Lecture 18 Notes:

Lect 18 – Goals for today's lecture

1. Drag force for low Re (creeping flow)
2. Intro. To Lift Force
3. How to calculate lift force & factors affecting lift force
4. Relationship between C_D and C_L
5. The concept of stall
6. Role of flaps in changing CD and CL
7. Finite versus infinite wing and the effect on C_D and C_L

Drag Force in Creeping (Stokes') Flow (Re<<1)

When Re<<1

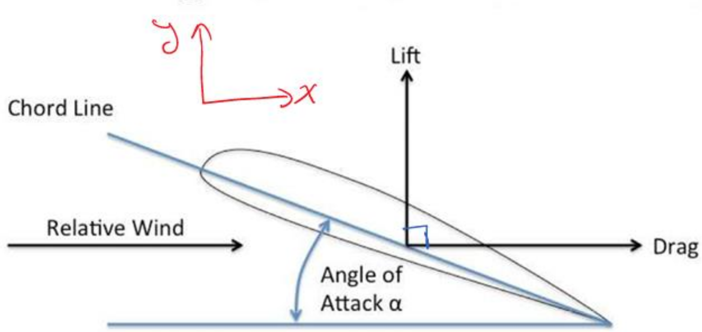
1) Acceleration terms in N.S. Eqs. Are negligible
2) Viscous stream, is dominant→↑ C_D since high τ_{wall}

Momentum eq. simplifies due to 1) as: $\nabla P \approx \mu \nabla^2 V$, $\nabla . \mathrm{V} = 0$ continuity incomp. Fluid
For simple shapes above eqs. Can be solved as they are linear O.D.E's

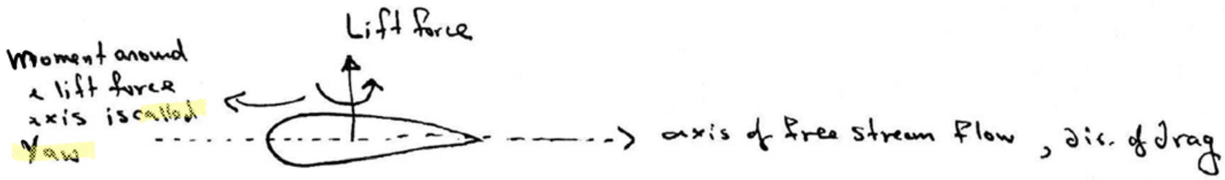
Stokes solves them for a sphere and found C_D theoretically as:
$C_D = \frac{2y}{Re_d}$, d→ dia. Of sphere, C_D→ sphere in creeping flow
Accounts up to $Re \approx 1$
$F_{drag} = C_D = \left(\frac{1}{2}\rho V^2\right) A = 3\pi\mu V$ d→ dia. Of sphere
See problem 7.725

Lift Force:

- Lift force is the force that an object in an external flow experience in the normal direction to the drag force.
- Unlike drag force that is mostly to be avoided (reduction of losses), lift force is a desirable force. Drag is only useful to stop an object. E.g., parachute
- Lift force is usually associated with useful work.
- Note: If lift force is in the negative y direction, sometimes it is called downforce



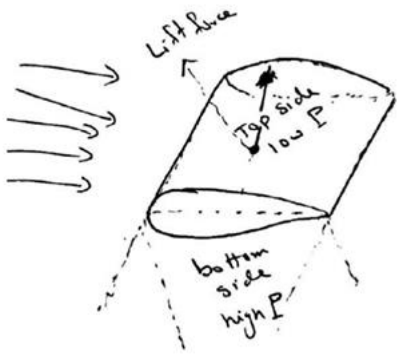
- The lift force allows an airplane to take off and remain afloat in the air or a wind turbine to twirl and produce mechanical work to run a generator.



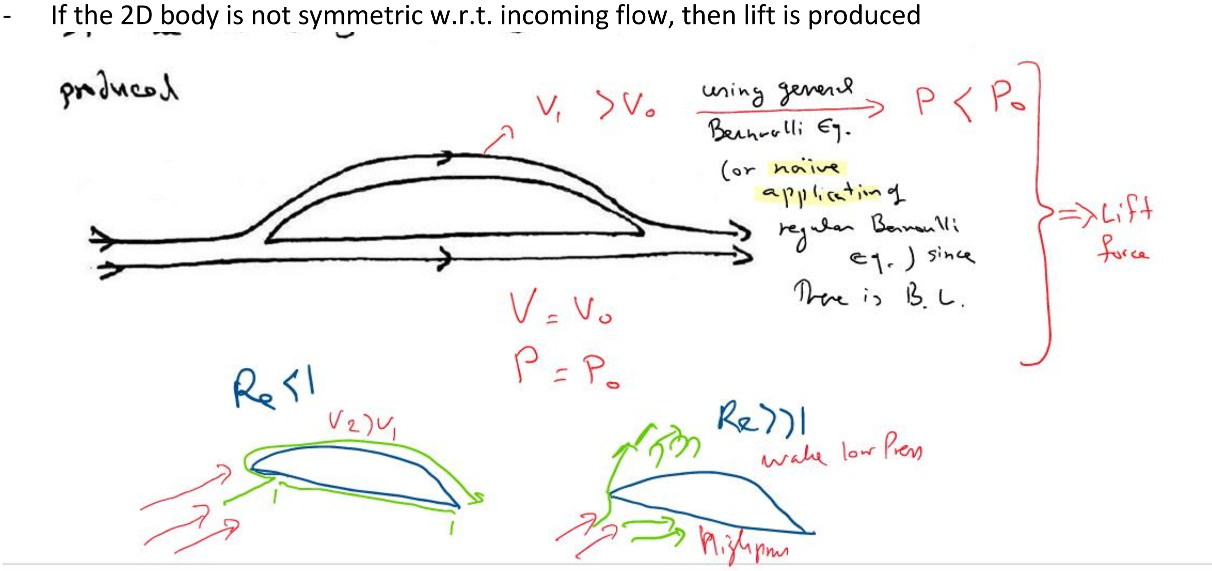
Moment around a lift force axis is called yaw.

Lift Force Resulted from Pressure Differences:

- Lift force is normally produced as a result of pressure differential between two sides of the object w.r.t. the drag force plan
- If the 2D body is symmetric w.r.t. incoming free stream flow no lift is produced as $P_{top}=P_{bottom}$



- If the 2D body is not symmetric w.r.t. incoming flow, then lift is produced



Lift force Calculations:

Lift Force Calculation:

Lift coefficient(C_L) concept is used to calculate Lift Force (L) similar to C_D used for drag force calculations but the area used is diff.

$L = C_L = \left(\frac{1}{2}\rho V^2\right) A_p$ where A_p→ platform(ex. Wing area)

C_L is found by experiments (eg. NACA≡ NASA has a large publicly available values) or by CFD

What affects C_L?

- Re, α, and shape (similar to C_D)
- For airfoils or hydrofoils, there is a sweet spot where C_L is max and C_D is min to produce the max work or performance

  For common airfoils: $20 \leq \frac{C_L}{C_D} \leq 50$

See Figs. 7.24 & 7.25

A pilot usually wants to fly at $1.2V_s$, where V_s→ stall value and α<12°
Recall: The use of flaps were to increase the lift at lower vel. So for ex., stall can be avoided. (stall was significant loss of lift force due to a) redirection of speed b) angle of attach)

Theoretically it can be show that:

1) (C_L Theory)→ $C_L \approx 2\pi \sin\left(\alpha + \frac{2h}{c}\right)$ where α→ deg., 2h→max. combos, c→ chord length (1)

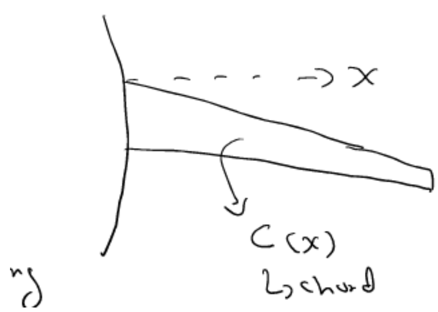
   deg

Stall Vel: $L = W = C_L\left(\frac{1}{2}\rho V^2 A_p\right)$, L→ lift, W→ weight, C_L→ max

$v_s = \left(\frac{2w}{C_L \rho A_p}\right)^{\frac{1}{2}}$, C_L→ max

Two Complicating Factors for Lift Force Calculation:

1) Tapered wing shape



$A_p = \int_0^b c\,dx$ b→ span of wing

2) Finite span

The C_L values in plots are for a 2D airdoil (infinite span)

Aspect Ratio = AR = $\frac{b^2}{A_p}$

AR can come α to increase (effective α')

$\alpha' - \alpha = \Delta\alpha \approx \frac{C_L}{\pi AR}$(2)

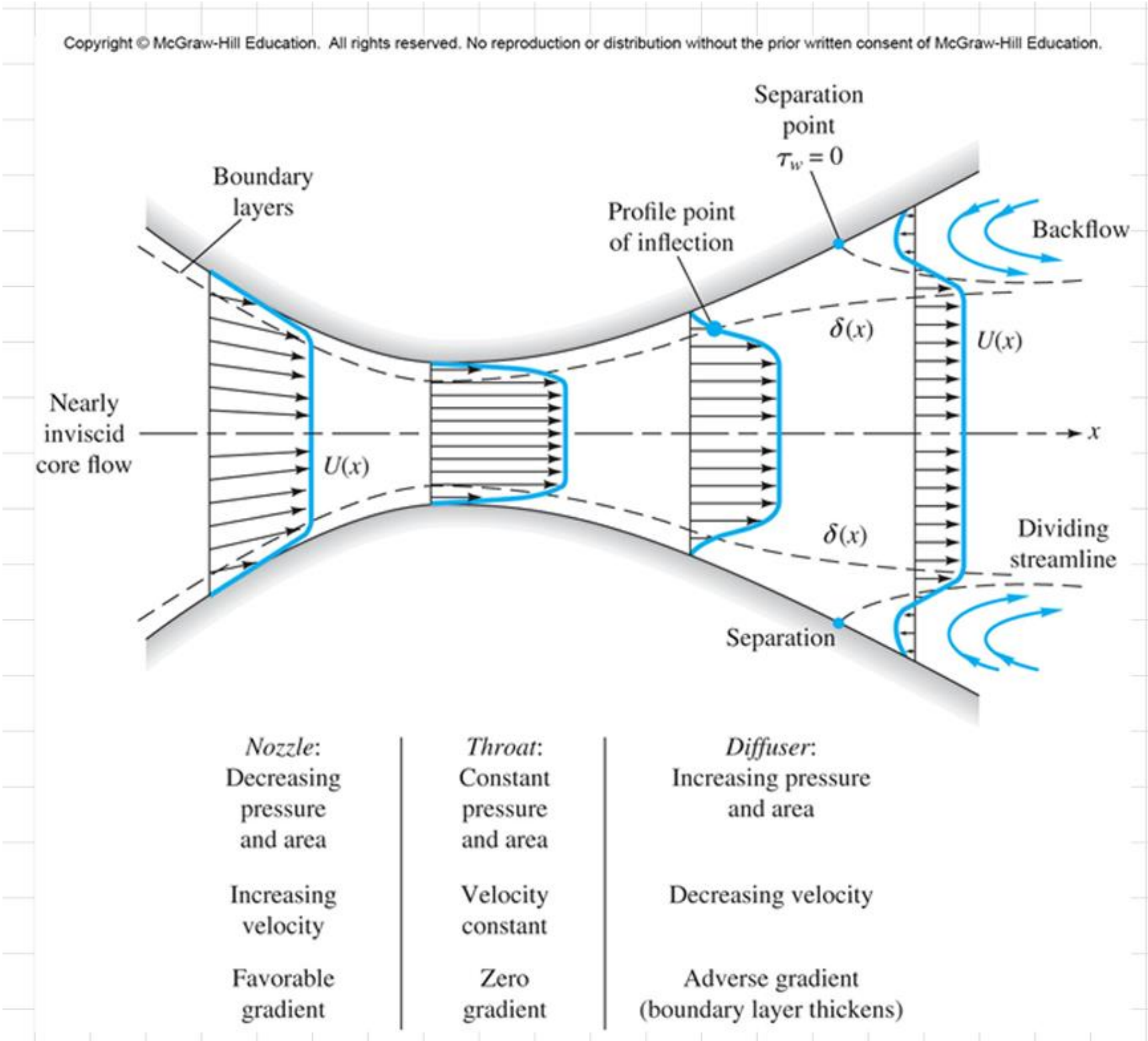
Combining Eqs. 1 & 2

$$C_L \approx \frac{2\pi \sin\left(\alpha + \frac{2h}{C}\right)}{1 + 2 / AR}$$

The associated drag increase is $\Delta C_D \approx C_L \sin \Delta\alpha \approx C_L \Delta\alpha$

Or $C_D = C_{D\infty} + \frac{C_L^2}{\pi AR}$, $C_{D\infty} \rightarrow$ infinite span

Figs Chap 7:

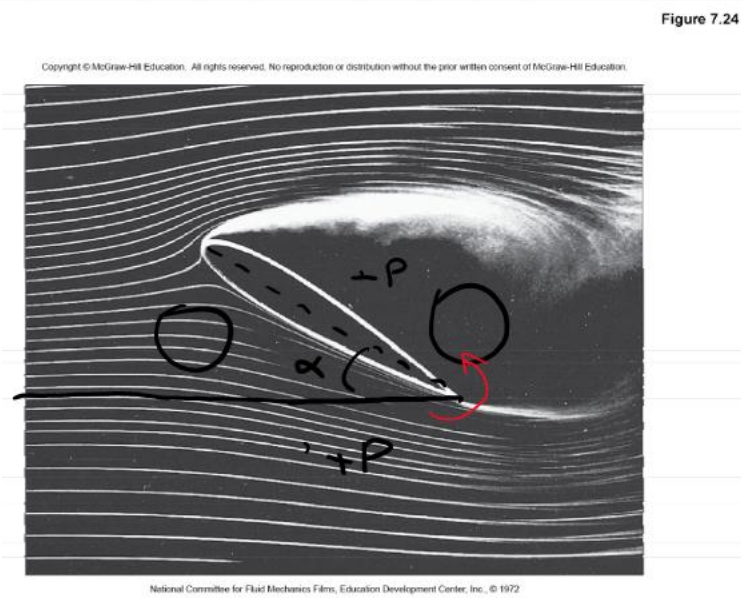


Nozzle:
Decreasing
pressure
and area
Increasing
velocity
Favorable
gradient

Throat:
Constant
pressure
and area
Velocity
constant
Zero
gradient

Diffuser:
Increasing pressure
and area
Decreasing velocity
Adverse gradient
(boundary layer thickens)

Figure 7.24



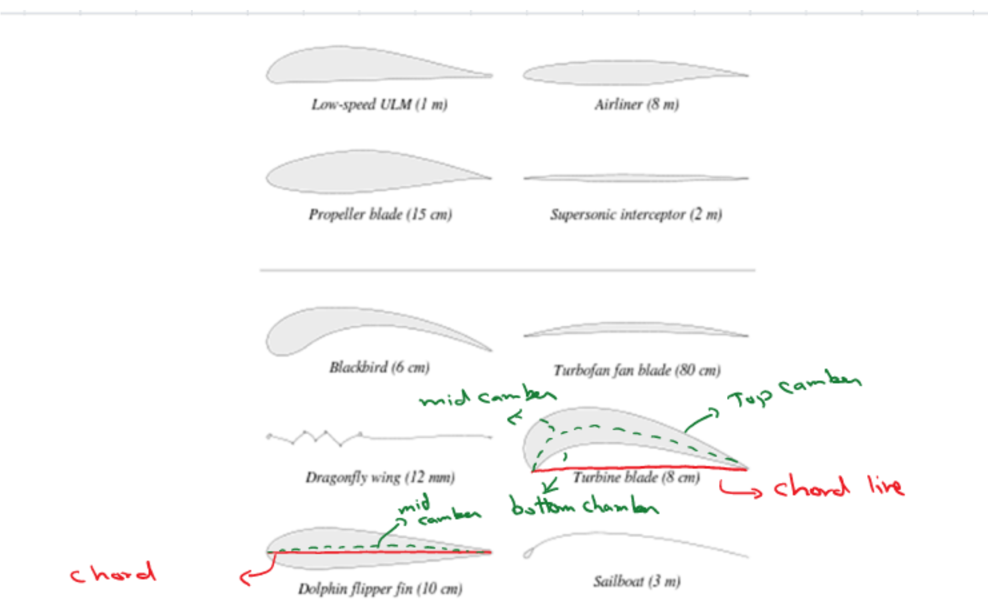


Figure 7.25:

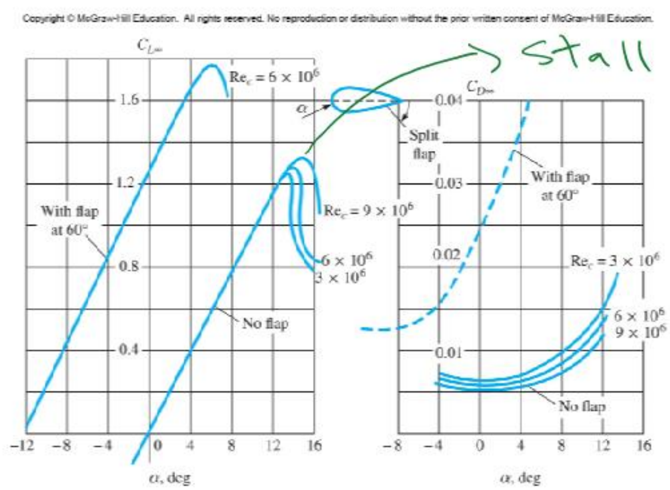
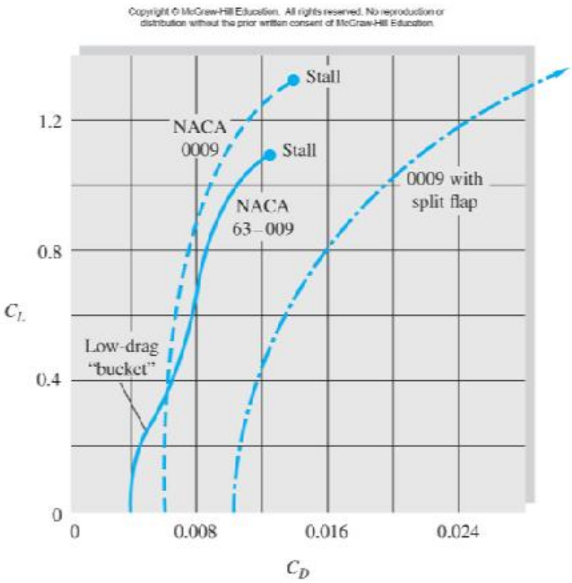
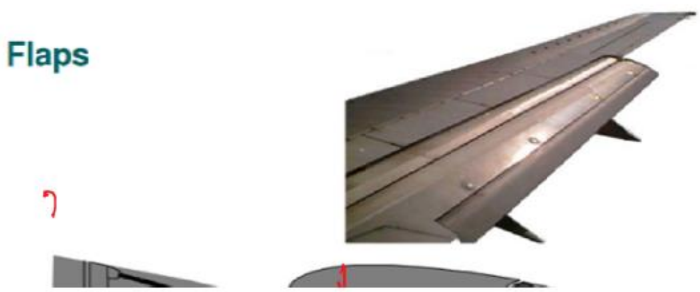


Figure 7.26:



Flaps:



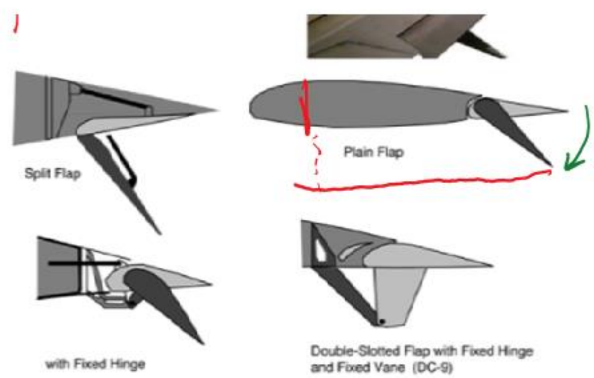
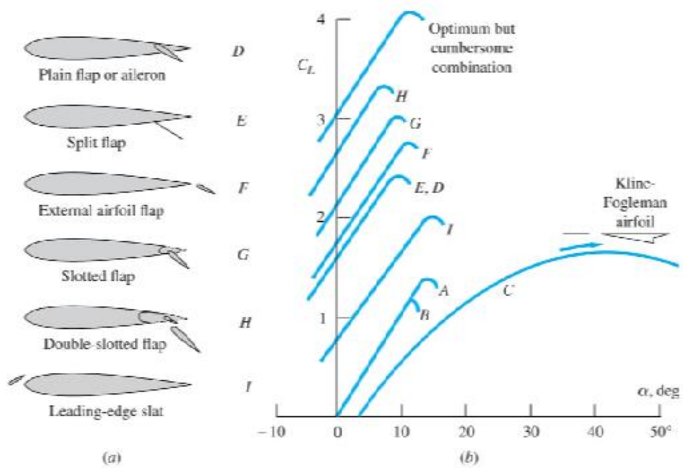
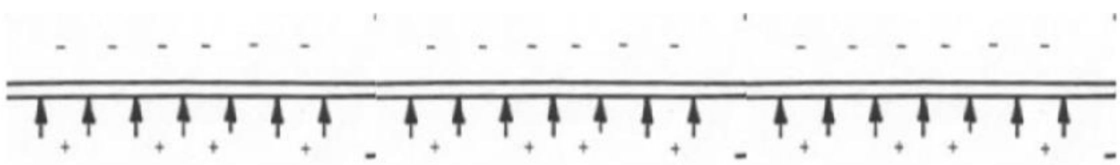
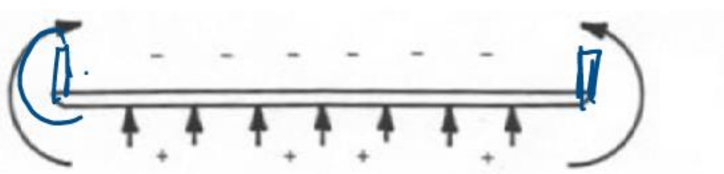


Figure 7.28:



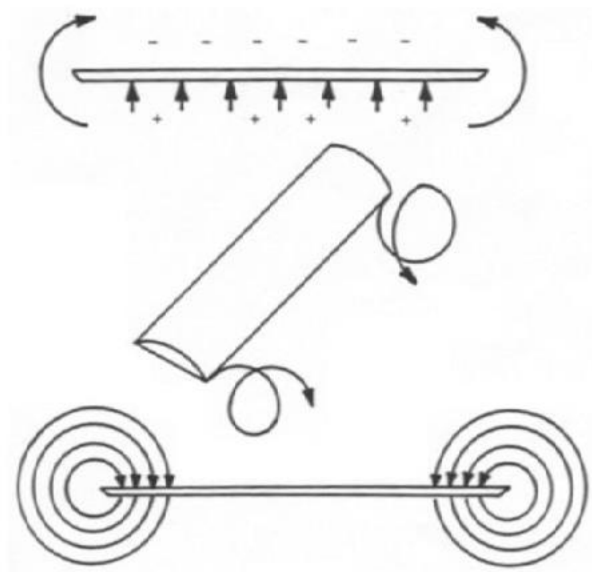


Infinite wing



Adapted from : www.aerospaceweb.org/question/aerodynamics/q0167.shtml

finite wing



http://www.aerospaceweb.org/question/aerodynamics/q0167.shtml

Finite wing Versus Infinite Wing:

Two benefits of wing let increase lift (a bit), decrease drag by weakening the vorticious

- Wing let (reduces vortex)
- Done poorly winglets, can increase flow separation and skim drag despite the feet that vorticious one reduced.