Driving characteristics and resistances

Example:

Calculate the driving resistance of a car when driving straight on a dry concrete road:

1. When driving at a constant speed of 0, 60, 120, 160 km / h.

a- along the horizontal plane
b- on a plane with a slope s = 2%
c- on a plane with a slope s = 6%

2. At constant acceleration and from zero instantaneous speed.

Define:

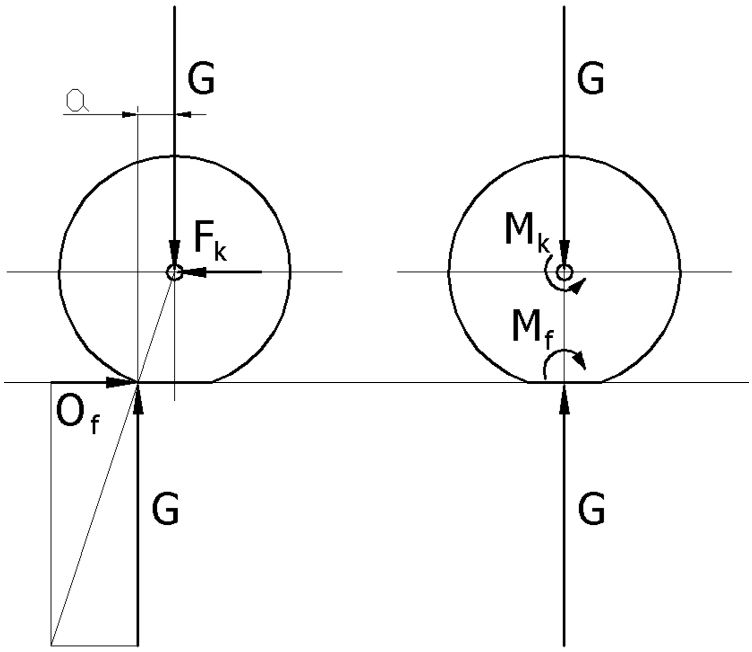
$m = 1450$ kg current mass of car
$S_x = 1{,}87\ m^2$ front view area of car
$c_x = 0{,}3$ coefficient air resistance
$a = 2\ m.s^{-2}$ car acceleration (average acceleration from 0 to 100 km/h is 13,9 s)

The following driving resistances act on the vehicle when driving directly
Of - rolling resistance,
Os - climb resistance,
Ov - aerodynamic resistance,
Oa - acceleration resistance

The total driving resistance Oc will be the sum of them.
The results will be recorded in a table.

v [km/h]	O_f [N]	O_v [N]	O_s [N]			O_c [N]		
			s=0%	s=2%	s=6%	s=0%	s=2%	s=6%

1. Rolling resistance in the horizontal plane



Define rolling resistance

$$O_f = G \cdot f = m \cdot g \cdot f \ \ [\mathrm{N}]$$

kde:

G [N]	Gravity of vehicle
m [kg]	mass of vehicle
g [kg.m.s^{-2}]	gravity acceleration g=9,81 m.$^{s-2}$
f	coefficient rolling resistance

coefficient rolling resistance *f* is depending from:

- Road surface (asphalt, concrete, country road, snow, ...)
- Type of tires (radial, diagonal, tread type, ...) and their inflation
- Vehicle speeds

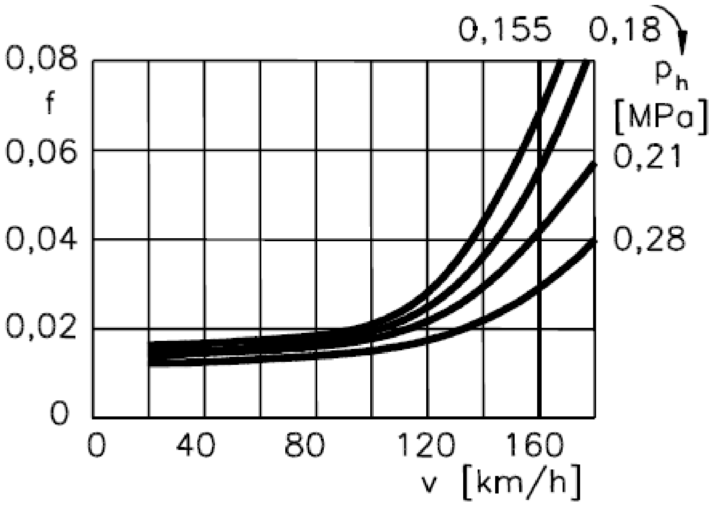
Usually values of coefficient rolling resistance *f*

Asphalt 0.01 - 0.025
Concrete 0.015 - 0.03
Paving 0.02
The snow 0.1 – 0.3

Vehicle propulsion systems

Part: **3**

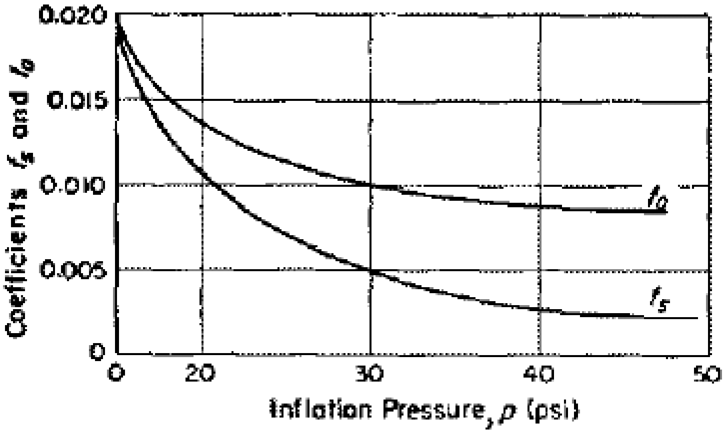
Graph of rolling resistance:



Dependence of rolling resistance coefficient on vehicle speed and tire inflation

Empirical relationships for dry concrete:

$$f = f_0 + 3{,}24 \cdot f_S \left(\frac{v}{160} \right)^{2{,}5}$$



An empirical relationship can be used for speeds up to 130 km / h and a pressure of 26 psi:

$$f = 0{,}01 \cdot \left(1 + \frac{v}{160} \right)$$

when:
v [km/h] current speed of vehicle

For our Example, it will suffice if we consider the rolling resistance coefficient to be constant. From the recommended values for concrete (0.015-0.03) I select:

f=0,02

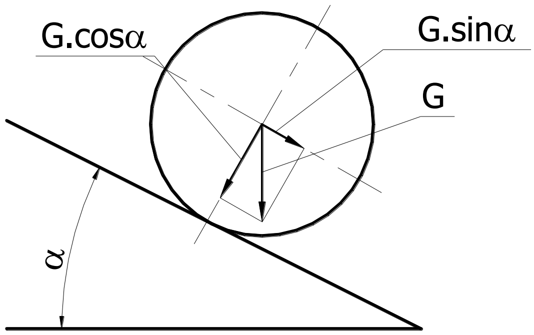
Calculate gravity:

$$G = m \cdot g = 1450 \cdot 9{,}81 = 14225 \ \text{[N]}$$

Calculate rolling resistance:

$$O_f = G \cdot f = 14225 \cdot 0{,}02 = 284{,}5 \ \text{[N]}$$

2. Climb resistance



Define climb resistance

$$O_f = G \cdot f \cdot \cos\alpha = m \cdot g \cdot f \cdot \cos\alpha \ \text{[N]}$$

From climb *s* calculate angle of climba α
If:

$$s = tg(\alpha)$$

Then:

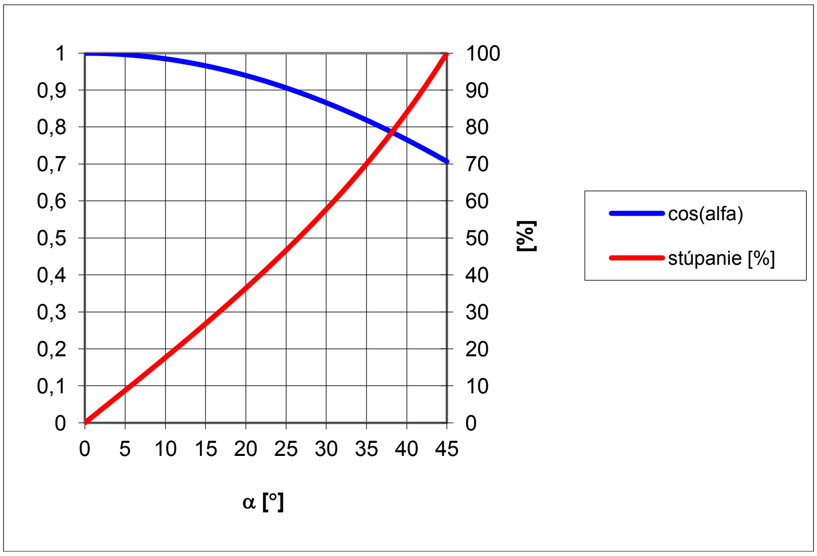
$$\alpha = arctg(s)$$

Calculate angle of climb for climb 2%:

$$\alpha(2\%) = arctg(0{,}02) = 1{,}146°$$

Calculate angle of climb for climb 6%:

$$\alpha(6\%) = arctg(0{,}06) = 3{,}434°$$



The climb resistance for angle α:

$$O_s = G \cdot \sin\alpha = m \cdot g \cdot \sin\alpha \quad [\mathrm{N}]$$

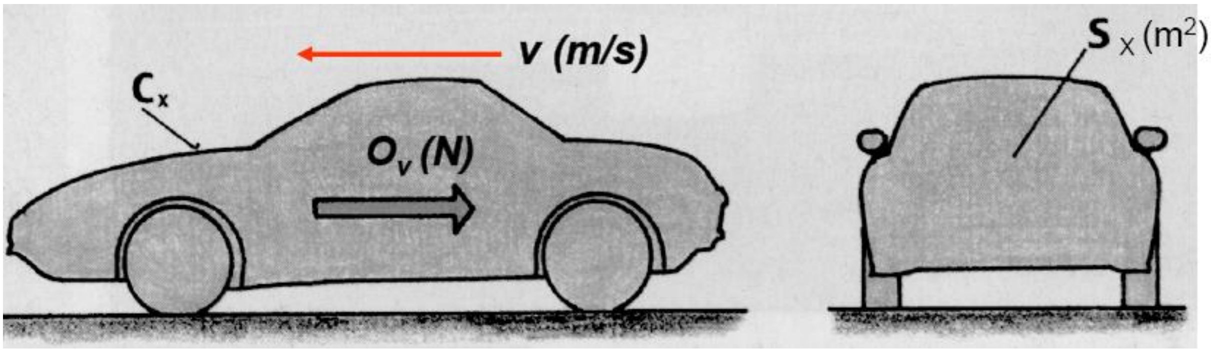
The calculate climb resistance for angle 2%:

$$O_s = G \cdot \sin\alpha = 14225 \cdot \sin 1{,}146° = 284{,}5 \quad [\mathrm{N}]$$

The calculate climb resistance for angle 6%:

$$O_s = G \cdot \sin\alpha = 14225 \cdot \sin 3{,}434° = 852 \quad [\mathrm{N}]$$

3. The aerodynamic resistance



The define of aerodynamic resistance:

$$O_v = \frac{1}{2}\rho_v \cdot c_x \cdot S_x \cdot v_c^2 \quad [\mathrm{N}]$$

When:

ρ_v [kg.m^{-3}] air density
c_x aerodynamic coefficient
S_x [m^2] front view area of vehicle
v_c [m.s^{-1}] total speed of air flow

Air density
Dry air by press 100 kPa (1 bar)
0 °C – 1,276 kg.m^{-3}
20 °C – 1,189 kg.m^{-3}

Used temperature 20 °C, then density of air ρ_v = 1,189 kg.m^{-3}

Usually values of aerodynamic coefficient:
Car 0,27 – 0,4
Truck 0,7 – 1
Bus 0,5 – 0,7

The total speed of air flow

$$v_c = v + v_v \quad [\mathrm{m.s^{-1}}]$$

kde:

v [m.s^{-1}] current vehicle speed
v_v [m.s^{-1}] wind speed – orientation wind is opposite to the moving of vehicle

For Example is v_v = 0 (no wind), then:

$$v_c = v$$

Speed of vehicle [km/h] must convert to the speed in [m/s]:

$$v[m/s] = \frac{1000[m/km] \cdot v[km/h]}{60[\min/h] \cdot 60[s/\min]}$$

$$v[m/s] = \frac{v[km/h]}{3,6}$$

After conversion:

60 km/h	100 km/h	120 km/h	160 km/h
16,667 m/s	27,778	33,333 m/s	44,444 m/s

The total aerodynamic resistance (substitution in [m/s]):

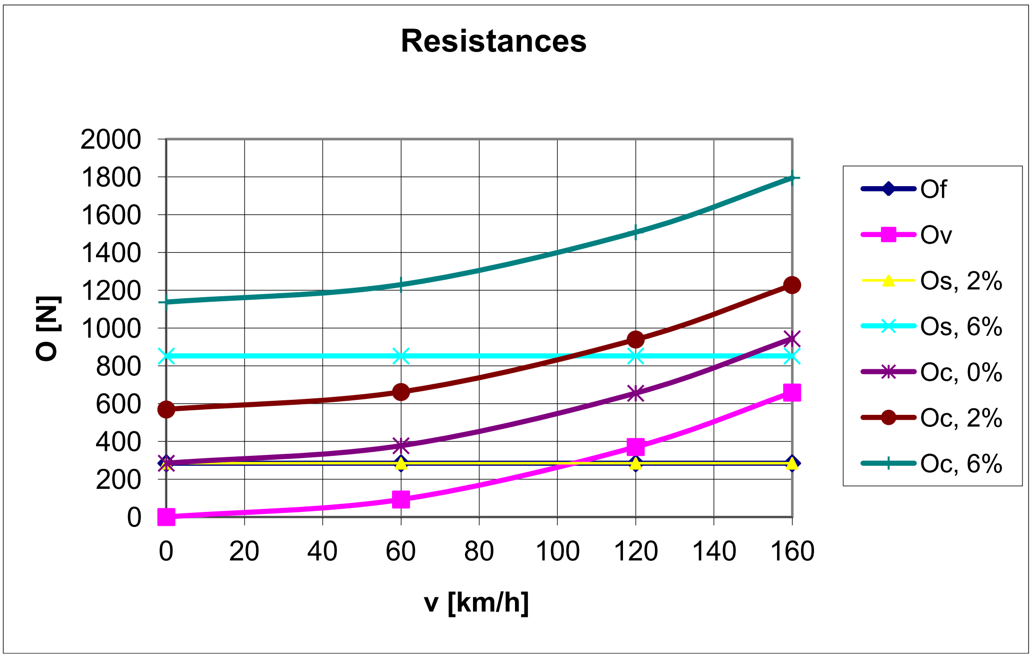
$$O_v = \frac{1}{2}\rho_v \cdot c_x \cdot S_x \cdot v^2 = \frac{1}{2} \cdot 1{,}189 \cdot 0{,}3 \cdot 1{,}87 \cdot v^2 \quad [\mathrm{N}]$$

Total resistence of vehicle is sum the parciant resistences:

$$O_c = O_f + O_v + O_s + O_a$$

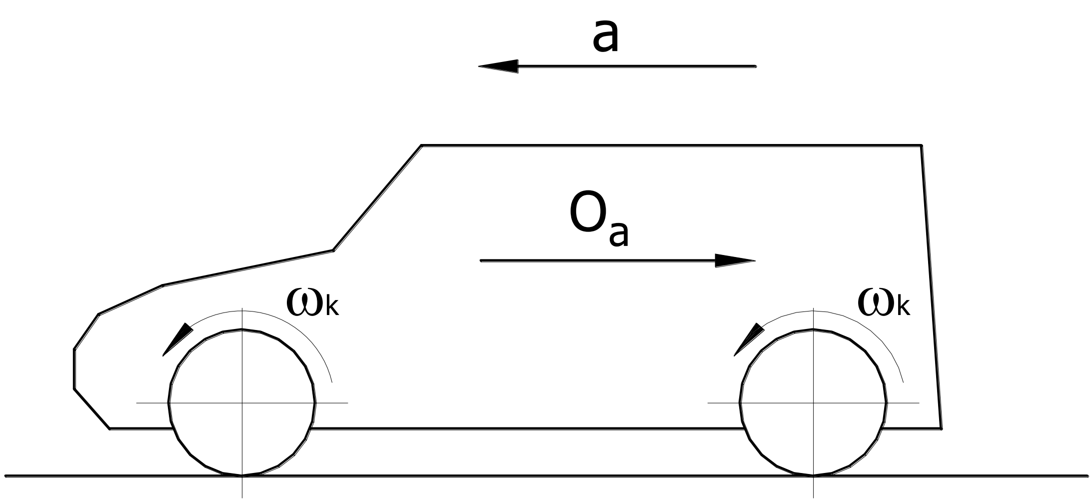
For constant speed driving, the acceleration resistance Oa will be zero.

v [km/h]	O_f [N]	O_v [N]	O_s [N]			O_c [N]		
			s=0%	s=2%	s=6%	s=0%	s=2%	s=6%
0	**284,5**	**0**	**0**	**284,5**	**852**	**284,5**	**569**	**1136,**
60		**92,6**				**377,1**	**661,6**	**1229,2**
120		**370,6**				**655,1**	**939,6**	**1507,1**
160		**658,8**				**943,3**	**1227,8**	**1795,3**



From the graph for our case we can say that:
- Rolling resistance is constant, regardless of incline and speed
- air resistance is significantly manifested only at higher speeds
- The resistance to the ascent is the greatest of all and will be significant even at a small ascent angle

4. The acceleration resistance



Define:

$$O_a = (m + m_R) \cdot a \text{ [N]}$$

when:
m [kg] current mass of vehicle
m_R [kg] reduced mass – from mass of inertia (rotating parts of vehicle – wheels, gear wheels, shaft, etc.) to the mass of moving
c_a coefficient rotating parts
a [m.s^{-2}] acceleration vehicle

Define of reducing mass:

$$m_R = \frac{I \cdot i^2}{r^2}$$

when:
I [kg.m^2] Mass of inertia
r [m] radius of wheel
i ratio

For simply define can used coefficient rotating parts follow:

$$O_a = (m + m_R) \cdot a = m \cdot c_a \cdot a \text{ [N]}$$

When:
c_a coefficient rotating parts

Usually value of coefficient rotating parts c_a:

Car:
c_a=1,5-1,8 reduce by 1st gear ratio
c_a=1,05 reduce by direct

Truck:
c_a=2,5-3 reduce by 1st gear ratio

Warning:
The formula applies to the case if we want to calculate the torque or power of the engine when accelerating the engine. When calculating the adhesive (or frictional) force between the wheel and the pad, we only calculate the rotational masses on the non-driven axles (when the vehicle accelerates due to engine torque).

At an instantaneous speed of 0km/h, we will assume that the car starts from 1st gear, so we choose from the recommended range of c_a:

$$c_a=1,65$$

Then:

$$O_a = m \cdot c_a \cdot a = 1450 \cdot 1,65 \cdot 2 = 4785 \ [\mathrm{N}]$$

The total resistance:

$$O_c = O_f + O_v + O_s + O_a$$

When calculating the total running resistance during acceleration, we take the values of other resistances from the previous table.

Then:

$$O_c = O_f + O_v + O_s + O_a = 284,5 + 0 + 0 + 4785 = 5069,5 \ [\mathrm{N}]$$