Measure of the rolling resistance for a set of 4 tires *Michelin Agilis* 175 / 65 R14 90T Mounted on the Van Citroën Berlingo Electrique *CATHI*	Sycomoreen CATHI http://sycomoreen.free.fr April 2nd, 2011

Theory

A vehicle undergoes two types of rubbing forces :

- The drag of aerodynamic rubbing $F_{aero} = \frac{1}{2}\rho\ S\ C_x\ V^2$ in Newton where :
  - ρ is the volumic mass of the air : 1.2 kg / m^3 at 20°C
  - S is the front area of the vehicle in m² (3.2 m²)
  - C_x is the penetrating coefficient in the air of the vehicle (0.29)
  - V is the relative speed of the air compared to the vehicle in m/s
- The drag of rolling resistance from the tires $F_{rr} = C_{rr} m\ g$ in Newton where :
  - C_{rr} is the rolling resistance coefficient of the tire (to evaluate)
  - m is the mass carried by the tire
  - g the acceleration of gravity : 9,81 m/s²

Protocol of experience

One is trying to measure the rolling resistance coefficient of a *Citroën Berlingo Electric* Van equipped with *Michelin Agilis* 175 / 65 R14 90T tires, inflated at the maximal recommended pressure (3,75 Bar cold). This Citroën has got a GPS and uses an hectometer device of distance. One achieves the following operations on a road in good state, little windy, quite horizontal and tared :
1) Launch of the vehicle until stabilized 20 km/h by the GPS : it detects the speed at nearly 1km/h,
2) Set of the speed lever at the neutral position (N) to get free rolling,
3) Measure of the drived distance until the complete stop with the hectometer device,
4) Repetition of the experiment in both ways of a same portion of the road, 5 times.

Energetic balance

One admits the hypothesis that under the previewed conditions, **the aerodynamic rubbing is negligible** and that only the drag of rolling resistance is contributing to stop the vehicle along the D distance.

One will check a posteriori that this hypothesis is right.

The theorem of kinetic energy gives : $\Delta E_c = W\left(\vec{F}_{rr}\right) \Rightarrow \frac{1}{2} m\ V^2 = F_{rr}\ D$; and $F_{rr} = C_{rr} m\ g$

One deducts : $\frac{1}{2} m\ V^2 = C_{rr}\ m\ g\ D$ $\boxed{\Rightarrow C_{rr} = \frac{V^2}{2\ g\ D}}$

Measures and uncertainties

The repeated stops of the van reveal a distance D = 150 m measured at nearly 10 m of precision by the hectometer device. The raw measured value is $C_{rr} = 0.0105$ with V= 5.55m/s

Calculation of uncertainty : $C_{rr} = \frac{V^2}{2\ g\ D} \Rightarrow \frac{\Delta C_{rr}}{C_{rr}} = 2\frac{\Delta V}{V} + \frac{\Delta D}{D} = 2\frac{1}{20} + \frac{10}{150} = 0.1666$

One raises the relative uncertainty to 20% (uncertainty on g is neglected) :

$\Delta C_{rr} = 0.0105 \times 20\% = 0.00210$ Result : $\boxed{C_{rr} = 0.01 \pm 0.002}$, or $\boxed{0.008 < C_{rr} < 0.012}$

Comparison between the aerodynamic drag and the rolling resistance drag

$$\text{One has } \frac{F_{aero}}{F_{rr}} = \frac{\frac{1}{2}\rho\, S\, C_x\, V^2}{C_{rr} m\, g} = \frac{\rho\, S\, C_x\, V^2}{2\; C_{rr} m\, g}$$

The numerical calculation gives for m = 1700 kg ; SC_x = 0.92 , C_{rr} = 0.01

$\boxed{\frac{F_{aero}}{F_{rr}} \simeq 0.1}$ at 5.55 m/s = 20 km/h and $\boxed{\frac{F_{aero}}{F_{rr}} \simeq 0.025}$ at 2.775 m/s = 10 km/h

The aerodynamic strength are about 5% of the rubbings of the vehicle in this experiment, either 4 times less as the heap of measuring uncertainties : **thus they are rightly neglected**.

Examples of rolling resistances for other tires, commentaries

Column "RRC Average" extracted from *Green Report March 2003* : "Low Rolling Resistance Tires : fuel savings for America "

TABLE 1: RECOMMENDED TIRE MODELS

BRAND	MODEL	SIZE	RRC AVERAGE	PRICE	TRACTION COMPOSITE	WOULD BUY AGAIN	COMPOSITE TREAD WEAR	COMPOSITE PERFOR-MANCE SCORE
Bridgestone	B381	185/70R14	0.0062	$62.00	8.00		5.96	6.98
Nokian	NRT2	185/70R14	0.0085	$67.00	8.00		5.72	6.86
Sumitomo	HTR 200	185/70R14	0.0092	$36.00	8.15	8.30	7.05	7.83
Dunlop	Graspic DS-1	185/70R14	0.0092	$46.00	7.50	7.90	6.60	7.33
Dunlop	SP40 A/S	185/70R14	0.0103	$41.00	8.00		7.18	7.59
Bridgestone	Blizzak WS-50	185/70R14	0.0103	$68.00	7.91	8.70	6.04	7.55
Goodyear	VIVA 2	185/70R14	0.0104	$47.96	7.00		6.52	6.80
Continental	ContiTouring Contact CH95	205/55R16	0.0083	$64.00	7.46	6.10	7.29	6.95
Michelin	Pilot Alpine	205/55R16	0.0090	$125.00	7.56	8.60	8.00	8.05
Michelin	EnergyMXV4 Plus	205/55R16	0.0090	$118.00	7.64	6.00	6.87	6.84
Dunlop	SP Winter Sport M2	205/55R16	0.0102	$98.00	8.55		7.80	8.17
Michelin	Arctic AlpineXL	235/75R15	0.0081	$79.00	8.10	8.50	7.10	7.90
Dunlop	Axiom Plus WS	235/75R15	0.0088	$43.00	8.00		5.88	6.94
BF Goodrich	Long Trail T/A	245/75R16	0.0092	$76.00	7.94	6.20	7.11	7.08
Michelin	XPS Rib	LT245/75R16	0.0101	$167.90	6.70	8.10	8.00	7.60
Michelin	LTX M/S	245/75R16	0.0103	$139.00	7.97	8.30	7.37	7.88
Bridgestone	Dueler A/T D693	245/75R16	0.0103	$104.00	8.00		7.20	7.60

NOTE: The lower the rolling resistance coefficent (RRC), the more efficient is the tire; all tires listed here meet Green Seal's criterion for rolling resistance of less than 0.0105 and are among the most efficient available in the market today. In contrast, the higher the value of Traction Composite, Would Buy Again, Composite Treadwear, and Composite Performance Score, the better in those measures the tire is; however, all tires listed here have a greater than average performance score in these respects.

 http://www.wbdg.org/ccb/GREEN/REPORTS/cgrtirerollingresistance.pdf

The *Michelin Agilis* 175/65 R14 90T tire *is not designed as a priority to decrease the rolling resistance*, but for a good adhesion both on dry *and* wet surfaces, notably for a heavy load (usual specifications for the vans).

Nevertheless, it shows a correct performance while rolling if it is inflated at the recommended maximum. It applies thus for an electric vehicle where this criteria significantly impacts the autonomy (about 10%). The best would be a *Michelin Energy* tire which has a harder siliceous rubber and whose *the design sets as a priority to decrease the dissipative effects inside and outside the tire*.

Conclusions, and to know more

The described modelling and experiment have measured *a good magnitude of the C_{rr} for a standard load* (625 kg/pneu) and a low speed. In fact, the C_{rr} is varying with the load, the pressure, the temperature, the speed, the state and type of tire, the state of the soil, and many other factors. **It has essentially an experimental aspect**.

http://www.profauto.fr/2-Apports_theoriques/Resistance_avancement.pdf
http://www.tut.fi/plastics/tyreschool/moduulit/moduuli_8/hypertext_1/3/3_3.html
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