Airfoils

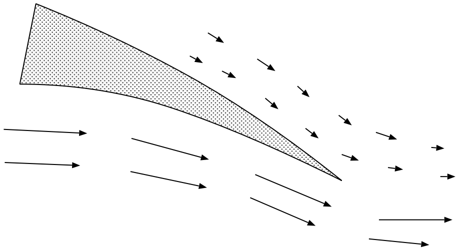
SOE3211/2 Fluid Mechanics lecture 7

Lift generation (A)

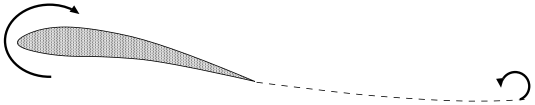
How does an airfoil generate lift?

Nothing to do with different path lengths between top and bottom!!! – possible to build airfoil with equal path lengths either side (a sail).

Airfoil has sharp edge at rear. Flow around edge when airfoil has just started moving :

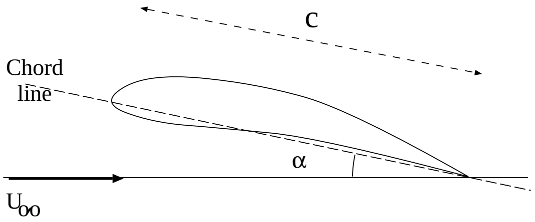


1. Flow from lower side faster than that from upper side (probably stationary).
2. This causes a vortex to form in the boundary layer behind the airfoil.
3. Eventually this vortex detatches and is carries away
4. Vorticity conserved – creation of this *free* vortex must imply creation of *bound* vortex of opposite sign attached to the airfoil



This is speeding airflow above the wing and slowing it below $\rightarrow$ providing greater pressure below the wing than above $\rightarrow$ lift
Alternatively – can consider it to be a lift force $\rho \Gamma U_\infty$ generated by a bound vortex of strength Γ in flow field U_∞ (use potential flow theory).

Definition of Terms (A)



Chord line: line connecting leading & trailing edge

Chord c: length of chord line

Angle of attack α: Angle between U_∞ and chord line

Camber line: centre line of airfoil section

Span b: length of airfoil $\perp$ to section

Plan area A: area of projection onto plane containing chord line. This is $A = c \times b$ if the airfoil is of constant section

Mean chord: $\bar{c} = A/b$

Camber δ: maximum distance between camber and chord lines. %camber $= 100\delta/c$ is a measure of the airfoil curvature

Lift and drag coefficients

Define coefficients :

$$C_L = \frac{F_L}{\frac{1}{2}\rho U_\infty^2 A} \qquad C_D = \frac{F_D}{\frac{1}{2}\rho U_\infty^2 A}$$

A is the *plan area* (not the frontal area)

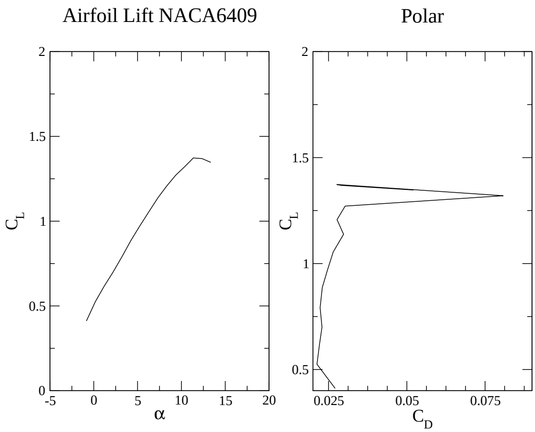
The ratio of lift to drag force is also important :

$$\frac{F_L}{F_D} = \frac{C_L}{C_D}$$

We want the wing to be efficient, i.e. to generate the maximum lift.

Coefficients usually plotted against α for specified airfoil sections.

Also plot *polar* – C_L vs. C_D



Evaluation of C_L, C_D (A)

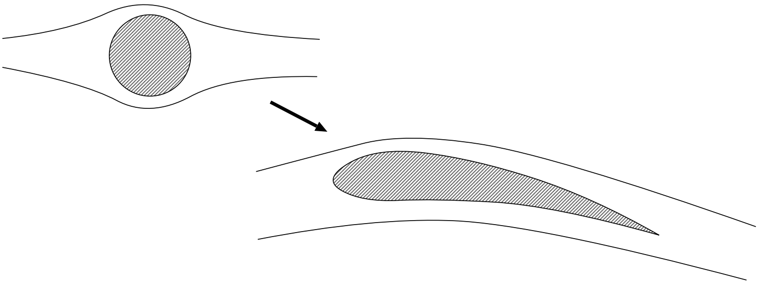
There are 3 basic methods used to determine these coefficients.

Experimental. Generally do the experiments on a scale model and used dynamical similarity

Conformal mapping. This is a complicated mathematical method which uses a class of mathematical transformations called *conformal mappings*. These transform the potential and stream functions for flow around one body into those for flow around another.

If we know the solution for the first body then we can use this to find the solution for the second.

In particular, there are a set of mappings called *Joukowski transformations* which turn a circle into a *Joukowski airfoil*



Note that

1. this is the reason why the lift on a body with circulation Γ is the same as that on a cylinder with Γ
2. the method can only be used in 2-d
3. the method cannot account for 'real fluid' properties

In particular, we can use this to show that

$$C_L \propto \sin\alpha \propto \alpha$$

for small values of α. However it cannot account for other properties such as *stall*.

Computational. *Panel codes* are often used to calculate lift properties.

Panel codes divide the surface of the wing into small elements E_i. Each element E_i has an associated vorticity and associated potential ϕ. The code then finds the velocity at any point by summing the contributions from all the panel elements, and thus the pressure distribution around the wing from Bernoulli.

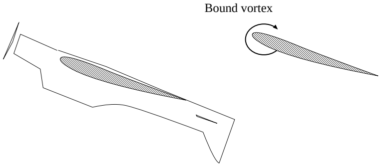
- The method is quite cheap compared with a full NS code
- It can deal with 3-d effects of the wing
- It can be enhanced to deal with real fluid effects such as separation.

Stall and other effects (A)

A wing is a device for generating bound vorticity on a wing, using the sharp trailing edge to create a vortex which is then shed, leaving vorticity of the reverse sign bound to the wing

Because of this, for small α, the size of the vorticity increases with α, and so does the lift.

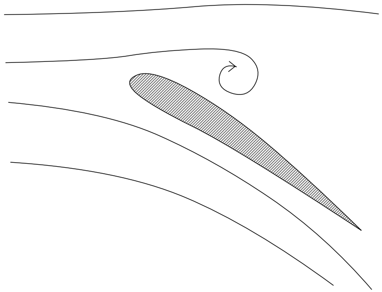
Completely symmetrical airfoils will still generate lift if $\alpha \neq 0$. This also explains why aircraft can fly upside down – if the wing is orientated at the correct α, it can still generate lift.



However : if α gets too large there becomes a risk of vortex formation behind the leading edge.

This can lead to a reverse vortex being shed from the leading edge, cancelling the bound vorticity associated with the wing.

This is known as *stall*.



In general, stall can be seen as an effect arising from separation of the b.l. Hence techniques for delaying stall involve trying to prevent separation.

Landing (A)

The lift force $\propto U^2$, i.e. $\propto$ the airspeed of the craft. This can cause problems when slowing down to land (and on takeoff).

Since the lift coefficient $\propto \alpha$, lift can be increased (at the expense of additional drag) by orientating the wing at a greater angle.

Another method is to change the geometry of the wing.

Aircraft are often equipped with *flaps* – sections of the end of the airfoil which can be bent downwards. This 'sharpens' the trailing edge of the airfoil, enhancing vortex generation and thus lift.

Summary (A)

- Airfoils are devices for generating bound vorticity
- The interaction of this vorticity with the surrounding airflow produces lift
- Define lift and drag coefficents

$$C_L = \frac{F_L}{\frac{1}{2}\rho U_\infty^2 A} \qquad C_D = \frac{F_D}{\frac{1}{2}\rho U_\infty^2 A}$$

- Area A is the *plan* area
- Generally presented as graphs versus α, and can be used to determine properties of the airfoil in flight.
- Bound vorticity also explains other effects such as stall.