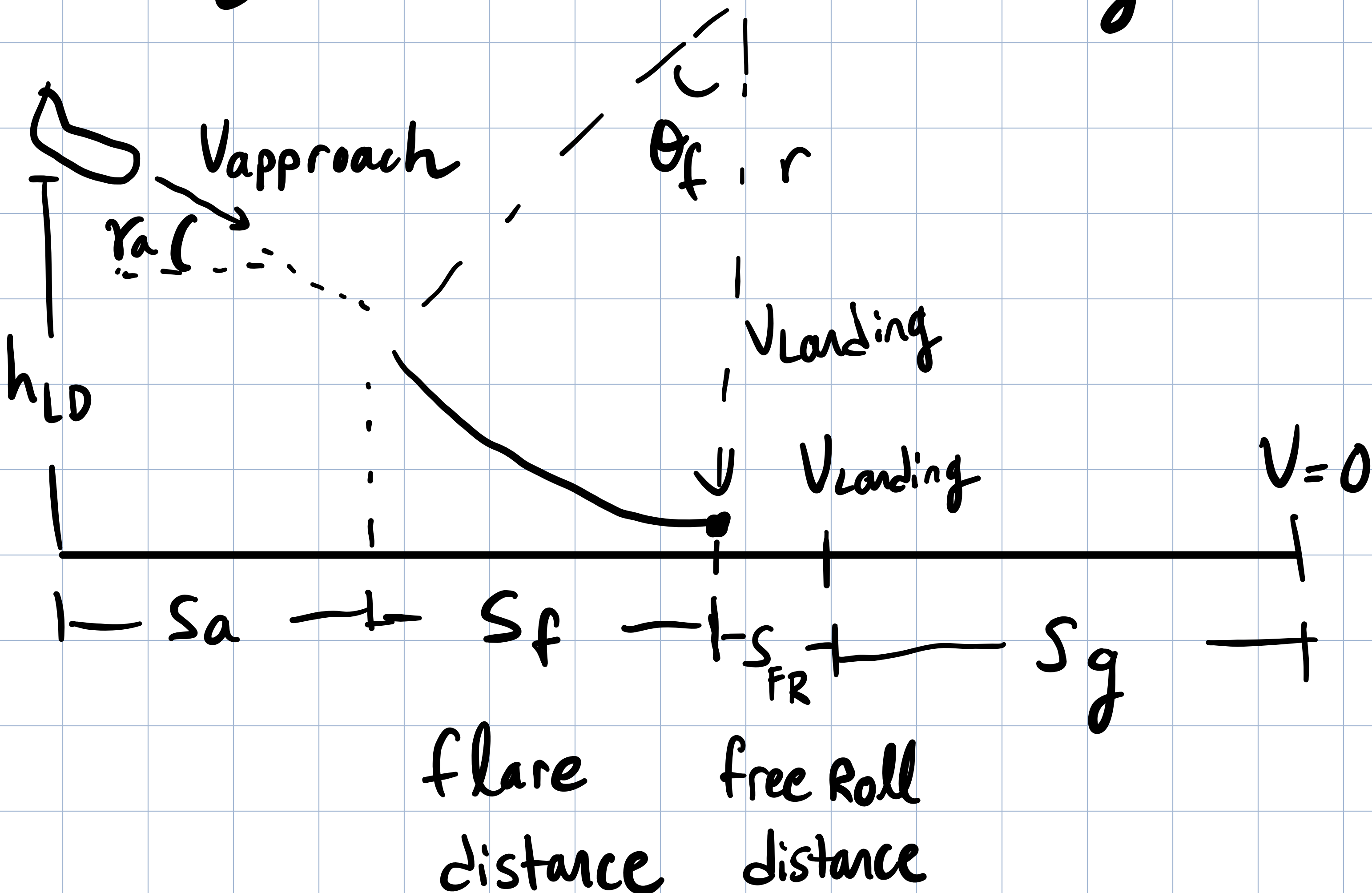
MAE 158 Lecture 14
Nov 14 2024

Announcements: Week 7 Quiz
Range, Endurance, Takeoff

Today's Objectives: Landing

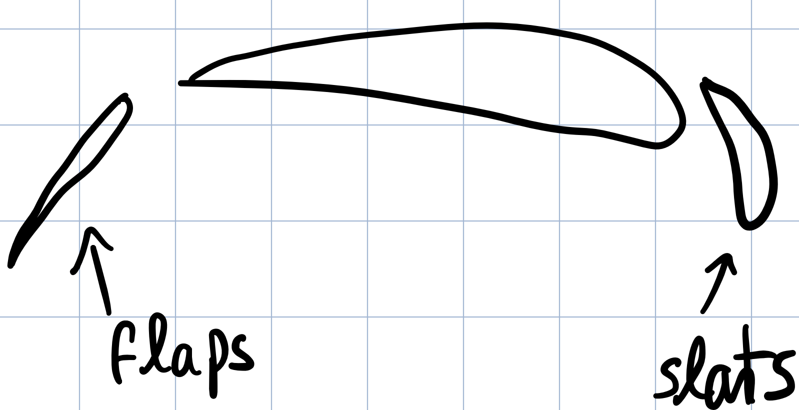


Sequence:

- Approach: → A/C needs to clear an obstacle at height h_{LD}
  flown @ $V_{approach}$ & γ_a

$V_{approach} \sim 1.3\, V_{stall}$ in landing config

$V_{REF} =$



→ high $C_{L_{max}}$

~ 30°, 40°

- flare: transition between approach @ γ_a to the horizontal ground Roll

→ circular Radius r

- free Roll: after touchdown, before brakes or thrust Reversers are implemented

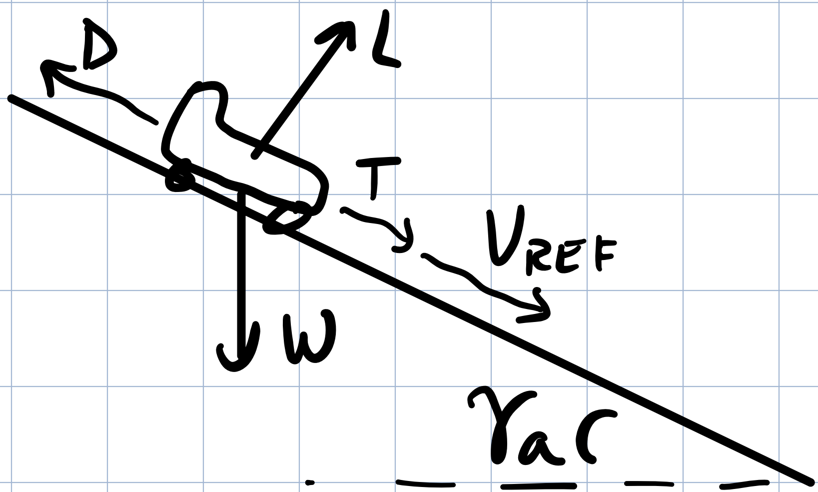
& Velocity ≈ const

@ $V_{Landing}$

$V_{Landing} \sim V_{REF}$

- ground Roll: deceleration from $V_{Landing}$ to $V=0$

Approach Segment



assume equilibrium flight conditions

$$L = W \cos \gamma_a$$

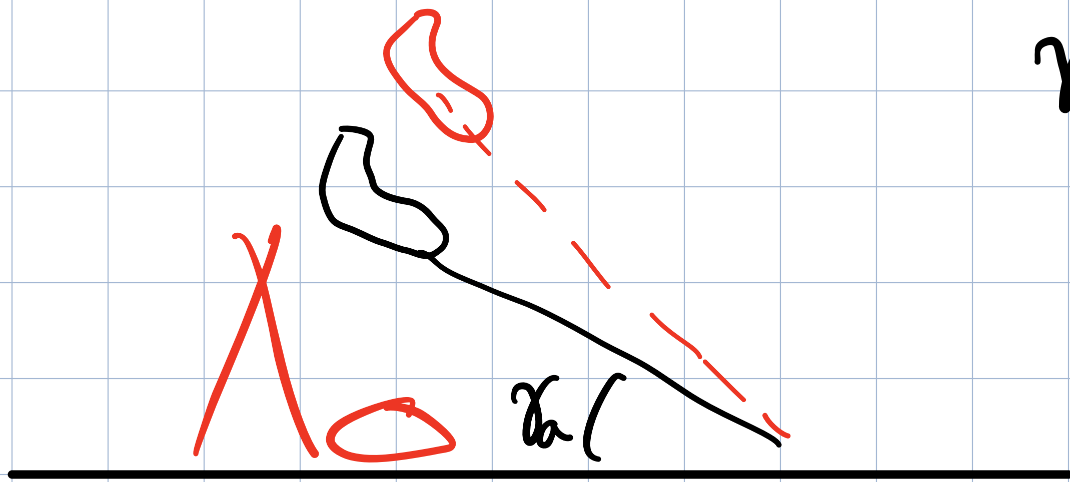
$$D = T + W \sin \gamma_a$$

$$\sin \gamma_a = \frac{D - T}{W}$$

either γ_a is given $\rightarrow$ solve for T or D

- or - T is given $\rightarrow$ solve for

γ_a



to fly @ a steeper γ_a

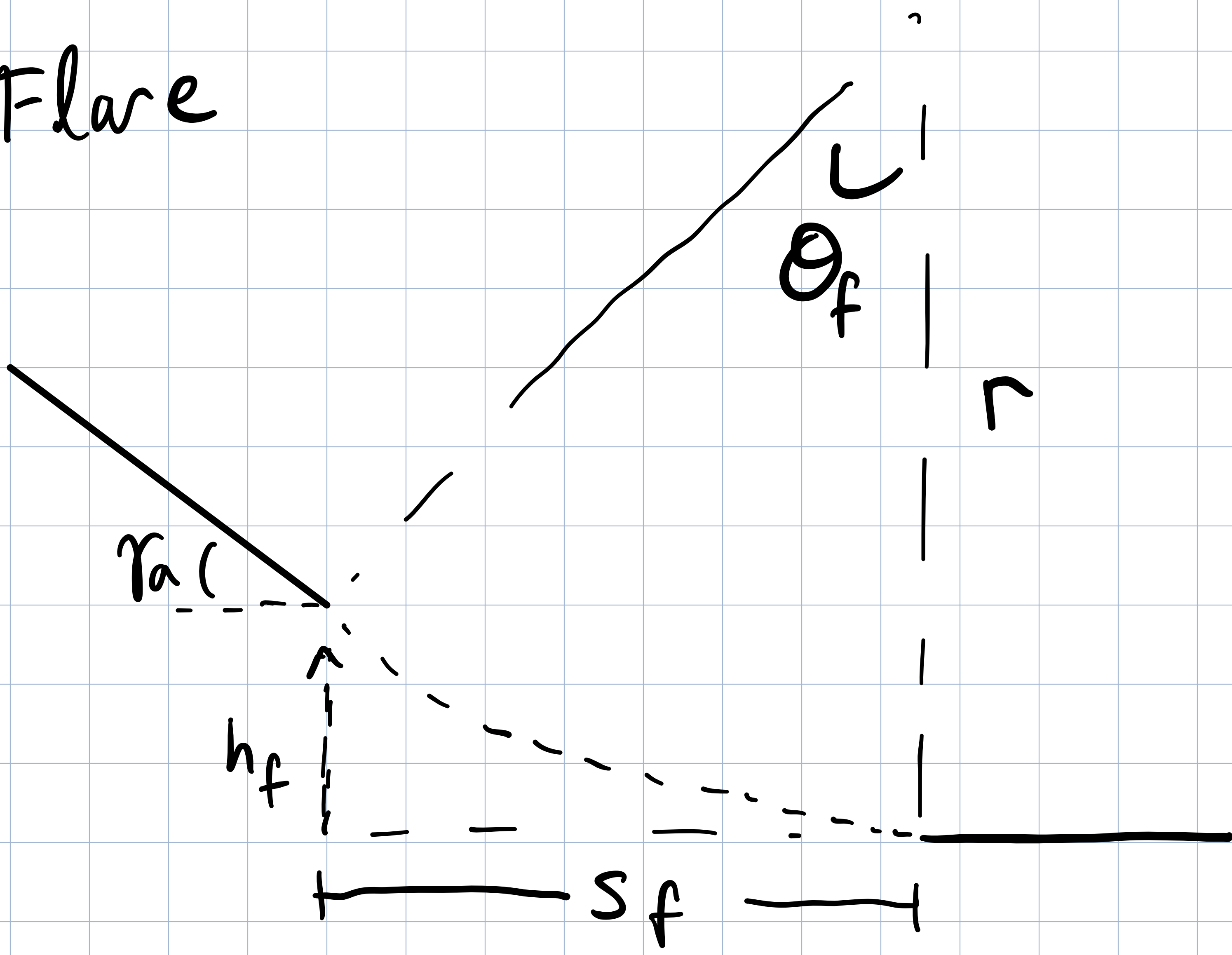
→ Want more Drag

-or- Thrust as low as possible → Tidle

typically, $\gamma_a \simeq 3°$

Steep approaches $\gamma_a > 3°$

Flare



$$h_f = r(1 - \cos\theta_f) = r(1 - \cos\gamma_a)$$

from geometry $\theta_f = \gamma_a$

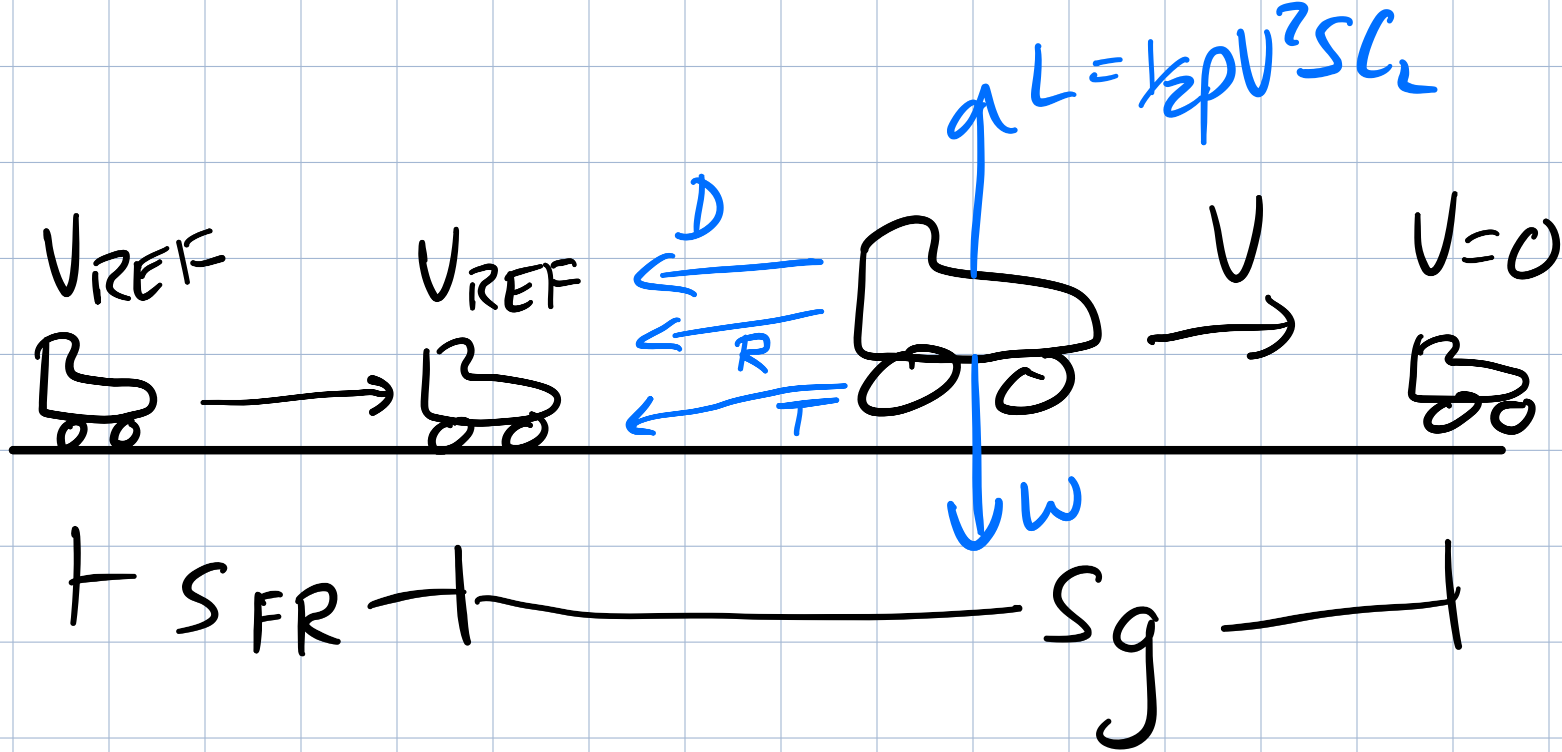
$$r = \frac{V_{flare}^2}{g(n-1)} \qquad n \equiv \text{Load factor}$$

$V_{flare} \sim V_{REF}$

$n \sim 1.2$ during flare

$S_f = r \sin \gamma_a$

free Roll + Ground Roll



Free Roll $\approx$ 1 to 3 second delay

t_{FR}

$S_{FR} = t_{FR} \cdot U_{REF}$

Ground Roll

$T_{REV} \equiv$ Reverse Thrust

$\approx$ 30% of Max Sea level static thrust

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

C_D is the drag coefficient in Landing configuration

ex: $C_{D_P} + K C_L^2$

low α

C_L is on RWY

$C_{D_{P_0},clean} + C_{D_P gear} + C_{D_P flaps}$, etc...

$$R = \mu_r (W - L)$$

$$L = \tfrac{1}{2}\rho V^2 S C_L$$

low α C_L on the RWY

brakes, typically higher than that during TO

$$S_g = \frac{V_{REF}^2}{2 a_{0.7 V_{REF}}}$$

$$a = \frac{\Sigma F}{m} = \frac{1}{W/g}\left(T + D + R\right)_{0.7 V_{REF}}$$

$$V_{REF} \approx 1.3 \sqrt{\frac{2W}{\rho S C_{L_{max}}}}$$

Landing config

if I want to Reduce S_g

- Reduce V_{REF}

  (increase $\frac{C_{Lmax}}{W/S}$)

  Reduce W/S

  $\rho \uparrow$

- $D \uparrow$ $T_{REV} \uparrow$ $R \uparrow$

Total Landing distance

$\underbrace{S_a, S_F, S_{FR}, S_g}$

Ex: Free Roll + Ground Roll

A/C: $W = 73000\ lb$

$S = 950\ ft^2$

$C_{L_{max_{LD}}} = 2.39$

$C_{D_0} = 0.015 + 0.08\,C_L^2$

ΔC_{D_P} when configured $= 0.0124$

$\mu_r = 0.4$ w/ brakes on

$T_{RW} = 0$

$\rho_{SL} = 0.00238\ slug/ft^3$

$t_{FR} = 3\ sec$

$$V_{stall} = \sqrt{\frac{2W}{\rho S C_{L_{max}}}}$$

$$= \sqrt{\frac{2\,(73000\,lb)}{\left(0.00238\,\frac{slug}{ft^3}\right)\left(950\,ft^2\right)\cdot 2.39}}$$

$$= 164.5\ ft/s$$

$$V_{REF} = 1.3 \cdot 164.5\ ft/s = 213\ \frac{ft}{s}$$

$$0.7 V_{REF} = 149\ ft/s$$

$$S_{FR} = V_{REF} \cdot t_{FR}$$

$$= 213\,\text{ft/s} \cdot 3\,\text{s} = \underline{639\,\text{ft}}$$

$$S_g = \frac{V_{REF}^2}{2a_{0.7V_{REF}}}$$

$$a_{0.7V_{REF}} = \frac{\sum F}{m} = \frac{1}{W/g}\left(D + \overset{0}{T} + \mu_r(W-L)\right)$$

$$D = \tfrac{1}{2}\rho \underset{0.7V_{REF}}{V^2} S C_D$$

$$C_D = 0.015 + 0.08\,C_L^2 + 0.0124$$

$C_L \approx 0.1$ on Runway

$$= 0.0282$$

$$D = \tfrac{1}{2}\left(0.00238\ \frac{slug}{ft^3}\right)\left(149\ \frac{ft}{s}\right)^2 950ft^2 \cdot 0.0282$$

$$= 707\ lbs$$

$\tfrac{1}{2}\rho U^2 S C_L$ ← on RWY

$U \leftarrow 0.7V_{REF}$

$$R = \mu_r (W - L)$$

$\mu_r \leftarrow 0.4$

$$0.4\left(73000\,lb - \tfrac{1}{2}(0.00238)\cdot 149\tfrac{ft}{s}^2 \cdot 950ft^2 \cdot 0.1\right)$$

$$= 28196\ lb$$

$$S_g = \frac{V_{REF}^2}{2a_{0.7V_{REF}}}$$

$$= \frac{\left(213\ \mathrm{ft/s}\right)^2}{2 \cdot \frac{32.2\ \mathrm{ft/s^2}}{73000\ \mathrm{lb}}\left(707\ \mathrm{lb} + 28196\ \mathrm{lb}\right)}$$

$$= \underline{1779\ \mathrm{ft}}$$

total distance on ground

$$= S_g + S_{FR}$$

$$= 639\ \mathrm{ft} + 1779\ \mathrm{ft}$$

$$= \underline{2418\ \mathrm{ft}}$$