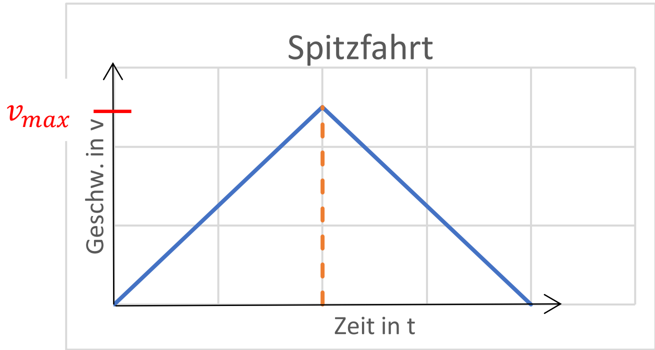
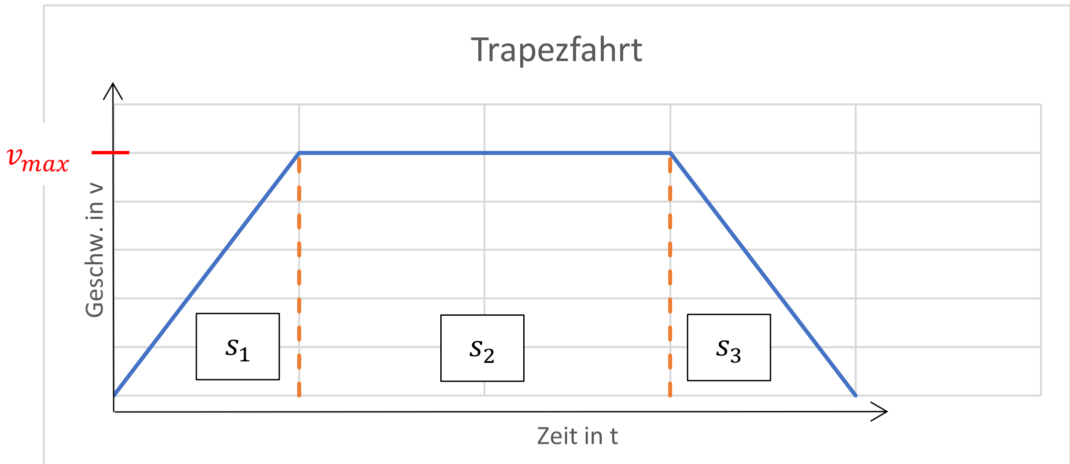
Fahrzeit- und Energiemodell

Fallunterscheidung (für Fahrzeit- und Energieberechnung relevant):

<u>Fall 1:</u> Spitzfahrt = Beschleunigen und Bremsen



<u>Fall 2:</u> Trapezfahrt = Beschleunigen, Fahrt mit konstanter Geschwindigkeit, Bremsen



Kritische Wegstrecke (bis zum Erreichen der Maximalgeschwindigkeit):

$a_1 = Beschleunigung$

$a_2 = Bremsbeschleunigung$

$v = Maximale\ Geschwindigkeit$

$s = Strecke$

$$s_{krit} = \frac{a_1}{2}\left(\frac{v}{a_1}\right)^2 + \frac{a_2}{2}\left(\frac{v}{a_2}\right)^2$$

$$s_{krit} = \frac{1}{2}v^2\left(\frac{1}{a_1} + \frac{1}{a_2}\right)$$

Fahrzeitmodell

Fall 1: Spitzfahrt ($s \leq s_{krit}$)

$v_x = erreichte\ Geschwindigkeit$

$a_1 \neq a_2$

$$t = \frac{v_x}{a_1} + \frac{v_x}{a_2} \qquad t_1 = \frac{v_x}{a_1}\ ,\ t_2 = \frac{v_x}{a_2}$$

$$s = \frac{1}{2}a_1{t_1}^2 + \frac{1}{2}a_2(t_1 - t_2)^2$$

$$s = \frac{1}{2}a_1\frac{{v_x}^2}{{a_1}^2} + \frac{1}{2}a_2\frac{{v_x}^2}{{a_2}^2}$$

$$s = \frac{1}{2}\frac{{v_x}^2}{a_1} + \frac{1}{2}\frac{{v_x}^2}{a_1}$$

$$s = \frac{1}{2}(v_x)^2\left(\frac{1}{a_1} + \frac{1}{a_2}\right)$$

$${v_x}^2 = \frac{2s}{\frac{1}{a_1} + \frac{1}{a_2}}$$

$$v_x = \sqrt{\frac{2s}{\left(\frac{1}{a_1} + \frac{1}{a_2}\right)}}$$

$$t = \frac{v_x}{a_1} + \frac{v_x}{a_2}$$

$$t = \frac{\sqrt{\frac{2s}{\left(\frac{1}{a_1} + \frac{1}{a_2}\right)}}}{a_1} + \frac{\sqrt{\frac{2s}{\left(\frac{1}{a_1} + \frac{1}{a_2}\right)}}}{a_2}$$

$$t = \left(\frac{1}{a_1} + \frac{1}{a_2}\right)\sqrt{\frac{2s}{\left(\frac{1}{a_1} + \frac{1}{a_2}\right)}}$$

Fall 2: Trapezfahrt ($s > s_{krit}$)

$$a_1 \neq a_2$$

1. kritische Wegstrecke bis v_{max} erreicht ist:

$$t_{krit} = \frac{v_{max}}{a_1} + \frac{v_{max}}{a_2} \qquad t_1 = \frac{v_{max}}{a_1}\ ,\ t_3 - t_2 = \frac{v_{max}}{a_2}$$

$$s_1 = \frac{1}{2} a_1 {t_1}^2$$

$$s_3 = \frac{1}{2} a_2 (t_3 - t_2)^2$$

$$s_{krit} = s_1 + s_3 = \frac{1}{2} a_1 \frac{v_{max}}{a_1} + \frac{1}{2} a_2 \frac{{v_{max}}^2}{{a_2}^2} = \frac{1}{2}\left(\frac{{v_{max}}^2}{a_1} + \frac{{v_{max}}^2}{a_2}\right) = \frac{1}{2} {v_{max}}^2 \left(\frac{1}{a_1} + \frac{1}{a_2}\right)$$

Wenn ($s > s_{krit}$) → Trapezfahrt

2. Trapezfahrt:

$$t = t_{krit} + t_{konst}$$

$$t = \frac{v_{max}}{a_1} + \frac{v_{max}}{a_2} + \frac{s - s_{krit}}{v_{max}}$$

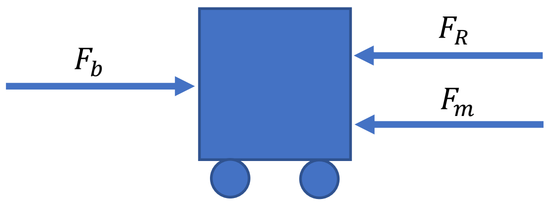
$$t = \frac{v_{max}}{a_1} + \frac{v_{max}}{a_2} + \frac{s - \frac{1}{2} {v_{max}}^2 \left(\frac{1}{a_1} + \frac{1}{a_2}\right)}{v_{max}}$$

$$t = \frac{v_{max}}{2}\left(\frac{1}{a_1} + \frac{1}{a_2}\right) + \frac{s}{v_{max}}$$

Energiemodell

<u>Fall 1</u>: Spitzfahrt:

Beschleunigung:



$$F_b = F_R + F_m = \mu_{roll} * m * g + m * a_1$$

$$W_b = F_b * s_1$$

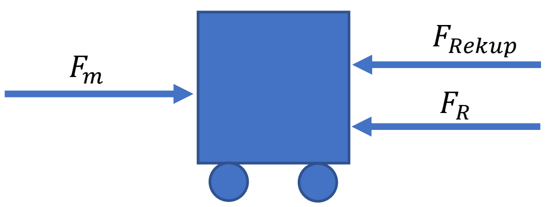
$$W_b = \mu_{roll} * m * g * s_1 + m * a_1 * s_1$$

$$W_b = \mu_{roll} * m * g * s_1 + \frac{1}{2} m v^2$$

$$W_b = \frac{1}{2} m v^2 + \mu_{roll} * m * g * s_1$$

$$W_b = \frac{1}{2} m \left(\frac{t}{\frac{1}{a_1} + \frac{1}{a_2}} \right)^2 + \mu_{roll} * m * g * \frac{1}{2} \frac{\left(\frac{t}{\frac{1}{a_1} + \frac{1}{a_2}} \right)^2}{a_1}$$

Rekuperation:



$$W_{Rekup} = F_m - F_R$$

$$W_{Rekup} = \frac{1}{2} m v^2 - \mu_{roll} * m * g * s_2$$

$$W_{Rekup} = \left(\frac{1}{2} m \left(\frac{t}{\frac{1}{a_1} + \frac{1}{a_2}} \right)^2 - \mu_{roll} * m * g * \frac{\left(\frac{t}{\frac{1}{a_1} + \frac{1}{a_2}} \right)^2}{2 a_2} \right) \eta_{Rekup}$$

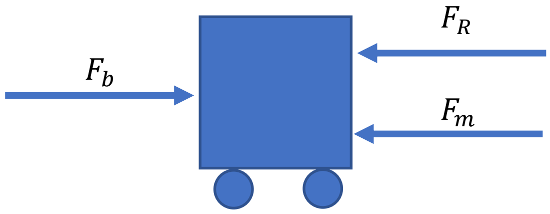
Gesamt Spitzfahrt:

$$W_{Gesamt} = W_b - W_{Rekup}$$

$$W_{Gesamt} = \left(\frac{1}{2} m \left(\frac{t}{\frac{1}{a_1} + \frac{1}{a_2}} \right)^2 + \mu_{roll} * m * g * \frac{1}{2} \frac{\left(\frac{t}{\frac{1}{a_1} + \frac{1}{a_2}} \right)^2}{a_1} \right) \frac{1}{\eta_{Shuttle}} - \left(\frac{1}{2} m \left(\frac{t}{\frac{1}{a_1} + \frac{1}{a_2}} \right)^2 - \mu_{roll} * m * g * \frac{\left(\frac{t}{\frac{1}{a_1} + \frac{1}{a_2}} \right)^2}{2a_2} \right) \eta_{Rekup}$$

<u>Fall 2:</u> Trapezfahrt:

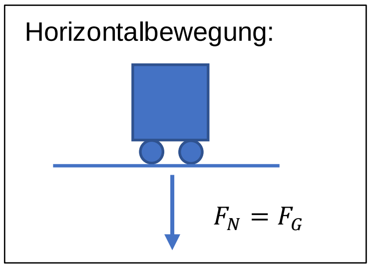
Beschleunigung:



$F_R = Reibung$

$(hauptsächlich\ Rollreibung)$

$F_m = Massenträgheit$



$F_b = F_R + F_m$

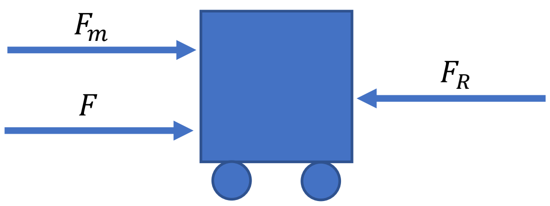
$F_m = m * a_1$

$F_R = \mu_{roll} * F_N = \mu_{roll} * F_G = \mu_{roll} * m * g$

$F_b = \mu_{roll} * m * g + m * a_1$

$W_b = F_b * s_1 = \mu_{roll} * m * g * s_1 + m * a_1 * s_1$

Konstante Fahrtgeschwindigkeit:



$F_m = 0, weil\ a_1 = a_2 = 0$

$a_2 = Bremsbeschleunigung$

$F_k = F_R - F_m$

$F_k = F_R = \mu_{roll} * m * g$

$W_k = F * s_2 = \mu_{roll} * m * g * s_2$

$W = W_b + W_k = F_b * s_1 + F_k * s_2$

$W = \mu_{roll} * m * g * s_1 + m * a_1 * s_1 + \mu_r * m * g * s_2$

$W = m * a_1 * s_1 + \mu_{roll} * m * g * s_1 + \mu_r * m * g * s_2$

$W = m * a_1 * s_1 + (m * g * \mu_r) * (s_1 + s_2)$

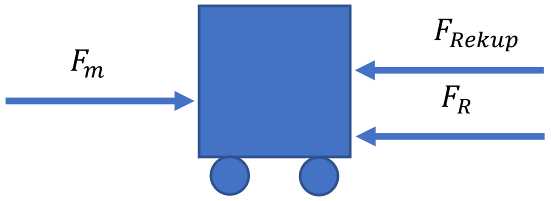
$W = m * a_1 * s_1 + m * g * \mu_r * (s - s_3)$

$$W = m * a_1 * \frac{1}{2} a_1 * \frac{v^2}{{a_1}^2} + m * g * \mu_{roll} * (s - s_3)$$

$$W = \frac{1}{2} m v^2 + m * g * \mu_r * \left(s - \frac{1}{2} * \frac{v^2}{a_2}\right)$$

Mit Wirkungsgrad: $W_{Wg} = \frac{1}{\eta_{Shuttle}} * W$

Rekuperation beim Bremsen:



$a_1 = Beschleunigung$

$a_2 = Bremsbeschleunigung$

$$F_{Rekup} = F_m - F_R = m * a_2 - \mu_{roll} * m * g$$

$$W_{Rekup} = F_{Rekup} * s_3 * \eta_{Rekup} = (m * a_2 * s_3 - \mu_{roll} * m * g * s_3)\eta_{Rekup}$$

$$W_{Rekup} = \left(\frac{1}{2}mv^2 - \mu_{roll} * m * g * \frac{1}{2} * \frac{v^2}{a_2}\right)\eta_{Rekup}$$

Gesamte Fahrtenergie:

$$W_{Gesamt} = W_{Wg} - W_{Rekup}$$

$$W_{Gesamt} = \frac{1}{\eta_{Shuttle}}\left(\frac{1}{2}mv^2 - m * g * \mu_r\left(s - \frac{1}{2} * \frac{v^2}{a_2}\right)\right) - \eta_{Rekup} * \left(\frac{1}{2}mv^2 - m * g * \mu_r * \frac{1}{2} * \frac{v^2}{a_2}\right)$$

Energiemodell Lift

Fallunterscheidung:

Fall 1: Fahrt nach oben

Fall 2: Fahrt nach unten

Fall 1: Fahrt nach oben (Energiebedarf)

$$W = \frac{1}{\eta_{Lift}} m * g * h$$

Fall 2: Fahrt nach unten (Energierückgewinnung, falls Rekuperation vorhanden)

$$W = -\eta_{Liftrekup} * m * g * h$$