OPEN ACCESS

JSC | Journal of Science & Cycling
Breakthroughs in Cycling & Triathlon Sciences

Conference Abstract

Science and Cycling Conference, Barcelona 2026

Validation of unsteady aerodynamic effects under real-world apparent flow conditions using high-frequency wind sensing and cycling performance data

Christoph Feichtinger [1,*] and Rene Hörschinger

Received: 26 February 2026 **Accepted:** 17 March 2026 **Published:** 31 October 2026

[1] Graz University of Technology

Correspondence

Christoph Feichtinger

Graz University of Technology

c.feichtinger@windpuls.com

Keywords

cycling aerodynamics; apparent wind; field testing; gust intensity; turbulence intensity; normalized resistance coefficient

1 Abstract

Aerodynamic drag is the dominant resistance term in road cycling at moderate to high speeds, yet real-world assessment remains challenging because the flow incident on the rider–bike system is disturbed, unsteady, and strongly route dependent. In controlled environments, cycling aerodynamics is typically characterized through steady wind-tunnel measurements and steady Computational Fluid Dynamics (CFD). However, agreement between CFD and wind-tunnel data does not necessarily translate into accurate performance prediction outdoors, where riders experience rapidly varying apparent wind due to meteorological variability, terrain effects, traffic-induced disturbances, and yaw-angle changes from steering and cornering. This motivates the need for a validation approach that explicitly represents the outdoor wind state and its unsteadiness.

We present a test and validation toolchain designed to bridge this validation gap by correlating steady-state aerodynamic maps with time-resolved measurements recorded in real riding conditions. The central contribution is demonstrating that comparison-ready aerodynamic descriptors can be reconstructed from standard cycling performance signals when these are combined with enhanced, high-frequency apparent wind sensing. Apparent flow is measured and expressed through apparent wind magnitude v_{∞} and

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

apparent yaw angle β_{app}. Inflow unsteadiness is quantified using segment-based Gust Intensity (GI) and Turbulence Intensity (TI), enabling outdoor datasets to be compared on the basis of both mean flow state and fluctuation level.

A representative validation use case combines Windpuls apparent wind sensor logging with common bike-computer data (e.g., Garmin, Wahoo), including power, speed, cadence, and altitude/grade information, alongside air-density inputs derived from temperature, pressure, and humidity. Data streams are time-aligned and analyzed in route- or lap-based segments. Measured mechanical power is converted to a conservative resistive-power signal by removing gravity and inertia contributions, and is then normalized using dynamic pressure based on measured apparent wind to compute a coefficient-like metric suitable for cross-condition comparison. This normalization yields a time-resolved, comparison-ready resistance descriptor that can be aggregated within yaw bins to reconstruct an outdoor yaw-sensitivity curve.

We demonstrate the pipeline for two operating environments: (i) road riding, which captures realistic variability in wind and terrain, and (ii) an outdoor velodrome, which provides repeatable geometry to isolate and interpret wind-driven effects under controlled lap structure. Across repeated passes, reconstructed yaw sensitivity remains consistent over a wide apparent yaw-angle range. Increased scatter at higher yaw angles is primarily attributable to quantified inflow unsteadiness (higher GI/TI) and reduced sample density at large yaw, rather than to a breakdown of the reconstruction approach. By reporting yaw distribution together with GI and TI, the framework provides a principled basis for selecting comparable subsets of outdoor data and for avoiding over-interpretation of day-to-day variability.

Overall, the pipeline supports rapid equipment or position comparisons in field tests while transparently documenting the wind-state context. The approach offers a scalable pathway to evaluate performance-relevant cycling aerodynamics under realistic, dynamic flow environments and to connect outdoor findings back to steady-state maps from CFD and wind-tunnel testing.