UNIT 5

DEFINITIONS

Aeroelasticity :

- aeroelastic problems would not exist if airplane structures where perfectly rigid.
- many important aeroelastic phenomena involve inertia forces as well as aerodynamic and elastic forces.

Static Aeroelasticity :

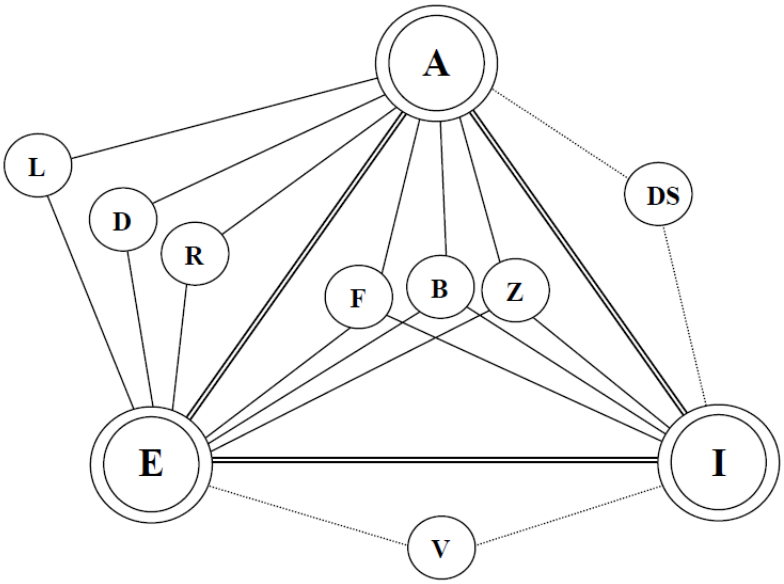
Science which studies the mutual interaction between aerodynamic forces and elastic forces, and the influence of this interaction on airplane design.

Dynamic Aeroelasticity :

Phenomena involving interactions of inertial, aerodynamic, and elastic forces.

Collar diagram :

Describes the aeroelastic phenomena by means of a triangle of forces



A – Aeroelastic force
E – Elastic force
I – Inertial force

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DYNAMIC AEROELASTICITY - Phenomena involving all three type of forces:

- F – **Flutter:** dynamic instability occurring for aircraft in flight at a speed called flutter speed
- B – **Buffeting:** transient vibrations of aircraft structural components due to aerodynamic impulses produced by wake behind wings, nacelles, fuselage pods, or other components of the airplane
- Z – **Dynamic response:** transient response of aircraft structural components produced by rapidly applied loads due to gusts, landing, gun reactions, abrupt control motions, and moving shock waves

STATIC AEROELASTICITY - Phenomena involving only elastic and aerodynamic forces:

- L – **Load distribution:** influence of elastic deformations of the structure on the distribution of aerodynamic pressures over the structure
- D – **Divergence:** a static instability of a lifting surface of an aircraft in flight, at a speed called the divergence speed, where elasticity of the lifting surface plays an essential role in the instability.
- R – **Control system reversal:** A condition occurring in flight, at a speed called the control reversal speed, at which the intended effect of displacing a given component of the control system are completely nullified by elastic deformations of the structure.

RELATED FIELDS :

- V – **Mechanical vibrations**
- DS – **Rigid-body aerodynamic stability**

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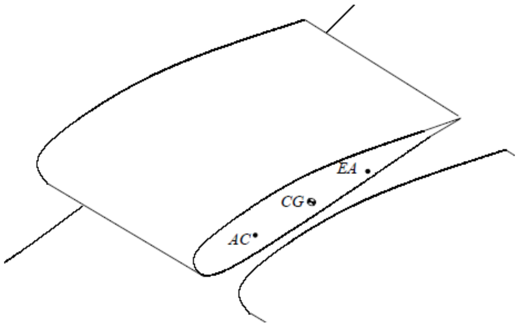
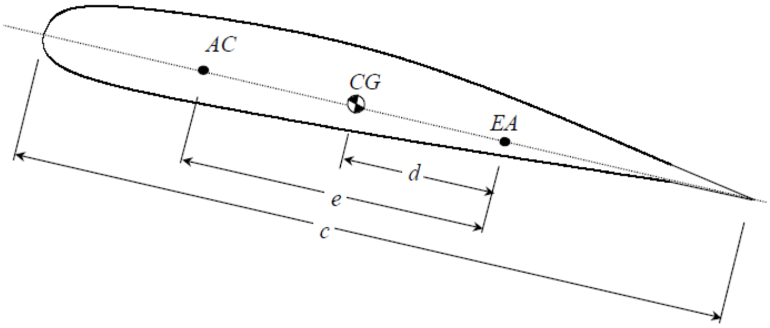
TERMINOLOGY

Let's consider a section of the wing:





AC Aerodynamic center
: point about which the pitching moment M_{AC} is independent of angle of attack α. Usually close to quarter chord, $(0.25\,c)$

CG Center of Gravity
: point of location of the net weight of the body.

EA Elastic axis
: located by drawing a spanwise line through the shear centers of the cross sections of the beam

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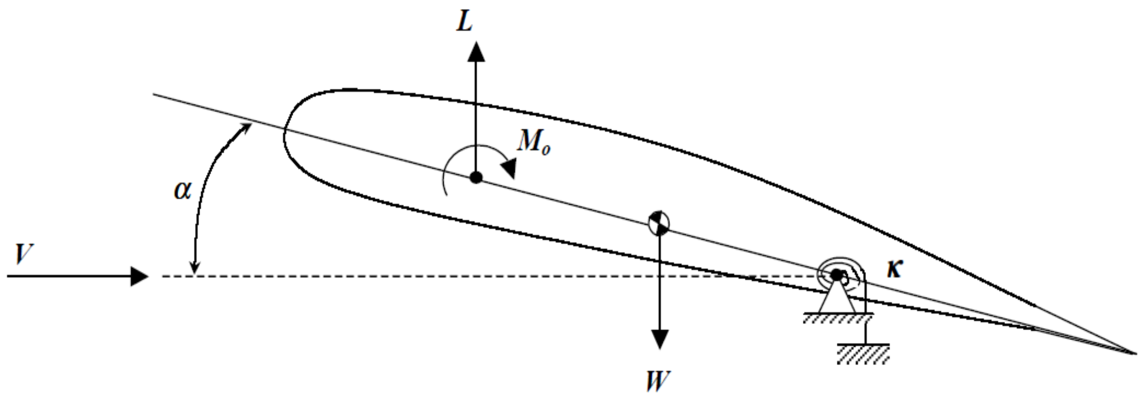

Neglect drag :

$$\frac{L}{D} \gg 1$$

K –Rotational spring stiffness. Represents $\frac{GJ}{L}$ of the real elastic wing

α – angle of attack relative to zero lift angle
Assume small angles

$$\tan\alpha \approx \alpha \qquad \sin\alpha \approx \alpha \qquad \cos\alpha \approx 1$$

$\alpha = \alpha_0 + \theta$

α_0 – rigid angle of attack; initial wing incidence; angle if no aero- or gravity loads were present.

θ – angle due to elastic deformation

L –Lift force, primarily produced by pressure forces on vehicle surface

$L = q\,S\,C_\ell$

$q = 0.5\,\rho\,V^2$: is the dynamic pressure

ρ – fluid density

V – aircraft's speed

$S = c\,b$: is the wing planform area

c – chord

b – span

$C_\ell = a_0\,\alpha$: is the dimensionless lift coefficient

$a_0 = \frac{\partial C_\ell}{\partial \alpha}$ is the lift curve slope (assumed constant between stall points)

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$\boldsymbol{M_{AC}}$ –Wing pitching moment about the aerodynamic center

$M_{AC} = q\,S\,c\,C_{m_{AC}}$

$q = 0.5\,\rho\,V^2$: is the dynamic pressure

$S = c\,b$: is the wing planform area

$C_{m_{AC}}$: is the dimensionless pitching moment coefficient about the AC independent of α

EQUILIBRIUM

Take ↻ $\sum$ of moments about EA:

$$\begin{aligned} e\,L\,\underbrace{\cos\alpha}_{\approx 1} + M_{AC} - d\,W\,\underbrace{\cos\alpha}_{\approx 1} - K\,\theta &= 0 \\ e\,q\,S\left(\frac{\partial C_\ell}{\partial \alpha}\right)\alpha + q\,S\,c\,C_{m_{AC}} - d\,W - K\,(\alpha - \alpha_0) &= 0 \end{aligned}$$

Rearranging,

$$\left[e\,q\,S\left(\frac{\partial C_\ell}{\partial \alpha}\right) - K\right]\alpha = d\,W - q\,S\,c\,C_{m_{AC}} - K\,\alpha_0 \tag{1}$$

$$\left[1 - \frac{q\,S\left(\frac{\partial C_\ell}{\partial \alpha}\right)e}{K}\right]\alpha = \alpha_0 - \frac{d\,W}{K} - \frac{q\,S\,c\,C_{m_{AC}}}{K} \tag{2}$$

DIVERGENCE

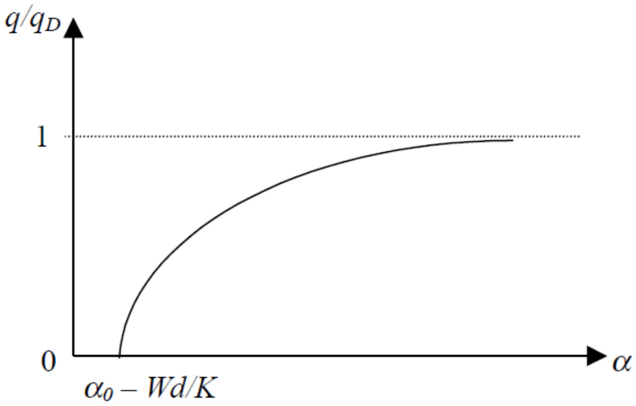
Let's define the divergence dynamic pressure

$$q_D = \frac{K}{S\left(\frac{\partial C_\ell}{\partial \alpha}\right)e} \tag{3}$$

Now eq. (2) can be rewritten as

$$\alpha = \frac{\alpha_0 - \dfrac{dW}{K} + \left(\dfrac{q}{q_D}\right) \dfrac{K}{S\left(\dfrac{\partial C_\ell}{\partial \alpha}\right) e} \dfrac{S\,c\,C_{m_{AC}}}{K}}{1 - \dfrac{q}{q_D}} \tag{4}$$

$$\alpha = \frac{\alpha_0 - \dfrac{dW}{K} + \left(\dfrac{q}{q_D}\right) \dfrac{c}{e} \dfrac{C_{m_{AC}}}{\left(\dfrac{\partial C_\ell}{\partial \alpha}\right)}}{1 - \dfrac{q}{q_D}} \tag{5}$$



The plot of q/q_D versus α shows that $\alpha \to \infty$ as $q \to q_D$ for $0 < q < q_D$.

In reality the wing will stall or twist off due to strength failure.

The divergence speed is calculated from the divergence dynamic pressure:

$$q_D = \frac{1}{2}\rho V_D^2 \qquad \Rightarrow \qquad V_D = \sqrt{\frac{2\,q_D}{\rho}} \tag{6}$$

Divergence corresponds to a static instability. At $V = V_D$ we get excessive rotation.