

A Novel Energy Imbalance Approach Applied to Rolling Resistance Assessment in Cycling

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Abstract

We present a novel approach for on-field rolling resistance testing, achieving repeatability below 2% using only 100-meter test sections. This method has been successfully applied to evaluate the influence of tire pressure, compare different tire versions within the same manufacturer, assess rolling resistance variations between manufacturers, and analyze the effect of tire temperature. Significant differences were observed, including a 26% increase in rolling resistance between 6 and 3 bar tire pressures, a 33% difference between Time-Trial and non-Time-Trial tire versions, a 9% average variation across three manufacturers, and a 26% increase between warm (18°C) and cold (14°C) tires.

Keywords

Rolling Resistance; Field Testing; Crr; Tire Temperature; Tire Pressure; Coast Down

1 Introduction

Rolling resistance is a key factor in cycling performance, directly influencing energy expenditure and overall efficiency [1]. Traditional methods for measuring rolling resistance in real-world conditions often suffer from limited precision or are difficult to implement in practice [2,3,4]. As an alternative, controlled laboratory environments, such as roller-based testing [5], offer greater measurement accuracy. However, these setups have limited applicability to real-world cycling conditions, where road surface, environmental factors, and rider dynamics play a significant role.

This study introduces a novel energy imbalance-based on-field tracking approach, designed to accurately quantify rolling resistance using short test sections (<100m). The method is entirely derived from fundamental energy equations and is demonstrated to effectively assess key factors influencing rolling resistance, including tire pressure, manufacturer differences, product line variations, and temperature effects. The results highlight its potential as a practical, high-precision solution for cyclists, researchers, and industry professionals aiming to optimize performance.



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1.1 Framework Description

When a rider moves along a path between two points A and B, the following energy imbalance relationship can be derived from Newton's 2nd Law:

$$W_{driving} + \Delta E_k + \Delta E_p = W_{res}$$

Equation (1)

where $W_{driving}$ is the driving energy (i.e. the power input on the pedals by the rider multiplied by time), $\Delta E_k = \frac{1}{2}(m + m_i)(V_B^2 - V_A^2)$ is the kinetic energy variations between A and B with m the total mass, m_i the inertial mass, V_X is the ground velocity at point X, $\Delta E_p = m \cdot g \cdot \Delta h$ is the potential energy variation with g the gravitational acceleration and Δh the altitude difference between points B and A, W_{res} represents the total work of resistive forces, including the work of aerodynamic drag and rolling resistance. A simplified model for W_{res} is used, neglecting bearing and chain friction [6]. Under these assumptions, the total work of resistive forces from A to B is expressed as $W_{res} = CdA \overline{\Delta P} L + m g C_{rr} L$ with CdA the aerodynamic drag of the rider and his bike, C_{rr} the coefficient of rolling resistance, $\overline{\Delta P}$ the average dynamic air pressure between points A and B (measurable as a differential pressure between a static and total pressure ports on a Pitot tube), and L the projected distance on a horizontal plane between points A and B.

The proposed approach aims to estimate all relevant variables affecting the energy imbalance equation (1), except for C_{rr} and CdA , using various electronic measurement devices and metrology tools (a complete description is beyond the scope of this abstract). Additionally, the exact front wheel revolution count, including fractional rotations, is recorded to determine the precise wheel circumference.

The experimental protocol consists of the rider coasting between A and B in a fixed position on the bike. The calibration phase begins

with 4 out-and-back passes, totaling 8 runs, performed at varying entry speeds ranging from 18 to 30 km/h. For each run, the average resistive force $F_{res} = \frac{\Delta E_k + \Delta E_p}{L}$ is computed. After 8 runs, a regression is performed between F_{res} and ΔP to determine both CdA and C_{rr} .

Once calibration is complete, CdA is assumed constant for subsequent rolling resistance assessments. Each C_{rr} test consists of 2 out-and-back passes, corresponding to 4 runs, conducted at low speeds (~15 km/h) to maximize the rolling resistance contribution relative to aerodynamic effects, minimizing the influence of small air drag variations. The rolling resistance coefficient is then calculated using the following equation:

$$C_{rr} = \frac{1}{m \cdot g} \left[\frac{\Delta E_k + \Delta E_p}{L} - CdA \overline{\Delta P} \right]$$

Equation (2)

The C_{rr} standard deviation $\sigma_{C_{rr}}$ is estimated across the 4 runs. The error associated with the mean rolling resistance value, $\overline{C_{rr}}$, is computed under the assumption of a normal distribution of errors.

2 Material and Methods

A 45-year-old experienced cyclist, weighing 73 kg, performed the tests using a Foil RC Pro 2023 racing bicycle (Scott Sports, Switzerland). The testing road was sheltered from side winds by trees along the path, ensuring consistent aerodynamic conditions.

The study utilized commercially available 28 mm tubeless race tires from three different manufacturers (M1, M2, and M3). Two variations from Manufacturer M2 were tested: a Time-Trial (TT) version and a non-Time-Trial (non-TT) version. All tires were new and pre-filled with 40 mL of sealant. To facilitate quick tire swaps, two pairs of identical wheels (35P Disc PRO, 21 mm inner width, Legend Wheels, France) were used.

Tire and ground temperatures were recorded before and after each run using an infrared thermometer (Exacto ThermoFlash Premium, Biosynex, France). For temperature-controlled tests, the tires were partially submerged in hot or cold-water baths, and the wheels were spun during immersion for five minutes to ensure uniform heating or cooling.

Tire inflation pressure was monitored before and after each test using a precision manometer (T300, Etenwolf, USA).

3 Results

3.1 Initial Calibration

The initial calibration is presented Figure 1.

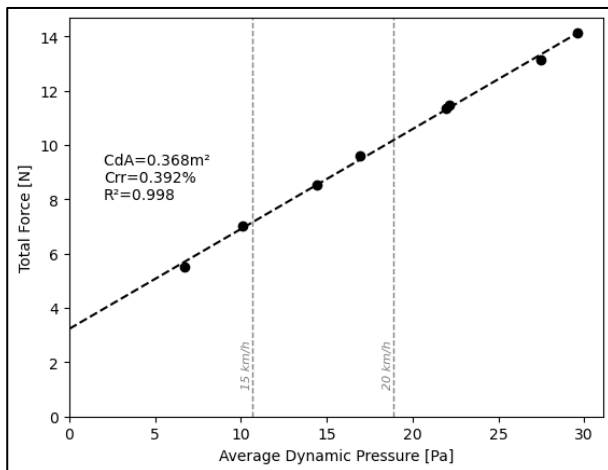


Figure 1. Initial calibration illustrating the relationship between Force and Dynamic Air Pressure.

The slope of the regression line corresponds to CdA . The value of $0.369m^2$, obtained through regression analysis, is used for all subsequent rolling resistance tests. The regression yields a coefficient of determination ($R^2=0.998$), indicating a strong correlation between the data and the model, which confirms the high consistency and reliability of the methodology.

3.2 Inflating Pressure Test

The effect of tire inflation pressure on M3 tires is presented in Figure 2. The measured average standard deviation across all runs is 0.00046 (or 1.4%), demonstrating the high accuracy of the proposed approach.

As expected [7], lower inflation pressure results in higher rolling resistance, primarily due to increased tire deformation. This deformation leads to a reduction in the effective wheel circumference, as illustrated in Figure 2.

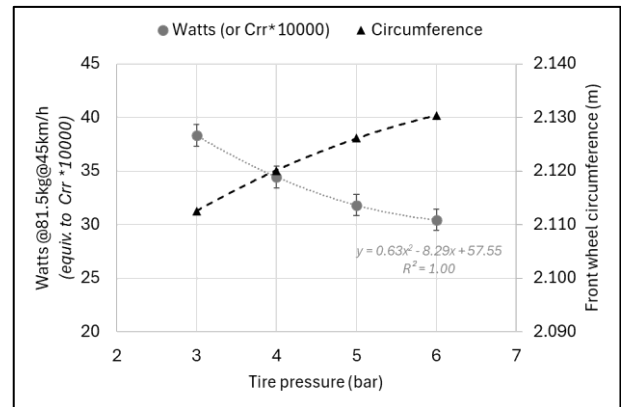


Figure 2. Evolution of tire rolling resistance and front wheel circumference as a function of tire pressure.

3.3 Tire Version Comparison

The effect of tire version is presented in Figure 3. A significant difference in rolling resistance is observed between the non-TT and TT versions of Manufacturer M2's tires, despite the TT tire being tested at a lower temperature. The rolling resistance difference is 6 W at 6 bar and 11 W at 3 bar, both values normalized at 45 km/h and at 81.5 kg load.

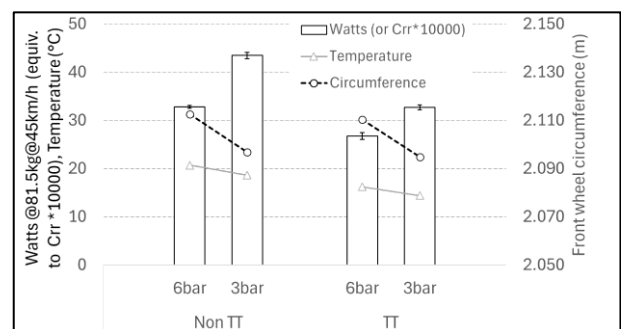


Figure 3. Comparison of non-TT and TT tire versions of Manufacturer M2.

3.4 Manufacturers Comparisons

Figure 4 compares the rolling resistance of three different pairs of new tires from manufacturers M1, M2, and M3. No significant difference is observed between M1 and M2, whereas M3 tires exhibit a significantly lower rolling resistance—7% to 11% lower, depending on tire pressure.

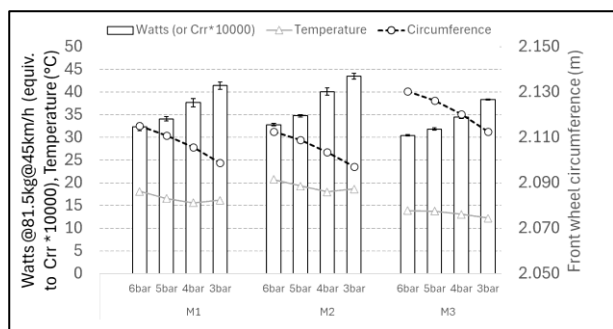


Figure 4. Comparison of rolling resistance across tires from manufacturers M1, M2, and M3.

3.5 Effects of Temperature

Figure 5 compares the impact of temperature on rolling resistance for Manufacturer M1's tires under two conditions: cold (13.7°C), and hot (18.1°C). A statistically significant increase in rolling resistance is observed between the hot and cold conditions, with a 2.8W increase, normalized at 45 km/h and an 81.5 kg load.

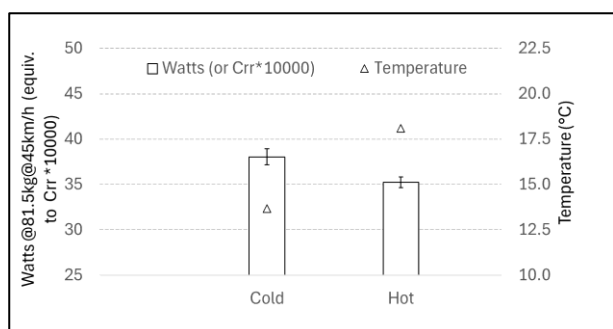


Figure 5. Effects of tire temperature on rolling resistance.

4 Discussion

The proposed approach demonstrates high accuracy, with repeatability below 2% for data recorded in under 30 seconds. This method successfully validates previous findings on the influence of tire pressure [4,7] and tire temperature [8]. However, this is the first time such a study has been conducted using a real rider, a real bike, and real outdoor road conditions, while maintaining both high precision and high throughput—with only a few minutes required to cover one pressure point.

This novel method serves as a reliable alternative to drum tests, which are often considered the gold standard but may not fully replicate real-world conditions. By offering more representative field data, this approach enhances practical applicability for performance optimization.

Further research could extend this methodology to different road surfaces, a wider range of temperatures and pressures, and other cycling conditions. These extensions would provide valuable insights for tire manufacturers and cycling teams, helping them optimize tire configurations based on race conditions and intended usage.

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Conflicts of Interest: The authors declare no conflict of interest.

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