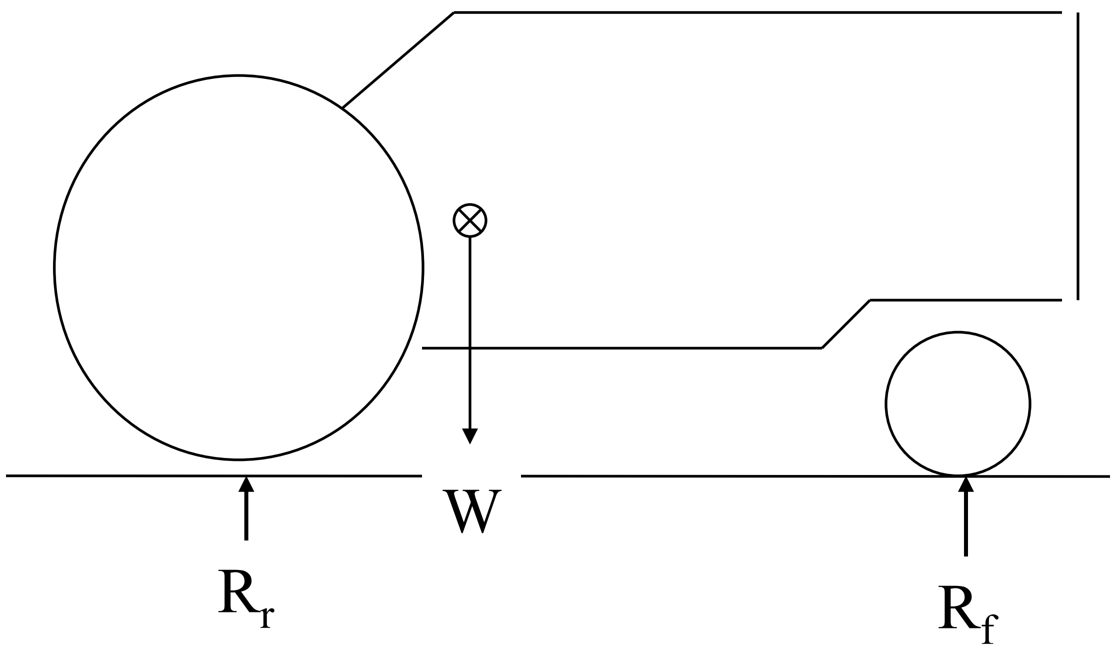
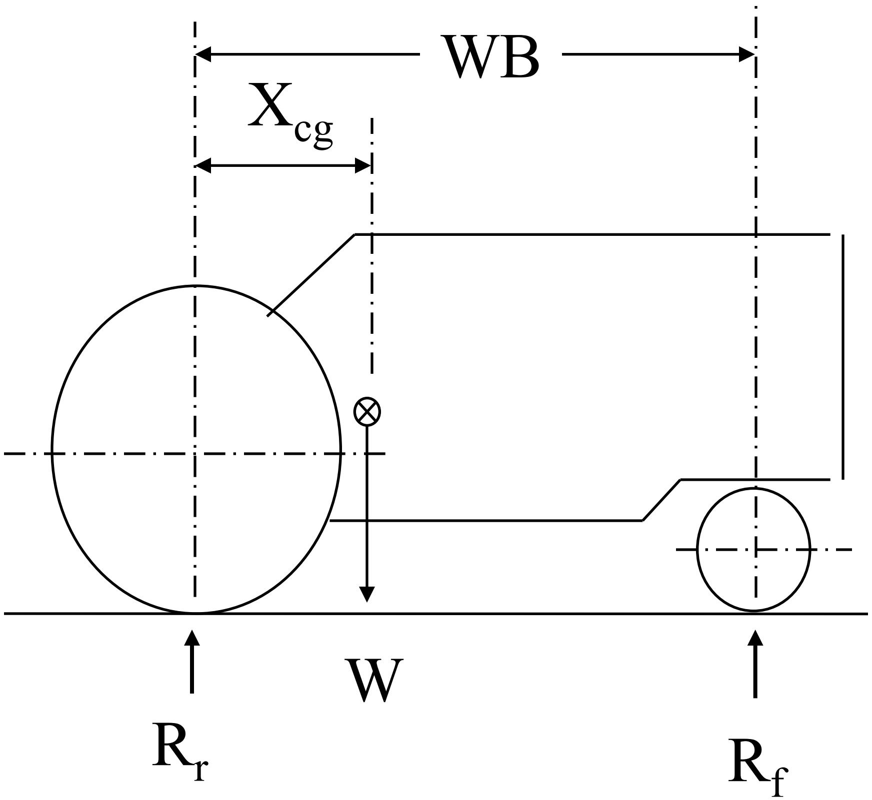
Weight Transfer, Traction & Stability

- Moments and Center of Gravity
  - ⇒ The center of gravity can be determined using moments about any point on the tractor
  - ⇒ For the tractor to be in equilibrium the clockwise moment must equal the anti-clockwise moment
    - Moment = Force * Perpendicular distance to line of force



Center of Gravity



- **Moments about rear axle**

Clockwise Moment = CounterClockwise Moment

$$W * X_{cg} = R_f * WB$$

⇨ $$X_{cg} = R_f * WB / W$$

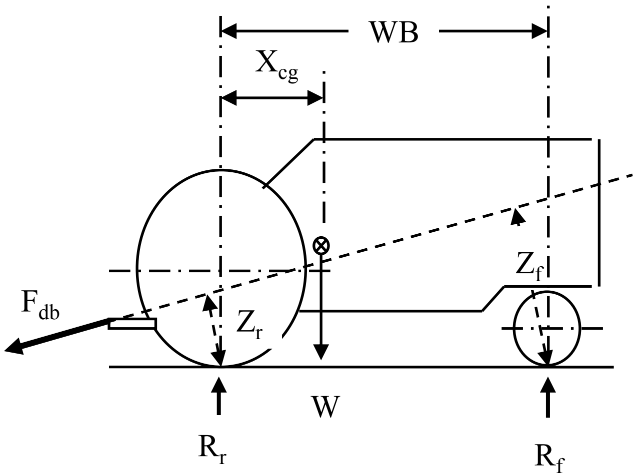
Metric

X_{cg} (mm) = R_f(kN) * WB(mm) / W(kN)

English

X_{cg} (in) = R_f(lb.f) * WB(in) / W(lb.f)

Weight Transfer



Moments about rear axle: Dynamic Front Wheel Reaction

Clockwise Moment = CounterClockwise Moment

$$W*X_{cg} = R_f*WB + F_{db}*Z_r$$

$$\Rightarrow \mathbf{R_f = (W*X_{cg} - F_{db}*Z_r)/WB}$$

Moments about Front axle: Dynamic Rear Wheel Reaction

Clockwise Moment = CounterClockwise Moment

$$R_r*WB = W*(WB-X_{cg}) + F_{db}*Z_f$$

$$\Rightarrow R_r = [W*(WB-X_{cg}) + F_{db}*Z_f]/WB$$

Static Reaction Forces	**Dynamic Reaction Forces**		**Dynamic Weight Transfer**
Drawbar Pull = 0	Drawbar Pull = F_{db}	⇨	ΔR= Dynamic Forces - Static
Front	Front		Front
$R_{fo} = (W*X_{cg})/WB$	$\mathbf{R_f = (W*X_{cg} - F_{db}*Z_r)/WB}$	⇨	$\mathbf{\Delta R_f = (}R_{fo} - R_f\mathbf{) = -(F_{db}*Z_r)/WB}$
Rear	Rear		Rear
$R_{ro} = [W*(WB-X_{cg})]/WB$	$R_r = [W*(WB-X_{cg}) + F_{db}*Z_f]/WB$	⇨	$\mathbf{\Delta} R_r \mathbf{= (}R_{ro} - R_r\mathbf{) =} F_{db}*Z_f/WB$

Reaction Forces

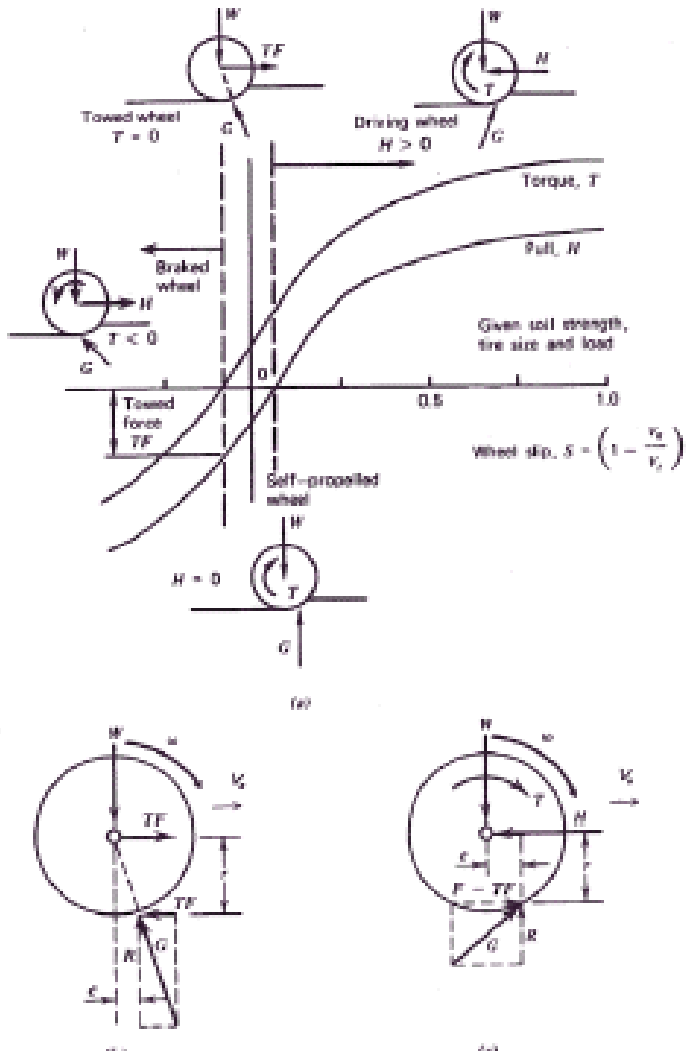


Figure 13.11. (a) Net traction (pull)-torque-slip relation for wheels on soil. (From Wismer and Luth, 1974.) (b) Free body diagram of a towed wheel. (c) Free body diagram of a driving wheel.

Basic Concepts of Traction: Travel Reduction

- Travel Reduction (TR): Reduction in actual forward speed that occurs due to increased slippage when the drawbar load is increased. Theoretically, Slip and Travel reduction are not identical although they are often used interchangeably.

$$TR = 100*(1 - S_a/S_o)$$

where: S_a = Actual travel Speed, S_o = Travel Speed on specified surface with no load

- Travel reduction must occur to develop drawbar pull
  - ⇒ Tire lug must compress the soil allowing it to develop tractive force
  - ⇒ Rear movement results in travel reduction

Basic Concepts of Traction: Tractive Force (Wismer-Luth)

- Gross Tractive Force Coefficient (μ_g): Gross Tractive Horizontal Force (F) divided by the Dynamic Weight (Reactive Force) on driving wheel.

$$\mu_g = F/W = 0.75*[1- \exp(-0.3C_nS)]$$

$$C_n = CI\ bd/W \text{ (Wheel Numeric)}$$

- Motion Resistance Ratio (ρ): Horizontal Towing Force (TF) divided by the Dynamic Weight (Reactive Force) on wheel.

$$\rho = TF/W = 1.2/C_n + 0.04$$

$$C_n = CI\ bd/W$$

- Net Tractive Force Coefficient (μ): Net Tractive Horizontal Force (H) divided by the Dynamic Weight (Reactive Force) on driving wheel.

$$\mu = H/W = (F-TF)/W = 0.75*[1- \exp(-0.3C_nS)] - [1.2/C_n + 0.04]$$

$$C_n = CI\ bd/W$$

Basic Concepts of Traction: Tractive Force (Bias Ply)

- Gross Tractive Force Coefficient (μ_g):

$$\mu_g = F/W = 0.88*[1- \exp(-0.1B_n)] *[1- \exp(-7.5S)]+0.04$$

$$B_n = [CI\ bd/W]*[(1+5*\delta/h)/(1+3*b/d)] \text{ (Mobility Number)}$$

$$C_n = CI\ bd/W \text{ (Wheel Numeric)}$$

$$b/d = \text{Width to Depth Ratio}$$

$$\delta/h = \text{deflection Ratio}$$

- Motion Resistance Ratio (ρ):

$$\rho = TF/W = 1.0/B_n + 0.04 + 0.5s/(B_n)^{1/2}$$

- Net Tractive Force Coefficient (μ):

$$\mu = H/W = (F-TF)/W = \mu_g - \rho$$

Basic Concepts of Traction: Tractive Force (Radial Ply)

- Gross Tractive Force Coefficient (μ_g):

$$\mu_g = F/W = 0.88*[1- \exp(-0.1B_n)\ ] *[1- \exp(-9.5S)\ ]+0.0325$$

$$B_n = [CI\ bd/W]*[(1+5*\delta/h)/(1+3*b/d)] \text{ (Mobility Number)}$$

$$C_n = CI\ bd/W \text{ (Wheel Numeric)}$$

$$b/d = \text{Width to Depth Ratio}$$

$$\delta/h = \text{deflection Ratio}$$

- Motion Resistance Ratio (ρ):

$$\rho = TF/W = 0.9/B_n + 0.0325 + 0.5s/(B_n)^{1/2}$$

- Net Tractive Force Coefficient (μ):

$$\mu = H/W = (F-TF)/W = \mu_g - \rho$$

Basic Concepts of Traction: Dynamic Traction Ratio

- Dynamic Traction ratio (DTR) is the ratio of drawbar pull (F_{db}) over the dynamic weight on the driving wheels

$$DTR_{(2\ \text{wheel Drive})} = F_{db} / [\ R_{ro} + \Delta R_r\ ]$$

where: R_{ro} is static weight on rear wheels and ΔR_r is weight transfer

- A high DTR needed for high drawbar pull
    - Improved lug design
    - Radial ply design

- Increase weight will also increase pull at the cost of higher compaction and increased stress on the axles

Basic Concepts of Traction: Tractive Efficiency

- Tractive Efficiency (TE) is the fraction of axle power (P_a) that is converted to drawbar power (P_{db}) by the drive wheels

$$TE = P_{db} / P_a$$

$$TE = [F_{db} * V] / P_a$$

Metric

$$TE = [F_{db}(kN) * V(km/h) * 1000(m/km) / 3600(sec/h)] / [P_a(kW)]$$

$$TE = [F_{db}(kN) * V(km/h)] / [P_a(kW) * 3.6 \text{ (km/h per m/s)}]$$

English

$$TE = [F_{db}(lb.f) * V(mph) * 5280(ft/m) / 60(sec/h)] / [P_a(Hp) * 33000(ft.lb/min \text{ per } Hp]$$

Basic Concepts of Traction: Tractive Efficiency

- $TE = P_{db} / P_a$

$P_{db} = [F_{db} * V_a]$

$\Rightarrow TE = [F_{db} * V_a] / P_a$

$P_a = T\omega$ — T = Axle Torque, ω = angular velocity

$\Rightarrow TE = [F_{db} * V_a] / T\omega$

$\Rightarrow TE = [F_{db} * V_a] / [(F*r)*(V_t/r)]$

$\Rightarrow \quad = [H / F]*[V_a / V_t]$

$\omega = V_t/r$ — r=rolling radius

$T = F*r$ — F = Gross Traction

$F_{db} = H$ (Net Traction)

$\Rightarrow TE = [H / F]*[1-S]$

$\Rightarrow TE = [(H/W) / (F/W)]*[1-S]$

$V_a / V_t = (1-S)$ — S=Slip

$\Rightarrow TE = [(\mu_g - \rho)/ \mu_g]*[1-S]$

$\Rightarrow TE = [1- \rho /\mu_g]*[1-S]$

Travel Reduction, Drawbar Pull and Maximum Tractive Efficiency

- Drawbar Pull
  - Zero Slip, Zero Drawbar Pull
  - 100% Slip, Max Drawbar Pull
- Dynamic Traction Ratio
  - Zero Slip, DTR=0
  - 100% Slip, DTR=maximum
- Tractive Efficiency

TE=Tractive/axle Power

Tractive Power = Drawbar Force * Velocity

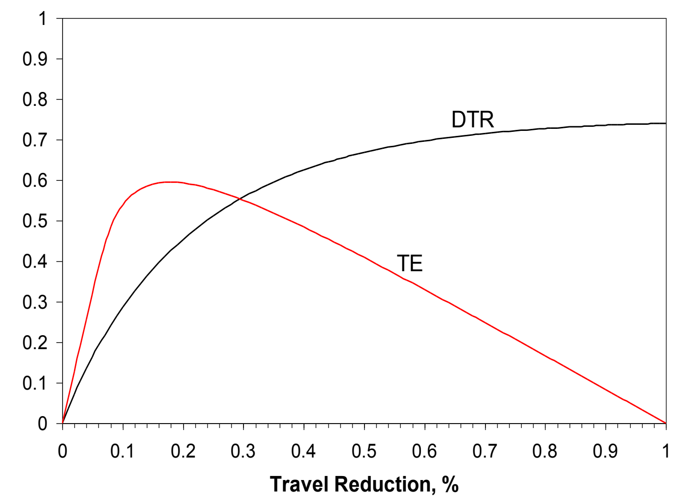


Figure 1: Variation of Tractive Efficiency and Dynamic Traction Ratio with travel reduction for a particular tractor on one specific soil

<u>Zero Slip</u>

Velocity=maximum, Drawbar Force =0

⇒ Tractive Power =0, TE=0

<u>100% Slip</u>

Velocity=0, Drawbar Force =maximum

⇒ Tractive Power =0, TE=0

Maximum tractive efficiency occurs at some intermediate slip conditions, generally between 10-15%, but will depend on the conditions.