VEHICLE LOADS

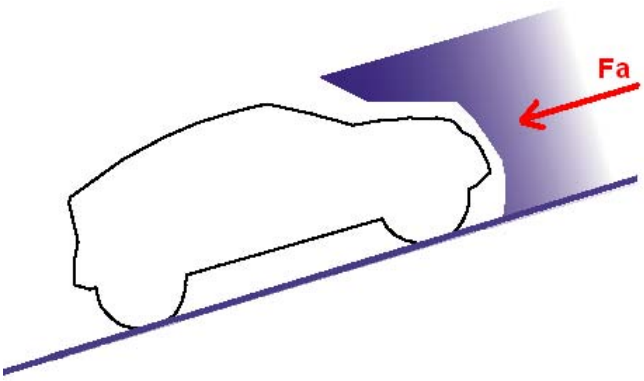
1. Introduction to vehicle loads:

A moving vehicle is subjected to loads according to physical laws relating to its environment. The principal loads on the vehicle are: gravity, the mass of the vehicle with regard to acceleration (Newton's second law), the rolling resistance at each tyre to road interface, and the aerodynamic resistance. Obviously a bulky heavy vehicle on an uneven surface will require more energy to move it than will a light streamlined vehicle on a smooth flat surface. To complicate things further, these loads are not constant but vary in a non-linear manner according to the vehicle's speed.

An intelligent test bench is able to simulate these different vehicle loads: testing is thereby undertaken under the same operating conditions that would be experienced on the road. The loads can be calculated according to physical laws, to take account of the actual characteristics of the vehicle and of the driving conditions.

2. The calculation of vehicle loads:

2.1 Aerodynamic resistance



The load resulting from the aerodynamic pressure generated by the vehicles speed is called the aerodynamic force Fa, commonly termed aerodynamic drag. The power consumed by the vehicle in overcoming this load is calculated according to the following relationship:

$$Pa = Fa.V = \frac{1}{2}.\rho_{air}.Cd.A.V^3$$

The power consumed is a function of:

- The drag coefficient Cd. Measured in a wind tunnel, this is a measure of the ease by which a vehicle slips through the air.
- The frontal area of the vehicle A (in m²). To picture this, imagine a photo taken facing perpendicular to the front of the vehicle. S is the area of the vehicle's image on the photo. For a car this area can be approximated by: A=0.9 x width x height.
- The air density ρ_{air} (in kg/m^3). Simply the mass of a cubic metre of air, this value varies as a function of altitude, temperature and humidity. At sea level, a temperature of 0°C, a barometric pressure of 1013Hpa and an ambient humidity of 0%, the value of ρ_{air} is 1,293 kg/m^3.
- The forward speed of the vehicle V (in m/s). With speed entering the relationship at the power of three, the aerodynamic rag tends to rise dramatically as speed increases.

Note : Cd and the frontal area A are frequently represented by their product, expressed simply as CdA. This value is the apparent aerodynamic surface commonly termed the drag area. Table 1 gives, in ascending order, an example of this value for different types of vehicle. It's this value that is used by the software for calculating the aerodynamic vehicle load.

Vehicle	Frontal surface A (in m^2)	Cd	CdA (in m^2)
Motorbike - tourer 	0.7	0.90	0.63
Motorbike - competition 	0.48	0.67	0.32
Kart 	0.35	0.80	0.28
"Streamlined" car 	1.8	0.30	0.54
"Boxy" car	1.8	0.50	0.9
Small commercial vehicle 	5	0.50	2.5
Small lorry 	7	0.73	5.11
Articulated lorry 	9	0.90	8.1
F1	1.6	0.90	1.44
Sports prototype	1.7	0.50	0.85
Light aircraft	5	0.12	0.6

Table 1: aerodynamic parameters for various types of vehicle

Example: For a car of Cd=0.30 and a frontal area of 1.8m² travelling at a speed of 90km/h. We have :

$$Pa=\frac{1}{2}\times 1{,}205\times 0{,}3\times 1{,}8\times\left(\frac{90}{3{,}6}\right)^3=5000W$$

Hence $Pa=$ 5kW or alternatively $Pa=6.7hp$

The power consumed by this vehicle in overcoming the aerodynamic resistance load is therefore 6.7hp.

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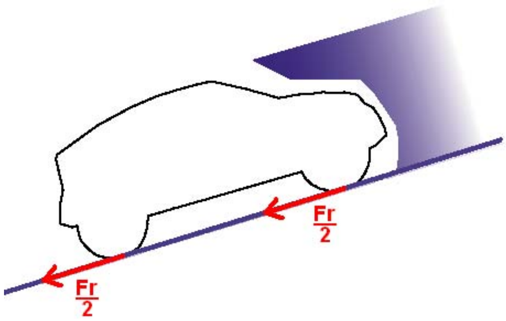
2.2 Rolling resistance



Under a vehicles weight a tyre deforms on contact with the road thus creating a contact surface. It's this surface that gives the vehicle the adhesion necessary for motion. Unfortunately both tyre deformation and road contact consume energy: this energy loss is due to the force termed rolling resistance. The power consumed by the vehicle in overcoming the rolling resistance load is given by the following relationship:

$$P_R = Fr.V = m.g.K_R.V$$

The power consumed is a function of :

- The vehicle's mass **m** (in kg).
- The gravitational acceleration **g** (in m/s²). Its value is 9,81 m/s².
- The rolling resistance coefficient **Kr** : depends on several parameters such as the road surface, the type and dimensions of the tyre, the temperature of the contact surface and the tyre pressure. Table 2 gives, in ascending order, examples of this coefficient for different types of road surface.
- The forward speed of the vehicle V (in m/s).

Road surface	Rolling resistance coefficient Kr
Cobbled	0.015
Asphalt, concrete	0.015
Rolled Tarmac	0.020
Tarmac	0.025
Packed earth	0.050
Wheel on rail	0.001 to 0.002

Table 2: rolling resistance coefficient as a function of road surface.

Continuing the previous example:

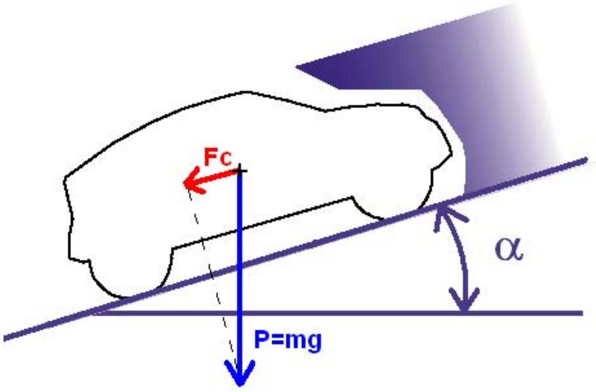
The same car weighs 1200kg and travels on a tarmac road surface (Kr=0.025). Therefore:

$$P_R = 1200 \times 9.81 \times 0.025 \times \left(\frac{90}{3.6}\right) = 7400W$$

Hence $P_R = 7.4kW$ or alternatively $P_R = 9.9hp$

The power consumed by this vehicle in overcoming the rolling resistance load at 90 Km/h is therefore 9.9hp.

2.3 Climbing resistance



When a vehicle climbs a slope it encounters a load related to the steepness of the road. The power consumed by the vehicle in overcoming this climbing resistance force is calculated as follows:

$$P_c = m.g.\sin(\alpha).V$$

The power consumed is a function of:

- The vehicle's mass **m** (in kg).
- The gravitational acceleration **g** (in m/s²).
- The slope angle **α** (in degrees). On our roads slope steepness expressed as a percentage (a 10% slope corresponds to a 10m rise over a 100m distance) : the angle **α** of the slope is given by the formula:

$$\alpha = \tan^{-1}\left(\frac{rise}{100}\right)$$

For a slope of 5%, we have: $\alpha = \tan^{-1}\left(\frac{5}{100}\right) = 2{,}86°$

Let's apply this formula to our example:

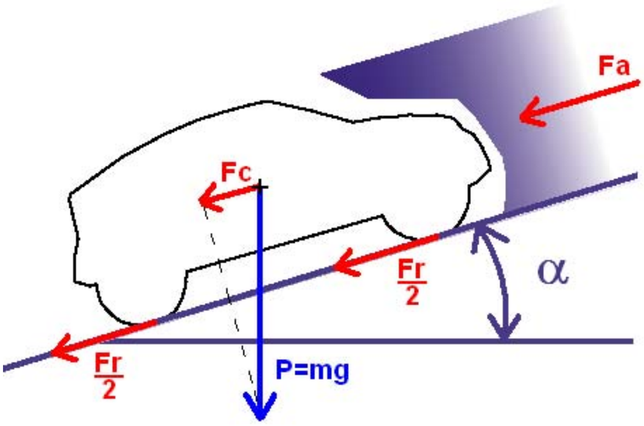
The car climbs a 5% slope(**α** =2,86°). Hence we obtain:

$$P_R = 1200 \times 9.81 \times \sin(2.86) \times \left(\frac{90}{3.6}\right)$$

$P_R = 14.7kW$ alternatively $P_R = 19.9hp$

The power consumed by this vehicle in climbing a 5% slope at 90 Km/h is therefore 19.9hp.

2.4 Total resistance



Under real driving conditions a vehicle is subjected to all of these loads simultaneously and at varying intensities. The vehicle's total power consumption, at constant speed, to overcome the external loads applied by its environment, is hence the sum of the preceding 3 loads:

$$Ptotal = Pa + \Pr + Pc$$

$$Ptotal\ (V) = \frac{1}{2} \cdot \rho_{air} A\, Cd V^3 + m.g.Kr.V + m.g.\sin(\alpha).V$$

Let us return to our example :

For a car of mass m=1200kg having a Cd=0.30 and a frontal area of 1,8m², climbing a slope of 5% (α =2,86°) on a tarmac road surface (Kr=0.025) at a speed of 90km/h, we obtain:

$$Ptotal. = 5000 + 7400 + 14700 = 27100W$$

Hence $Ptotal. = 27{,}1kW$ or alternatively $Ptotal. = 36.8hp$

The vehicles total power consumption will therefore be 36.8hp to travel at constant speed in these conditions.

3. Values calculated according to vehicle loads

3.1 The available power

Knowing the power consumed by a vehicle when travelling at constant speed in a given environment, one can introduce idea of available power. This is the remaining power available for accelerating the vehicle: it is defined as the difference the power of the engine and the power consumed at constant speed. During a bench test, it is the difference between the engines power output and the power absorbed by the bench:

$$Pavailable(V) = Pengine(V) - Pabsorbed(V)$$

$$= Pengine(V) - \left(\frac{1}{2}.\rho_{air}.CdA.V^{3} + m.g.Kr.V + m.g.\sin(\alpha).V\right)$$

This power is a function of:

- The actual parameters of the vehicle and the road conditions as studied above (Cd, Kr…).
- The vehicle's speed.
- The engine's power curve.
- The gear engaged on the gearbox the engine is driving through. In effect the same vehicle speed being possible in several different gears, the engine speed and therefore its power output will be different.

For our example :

- Case 1: The vehicle attains a speed of 90km/h in 5th gear at 2400rpm at which a power of 50kW (68hp) is available. The power necessary for motion in the conditions being 27kW (37hp), the available power remaining is 23kW (31hp).
- Case 2 : The vehicle attains a speed of 90km/h in 4th gear at 3200rpm at which a power of 66kW (90hp) is available. The power necessary for motion in the conditions being 27kW (37hp), the available power remaining is 39kW (53hp).

The Rotronics software allows the calculation of available power in each gear, as a function of the vehicles speed.

3.2 Available acceleration

From knowledge of the available power, it is possible to calculate the available acceleration. This value represents the vehicle's remaining acceleration capacity for a particular set of road conditions, at a given speed, and gear selection. This available acceleration $\gamma_{available}$ is given by the following relationship:

$$\gamma_{available}(V) = \frac{Pavailable(V)}{m.V}$$

The acceleration depends on :

- The available power Pavailable (in W) and therefore the selected gear.
- The vehicle's mass **m** (in kg).
- The forward speed of the vehicle V (in m/s).

For our example :

- Case 1 : Vehicle at 90km/h in 5th, available power of 23kW (31hp).

$$\gamma_{available}(V) = \frac{23000}{1200 * \left(\frac{90}{3.6}\right)}$$

$$\gamma_{available}(V) = 0.767 m/s^2$$

The vehicle can therefore accelerate at 0.767m/s per second, being a speed increase of 2.76km/h in one second.

- Case 2 : Vehicle at 90km/h in 4th, available power of 39kW (53ch).

$$\gamma_{available}(V) = \frac{39000}{1200 * \left(\frac{90}{3.6}\right)}$$

$$\gamma_{available}(V) = 1.3 m/s^2$$

The vehicle can therefore accelerate at 1.3m/s per second, being a speed increase of 4.68km/h in one second.

The Rotronics software allows the calculation of available acceleration in each gear, as a function of the vehicles speed.