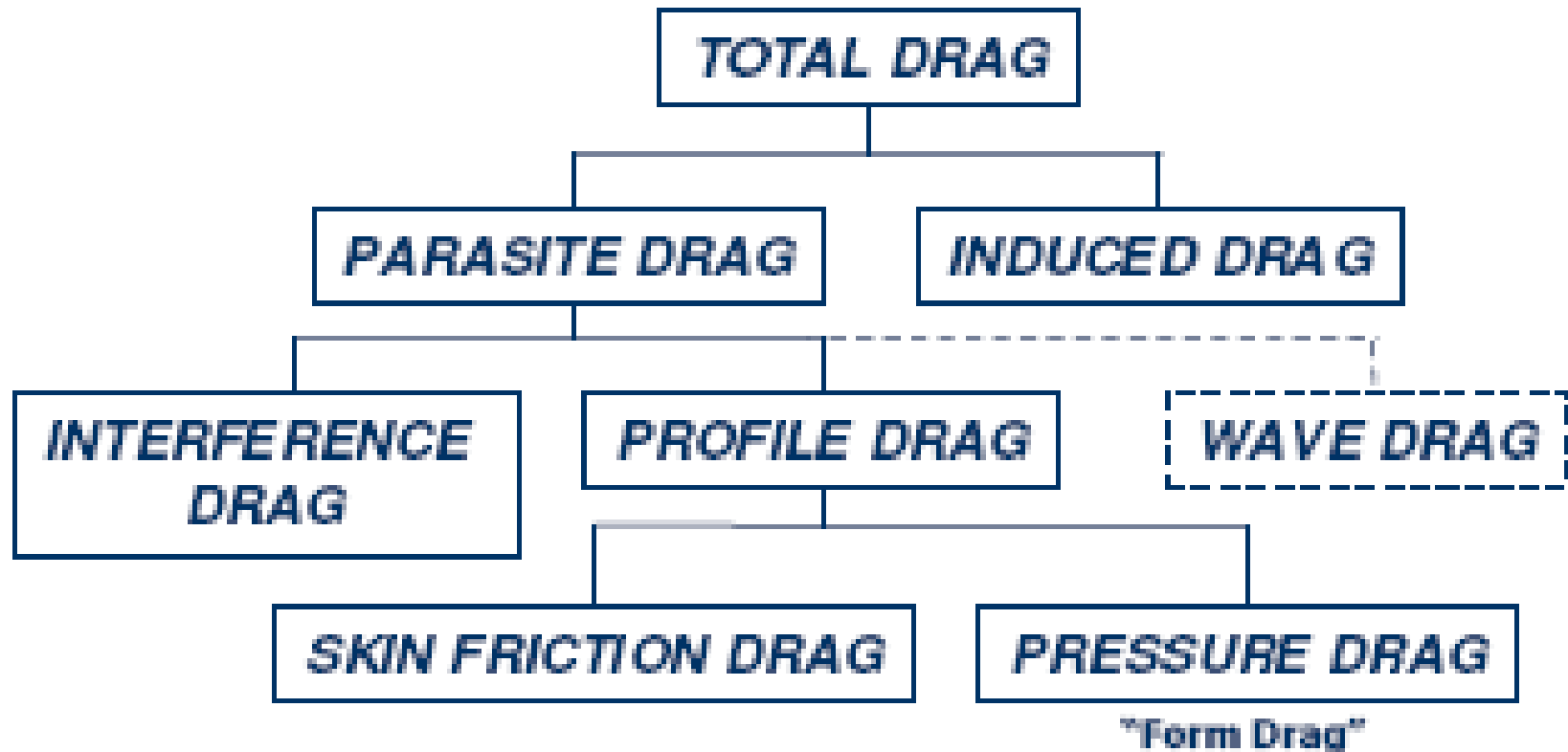


DRAG

Sangram Samal

TYPES OF DRAG



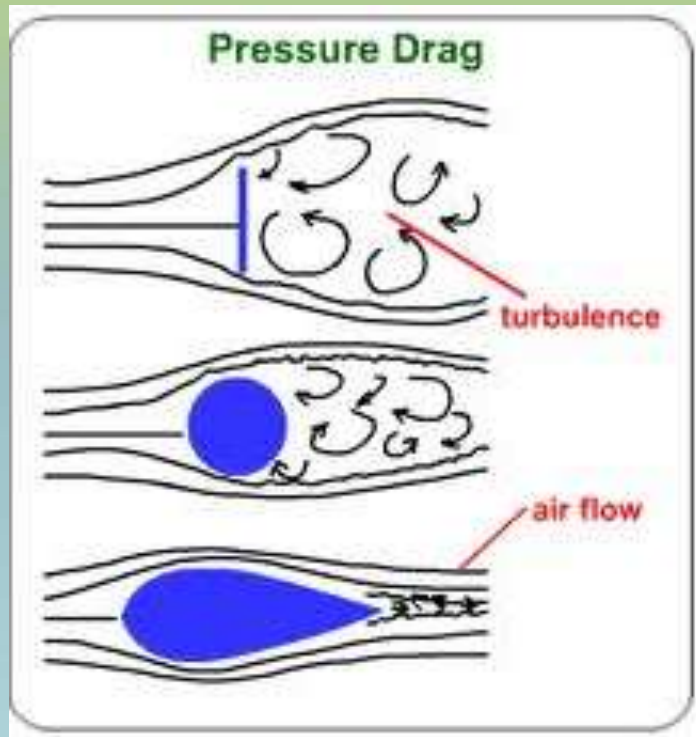
Skin Friction and Roughness Drag

- Aerodynamic resistance or drag due to the contact of moving air with the surface of an airplane.
- It increases considerably if the airplane's surfaces are dirty and rough.
- The skin friction or surface friction drag is determined by the total surface area of the aircraft, the coefficient of the viscosity of the air, and the rate of change of the velocity across the airflow.
- To reduce the skin friction, the surface should be smoothed to the maximum extent.

Pressure or Form Drag

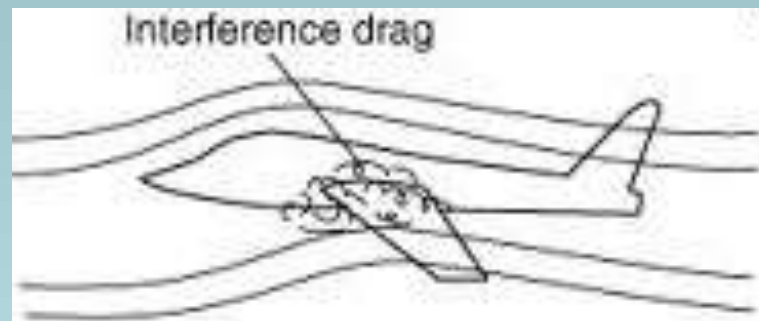
- Drag caused by the pressure difference between the front and behind is called pressure drag.
- The general size and shape of the body is the most important factor in form drag.
- Bodies with a larger frontal cross-section will have a higher drag than thinner bodies
- Sleek designs, or designs that are streamlined and change cross-sectional area gradually are also critical for achieving minimum form or pressure drag.

Pressure or Form Drag



Interference drag

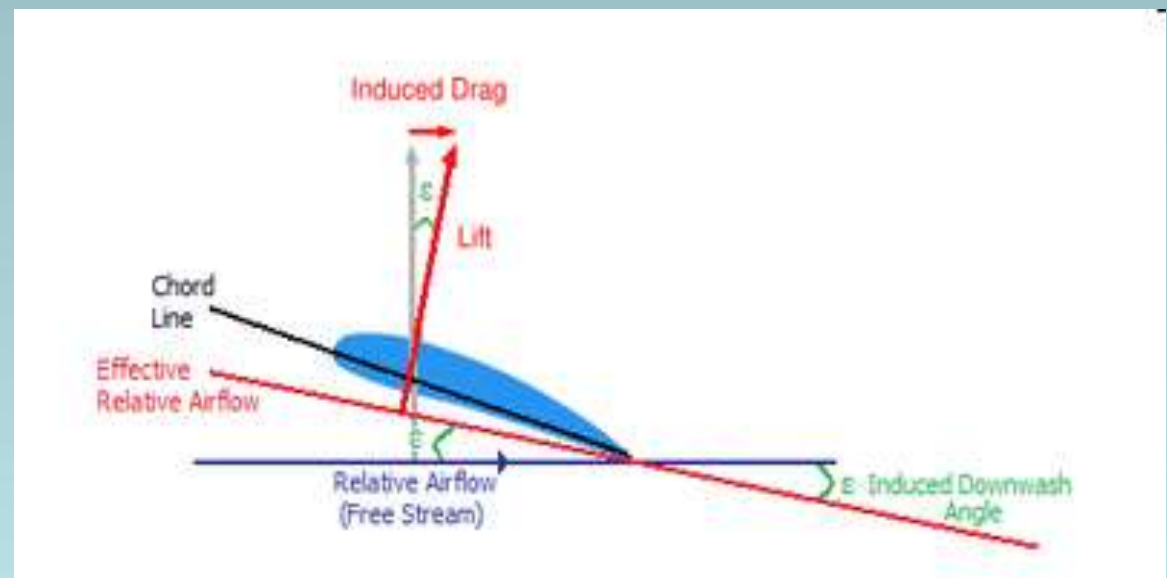
- The drag on an aircraft caused by the interaction of two aerodynamic bodies.
- Joints of aerodynamics parts should be smooth and aerodynamics shape to reduces the interference drag.



Induced drag

- This drag is also known as **lift-induced drag**, **induced drag**, **vortex drag**, or sometimes **drag due to lift**.
- This drag is created due to downwash behind the 3-D wing (wing of finite span).
- Induced drag is zero for 2-D wing.
- Theoretically a wing of infinite [span](#) and constant [airfoil](#) section would produce no induced drag.
- It decreases with the air speed increases

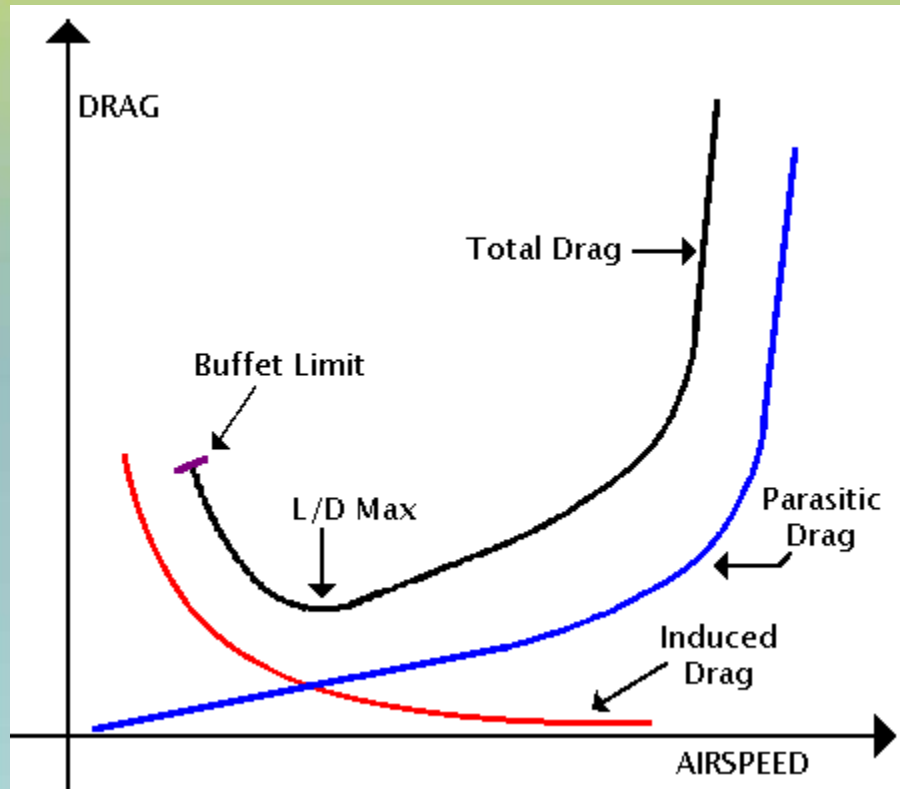
$$C_{Di} = \frac{C_L^2}{\pi e AR}$$



Wave Drag

- Wave drag is occurred in transonic or in supersonic (Mach no > 1)
- Drag rise is due to the presence of shock waves.
- There is strong adverse pressure gradient across the shock wave.
- Shock angle to be minimum to reduce the wave drag.

VARIATION OF DRAG WITH SPEED



Induced drag decreases as V increases, because we need less values of C_L at high speeds.

Other drag forces (form, skin friction, interference) increase.

Result: Drag first drops, then rises.

Minimum Drag & Power Speeds

- This gives a simple theoretical relationship between the flight speeds required for minimum drag and power conditions.

$$\begin{aligned} \text{i.e. } V_{P,\min} &= (k_2/3k_1)^{1/4} = 0.76 (k_2/k_1)^{1/4} \\ &= 76\% V_{D,\min} \end{aligned}$$

- Also, at *minimum power* speed,

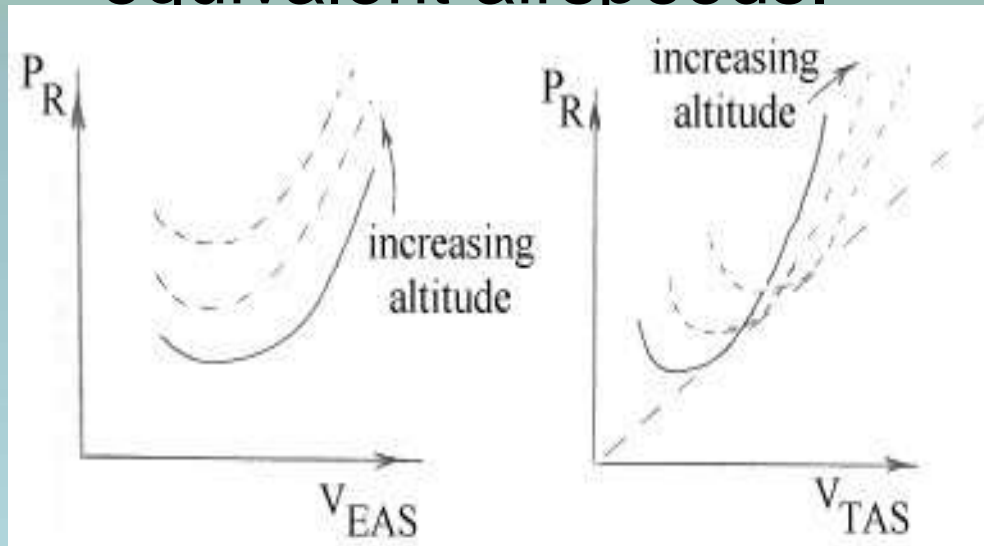
$$3k_1 V^2 = k_2 V^{-2}$$

$$\therefore 3C_{D0} = C_L^2 / (\pi A e)$$

(or lift-induced drag = 3 x parasite drag)

Altitude Effects on P_R v Airspeed

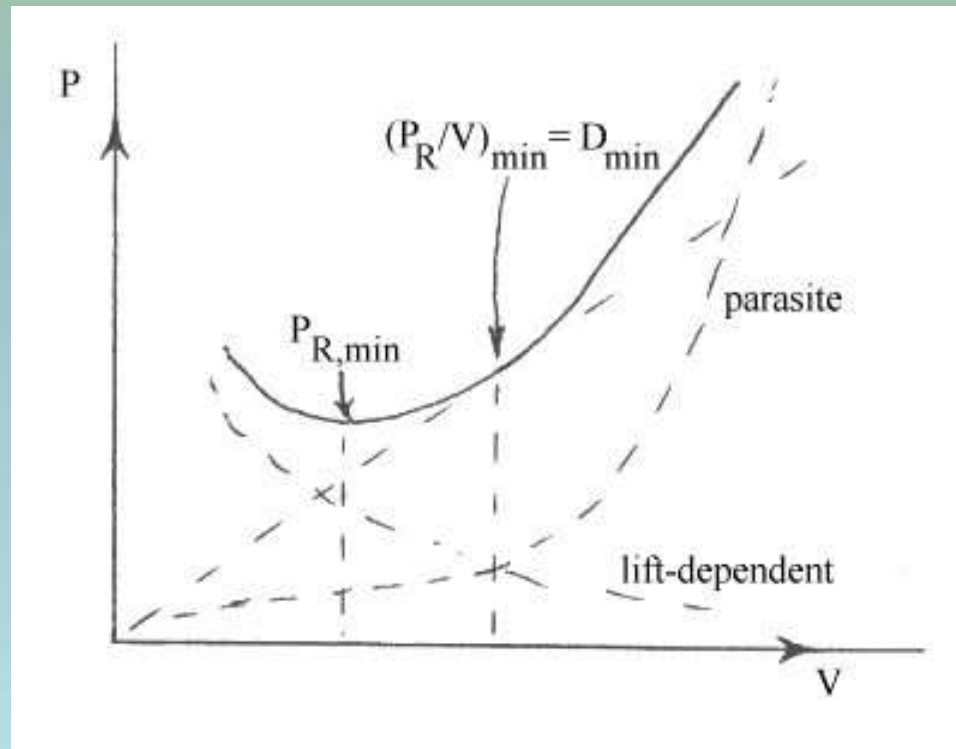
- P_R varies with $1/\sqrt{\sigma}$ (or $\sqrt{\rho_0 / \rho}$).
- Minimum power required increases with altitude but $V_{P,\min}$ fixed if plotted as equivalent airspeeds.



- True airspeed for minimum power condition increases with altitude.

Minimum Drag & Power Speeds

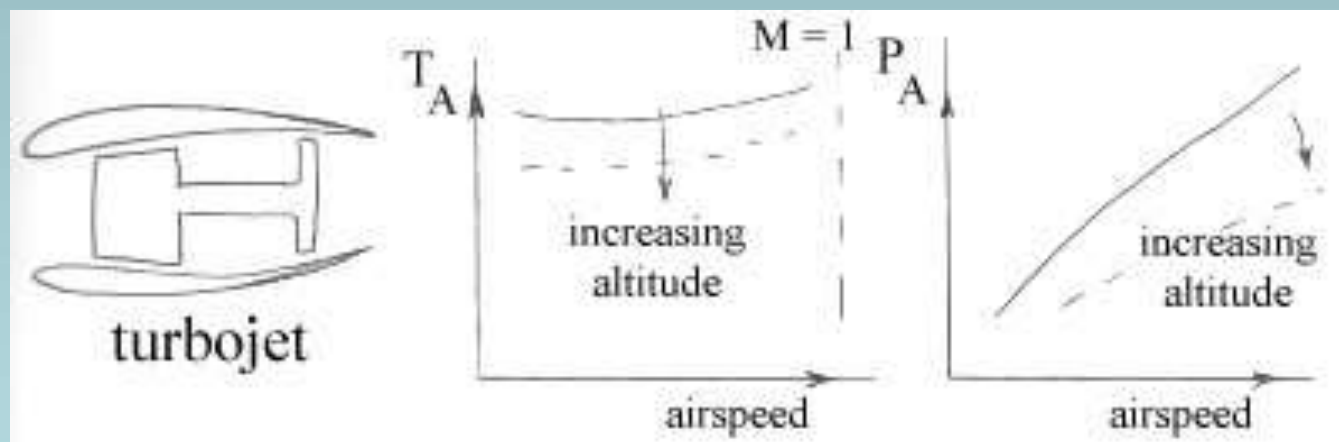
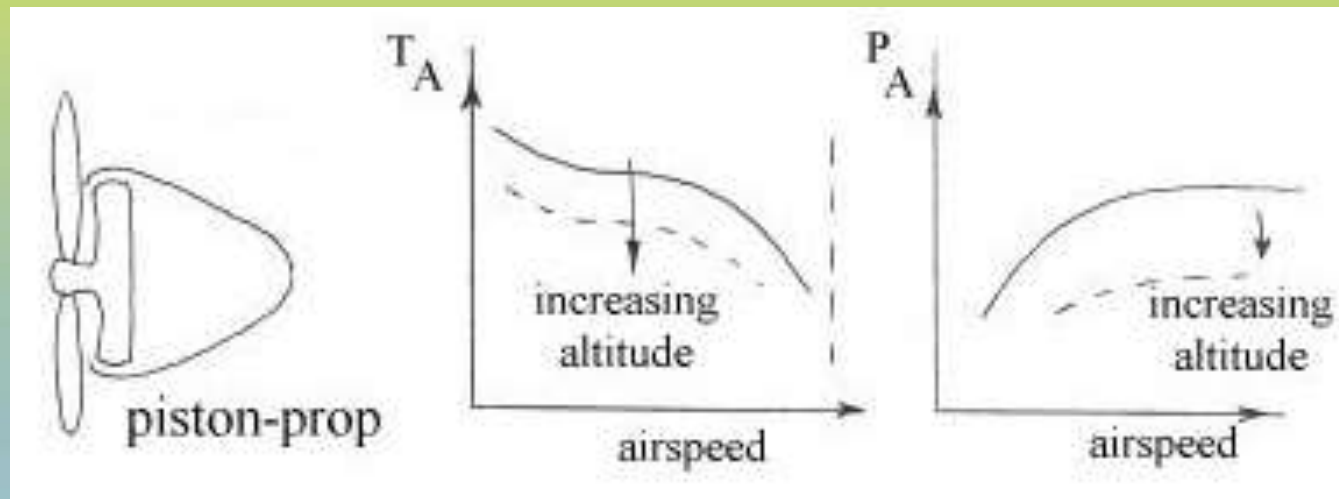
- Since $P = D \times V$, $\therefore D = P / V$ so a single plot of P against V may be used to determine both $V_{P,\min}$ & $V_{D,\min}$.



Available Thrust & Power (T_A , P_A)

- Required thrust is determined by aerodynamics & weight considerations while available thrust and power are functions of the propulsion system performance.
- Big differences between piston-props & turbojets so considered separately.
 - *Turbojets & fans* have reasonably constant thrust values so *thrust-rated*.
 - *Piston-props* are *power-rated*.
- Both thrust & power reduce with increased altitude (reduced density).

Available Thrust & Power

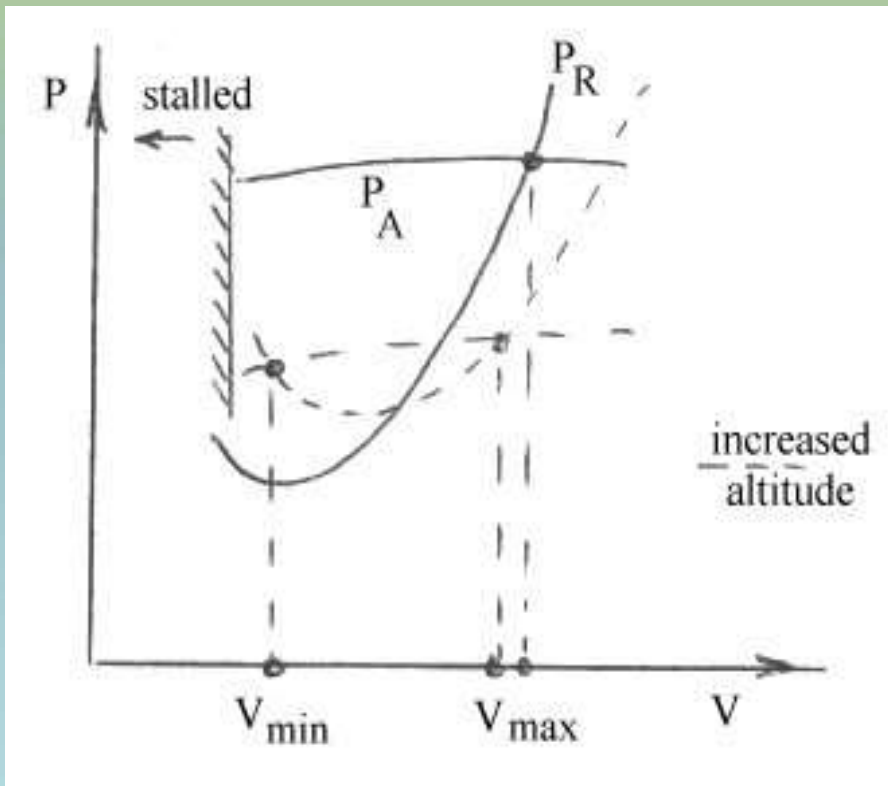


Maximum Velocity

- May be determined from plots of either T_R (or P_R) and T_A (or P_A) against V .
- Intersection of curves gives maximum speed capability and possibly also minimum speed capability (if intersection is above stall speed).
- Piston-props and turbojets/fans usually considered separately.

Maximum Velocity for Piston-Prop

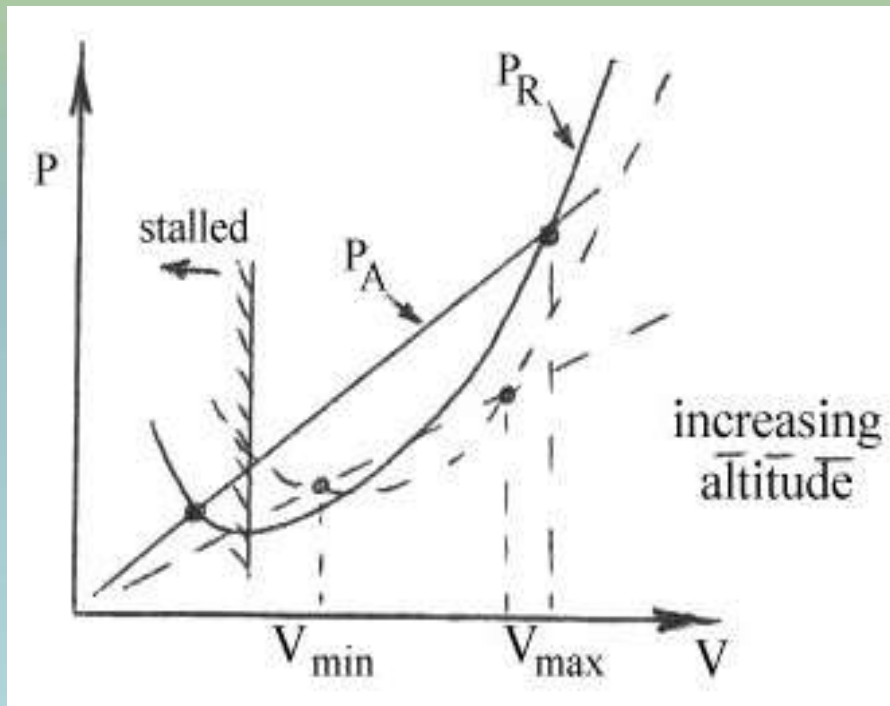
- Most conveniently determined from plots of P_R and P_A against V .



- Dashed lines give curves at increased altitude - both minimum and maximum speeds affected in this case.

Maximum Velocity for Jet/Fan

- Most conveniently determined from plots of T_R and T_A against V .



- Dashed lines give curves at increased altitude - both minimum and maximum speeds again affected in this case.

Breguet Formulae for Piston-Prop A/C

Range Formula

$$R = (\eta/\text{sfc}) \cdot (C_L/C_D) \cdot \ln(W_0/W_1)$$

- Where

W_0 = gross aircraft weight, W_F = fuel weight

$W_1 = W_0 - W_F$, η = propeller efficiency

Endurance Formula

$$E = (\eta/\text{sfc}) \cdot (C_L^{1.5}/C_D) \cdot \sqrt{(2\rho S)(W_1^{-0.5} - W_0^{-0.5})}$$

Range & Endurance Formulae for Jet/Fan A/C

Endurance Formula

$$E = (1/tsfc) \cdot (C_L/C_D) \cdot \ln (W_0/W_1)$$

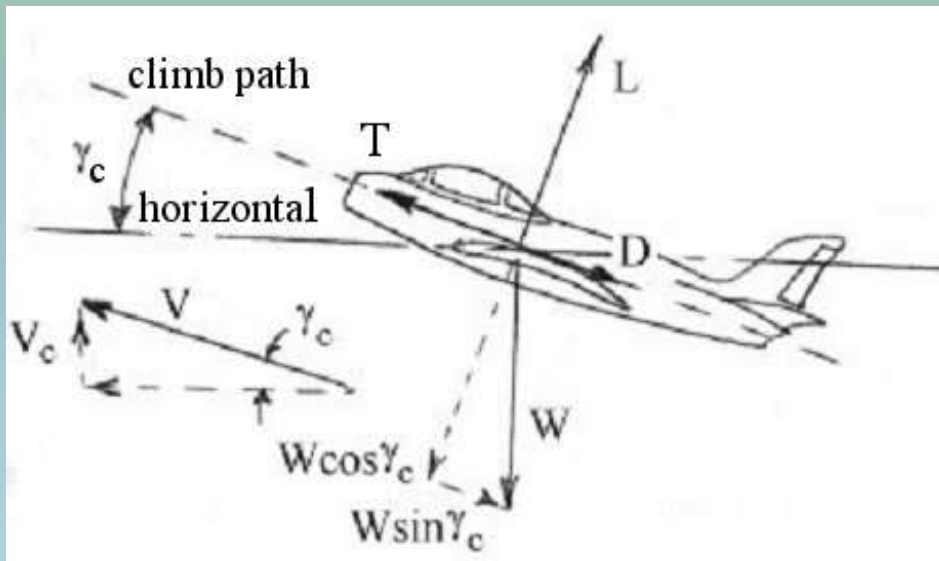
Range Formula

$$R = 2\sqrt{(2/\rho S)} \cdot (1/tsfc) \cdot (C_L^{0.5}/C_D) \cdot (W_1^{-0.5} - W_0^{-0.5})$$

- Note that range is altitude dependent while endurance is not - opposite for piston-props.
- However, tsfc also varies with altitude and eventually increases.

Climbing

- Consider aircraft in a steady unaccelerated climb with vertical climb speed of V_c .
- Force balance gives:



$$L = W \cos \gamma_c$$

$$T = D + W \sin \gamma_c$$

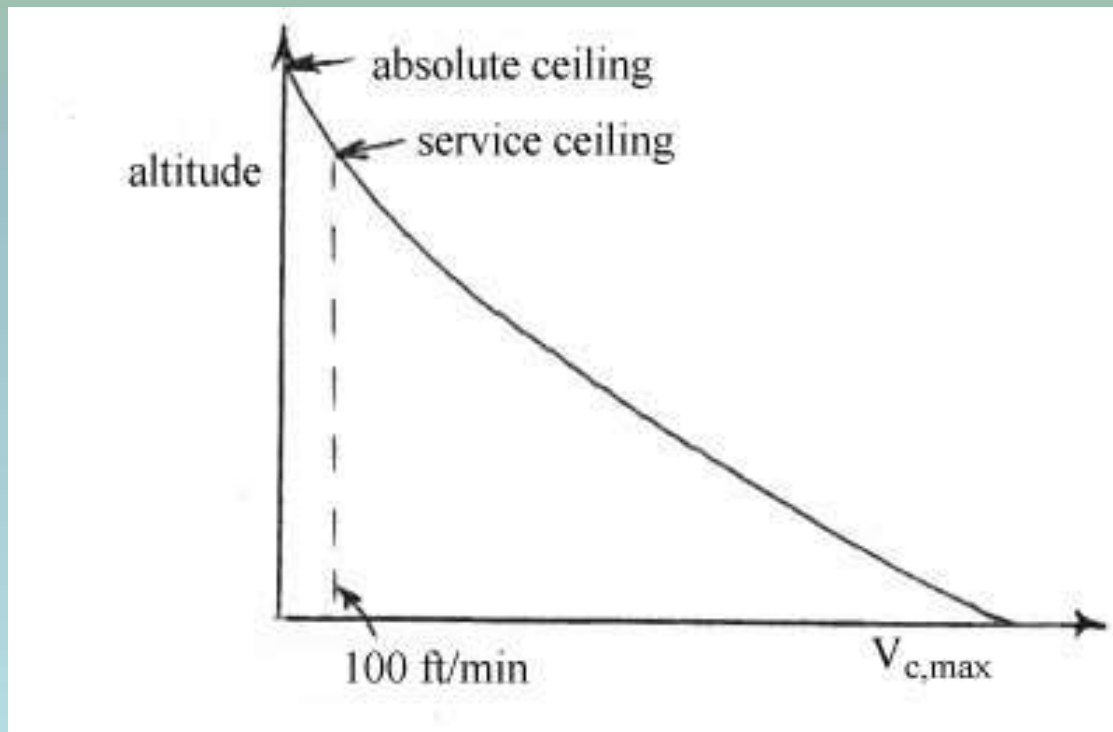
$$\therefore (T - D) / W =$$

$$\sin \gamma_c = V_c / V$$

$$\therefore V_c = (T - D)V / W$$

Ceilings

- Absolute ceiling - altitude for $V_{c,max} = 0$
- Service ceiling - altitude for $V_{c,max} = 100$ ft/min



Diving

- Similar to the steady unaccelerated climb case.
- Force balance for dive speed or sink rate (V_d) gives:

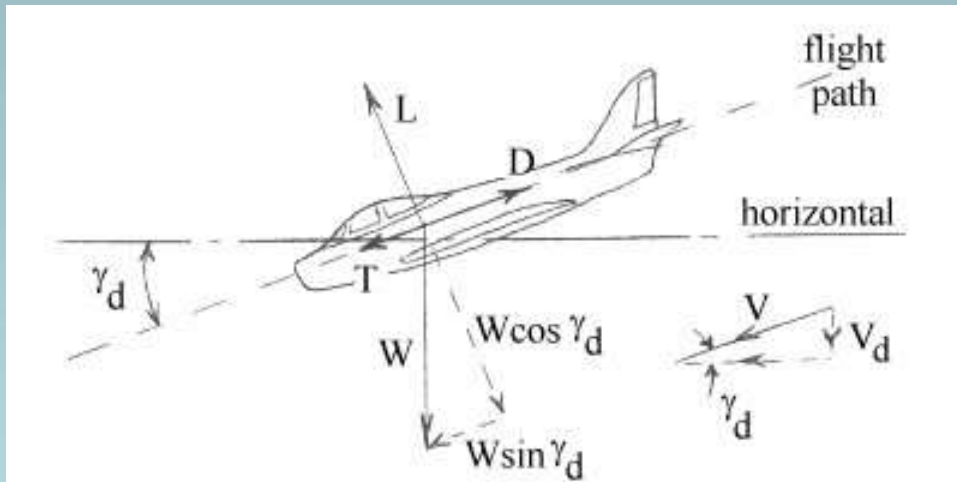
$$L = W \cos \gamma_d$$

$$T = D - W \sin \gamma_d$$

$$\therefore (D - T) / W =$$

$$\sin \gamma_d = V_c / V$$

$$\therefore V_d = (D - T)V / W$$



THANK YOU