Physics in daily life: Drag 'n' Roll

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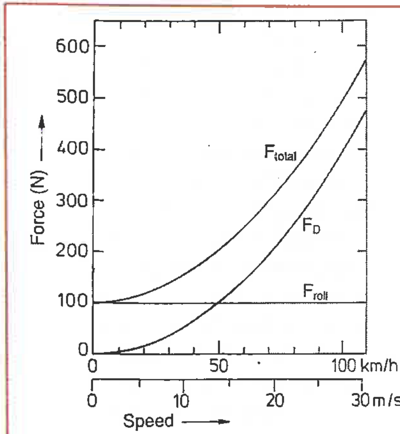
Whether we ride our bike or drive our car: there is resistance to be overcome, even on a flat road; that much we know. But when it comes to the details, it's not that trivial. Both components of the resistance—rolling resistance and drag—deserve a closer look. Let us first remember the main cause of the rolling resistance. It's not friction in the ball bearings, provided they are well greased and in good shape. It's the tires, getting deformed by the road. In a way, that may be surprising: the deformation seems elastic, it's not permanent. But there is a catch here: the forces for compression are not compensated for by those for expansion of the rubber (there is some hysteresis, if you wish). The net work done shows up as heat.

The corresponding rolling resistance is, to a reasonable approximation, independent of speed (which will become obvious below). It is proportional to the weight of the car, and is therefore written: $F_{roll} = C_r mg$, with C_r the appropriate coefficient. Now we can make an educated guess as to the value of C_r. Could it be 0,1? No way: this would mean that it would take a slope of 10% to get our car moving. We know from experience that a 1% slope would be a better guess.

Right! For most tires inflated to the recommended pressure, $C_r = 0{,}01$ is a standard value. By the way: for bicycle tires, with pressures about twice as high, C_r can get as low as 0,005.

The conclusion is that, for a 1000 kg car, the rolling resistance is about 100N.

What about the drag? In view of the Reynolds numbers involved ($Re \approx 10^6$) forget about Stokes. Instead, we should expect the drag F_D to be proportional to $\frac{1}{2}\rho v^2$, as already suggested by Bernoulli's law. On a vehicle with frontal area A, one can write $F_D = C_D A \cdot \frac{1}{2}\rho v^2$. Now, C_D is a complicated function of speed, but for the relevant v-range we may take C_D constant. For most cars, the value is between 0,3 and 0,4.



▲ Fig. 1

The total resistance is now shown in the figure, for a mid-size model car (m=1000 kg, C_r = 0.01, C_D= 0,4 and A=2 m²). It is funny to realize that the vertical scale immediately tells us the energy consumption. Since 1 N is also 1 J/m, we find at 100 km/h approximately 500 kJ/km for this car. Assuming an engine efficiency of 20%, this corresponds to about 7 liters of gasoline per 100 km. At still higher speeds, the figure suggests a dramatic increase in the fuel consumption. Fortunately, it's not that bad, since the engine efficiency goes up, compensating part of the increase.

What about the engine power? Since $P = F \cdot v$, we find at 100 km/h about 15 kW is needed. That's a moderate value. But note that, at high speed where drag is dominant, the power increases almost as v^3! Should we want to drive at 200 km/h, the engine would have to deliver the 8-fold power, or 120 kW. That's no longer moderate, I would say, and I'm sure the police would agree....