Vibrations 2, Lecture 21
Static Aeroelasticity
Control effectiveness & control reversal

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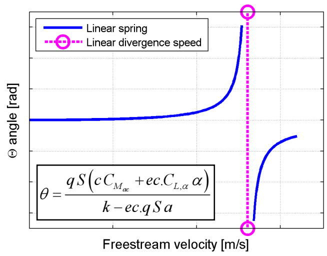
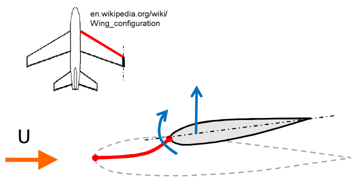
Lecture 20 review

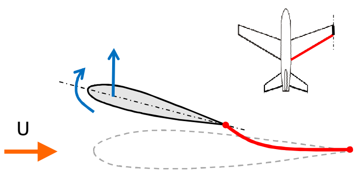
Divergence:



$$\theta = \frac{qS\left(cC_{M_{\alpha0}} + ec.C_{L,\alpha}\,\alpha\right)}{k - ec.qSa}$$



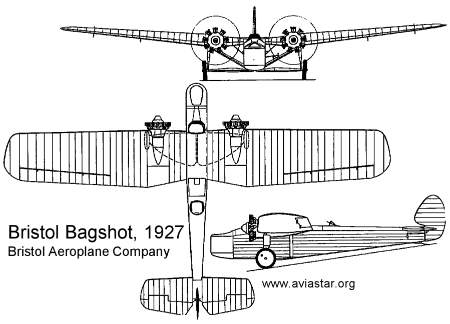
$$U_D = \sqrt{\frac{2k}{ec.SC_{L,\alpha}\,\rho}}$$



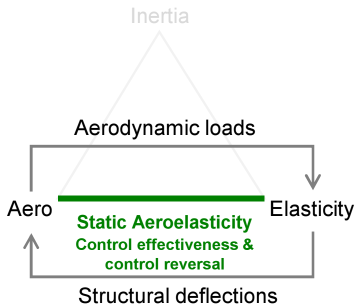
Background

- Control surfaces
  - Change effective camber of aerofoil and therefore lift
  - Used to manoeuvre aircraft in-flight
- Static aeroelastic deflections
  - Application of control surface rotation causes wing deflection
  - Changes effectiveness of control surfaces
- Reversal speed and Control reversal
  - Speed at which control surfaces have no effect
  - Beyond reversal speed, control surfaces have opposite effect

Bristol Bagshot



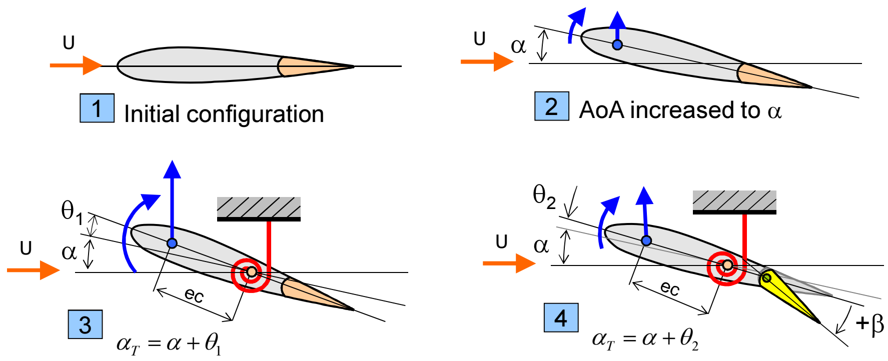
Bristol Bagshot, 1927
Bristol Aeroplane Company
www.aviastar.org



“The Bagshot was first flown … at Filton on 15 July 1927 by Cyril Uwins, Bristol's chief test pilot. This first flight was short: 'Always a bad sign' remarks Archibald Russell (later Sir Archibald), who at that time was working in the stress calculations office at Filton. Uwins reported that **control in the roll axis was poor.** A second flight, during which Uwins pushed the speed up to 100 mph, revealed that **the problem became worse as the speed increased**. … By the time the aircraft reached the agreed speed and height for the trials … **the "writhing movements" of the wing were "large and alarming"** … **It was concluded that control reversal resulting from twisting of the wing when the ailerons were applied was the cause of the problems. The aircraft was grounded for a structural test to be made.**“, https://en.wikipedia.org/wiki/Bristol_Bagshot

Aeroelastic response with flap

Torsionally supported rigid wing with a control surface placed in airstream:



Deformation θ_1 caused by aero-loads and change in aero-loads due to change in θ_1.

$$C_L = C_{L0} + C_{L,\alpha}\,\alpha_T$$

$$C_{Mac} = C_{M0}$$

Further change from θ_1 to θ_2 caused by aero-loads changes induced by the application of flap, i.e. $\beta>0$.

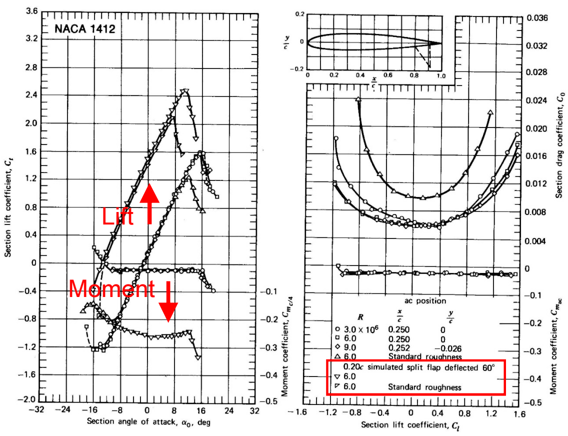
$$C_L = \cancel{C_{L0}} + C_{L,\alpha}\,\alpha_T + C_{L,\beta}\,\beta$$

$$C_{Mac} = \cancel{C_{M0}} + C_{M,\beta}\,\beta,\; C_{M,\beta} < 0$$

Symmetric airfoil

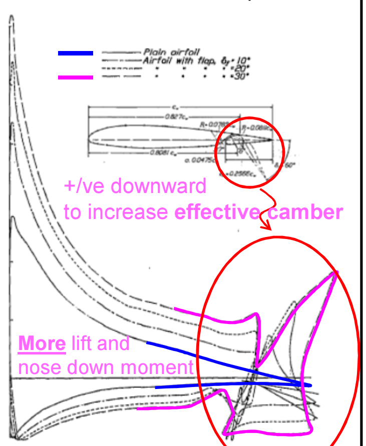
Static airfoil characteristics

e.g. NACA charts:



$$\boxed{C_{M,\beta} < 0}$$

Pressure distribution **change** over an airfoil with a slotted flap



At the same angle of attack 8 deg.

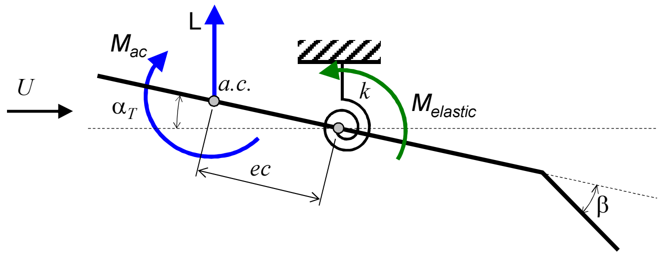
NACA Report 633

Equation of moment equilibrium

Aerodynamics:

$$C_L = C_{L,\alpha}\alpha + C_{L,\beta}\beta$$

$$C_{Mac} = \cancel{C_{M0}} + C_{M,\beta}\beta$$



Static equilibrium:

$$\sum_{(i)} M_i = 0$$

$$ec.L + M_{ac} = M_{elastic}$$

$$ec.qS(C_{L,\alpha}\alpha_T + C_{L,\beta}\beta) + qSc(C_{M,\beta}\beta) = k\theta$$

$$ec.qS(C_{L,\alpha}(\alpha_r + \theta) + C_{L,\beta}\beta) + qSc(C_{M,\beta}\beta) = k\theta$$

Aeroelastic response:

$$\theta = \frac{qS(ecC_{L,\alpha}\alpha_r + (cC_{M,\beta} + ecC_{L,\alpha})\beta)}{k - ec.qSC_{L,\alpha}}$$

Lift:

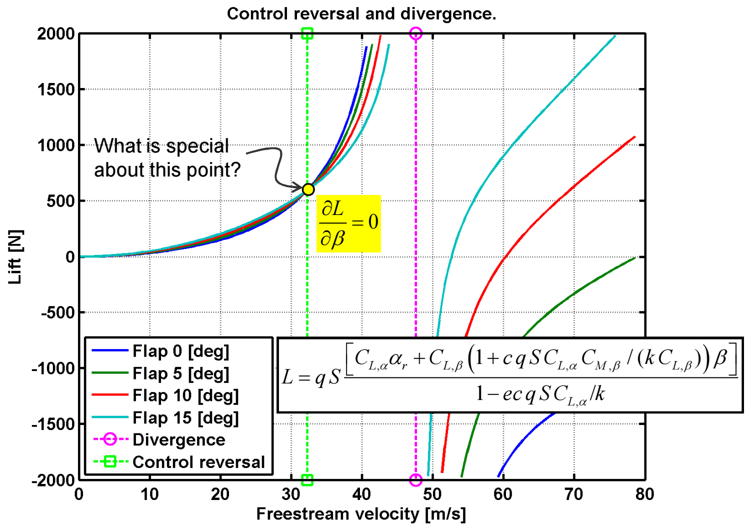
$$L = qSC_L = qS(C_{L,\alpha}(\alpha_r + \theta) + C_{L,\beta}\beta) = \ldots$$

$$\ldots$$

$$L = qS\frac{\left[C_{L,\alpha}\alpha_r + C_{L,\beta}\left(1 + \frac{cqSC_{L,\alpha}C_{M,\beta}}{kC_{L,\beta}}\right)\beta\right]}{1 - \frac{ecqSC_{L,\alpha}}{k}}$$

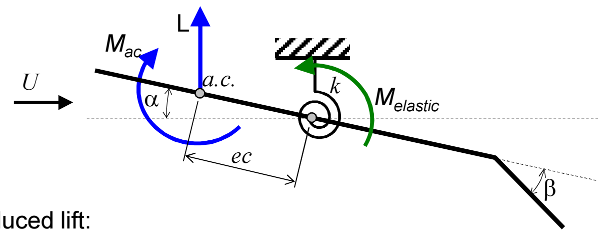
… from this: **Lift sensitivity = d*L*/dβ**

Lift = function(U,beta)



Download example script from BB: ae_controlrev.m

Control reversal speed U_R



Resulting induced lift:

$$L = qS\frac{\left[C_{L,\alpha}\alpha_r + C_{L,\beta}\left(1+\frac{c\,q\,S\,C_{L,\alpha}\,C_{M,\beta}}{k\,C_{L,\beta}}\right)\beta\right]}{1-\frac{ec\,q\,S\,C_{L,\alpha}}{k}}$$

Divergence pressure:

$$\boxed{1-\frac{ec\,q\,S\,C_{L,\alpha}}{k}=0 \Rightarrow q_D = \frac{k}{ec\,S\,C_{L,\alpha}}}$$

Control reversal point:

$$\frac{\partial L}{\partial \beta} = qS\frac{C_{L,\beta}\left(1+\frac{c\,q\,S\,C_{L,\alpha}\,C_{M,\beta}}{k\,C_{L,\beta}}\right)}{1-\frac{ec\,q\,S\,C_{L,\alpha}}{k}} = 0$$

$$q\,S\,C_{L,\beta}\left(1+\frac{c\,q\,S\,C_{L,\alpha}\,C_{M,\beta}}{k\,C_{L,\beta}}\right)=0$$

$$\boxed{q_R(U_R) = -\frac{k\,C_{L,\beta}}{Sc\,C_{L,\alpha}\,C_{M,\beta}}}$$ Reversal pressure

Lift effectiveness

Rigid aerofoil: k→Infinity $\quad \frac{\partial L}{\partial \beta} = qSC_{L,\beta}\frac{1+\frac{c\,q\,S\,C_{L,\alpha}\,C_{M,\beta}}{k\,C_{L,\beta}}}{1-\frac{ec\,q\,S\,C_{L,\alpha}}{k}} \rightarrow \left.\frac{\partial L}{\partial \beta}\right|_{rigid} = qSC_{L,\beta}$

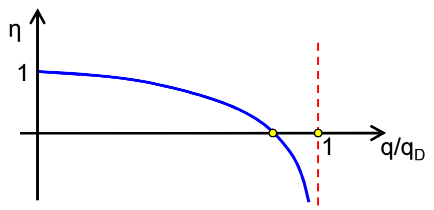
Divergence and control reversal dynamic pressures: $\quad q_D = \frac{k}{ec.SC_{L,\alpha}} \qquad q_R = -\frac{k\,C_{L,\beta}}{Sc\,C_{L,\alpha}\,C_{M,\beta}}$

Then, lift sensitivity to control: $\quad \frac{\partial L}{\partial \beta} = qSC_{L,\beta}\frac{(1-q/q_R)}{(1-q/q_D)}$

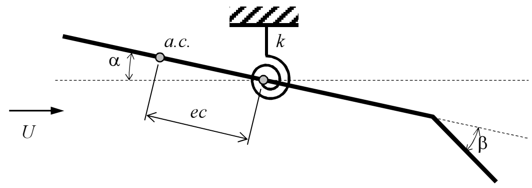
Finally, **lift effectiveness**:

(or normalized lift sensitivity)

$$\boxed{\eta = \frac{\left.\partial L/\partial \beta\right|_{elastic}}{\left.\partial L/\partial \beta\right|_{rigid}} = \frac{1-q/q_R}{1-q/q_D}}$$



Control reversal and roll control



Downward displacement of aileron causes extra lift:

(a) rolling moment

(b) nose-down pitching moment:

elastic deformation → reduced lift → reduced rolling moment!

At a critical speed, the net effect of deflecting the aileron becomes zero, in which case the aileron is totally ineffective! This is the *critical aileron reversal speed.*

- Below critical speed, right aileron deflection left wing tip down,
- Above critical speed, right aileron deflection right wing tip down,
- Aileron becomes more ineffective nearer to critical speed.

Summary

- Control reversal (flaps, ailerons, etc.):
  - **Definition:** Control reversal is the loss, due to the flexibility of the primary aerostructure, of aircraft maneuvering loads induced by control surfaces [Platanitis & Strganac, 2005].
- Important parameters:
  - Torsional stiffness,
  - Aerodynamic derivatives.