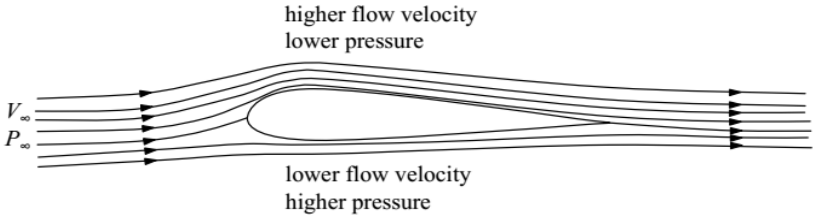
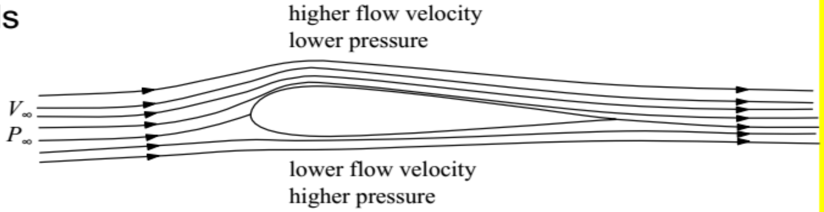
Aerodynamics: Airfoil

- An *airfoil* is simply a section cut of a wing.
- It is often called infinite wing.
- The flow characteristics around an airfoil are significantly different from those around a wing.
- The flow around the airfoil is two dimensional.

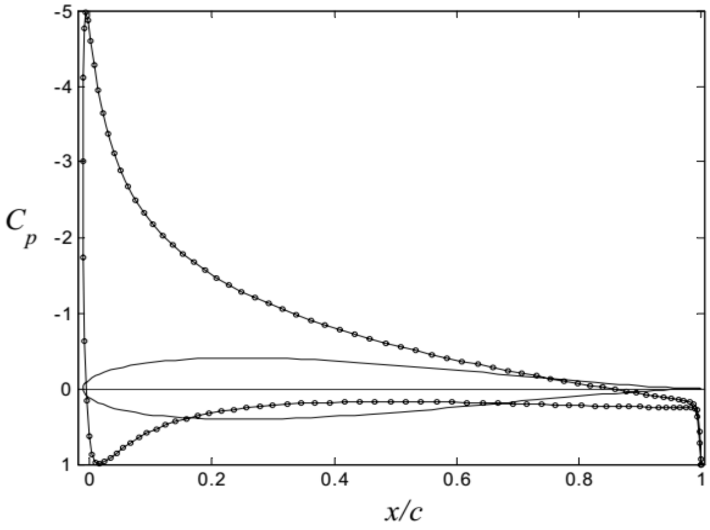


- The pressure and velocity fields around the airfoil are related via the *Bernoulli's equation*



$$P_\infty + \frac{1}{2}\rho V_\infty^2 = P + \frac{1}{2}\rho V^2$$

- The pressure distribution over Joukowski airfoil at $\alpha = 10^o$.



- The pressure coefficient is negative (means lower than the freestream pressure, *P*∞) over the top surface and positive (higher than the freestream pressure, *P*∞) on the bottom surface of the airfoil.
- The net imbalance of pressure distribution produces the lift.

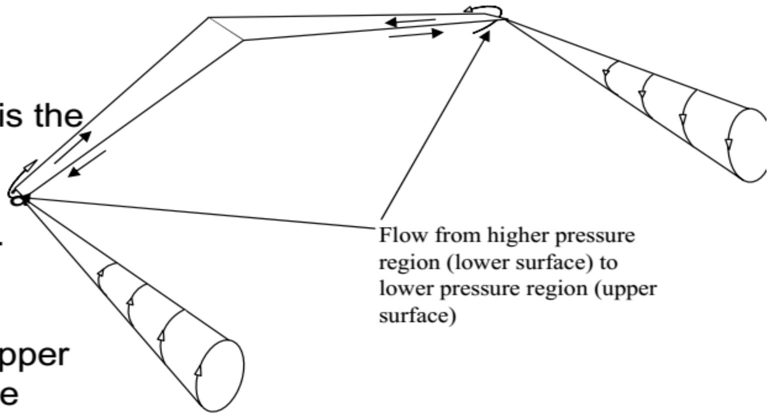
Aerodynamics: Wings

- Often called finite wing

- The flow around a wing is three dimensional; there is a flow in the spanwise direction.

- The mechanism for generating lift is the same as that for the airfoil, a higher pressure on the bottom surface and a lower pressure over the top surface.

- As consequence of the pressure imbalance between the lower and upper surface of the wing, the flow near the wing tips tends to curl around the tips; the flow is forced from the higher pressure region just underneath the wing tips to the lower pressure region on the top of the wing.



- This causes the flow *underneath* the wing to move along the spanwise direction from the wing root to the tip and the flow *on top* of the wing to move from the wing tip to the root.

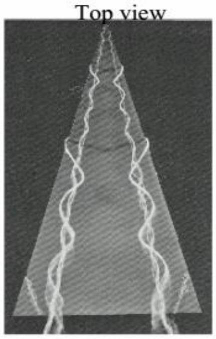
- This flow produced a *trailing vortex* at both wing tips that trails downstream of the wing.

- For large airplanes such as the Boeing 747, these vortices are powerful enough to cause light airplanes flying closely behind to go out of control.

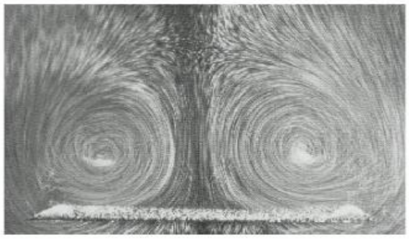
- Accidents due to these vortices have occurred and that is one of the reasons for large spacing between aircraft during landing and take-off at airports.

- The vortices draw the air behind the wind thus inducing a *downwash* (downward flow) in the neighborhood of the wing.

Top view



Cross section view



Aerodynamics: Flow Characteristics for Wings

- This downwash results in an increase of drag.
- The additional drag is called induced drag, D_i, and is related to the lift by

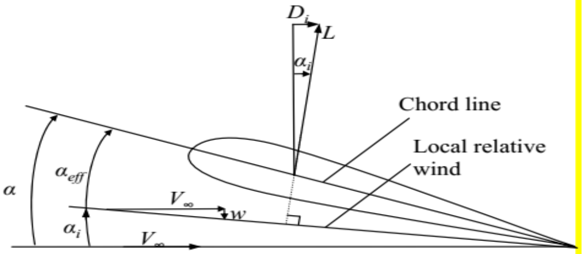
$$D_i = L \sin \alpha_i$$

- The downwash also affects the angle of attack.

The angle of attack actually seen by the wing is the angle between the chord line and the local relative wind defined as the *effective angle of attack*, α_{eff}.

- The "geometric angle of attack" α and the "aerodynamic angles of attack" α_{eff} and α_i is given by

$$\alpha_{eff} = \alpha - \alpha_i$$



Aerodynamics: Lift on Airfoil

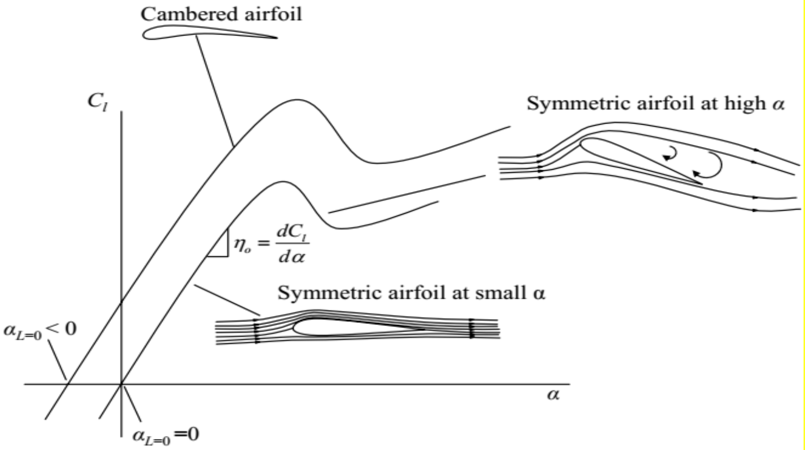
- At small angles of attack the lift coefficient varies linearly with the angle of attack for both symmetric and cambered airfoils.
- The mathematical analysis shows that for a symmetric airfoil

$$C_l = 2\pi\alpha$$

- for a cambered airfoil :

$$C_l = 2\pi(\alpha - \alpha_{L=0})$$

- The slopes of the lift coefficient for symmetric and cambered airfoils are the same.



$$\eta_o = dC_l / d\alpha = 2\pi$$

Aerodynamics: Lift on Airfoil

- As the angle of attack increases, an adverse pressure gradient starts to develop over the top surface of the airfoil which will cause the boundary layer to separate.

- At a certain angle of attack, this adverse pressure becomes strong enough to cause flow separation over the top surface of the airfoil.

- Once the flow separates the lift coefficient drop drastically and as a consequence *stall* occurs as shown in Figure 9.