Experimental Characterization of a Cyclist's Wake

Adam, Florian; Terra, Wouter; Sciacchitano, Andrea

DOI
10.28985/jsc.v8i2.498

Publication date
2019

Document Version
Accepted author manuscript

Published in
Journal of Science and Cycling

Experimental Characterization of a Cyclist's Wake

F. Adam[1], W. Terra[1], A. Sciacchitano[1]
[1] Aerospace Engineering Department, TU Delft, The Netherlands

At racing speeds, up to 90 % of the total resistance of a cyclist is attributed to the aerodynamic drag (Kyle and Burke, 1984). This implies that the performance of cyclists can be improved, on one hand by optimizing the aerodynamics of bikes, clothing and gear (Lukes et al., 2005) and, on the other hand by improving the rider's position. Griffith et al. (2014) state that 80 % of the aerodynamic drag is caused by the rider itself when using aerodynamic gear.
Many cycling aerodynamic investigations are reported in literature, which are traditionally conducted by balance measurements in wind tunnels. Although this approach can measure drag with very high accuracy (within 0.1 %; Steinly et al., 1982), balance measurements are considered blind, in the sense that they do not allow to relate the drag to the flow structures responsible for generating this resistance. Alternatively, flow measurements may be conducted using, for example, pressure probes scanning the wake to investigate the time-average flow topology. This can also be referred to as a pressure probe wake rake (e.g. Betz (1925); Jones (1936);), which has a long history in aerodynamic research as it allows measurements of small drag values, which is not always possible with a force balance. Within the last decade, the use of flow measurement techniques have become more popular within cycling aerodynamic research to better understand the flow structures that generate the aerodynamic drag.
By conducting pressure measurements in the wake of a pedalling cycling model, Crouch et al. (2014) showed variations of the aerodynamic drag by 20% over the crank cycle. Such drag variations were attributed mainly to the effect of the leg position onto the large-scale flow structures in the cyclist's wake, rather than to the change in frontal area. However, the use of such a pointwise measurement technique precludes the investigation of the dynamics of the wake flow. Instead, Particle Image Velocimetry (PIV) does allow whole-field measurements and, therefore, potentially allows researching the unsteady nature of the flow, across a cyclist. PIV relies on seeding the flow with small tracer particles that are illuminated and imaged by a laser and cameras, to extract the flow velocity from a displacement of the particles over a known time increment. Using Helium-filled soap bubbles as flow tracers for large-scale PIV (Scarano et al., 2015) nowadays enable full-field flow measurements in human-size volumes which is demonstrated in the work of Jux et al. (2018) and Terra et al. (2019). These works mainly focus on the PIV measurement technique and do not use it to investigate the flow around the cyclist in particular. Furthermore, they present the time-average flow topology only and a cyclist wake dynamic investigation is still missing in the literature.
In this work, therefore, large-scale PIV is used to characterize the dynamics of the unsteady wake of a non-pedalling full-scale cyclist, preceding future investigations on pedalling models. Experiments are conducted in the Open Jet Facility (OJF) of the TU Delft Aerodynamic laboratory. The OJF is a closed-loop wind tunnel with a test section of 2.85x2.85m^2 and a free-stream turbulence intensity below 1%. Sets of 500 images are acquired at a frequency of 5.5Hz and with a flow velocity of 14m/s. Two cameras image a plane of approximately 1.5m^2 that is illuminated by a laser and seeding is provided by an in-house built aerodynamically shaped seeder that is installed 1.5m upstream of the front wheel axis (see Figure 1) allowing to measure the wake sufficiently for into the freestream and onto the floor. The instantaneous flow fields are averaged to obtain the time-average flow topology (Figure 2 depicts the streamwise velocity component), which matches well to literature.
Afterwards, a Proper Orthogonal Decomposition (POD; Berkooz et al., 1993) analysis is conducted using the instantaneous flow fields to identify the most energetic structures in the cyclists wake. Figure 3 and Figure 4, depict the mean streamwise vorticity added and subtracted by the first and second POD mode, respectively. Mode 1 (Figure 3) is associated with a tilting of the main vortex pair emanating from the hip and thighs while mode 2 noticeably increases/decreases the strength of this vortex pair. This suggests that this main vortex pair, although the model is non-pedalling, rotates and shrinks/grows in time, which can be attributed to an unsteady separation location. A more extensive discussion on these modes will follow during presentation.
From these results, it can be concluded that PIV has the potential to measure instantaneous velocity fields using aerodynamic investigation in cycling and allows an analysis of the instantaneous velocity fields by Proper Orthogonal Decomposition revealing the most energetic flow structures in the cyclist's wake. Finally, application of the conservation of momentum enables the determination of the aerodynamic drag of the wind tunnel model.

From the time-average flow field the mean drag is calculated. Table 1, provides an overview of the momentum drag compared to the drag measured by a state-of-the-art force balance for two example cases that are relevant in time-trail competition: helmet pointing up and helmet pointing down. Although the absolute drag from the PIV wake rake is 5% off from the balance reading, the relative drag uncertainty is close to 1%.

References

G. Berkooz, P. Holmes, and J. Lumley. The proper orthogonal decompostition in the analysis of turbulent flows. *Annual Review of Fluid Mechanics*, 25:539–575, 1993.

A. Betz. A method for the direct determination of profile drag. *Zeitschrift für Flugtechnik und Motorluftschifffahrt*, 16:42–44, 1925.

T. Crouch, D. Burton, N. Brown, M. Thompson, and J. Sheridan. Flow topology in the wake of a cyclist and its effect on aerodynamic drag. *Fluid Mechanics*, 748:5–35, 2014.

M. Griffith, T. Crouch, M. Thompson, N. Brown, and J. Sheridan. Computational fluid dynamics study of the effect of leg position on cyclist aerodynamic drag. *Fluid Mechanics*, 136(10):101–105, 2014.

B. Jones. Measurement of profile drag by the pitot-traverse method. *ARC RM No. 1688*, 1936.

C. Jux, A. Sciacchitano, J. Schneiders, and F. Scarano. Robotic volumetric piv of a full-scale cyclist. *Experiments in Fluids*, 59:74, 2018.

C. Kyle and E. Burke. Improving the racing bicycle. *Mechanical Engineering*, 106(9):34–35, 1984.

R. Lukes, S. Chin, and S. Haake. The understanding and development of cycling aerodynamics. *Sports Engineering*, 8(2):59–74, 2005.

F. Scarano, S. Ghaemi, G. Caridi, J. Bosbach, U. Dierksheide, and A. Sciacchitano. On the use of helium-filled soap bubble for large-scale tomographic piv in wind tunnel experiments. *Experiments in Fluids*, 56:42, 2015.

F. Steinly, E. Stanewsky, and R. Dietz. Wind tunnel flow quality and data accuracy requirements. *AGARD Advisory Report No. 184*, 1982.

W. Terra, A. Sciacchitano, and Y. Shah. Aerodynamic drag determination of a full-scale cyclist mannequin from large-scale ptv measurements. *Experiments in Fluids*, 60(2), 2019.

	Balance Drag [N]	PIV Momentum Drag [N]
Helmet Down	22.20	21.64
Helmet Up	21.24	20.48

Table 1: Average Momentum Drag for Different Cases

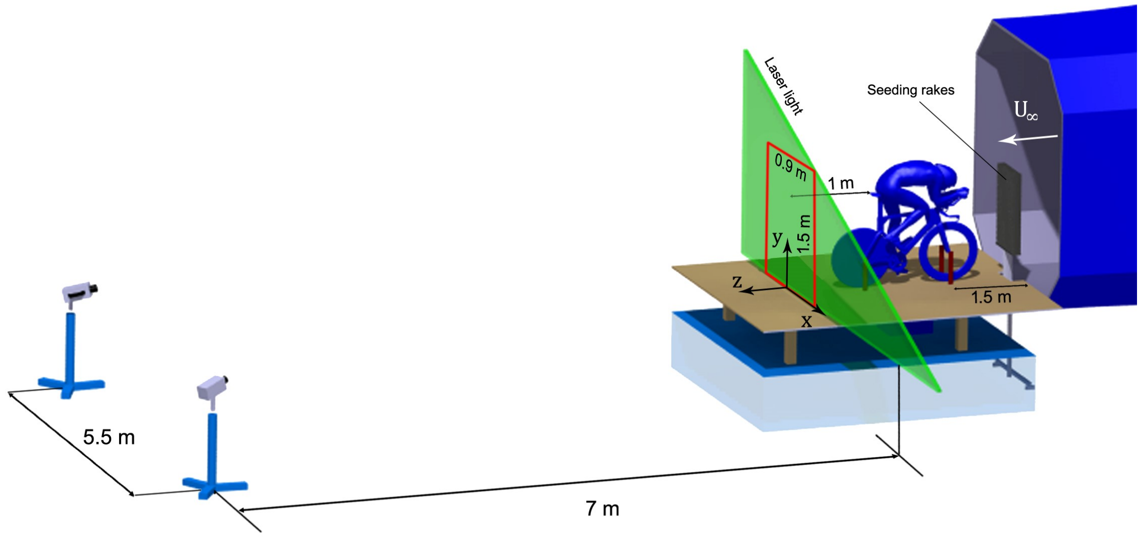

Figure 1: Experimental Set-Up

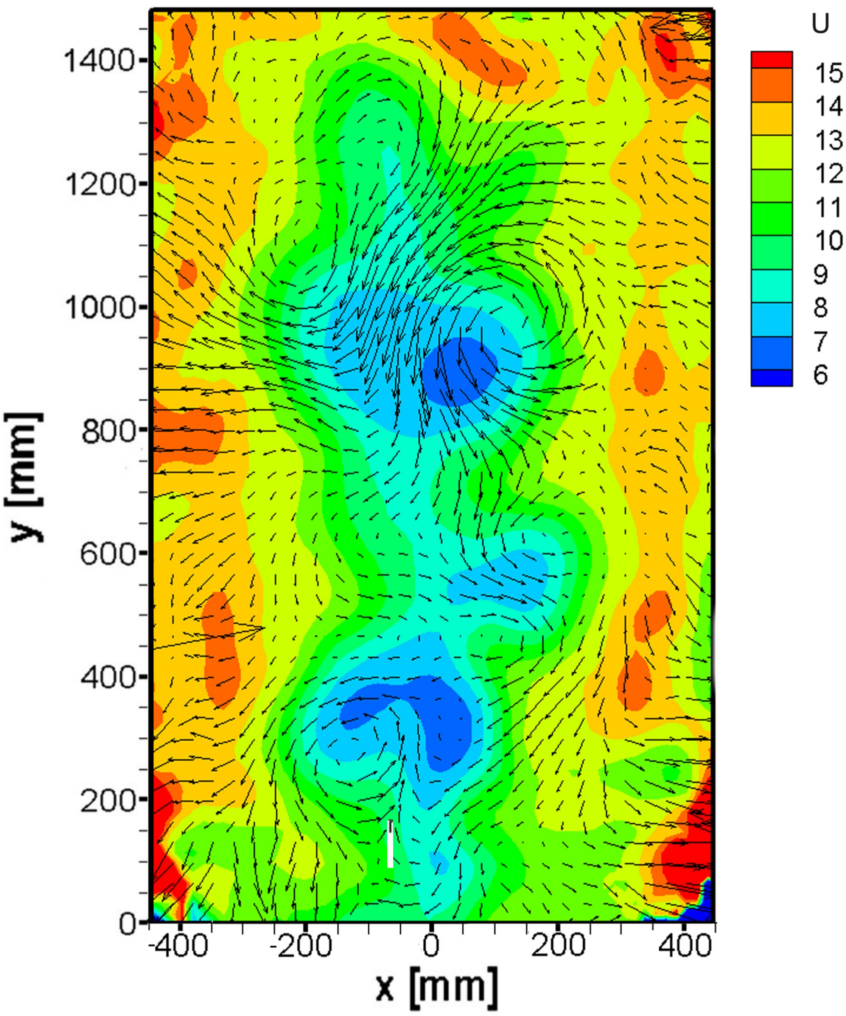

Figure 2: Average Velocity Field in Streamwise Direction

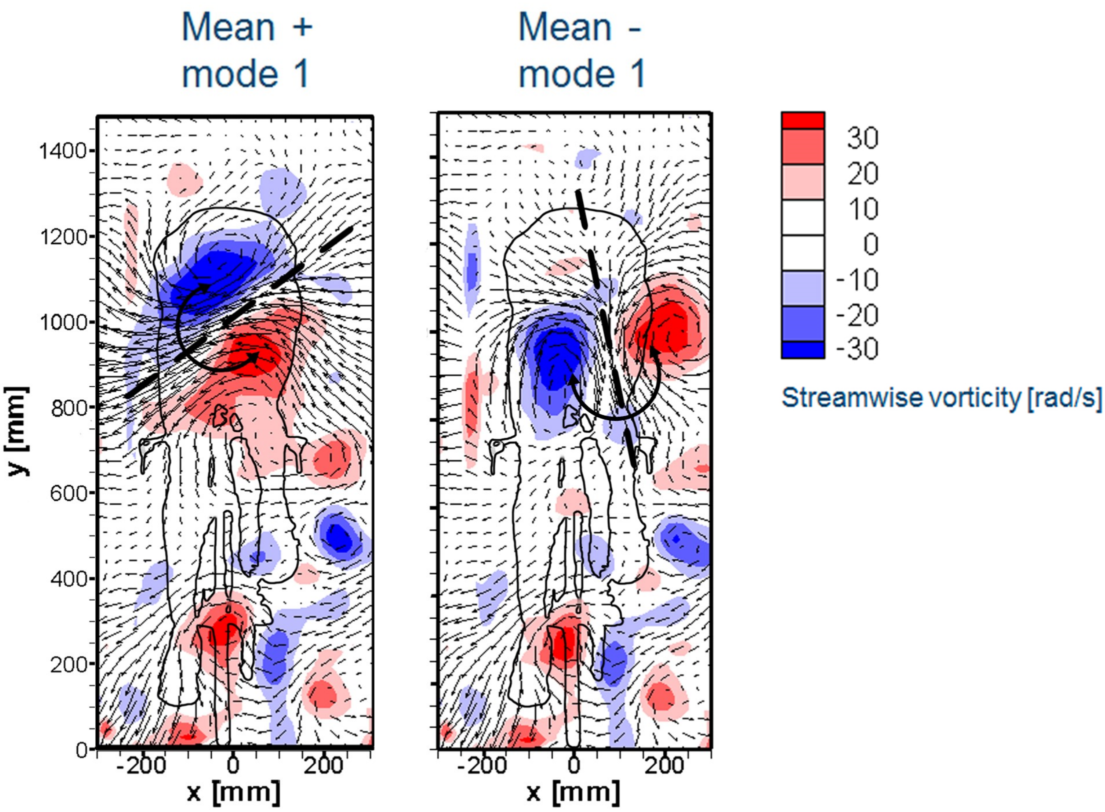

Figure 3: POD Mode 1

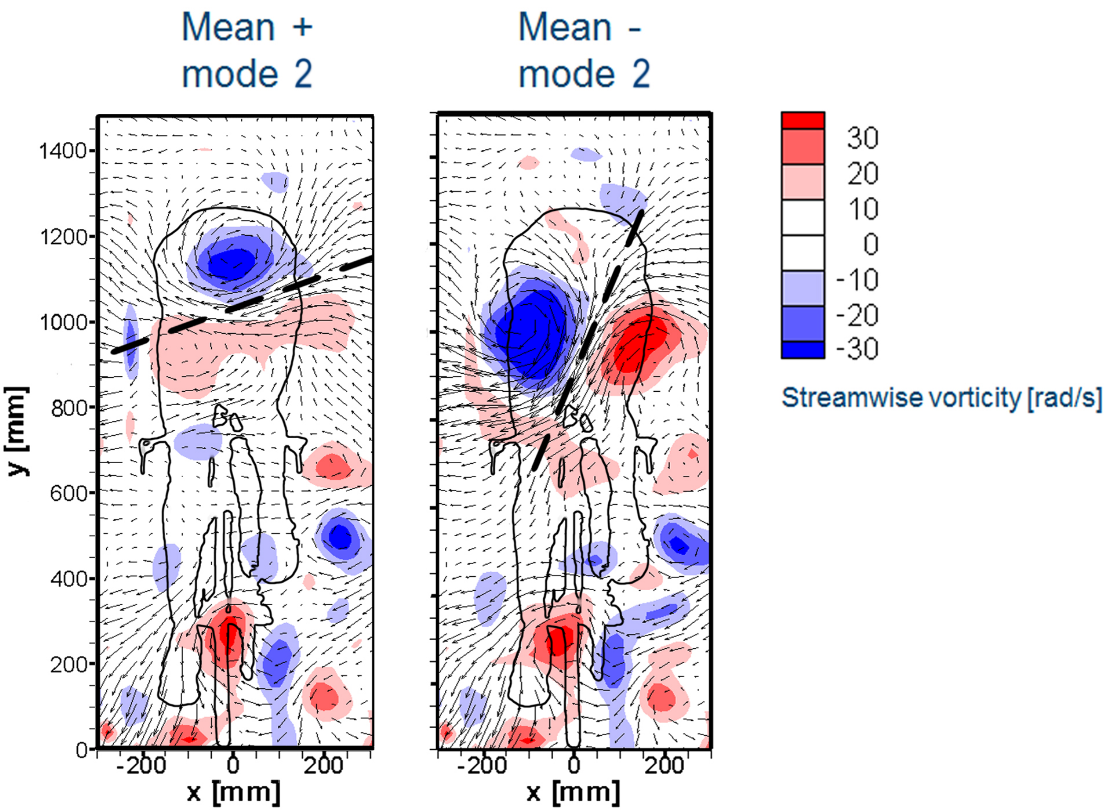

Figure 4: POD Mode 2