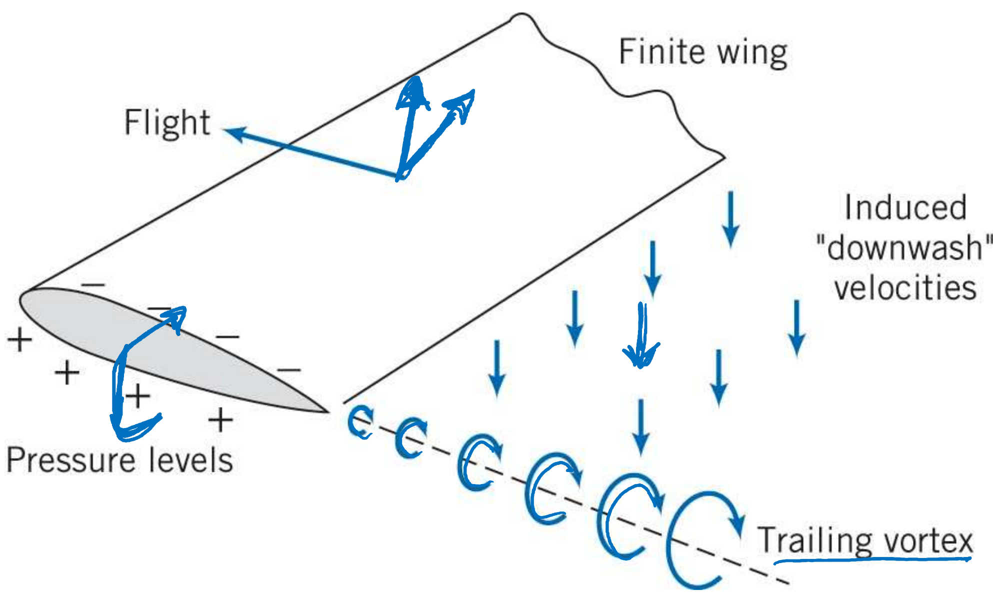
End Effects (3D Airfoils)



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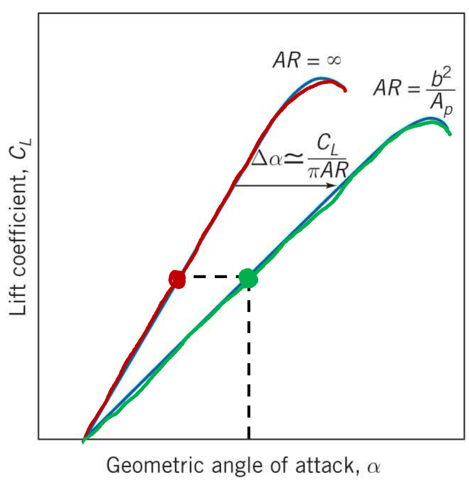
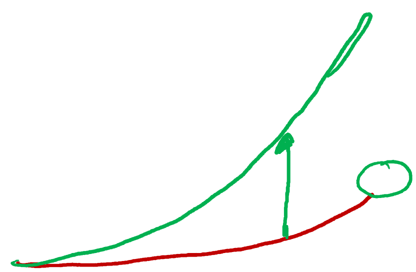
End Effects (3D Airfoils)



reduction of effective
angle of attack



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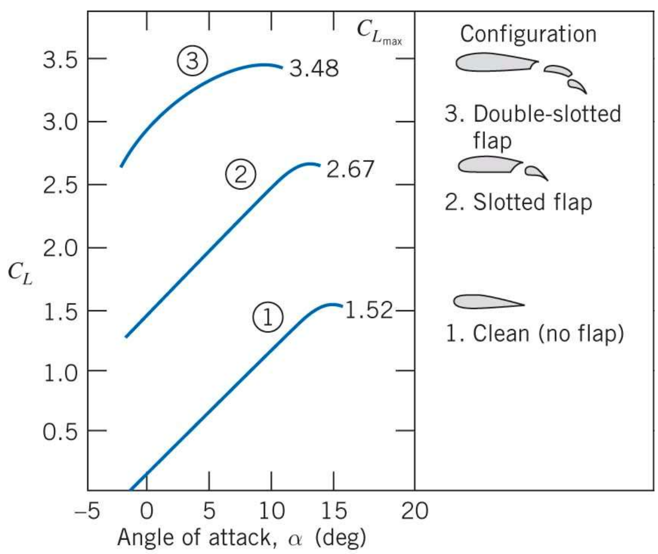
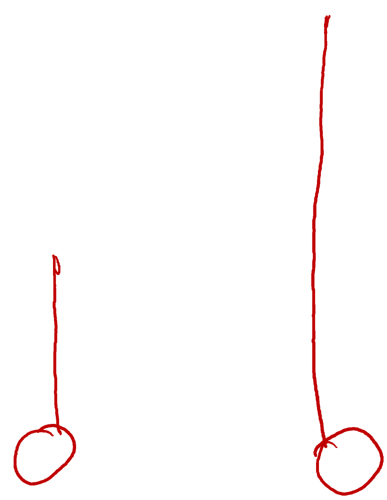
Wing Flaps





3-fold ↑

10-fold ↑

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Questions??

Thank you for your attention!

Let me or the TAs know if you have questions

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