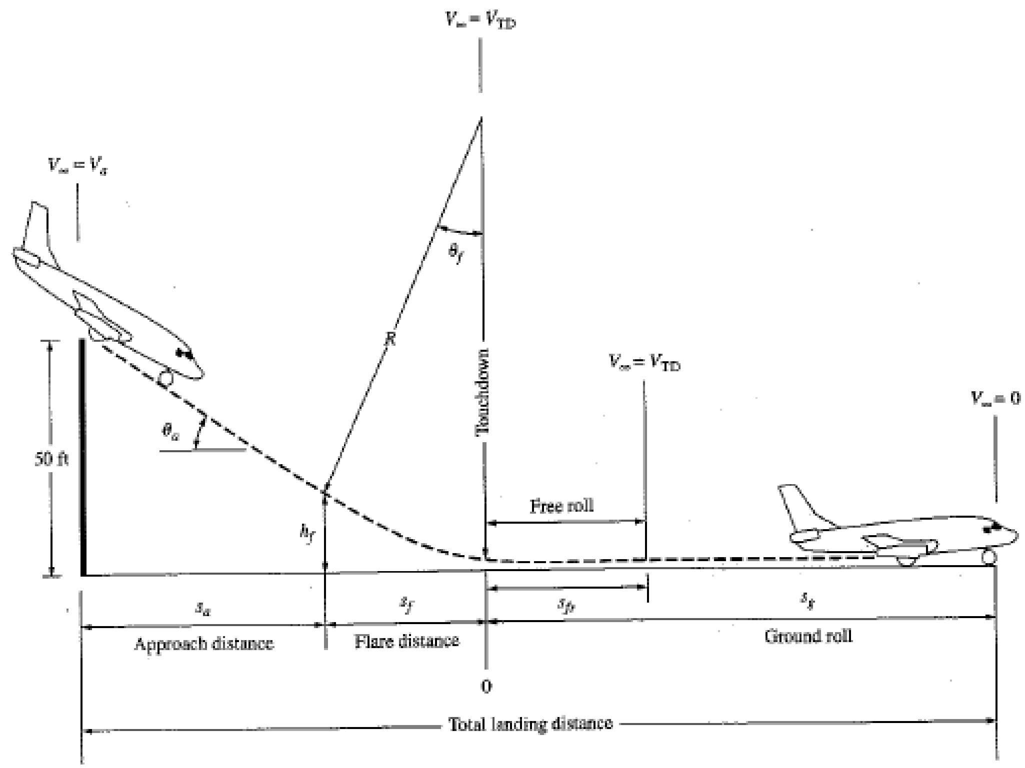
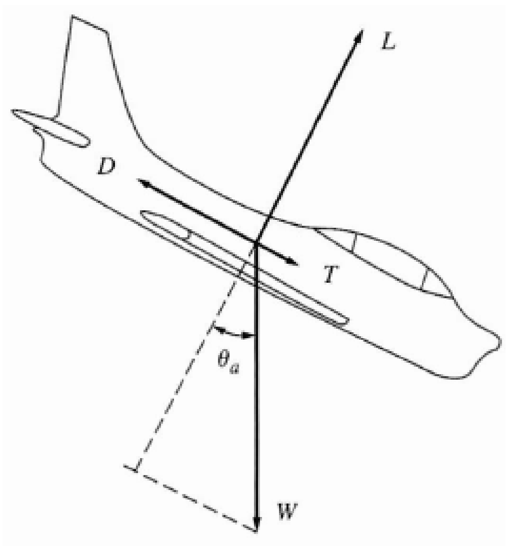
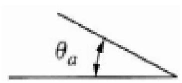
Landing Performance

Landing distance begins when the airplane clears an obstacle 50ft height. At that instant the plane is following a straight approach path with an angle θ_a. The velocity V_a=1.3 V_{stall} for civil planes, V_a=1.2V_{stall} for military. At a distance hf from the ground the airplane flares as a transition to the horizontal ground roll. The distance measured on the ground from the obstacle to the flare is s_a.



The distance covered during the flare on the ground is s_f. The velocity at touchdown is V_{td}=1.15V_{stall} (1.1V_{stall} for military). After the touchdown there is a Free roll distance before the pilot use the brakes (the velocity is assumed constant to V_{td}). The distance up to the point where velocity is 0, is the ground roll s_g.





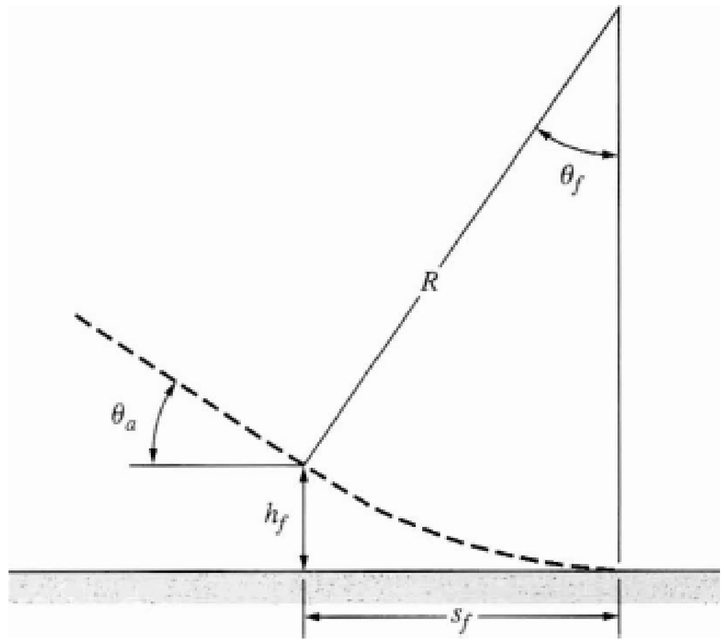
$$L = W\cos\theta_a$$

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

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

for transport aircraft $\theta < 3$. Hence, cos(θ) is about 1

1 compute theta $\sin\theta_a = \frac{1}{L/D} - \frac{T}{W}$



$\theta_f = \theta_a$

V varies from V_a =1.3 V_{stall} to V_{TD}=1.15 for commercial aircraft

V varies from 1. 2 V_{stall} to V_{TD}=1.1 V_{stall} for military aircraft,

yielding an average velocity during the flare of

Vf = 1.23 V_{stall} for commercial airplanes and

Vf = 1.15 V_{stall} for military airplanes.

2 calculate $R = \frac{V_f^2}{g(n-1)} \xrightarrow{n=1.2} R = \frac{V_f^2}{0.2g}$

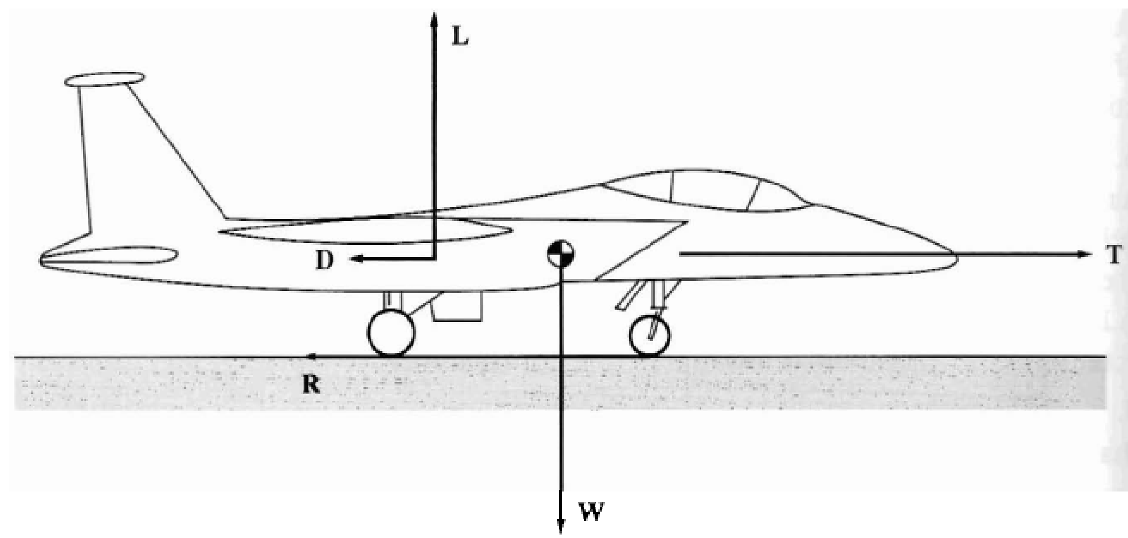
3 The flare height should be calculated from $h_f = R - R\cos\theta_f$

4 Calculate $s_a = \frac{50 - h_f}{\text{Tan}\,\theta_a}$

5 Calculate $s_f = R\sin\theta_f \qquad s_f = R\sin\theta_a$

Calculation of Ground Roll

The force diagram for the airplane during the landing ground roll is the same as take off. Hence, the equation of motion is the same (normal landing practice assumes that upon touchdown, the engine thrust is reduced to idle essentially zero):



$$m\frac{dV_\infty}{dt} = -D - \mu_r(W - L)$$

Many jet aircraft are equipped with thrust reversers which typically produce a negative thrust equal in magnitude to 40% or 50% of the maximum forward thrust. Some reciprocating engine/propeller-driven airplanes are equipped with reversible propellers that can produce a negative thrust equal in magnitude to about 40% of the static forward thrust. For turboprops, this increases to about 60%.

$$m\frac{dV_\infty}{dt} = -T_{\text{rev}} - D - \mu_r(W - L)$$

$$\frac{dV_\infty}{dt} = -\frac{g}{W}\left[T_{\text{rev}} + \frac{1}{2}\rho_\infty V_\infty^2 S C_D + \mu_r\left(W - \frac{1}{2}\rho_\infty V_\infty^2 S C_L\right)\right]$$

$$= -g\left[\frac{T_{\text{rev}}}{W} + \mu_r + \frac{\rho_\infty}{2(W/S)}\left(C_D - \mu_r C_L\right)V_\infty^2\right]$$

$$= -g\left\{\frac{T_{\text{rev}}}{W} + \mu_r + \frac{\rho_\infty}{2(W/S)}\left[C_{D,0} + \Delta C_{D,0} + \left(k_1 + \frac{G}{\pi \text{eAR}}\right)C_L^2 - \mu_r C_L\right]V_\infty^2\right\}$$

assuming

$$J_T \equiv \frac{T_{\text{rev}}}{W} + \mu_r$$

$$J_A \equiv \frac{\rho_\infty}{2(W/S)}\left[C_{D,0} + \Delta C_{D,0} + \left(k_1 + \frac{G}{\pi \text{eAR}}\right)C_L^2 - \mu_r C_L\right]$$

We obtain $$\frac{dV_\infty}{dt} = -g\left(J_T + J_A V_\infty^2\right)$$

$$ds = \frac{d(V_\infty^2)}{2(dV_\infty/dt)} = -\frac{d(V_\infty^2)}{2g\left(J_T + J_A V_\infty^2\right)}$$

$$\int_{s_{\mathrm{fr}}}^{s_g} ds = -\int_{V_{\mathrm{TD}}}^{0} \frac{d(V_\infty^2)}{2g(J_T + J_A V_\infty^2)}$$

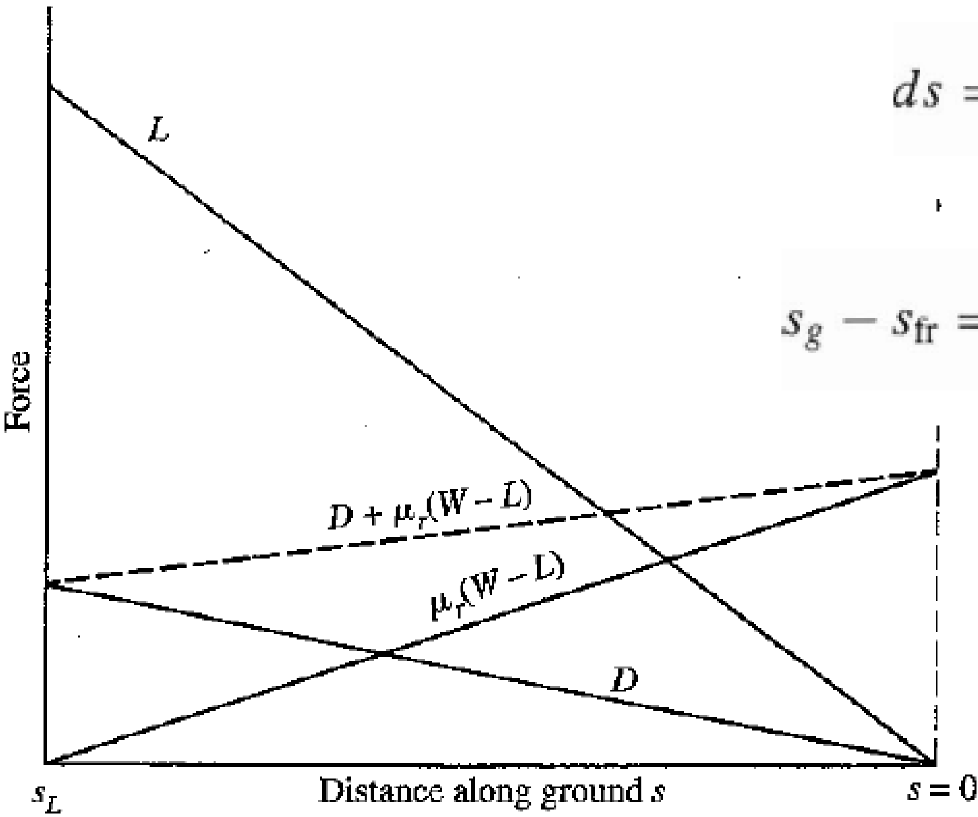
$$s_g - s_{\mathrm{fr}} = \int_0^{V_{\mathrm{TD}}} \frac{d(V_\infty^2)}{2g(J_T + J_A V_\infty^2)}$$

If Jt and Ja are constant

$$s_g - s_{\mathrm{fr}} = \frac{1}{2gJ_A} \ln\left(1 + \frac{J_A}{J_T} V_{\mathrm{TD}}^2\right)$$

According to Raymer the free roll depends partly on pilot technique and usually lasts for 1 to **3** seconds.
Letting N be the time increment for the free roll, we have $\boldsymbol{s_{fr}}$ = N VTD then:

$$\boxed{s_g = N V_{\mathrm{TD}} + \frac{1}{2g J_A} \ln\left(1 + \frac{J_A}{J_T} V_{\mathrm{TD}}^2\right)}$$



$$ds = \frac{m}{2} \frac{d(V_\infty^2)}{-T_{\text{rev}} - D - \mu_r (W - L)}$$

$$s_g - s_{\text{fr}} = \frac{W}{2g} \int_{V_{\text{TD}}}^{0} \frac{d(V_\infty^2)}{-T_{\text{rev}} - D - \mu_r (W - L)}$$

$$s_g = N V_{\text{TD}} + \frac{W}{2g} \int_{0}^{V_{\text{TD}}} \frac{d(V_\infty^2)}{T_{\text{rev}} + D + \mu_r (W - L)}$$

$$s_g = N V_{\text{TD}} + \frac{W V_{\text{TD}}^2}{2g} \left[\frac{1}{T_{\text{rev}} + D + \mu_r (W - L)} \right]_{0.7 V_{\text{TD}}}$$

for military aircraft to VTD=1.15 for commercial aircraft and VTD=1.1 Vstall

VTD=j Vstall

$$V_{\text{stall}} = \sqrt{\frac{2}{\rho_\infty}\frac{W}{S}\frac{1}{(C_L)_{\max}}}$$

$$s_g = jN\sqrt{\frac{2}{\rho_\infty}\frac{W}{S}\frac{1}{(C_L)_{\max}}} + \frac{j^2(W/S)}{g\rho_\infty(C_L)_{\max}\left[T_{\text{rev}}/W + D/W + \mu_r(1 - L/W)\right]_{0.7V_{\text{TD}}}}$$

s_g increases with an increase in W/S.

s_g decreases with an increase in $(C_L)_{\max}$.

s_g decreases with an increase in T_{rev}/W.

s_g increases with a decrease in ρ_∞.