Steady-State Power Requirements for Road Vehicles on Steep Gradients

Introduction

This note describes a model for estimating horsepower requirements for road vehicles climbing or descending a gradient at constant speed.

The model was developed to assess braking requirements for light and heavy trucks descending steep gradients at constant speed. The equations estimate power requirements at the driven or braked wheels. Drivetrain power losses are not covered by this model. The model also does not assess the power needed to accelerate or decelerate.

Model Equations

The following equations evaluate wheel power for a vehicle travelling at a constant speed.

Power $P = F_W V$

For a vehicle climbing a constant gradient at a steady speed,

Driving force (drive wheel thrust) $F_W = F_G + F_{AE} + F_{RO} + F_{IF}$

For a vehicle descending a constant gradient at a steady speed,

Braking force $F_W = F_G - F_{AE} - F_{RO} - F_{IF}$

These equations do not account for power loss in the vehicle’s gearbox, driveshaft(s), and axle gearing. Climbing a hill, a vehicle needs an additional 5% to 10% engine power to account for transmission losses.

Nomenclature

A	projected frontal area (m^2)
C_D	drag coefficient (dimensionless)
C_{RO}	rolling resistance coefficient (dimensionless)
F_W	force at driving or braked wheels (N)
g	acceleration of gravity (m/s^2)
m	mass (kg)
M_{IF}	moment of internal (bearing) friction, non-driven or non-braked wheels (Nm)
P	power (W)
R_B	bearing radius (m)
R_W	wheel radius (dynamic) (m)
V	velocity (parallel to road surface) (m/s)
W	weight (N)
α	slope angle (for a level road, $\alpha = 0$)
ρ	air density (kg/m^3)
μ	friction coefficient (dimensionless)

Components of Force

Hill climb (gravity) force (N)	$F_G = m\, g \sin(\alpha)$
Aerodynamic drag (N)	$F_{AE} = \frac{1}{2} \rho\, A\, C_D\, V^2$
Rolling resistance (N)	$F_{RO} = m\, g\, C_{RO} \cos(\alpha)$
Internal friction (undriven or unbraked wheels) (N)	$F_{IF} = \mu\, m\, g\, R_B / R_W$

Notes

Unless otherwise noted, force equations have been derived from The Engineering Toolbox and Hannah & Hillier, 1970.

Aerodynamic Resistance

The model ignores the effect of wind. Air velocity is assumed to be equal to the vehicle speed, parallel to the road surface.

The model allows the drag coefficient to be set by the user.

For heavy trucks, drag coefficients are based on results in Chowdhury et al., 2013. Chowdhury et al. tested a model semi-trailer, with 6x4 tractor and three-axle trailer. They found aerodynamic drag coefficient for a conventional rig ~0.8. With a typical cab fairing, C_D drops to about 0.66 at 50 km/h, slightly less at higher speeds.

Rolling Resistance

Tyre rolling resistance is a function of speed. The model uses functions for “heavy truck”, and “light truck”.

For light vehicles the coefficient is derived from $C_{RO} = 0.005 + (1 / p)(0.01 + 0.0000123 V^2)$

where p = tyre pressure in bar

For a light truck, p = 3 bar (44 psi):

when V= 0, $C_{RO} = 0.00833$

when V= 14 m/s (50 km/h), $C_{RO} = 0.00914$

For heavy vehicles, the light vehicle model underestimates the coefficient

I used $C_{RO} = 0.0055 + (1 / p)(0.01 + 0.0000123 V^2)$

p = 8.5 bar (123 psi)

when V= 0, $C_{RO} = 0.0067$

when V= 14 m/s, $C_{RO} = 0.00696$

Ref: https://www.engineeringtoolbox.com/rolling-friction-resistance-d_1303.html. See also NRC, 2012

Internal Friction

Internal friction is the friction on undriven or unbraked wheels. This is assumed to be the friction of the wheel bearings, typically tapered roller bearings.

Roller bearing friction is derived from JTekt, 2026, and Hannah and Hillier, 1970 (pg. 79) , as follows:

Moment (torque) of internal friction	$M_{IF} = \mu W R_B$
Internal friction force	$F_{IF} = M_{IF} / R_W$
That is, Internal friction force	$F_{IF} = \mu m g R_B / R_W$

JTekt, 2026, gives roller bearing friction coefficient $\mu = 0.0017 \sim 0.0025$

Author

Kevin Cudby
71 Manuka Street, Masterton, New Zealand
https://kevincudby.com

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