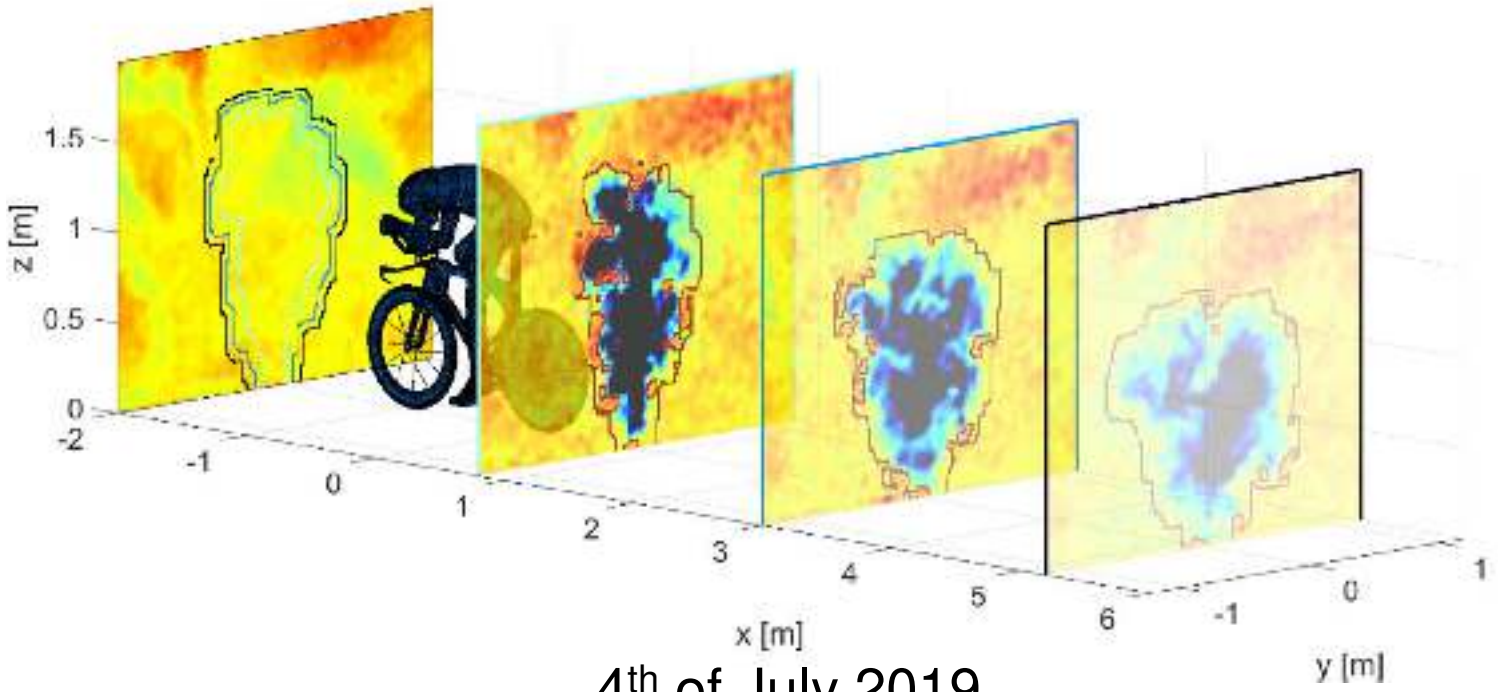
Accuracy assessment of the Ring of Fire system for on-site aerodynamic drag measurements

A. Spoelstra, Dr. A. Sciacchitano, Prof. Dr. F. Scarano

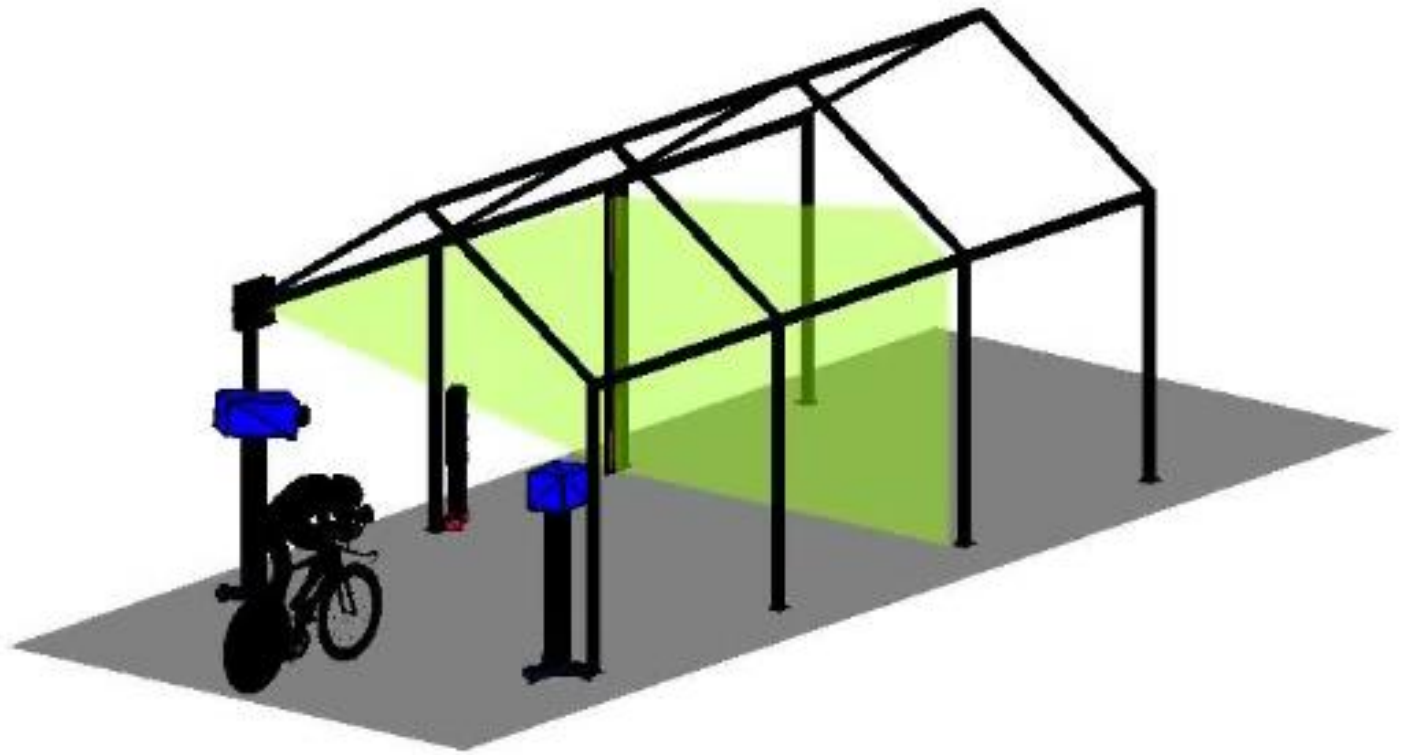
a.m.c.m.g.spoelstra@tudelft.nl



4th of July 2019

Department of Aerospace Engineering
TU Delft, The Netherlands

Ring of Fire?

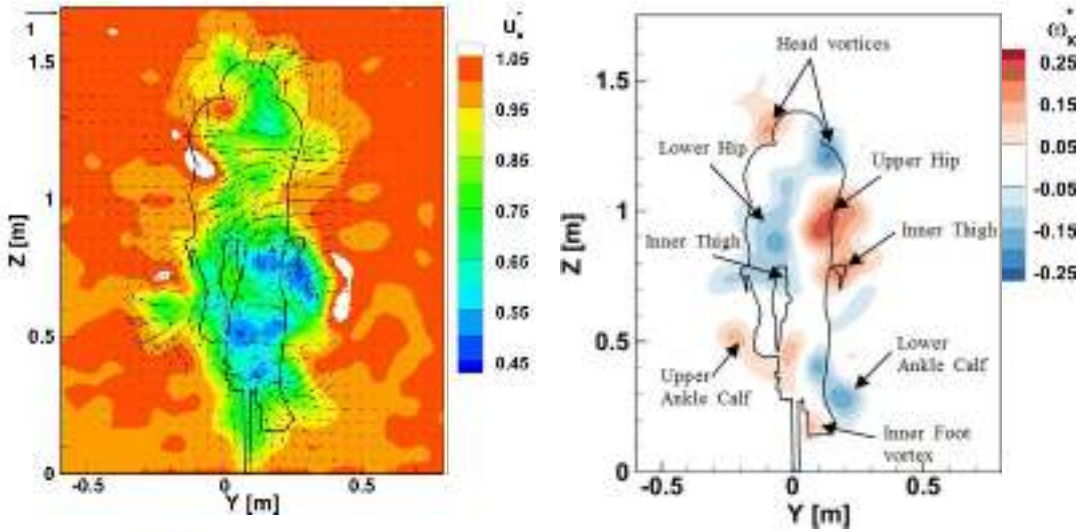


•Quantifies the **on-road aerodynamic drag** of athletes in motion

• Quantitative **flow visualization** of the flow field in the wake of the athlete

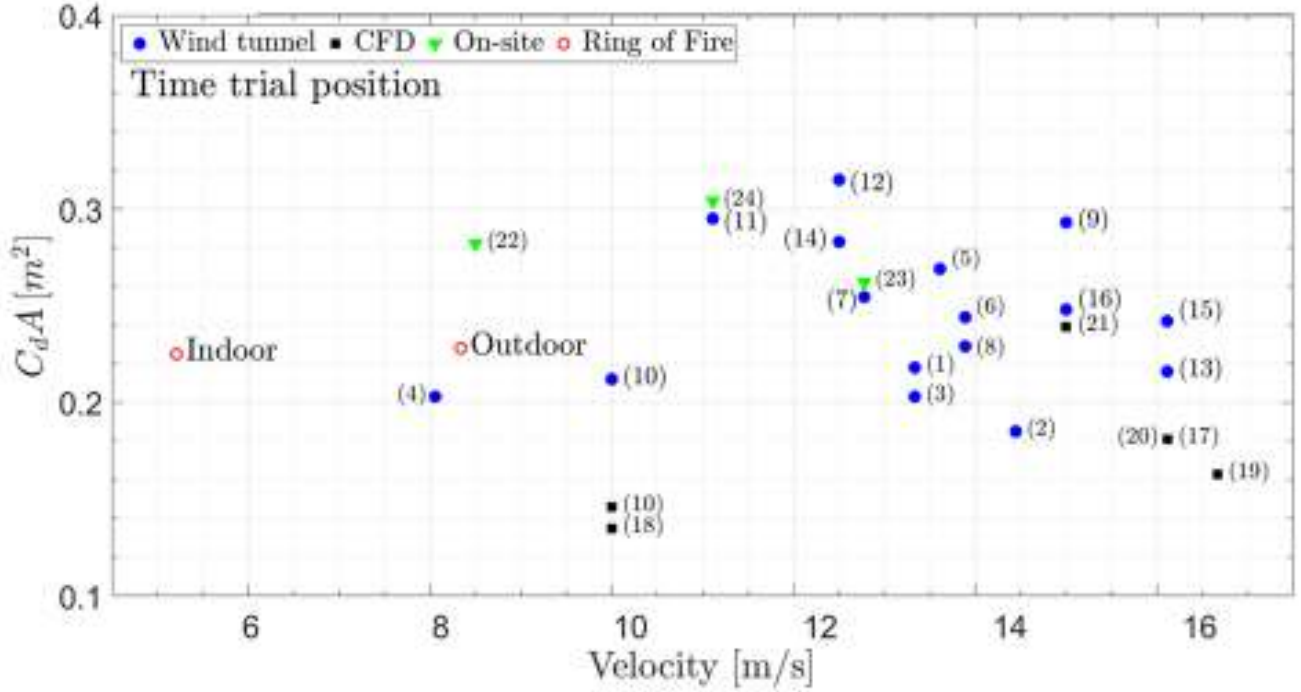
•Large-scale stereoscopic **particle image velocimetry (PIV)** measurements over a plane crossed by the athlete

Flow visualizations



Spoelstra et al. (2018)

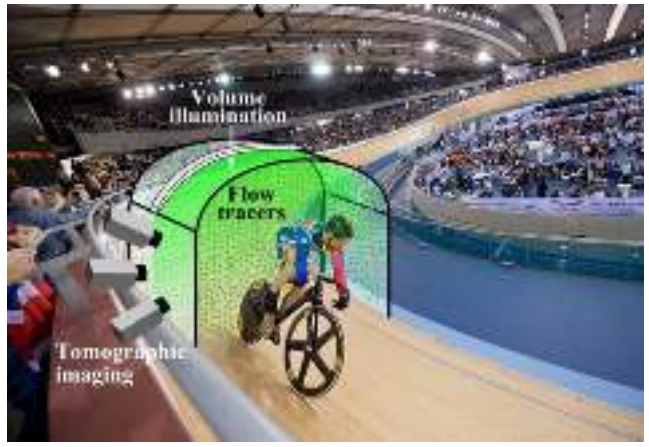
Drag measurements



Spoelstra et al. (2019)

Objective

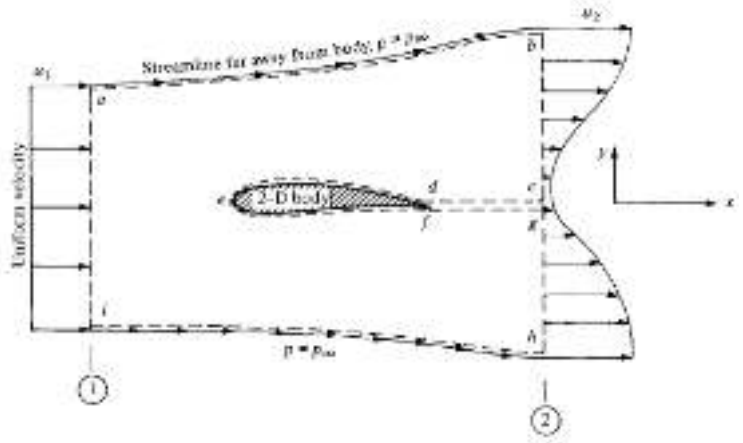
Assess the accuracy of the drag obtained from the Ring of Fire by comparing it to simultaneous acquired power meter data (the current state-of-the-art for on-site aerodynamic measurements).



Sciacchitano et al. (2015)

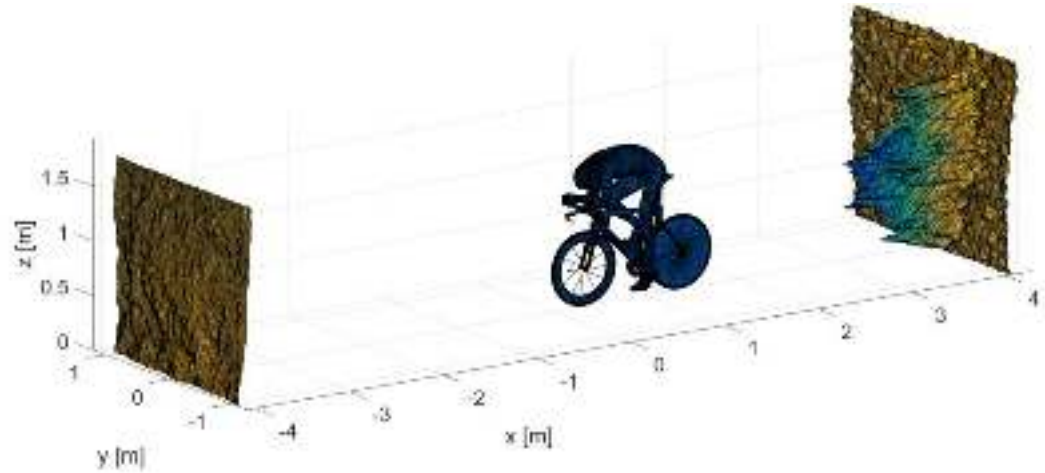
C_DA evaluation through Ring of Fire

Mass and momentum conservation in a control volume



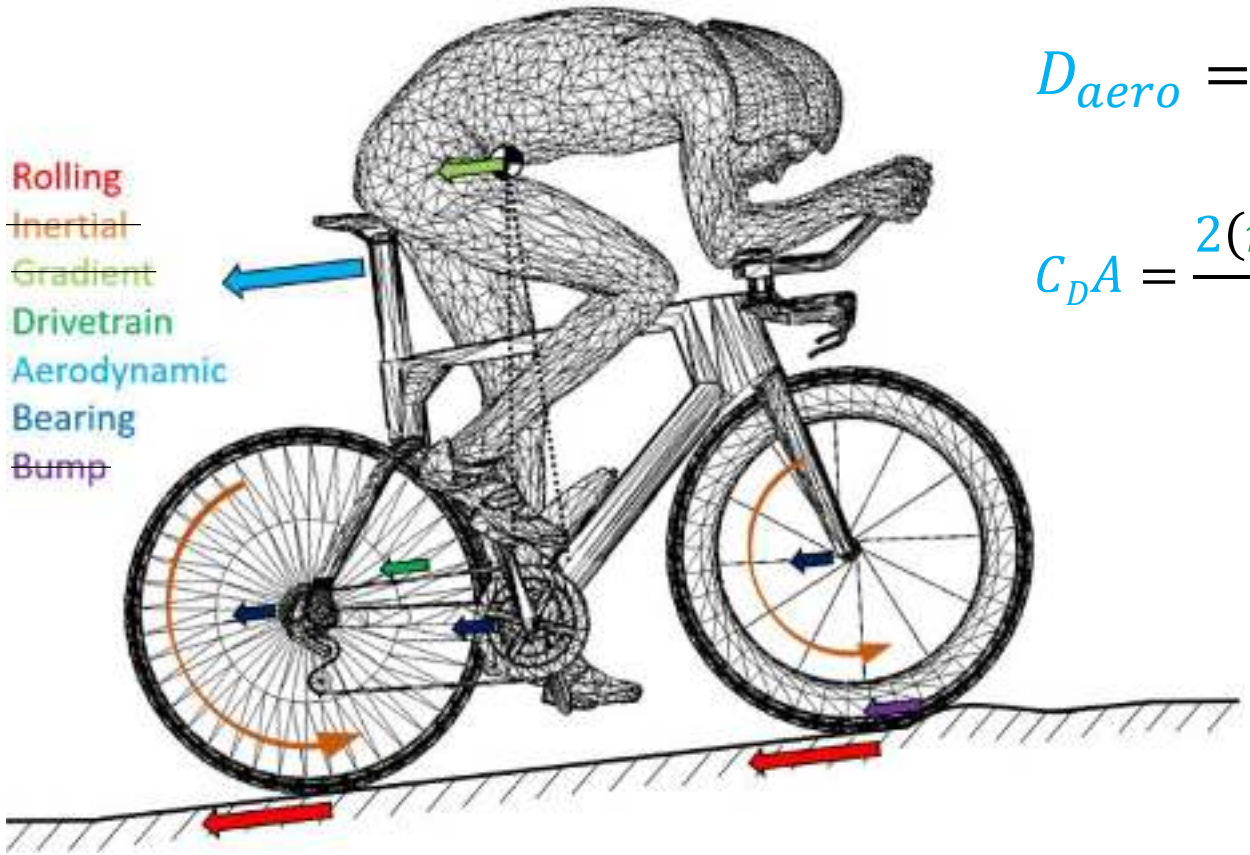
Anderson (2011)

Mass and momentum conservation between freestream and wake plane



$$C_DA = \frac{2(M_{inlet} - M_{outlet})}{\rho V^2} = \frac{2\left(\iint \rho(V + V_{inlet})^2 dS_{inlet} - \iint \rho(V + V_{outlet})^2 dS_{outlet}\right)}{\rho(V + \overline{V_{inlet}})^2}$$

C_DA evaluation through power meter

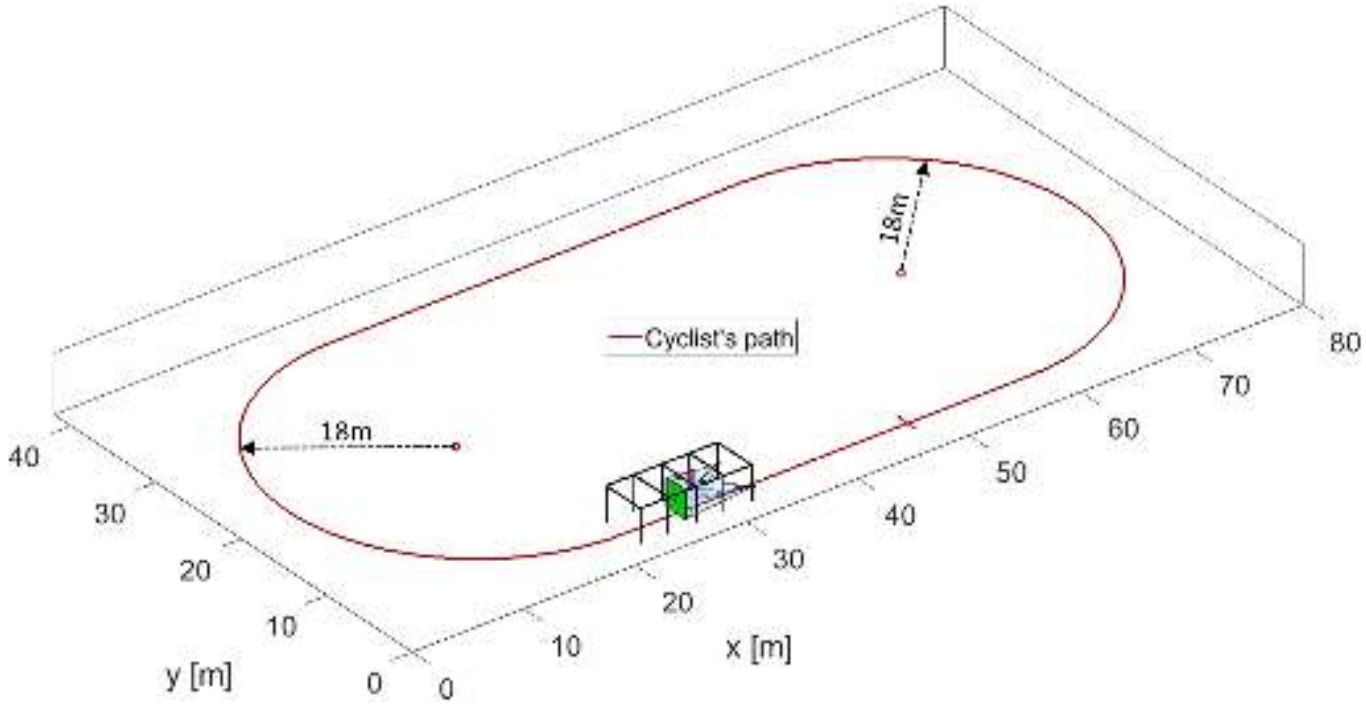


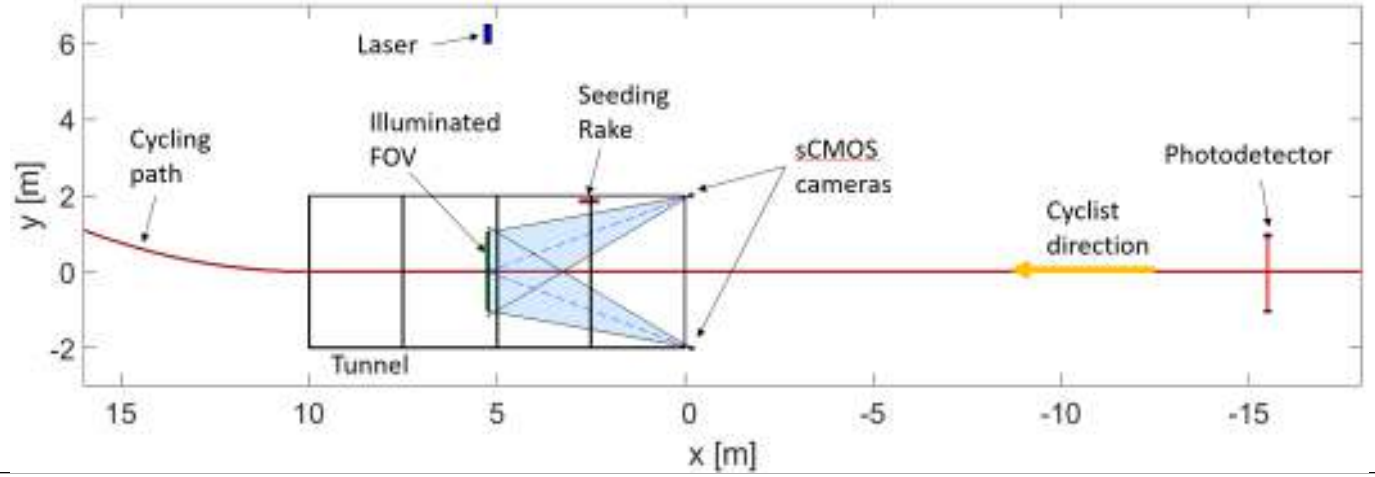
$$D_{total} = P_{total}/V$$

$$D_{aero} = D_{total} - D_{rolling} - D_{drivetrain} - D_{bearing}$$

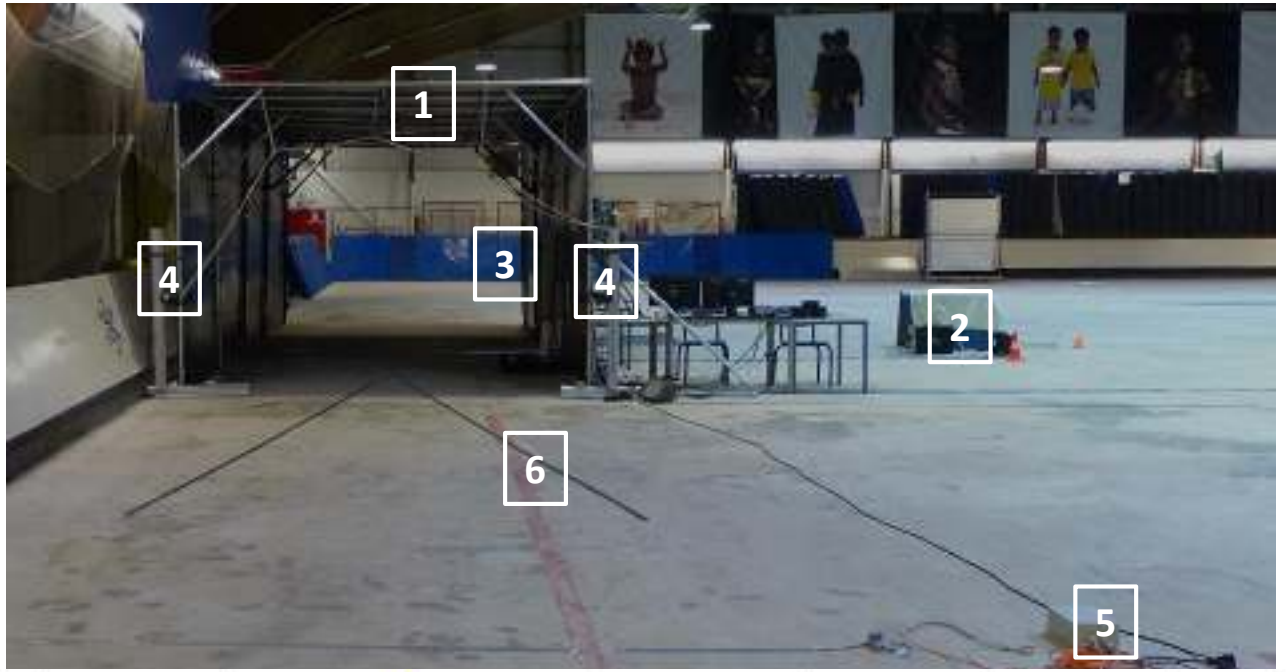
$$C_DA = \frac{2(\eta_{drivetrain}P_{total}/V - C_{rr}mg - (91 + 8.7V) * 10^{-3})}{\rho V^2}$$

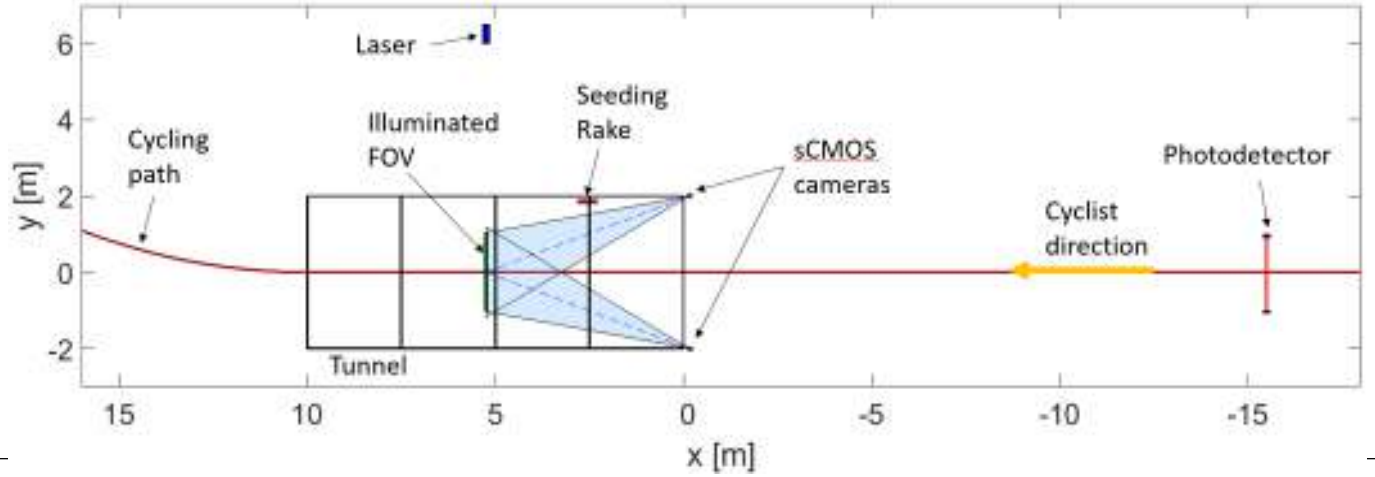
Testing facility





Experimental setup





1 Tunnel [4m x 3m x 10m]

2 Evergreen laser

3 Seeding rake

4 sCMOS cameras

5 Photo-detector

6 Convergent trajectory markings

Test subjects

The riders

2 professional cyclists from Team Sunweb
Male: 187cm, 79kg
Female: 170cm, 56kg

The bikes

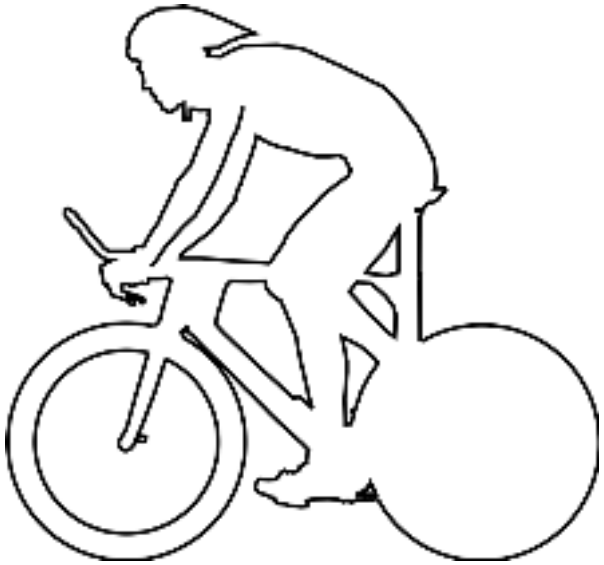
Giant Trinity Advanced SL 2018
Tyre pressure of 5 bar
Weight 8.8kg

Power measuring device

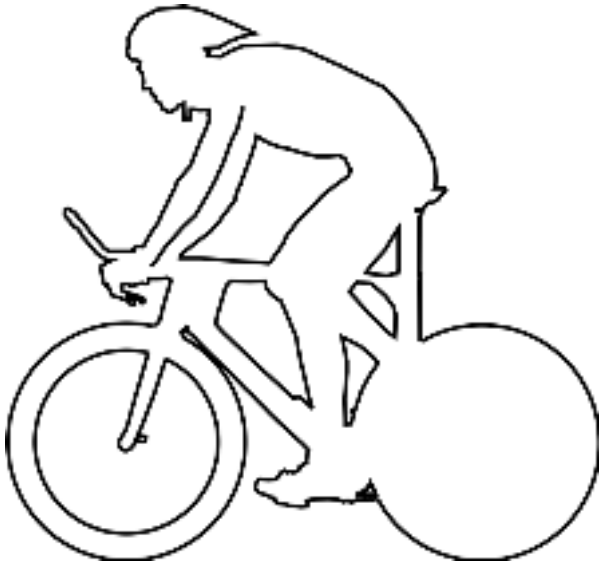
Crank-spider based power meter from Schober Rad Messtechnik (SRM)
Accuracy of ±2% over a range of 0 – 4096 W

Test cases (30km/h)

Test cases (30km/h)



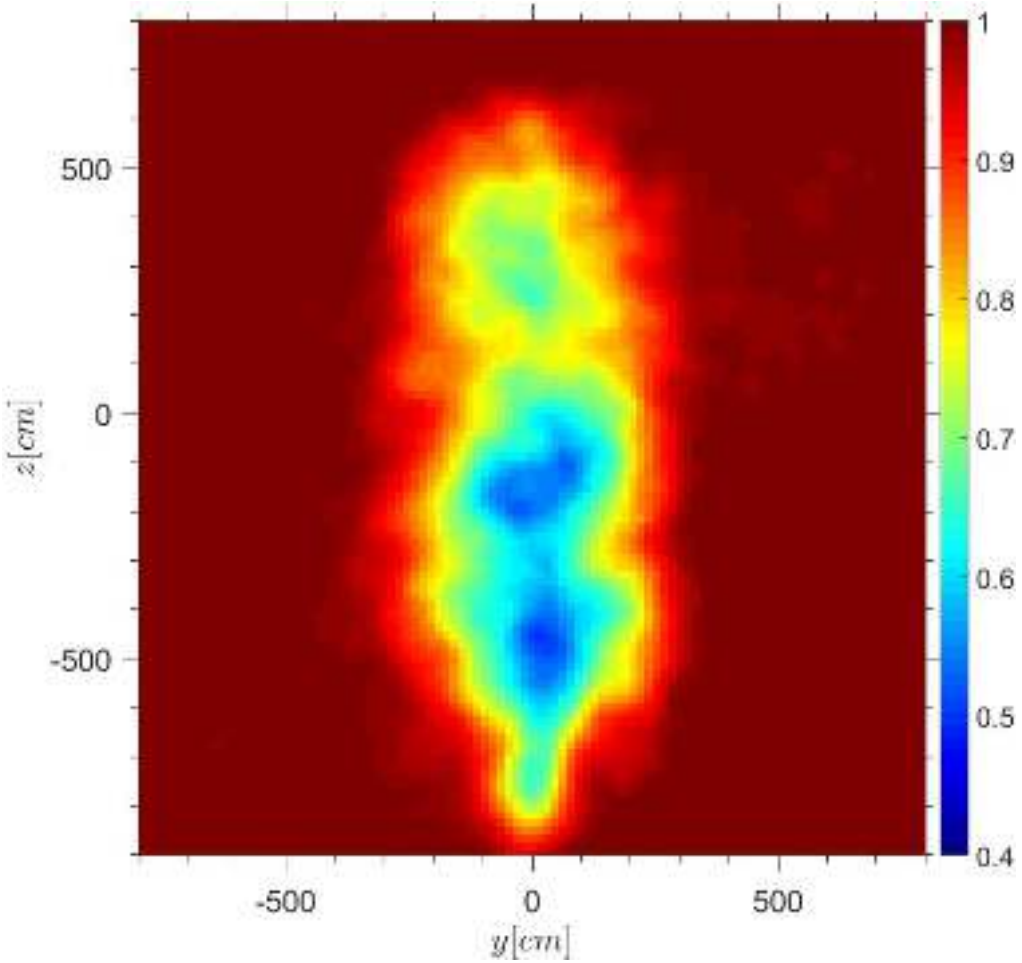
Test cases (30km/h)



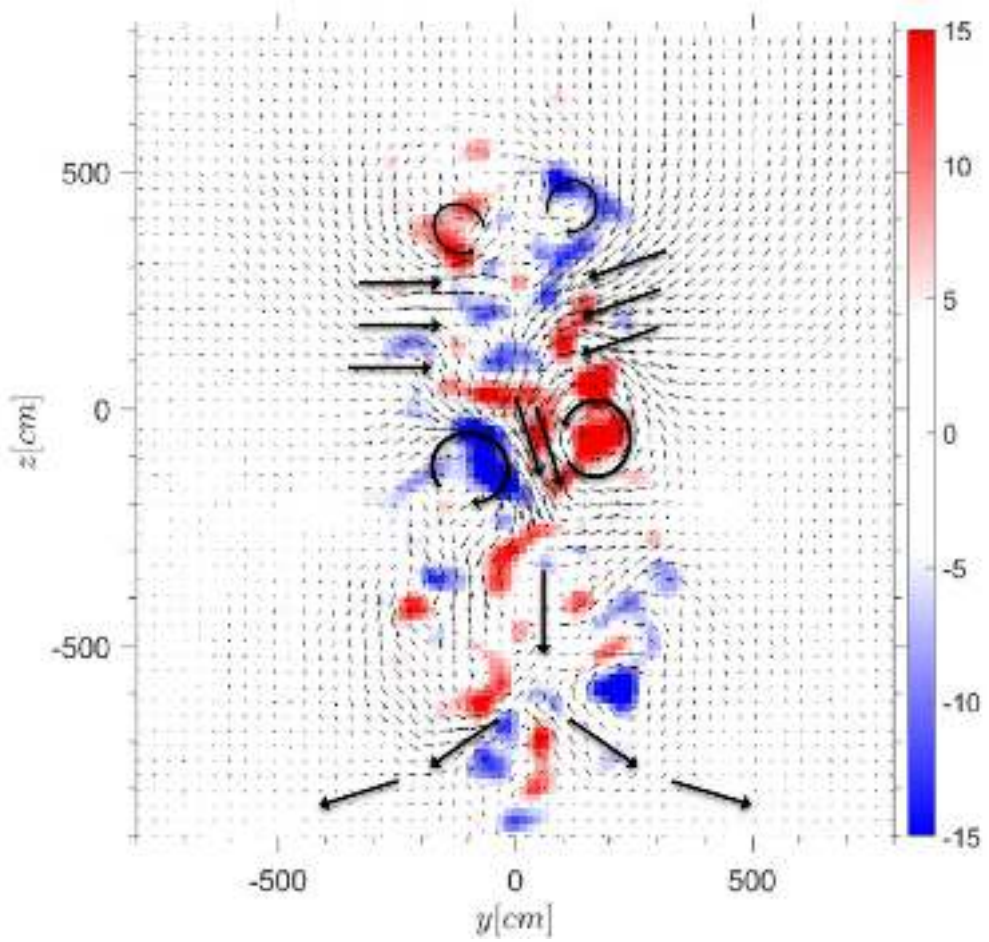
Experimental procedure

Video: Rado Dukalski

Results - Flow visualization

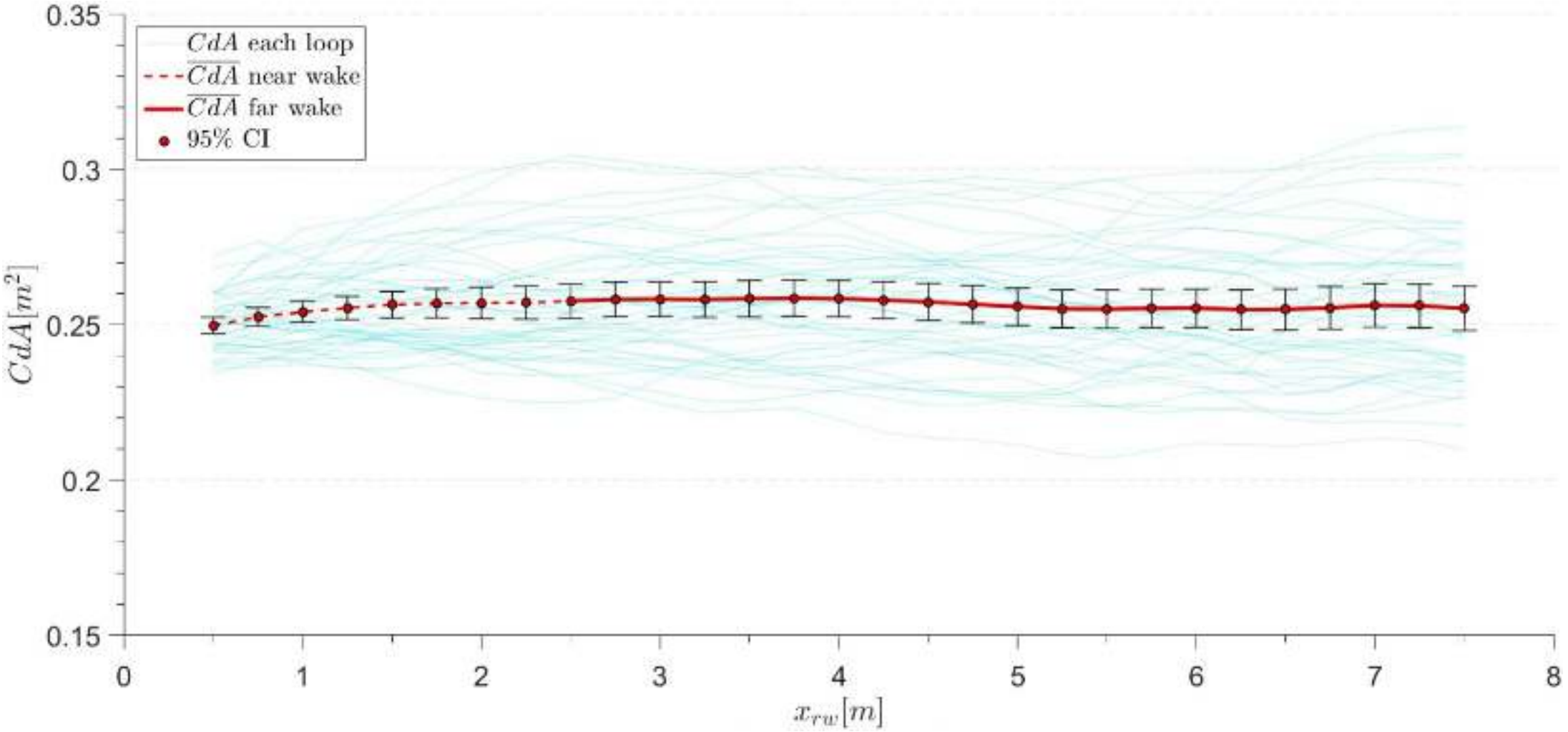


OUT-OF-PLANE VELOCITY



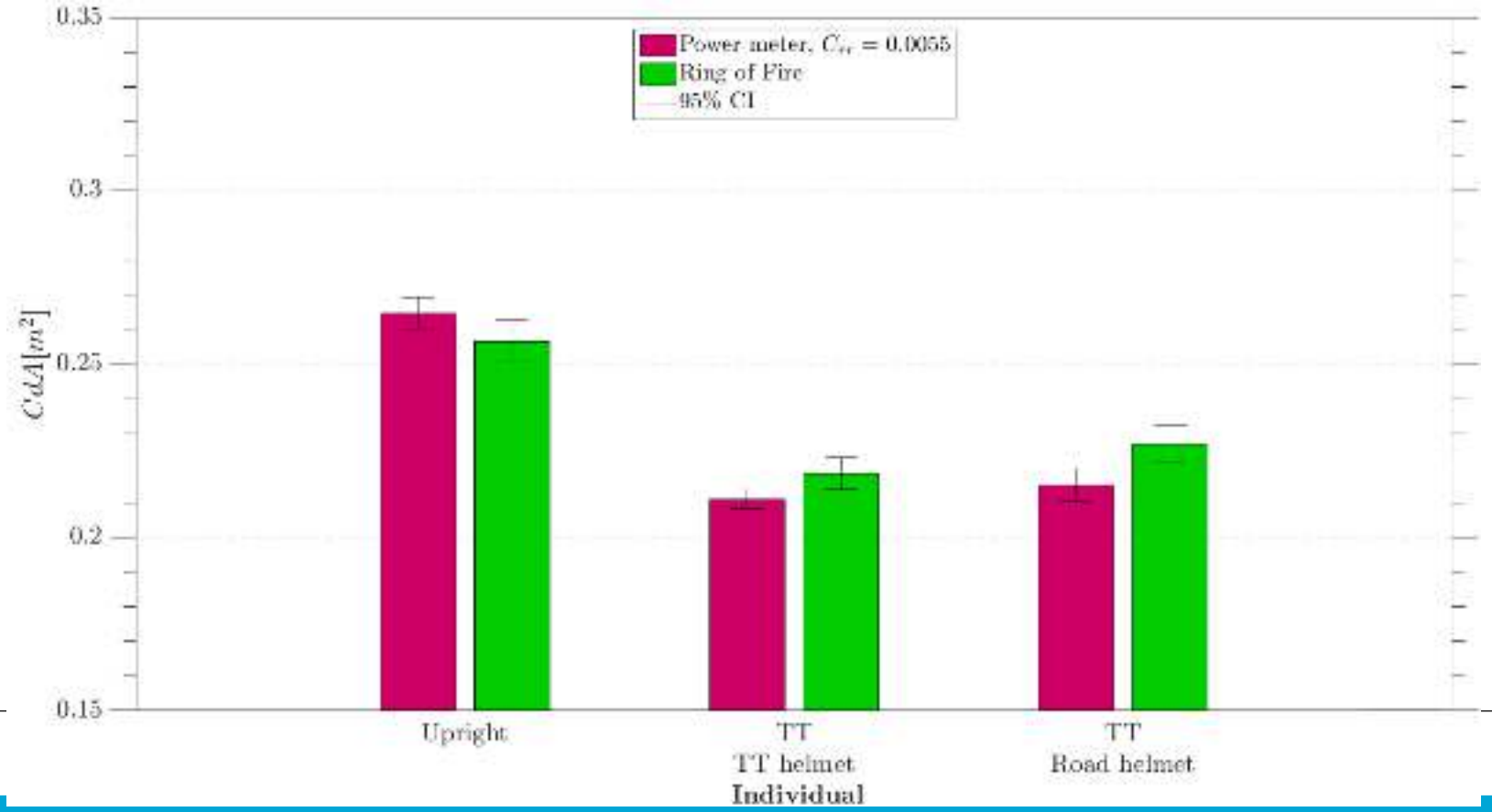
VORTICITY IN WAKE

Results – Drag from Ring of Fire

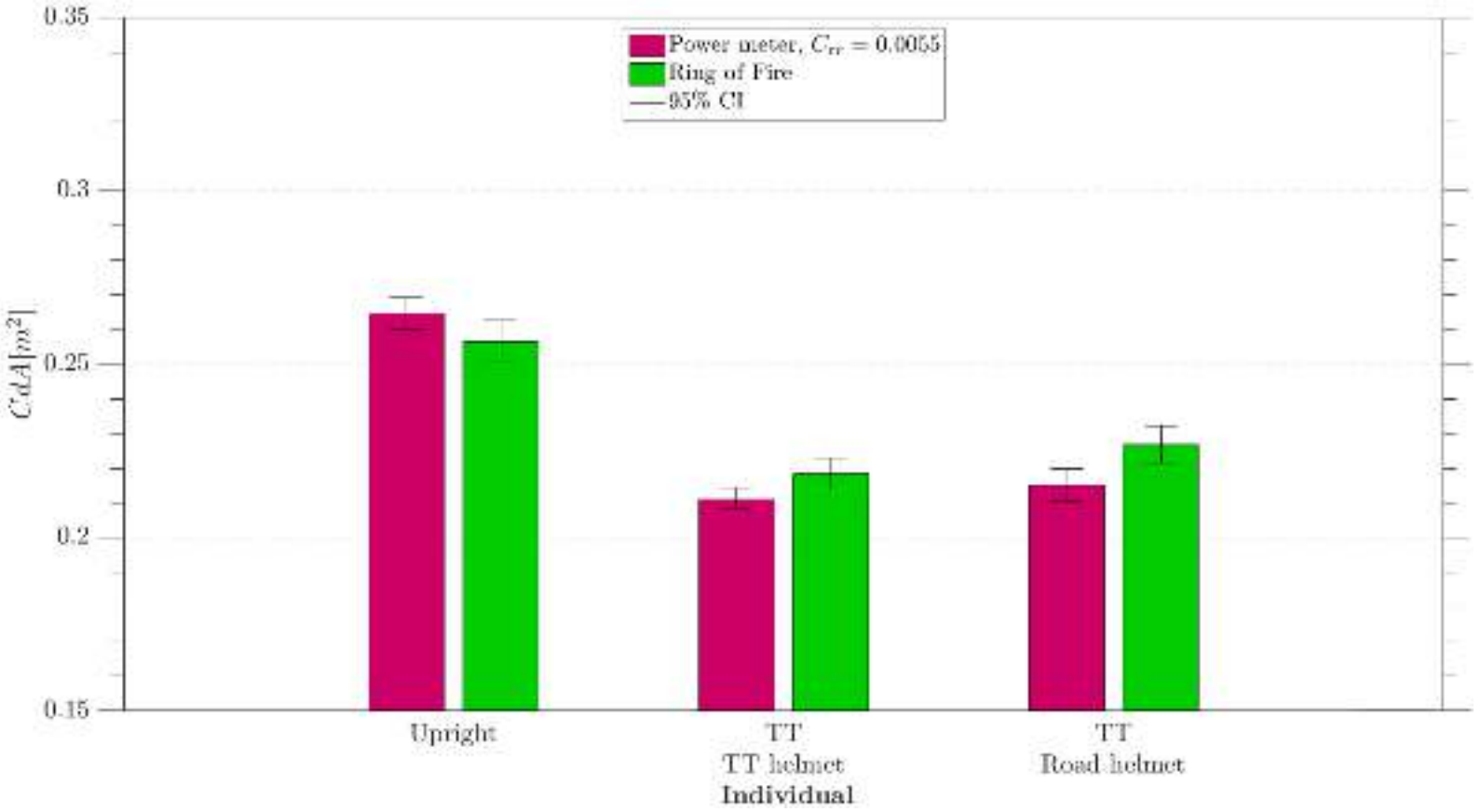


Results – Ring of Fire vs. power meter

	Upright (46 samples)	Time trial – Aero helmet (49 samples)	Time trial – Road helmet (42 samples)
Ring of Fire	0.2556 ± 0.0061	0.2183 ± 0.0046	0.2268 ± 0.0053
Power meter	0.2647 ± 0.0047	0.2111 ± 0.0031	0.2151 ± 0.0047



Results – Ring of Fire vs. power meter



1. The accuracy of the ring of fire system is estimated to be better than 5%

2. Large-scale drag area increase obtained from the power meter (23 %) and the Ring of Fire (17 %)

3. Small-scale drag area increase obtained from the power meter (2 %) and the Ring of Fire (4 %)

Conclusions

- Compared to previous experiments we were able to:
  1. Perform continuous measurements (time between measurements < 25 sec)
  2. Perform simultaneous drag measurements from both ring of fire and the state-of-the-art technique (power meter) for on-site drag measurements

- Outcomes
  1. The ring of fire agrees with the power meter within 2 to 5%
  2. The accuracy of the ring of fire system is estimated to be better than 5%
  3. Variations in posture (ΔCdA typically up to 20%) can be detected
  4. Variations in helmets (ΔCdA typically up to 4%) fall within the uncertainty of the system.


Thank you for your attention