Driving Resistances

One-dimensional longitudinal consideration along the trajectory

Neglection of lateral forces and curve resistance

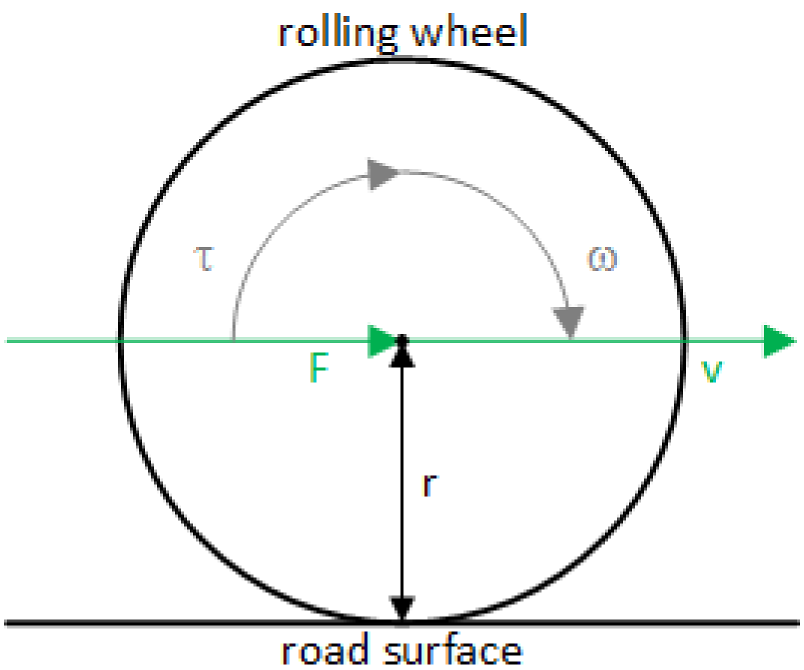
Summarized in Modelica.Mechanics.Translational.Components.Vehicle

Equation of motion:

$$F - F_{DR} = m_{dyn} \cdot \frac{dv}{dt}$$

- F Driving force
- F_{DR} Driving resistances
- m_{dyn} (dynamic) mass of vehicle (incl. driver, cargo)
  incl. contribution of rotating masses
- $\frac{dv}{dt}$ Acceleration along the trajectory

Coupling translational - rotational



$$v = r \cdot \omega$$

$$\tau = r \cdot F$$

$$F - F_{DR} = m \cdot \frac{dv}{dt}$$

$$\tau - \tau_{DR} = J \cdot \frac{d\omega}{dt}$$

$$E_{kin} = m \frac{v^2}{2}$$

$$E_{kin} = J \frac{\omega^2}{2}$$

Static – Dynamic mass

Addition due to rotating masses:

- Rotating masses with respect to rotating wheels
- Summed up torque of all wheels
- Relevant radius of wheels r

Equation of motion

$$F - F_{DR} = m_{dyn} \cdot \frac{dv}{dt}$$

$$\tau - \tau_{DR} \cdot r = m_{stat} \cdot \frac{dv}{dt} \cdot r + J_{Tot} \cdot \frac{d\omega}{dt} = m_{stat} \cdot \frac{dv}{dt} \cdot r + J_{Tot} \cdot \frac{dv}{dt} \cdot \frac{1}{r}$$

$$F - F_{DR} = \left(m_{stat} + J_{Tot} \cdot \frac{1}{r^2}\right) \cdot \frac{dv}{dt}$$

$$m_{dyn} = m_{stat} + J_{Tot} \cdot \frac{1}{r^2}$$

Driving Resistances

$$F_{DR} = F_R + F_A + F_G$$

- F_R Rolling resistance
- F_A Air drag
- F_G Inclination resistance (gravitational force)

Max. speed (driving power)

$$P = F \cdot v = (F_R + F_A + F_G) \cdot v$$

On flat track without inclination and wind force

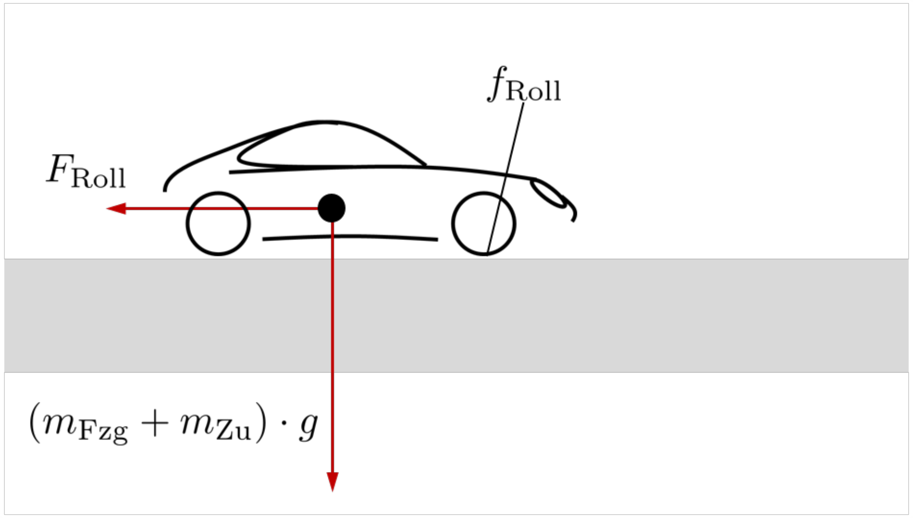
$$P = c_R \cdot m \cdot g \cdot v + c_W \cdot A \cdot \rho_A \cdot \frac{v^3}{2}$$

Rolling Resistance

Reason: deformation of tyres

dominating at low speed

$$F_R = c_R \cdot m_{stat} \cdot g \cdot cos(\alpha)$$



source: wikipedia

Rolling resistance coefficient c_R – examples:

- Train wheel on rail $c_R \approx 0{,}001$
- Car tyre on asphalt $c_R \approx 0{,}01$
- Car tyre on loose sand $c_R \approx 0{,}3$

Air Drag

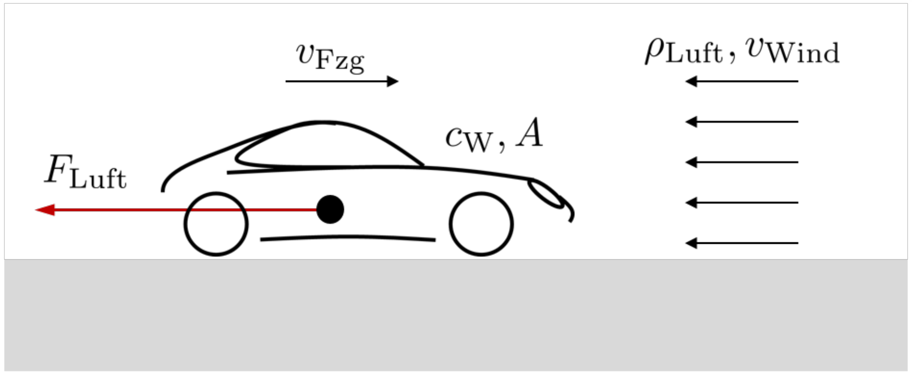
Reason: dynamic pressure of air

Dominating at high speed

$$F_A = c_W \cdot A \cdot \rho_A \cdot \frac{(v+v_A)^2}{2}$$

velocity of wind is counted positive

against velocity of car

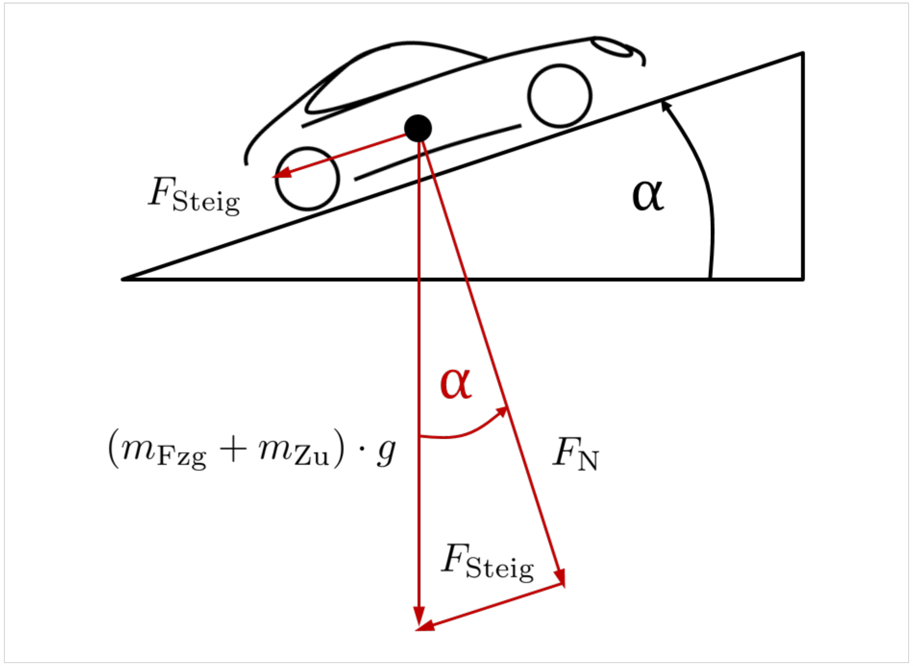


source: wikipedia

c_W	Air drag coefficient
A	Front cross section
$v + v_A$	speed of car with respect to surrounding air
$\rho_A = 1{,}2\ \frac{kg}{m^3}$	Density of air at sea level and 20°C

Inclination Resistance

Gravitational force



source: wikipedia

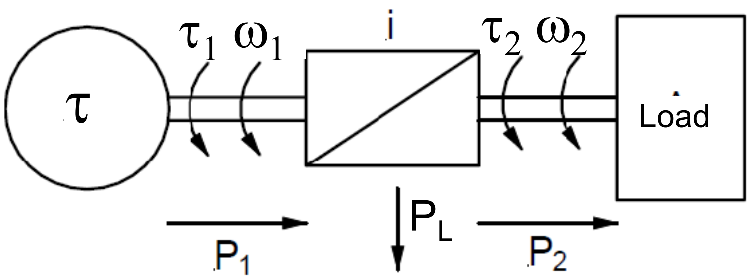
$$F_G = m \cdot g \cdot sin(\alpha)$$

$$Inclination = tan(\alpha)$$

Gearbox

$$\omega_1 = i \cdot \omega_2$$

$$P_1 = P_2 + P_v$$



	Driving	Braking
Power balance	$P_2 = P_1 \cdot \eta_T > 0$	$P_1 = P_2 \cdot \eta_B < 0$
Torque balance	$\tau_2 = \tau_1 \cdot i \cdot \eta_D$	$\tau_1 = \tau_2 \cdot \frac{1}{i} \cdot \eta_B$
Equivalent conversion of moment of inertia	$J_{2\to 1} = J_2 \cdot \frac{1}{i^2} \cdot \frac{1}{\eta_D}$	$J_{2\to 1} = J_2 \cdot \frac{1}{i^2} \cdot \eta_B$

In detail: Losses P_L (friction) and efficieny η depend on point of operation.