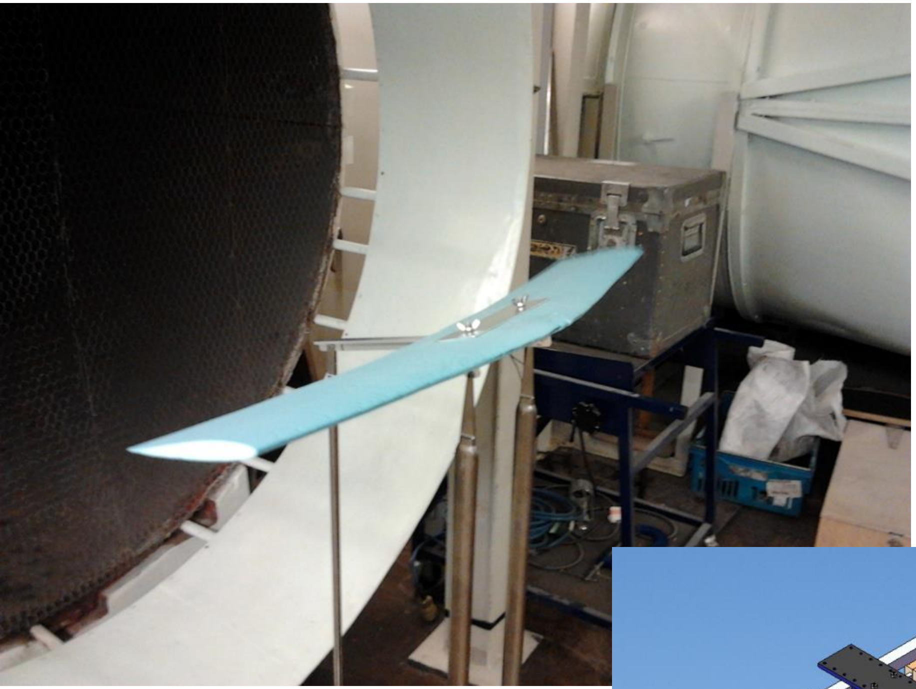
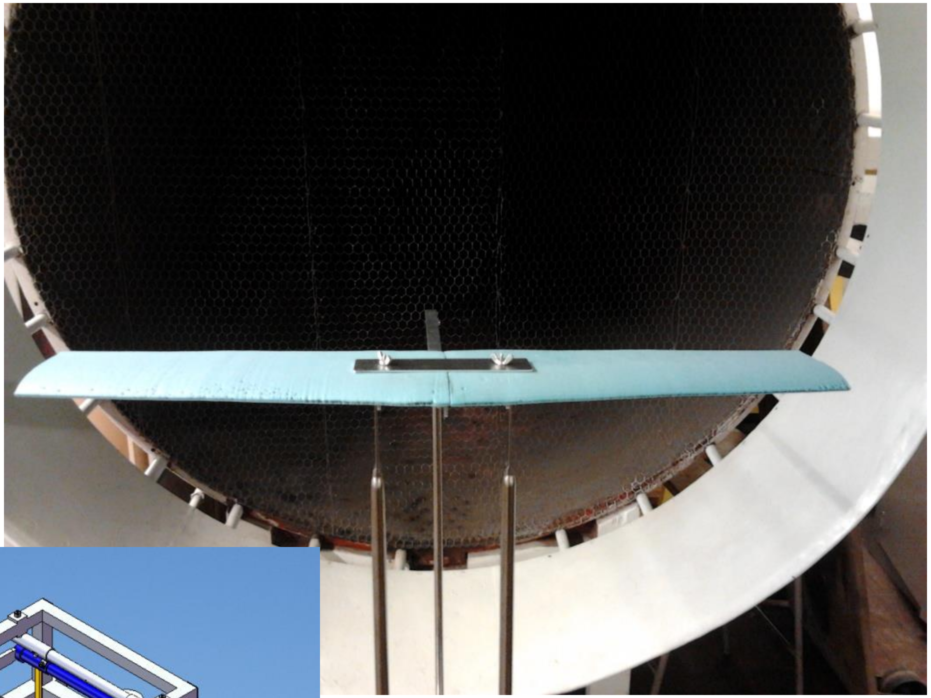
D&C Flight Project

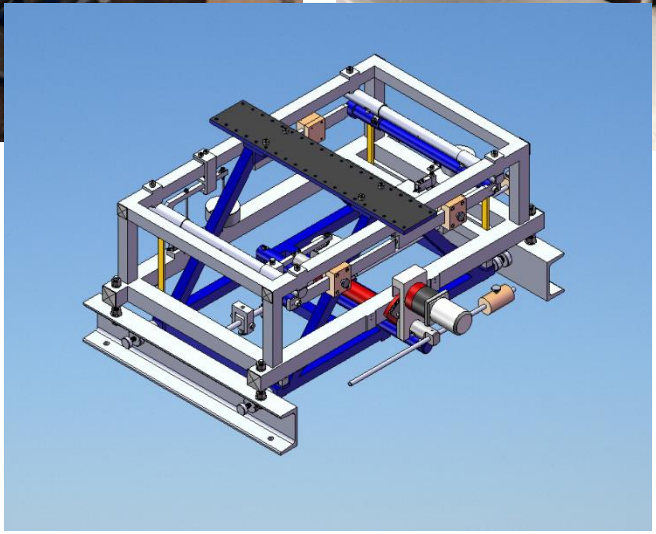
(20% weighting)

Dr T Rendall

Foam wings!

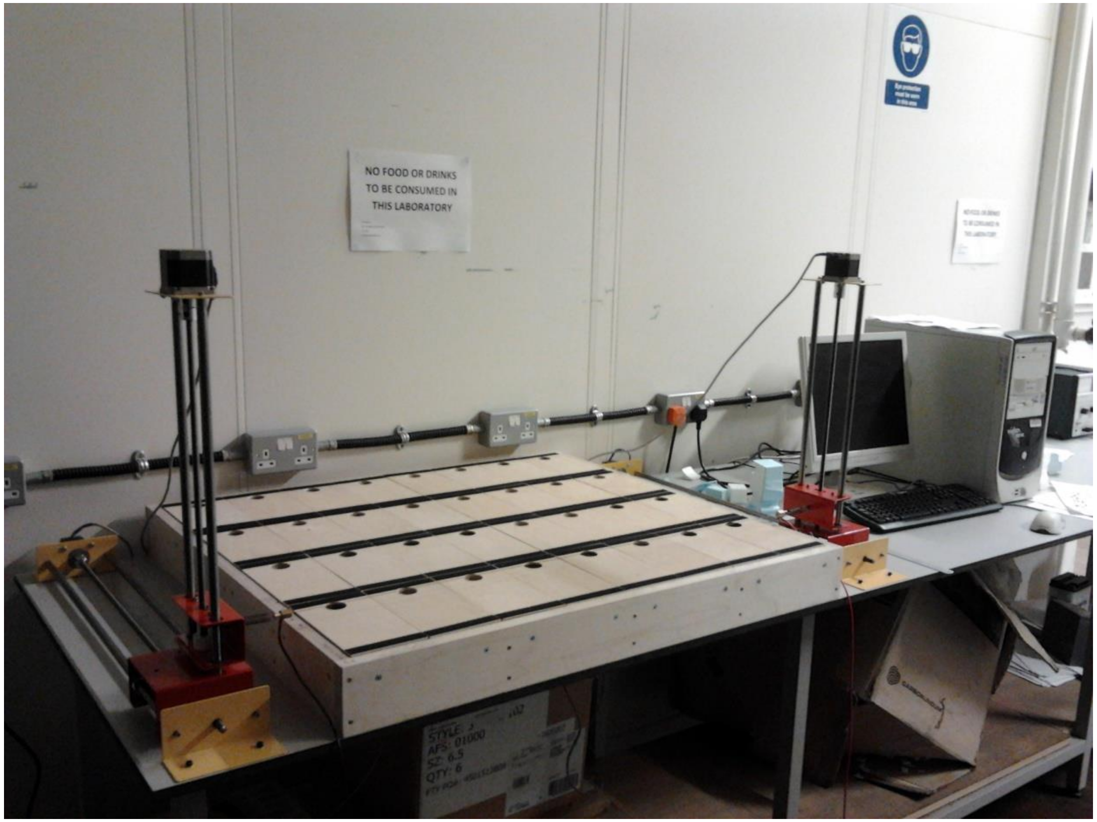






Foamcutter

Runs using Gcode



Purchased using a donation from BOEING

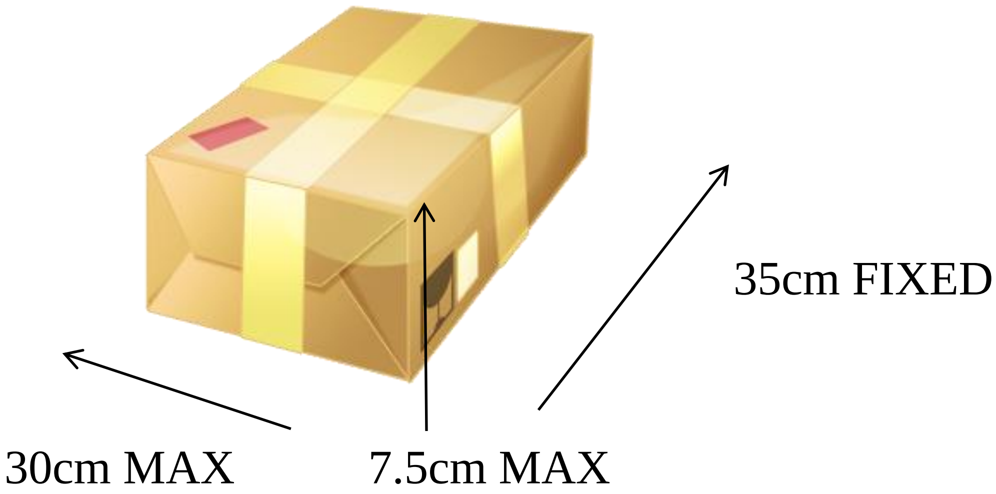
Task

Design/test a foam cantilevered wing to optimise a set of objectives subject to particular constraints + write a report!

Work in tutor groups

Foam block dimensions

Aircraft will have a fixed span of 70cm**. You cannot change this**
Max chord is 30cm
Max depth is 7.5cm



Objectives

1) Best L/D at any angle of attack
2) Highest value of lift in [N] at any angle of attack at the tunnel test conditions (~15-20m/s)
3) Highest value of leading edge sweep (forwards *or* backwards)
4) Minimum wing volume
5) Tip deflection < specified value at a set tip load

Timeline

3 lectures over the next weeks:

- Intro+aero (today)
- Structures (Ben Woods)
- Dynamics (Brano Titurus)

Wings will then be cut out – we need time to do this, so please keep to the deadline

3 Tests:

- Static structural - BW
- Dynamic structural - BT
- Aerodynamic - TR

Competition…

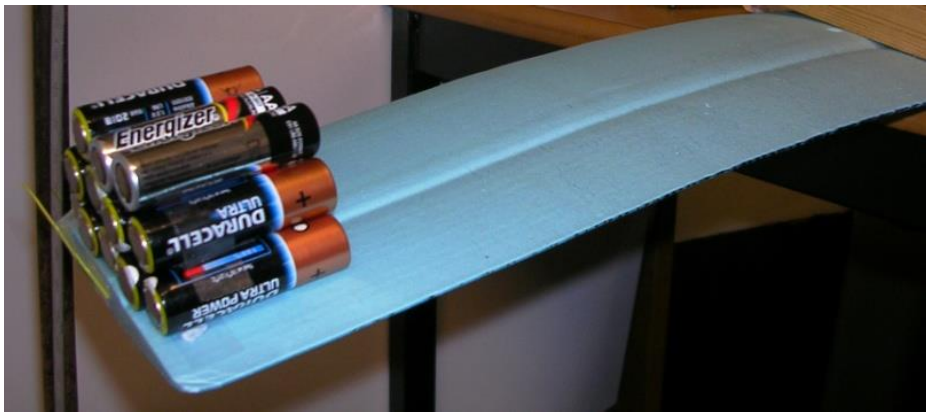
The important aspects of this project are analysis, design and comparison to experimental results. These will be assessed primarily through the report

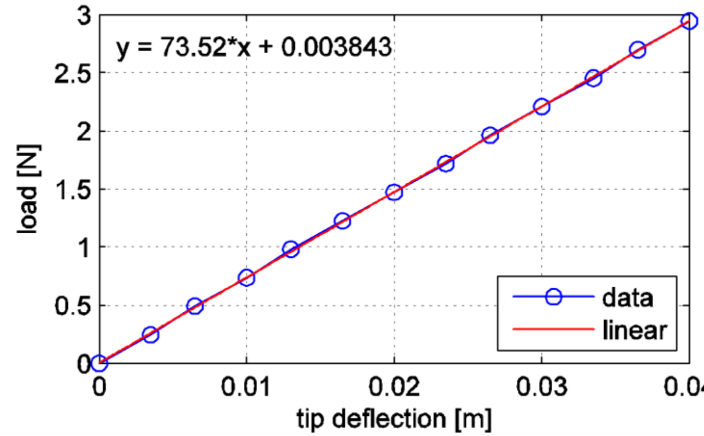
80% of marks will be for the final group report, and 20% for the design's performance

Groups will be ranked in objectives (1)-(4), 1=best. The group with the lowest summed rankings will be the winner

Coming up in the next few weeks…

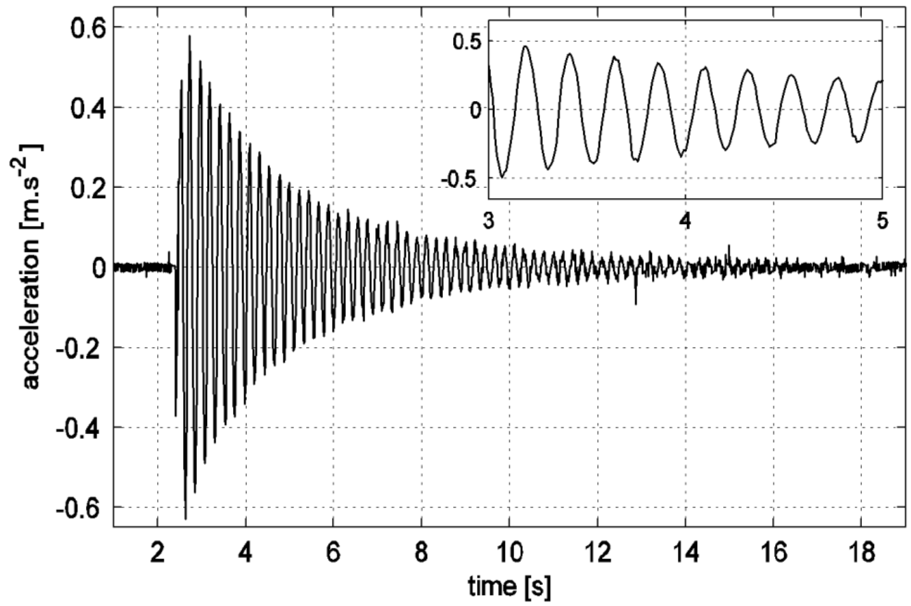
Structural design

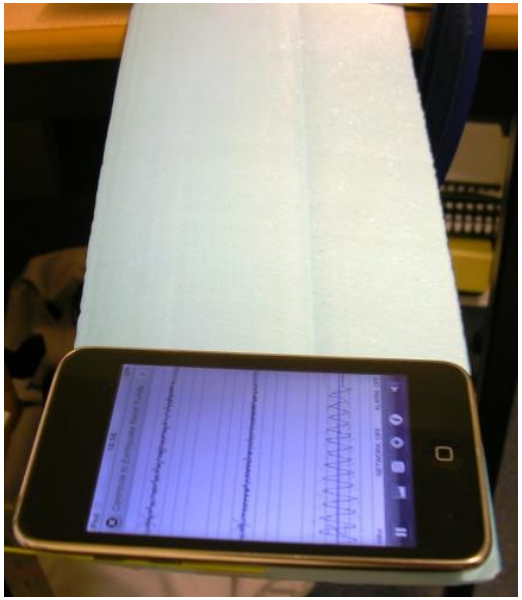




Tip deflection needs to be <4cm @ 300g

Dynamic estimates





Wing design software

Wing design tool written in Matlab will be available for download shortly. You must use this to create your Gcode for the foam cutter. This must be done outside the CAD suite. The settings file for this will be what we use to cut your wings**.**

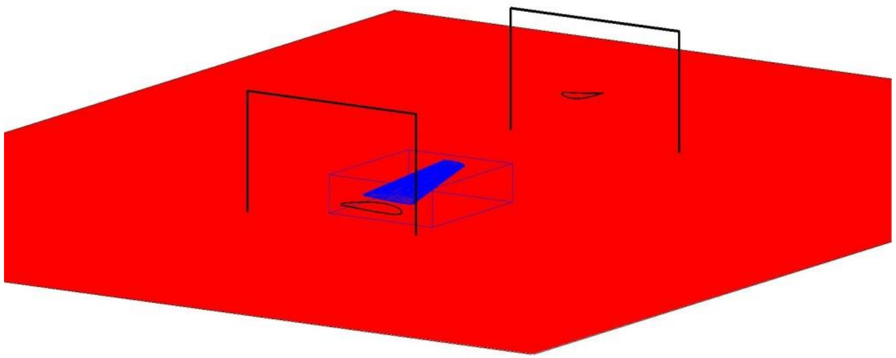
It also calculates 2nd moments of areas of your aerofoils!

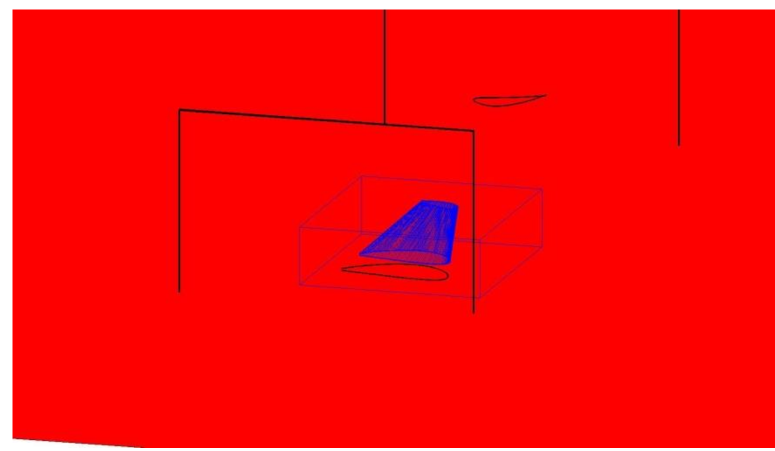
You should also create 3-views in CAD **as a parallel task**

```
****** GCODE GENERATION SCRIPT V1.0 ******
Data Read
Geometry Scaled
Head Positions Extrapolated
Plot Complete
Limit Checks Complete
GCode Output
Mirror GCode Output

Root area is 18.493 cm^2
Root centroid is [6.307,0.231] cm realtive to leading edge
Root moments are: Ixx=4.375cm^4 Iyy=1627.216cm^4 Ixy=-33.680cm^4

Tips area is 2.959 cm^2
Tips centroid is [2.522,0.008] cm realtive to leading edge
Tips moments are: Ixx=0.418cm^4 Iyy=41.327cm^4 Ixy=3.686cm^4

Volume of wing: 375.417cm^3
>>
```

2nd moments!

Volume





NACA 2412

1.000000	0.001260
0.993811	0.002536
0.983033	0.004731
0.970479	0.007248
0.956440	0.010011
0.941370	0.012917
0.925684	0.015878
….	
0.275089	0.077923
0.259577	0.077164
0.244152	0.076219
0.228824	0.075083
0.213607	0.073751
0.198520	0.072215
…	
0.993685	-0.001724
1.000000	-0.001260

Xfoil format

Anti-clockwise starting from trailing edge

Check the example input files if you are unsure

Today: aerodynamics

You need information to start with for aerofoils operating at the right Reynolds numbers (approx 100000)

A good source of 2D aerofoil data is:
http://www.ae.illinois.edu/m-selig/uiuc_lsat.html and
http://www.ae.illinois.edu/m-selig/pd.html
Alternatively: `Theory of Wing Sections' (many reference copies in library), but check Re

This will provide 2D values for Cd, Cl and Clmax, as well as the lift curves. You will need to use some approximate methods to adjust these values for 3D influences...so far you haven't been taught how many of these work, but rest assured, this will feature in coming years!

Aero tips

$$\frac{dC_L}{d\alpha}_{3D} = \frac{2\pi A_R}{2 + \sqrt{\frac{A_R^2}{\kappa^2}\left(1 + \tan^2\left(\Lambda_{\frac{1}{2}}\right)\right) + 4}}$$

Fairly approximate!
(Helmbold-Diederich)

$$\kappa = \frac{\frac{dC_L}{d\alpha}_{2D}}{2\pi}$$

3D lift gradient < 2D lift gradient

Why?

$$C_{L_{3D}} = \frac{dC_L}{d\alpha}_{3D}\left(\alpha - \alpha_{0_{3D}}\right)$$

Reliable in the attached region

$$C_{D_{3D}} = C_{D_o} + \frac{C_{L_{3D}}^2}{e\pi A_R}$$

Reliable in the attached region
Take e=0.7
Obtain Cd0 from aerofoil database

Stall

$$C_{L_{max_{2D}}} = min(C_{L_{max_{root}}}, C_{L_{max_{tip}}})$$

From 2D data

$$C_{L_{max_{3D}}} = 0.9 C_{L_{max_{2D}}} \cos\left(\Lambda_{\frac{1}{4}}\right)$$

Note that sweep lowers Clmax

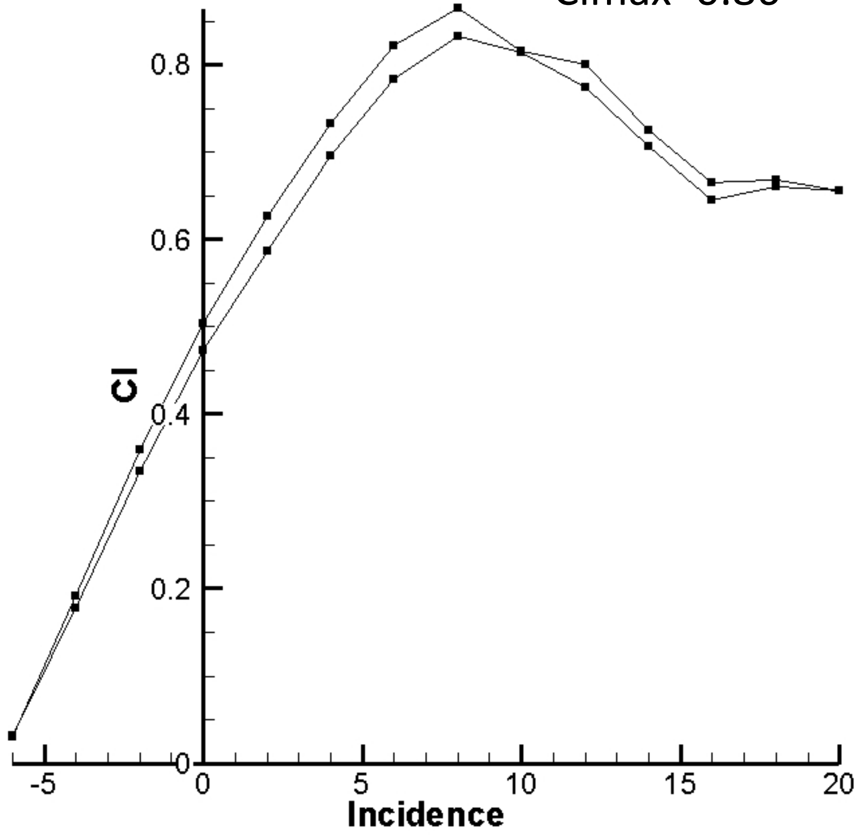
These are firmly empirical!

Clmax predictions for full size aircraft are still firmly based on experimental/empirical results...

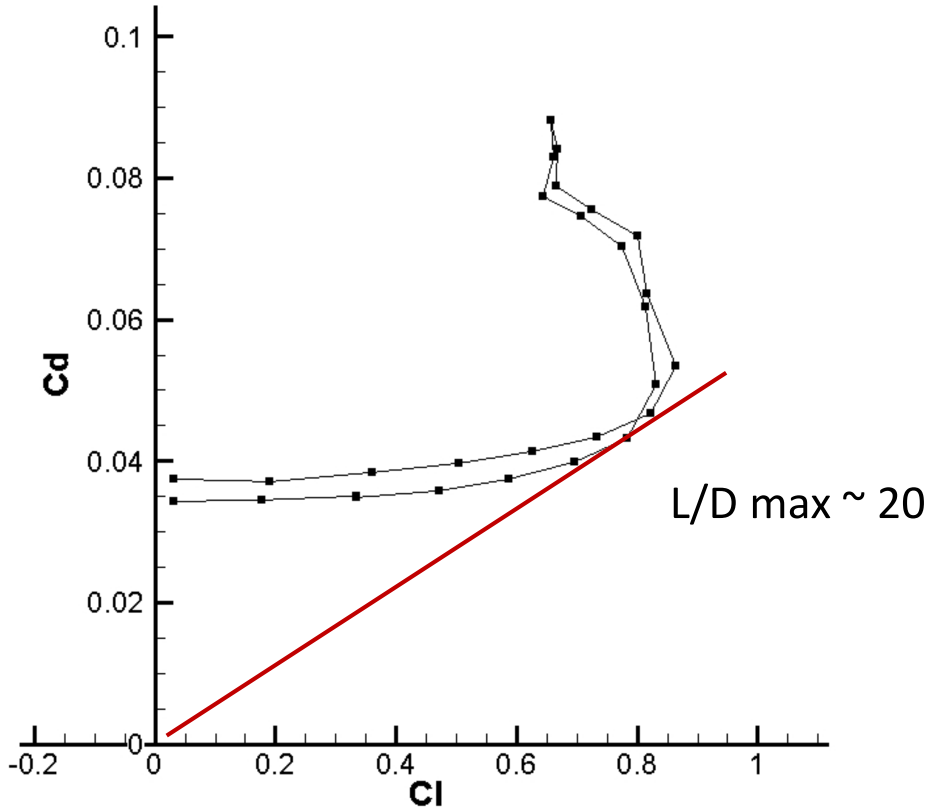
Sweep and taper tend to produce a higher local lift coefficients near the tips, which is why most wings use 'washout', which twists the aerofoil nose down towards the tip. This allows the spanwise location of stall to be altered. 3-5 degrees would be typical.

Aero Testing: Cl

Clmax=0.86

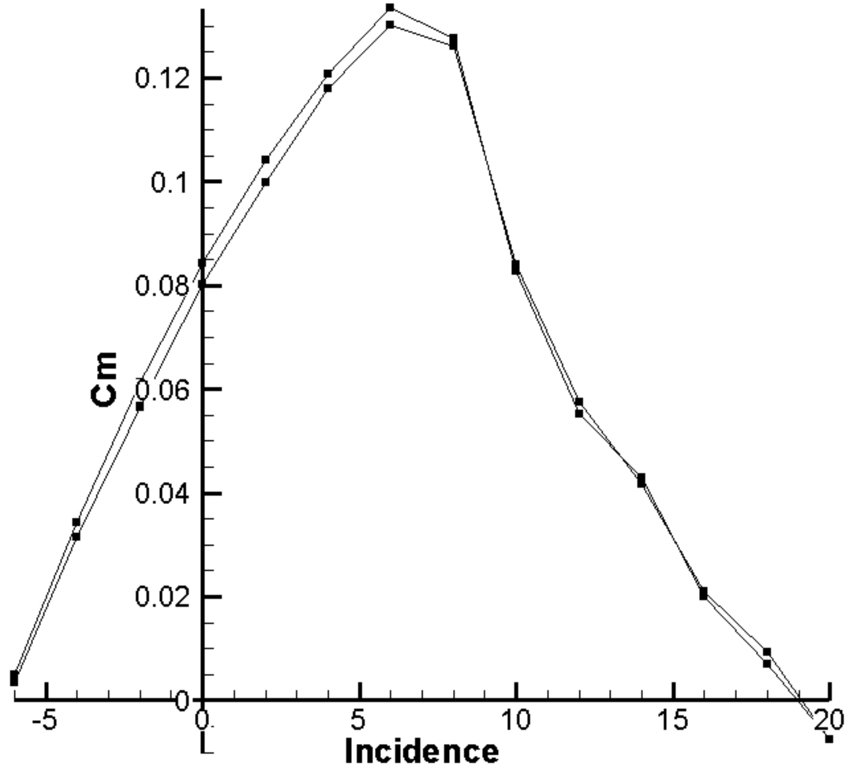


Aero Testing: Cd vs. Cl



Aero Testing: Cm

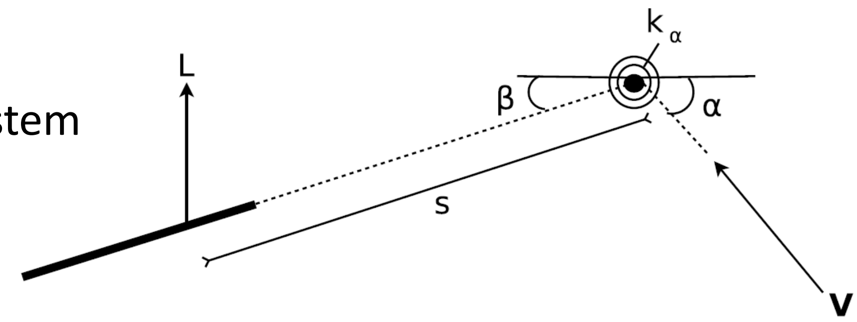
(+ve nose up)



For information only

Aeroelasticity – why aerodynamics ('aero…') cares about structural behaviour ('…elasticity')

2D torsional spring system



Angles exaggerated for clarity - all angles 'small'

$$L s \cos(\beta) = k_\alpha \beta$$ Moment equilibrium

$$\left(\frac{dC_L}{d\alpha}(\beta+\alpha)+C_{L_0}\right)q_\infty c s = k_\alpha \beta$$

$$\beta = -\frac{\alpha + \frac{C_{L0}}{\frac{dC_L}{d\alpha}}}{1-\frac{k_\alpha}{\frac{dC_L}{d\alpha}q_\infty c s}}$$

$$C_{L_{AE}} = \frac{dC_L}{d\alpha}(\alpha+\beta)+C_{L_0} = \frac{dC_L}{d\alpha}\left(\alpha - \frac{\alpha+\frac{C_{L0}}{\frac{dC_L}{d\alpha}}}{1-\frac{k_\alpha}{\frac{dC_L}{d\alpha}q_\infty c s}}\right)+C_{L_0}$$

Real world

(a) Unloaded

(b) Loaded

Design Tradeoffs

Sweep lowers Clmax

Higher aspect ratio reduces induced drag, but for fixed span lowers area, reducing maximum available lift

High 2nd moment of area lowers tip deflection for a fixed volume, but will increase Cd0 as the aerofoil becomes more bluff

High Clmax is not necessarily associated with good L/D – probably the opposite

Don’t forget…

Make sure to download the advice document (also gives requirements for final report) and Matlab software from BB, located in Design/Flight Design Project

This is a **group task**. You need to **work together** – this is how engineering functions in the real world, and it is therefore part of an engineering degree.

You are adults. I am not going to tell you how to work together (but a hint is – **cooperate**).

So, if you do not each complete the pieces of work required by your group you will loose the **trust and respect** of your colleagues. You can **never** get this **trust and respect** back.

Do not go down this route – it is the road to ruin!

(I should not need to tell you this)

Submission Protocol

- **No extensions will be granted for IT failures (personal or University). Back up your work. If you have a failure and ask for an extension I will refer you to this statement. Not reading this statement or not being present for this lecture will not create an exception to this rule**
- **Always take a receipt (print screen) to confirm your report has been uploaded to BlackBoard. I will not consider extensions based on BlackBoard submission problems unless supported by a receipt clearly showing the date and time of submission**
- **You have been warned**
- **Wing designs must be submitted by 24th Feb to be cut out!**