Design, Build, Test: Aerodynamics (1)

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!

- Time constraints mean that you need to start your design soon. This means that some of the concepts you will see in this lecture have not yet been covered in your aerodynamics course (primarily induced drag), so I'll go through these at an introductory level. If you don't understand completely, don't worry too much at this point - things will become clearer in coming weeks
- Today the objective is to give you enough information to start your exploratory design in your 'comms groups'
- There will be a more detailed lecture in ~week 5 to cover extra material not included here
- The design element of this coursework is there to add engineering realism and interest - but it is not the end goal. The objective is to give you the experience of the design and analysis process, and to understand shortcomings of methods you use. If your final design is poor, this is not necessarily a failure on your part, providing you understand why, and how it might be improved. You cannot be expected to be completely right first time - and often failure teaches more than success!

Aero objectives

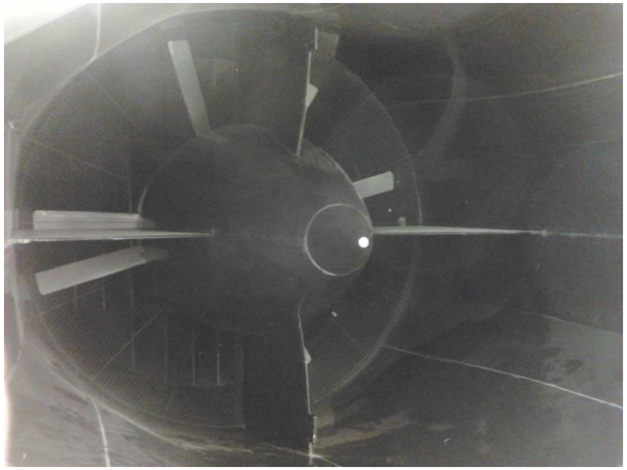
Design a wing with droop/flap settings to give:

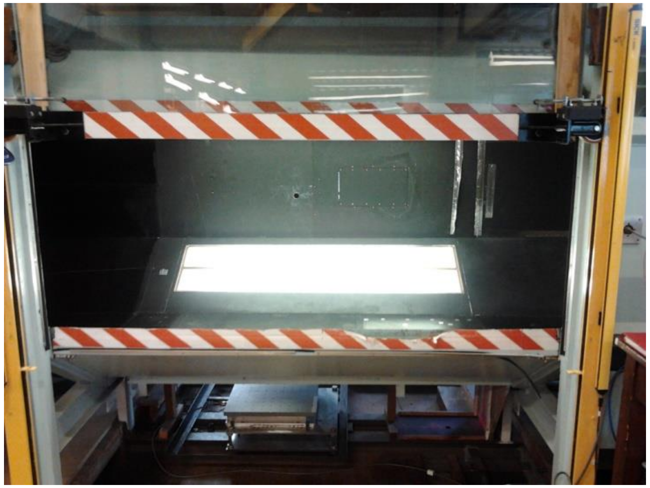
1) Shortest takeoff distance from concrete/asphalt (rolling friction coefficient =0.025) – 'takeoff'. Allows convenient operation in confined spaces. At zero incidence minimise $C_D - \mu C_L$
2) Highest top speed – 'dash' (min Cd0). Can make a getaway if needed, or follow a misbehaving motorist
3) Best endurance – 'loiter' (min Cd @ Cl=0.5). Spend as long as possible over a particular area taking souvenir photos, or waiting for the burglar to leave the bushes
4) Slowest landing speed – 'land' (max Clmax). Safer and easier if done slowly

…approximately a complete UAV mission. The requirements conflict – this is life!

Final wind tunnel test

- A tunnel test will be run for each of the objectives in our 7x5 tunnel at Easter. You need to select your wing design and droop/flap settings to get the best result across all of the four conditions - you will not be able to change these within each test, only between them. Tunnel speed ~20m/s





Restrictions

- Wing planform is fixed, so all wings have same reference area. We need this to allow easy, consistent testing
- Flap and droop layout is fixed
- Can select aerofoil and droop/flap angles (subject to a minimum thickness to allow manufacture, otherwise you can't fit your hands inside!)

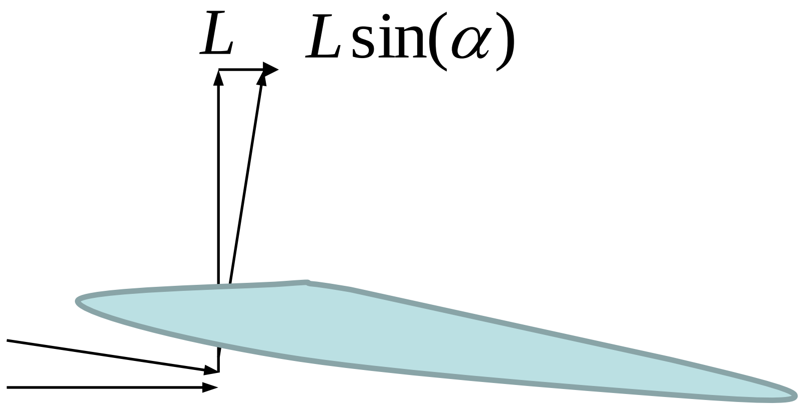
Lift induced drag

The ‘stirring a teacup’ explanation…

->Kinetic energy is deposited in the vortices

This is OK, but not that helpful for understanding things quantitatively

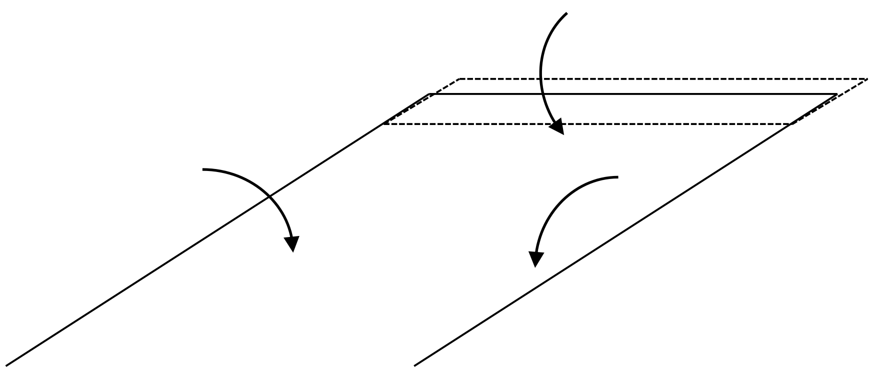
Lift induced drag



$$\sin(\alpha) \approx \alpha \approx const \times C_L$$

$$C_L \sin(\alpha) \approx const \times C_L{}^2$$

Model wing as bound vortex + two trailing vortices



The trailing vortices induce a downwards velocity at the bound vortex that is proportional to the lift

This in turn shifts the lift vector back by an angle proportional to the lift

The actual lift is unchanged (depends on cosine)

This will be covered in much more detail after Christmas in aerodynamics 2

Takeoff

$$ma = f_{net} = T - D - \mu(W - L)$$

$$= T - \mu W - \frac{1}{2}\rho V^2 S(C_D - \mu C_L)$$

Want highest acceleration… this ignores the fact that if flaps are used, the stall speed is also lower, so the aircraft can fly at a lower speed

So minimise… $C_D - \mu C_L$

But in 3D drag is linked to lift by $C_D = C_{D_0} + KC_L{}^2$

So… $C_{D_0} + KC_L{}^2 - \mu C_L$

Differentiate and set to 0 to find minimum $2KC_L - \mu = 0$

$$C_L = \frac{\mu}{2K}$$

There is an optimum lift coefficient to minimise ground run!

Takeoff

- Assume wings fixed to fuselage (not always true, consider the Vought F-8), fuselage fixed to undercarriage, and all wheels on the ground, then wing incidence is fixed for the ground run
- Cl at fixed incidence can be changed by setting flaps, so this can be used to achieve the optimum lift coefficient
- Both Cd0 and K depend on flap setting (described in detail in later weeks, will treat in simplified manner today)
- So there is an optimum flap setting to minimise ground run
- Too little lift and the rolling friction is too high, too much lift and the induced drag is too high
- This is why ‘some’ flap is applied at takeoff, but not too much!

Takeoff example

$$K = \frac{1}{\pi A_R e} \approx \frac{1}{\pi A_R} = \frac{1}{6\pi} = 0.05$$

(To be shown in aero 2)

$$C_{L_{TOConcrete}} = \frac{0.025}{2 \times 0.05} = 0.25$$

$$C_{L_{TOGrass}} = \frac{0.1}{2 \times 0.05} = 1$$

Dry concrete/Asphalt - 0.025
Hard turf/Gravel - 0.04
Short, dry grass - 0.05
Long grass - 0.10
Soft Ground - 0.10 to 0.30

Using Xfoil (see later – assumes 2D) at zero incidence and zero flap (30% chord device), Cl=0.12, then at

5deg flap Cl=0.48
10deg flap Cl=0.76
15deg flap Cl=0.96

…flaps 2.5 for concrete, and flaps 15 for grass?

This calculation will be refined in the second aero lecture

Dash

- When max propulsive power=max engine power, maximum speed reached
- At high speed Cl is very small, so Cl^2 is even smaller -> neglect
- Roughly, Cd0 is all that matters

$$C_L = \frac{W}{\frac{1}{2}\rho V^2 S}$$

assume V large

$$TV = P = C_D \frac{1}{2}\rho V^3 S \approx C_{D_0} \frac{1}{2}\rho V^3 S$$

$$C_D = C_{D_0} + \cancel{K C_L^{\,2}}$$

Cl ~ 0

$$V_{\max} = \left(\frac{2P}{C_{D_0}\rho S}\right)^{1/3}$$

Loiter

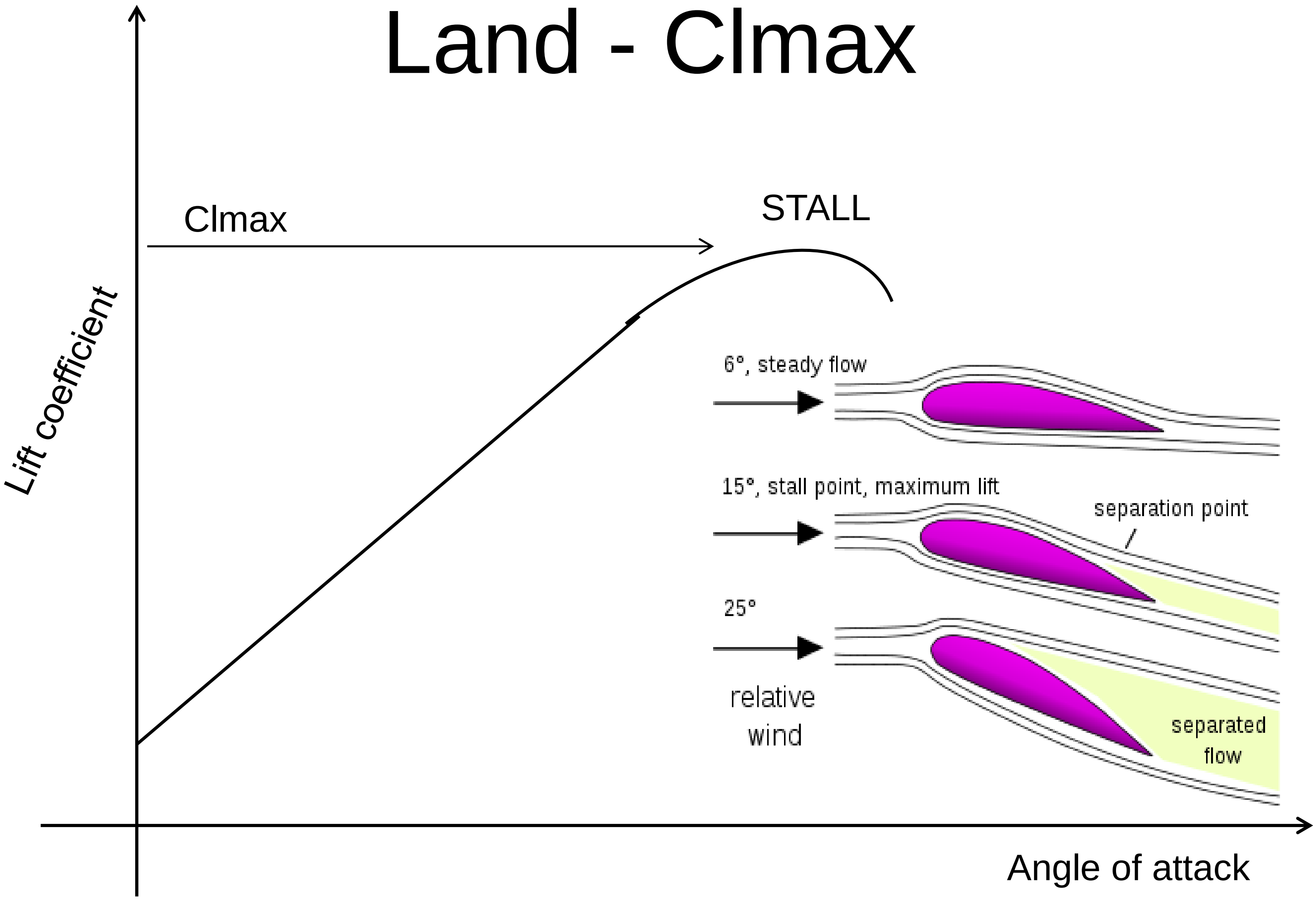
$$DV = W\frac{D}{L}V = W\frac{C_D}{C_L}\sqrt{\frac{2W}{\rho S C_L}}$$

$$\frac{{C_L}^{\frac{3}{2}}}{C_D}$$

So if Cl fixed, just a question of minimum Cd

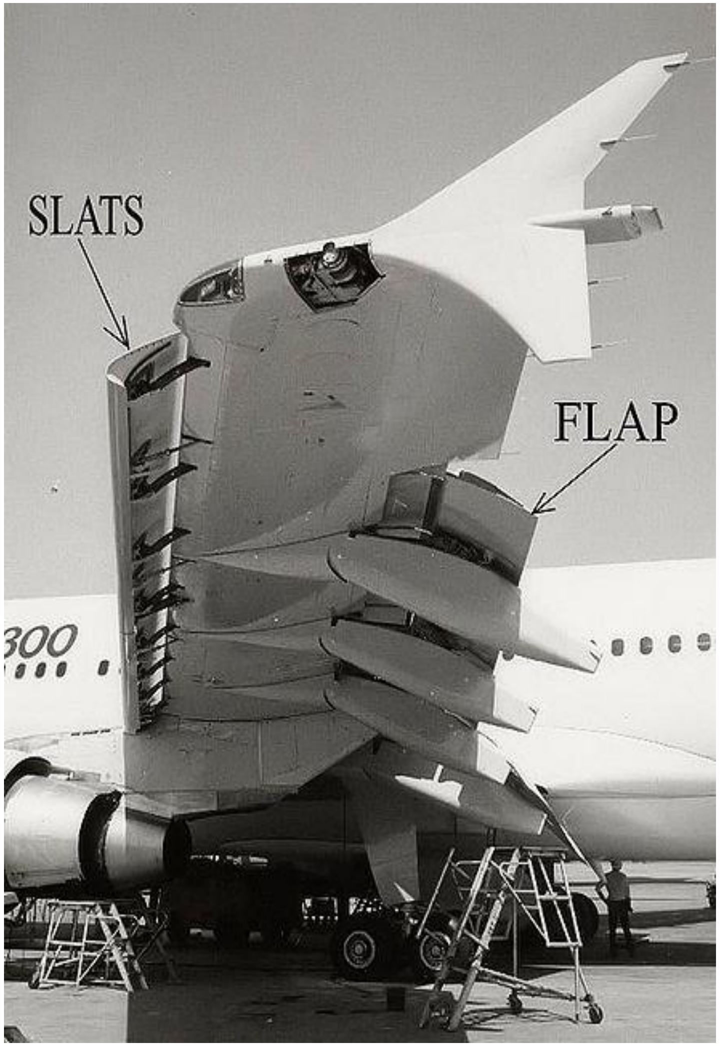
Cl=0.5 is chosen arbitrarily here to be representative of aircraft weight. In a real design loop this would be changing (as would be the wing area)

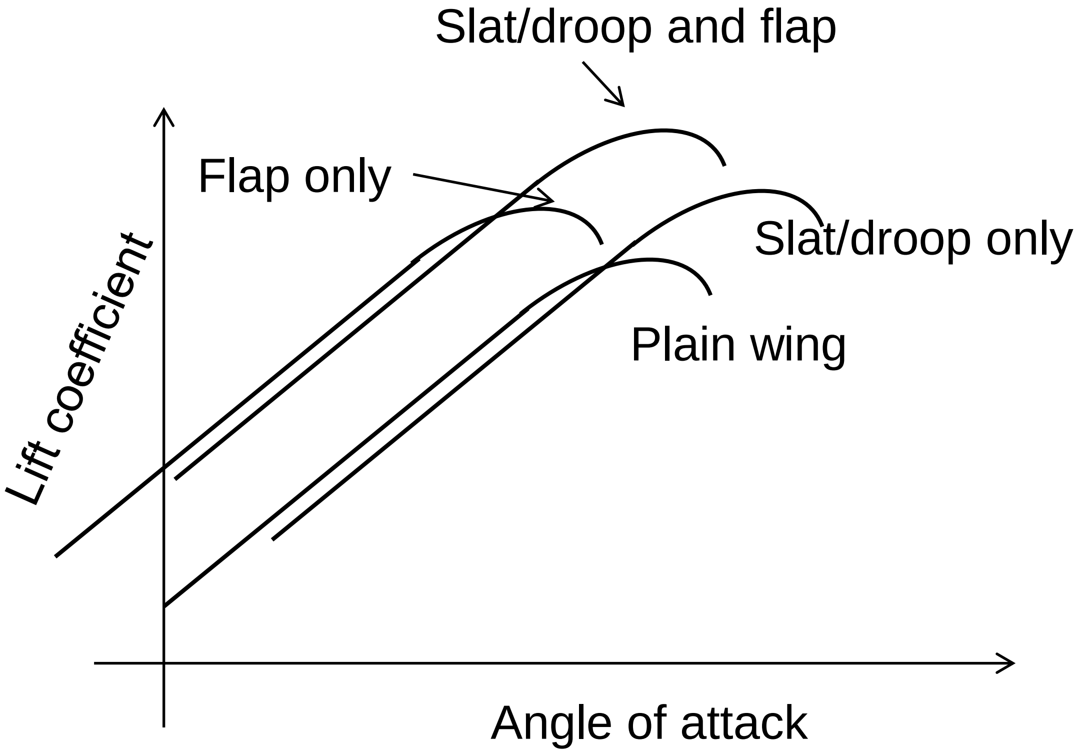
Land - Clmax



Clmax
STALL
Lift coefficient
6°, steady flow
15°, stall point, maximum lift
separation point
25°
relative wind
separated flow
Angle of attack

Clmax





Note slight drop in Cl at fixed AoA from LE device

Land

$$W = C_{L_{\max}} \frac{1}{2} \rho V^2 S$$

$$V_{\min} = \sqrt{\frac{2W}{\rho S C_{L_{\max}}}}$$

You don’t land at Vmin (tricky…), but Vland is usually about 10% above Vmin

Droop behaviour similar to slat behaviour

Clmax comparisons

- B-52 = 1.8
- 707=1.78-2.2
- 727=2.79
- DC-9 = 3
- 737-200=3.2
- 747=2.45
- 767=2.45
- 777=2.5

Comms groups

- Each group choose a 4 or 5 series NACA aerofoil (eg 4412 or 23015)
- Estimate Cd0 and Cd @ Cl=0.5 using Xfoil, or get data from *Theory of Wing Sections.* At zero incidence find best value of takeoff objective (Xfoil allows flap deflections to be set)
- Use the cross section of the aerofoil to compute a structural design
- This is a suggestion to get you started, not the 'answer'!

Xfoil

- This is a straightforward tool for analysis of aerofoils (it is 2D only!)
- It uses a linear vortex distribution panel method; this will be described later in your incompressible aerodynamics course. A boundary layer module is added to this to allow some viscous predictions

- Usage is simple. Double-click executable and type

naca23015 <return> (loads 23015)

oper <return> (enters operation menu)

v <return> (sets to viscous mode)

re <return> (enter Reynolds number, approx 670,000)

alfa 0 <return> (runs at incidence=0)

dump outputfilename <return> (outputs pressures to a file)

quit <return>

- **What it can give you: L/D, Cd0**
- **What it cannot give you: Clmax (a method will be given in later lecture)**

Example

Can also compute a trimmed case using the ‘Cl’ command