Sizing of the EV powertrain

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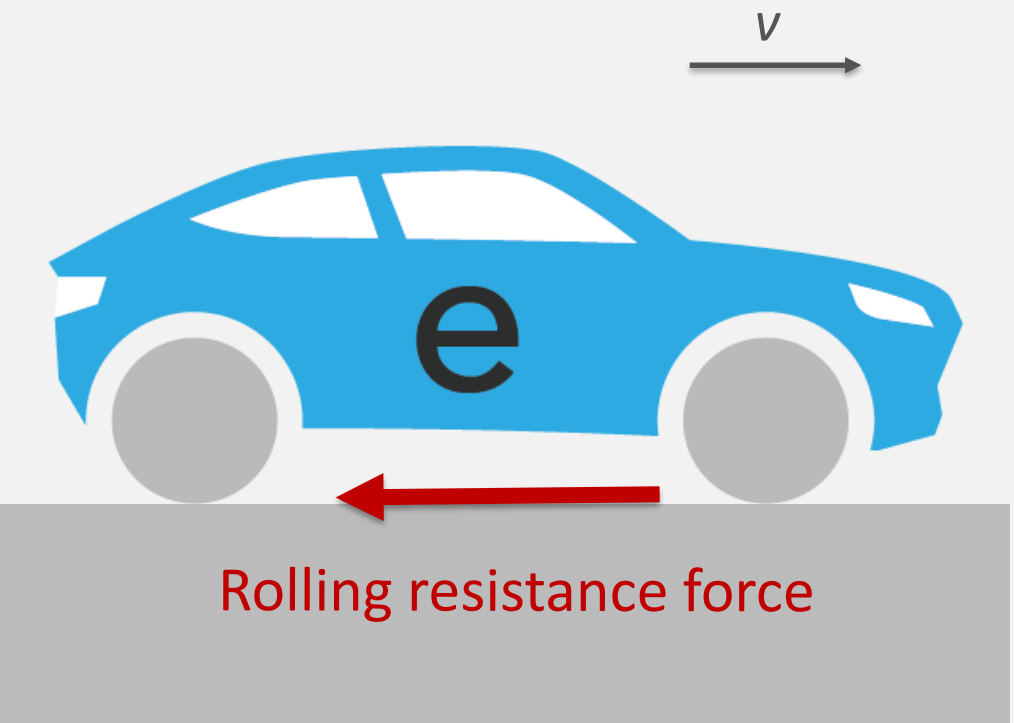
Learning objectives

- What are the forces on a vehicle while driving?
  - Rolling resistance force
  - Aerodynamic drag force
  - Gradient force
- How to use the traction force to control the speed?
- How should the powertrain of the vehicle be sized?

Rolling resistance force



$$F_{roll} = c_r m g$$

where

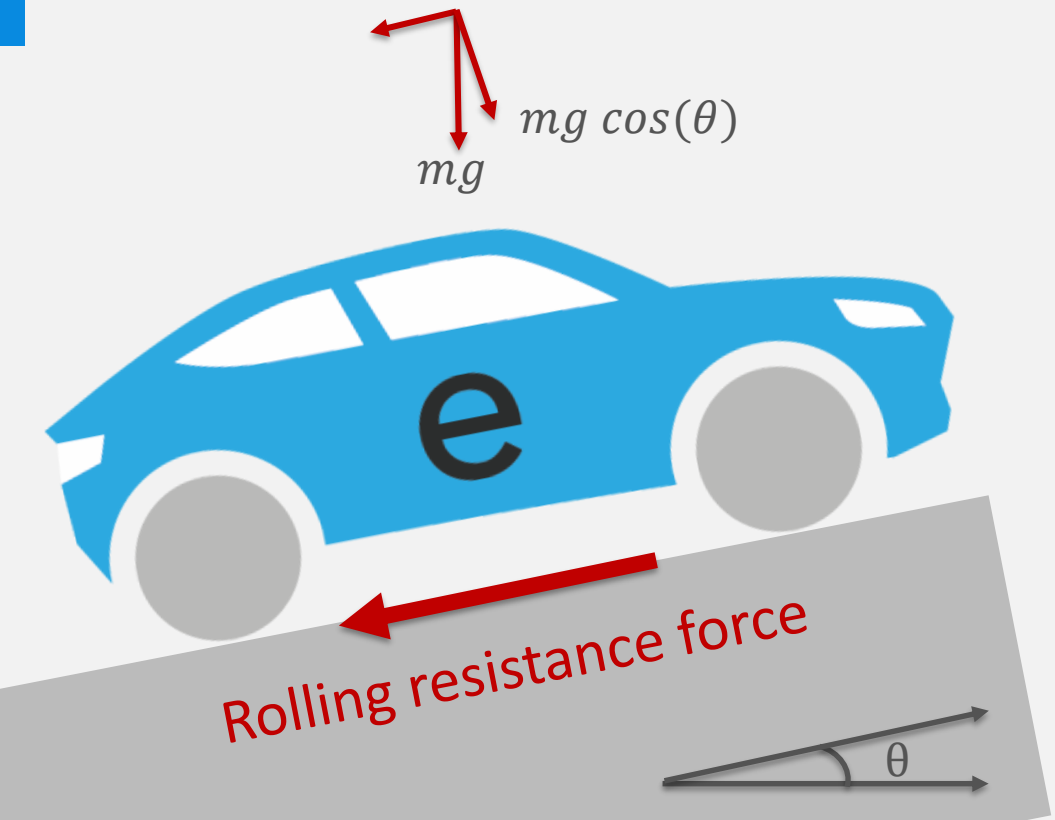
c_r - coefficient of rolling resistance

m - mass of the vehicle [kg]

g - standard gravity [9.8 m/s^2]

v - speed of the vehicle [m/s]

Rolling resistance force



$$F_{roll} = c_r mg\ cos(\theta)$$

where

c_r - coefficient of rolling resistance

m - mass of the vehicle [kg]

g - standard gravity [9.8 m/s^2]

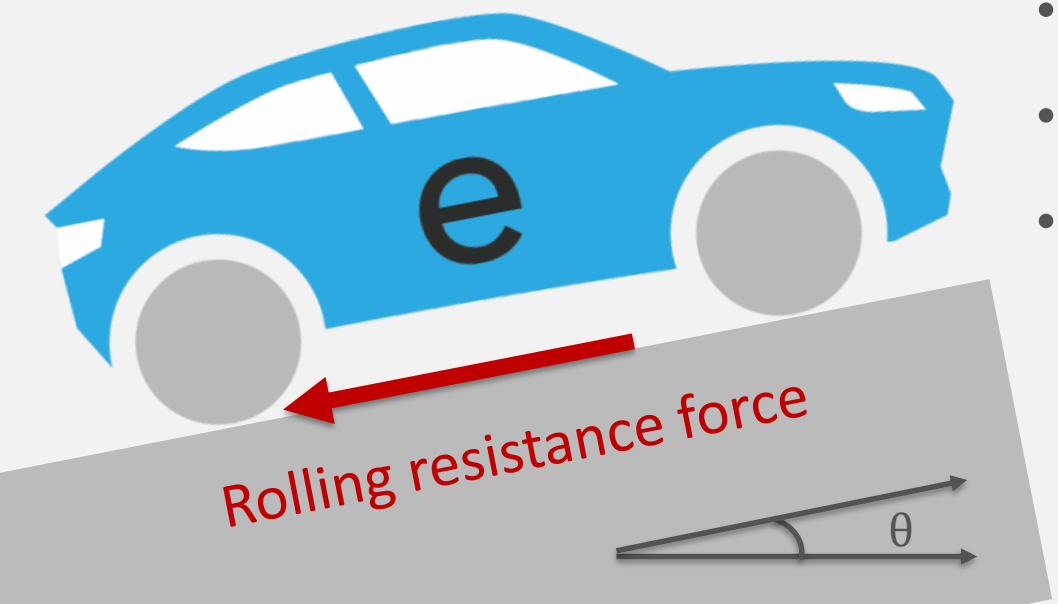
θ - road gradient angle [rad or ^{0}]

v - speed of the vehicle [m/s]

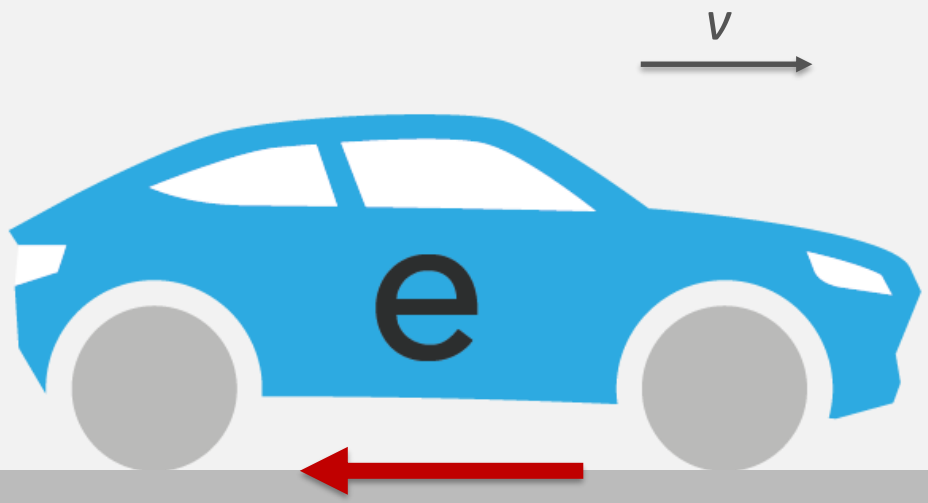
Rolling resistance force

$$F_{roll} = c_r m g \cos(\theta)$$

- Approx. independent of speed
- Opposing the driving direction
- Coefficient c_r is around 0.01-0.02



Aerodynamic drag force



$$F_{aero} = \frac{1}{2} c_d A_f \rho v^2$$

where

c_d - coefficient of drag

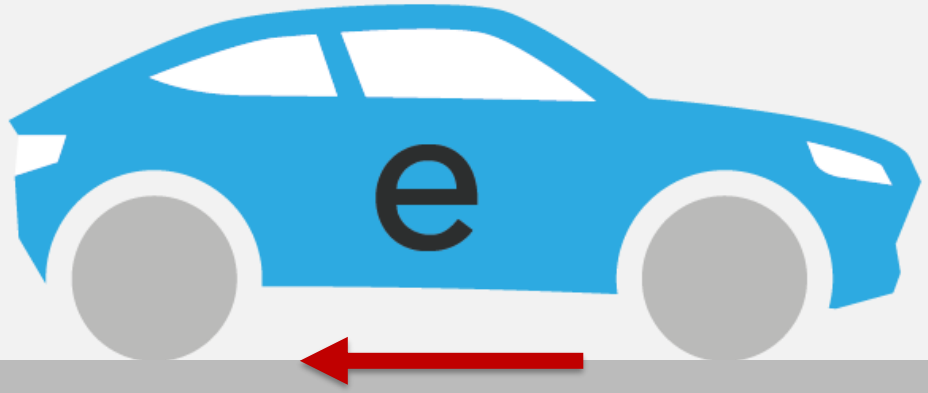
A_f - frontal area of vehicle [m^2]

ρ - density of air [~1.22 kg/m^3]

v - speed of the vehicle [m/s]

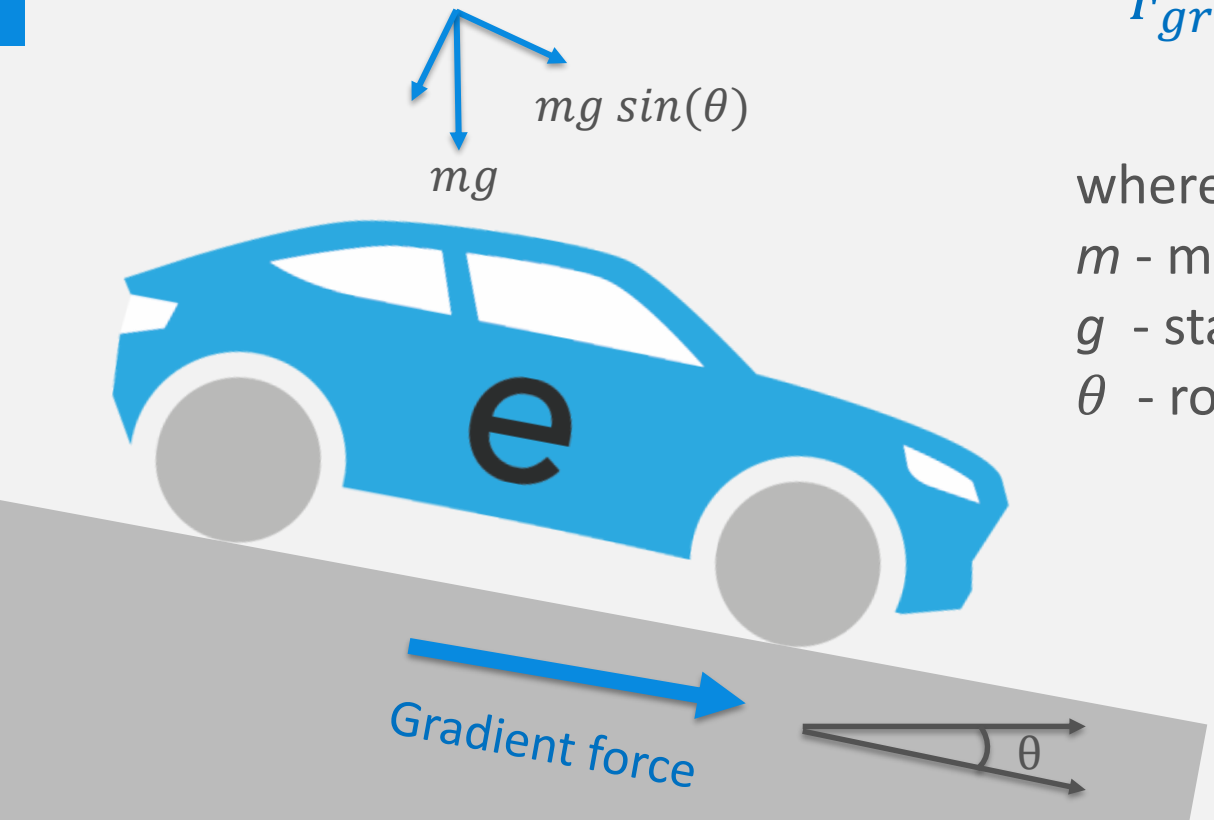
Aerodynamic drag force

$$F_{aero} = \frac{1}{2} c_d A_f \rho v^2$$



- Independent of vehicle weight
- Increases with square of speed
- Coefficient c_d is 0.25-0.35

Gradient force



$$F_{grad} = mg\ sin(\theta)$$

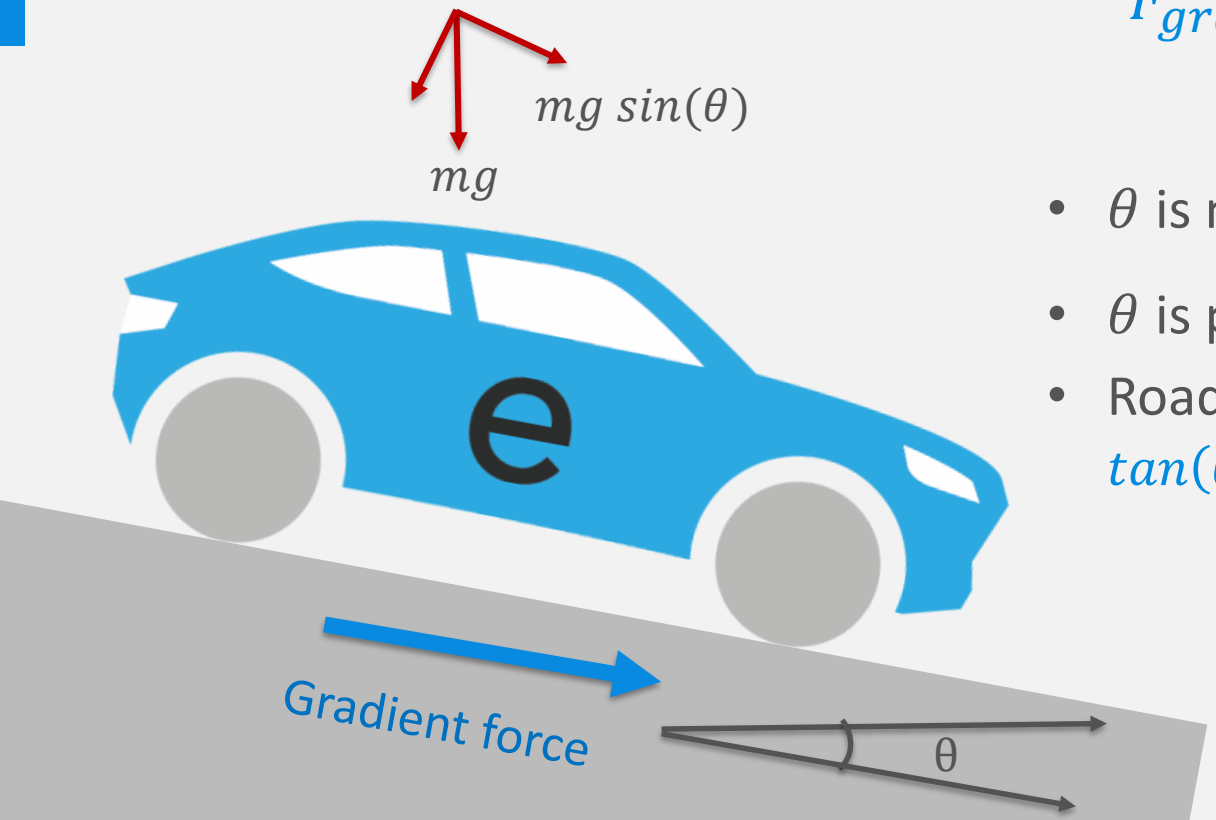
where

m - mass of the vehicle [kg]

g - standard gravity [9.8 m/s^2]

θ - road gradient angle [rad or ^{0}]

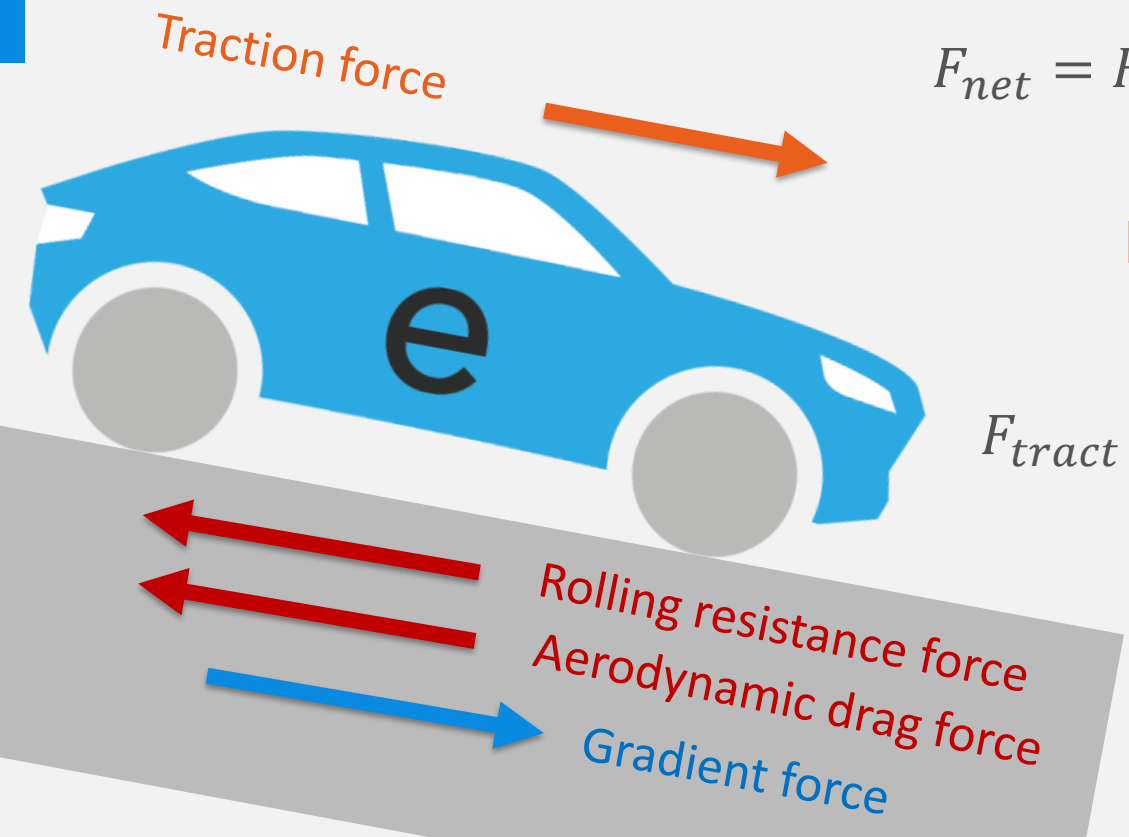
Gradient force



$$F_{grad} = mg\ sin(\theta)$$

- θ is negative for downhill
- θ is positive for uphill
- Road gradient is expressed as $tan(\theta)$ and typically within ±10%

Net force on the vehicle



$$F_{net} = F_{tract} - (F_{aero} + F_{roll} + F_{grad})$$

Newton's second law,

$$F_{net} = ma$$

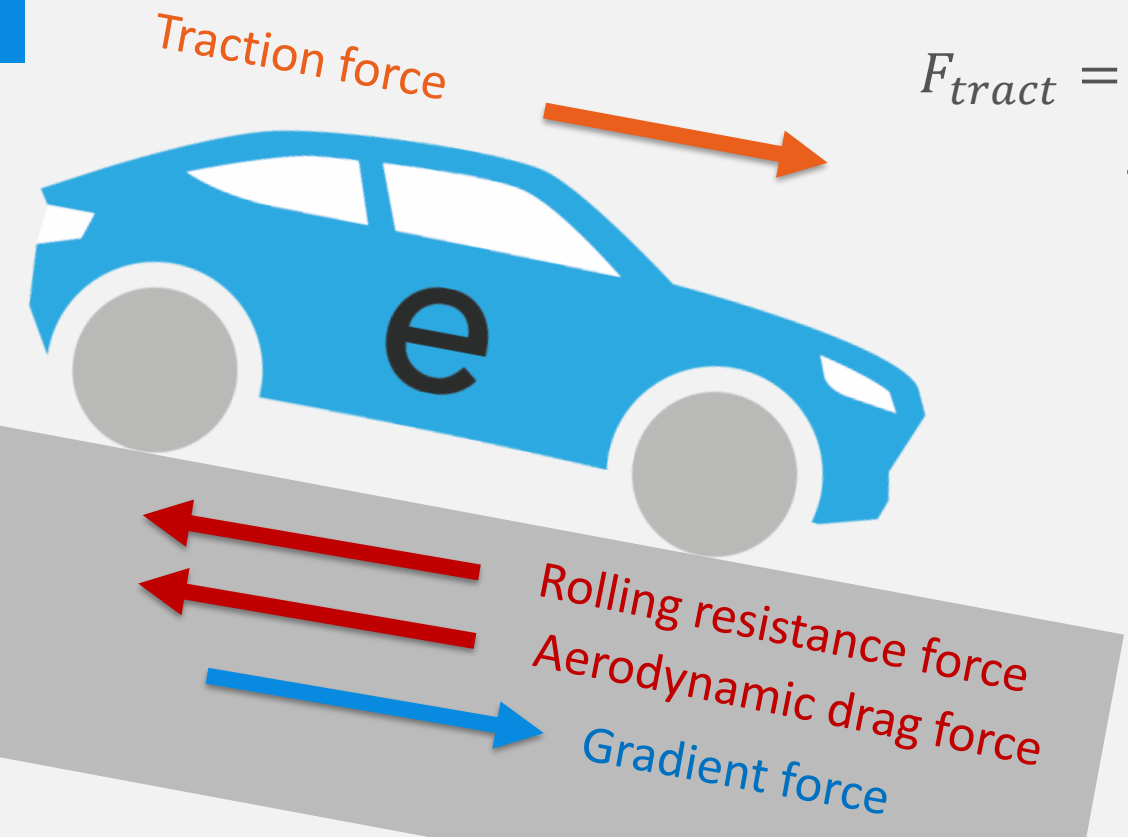
$$F_{tract} = ma + (F_{aero} + F_{roll} + F_{grad})$$

where

m - mass of the vehicle [kg]

a - vehicle acceleration

Net force on the vehicle



$$F_{tract} = c_r mg\ cos(\theta) + \frac{1}{2} c_d A_f \rho v^2 + mg\ sin(\theta) + ma$$

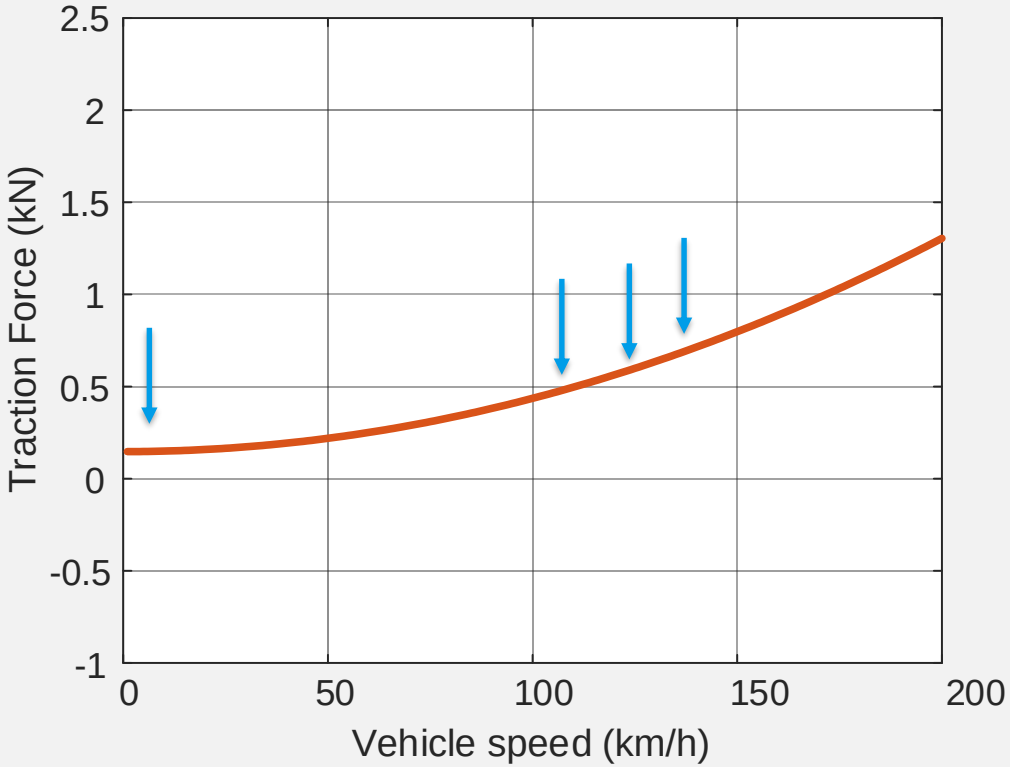
$$P_{tract} = F_{tract} v$$

where

v - speed of the vehicle [m/s]

Force-speed diagram

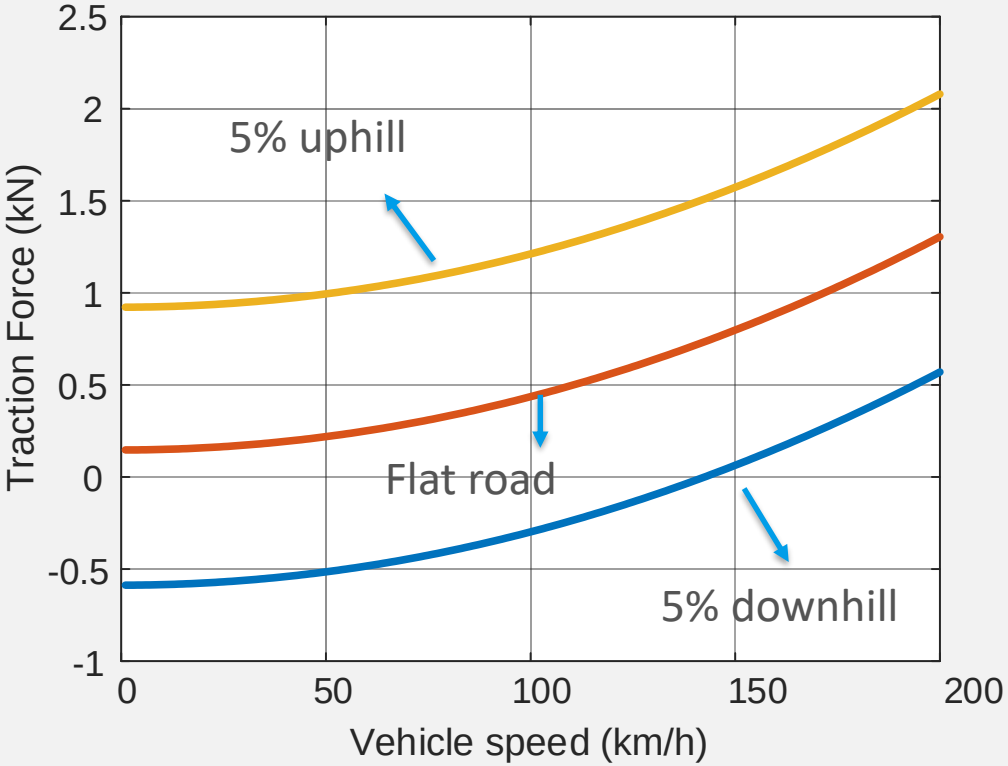
$$F_{tract} = ma + (F_{aero} + F_{roll} + F_{grad})$$



- Vehicle mass is 1.5t
- Frontal area is 2.5m^2
- Acceleration is zero
- No road gradient

Force-speed diagram

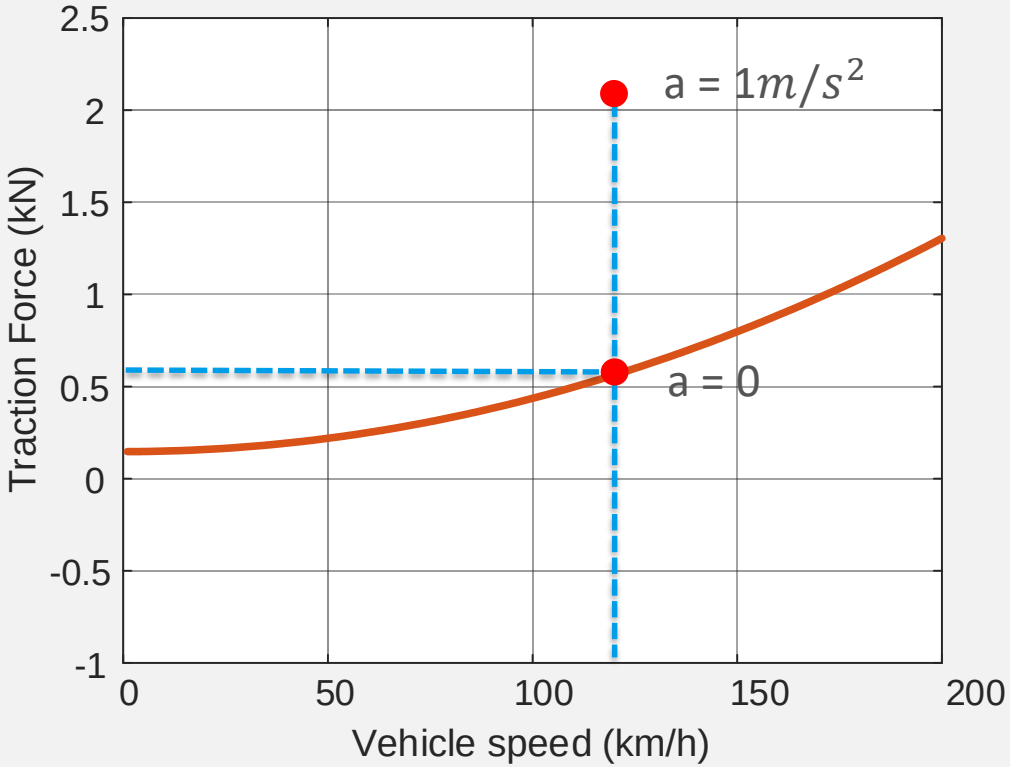
$$F_{tract} = ma + (F_{aero} + F_{roll} + F_{grad})$$



- Road inclination
  - No road gradient
  - 5% road gradient downhill
  - 5% road gradient uphill

Force-speed diagram

$$F_{tract} = ma + (F_{aero} + F_{roll} + F_{grad})$$



- Acceleration
  - a = 1 $m/s^{2,}$
  - ma = 1500N

Power for auxiliaries

- Vehicle auxiliaries:
  - Heating, air conditioning
  - Lighting
  - Wiper
  - Window, seat adjustment
  - Lock system
  - ……

$$P_{batt} = P_{tract} + P_{aux}$$

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