Rolling Resistance Is Not Friction: It Vanishes for a Perfectly Elastic Wheel and Does Not Depend on Speed

— Rolling one tonne over one kilometre takes **14.7100** kJ on steel wheels and rails and **117.6798** kJ on car tyres and asphalt, a difference of **102.9698** kJ and a ratio of exactly **8** — the separator is elastic against viscoelastic — [Paper 667]

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— From thinking to syncing. —

Abstract

It is natural to think that what stops a rolling wheel is friction. But rolling resistance is not sliding friction; it is the part of the deformation that does not come back.So it vanishes for a perfectly elastic wheel and does not depend on speed. That is shown in numbers.No new theorem or law is claimed. First, the same load over the same distance differs by eight times——rolling 1 t over 1 km takes 14.7100 kJ on steel wheels and rails and 117.6798 kJ on car tyres and asphalt, a ratio of exactly 8 and a difference of 102.9698 kJ (Section 2). **Second, and this is the core. What it really is, is the forward shift of the line of the normal force——turned into a length, the same coefficient gives 0.690000 mm for a steel wheel (radius 0.46 m), 3.840000 mm for a car tyre (0.32 m) and 1.400000 mm for a bicycle tyre (0.35 m)** (Section 3). **Third, for a perfectly elastic wheel it is 0——varying the fraction of the deformation that is returned, the coefficient moves in proportion to what is lost, and at a returned fraction of 1, perfect elasticity, it came out exactly 0** (Section 3). **Fourth, independence of speed is the fingerprint——the rolling resistance of a car of 1500 kg is 176.5197 N at every speed, and air drag draws level with it only at 73.046099 km/h** (Section 4). **Fifth, at low speed there is almost nothing else——air drag is 0.074966 of the rolling resistance at 20 km/h, 0.468539 at 50 km/h, and only at 100 km/h does it reach 1.874157** (Section 4). **Sixth, the separator is elastic against viscoelastic——it is neither the roughness of the surfaces nor the area of contact, but whether part of the deformation fails to come back** (Section 4). **Keywords**: rolling resistance, rolling resistance coefficient, hysteresis loss, viscoelasticity, road load, railway.

Scope of this paper (scope note): **No new theorem or law is claimed——the rolling resistance coefficient, its expression as a forward shift of the line of the normal force, and its origin in hysteresis loss are all standard (Wong 2008, Gillespie 1992).Representative values are used——the coefficients, wheel radii, drag area and vehicle mass are representative, not measurements of a particular vehicle.Tyre construction is not treated——rubber compounds, inflation pressure, temperature and wear are not the subject.No viscoelastic model is solved——the returned fraction is assumed, and only the perfectly elastic end is checked. Frequency and temperature dependence are not treated.The whole of road load is not discussed——gradients, acceleration and driveline losses are not included. Only steady running on the level is examined.Relation to earlier papers**: **Paper 449 showed that what sets the speed is the power and not the gear, and stated that it took a rolling resistance of 0.005 as a representative value, where the coefficient was one of the inputs——this paper enters that coefficient and counts where it comes from and why it does not depend on speed.**What is added is **setting steel wheels and tyres side by side in work per tonne-kilometre**, **turning the coefficient into a length as the forward shift of the normal force**, **placing the end at which a returned fraction of 1 gives 0**, **deriving the speed at which air drag draws level**, and **placing the separator on elastic against viscoelastic**.

1. Notation and the Question

Setting: **a load of mass m is rolled a distance D on wheels of rolling resistance coefficient C_{rr}. The work required and the force on the wheel are**

$$E = C_{rr}\, m\, g\, D, \qquad F = C_{rr}\, m\, g = \frac{e}{R}\, m\, g$$

where e is the distance by which the line of the normal force shifts forward in the contact patch and R is the wheel radius. No speed appears in this way of writing it.

Question: **is a rolling wheel stopped by friction at the surfaces, or by deformation that does not come back?**

2. Eight Times, for the Same Load

Computation 2.1: **the work to roll 1 t over 1 km was derived for three pairings.**

pairing	C_{rr}	1 t over 1 km
steel wheel on rail	**0.0015**	**14.7100** kJ
bicycle tyre (high pressure)	**0.004**	**39.2266** kJ
car tyre on asphalt	**0.012**	**117.6798** kJ

The steel wheel takes exactly one eighth of the tyre, a difference of 102.9698 kJ per tonne-kilometre.

> **Observation 2.2**
>
> this difference is not one of hardness but of what fails to come back.A steel wheel on a steel rail barely deforms, and what does deform is returned almost entirely. A rubber tyre deforms a great deal, and part of it turns to heat on the way back——that is where the difference in the work of carrying arises.

3. What It Really Is: a Shifted Line of Force

Computation 3.1: the coefficient was turned into the forward shift of the line of the normal force, $e = C_{rr} R$.

pairing	wheel radius	shift e
steel wheel on rail	0.46 m	0.690000 mm
car tyre on asphalt	0.32 m	3.840000 mm
bicycle tyre (high pressure)	0.35 m	1.400000 mm

In the front half of the contact patch the material is being compressed; in the rear half it is recovering. If it does not fully recover, the front half pushes back harder, and that imbalance shifts the line of force forward.

Computation 3.2: taking a model in which the coefficient is proportional to what is lost, calibrated so that a returned fraction of 0.90 gives the car's 0.012, a returned fraction of 0.95 gives 0.006000, 0.99 gives 0.001200, and 1, perfect elasticity, gives exactly 0.

> **Observation 3.3**
>
> this is the core: for a perfectly elastic wheel it is 0.With sliding friction, a force remains as long as the surfaces are pressed together. Rolling resistance stands on nothing but the part that fails to return——set that part to zero and, with contact and load unchanged, the resistance alone disappears.

4. The Separator

Computation 4.1: for a car (1500 kg, $C_{rr} = 0.012$, drag coefficient times frontal area 0.70 m^2), rolling resistance and air drag were derived by speed.

speed	rolling resistance	air drag	air ÷ rolling
20 km/h	176.5197 N	13.2330 N	0.074966
50 km/h	176.5197 N	82.7064 N	0.468539
100 km/h	176.5197 N	330.8256 N	1.874157

The two draw level at 73.046099 km/h. The rolling-resistance column is the same in all three rows: no speed enters it.

> **Observation 4.2**
>
> the separator is elastic against viscoelastic.It is not sliding friction and not surface roughness. With the same load and the same contact, changing only the returned fraction moves the resistance——and independence of speed is the fingerprint: a viscous resistance would grow in proportion to speed, and air drag as its square.

> **Observation 4.3**
>
> beside Paper 449.Paper 449 solved the balance of road running from power and took a rolling resistance of 0.005 as a representative value, where the coefficient was a given input——this paper enters its contents and counts what the eightfold difference between 0.0015 and 0.012 is a difference of.

> **Observation 4.4**
>
> what is not said.Compounds, pressures and temperatures are not treated, and no viscoelastic model is solved; the returned fraction was assumed——what is shown is that the resistance stands on the part that fails to return, that it is 0 at the elastic end, and that it does not depend on speed.

5. Roll Call and Closing

1. **14.7100 kJ on steel** (Computation 2.1): **1 t over 1 km.**
2. **117.6798 kJ on tyres** (Computation 2.1): **exactly 8 times.**
3. **a difference of 102.9698 kJ** (Computation 2.1): **per tonne-kilometre.**

4. **a shift of 0.690000 mm** (Computation 3.1): **the steel wheel.**
5. **3.840000 mm for a tyre** (Computation 3.1): **the same coefficient, another face.**
6. **0 when perfectly elastic** (Computation 3.2): **the core.**
7. **176.5197 N at every speed** (Computation 4.1): **all three rows alike.**
8. **level at 73.046099 km/h** (Computation 4.1): **where air drag catches up.**
9. **0.074966 at 20 km/h** (Computation 4.1): **almost all rolling.**
10. **elastic or viscoelastic** (Observation 4.2): **the separator; Paper 449.**

Closing: **What stops a rolling wheel is not sliding at the surfaces.Rolling 1 t over 1 km takes 14.7100 kJ on steel wheels and 117.6798 kJ on tyres, exactly eight times as much.The coefficient can be turned into a length, the forward shift of the line of the normal force (0.690000 mm for steel, 3.840000 mm for a tyre), and setting the returned fraction to 1 made it exactly 0——rolling resistance stands on nothing but the part of the deformation that fails to come back.And independence of speed is its fingerprint——for a car, 176.5197 N at every speed, with air drag drawing level only at 73.046099 km/h.The separator is elastic against viscoelastic.Placed among the earlier papers——the contents of the coefficient Paper 449 took as a representative value were counted.To be honest——the returned fraction is an assumed model, and tyre construction and temperature are not treated.**

References

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