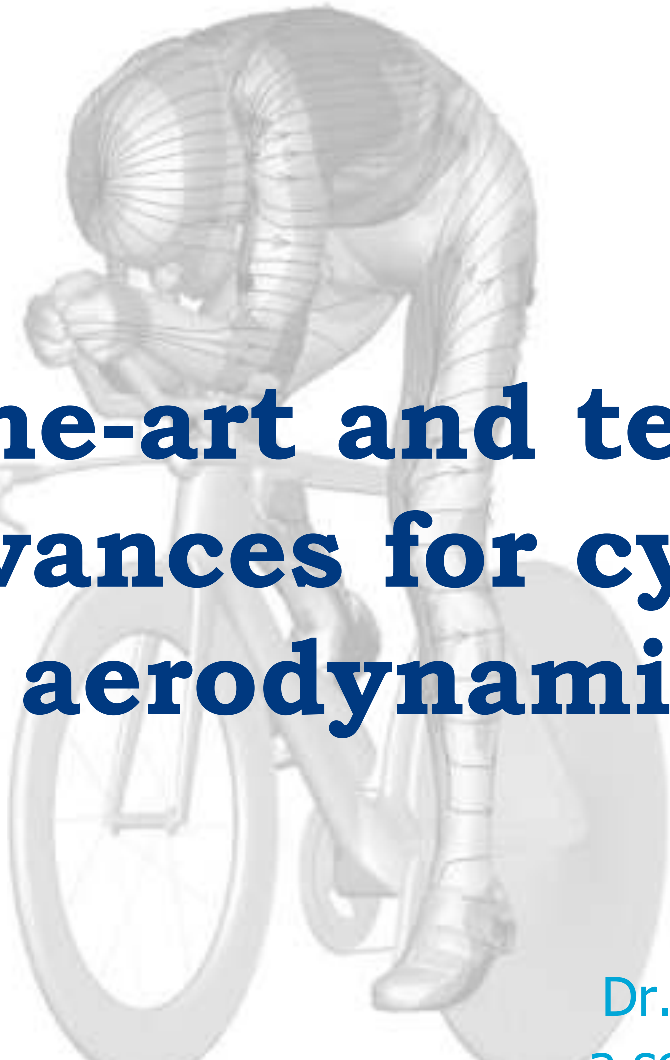


State-of-the-art and technology advances for cycling aerodynamics

Dr. Andrea Sciacchitano
a.sciacchitano@tudelft.nl

TU Delft
Delft University of Technology
aerodynamics

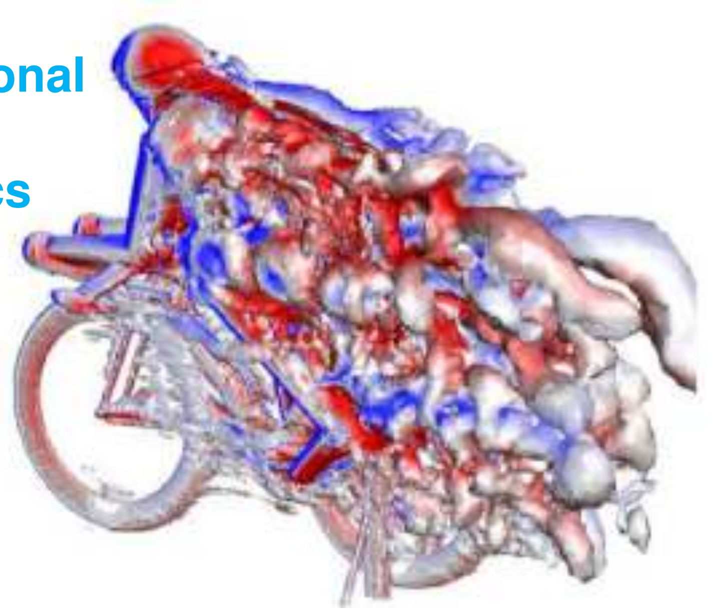
Science & Cycling
3-4 July 2019, Brussels, Belgium

Aerodynamics
Relevance in cycling

- Aerodynamic drag constitutes up to 90% of the drag a rider has to overcome
- Reduction of the aerodynamic drag can give a competitive advantage to the riders

Cycling aerodynamics
Methods of investigation

Wind tunnel measurements

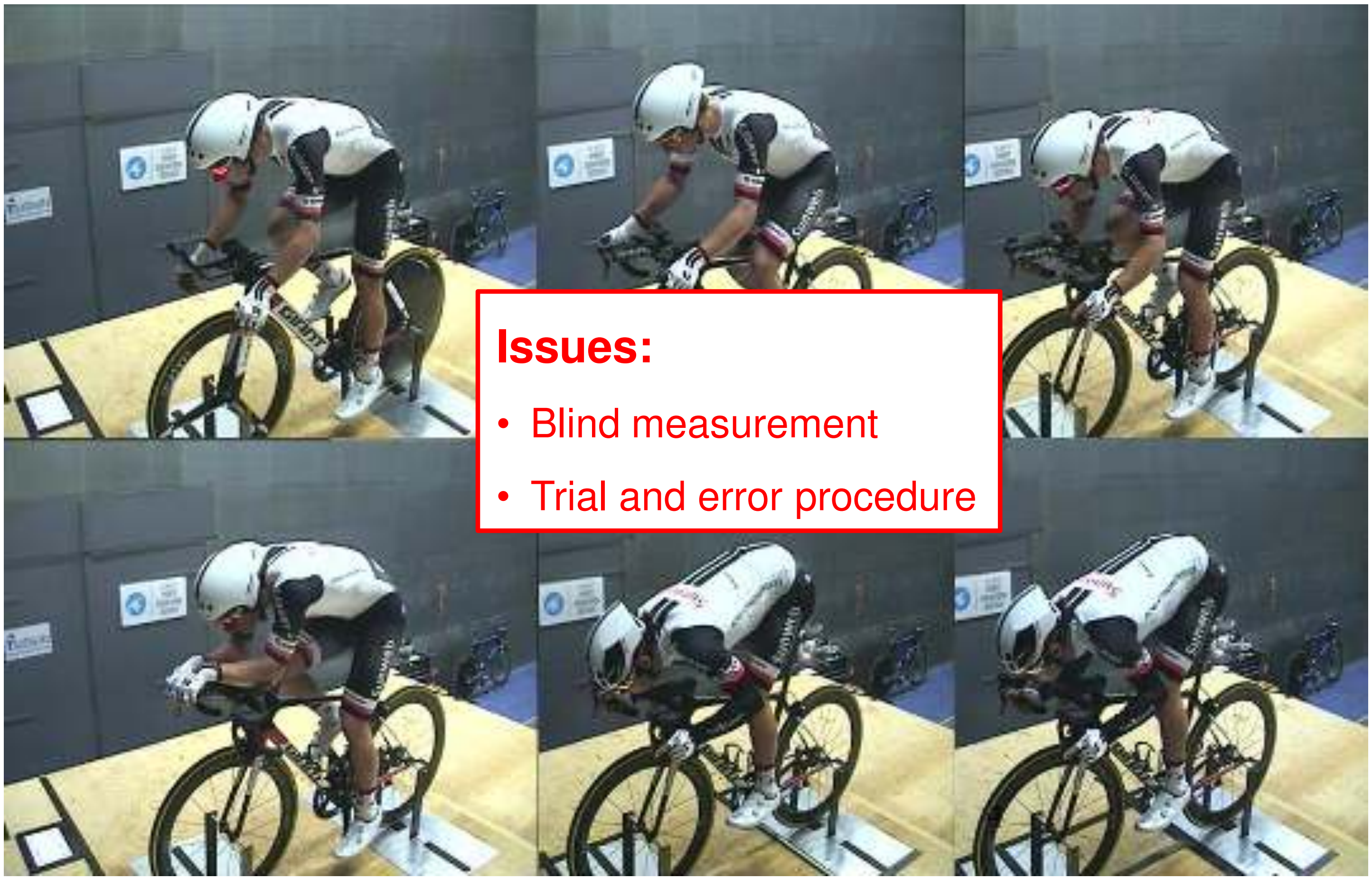


Computational Fluid Dynamics (CFD)

Track/Field testing

Wind tunnel measurements

Drag by Force Balance



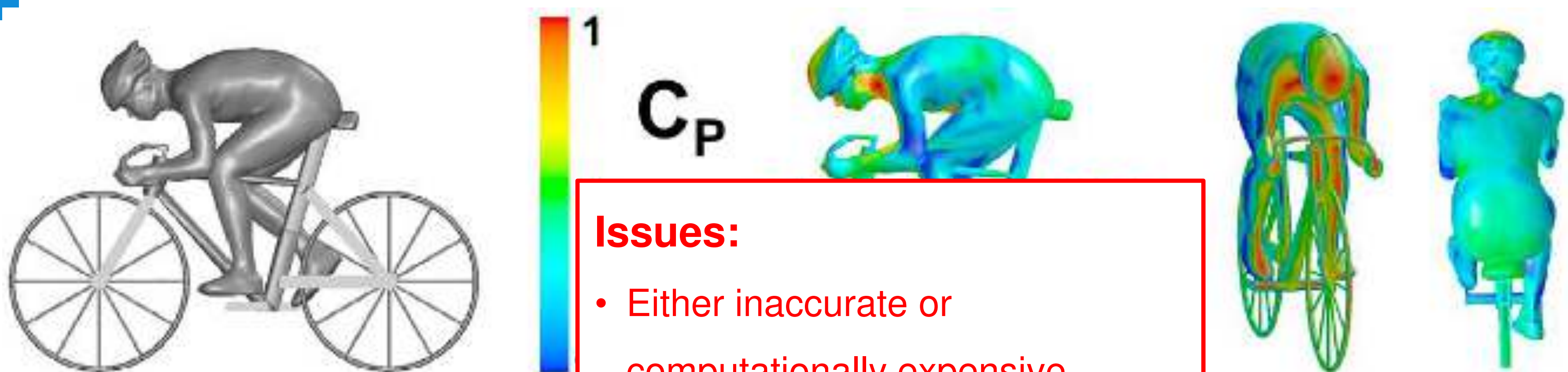
Issues:

- Blind measurement
- Trial and error procedure

Numerical simulations by CFD

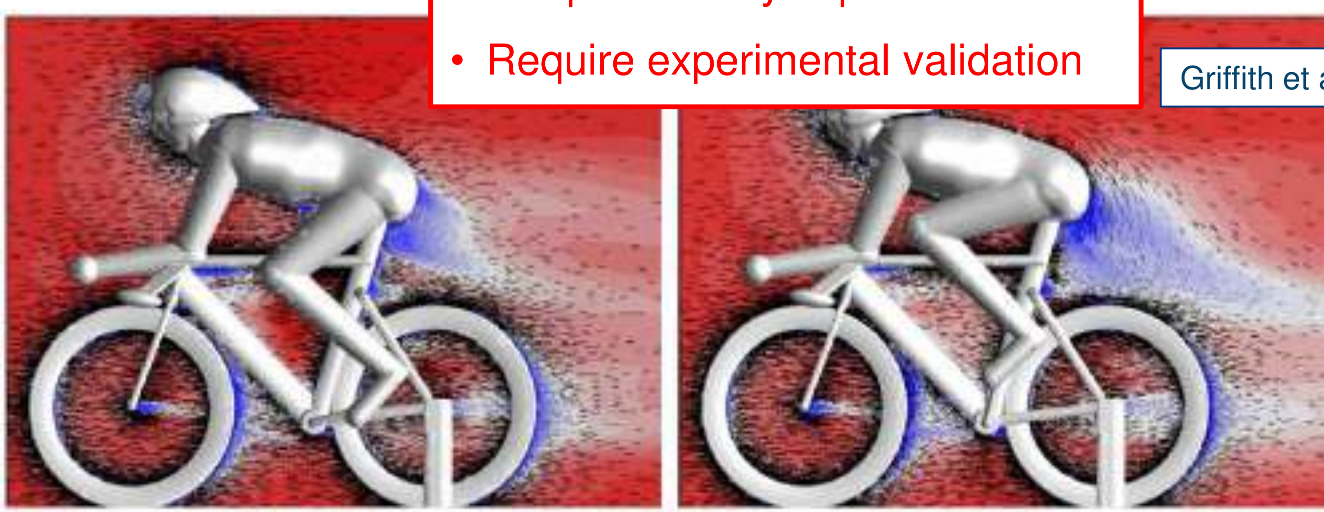
RANS or LES simulations

Blocken et al. (2018)



Issues:

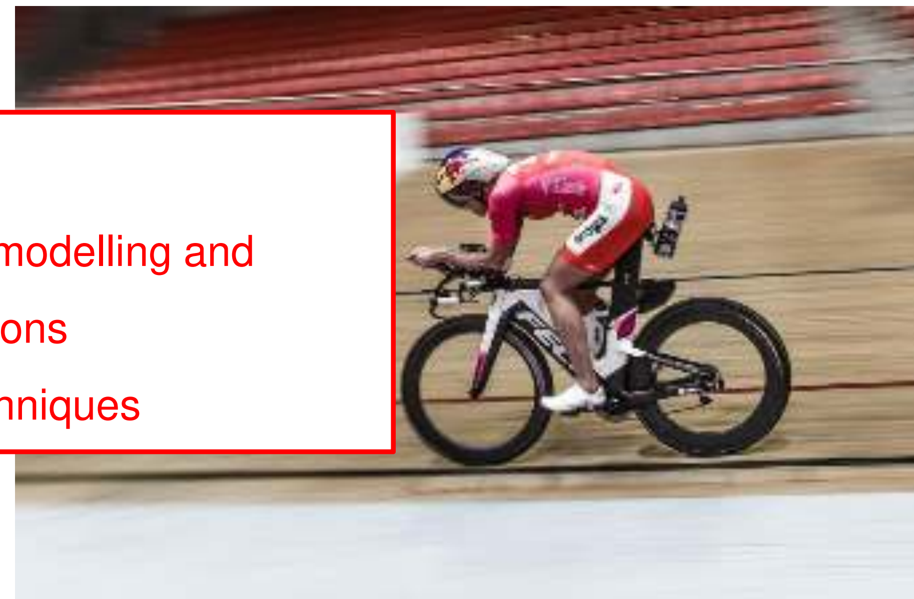
- Either inaccurate or computationally expensive
- Require experimental validation



Griffith et al. (2014)

Track/Field testing

Coast Down or Power Meter measurements



Issues:

- Require modelling and assumptions
- Blind techniques

Can we measure the flow around the cyclist?

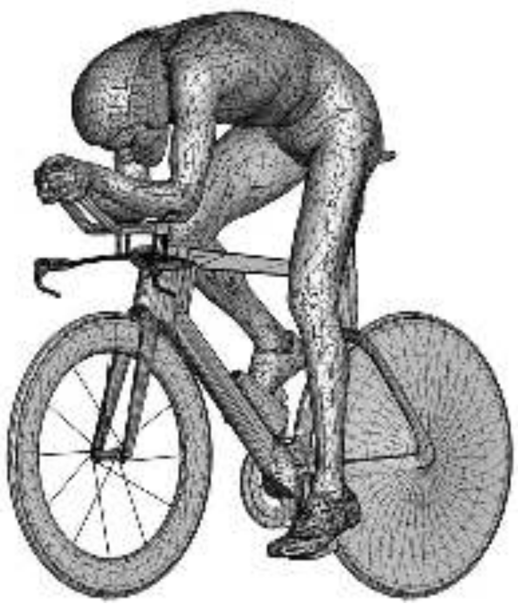
Particle Image Velocimetry (PIV)

- Small particles inserted into the flow and carried by the fluid
- Particles illuminated by a light source (laser)
- Images acquired by a digital camera
- Velocity field determined from cross-correlation-based image analysis

Dutch cyclist Tom Dumoulin

3D scan of athlete in time-trial position

CAD model

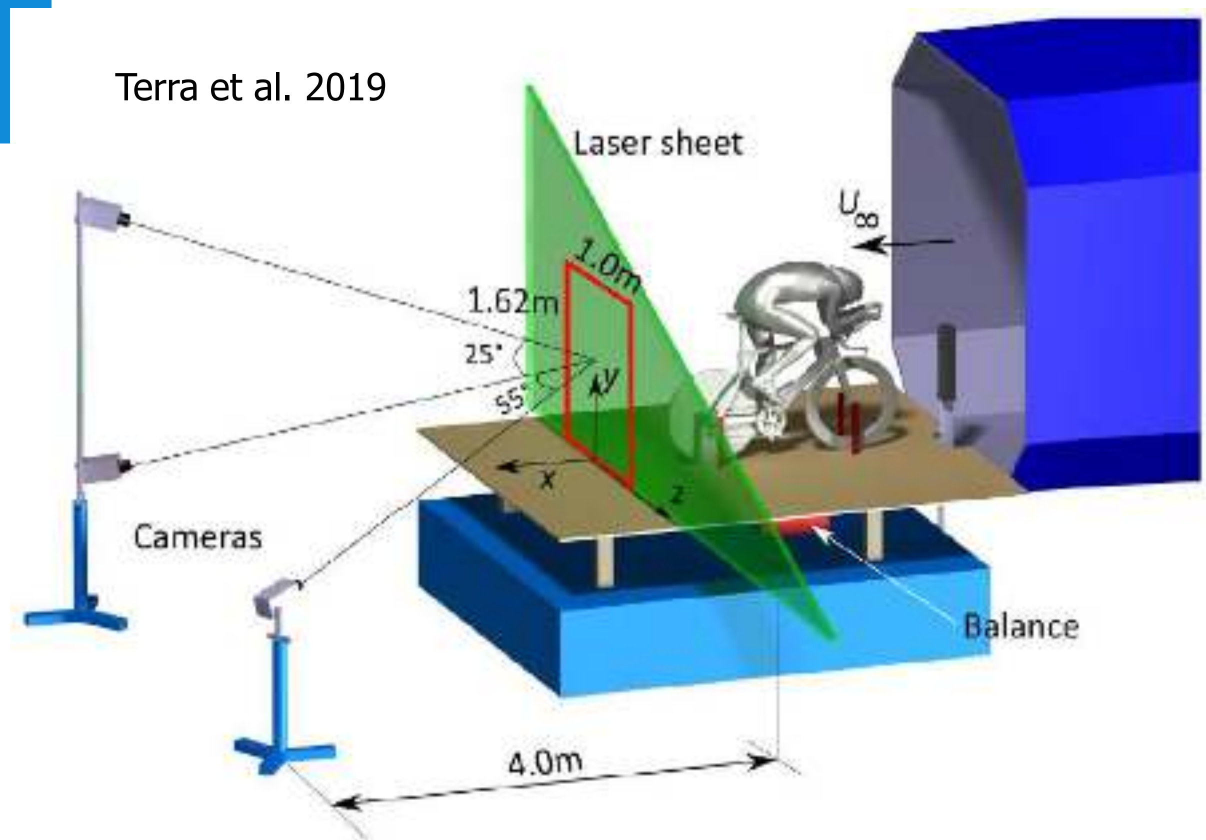


3D-printed mannequin in the wind tunnel

Flow analysis by large-scale PIV

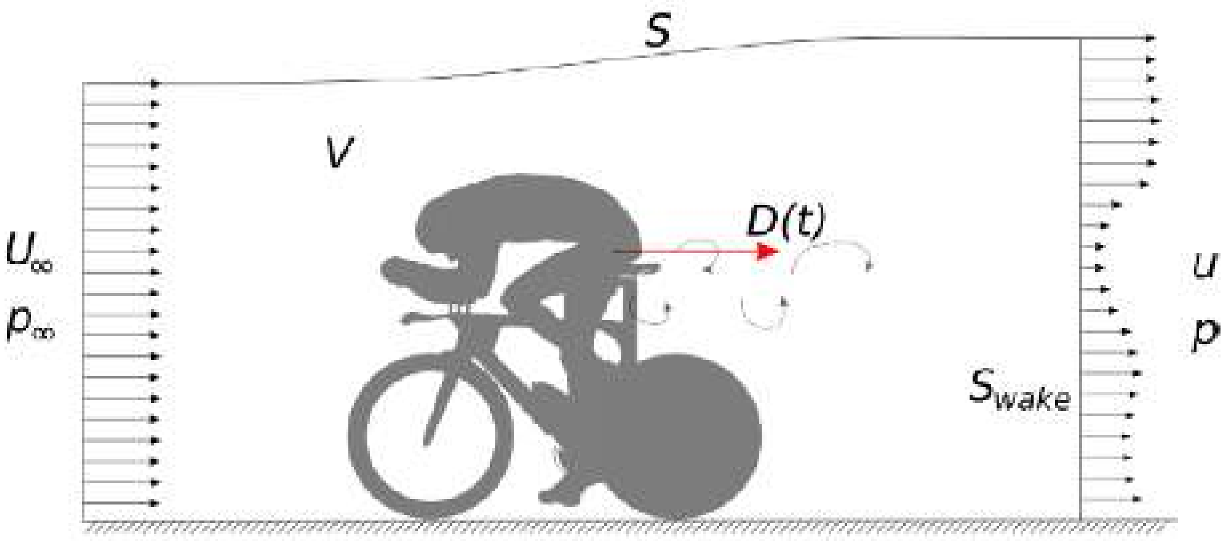
Wake flow measurements

Terra et al. 2019



- V_∞ = 12.5 to 15 m/s (Re ~ $5x10^5$)
- Field of view: 1.0x1.6 m^2
- 5 cm laser sheet thickness
- Images recorded with three high-speed cameras
- Digital resolution: 1.6 mm/px
- Force measurements via 6-component balance
- Drag estimated via PIV wake rake approach

Drag determination from PIV measurements
Conservation of momentum in a control volume



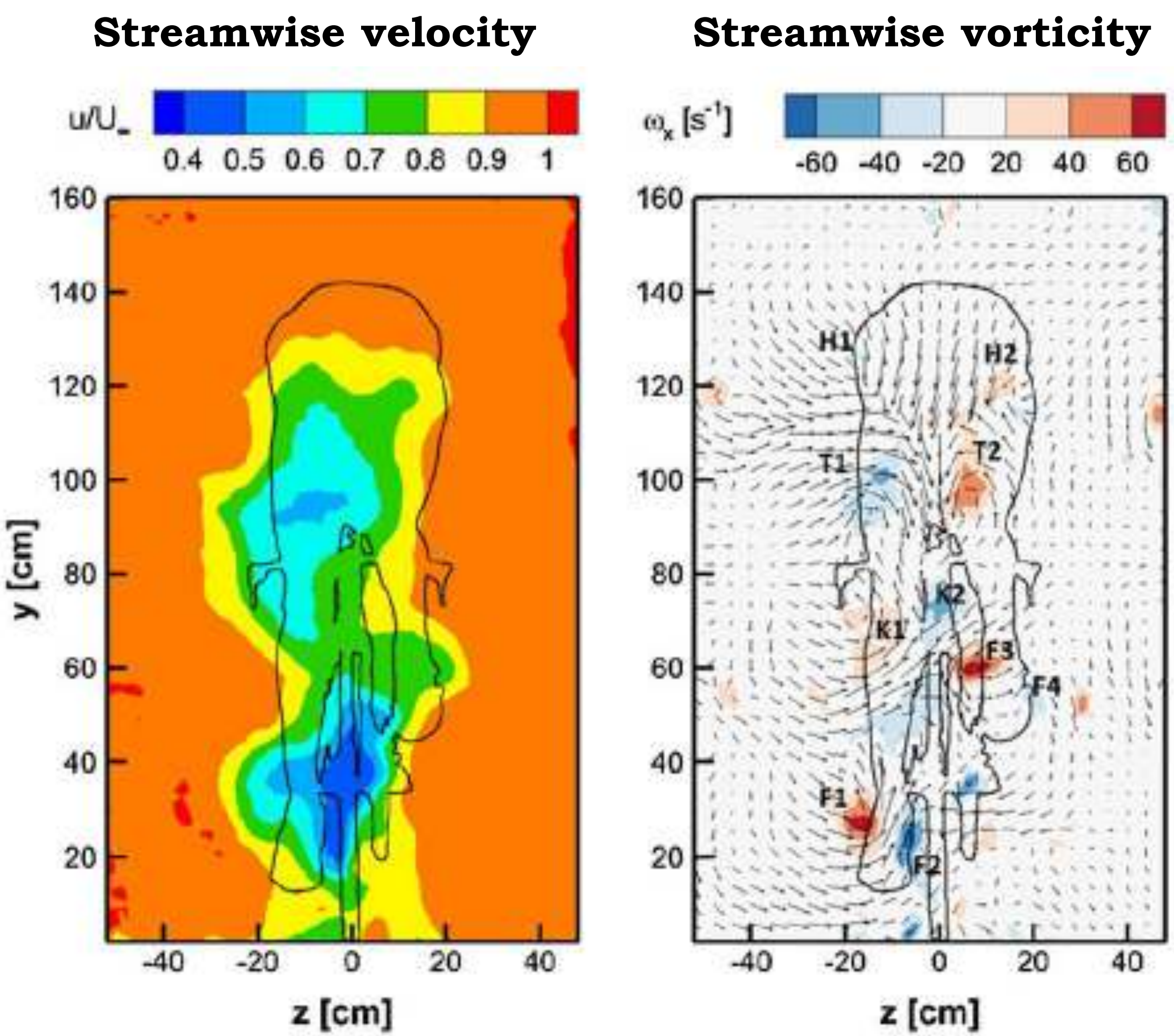
Time-averaged drag:

$$\overline{D} = \rho \iint_{S_{wake}} (U_\infty - \overline{u})\overline{u}\,dS - \rho \iint_{S_{wake}} \overline{u'^2}\,dS + \iint_{S_{wake}} (p_\infty - \overline{p})\,dS$$

Momentum term | Re stress term | Pressure term

Time-averaged velocity and vorticity fields

Terra et al. 2019

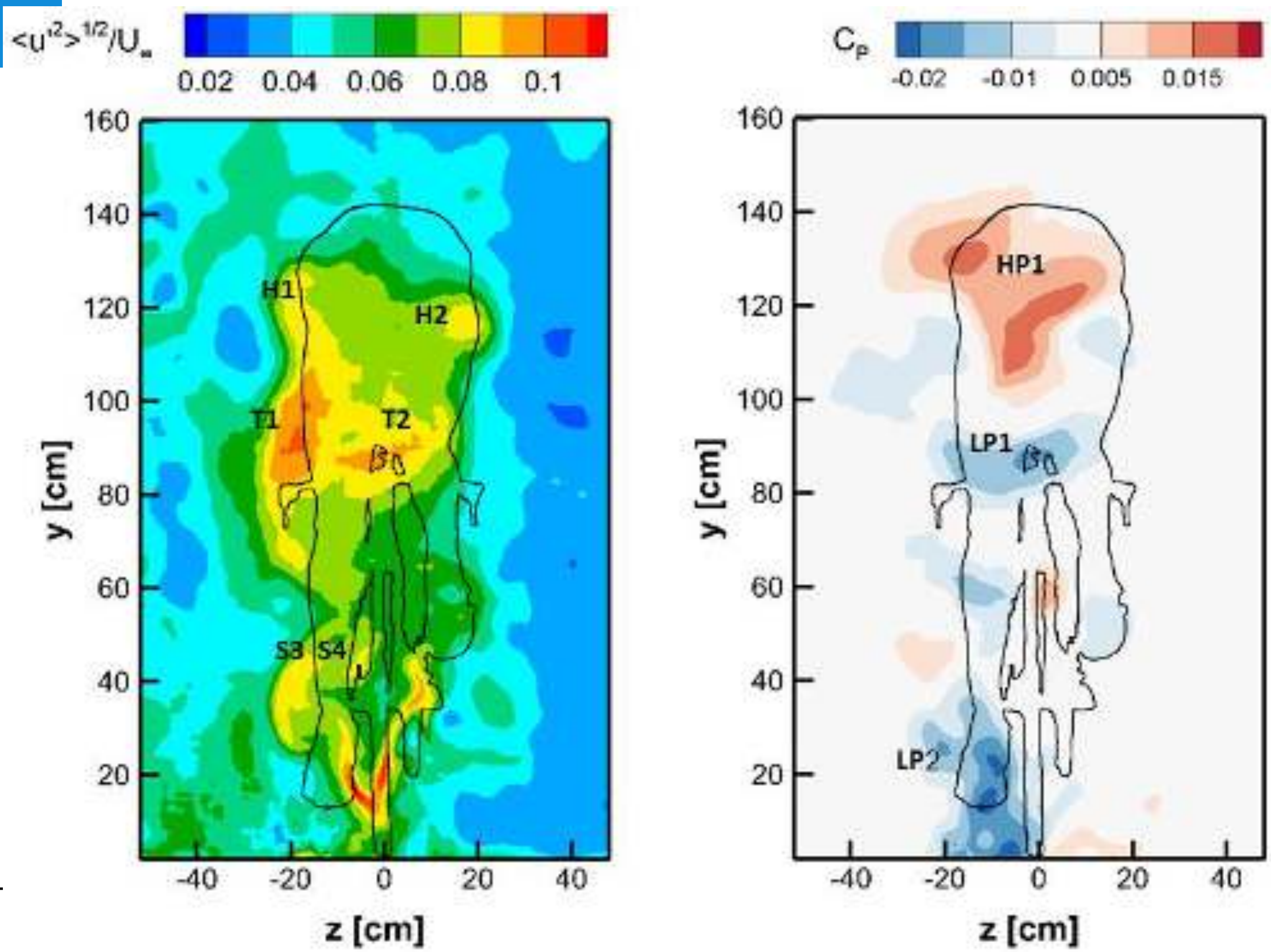


- Highest momentum deficit behind the rear wheel and the top of the stretched leg
- Vortices shed by the thighs, hips, feet and knee of the stretched leg

Velocity fluctuations and time-averaged pressure

Terra et al. 2019

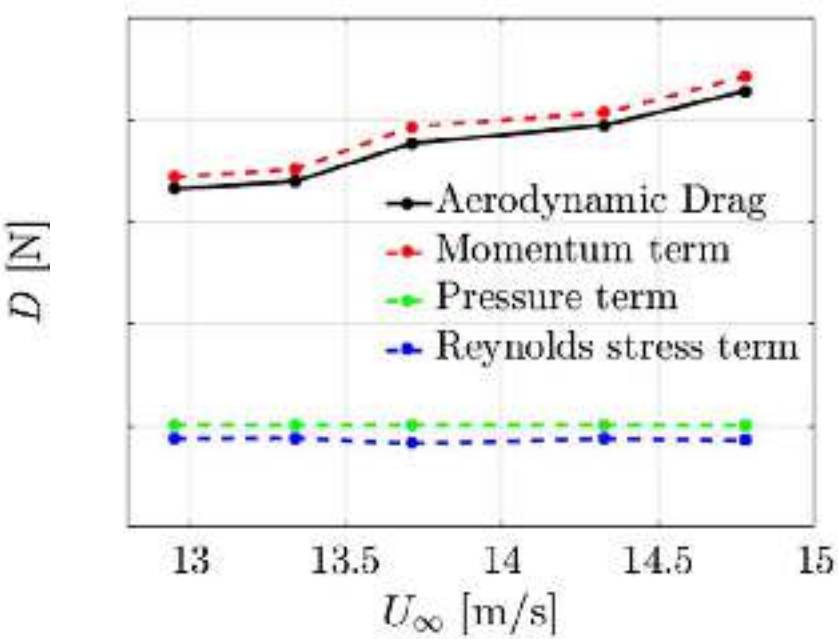
Streamwise fluctuations **Pressure coefficient**



- **High velocity fluctuations** due to shear layers at the hips location, thigh location and stretched leg location
- **High pressure** in the upper back of the cyclist
- **Low pressure** in the separated regions behind the lower back, and between the left foot and the rear wheel

Drag estimate
Contribution of the individual terms

Aerodynamic drag

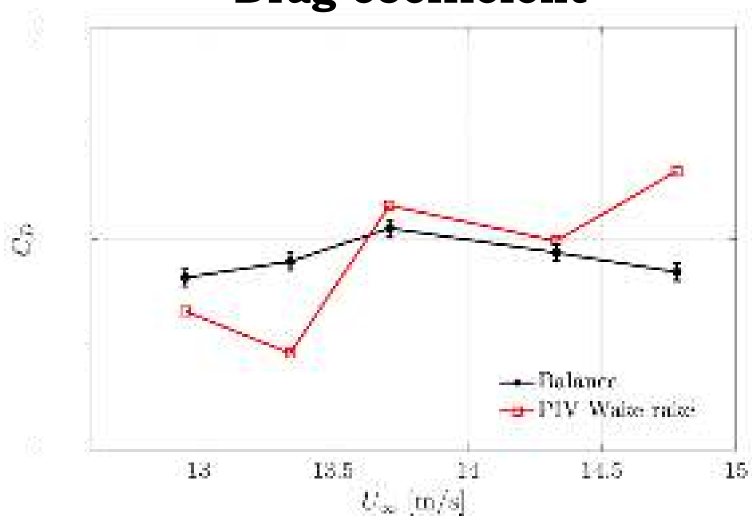


$$\overline{D} = \underbrace{\rho \iint_{S_{wake}} (U_\infty - \overline{u})\overline{u}\,dS}_{\text{Momentum term}} - \underbrace{\rho \iint_{S_{wake}} \overline{u'^2}\,dS}_{\text{Re stress term}} + \underbrace{\iint_{S_{wake}} (p_\infty - \overline{p})\,dS}_{\text{Pressure term}}$$

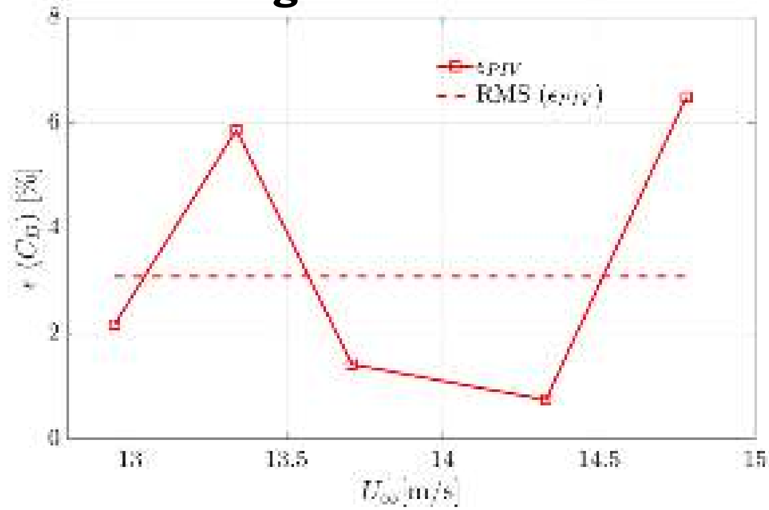
Contribution to total drag	
Momentum term	95%
Re stress term	5%
Pressure term	<1%

Drag estimate
Comparison with force balance

Drag coefficient

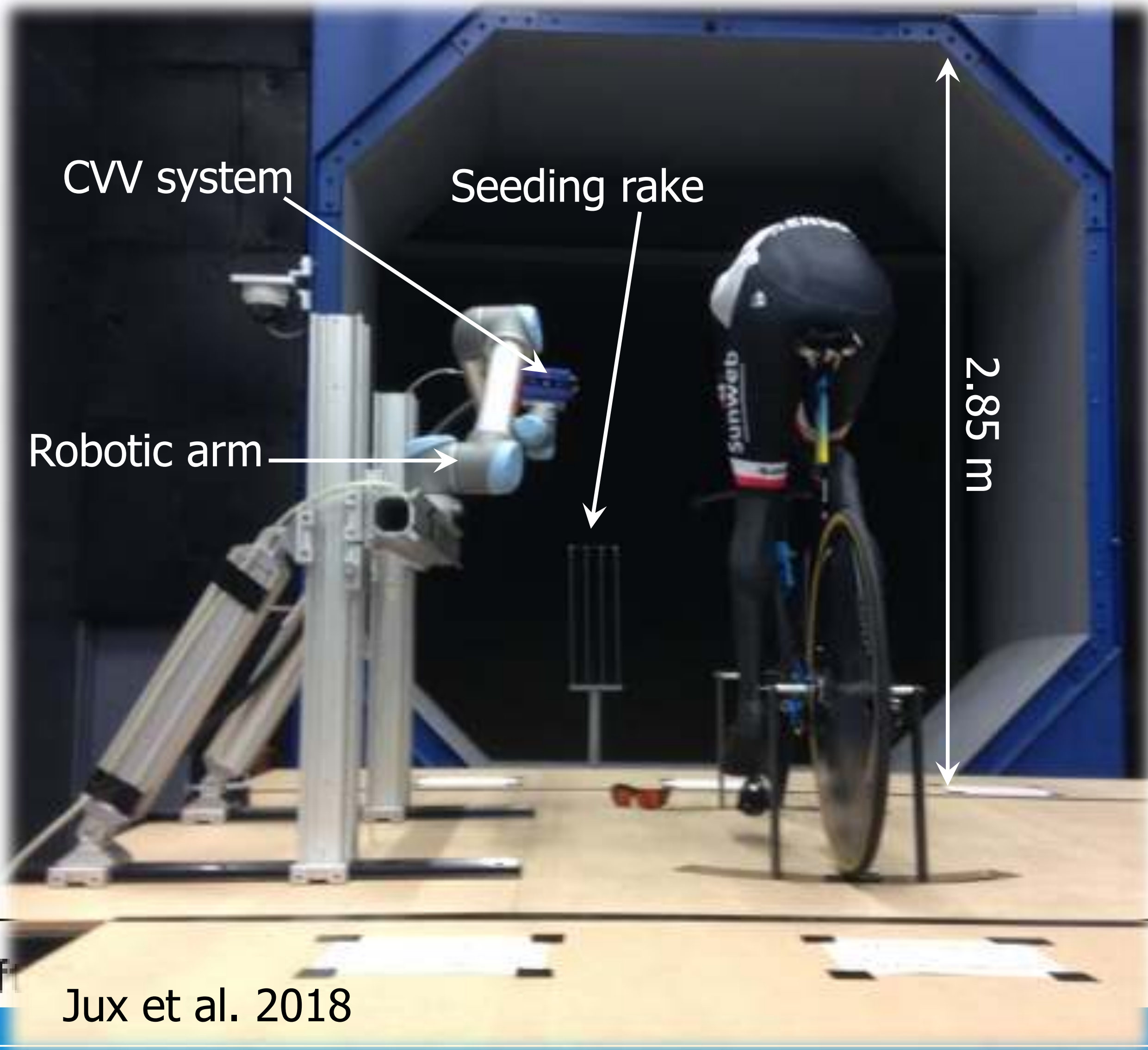


Drag coefficient error



Typical uncertainty of the PIV wake rake of the order of 3%

Flow mapping around the cyclist
Robotic volumetric PIV measurement

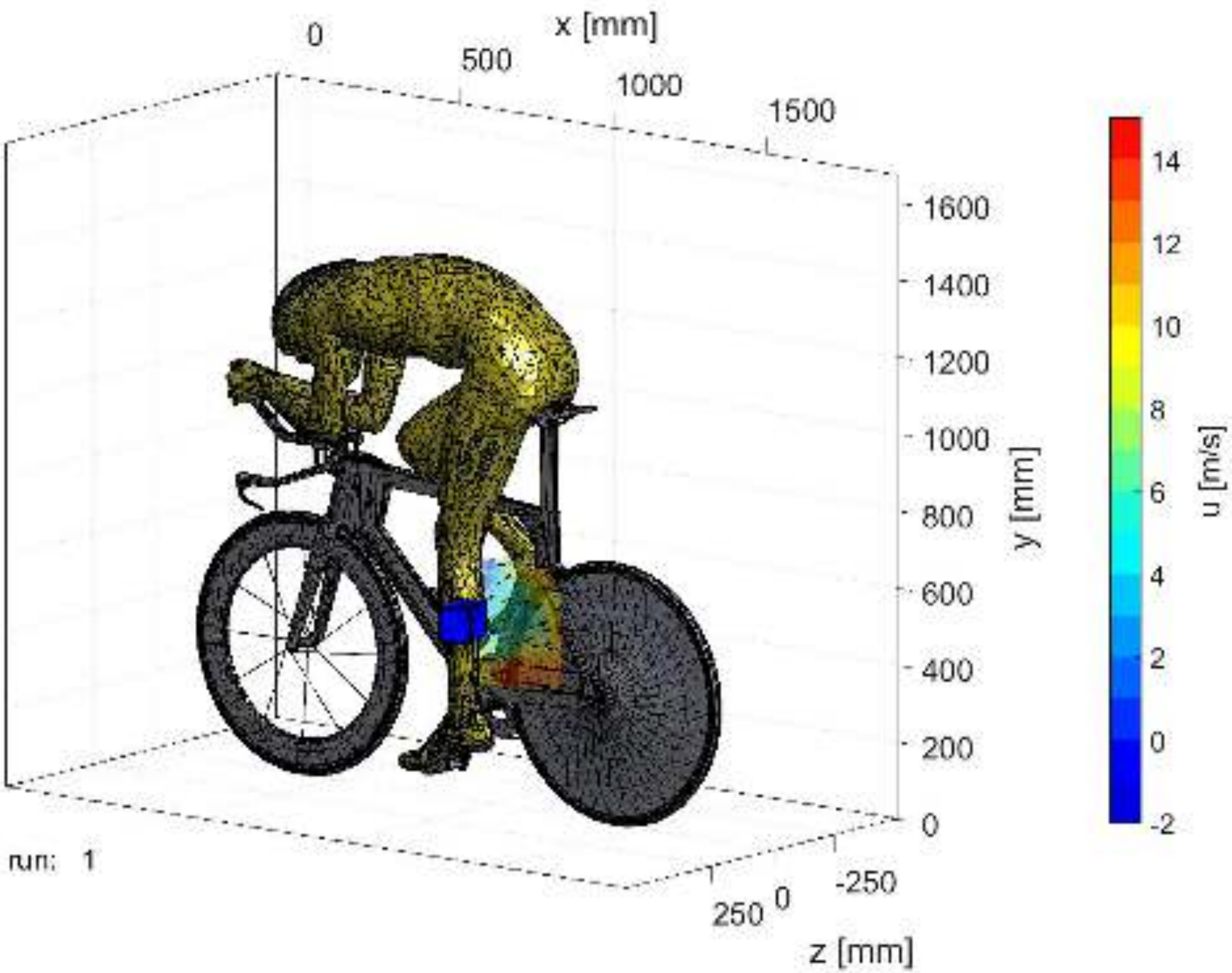


Jux et al. 2018

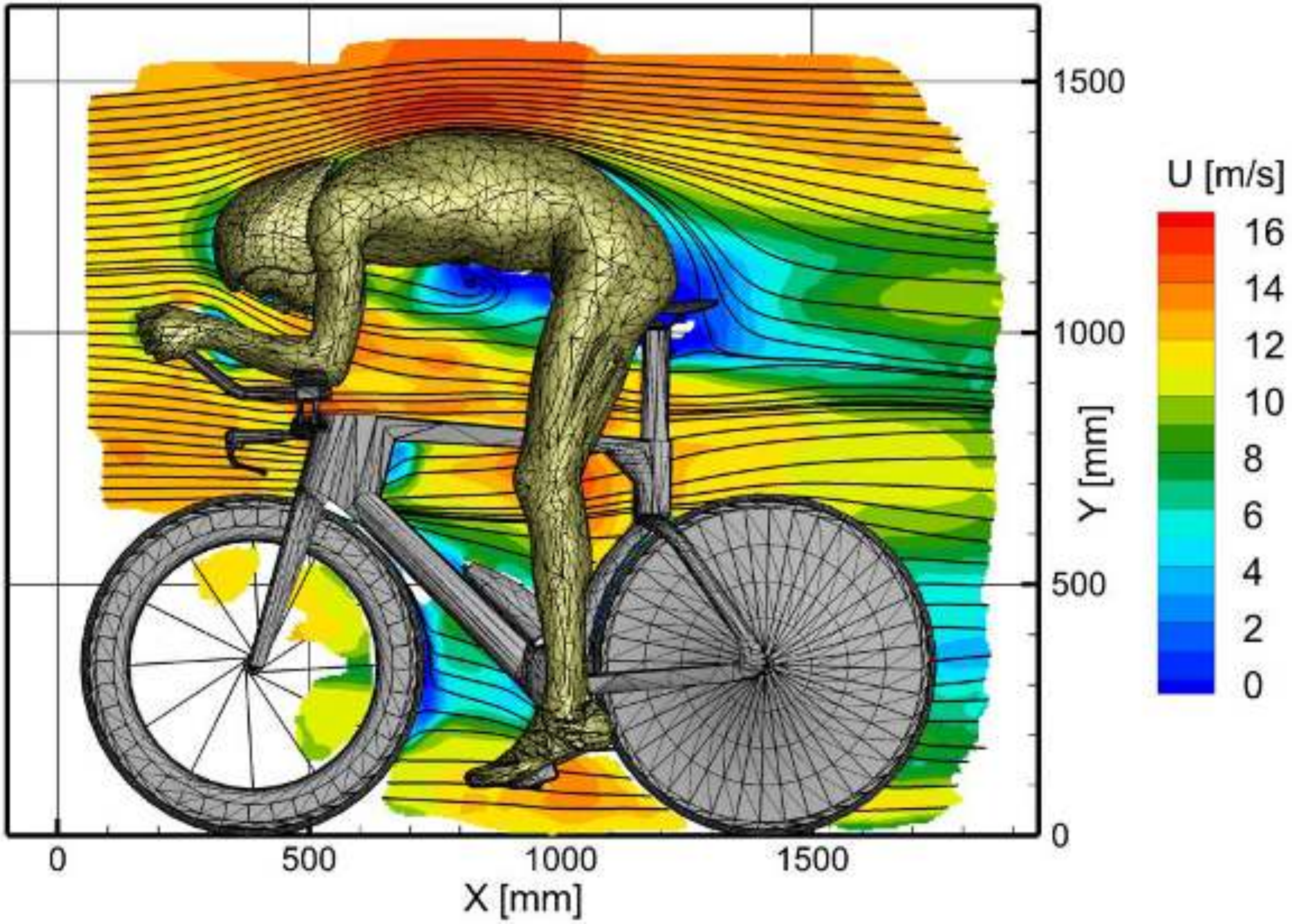
Robotic volumetric velocimetry around a cyclist
Example of operations

Robotic volumetric velocimetry around a cyclist

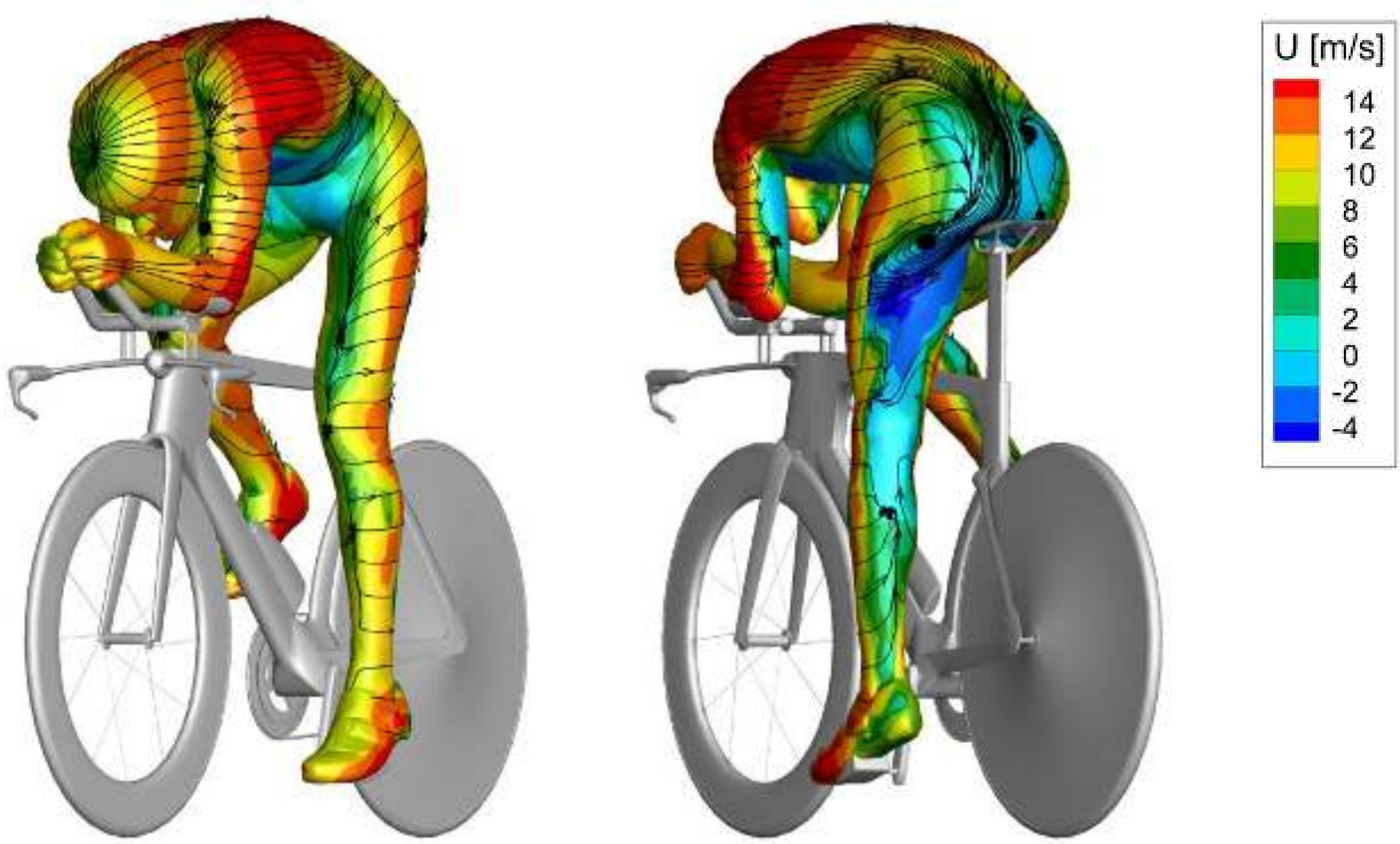
Velocity field reconstruction



Velocity field with streamlines

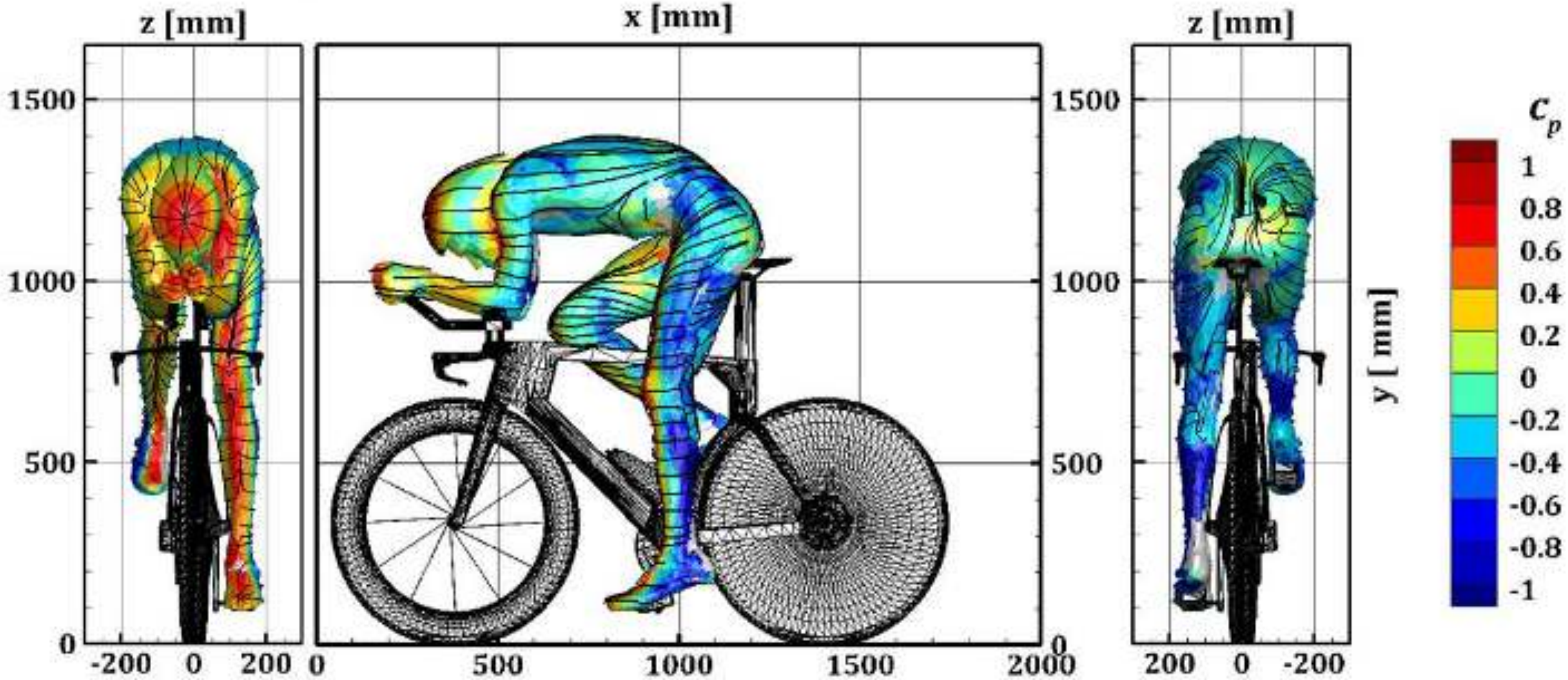


Flow 5 mm away from the surface



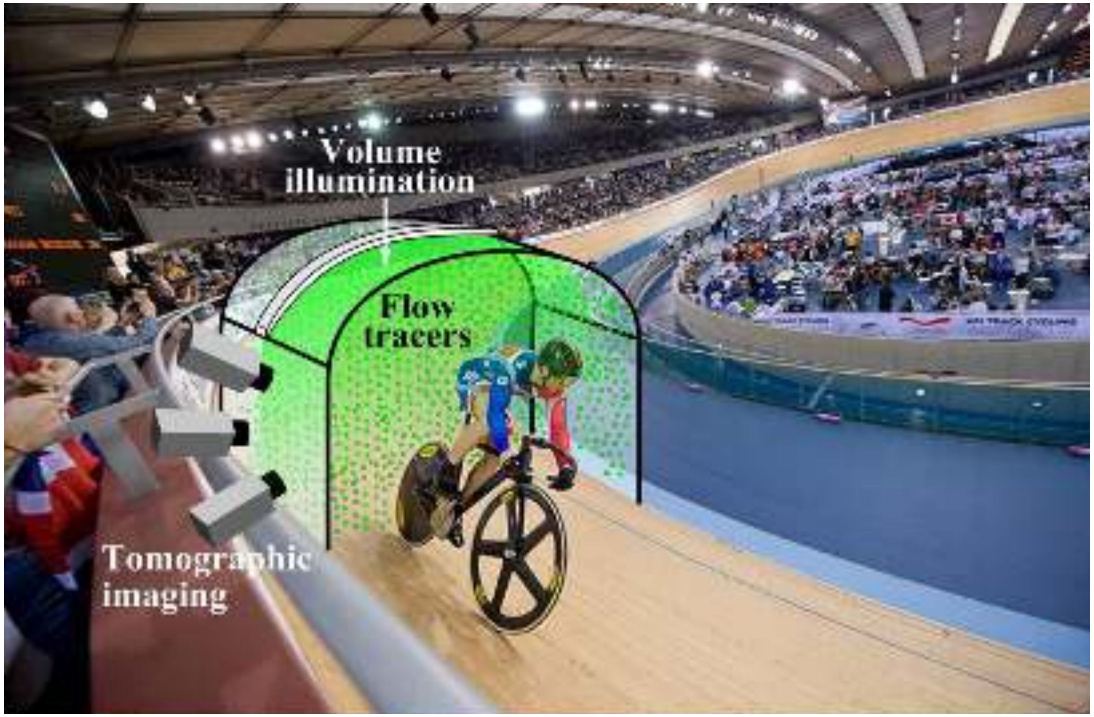
Surface Pressure

From Navier-Stokes equations: $\nabla p = -\rho \frac{D\mathbf{u}}{Dt} + \mu \nabla^2 \mathbf{u}$



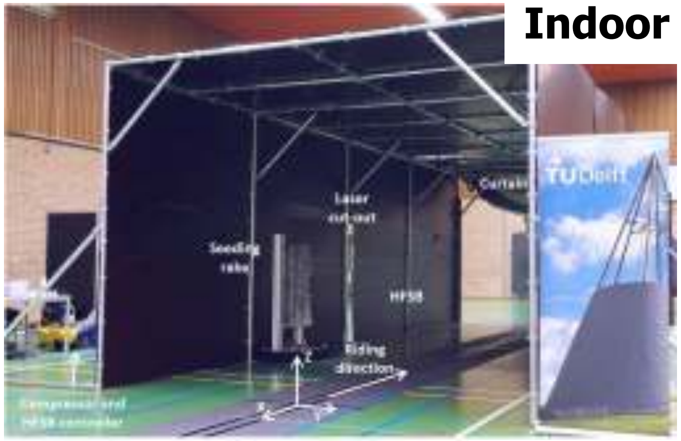
Can we measure the cyclist's flow in-field?

Ring of Fire concept



- Cyclist passing through the measurement domain
- Flow measurements in the front and the back of the cyclist
- Drag from conservation of momentum in a control volume

Some of the Ring of Fire measurement campaigns



Indoor

Indoor

Outdoor

Outdoor

Individual Rider

Video

Ring of Fire Measurements

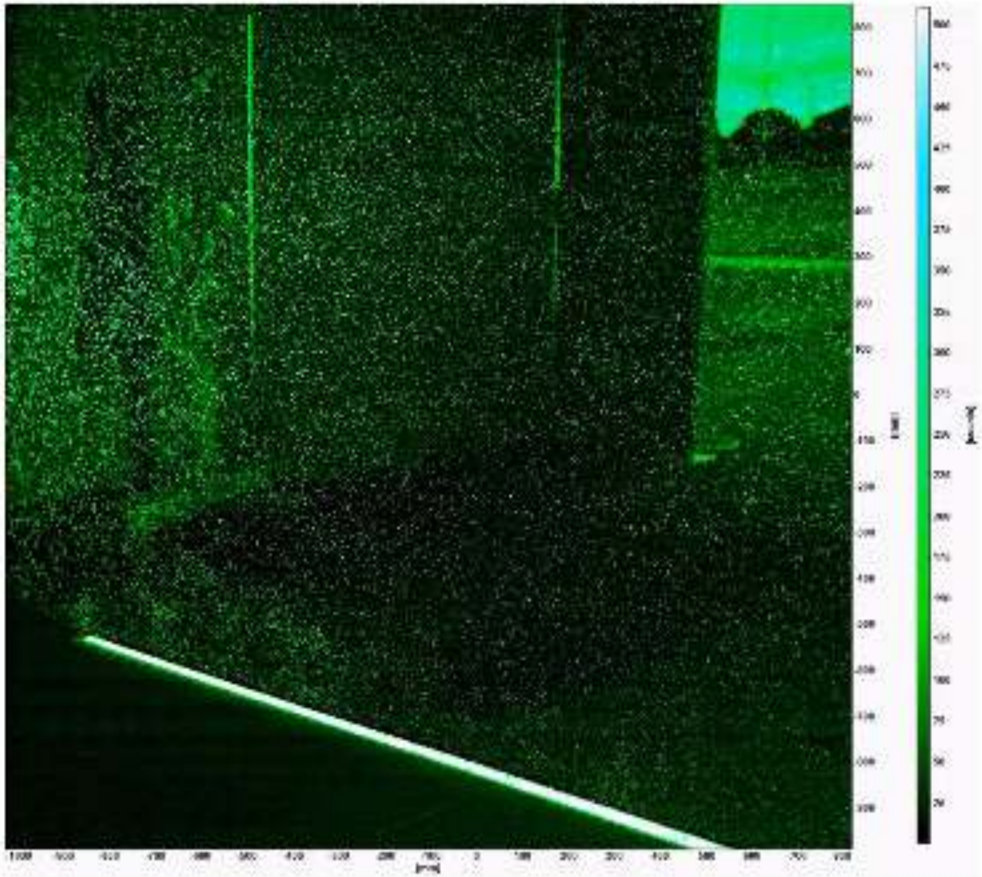
June 2019
Tom Dumoulin Bike Park
Sittard-Geleen
The Netherlands

Large-scale PIV
500 Hz acq. Frequency

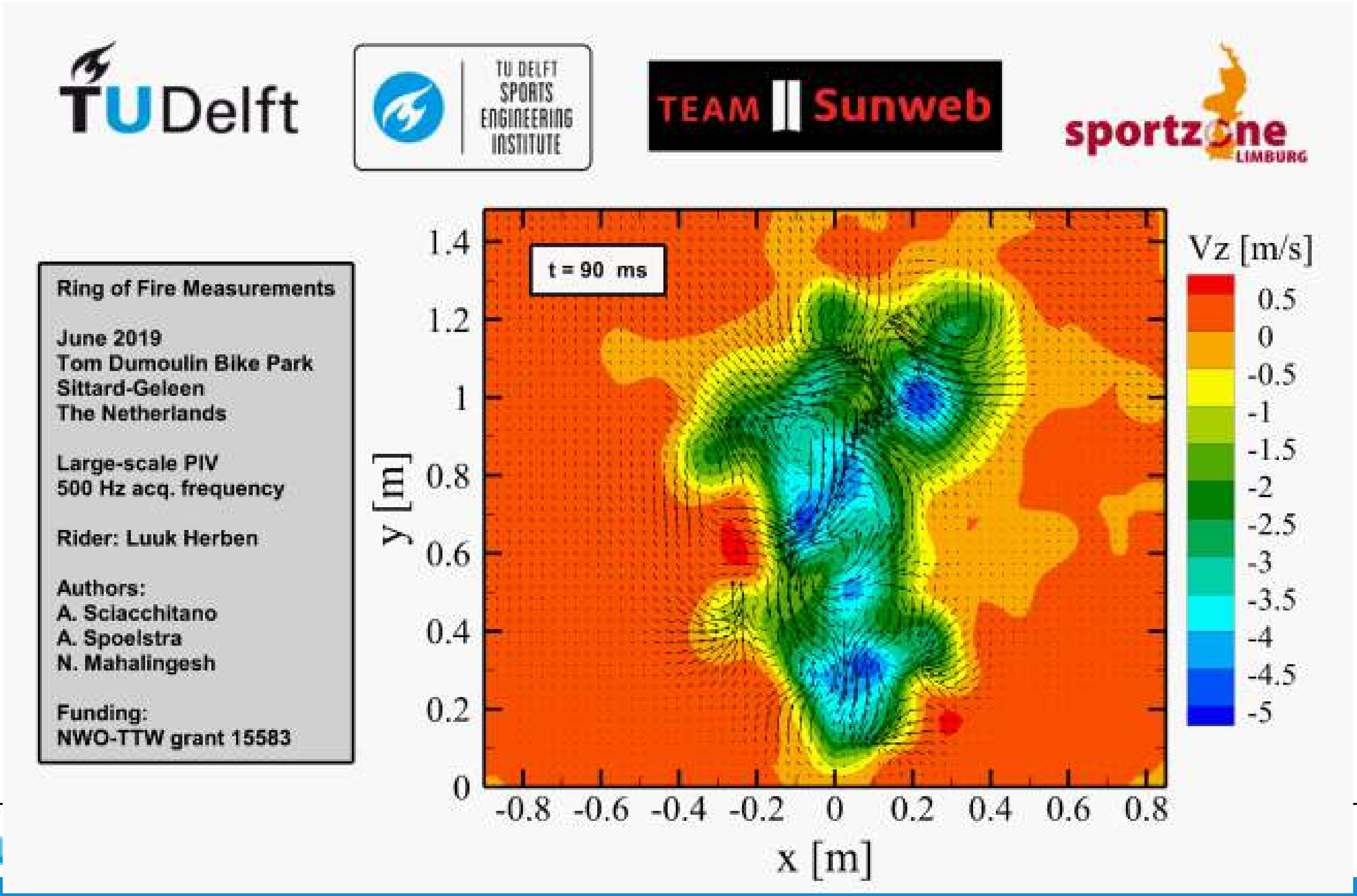
Rider: Luuk Herben

Authors:
A. Sciacchitano
A. Spoelstra
N. Mahalingesh

Funding:
NWO-TTW grant 15583



Individual Rider
Wake Velocity Field



Individual Rider
Wake Vorticity Field

TU Delft | TU Delft Sports Engineering Institute | Team Sunweb | sportzone Limburg

Ring of Fire Measurements

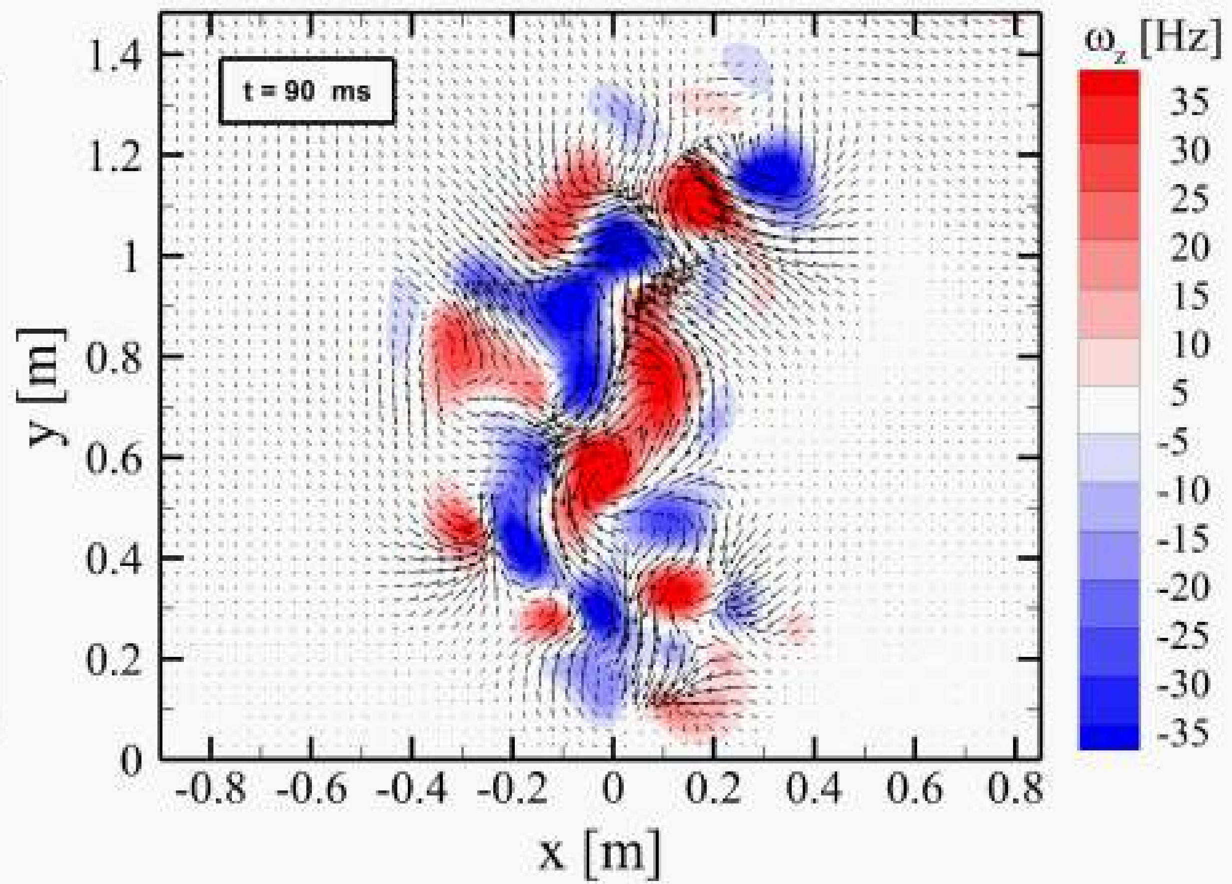
June 2019
Tom Dumoulin Bike Park
Sittard-Geleen
The Netherlands

Large-scale PIV
500 Hz acq. frequency

Rider: Luuk Herben

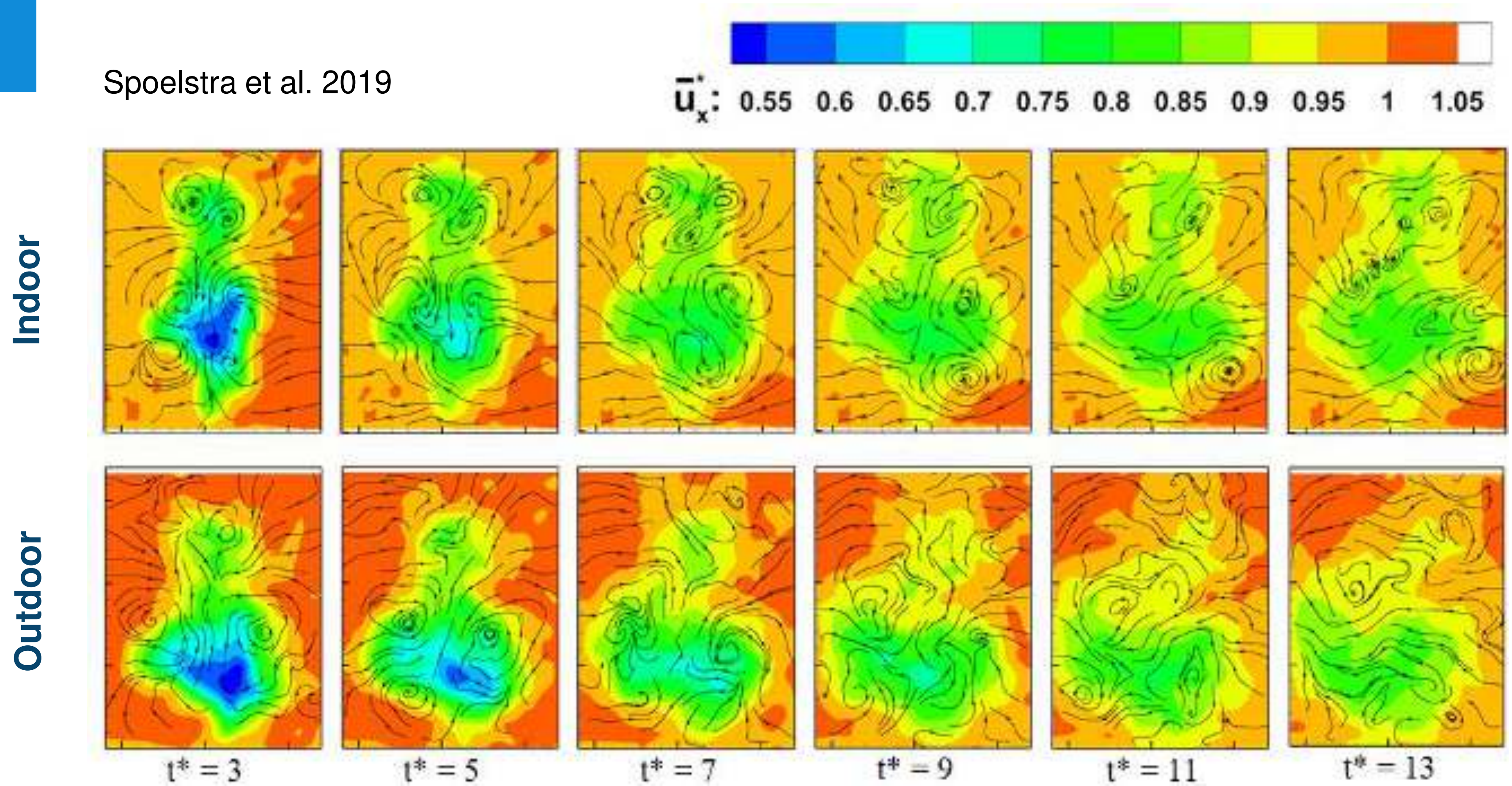
Authors:
A. Sciacchitano
A. Spoelstra
N. Mahalingesh

Funding:
NWO-TTW grant 15583



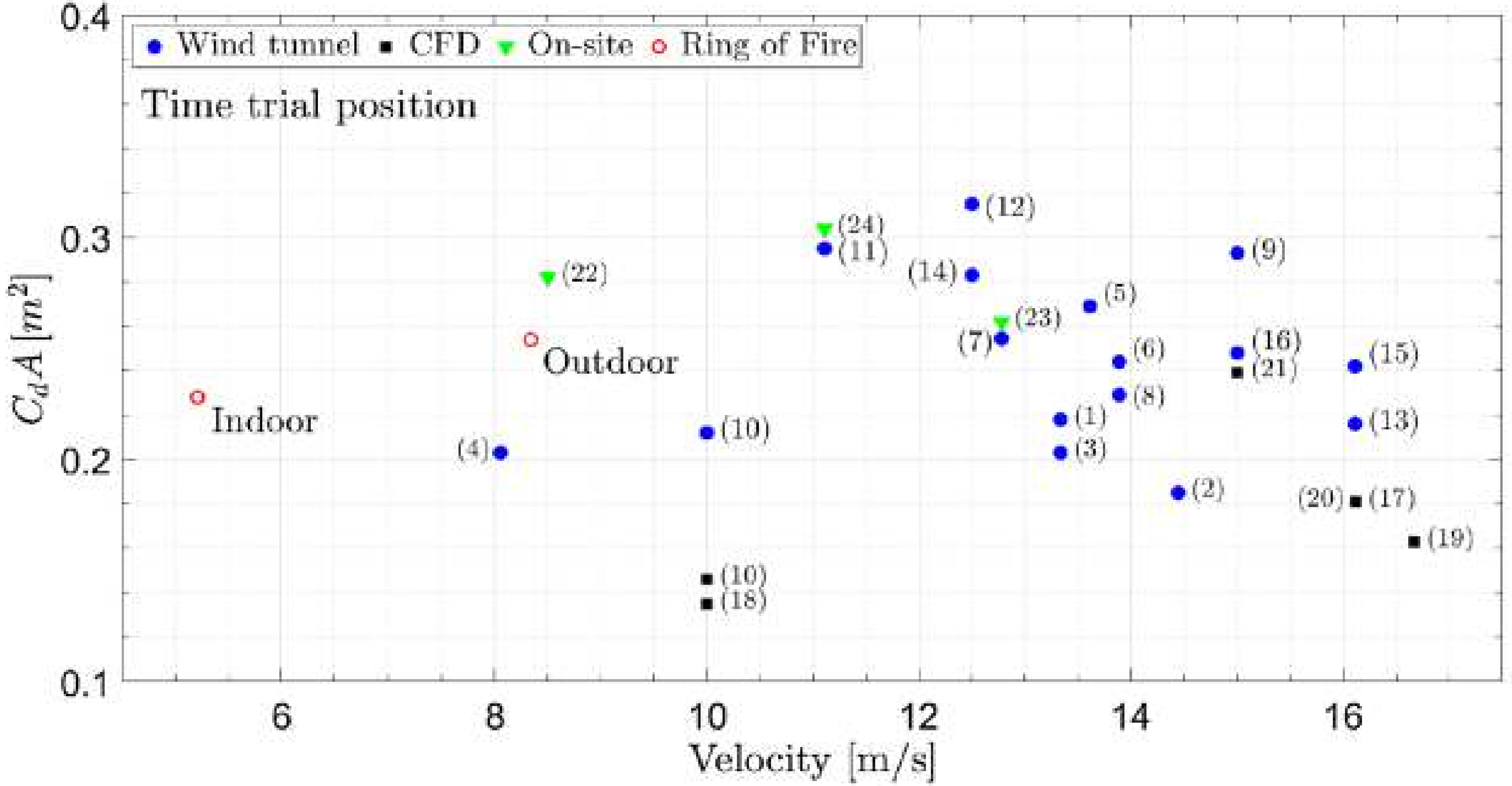
Wake evolution over time

Spoelstra et al. 2019



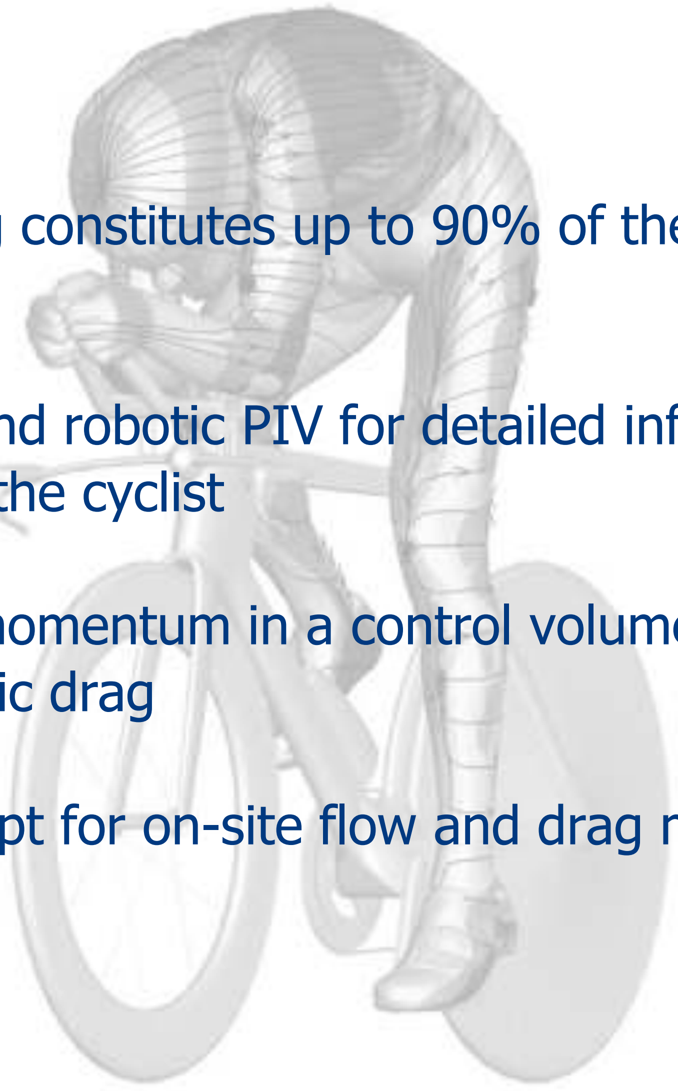
Drag comparison with literature

Spoelstra et al. 2019



More details on the accuracy of the system in the next presentation

Conclusions



- Aerodynamic drag constitutes up to 90% of the total resistance in cycling
- Large-scale PIV and robotic PIV for detailed information on the flow field around the cyclist
- Conservation of momentum in a control volume for determination of the aerodynamic drag
- Ring-of-fire concept for on-site flow and drag measurements