Sink speed $v = V\sin\theta$

$\sin\theta = \frac{D}{L}$

$V_{min\,\theta} \approx V_{MD}$ but $V_{min\,sink} \approx V_{MP}$

glide angle $\theta = \tan^{-1}\left(\frac{1}{C_L/C_D}\right)$

climb angle $\theta = \sin^{-1}\left(\frac{T-D}{W}\right)$

rate of climb

$v = V\sin\theta$

Climb & Glide

rate of increase of

PE = $Wv = TV - DV$

power avaliable (→ TV)

power required (→ DV)

$\frac{C_L}{C_D} = \frac{L}{D}$

→ ratios same as they use the same constants

wing loading $\frac{W}{S}$

$C_L = \frac{w}{q}$

dynamic pressure $\frac{1}{2}\rho V^2$

$C_L = \frac{L}{\frac{1}{2}\rho_\infty V^2 S}$

$V_{min} \propto \frac{1}{\sqrt{C_{L\,max}}}$

$V_{MP} = \left(\frac{2W}{\rho S}\right)^{\frac{1}{2}}\left(\frac{K}{3C_{D_0}}\right)^{\frac{1}{4}}$

Power = TV = DV

→ multiply D equations by V

$C_{D_{MP}} = 4C_{D_0}$

$C_{L_{MP}} = \sqrt{3C_{D_0}/K}$

Lift varies with V^2 as it's a function of mass flow rate & vertical velocity

Lift - perp comp to relative wind

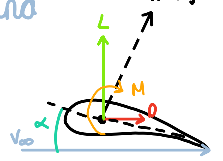
$\frac{x_{ac}}{c} = 0.25$

$C_{M_{ac}} = C_{M_0}$

$C_{Mx} = C_{Mle} + \left(\frac{x}{c}\right)C_L$

$C_M = \frac{M}{\frac{1}{2}\rho V^2 S c}$

pitching moment



Aerodynamic force

$V_{EAS} = V\sqrt{\sigma}$

Density

$\sigma = \frac{\rho}{\rho_{SL}} = \frac{20-H}{20+H}$ (H in km)

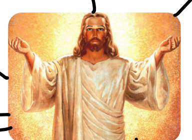
above trop. = 216.65K

Temp

below trop

$= 288.15 - 6.5\times10^{-3}h$

Atmosphere



Drag - parallel comp to relative wind

Min drag at

$C_{D\,min} = 2C_{D_0} = 2KC_L^2$

$C_{L_{MD}} = \sqrt{C_{D_0}/K}$

$\left(\frac{C_D}{C_L}\right)_{min} = 2\sqrt{C_{D_0}K}$

$C_D = \frac{D}{\frac{1}{2}\rho V^2 S}$

$C_D = C_{D_0} + KC_L^2$

profile (C_{D_0}), induced (KC_L^2)

$K = \frac{1}{\pi e AR}$

Cruise

Thrust, $T = kT_0\sigma^x$

Throttle setting (k)

Max thrust at SL (T_0)

x: 0.7 below 11km, 1 above 11km

Critical mach (M_{crit})

- lowest free stream M_∞ at which any part of aerofoil flow reaches speed of sound

Drag divergence M_∞

- M_∞ where D↑ due to wave drag caused by shock waves

Mach N°

$M = \frac{V_\infty}{a}$

important at high speed

a is the speed of sound

$a = \sqrt{\gamma RT}$

$\gamma = 1.4$, $R = 287$

a also $= a_{SL}\sqrt{\theta}$

Reynold's Number

$Re = \frac{\rho V_\infty c}{\mu}$

important at low speed

Ratio of inertial to viscous forces

Induced drag ($\propto L^2$)

- formation of wingtip vortices

→ downwash with tip vortices with KE

downwash reduces L & α

Sources of Drag

Pressure

Wave Drag

- due to shock formation at high speed

Form drag

- due to front to rear pressure assymmetry

→ ↑ with ↑ wake size

Skin friction

- streamwise component of surface shear stress

→ boundary layer growth

Profile = form + skin

$V_{MD} = \left(\frac{2W}{\rho S}\right)^{\frac{1}{2}}\left(\frac{K}{C_{D_0}}\right)^{\frac{1}{4}}$

Endurance & Range (Jet)

time aircraft can remain in flight

$E = \frac{1}{fg}\frac{C_L}{C_D}\ln\left(\frac{W_1}{W_2}\right)$

TSFC (f)

Max endurance at max $\frac{C_L}{C_D}$ → $C_{D_{max\,E}} = 2C_{D_0}$, $C_{L_{max\,E}} = \sqrt{C_{D_0}/K}$

horizontal distance aircraft can cover

$= V \times E$

subbing $V = \sqrt{\frac{W}{\frac{1}{2}\rho S C_L}}$ → $R = \sqrt{\frac{8}{\rho S}}\frac{1}{fg}\frac{C_L^{\frac{1}{2}}}{C_D}\left(W_1^{\frac{1}{2}} - W_2^{\frac{1}{2}}\right)$

in Mach terms

$R = \frac{a}{fg}\left(M\frac{L}{D}\right)\ln\left(\frac{W_1}{W_2}\right)$

Max R at max $\frac{C_L^{\frac{1}{2}}}{C_D}$ → $C_{D_{max\,R}} = \frac{4}{3}C_{D_0}$ → $C_{L_{max\,R}} = \sqrt{C_{D_0}/3K}$

For propeller

$$E = \frac{\eta}{fg}\frac{1}{V}\frac{C_L}{C_D}\ln\left(\frac{W_1}{W_2}\right)$$

$$C_{D_{max E}} = 4C_{D_0}$$

$$C_{L_{max E}} = \sqrt{\frac{3C_{D_0}}{K}}$$

$$R = V \times E$$

$$C_{D_{max R}} = 2C_{D_0}$$

$$C_{L_{max R}} = \sqrt{\frac{C_{D_0}}{K}}$$

Weight

W_{final} = Operational empty weight + payload + reserve fuel weight

$W_{initial} = W_{final}$ + Trip fuel weight

Manoeuvres

Load factor $n = \frac{L}{W}$

Corner velocity

$$V^* = \sqrt{\frac{2n_{max}W}{\rho S C_{L_{max}}}}$$

$$n = \frac{\rho a_1 V}{2W/S} + 1$$

Banked Turns

Turn radius, $R = \frac{V^2}{g\sqrt{n^2-1}}$

Turn rate, $\omega_t = \frac{g\sqrt{n^2-1}}{V}$

Time through angle, $\theta = \frac{\theta_{rad} V}{g\sqrt{n^2-1}}$

$\cos\phi = \frac{1}{n}$ → bank angle

Stall limited turn

$$n = \left(\frac{V}{V_{S1}}\right)^2$$

subbing in

$$R = \frac{V_{S1}}{g}\left(1-\left(\frac{V_{S1}}{V}\right)^4\right)^{-\frac{1}{2}}$$

Change in drag between steady level & load factor n

$$\Delta T = \frac{KW^2}{\frac{1}{2}\rho S g^2}\frac{V^2}{R}$$

$$\Delta P = \frac{KW^2}{\frac{1}{2}\rho S g^2}\frac{V^3}{R}$$

$\frac{C_L}{C_D}$ relation	Maximised When	C_L	C_D	Relates to
$\frac{C_L^{3/2}}{C_D}$	$C_{D_0} = \frac{1}{3}KC_L^2$	$\sqrt{\frac{3C_{D_0}}{K}}$	$4C_{D_0}$	Min power required Min sink rate Max prop endurance
$\frac{C_L}{C_D}$	$C_{D_0} = KC_L^2$	$\sqrt{\frac{C_{D_0}}{K}}$	$2C_{D_0}$	Min drag Max glide angle Max prop range Max jet endurance
$\frac{C_L^{\frac{1}{2}}}{C_D}$	$C_{D_0} = 3KC_L^2$	$\sqrt{\frac{C_{D_0}}{3K}}$	$\frac{4}{3}C_{D_0}$	Max jet range