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# A quantitative flow visualization technique for on-site sport aerodynamics optimization

Andrea Sciacchitano\*✉, Giuseppe Caridi, Fulvio Scarano

## Abstract

Aerodynamics plays a crucial role in cycling as in many other speed sports. Aerodynamic investigation is required primarily for two reasons:

1. Optimization of the athletes' posture and equipment geometry (e.g. bicycle frame, wheels, helmet) to minimize the aerodynamic drag, thus achieving higher velocity;
2. Enhancement of the directional stability to guarantee the cyclists' cornering capabilities and safety.

To date, sport aerodynamics investigation has been conducted mainly via computational fluid dynamics (CFD) simulations or wind tunnel tests around scaled models. The effect cyclist's posture, helmet shape, wheel and frame design on bicycle aerodynamics has been investigated by several authors (Gibertini and Grassi, 2008; Alam *et al.*, 2009; Kyle, 1990, among others).

CFD simulations rely upon the introduction of turbulence models to predict the effect of turbulence. As a consequence, their accuracy is questionable when separated flows downstream of bluff bodies (as cyclists and their bike) are researched. Conversely, wind tunnel tests allow a direct measurement of the flow properties. However, measurements are typically conducted around a model in fixed position, giving little information on the actual aerodynamics occurring during races, when the cyclist is in motion while riding the bike. A technique for on-site aerodynamic measurements during the athletes' motion is currently missing.

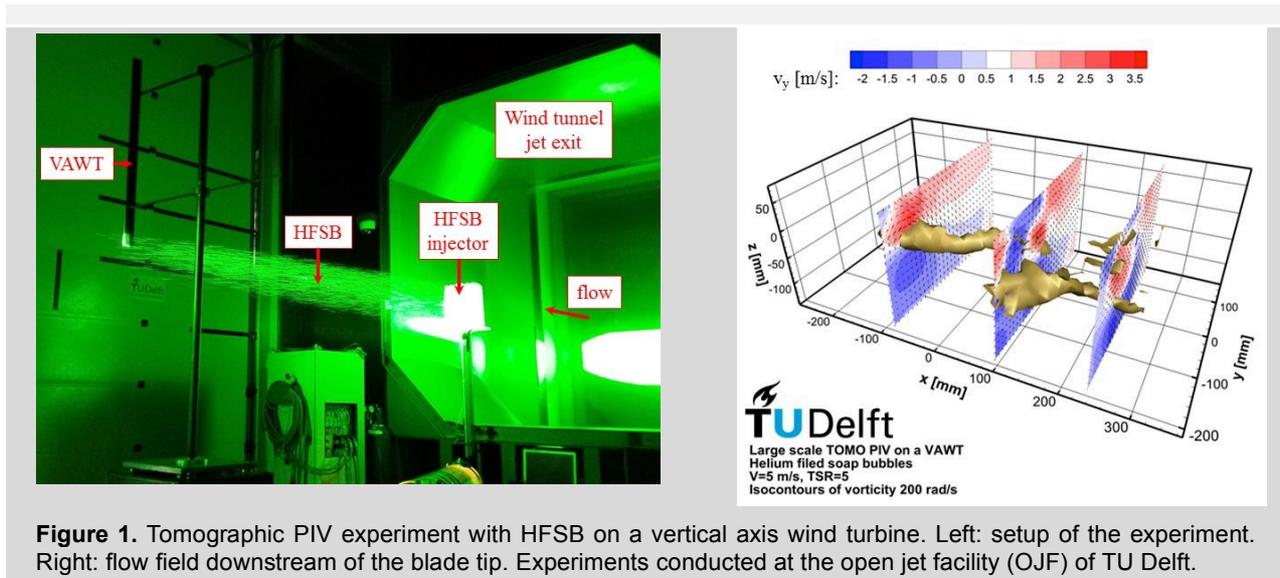
Particle image velocimetry (PIV) is an experimental technique that allows measuring the flow velocity in a two- or three-dimensional domain. Micrometric particles are added to the flow and carried by the fluid. The particles are illuminated twice by a light source, typically a laser, and imaged by a digital camera. The measurement of the particle images displacement within a short time interval  $Dt$  leads to the computation of the velocity field in the imaged region (Raffel *et al.*, 2007).

In tomographic PIV (shortly tomo-PIV), the particles are illuminated in a volume and imaged by several cameras at different viewing angles to determine the three-dimensional velocity field (Scarano, 2013). Up to date, small measurement volumes up to 50 cm<sup>3</sup> have been achieved due to the low light scattering efficiency of conventional tracer particles. To achieve significantly larger measurement volumes (thousands of cubic centimeters), helium-filled soap bubbles (HFSB) have been proposed as flow tracers due to their large size (diameter of 300 μm) and scattering efficiency (Scarano *et al.*, 2015). Tomo-PIV experiments with HFSB have been successfully conducted in the Aerospace Engineering department of Delft University of Technology. In particular, the technique has been used in the wind energy sector to assess the flow dynamics downstream of wind turbine blades. An example of application is illustrated in figure 1, where the flow induced by the blade tip of a vertical axis wind turbine (VAWT) is investigated over a measurement volume of 30,000 cm<sup>3</sup>.

The use of large-scale tomographic PIV opens unprecedented possibilities for aerodynamics investigation in cycling. On-site aerodynamic measurements could be conducted during the cyclist motion, reproducing the same conditions as those encountered in actual competitions. The technique would allow aerodynamic measurements during cornering, which up to date are not possible neither via wind tunnel tests nor through numerical simulations. From the velocity measurements, pressure and forces can be calculated, which serve for optimization of the cyclist's posture and equipment geometry.

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✉ **Contact email:** [a.sciacchitano@tudelft.nl](mailto:a.sciacchitano@tudelft.nl), (A. Sciacchitano)

\*Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 2, 2629 HT, Delft, The Netherlands