Wind engineering ten dienste van sport en steden

Marginale winsten… en meer

Prof.dr.ir. Bert Blocken

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KU LEUVEN

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WIND ENGINEERING

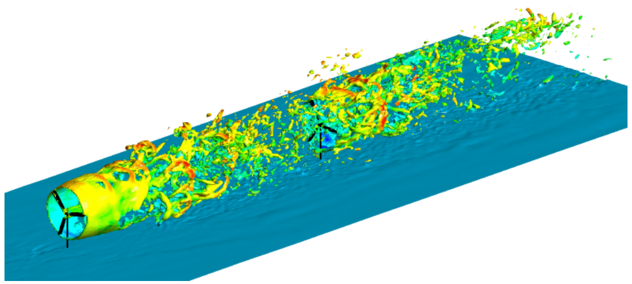
WIND ENGINEERING

Definition: Wind Engineering is best defined as (Cermak 1975):

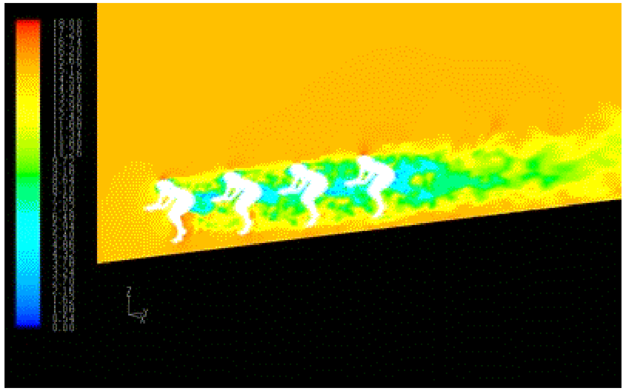
"The rational treatment of interactions between wind in the atmospheric boundary layer and man and his works on the surface of Earth." (Cermak,1975).

Topics: very wide range of topics:

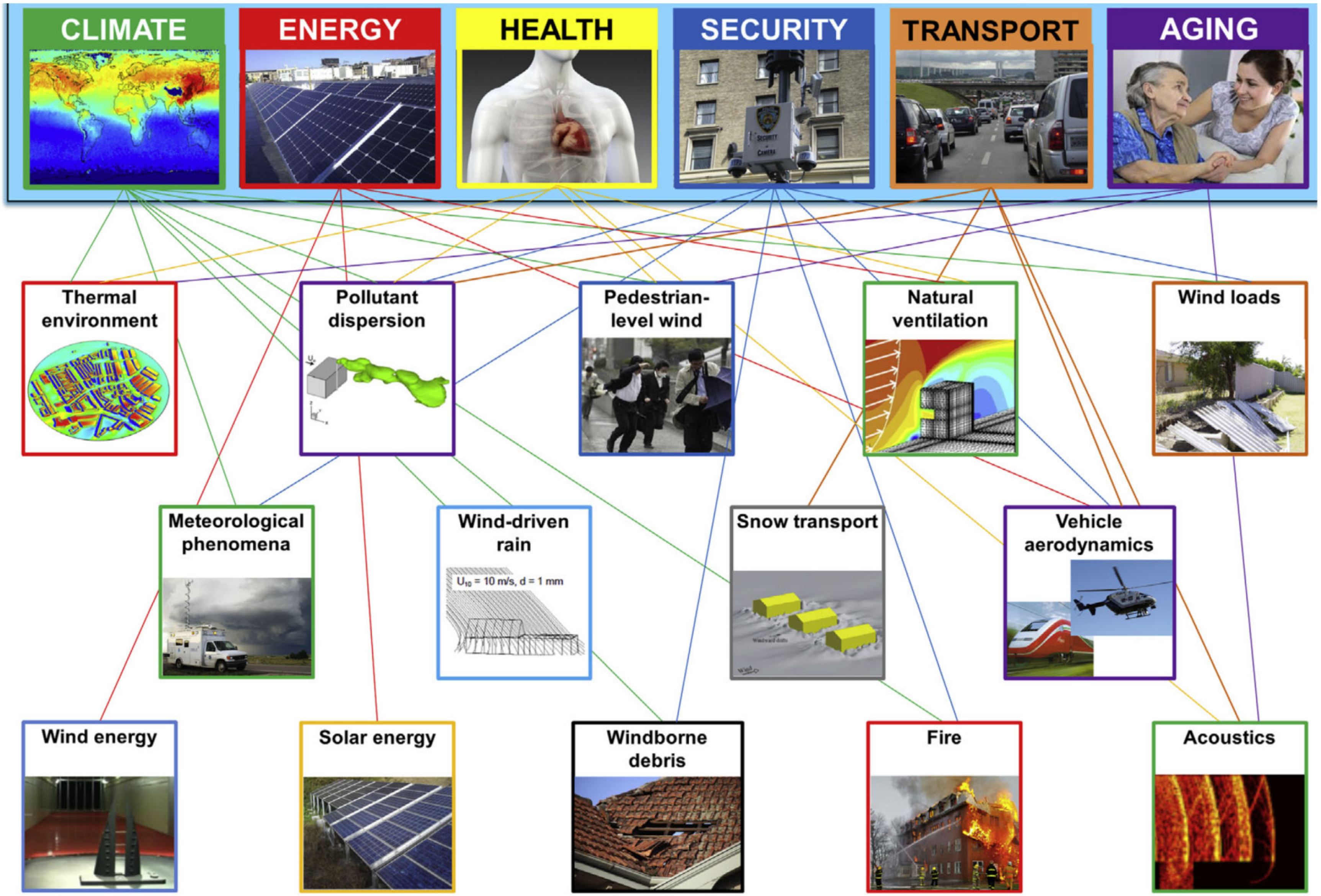
***Architectural Institute of Japan** (Tominaga et al. 2008)*



***University of Auckland, New Zealand** (Storey et al. 2012)*



***Eindhoven University of Technology, The Netherlands** (Blocken et al. 2012)*



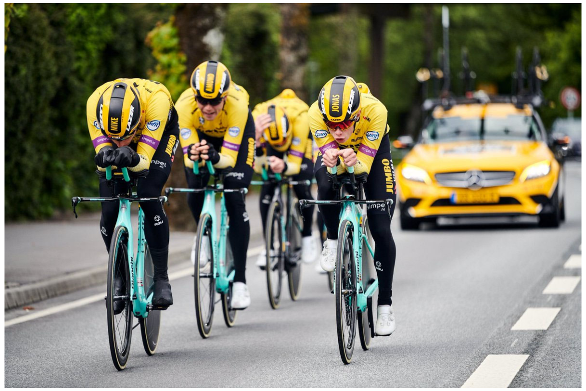
CLIMATE
ENERGY
HEALTH
SECURITY
TRANSPORT
AGING
Thermal environment
Pollutant dispersion
Pedestrian-level wind
Natural ventilation
Wind loads
Meteorological phenomena
Wind-driven rain
U_{10} = 10 m/s, d = 1 mm
Snow transport
Vehicle aerodynamics
Wind energy
Solar energy
Windborne debris
Fire
Acoustics

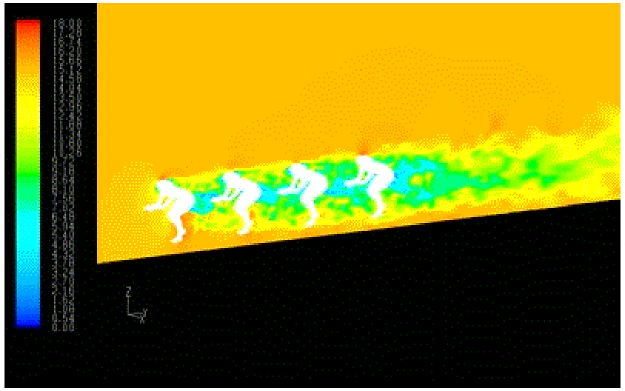
WIND ENGINEERING

Definition: Wind Engineering is best defined as (Cermak 1975):

"The rational treatment of interactions between wind in the atmospheric boundary layer and man and his works on the surface of Earth." (Cermak,1975).

Methods: field measurements, wind tunnel testing, CFD (= computational fluid dynamics)

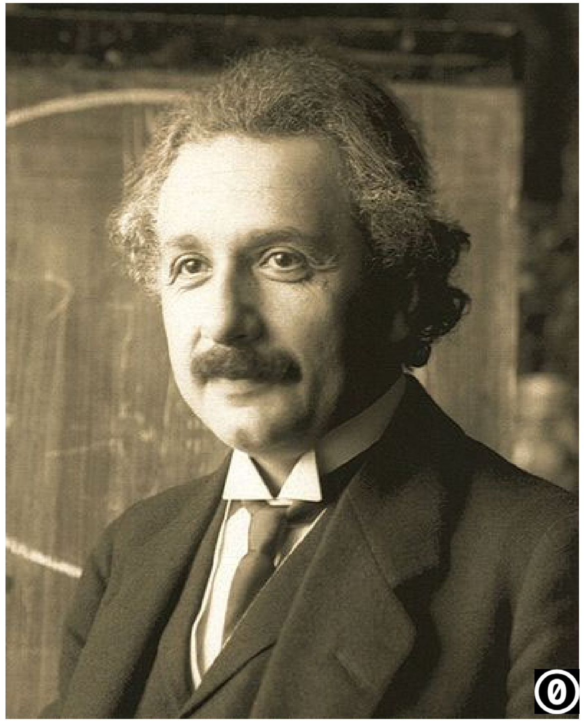




QUOTES

QUOTE 1

"One thing I have learned in a long life: that all our science, measured against reality, is primitive and childlike - and yet it is the most precious thing we have." (Albert Einstein 1879 – 1955)

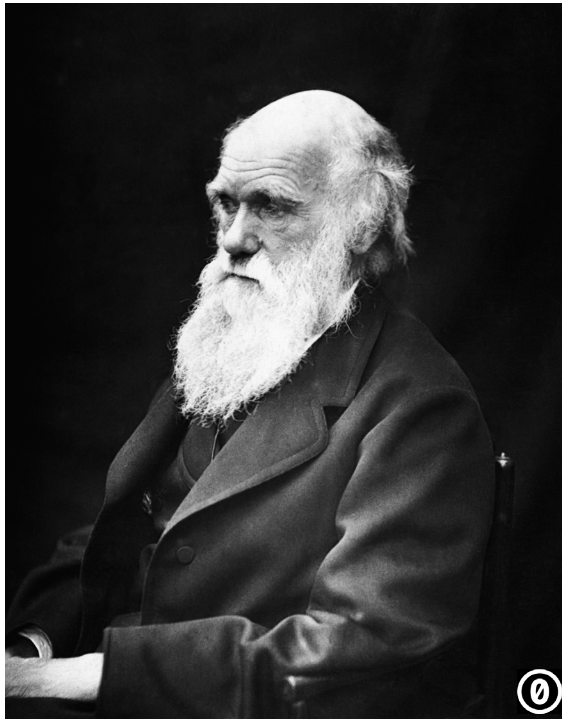


QUOTE 2

“Scientists study the world as it is, engineers create the world that never has been.” (Theodore von Kármán 1881-1963)

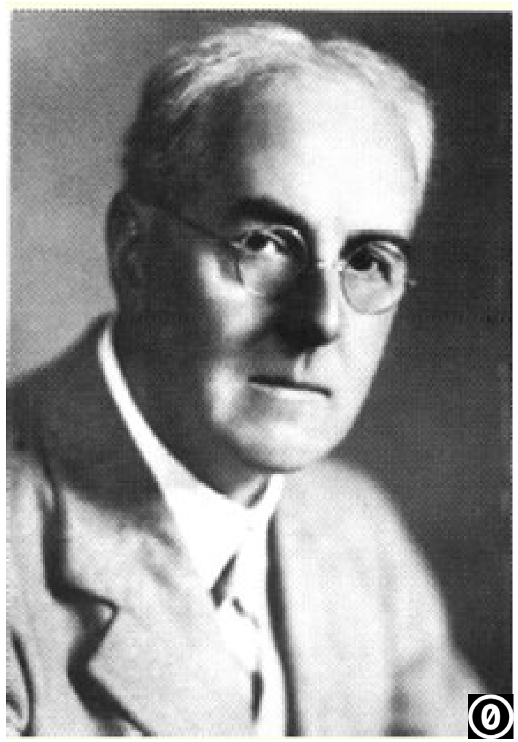
QUOTE 3

"A man who dares to waste one hour of time has not discovered the value of life."
(Charles Darwin 1809-1882)



QUOTE 4

"The root of the matter is that the greatest stimulus of scientific discovery are its practical applications." (Lewis Fry Richardson 1908)



BRIEF INTRO

PERSONAL BACKGROUND

Born: 1974, Hasselt, Belgium

MSc: 1998, Civil Engineering, KU Leuven

PhD: 2004, Civil Engineering / Building Physics, KU Leuven

Postdoc: FWO-Flanders, Concordia University, Montreal

Expertise: Urban Physics, Wind Engineering, Sports Aerodynamics

Main affiliation:
Unit Building Physics & Services
Department of the Built Environment
Eindhoven University of Technology

Secondary affiliation:
Building Physics Section
Department of Civil Engineering
KU Leuven

Hobbies:
Sports (and others)

RESEARCH ACTIVITIES

BUILDING, CITY & SPORTS AERODYNAMICS

Wind Energy

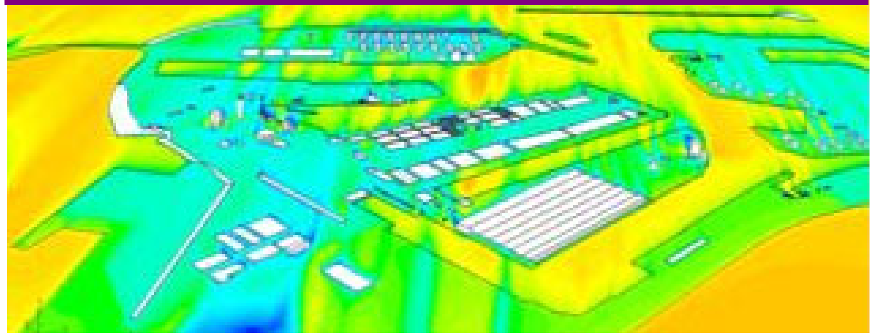
Safety

Smart Systems for Heli Landing

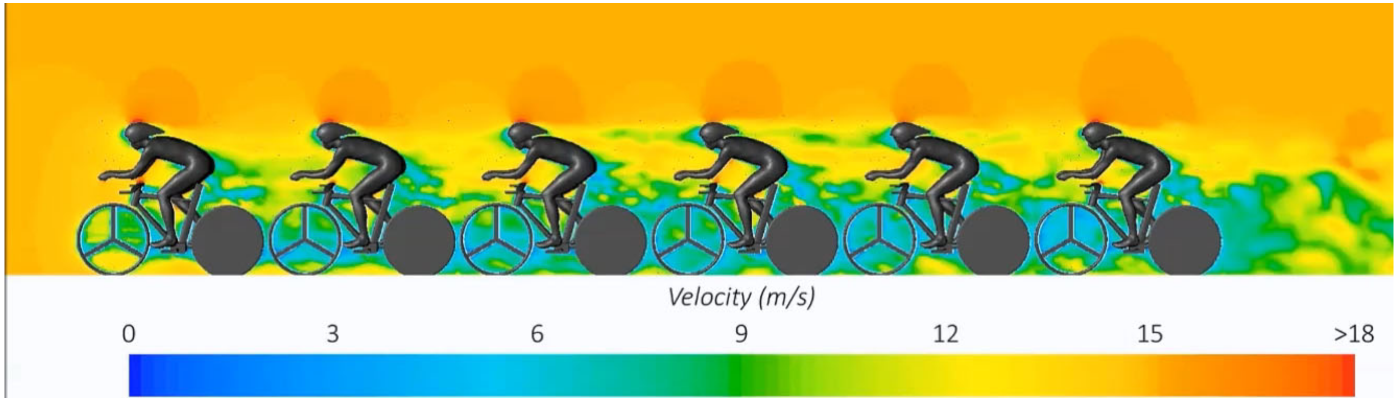
Wind Energy

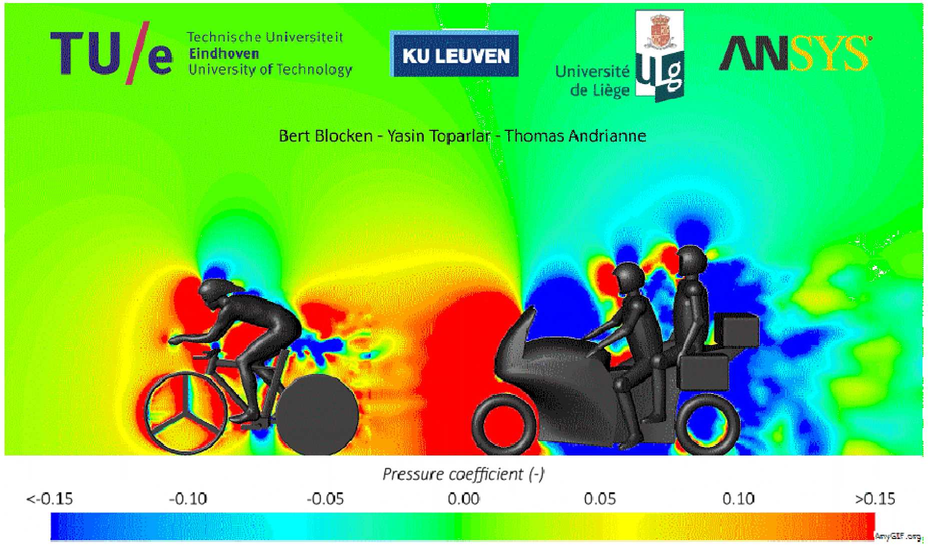
Indoor Air Quality

Wind Conditions in Harbors

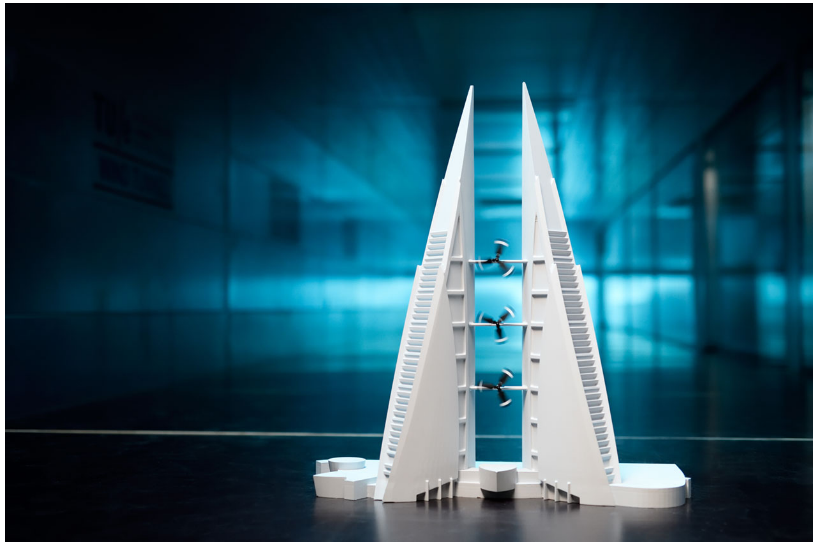


BUILDING, CITY & SPORTS AERODYNAMICS





BUILDING, CITY & SPORTS AERODYNAMICS



BUILDING, CITY & SPORTS AERODYNAMICS

2005: Collaboration with prof. **Peter Hespel**, KU Leuven, for **Flemish Cycling Union**.

2011: Personal (hobby) work in cycling aerodynamics, evenings & weekends

2013: **MOOC** “Sports & Building Aerodynamics”

MOOC = **M**assive **O**pen **O**nline **C**ourse

Em. Prof.dr.ir. Hans van Duijn
Former Rector Magnificus of TU/e

BUILDING, CITY & SPORTS AERODYNAMICS

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2011: Personal (hobby) work in cycling aerodynamics, evenings & weekends

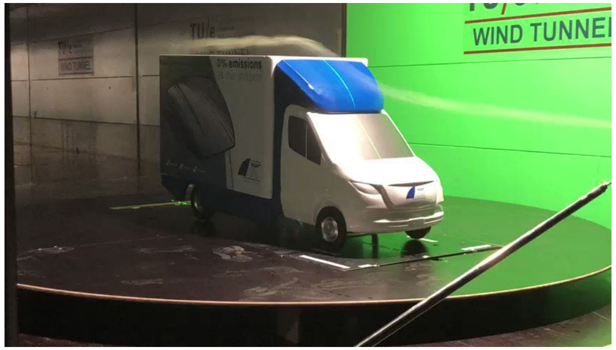
2013: **MOOC** "Sports & Building Aerodynamics"

2015: Official course "Sports & Building Aerodynamics" at TU Eindhoven

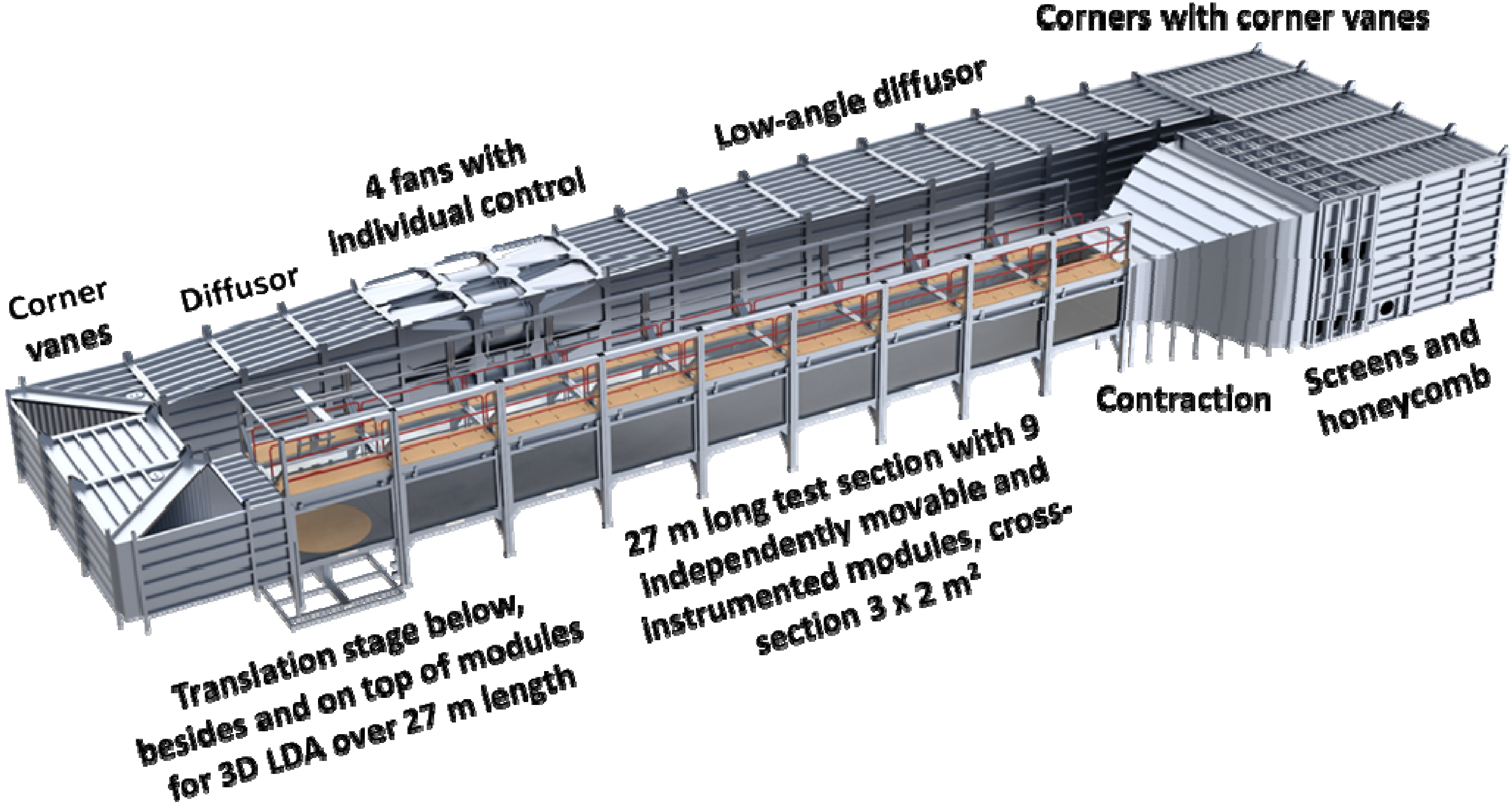
2016: Official ATHENS course "Sports, Building & City Aerodynamics" at KUL
Start collaboration with Paralympics Ireland

2017: Inauguration TU Eindhoven **wind tunnel facility**
Start collaboration with LottoNL-Jumbo, later **Jumbo-Visma**
Start collaboration with H5 handcyclist Tim de Vries

BUILDING, CITY & SPORTS AERODYNAMICS



BUILDING, CITY & SPORTS AERODYNAMICS



BUILDING, CITY & SPORTS AERODYNAMICS

You Tube movie: Wind Tunnel

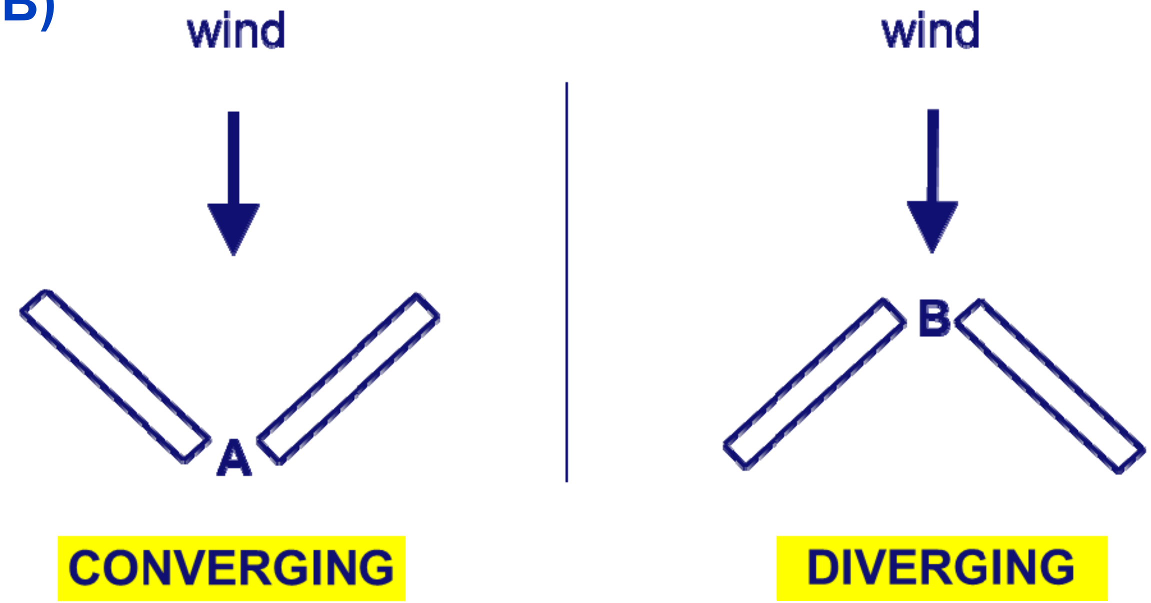
https://www.youtube.com/watch?v=VEDn_IUJQfs

9 QUESTIONS

QUESTION 1

Top view of two high-rise buildings, left in a converging and right in a diverging arrangement. The wind direction is as indicated. Which configuration yields the highest wind speed in the passage?

A) Converging arrangement (A)
B) Diverging arrangement (B)
C) Same in A and B



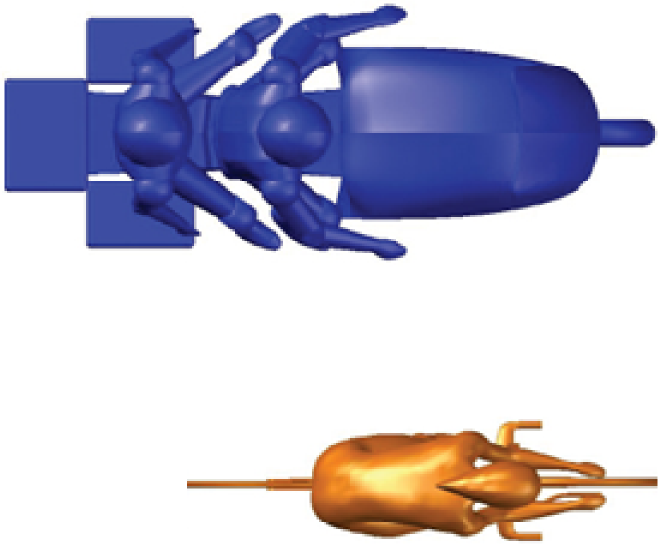
QUESTION 2

A cyclist is drafting close behind a motorcycle. How much does the cyclist's aerodynamic resistance (drag) decrease?

A. 10%
B. 25%
C. 50%
D. 75%

QUESTION 3

A motorcycle is riding next to a cyclist. Distance in between is 1.3 m. How does the cyclist's aerodynamic resistance change due to the presence of the motorcycle?



A. Increases with 15%
B. Increases with 5%
C. Remains the same
D. Decreases with 5%
E. Decreases with 15%

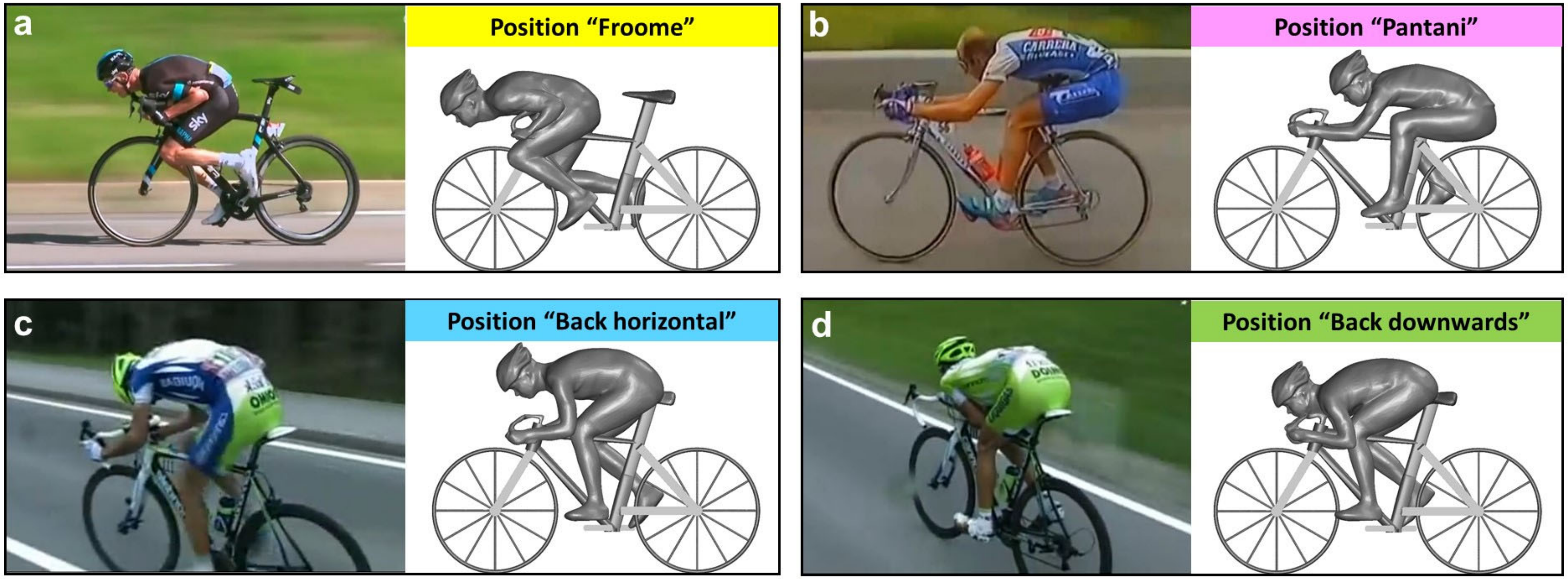
QUESTION 4

A cyclist is riding in front of a motorcycle. How does the cyclist aerodynamic resistance (drag) change due to the presence of the motorcycle?

A. Increases with 15%
B. Increases with 5%
C. Remains the same
D. Decreases with 5%
E. Decreases with 15%

QUESTION 5

Different professional cyclists use very different hill descent positions indicating there is no consensus on which is best. Which hill descent position is most aerodynamic?



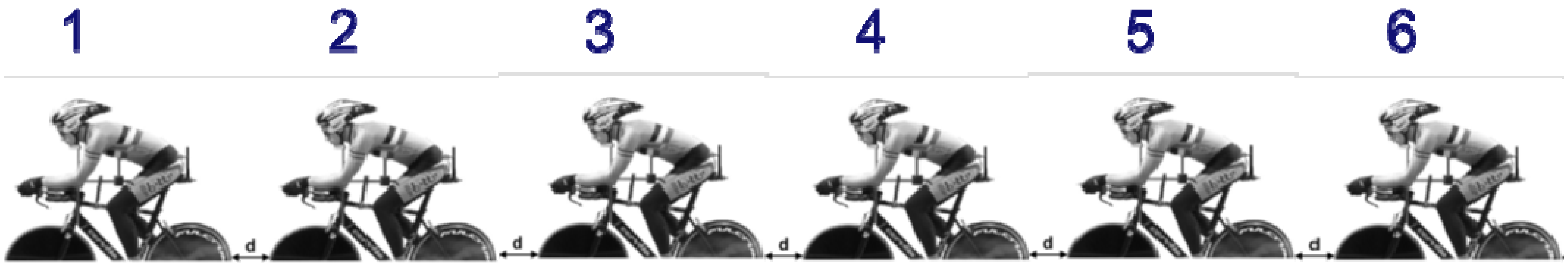
Sources: sporza.be

QUESTION 6

Team time trial: Which cyclist has the lowest air resistance?

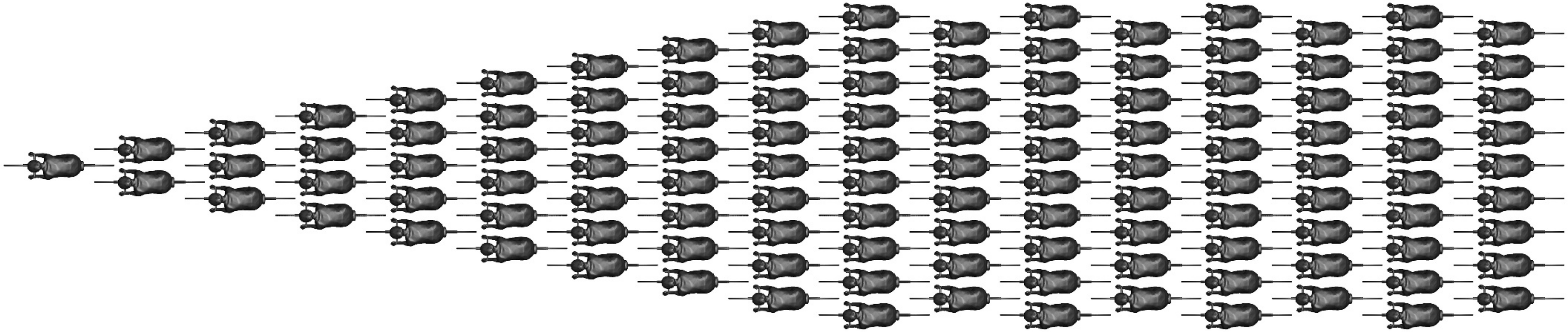
Six cyclists (same body geometry) are riding behind each other in a team time trial in zero-wind conditions. Which position has the lowest aerodynamic resistance?

A) Position 2
B) Position 3
C) Position 4
D) Position 5
E) Position 6



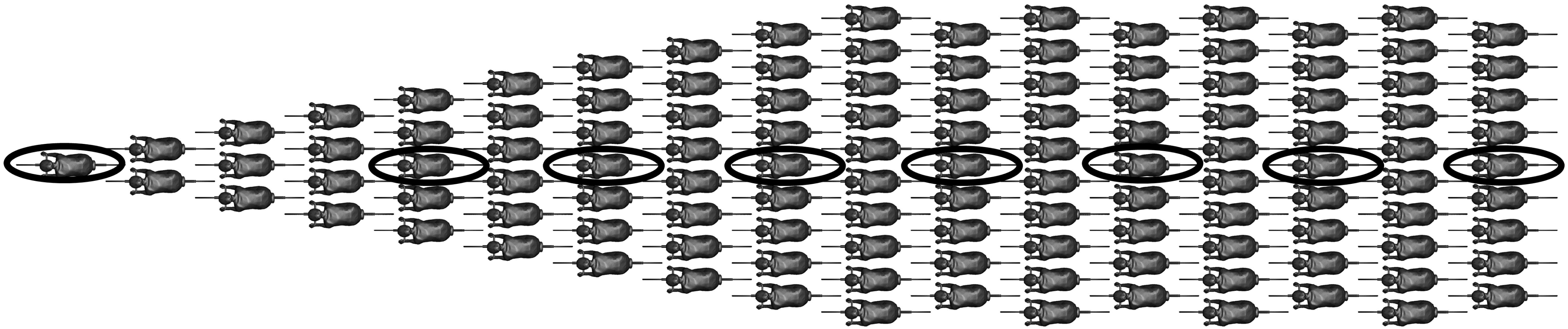
QUESTION 7

Peloton: Which cyclist has the lowest air resistance?



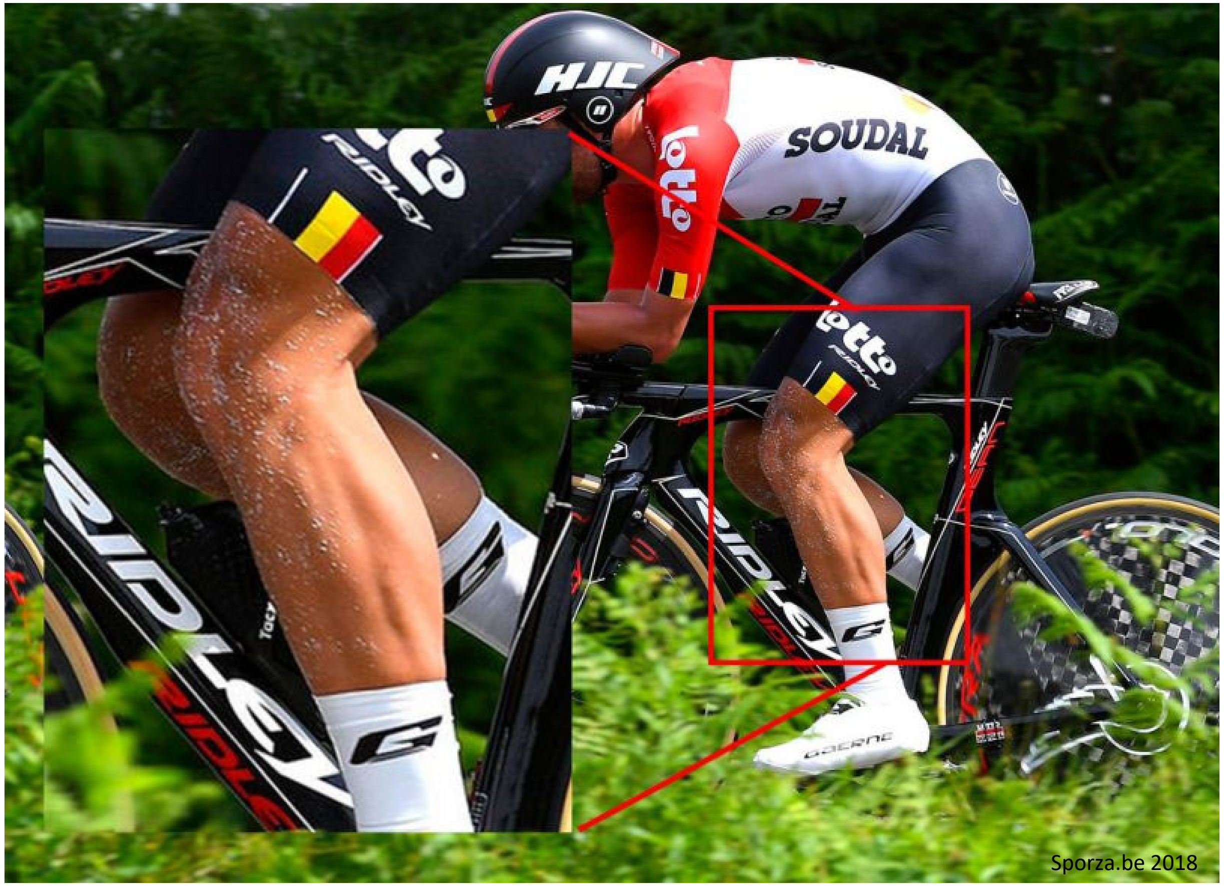
QUESTION 7

Peloton: Which cyclist has the lowest air resistance?



QUESTION 8

What is the effect of the so-called speed gel?



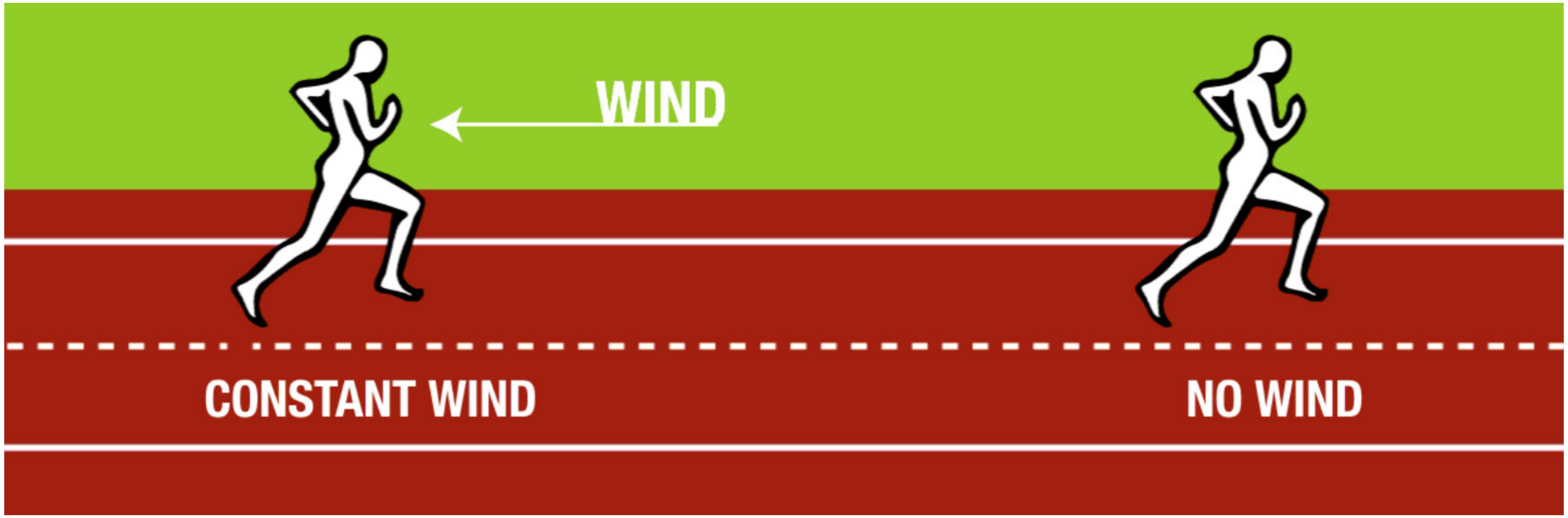
Cyclist will go:

A. Faster
B. Equally fast
C. Slower

QUESTION 9

What is fastest?

A) 400 m lap without wind
B) 400 m lap with 200 m head wind and 200 m tail wind of the same magnitude



EXAMPLE RESEARCH PROJECTS

BUILDING, CITY & SPORTS AERODYNAMICS

Types of (research) projects in building aerodynamics:

1. **Not for specific companies/cities/design offices**

2. For specific companies/cities/design offices

BUILDING, CITY & SPORTS AERODYNAMICS

Types of (research) projects in sports aerodynamics:

1. **Not for specific teams/individuals/organizations**

2. For specific teams/individuals

BUILDING AERODYNAMICS

Building aerodynamics

Top view of two high-rise buildings, left in a converging and right in a diverging arrangement. The wind direction is as indicated. Which configuration yields the highest wind speed in the passage?

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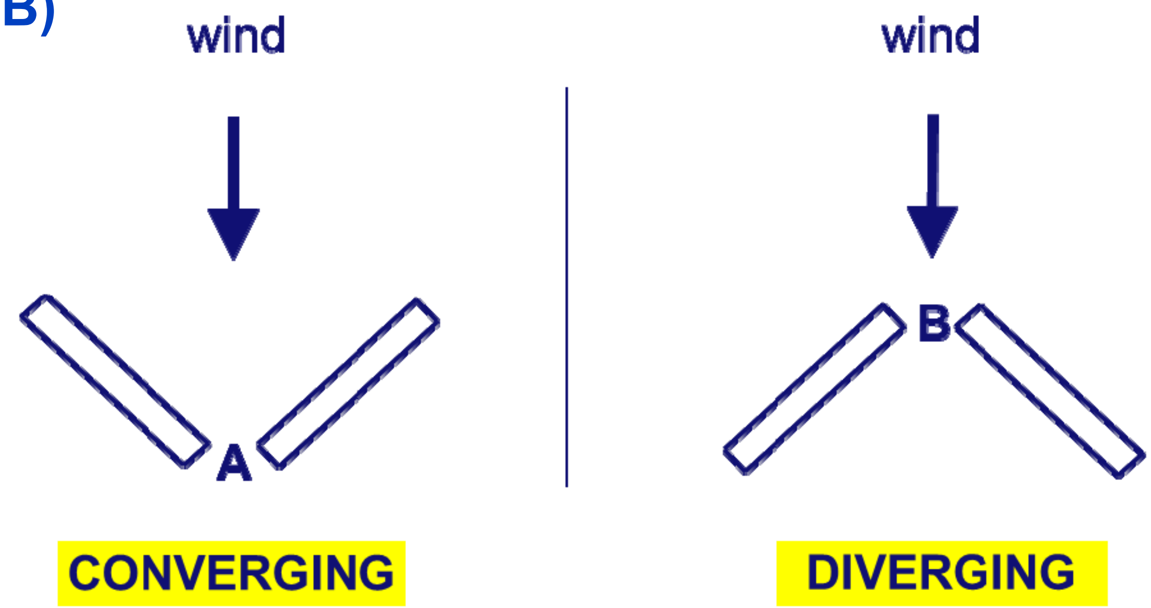
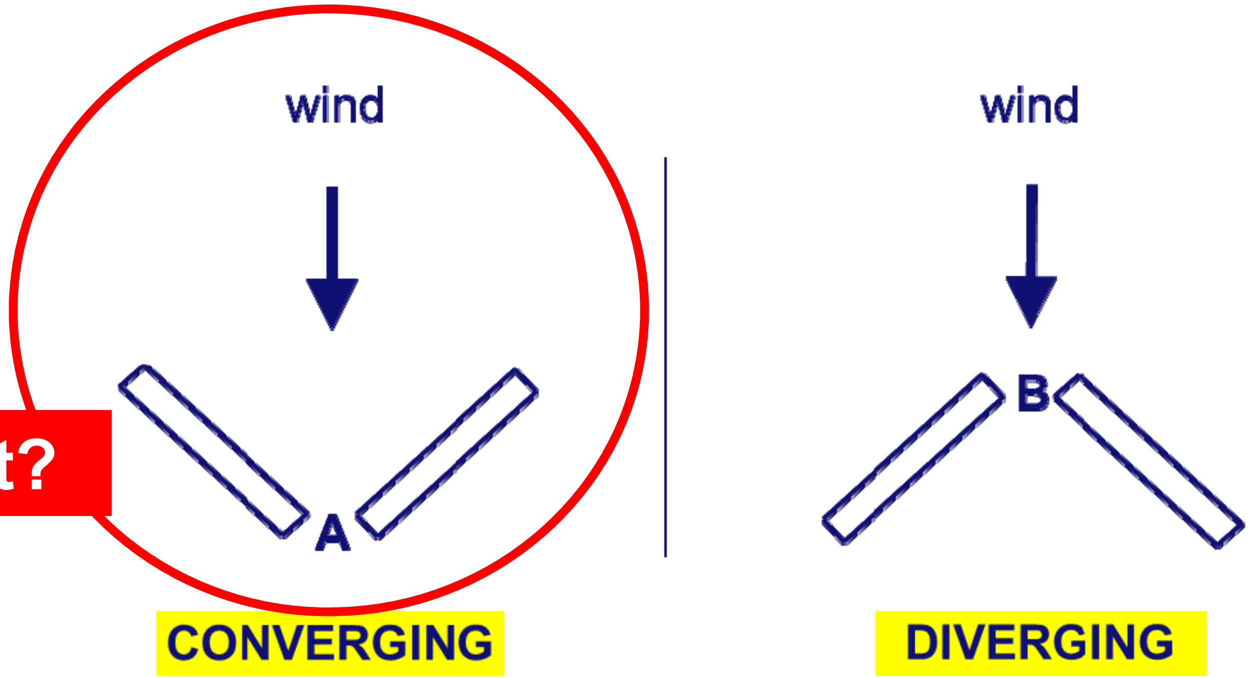


Building aerodynamics

The Venturi effect between buildings: **fact or fiction?**

Venturi effect?

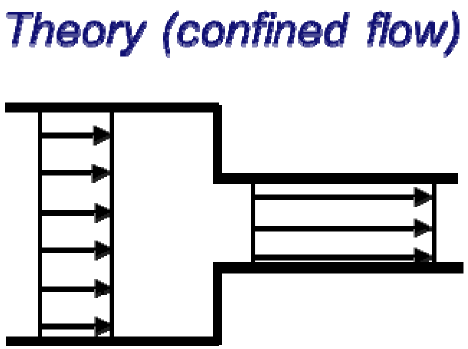


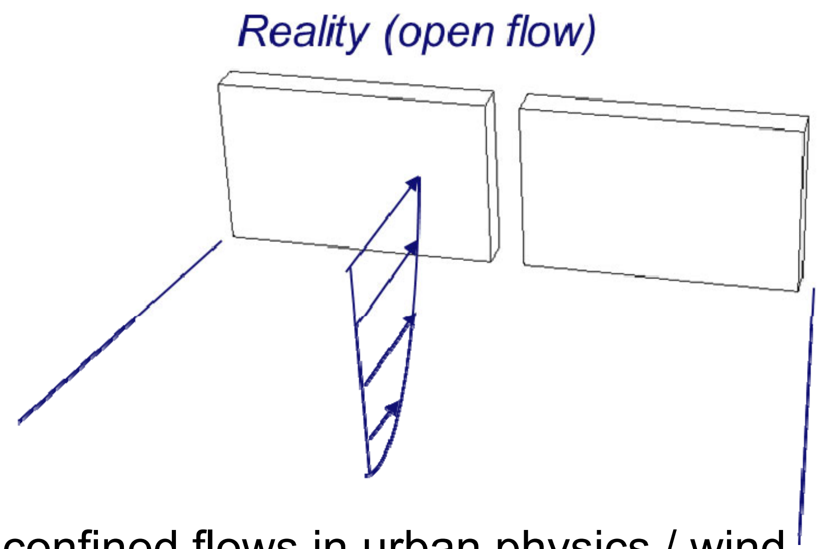
Building aerodynamics

The Venturi effect between buildings: **fact or fiction?**

Venturi effect: ***increase of fluid speed due to a decrease of the flow section*** (*Giovanni Battista Venturi 1799*)

Confined versus **open flow**



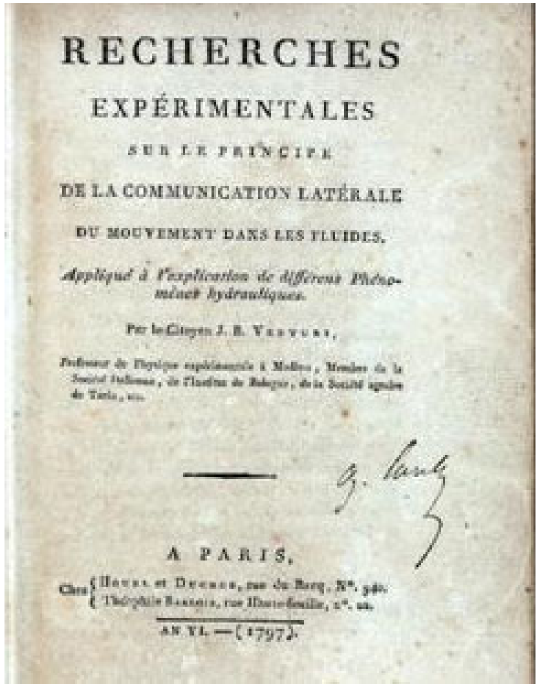


→ Is the Venturi effect present in the non-confined flows in urban physics / wind engineering?

Building aerodynamics

The Venturi effect between buildings: **fact or fiction?**

Venturi effect: ***increase of fluid speed due to a decrease of the flow section***
(*Giovanni Battista Venturi 1799*)

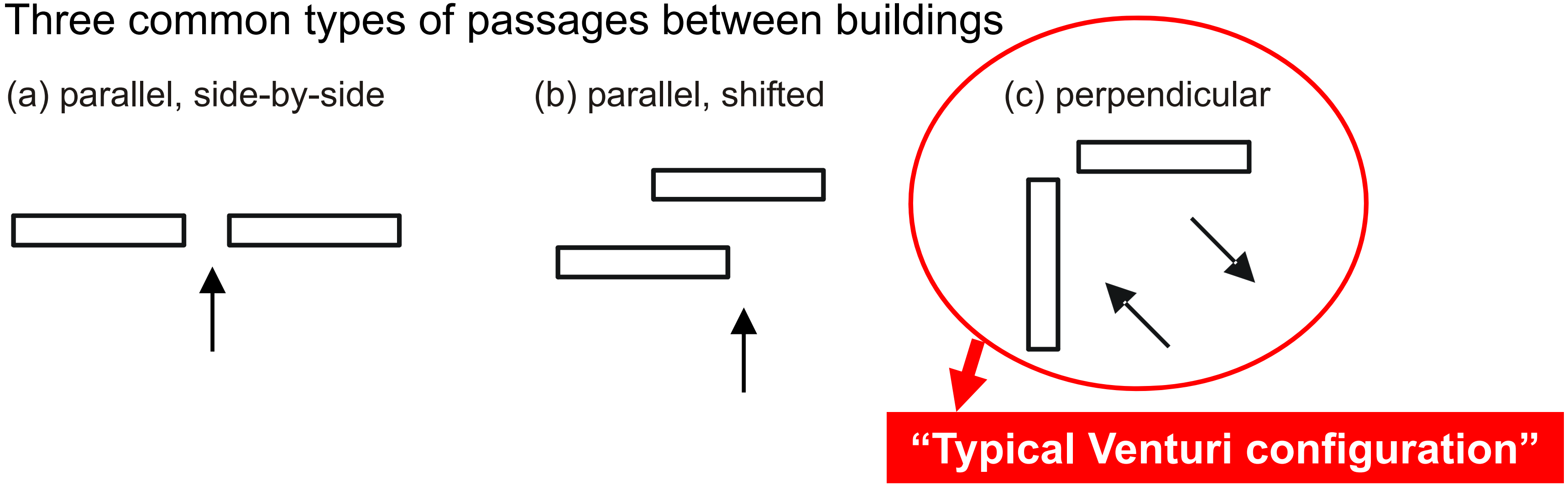

RECHERCHES
EXPÉRIMENTALES
SUR LE PRINCIPE
DE LA COMMUNICATION LATÉRALE
DU MOUVEMENT DANS LES FLUIDES,
Appliqué à l'explication de différens Phénomènes hydrauliques.
Par le Citoyen J. B. VENTURI,
A PARIS,
AN VI. — (1797).

Special thanks to Sandra Johnson and her colleagues from the **Niels Bohr Library** of the American Institute of Physics for copying this precious (and fragile) book for me.

Giovanni Battista Venturi
(1746 - 1822)

Building aerodynamics

Three common types of passages between buildings



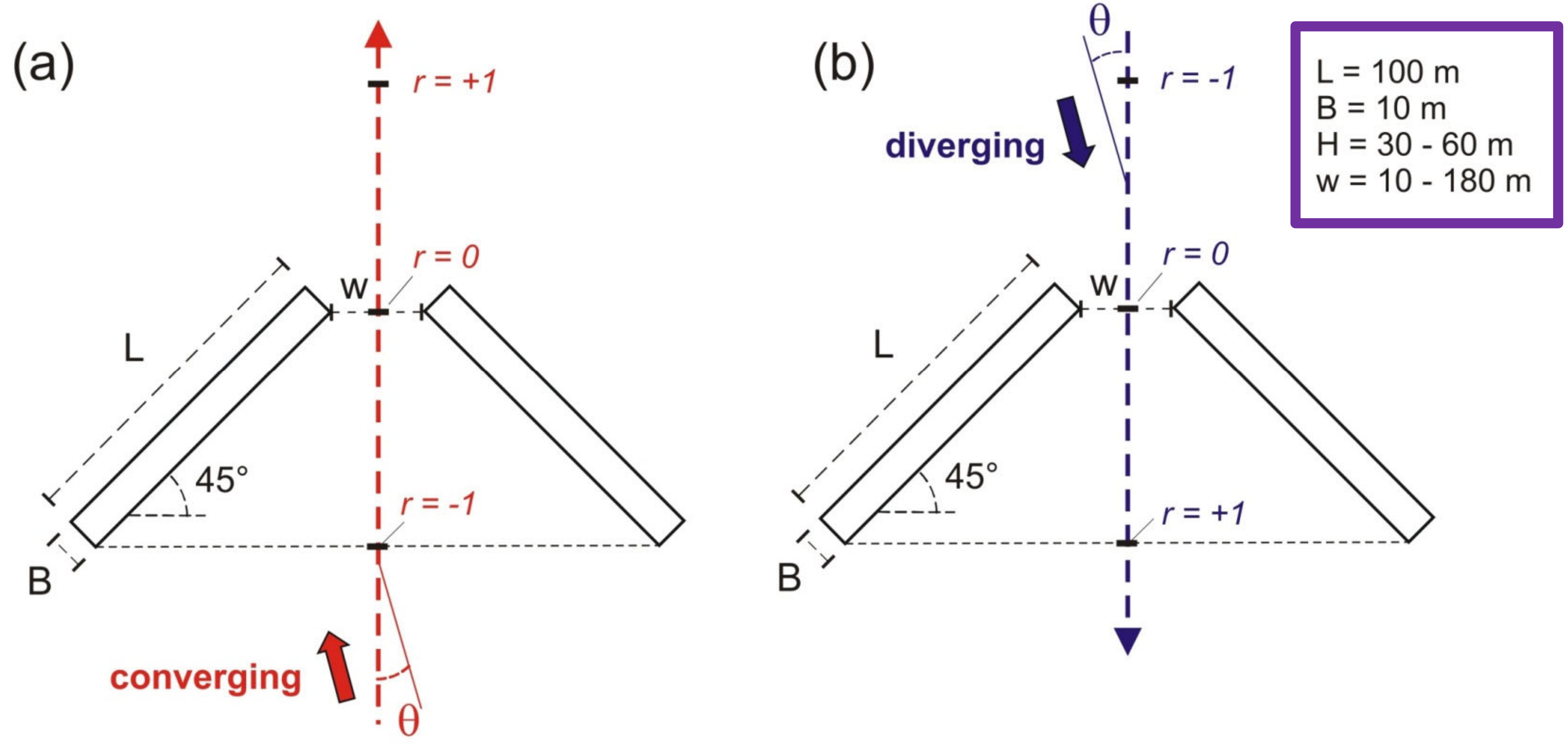
Conditions for the occurrence of the Venturi effect (Gandemer 1975):

1) $H > 15$ m
2) $L_1 + L_2 > 100$ m
3) Exposed site

“Maximum flow through the passage when passage width is 2 or 3 times the height”

Building aerodynamics

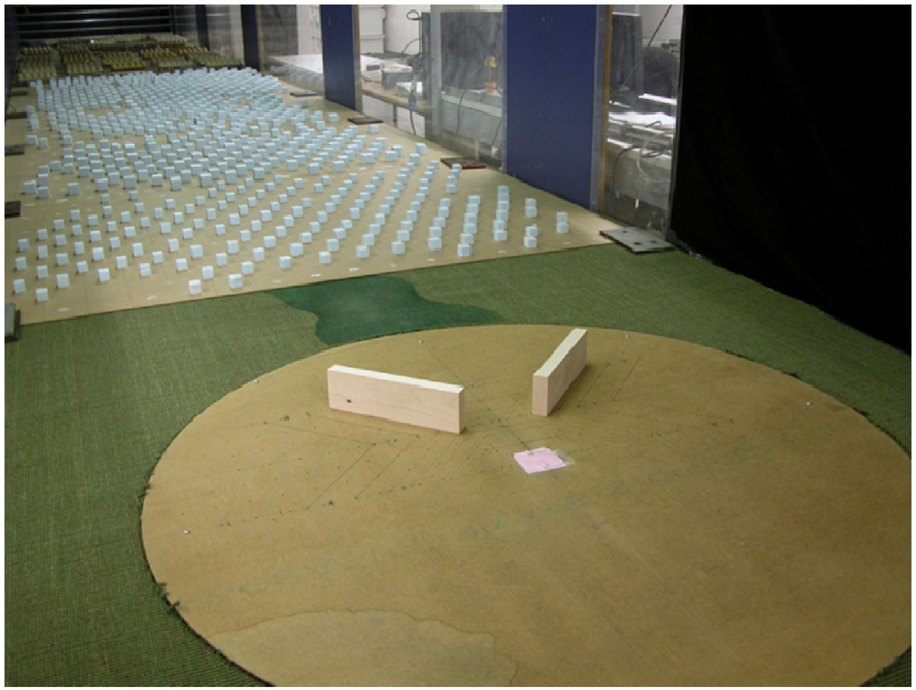
Wind-tunnel measurements for **converging** and **diverging** arrangements:



Building aerodynamics

Wind-tunnel measurements for **converging** and **diverging** arrangements

Atmospheric boundary layer wind tunnel at the Building Aerodynamics Laboratory, Concordia University, Montreal (Dr. Ted Stathopoulos)



Building aerodynamics

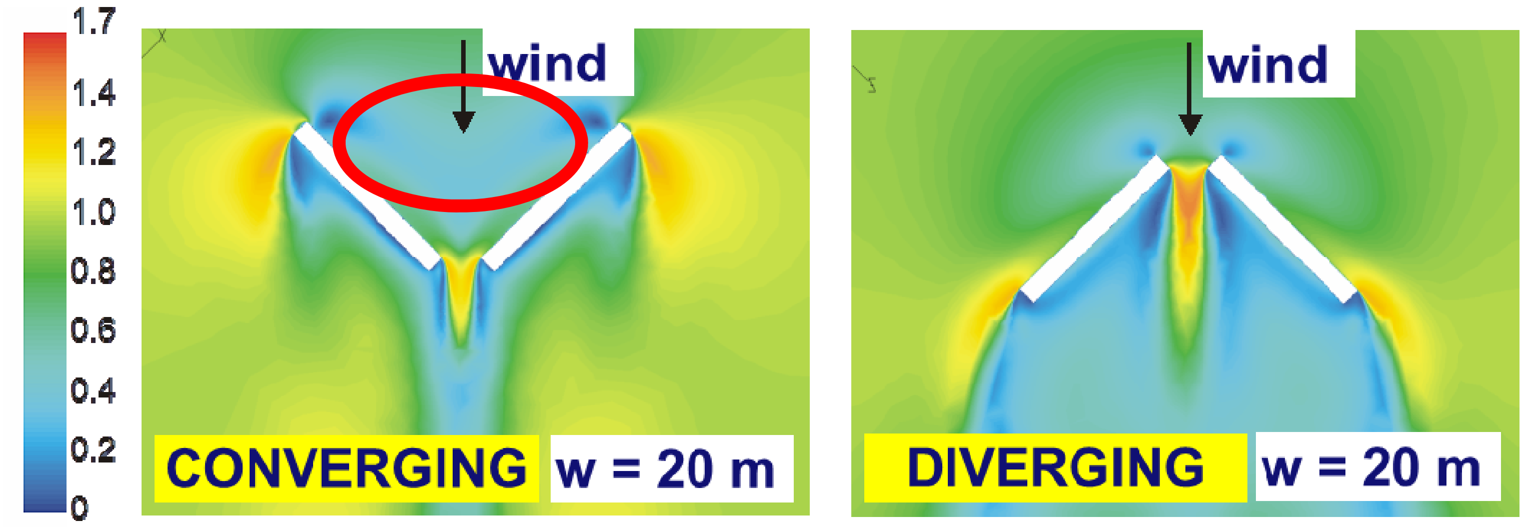
CFD simulations for **converging** and **diverging** arrangements

- ANSYS Fluent CFD code
- Steady RANS with realizable k-ε model (*Shih et al. 1995*)
- Standard wall functions with sand-grain-based roughness modification
- Equivalent sand-grain roughness k_S and roughness constant C_S based on aerodynamic roughness length y_0 and equation $\mathbf{k_S = 9.793y_0/C_S}$.
- SIMPLE for pressure velocity-coupling
- Second order discretization schemes
- Pressure interpolation: second order

For other computational details, see: *Blocken B, Moonen P, Stathopoulos T, Carmeliet J. 2008. A numerical study on the existence of the Venturi-effect in passages between perpendicular buildings.* ***Journal of Engineering Mechanics – ASCE*** *134(12): 1021-1028.*

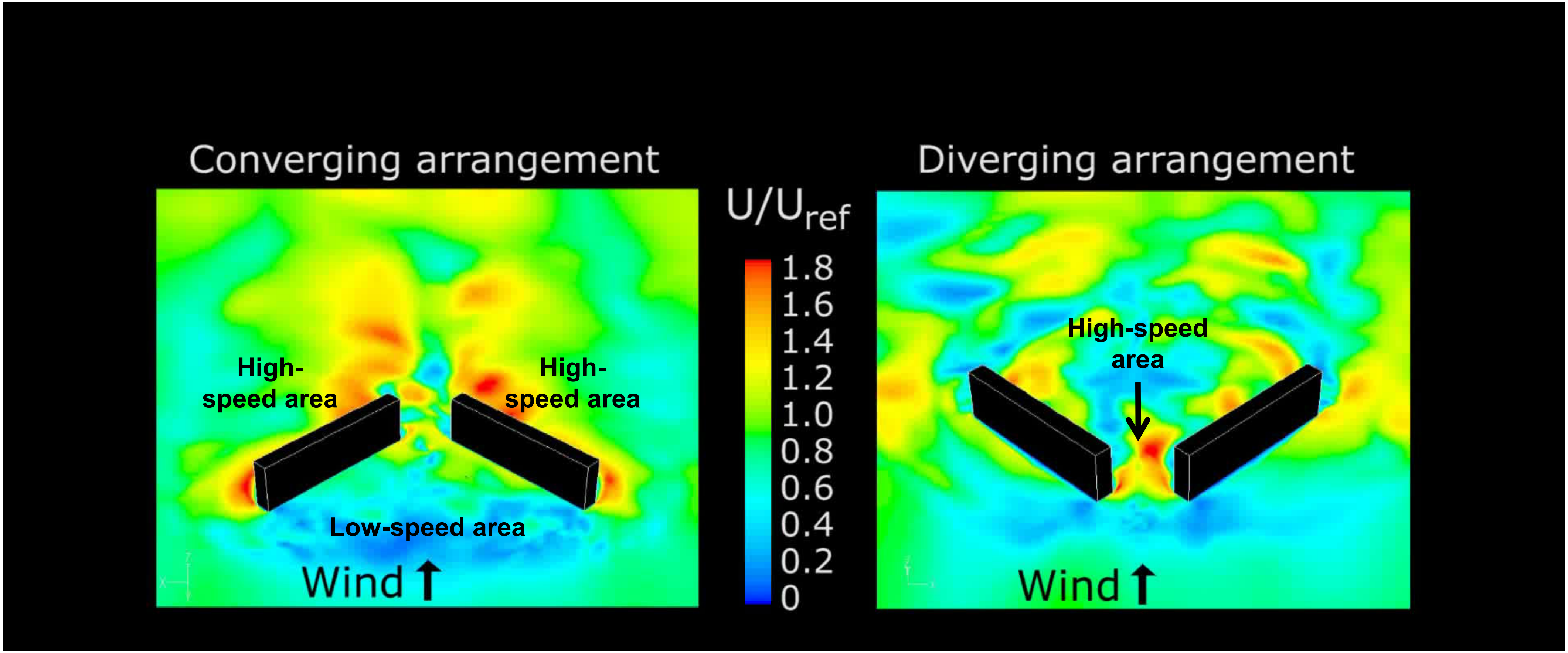
Building aerodynamics

CFD simulations for **converging** and **diverging** arrangements



→ **Counter-intuitive result: wind-blocking effect: upstream wind-speed slow-down**

"**Subsonic upstream disturbance** in the wind-flow pattern"


Converging arrangement
Diverging arrangement
U/U_ref
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
High-
speed area
High-
speed area
Low-speed area
Wind
High-speed
area
Wind

Building aerodynamics

This work was published, received very positive reviews and quite a good number of citations.

Blocken B, Stathopoulos T, Carmeliet J. 2008. A numerical study on the existence of the Venturi-effect in passages between perpendicular buildings. ***Journal of Engineering Mechanics - ASCE*** *134(12): 1021-1028.*

Blocken B, Stathopoulos T, Carmeliet J. 2008. Wind environmental conditions in passages between two long narrow perpendicular buildings. ***Journal of Aerospace Engineering - ASCE*** *21(4): 280-287.*

Blocken B, Carmeliet J, Stathopoulos T. 2007. CFD evaluation of the wind speed conditions in passages between buildings – effect of wall-function roughness modifications on the atmospheric boundary layer flow. ***Journal of Wind Engineering and Industrial Aerodynamics*** *95(9-11): 941-962.*

Who cares?

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US Dept of State Geographer
© 2011 Europa Technologies
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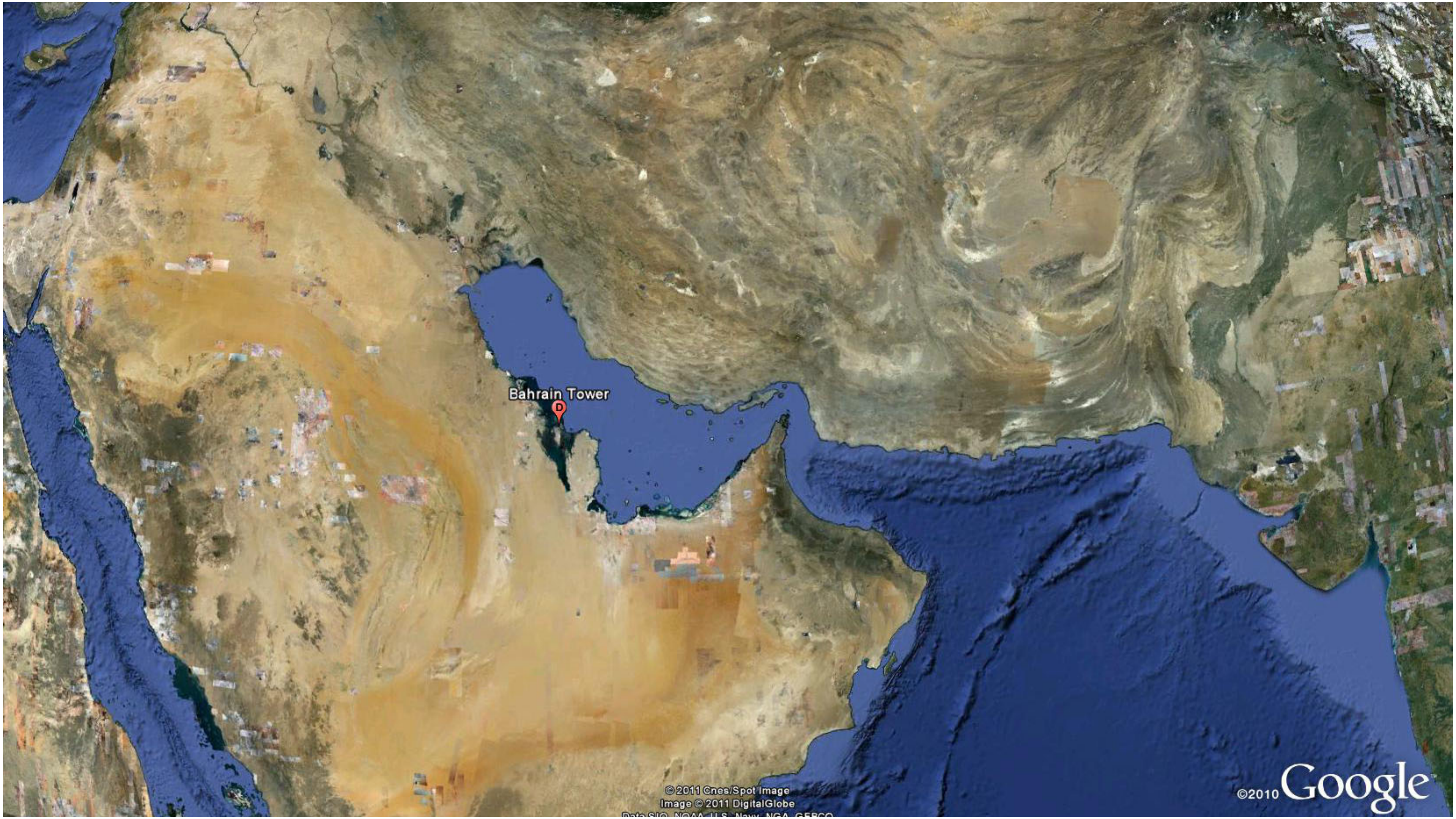
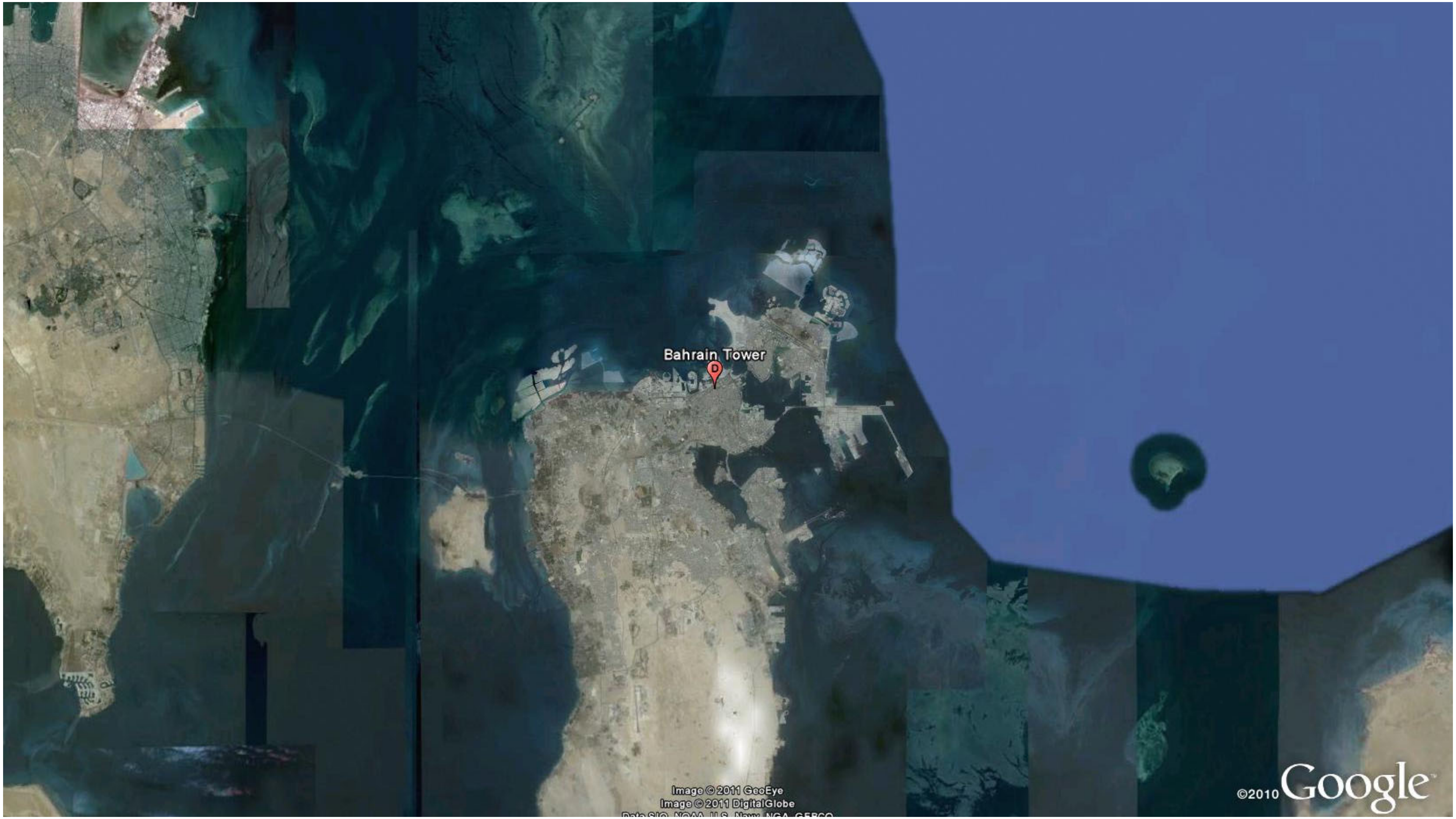
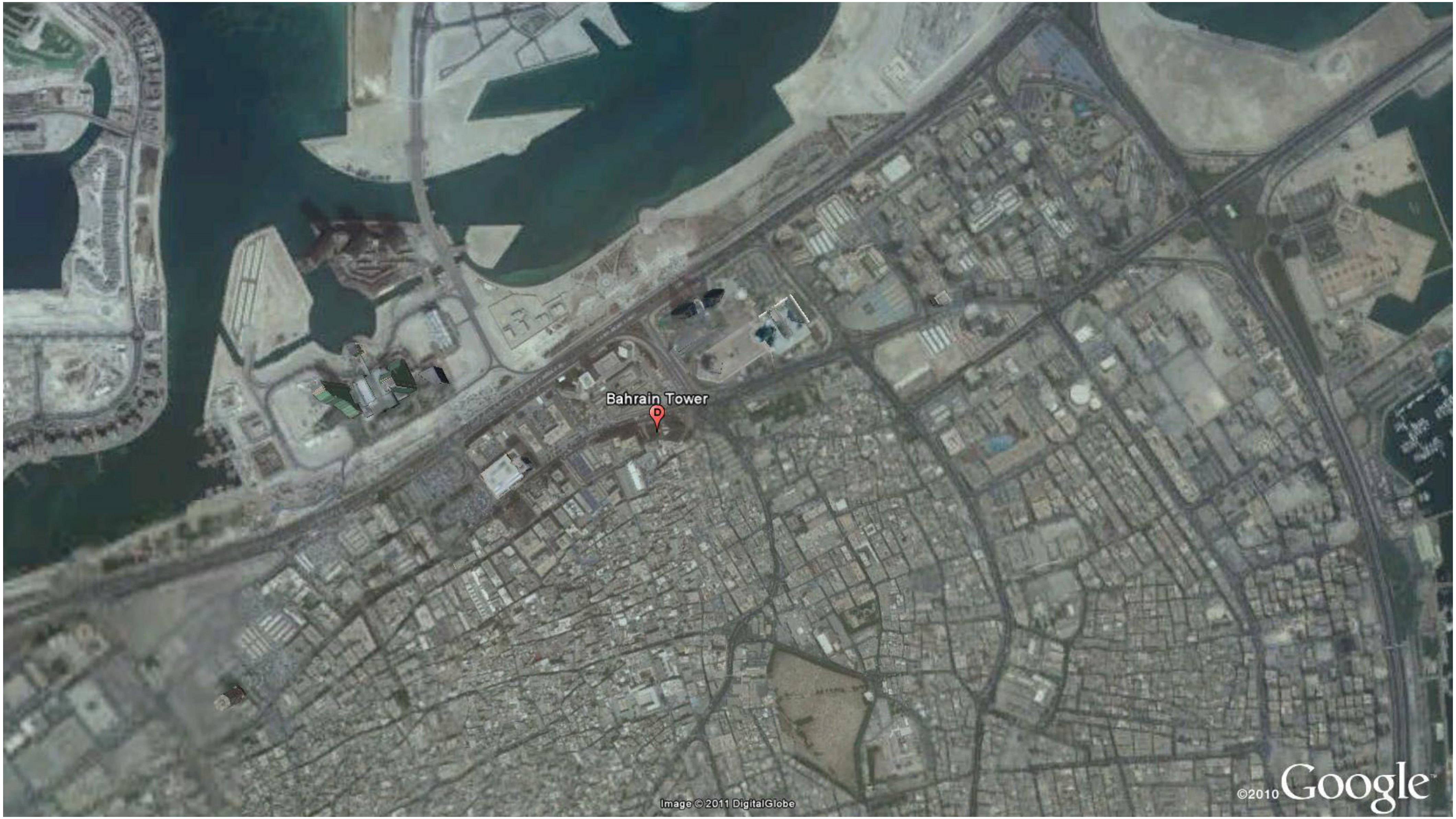

Bahrain Tower
© 2011 Cnes/Spot Image
Image © 2011 DigitalGlobe
©2010 Google


Bahrain Tower
Image © 2011 GeoEye
Image © 2011 DigitalGlobe
©2010 Google


Bahrain Tower
Image © 2011 DigitalGlobe
©2010 Google

Bahrain World Trade Center

- Opened in 2008
- USD $150 million
- 240 m height
- Three 29 m wind turbines (225 kW)
- Oriented to “capture the prevailing on-shore Gulf breeze”…

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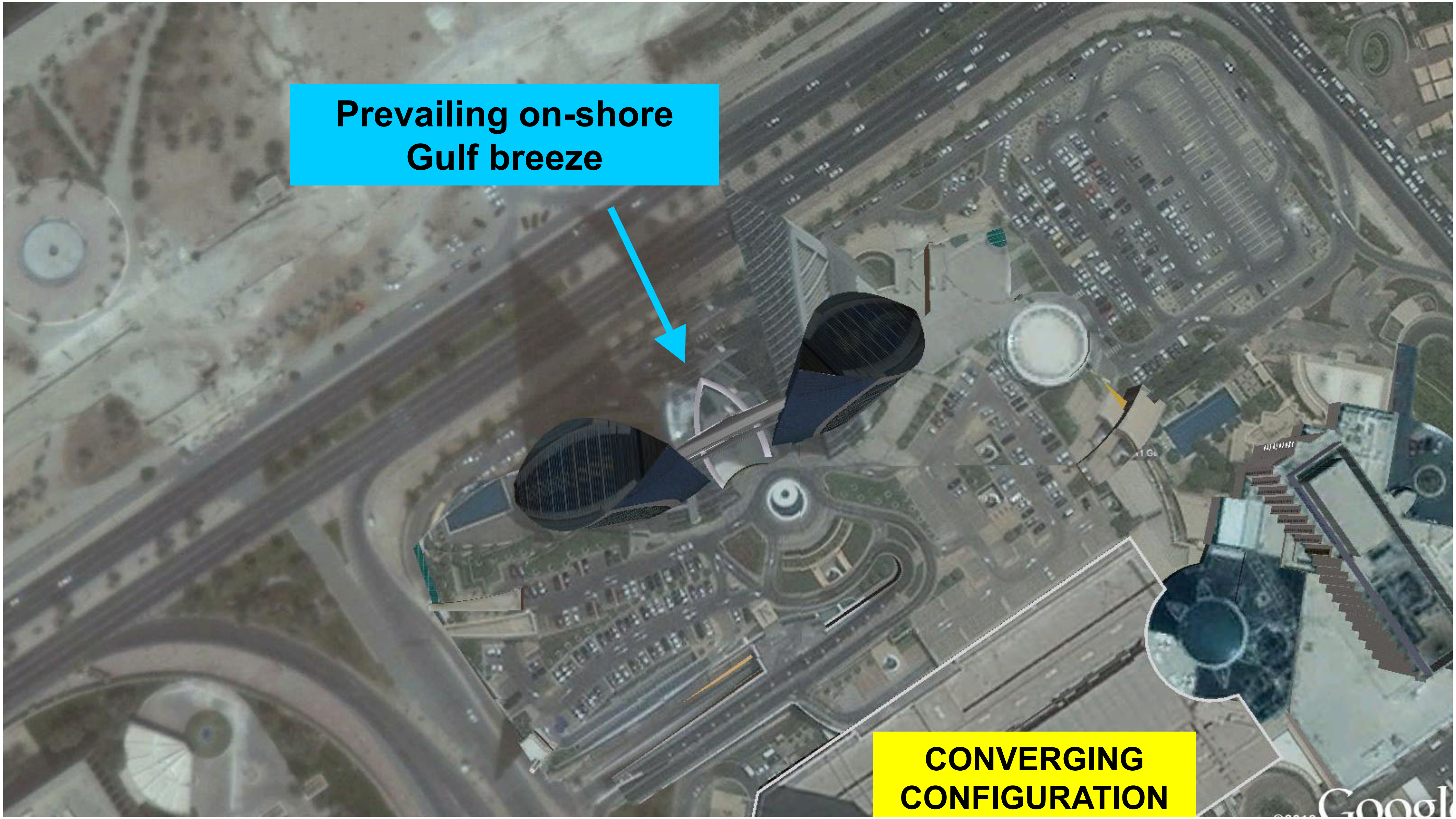
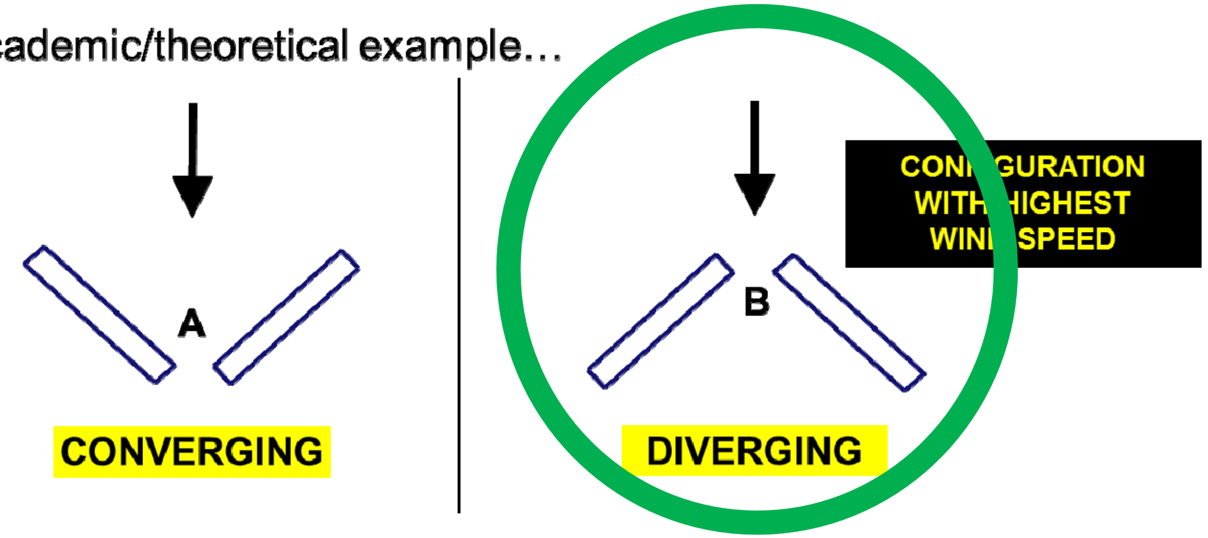
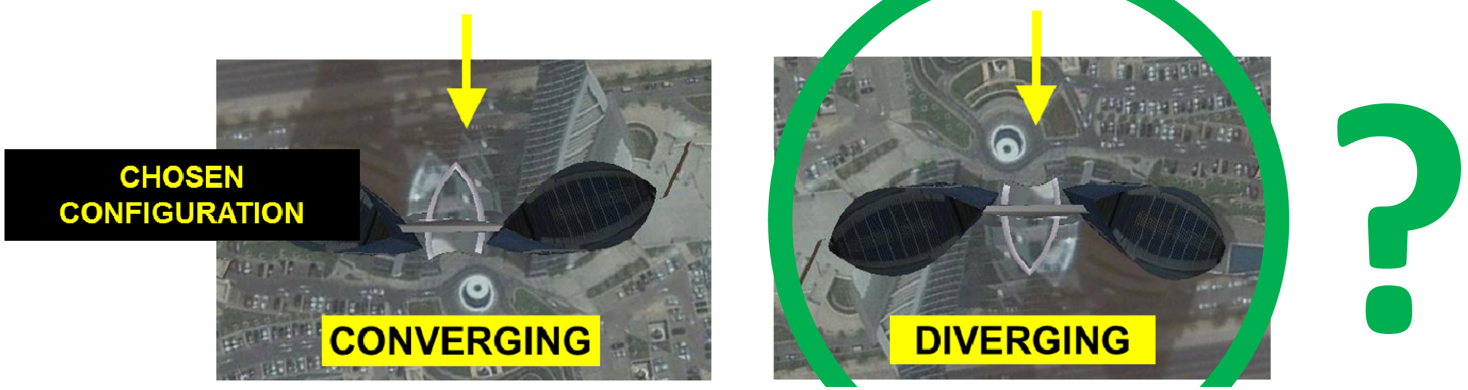

Prevailing on-shore Gulf breeze
CONVERGING CONFIGURATION
Google

Building aerodynamics

The earlier academic/theoretical example…



… shows a striking resemblance to the configuration of the Bahrain WTC.

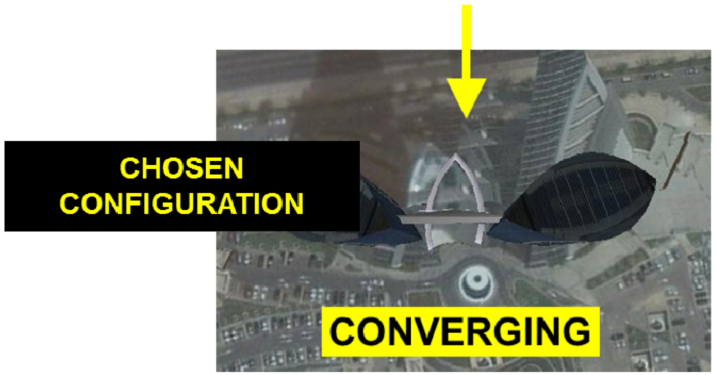


Building aerodynamics

Hypothesis

The Bahrain WTC design would have yielded **higher wind energy** output if the buildings were positioned in **diverging rather than converging** arrangement.

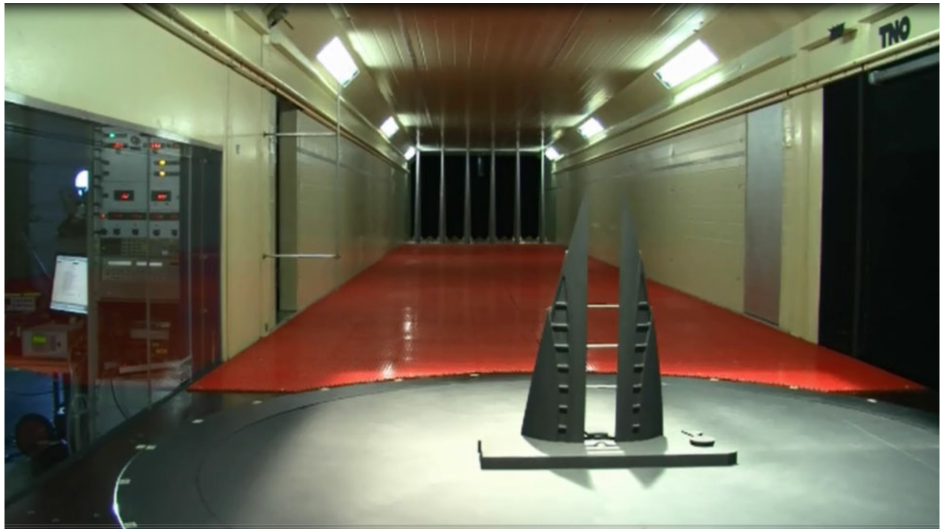
In other words: from wind energy point of view, the towers should have been **turned 180° around**.

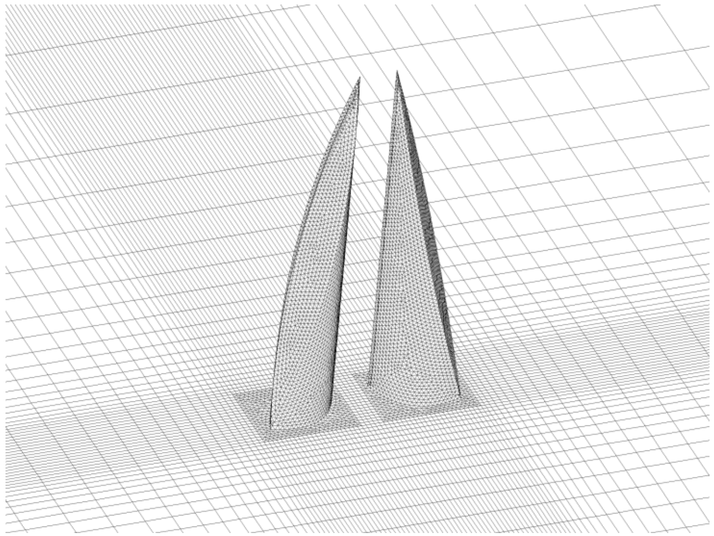


Building aerodynamics

Investigation

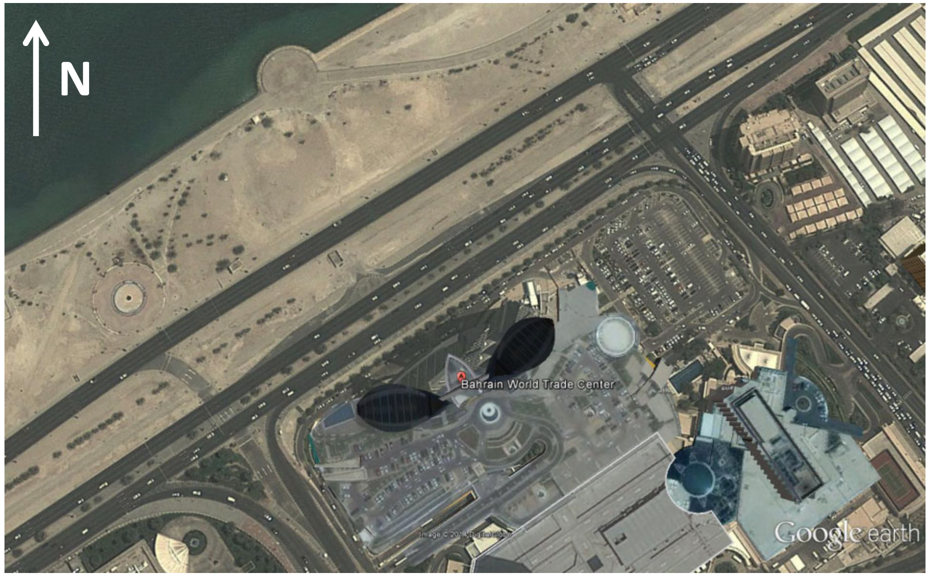
→ Detailed study by **wind-tunnel testing** and **Computational Fluid Dynamics** simulations.

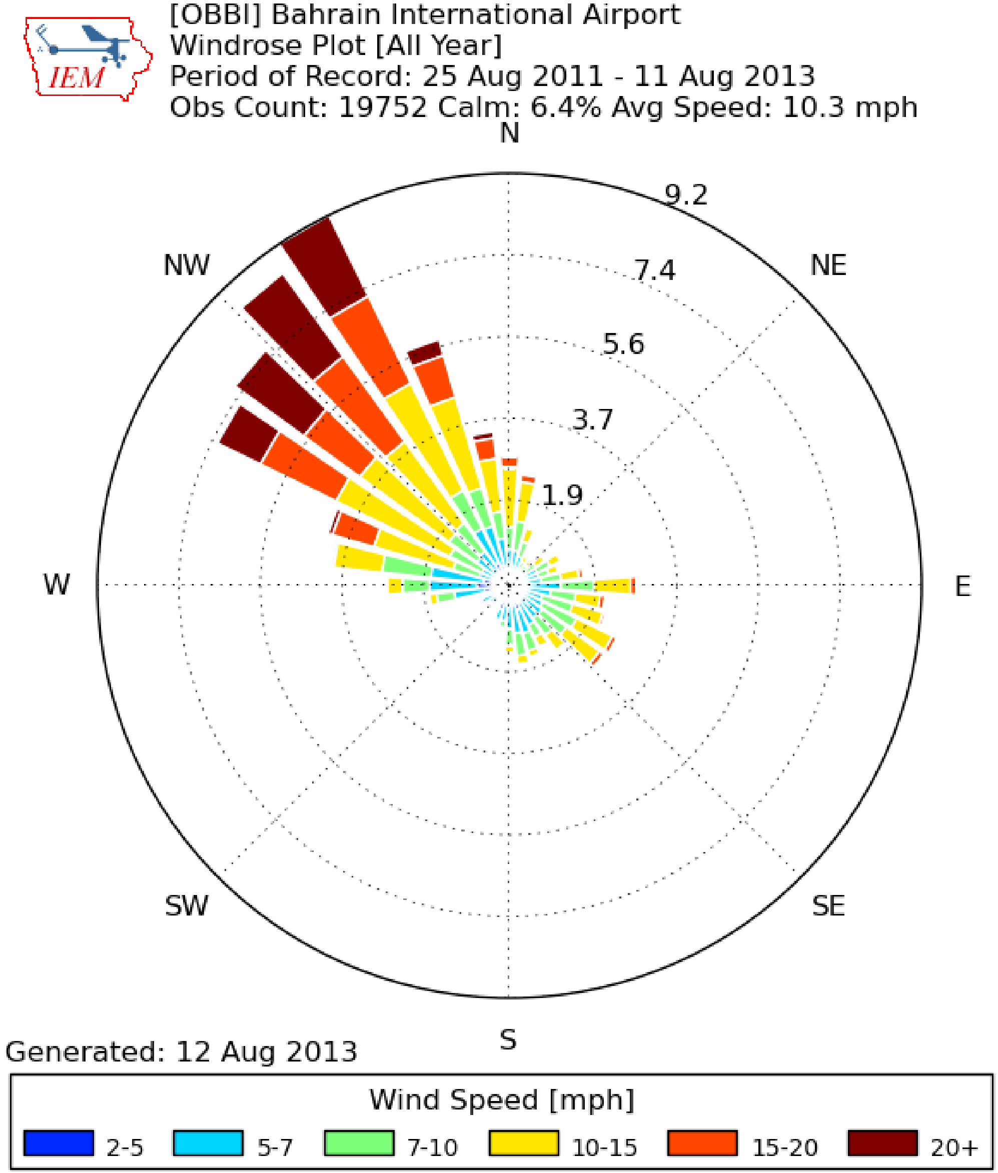




Building aerodynamics

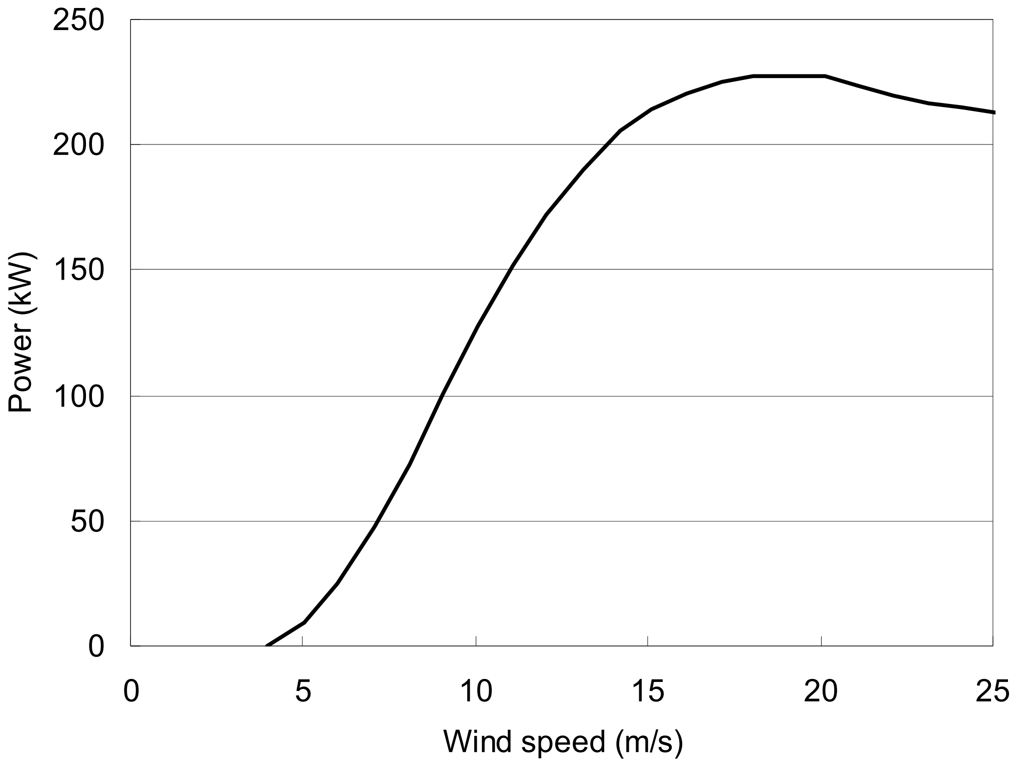
Wind statistics





Building aerodynamics

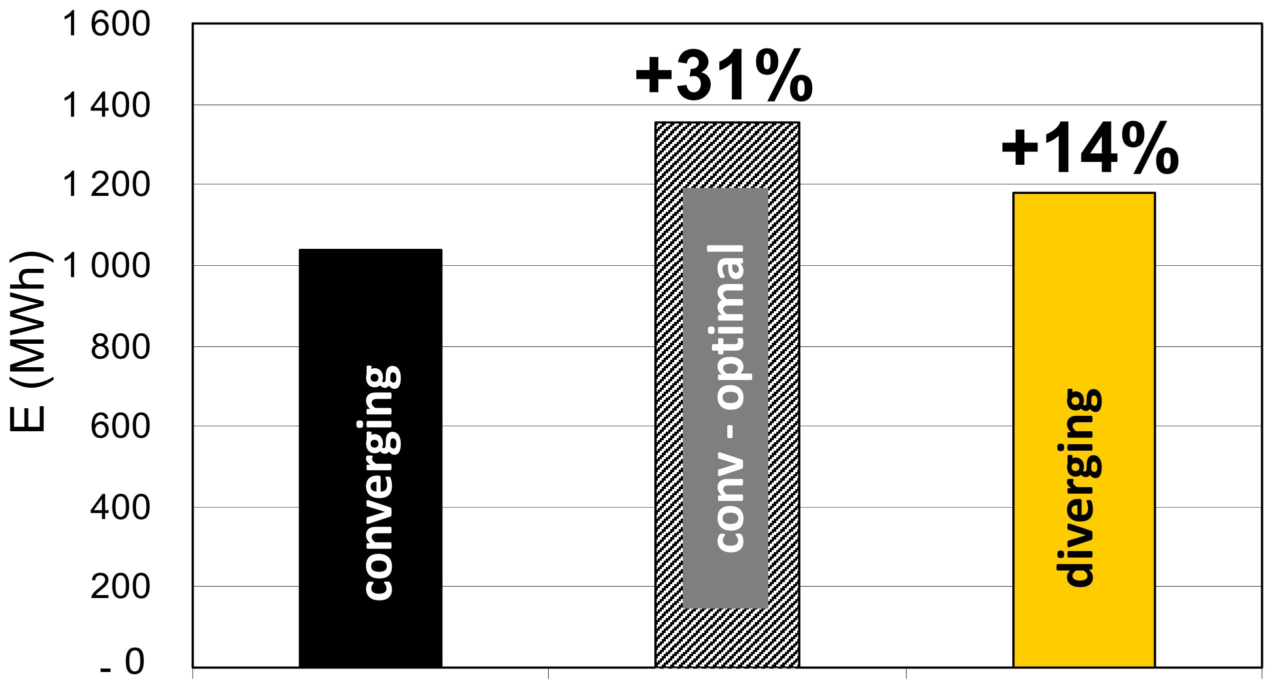
Wind turbine power curve



Reference: Shaun K, Smith RF, 2008. Harnessing energy in tall buildings: Bahrain World Trace Center and Beyond. CTBUH Technical paper.

Building aerodynamics

CFD simulations: yearly wind energy output



Conclusion: Bahrain WTC has a good design, but it can be improved significantly.

A FOLLOWING MOTORCYCLE

Accidents

Date	Race	Rider	Motorcycle	Consequences
2015/08/01	Clasica San Sebastian (Spain)	Greg Van Avermaet (Belgium)	TV motorcycle	Broken frame and back wheel, race lost

Accidents

Date	Race	Rider	Motorcycle	Consequences
2016/05/28	Tour of Belgium	Stig Broeckx (Belgium)	/	Coma

Sporza.be

Out of respect for the rider, his team and his family, we do not show pictures and movies of the crash.

Since 12 December 2016, Stig is out of coma!

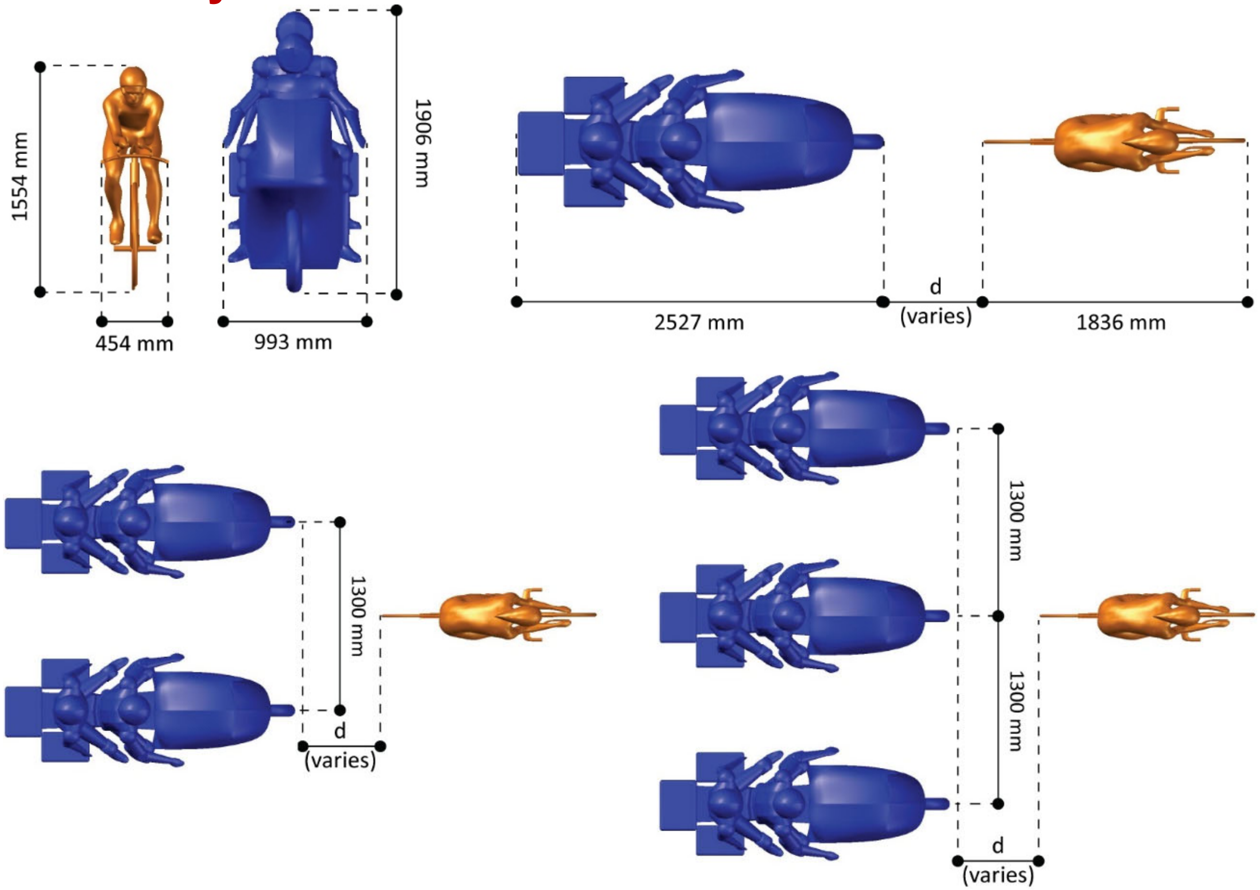
Drag interaction with a following motorcycle

Research hypothesis: Following motorcycles provide an aerodynamic benefit to the cyclist.

Source: www.zimbio.com

Drag interaction with a following motorcycle

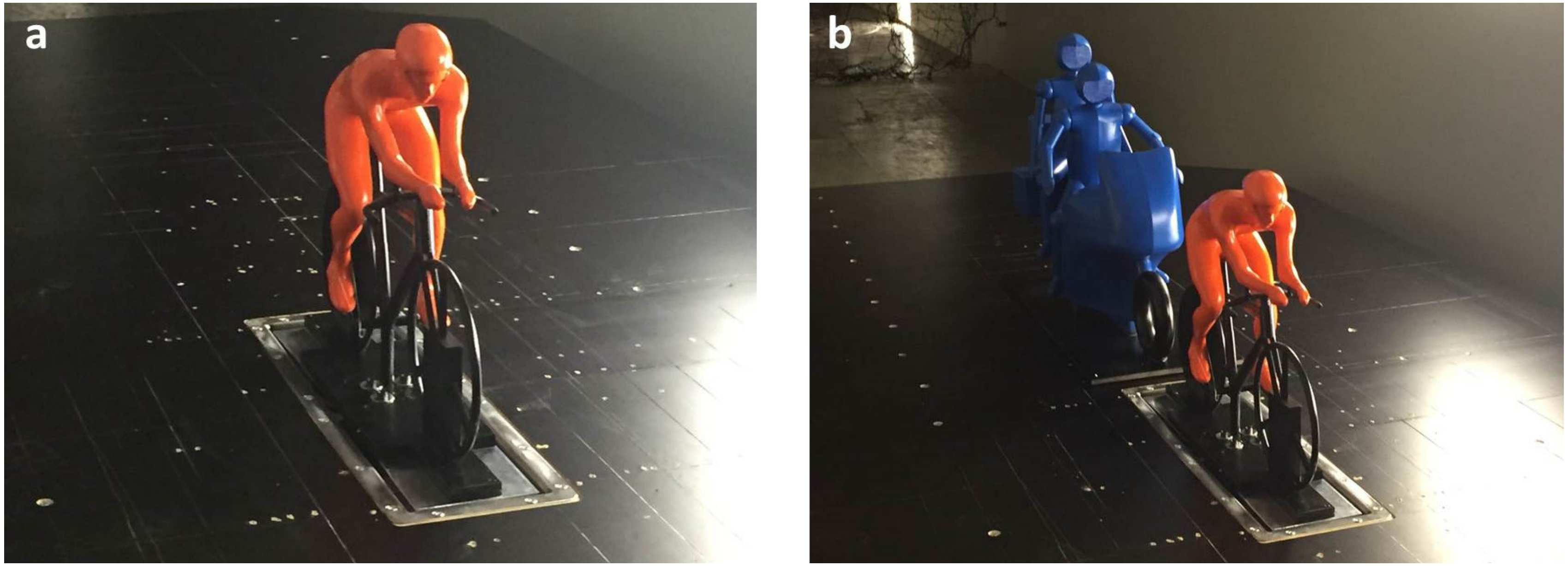
Geometry



Dimensions in mm

Drag interaction with a following motorcycle

Wind-tunnel tests

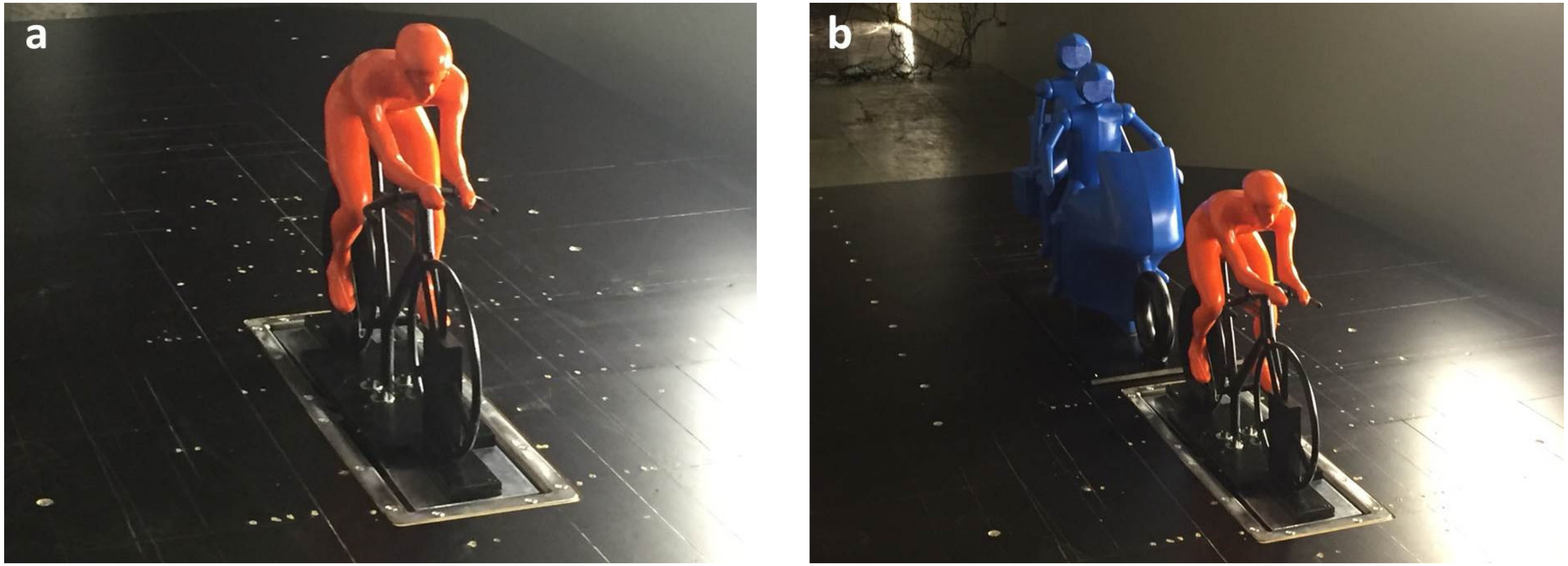


Wind-tunnel tests:

- Scale: ¼
- Cyclist model on force balance
- Wind speed U = 54 km/h x 4 = 216 km/h, turbulence intensity TI = 0.2%

Drag interaction with a following motorcycle

Wind-tunnel tests

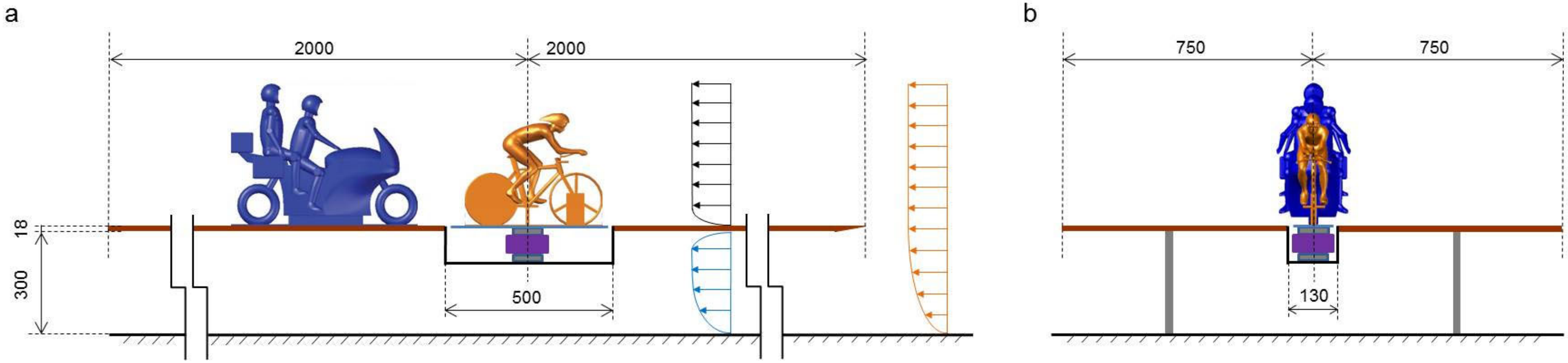


Wind-tunnel tests:

- Scale: ¼
- Cyclist model on force balance
- Wind speed U = 54 km/h x 4 = **216 km/h**, turbulence intensity TI = 0.2%

Drag interaction with a following motorcycle

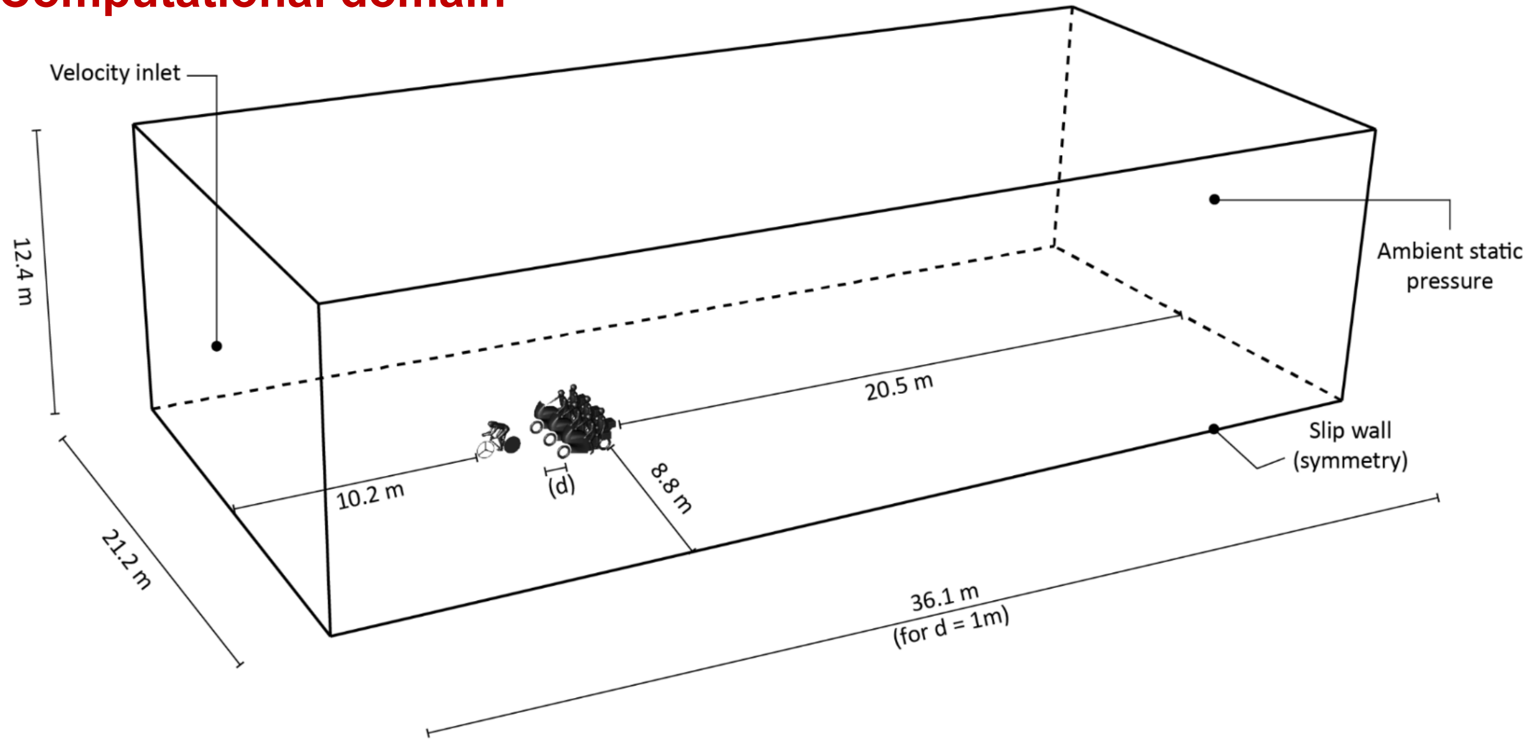
Wind-tunnel tests



- Dimensions in mm
- Elevated platform to reduce boundary layer height
- Cyclist full-scale height and weight: 183 cm & 72 kg
- Frontal area: 0.34 m², blockage ratio: 3.5 %
- Wheels fixed / Separation distances: d = 0.25, 0.5, 1, 1.5, 2, 2.5 m
- Boundary-layer height (model-scale): 6 cm

Drag interaction with a following motorcycle

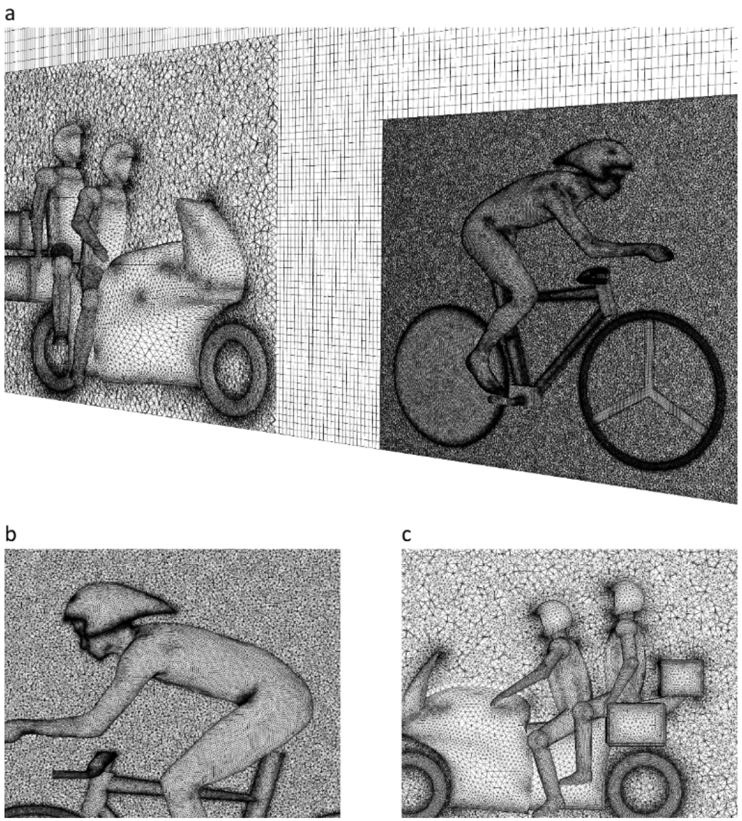
Computational domain

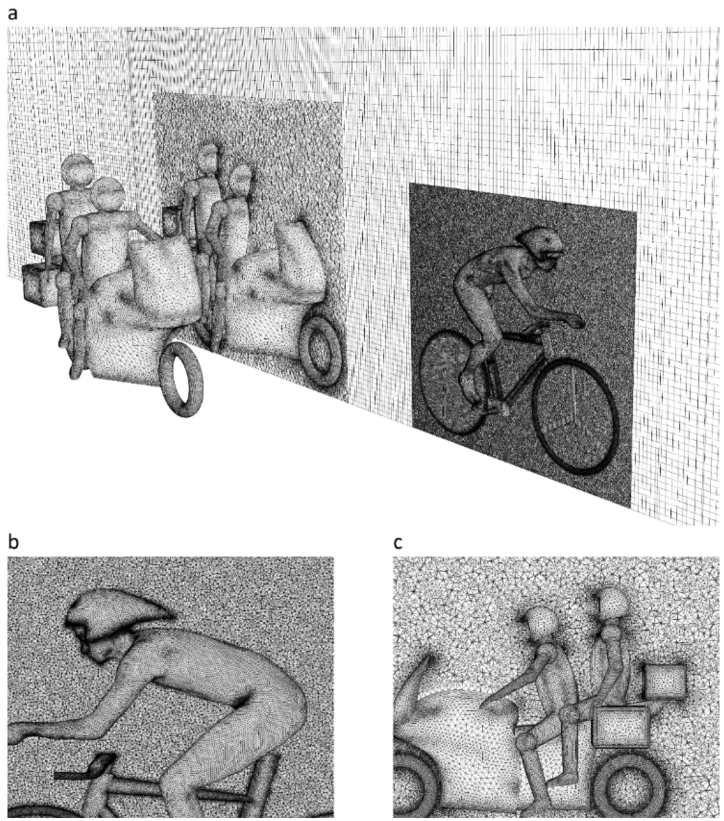


- Maximum blockage ratio: 1.6%

Drag interaction with a following motorcycle

Computational grids





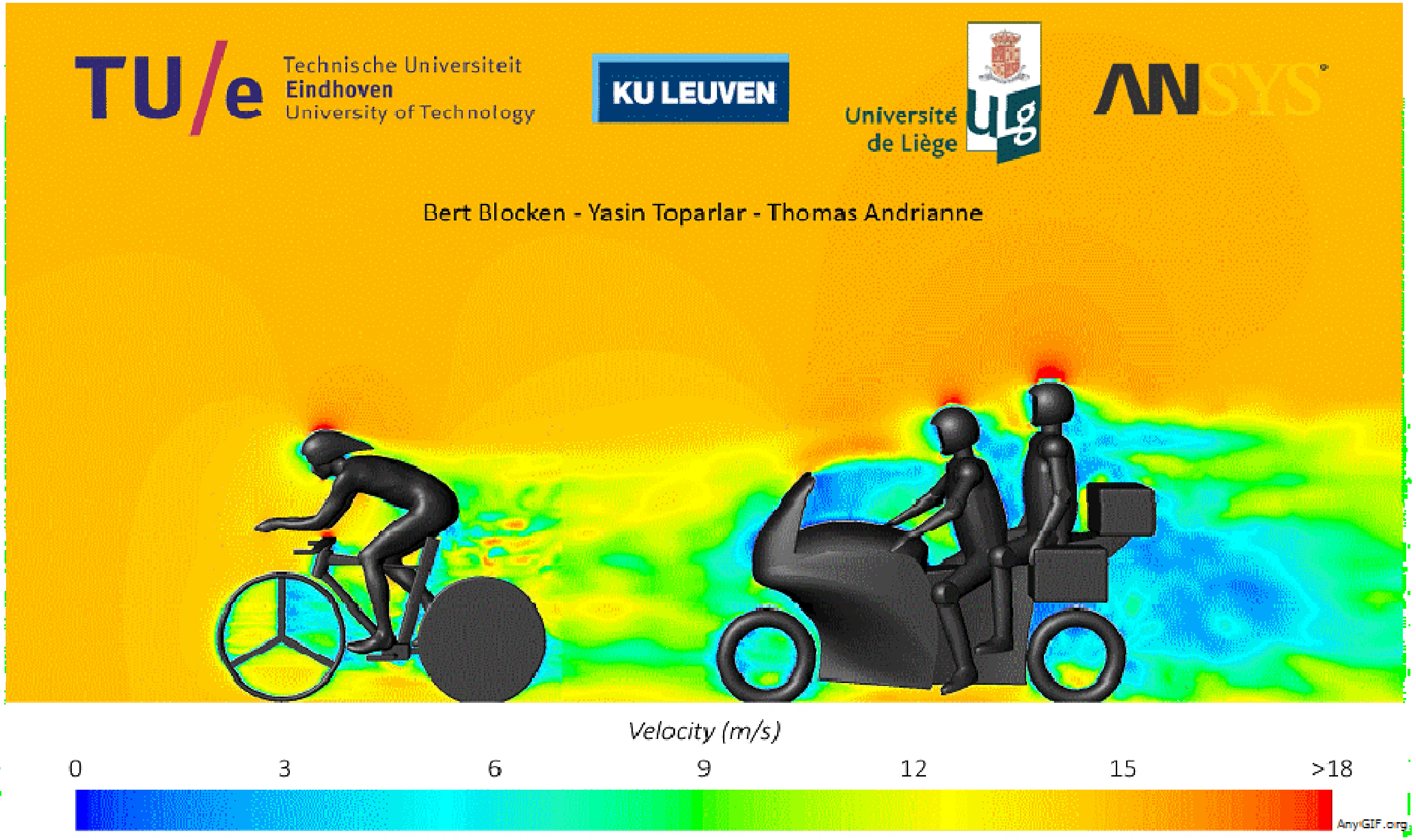
Drag interaction with a following motorcycle

Solver settings

- ANSYS Fluent 15
- **3D steady RANS** equations (and LES for visualization)
- **Standard k-ε model** (*Jones and Launder 1972*)
- Pressure-velocity coupling: SIMPLEC algorithm
- Pressure interpolation: second order
- Second-order discretization schemes for both the convection terms and the viscous terms of the governing equations
- Gradients computed with the Green-Gauss cell-based method
- Convergence with scaled residuals of 10^{-4} for continuity, 10^{-7} for momentum, 10^{-5} for turbulent kinetic energy and 10^{-5} for turbulence dissipation rate

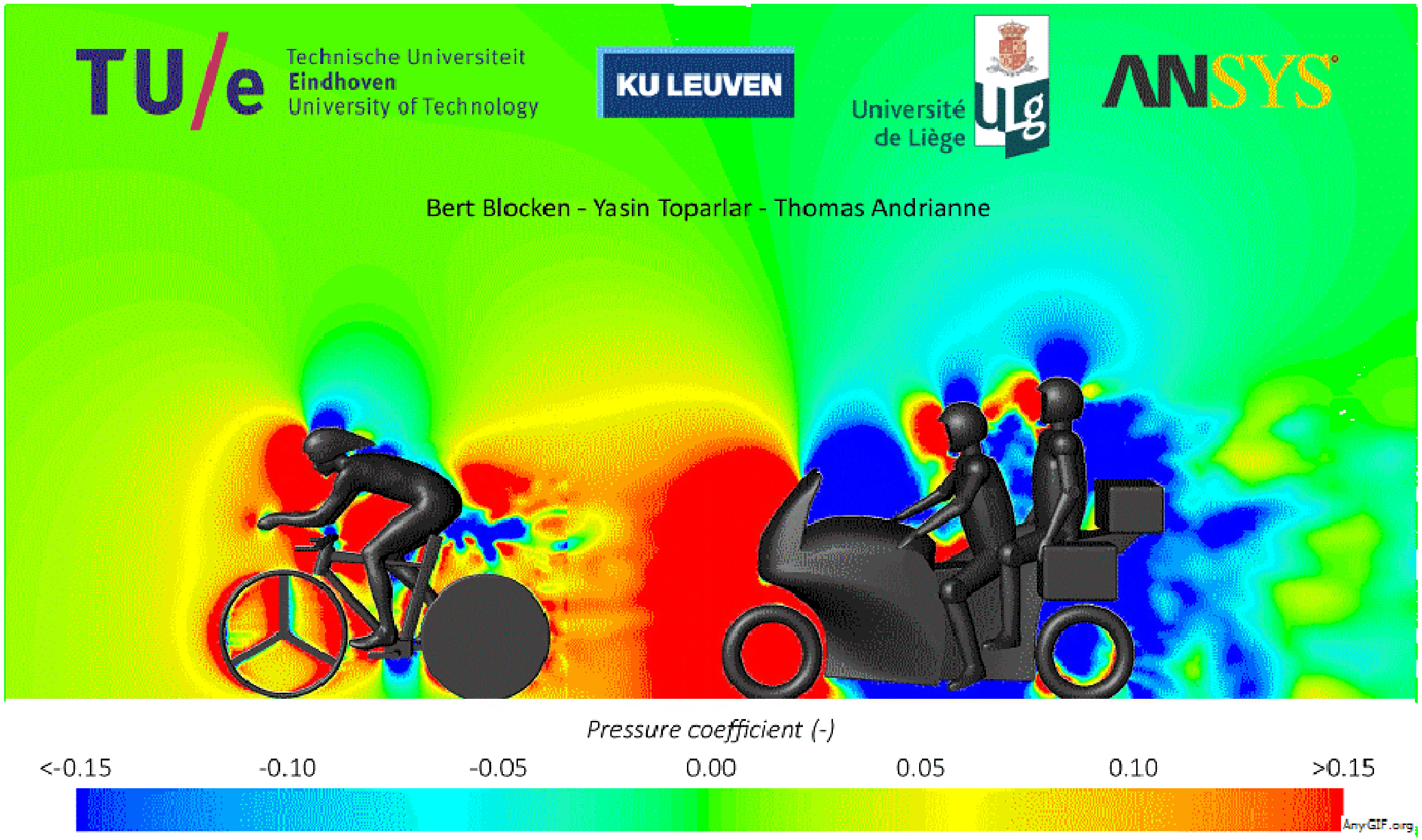
Drag interaction with a following motorcycle

Wind speed contours



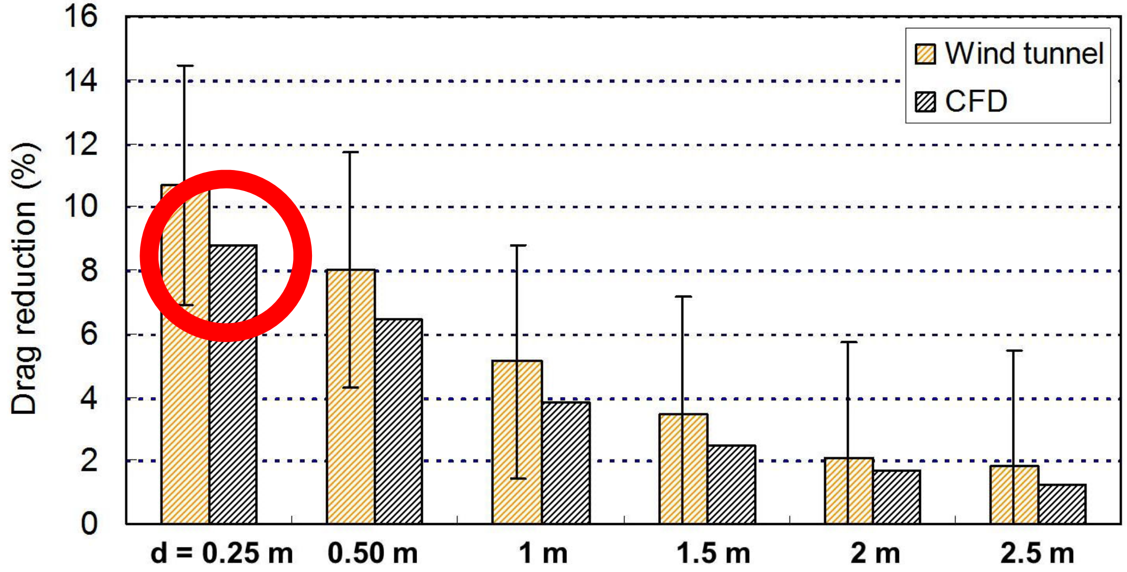
Drag interaction with a following motorcycle

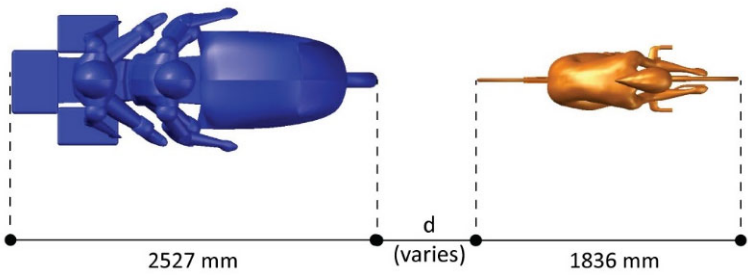
Pressure coefficient contours



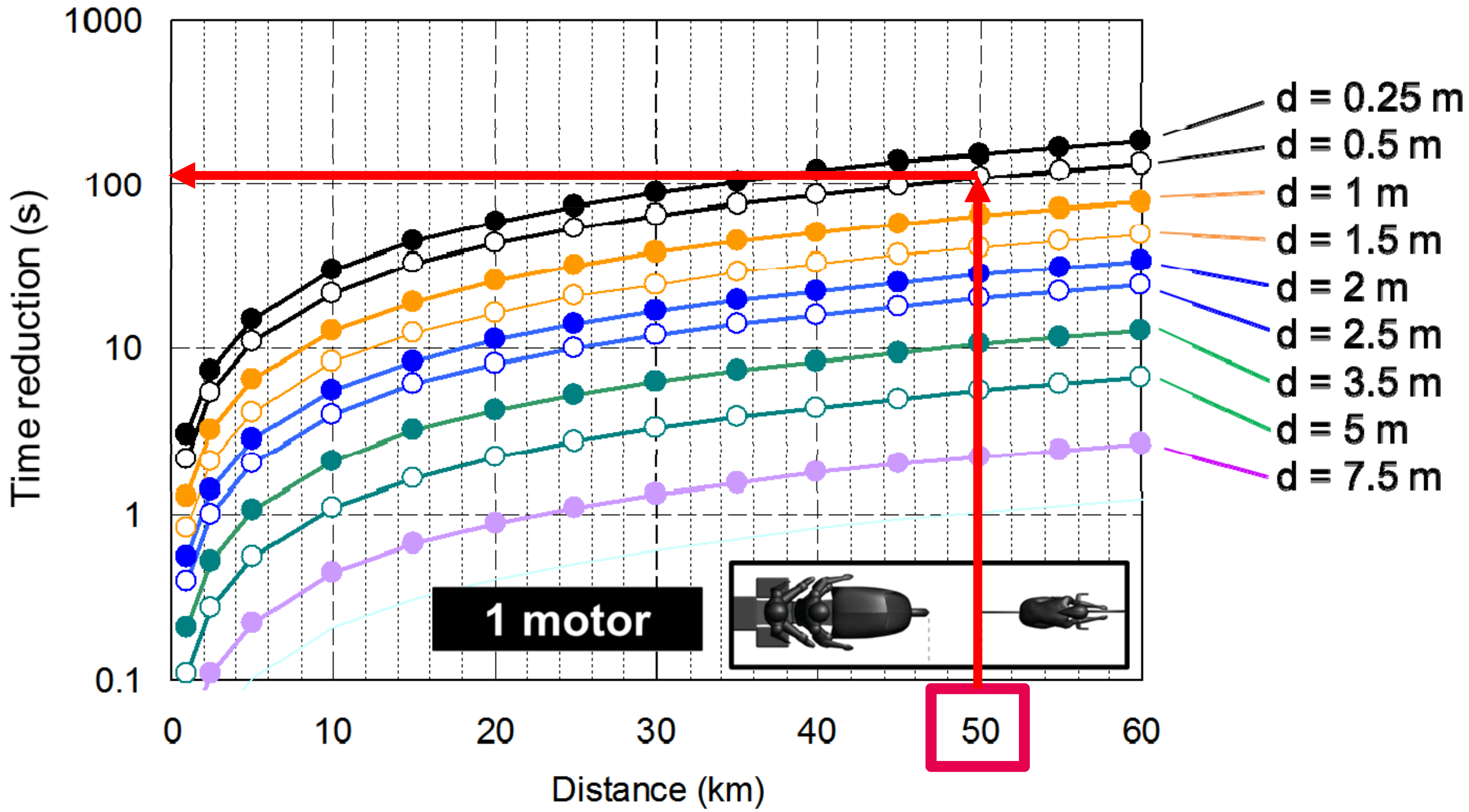
Drag interaction with a following motorcycle

Measured and simulated drag force (full-scale equivalent)





Drag interaction with a following motorcycle



Drag interaction with a following motorcycle

For a typical time trial distance of 50 km:

• d = 0.5 m:	108.7 s
• d = 1 m:	64.2 s
• d = 2.5 m:	20.1 s
• d = 5 m:	5.6 s
• d = 10 m:	1.0 s

Drag interaction with a following motorcycle

It is highly unlikely that a motorcycle will follow the cyclist at this distance for the total duration of the time trial (unless bad intentions would be in play). Therefore, it is more practically relevant to consider benefits obtained over shorter distances within a long time trial. If the motorcycle only follows the cyclist for only 1 km (2%):

- d = 0.25 m: 2.98 s
- d = 0.5 m: 2.17 s
- **d = 1 m: 1.28 s**
- d = 2.5 m: 0.40 s
- d = 5 m: 0.11 s
- d = 10 m: 0.02 s

Drag interaction with a following motorcycle

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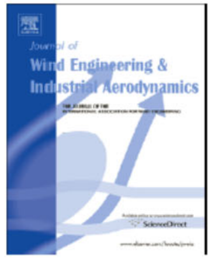
Journal of Wind Engineering and Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia



ELSEVIER

Aerodynamic benefit for a cyclist by a following motorcycle

Bert Blocken [a,b,*], Yasin Toparlar [a], Thomas Andrianne [c]

[a] Department of the Built Environment, Eindhoven University of Technology, P.O. Box 513, 5600 Eindhoven, The Netherlands
[b] Department of Civil Engineering, KU Leuven, Kasteelpark Arenberg 40 – Bus 2447, 3001 Leuven, Belgium
[c] Department of Aerospace and Mechanical Engineering, University of Liège, Allée de la Découverte, 9 Quartier Polytech 1, B52/3, B-4000 Liège, Belgium

BUILDING, CITY & SPORTS AERODYNAMICS

Types of (research) projects in sports aerodynamics:

1. Not for specific teams/individuals

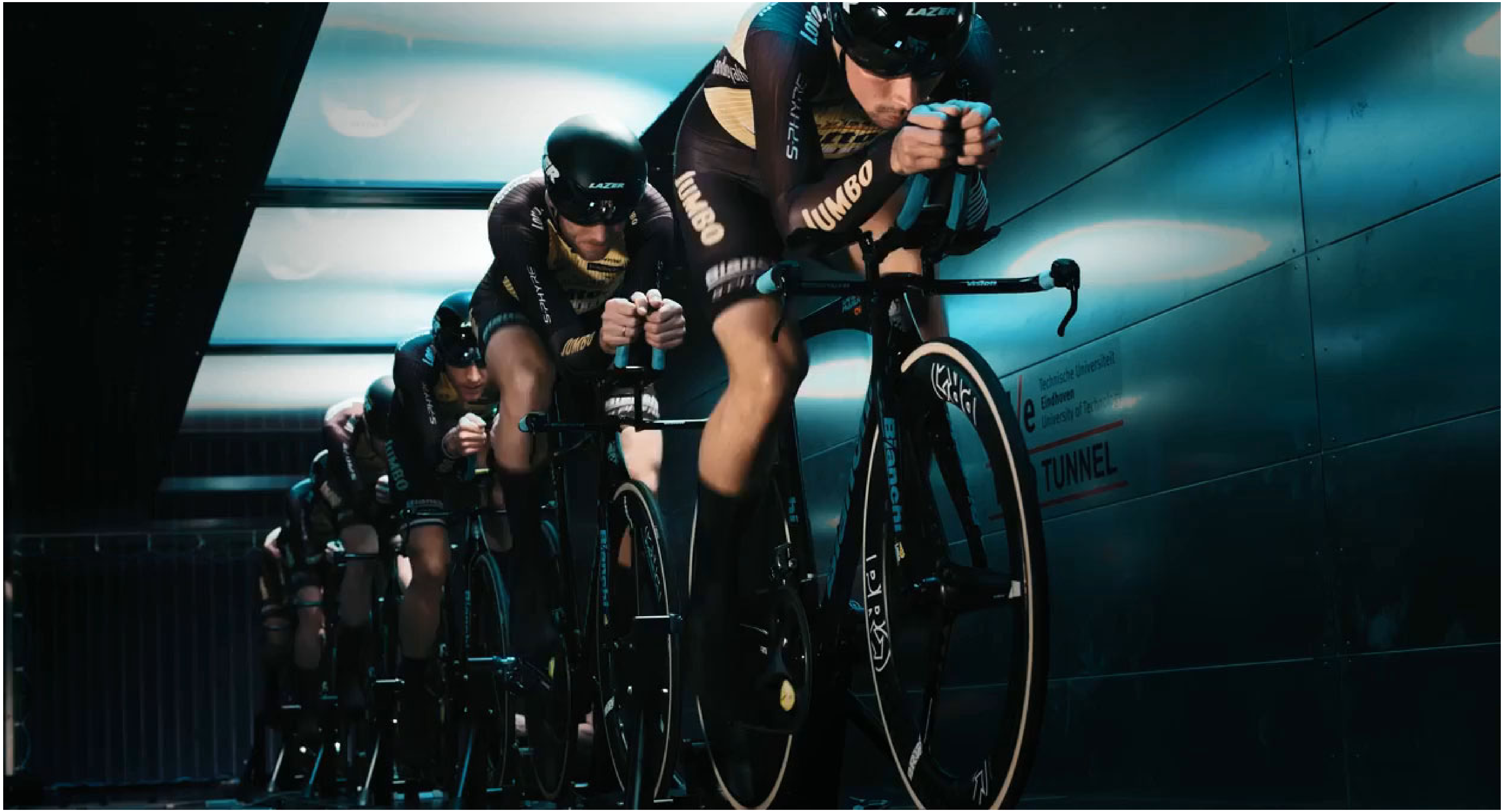
2. **For specific teams/individuals**

RESEARCH SUPPORT IN PRACTICE

CYCLING TEAM TIME TRIALS

2018 Tour de France: Winner Team Time Trial with BMC Cycling Team
→ Belgian rider Greg van Avermaet 8 days in yellow jersey

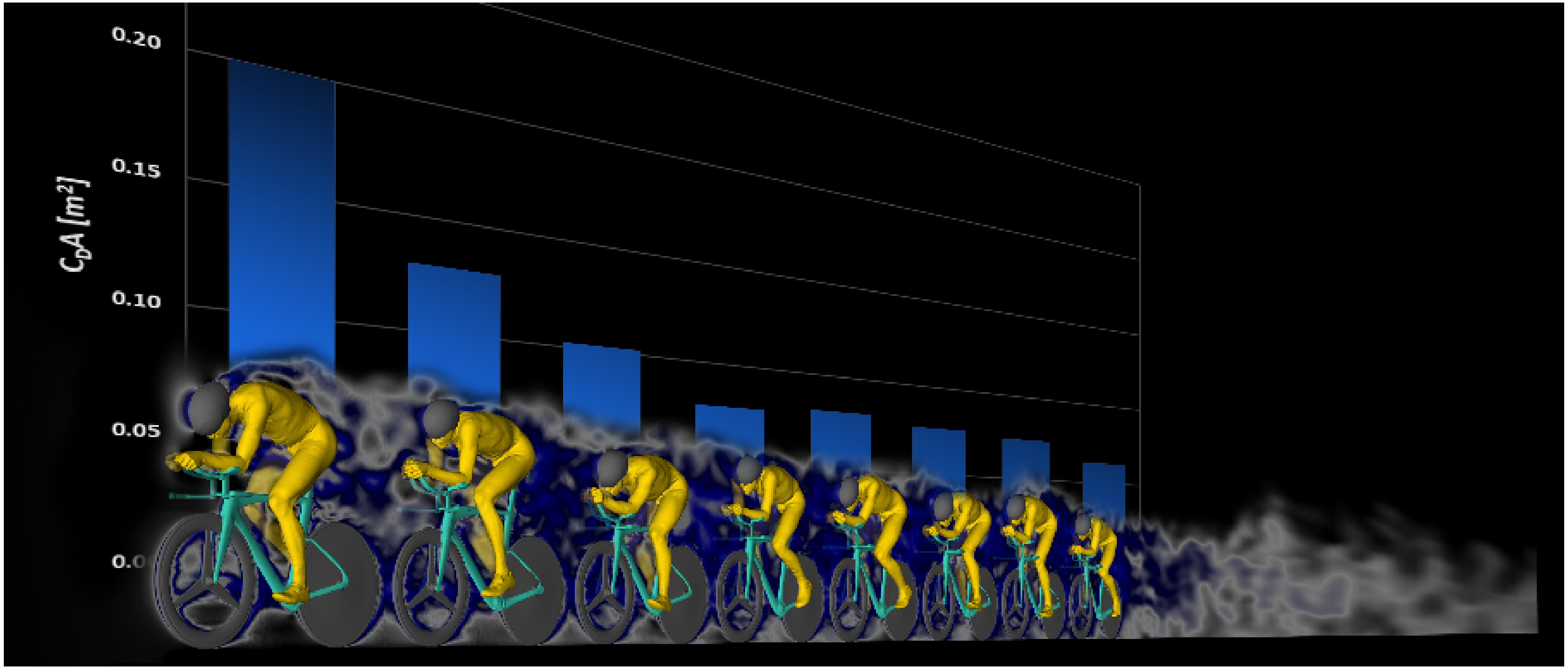
(©UCI 2018)


LAZER
JUMBO
Bianchi
Technische Universiteit
Eindhoven
TUNNEL

CYCLING TEAM TIME TRIALS

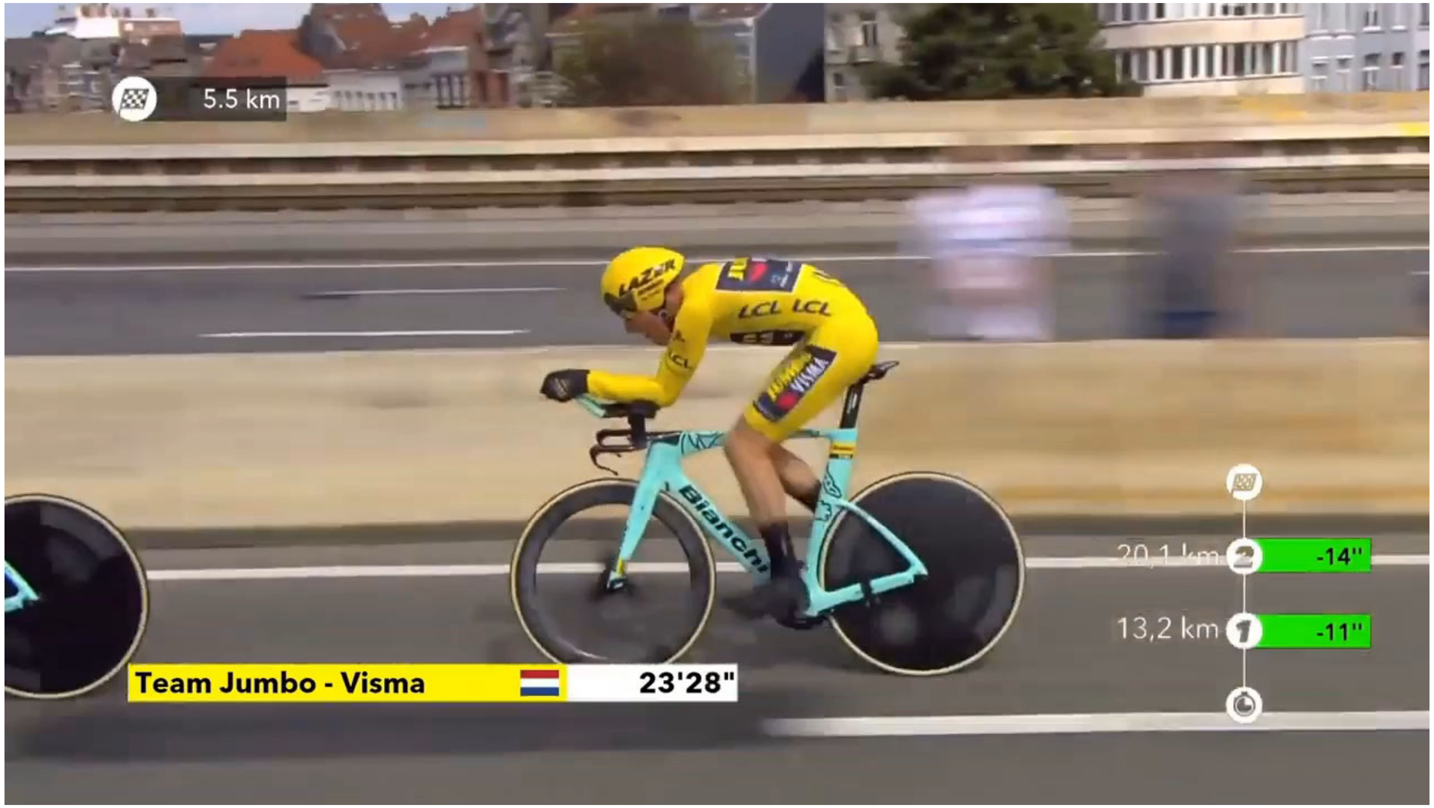
Optimization of team time trials: 40320 different sequences!

CFD simulation of Tour de France 2019 TTT for Team Jumbo-Visma



CYCLING TEAM TIME TRIALS

2019 Tour de France: Winner Team Time Trial with Jumbo-Visma Cycling Team

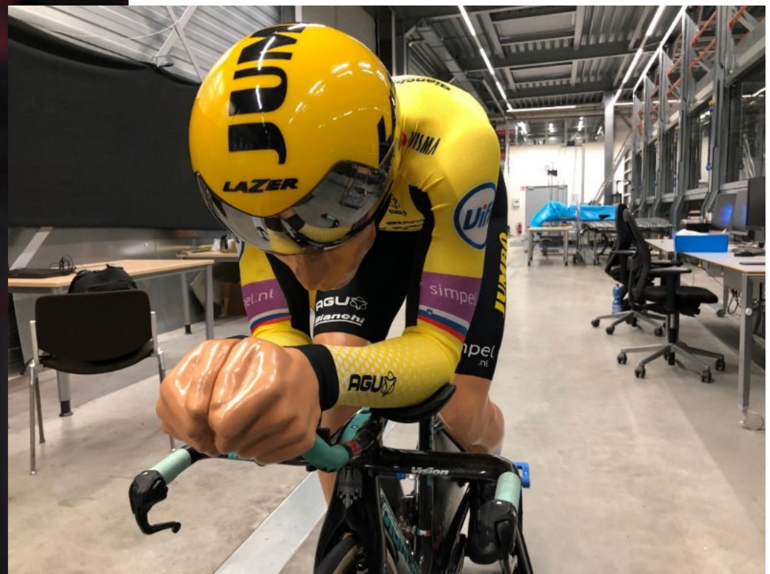


(©UCI 2019)

CYCLING TIME TRIALS & TEAM TIME TRIALS

2019 Winner of La Vuelta, Spain: Primoz Roglic

(©Cor Vos Agency)



PARACYCLING

2017, 2018, 2019 World Champion in H5 Paracycling: Tim de Vries

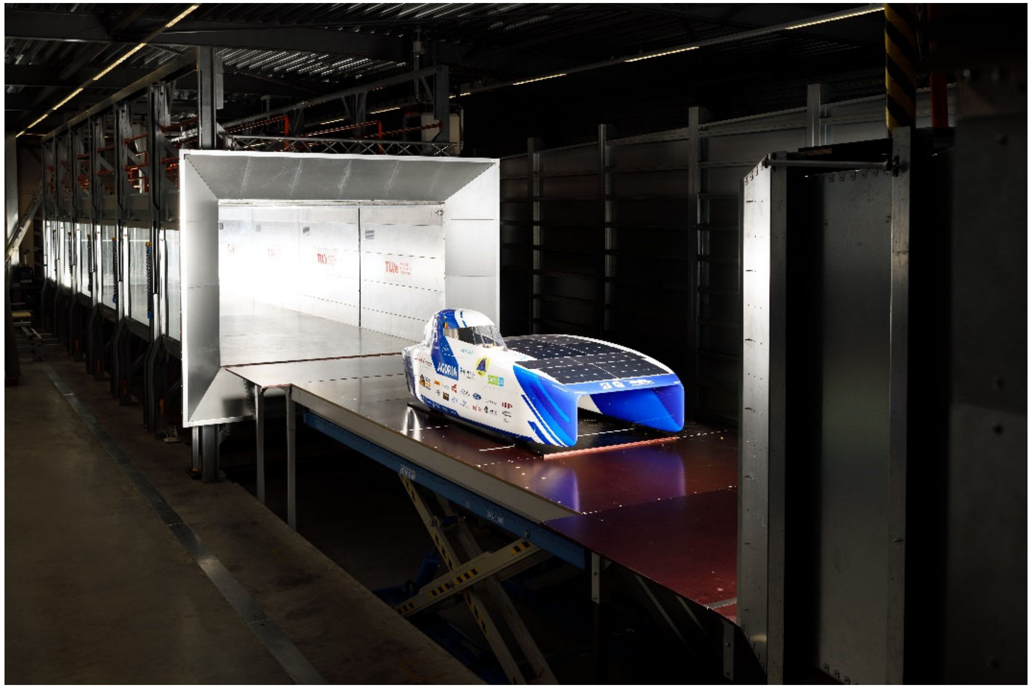
CYCLING WORLD HOUR RECORD

2019 Victor Campenaerts

(©sporza.be)

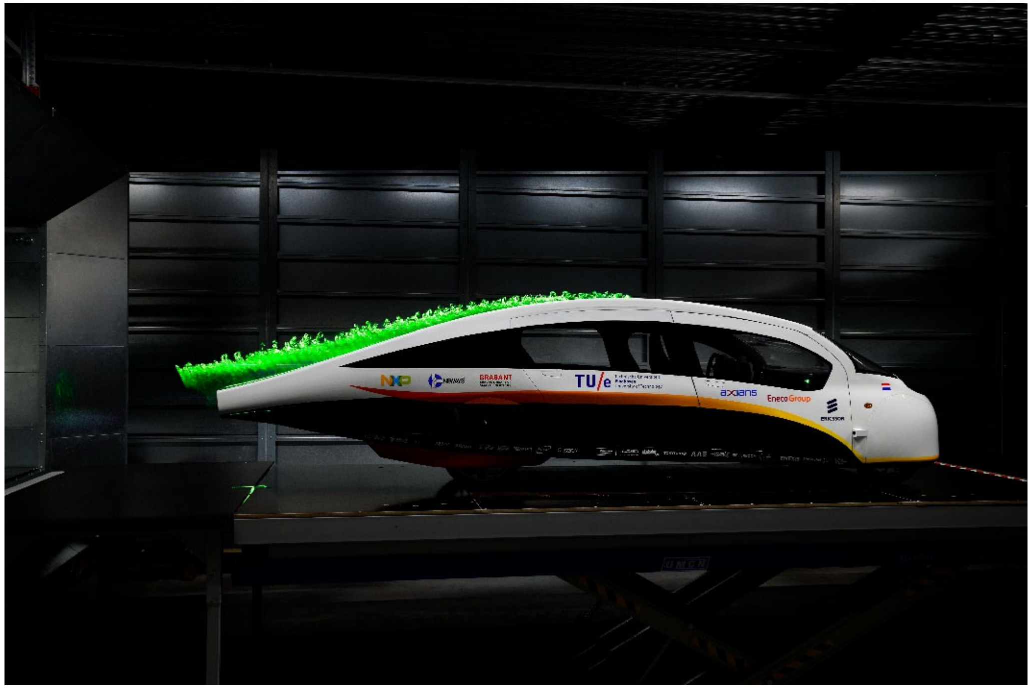
CAR AERODYNAMICS

2019 World Champion in Challenger Class: KU Leuven Agoria Solar Team



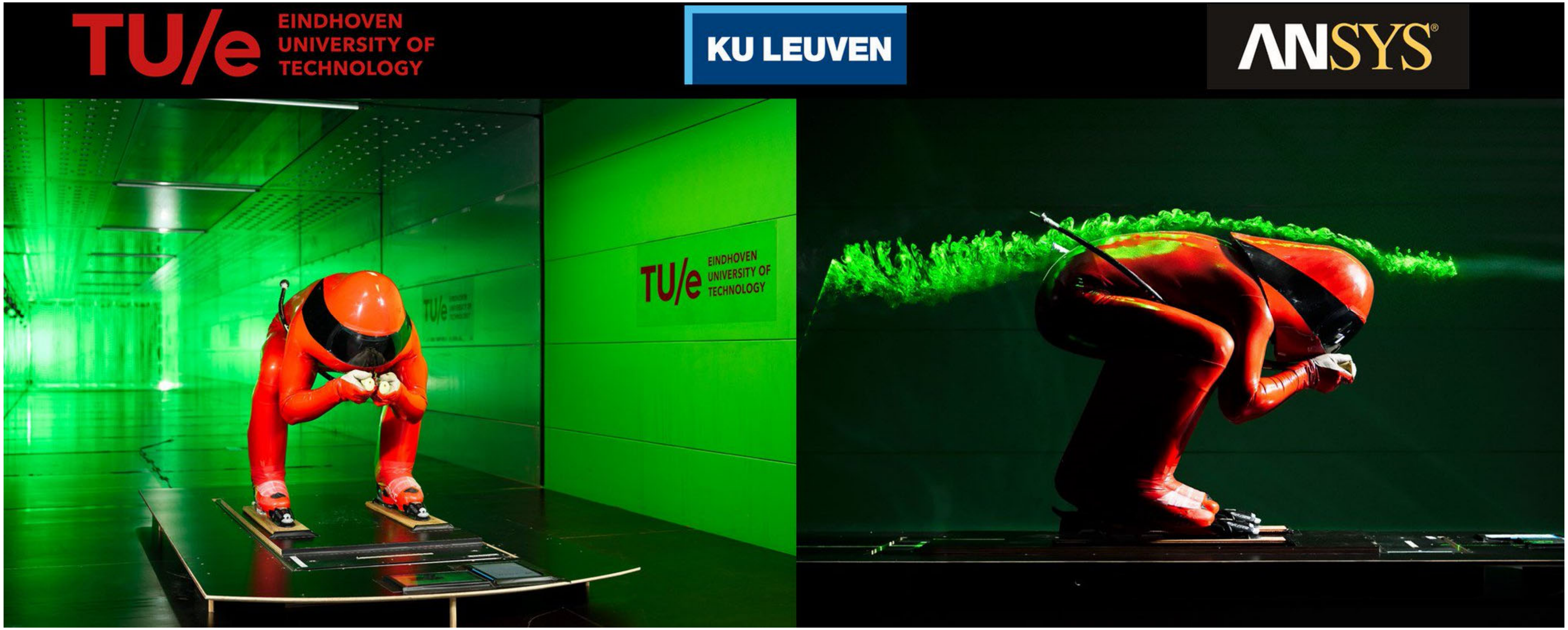
CAR AERODYNAMICS

2013, 2015, 2017, 2019 World Champion in Cruiser Class: Eindhoven Solar Team



SPEED SKI AERODYNAMICS

2019 Belgian Record Joost Vandendries



MARATHON RECORD

INEOS 1:59 Challenge: Eliud Kipchoge

You Tube movie: Primoz meets Primoz:

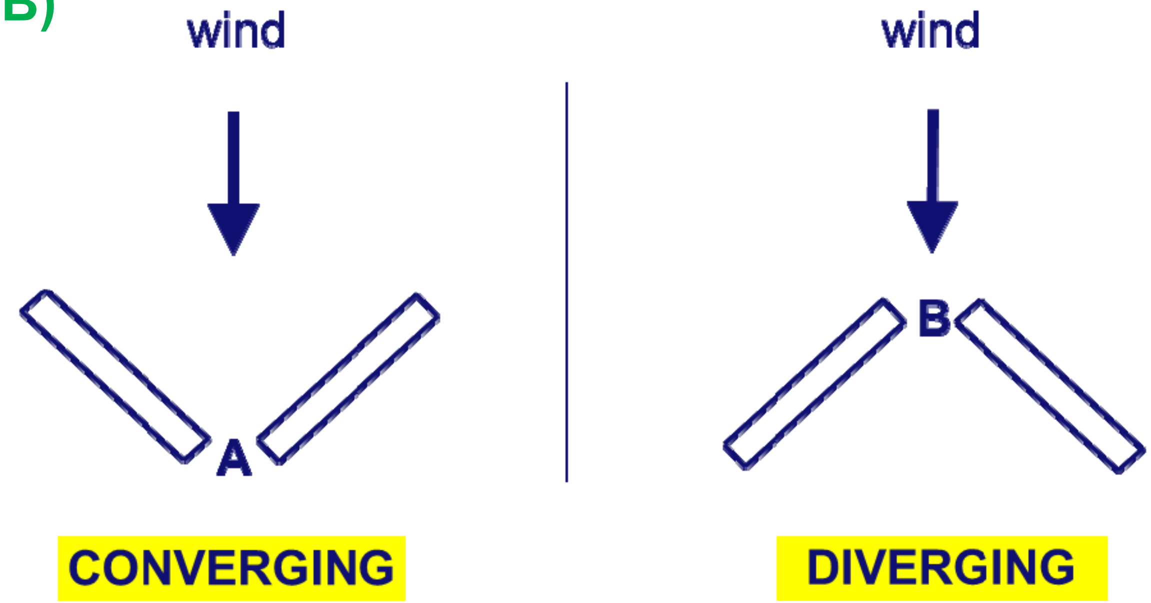
https://www.youtube.com/watch?v=2gWtpsBprk0

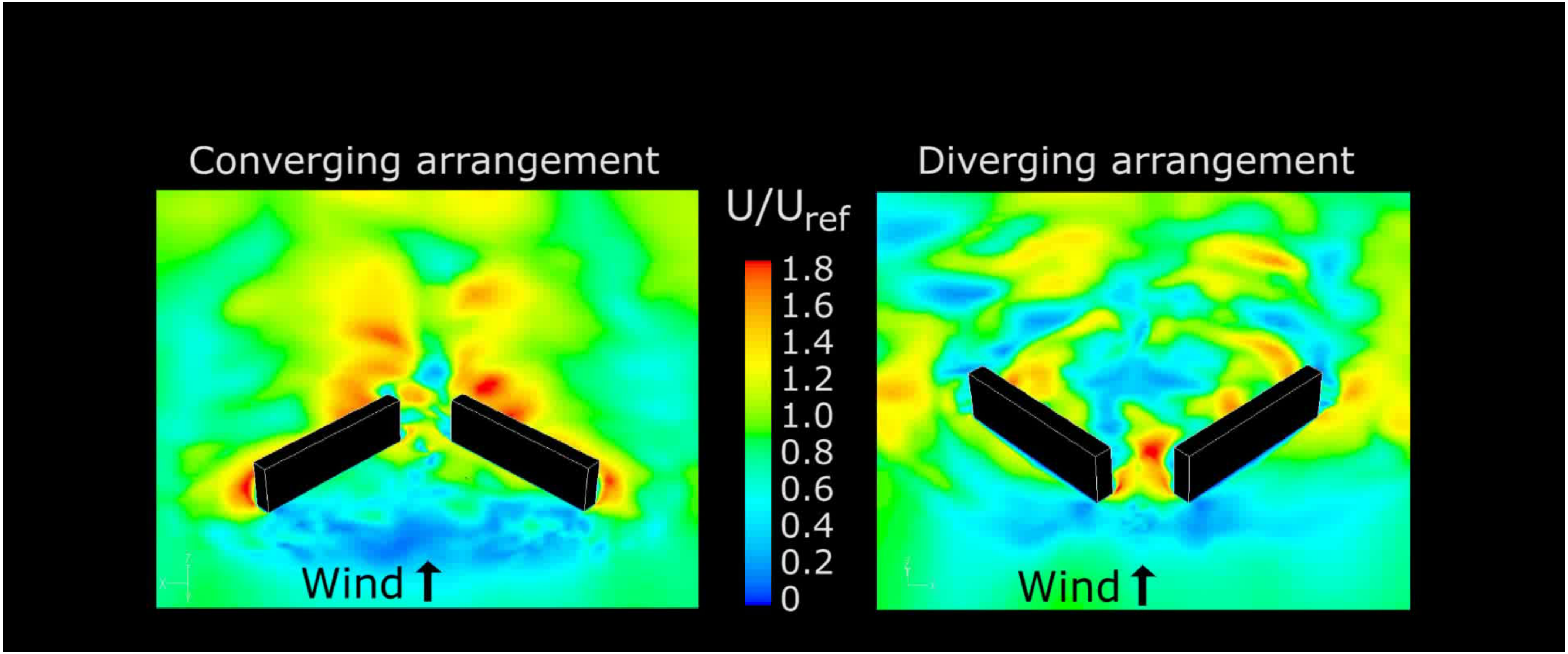
9 ANSWERS

QUESTION 1

Top view of two high-rise buildings, left in a converging and right in a diverging arrangement. The wind direction is as indicated. Which configuration yields the highest wind speed in the passage?

A) Converging arrangement (A)
B) Diverging arrangement (B)
C) Same in A and B





→ **Counter-intuitive result**

QUESTION 1

Navier-Stokes equations

$$\rho\frac{\partial u}{\partial t}+\rho\,\mathrm{div}\left(u\,\vec{v}\right) = G_x-\frac{\partial p}{\partial x}+\mu\,\nabla^2 u$$

$$\rho\frac{\partial v}{\partial t}+\rho\,\mathrm{div}\left(v\,\vec{v}\right) = G_y-\frac{\partial p}{\partial y}+\mu\,\nabla^2 v$$

$$\rho\frac{\partial w}{\partial t}+\rho\,\mathrm{div}\left(w\,\vec{v}\right) = G_z-\frac{\partial p}{\partial z}+\mu\,\nabla^2 w$$

Elliptical character for subsonic flow

where	u, v, w =	instantaneous fluid velocity components (m/s)
	p =	instantaneous pressure (Pa)
	G_x, G_y, G_z =	body forces in x, y and z direction (N/m³)

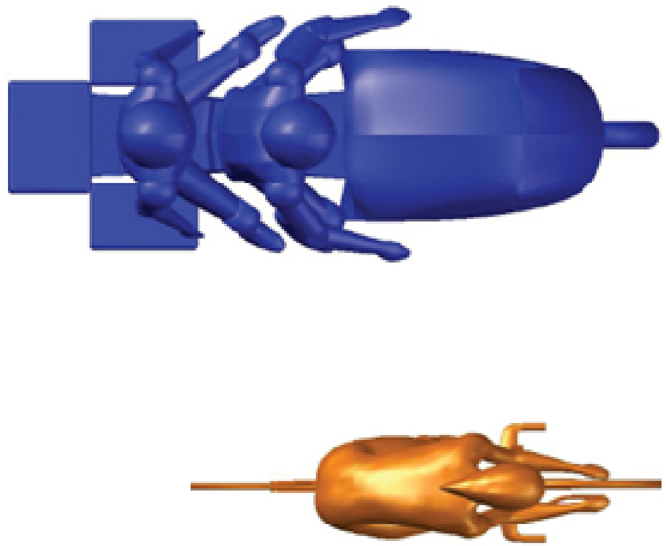
QUESTION 2

A cyclist is drafting close behind a motorcycle. How much does the cyclist's aerodynamic resistance (drag) decrease?

A. 10%
B. 25%
C. 50%
D. 75%

QUESTION 3

A motorcycle is riding next to a cyclist. Distance in between is 1.3 m. How does the cyclist's aerodynamic resistance change due to the presence of the motorcycle?

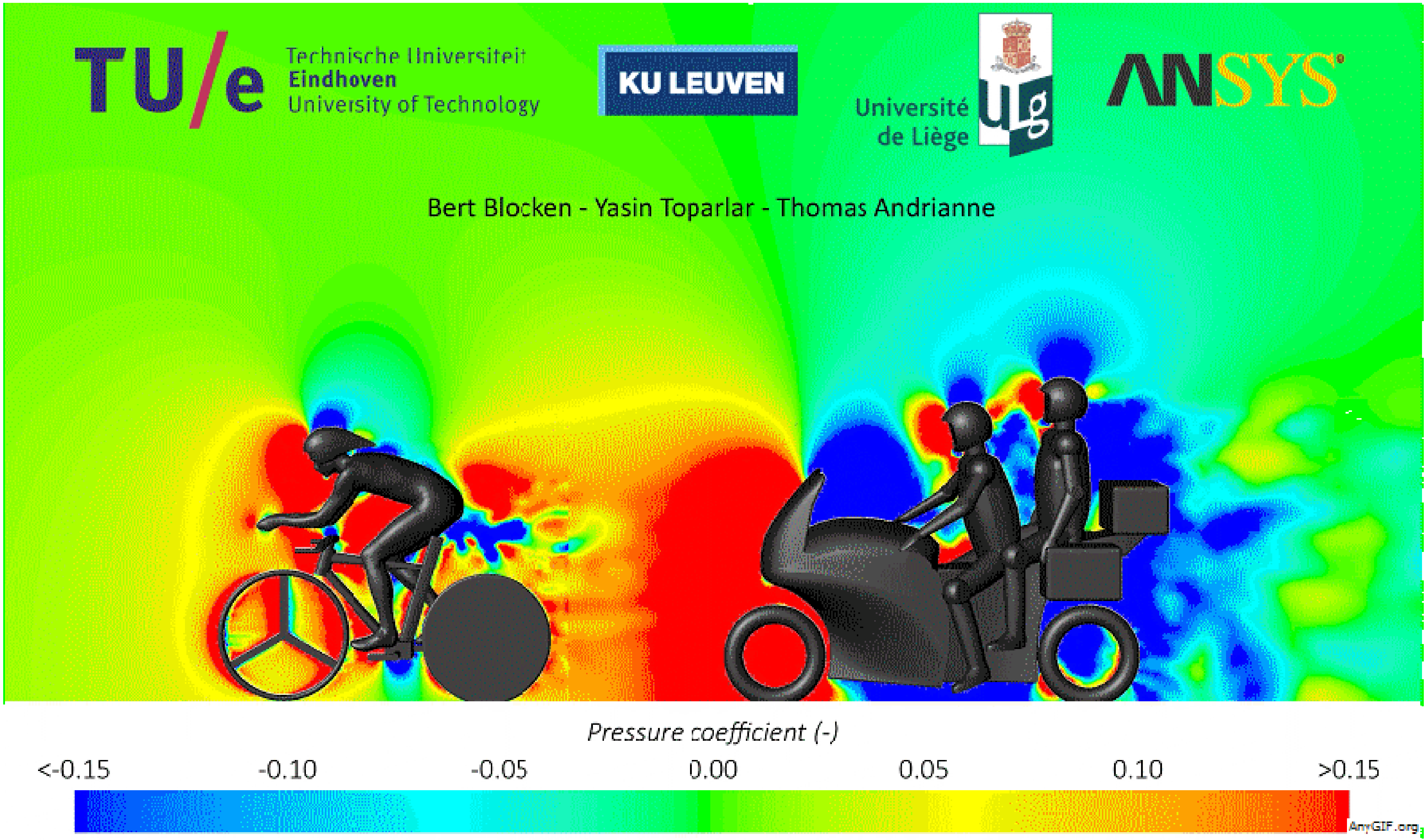


A. Increases with 15%
B. Increases with 5%
C. Remains the same
D. Decreases with 5%
E. Decreases with 15%

QUESTION 4

A cyclist is riding in front of a motorcycle. How does the cyclist aerodynamic resistance (drag) change due to the presence of the motorcycle?

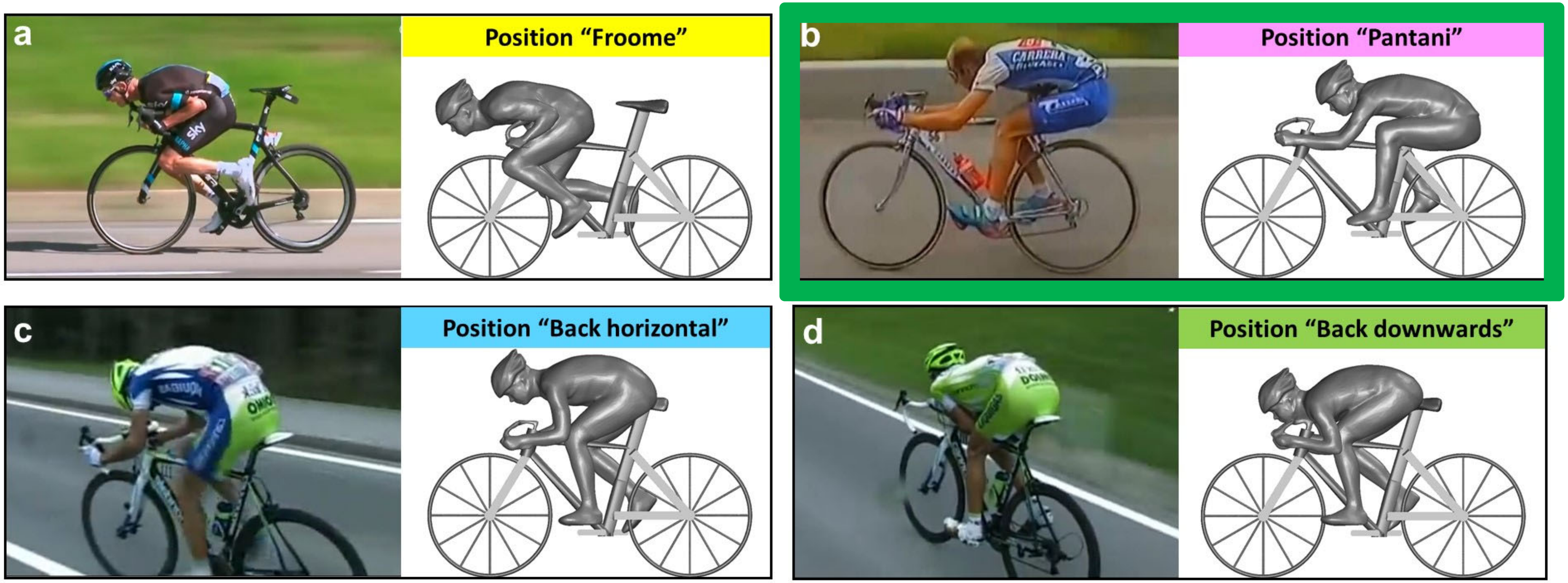
A. Increases with 15%
B. Increases with 5%
C. Remains the same
D. Decreases with 5%
E. Decreases with 15%



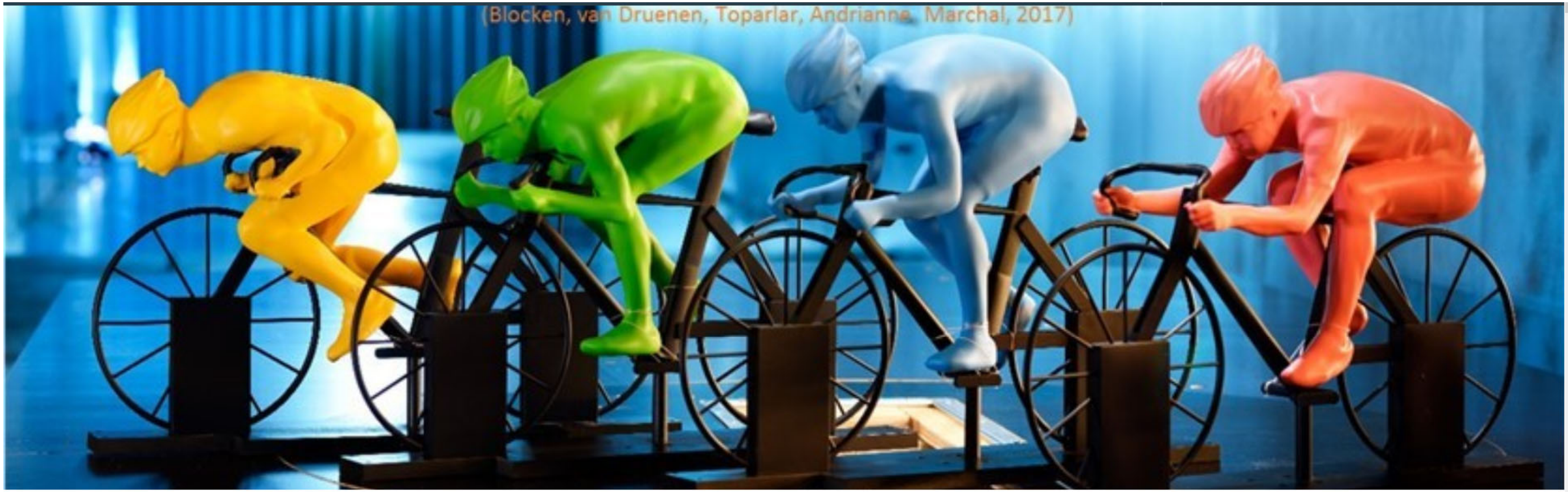
Technische Universiteit Eindhoven University of Technology
KU LEUVEN
Université de Liège
ANSYS
Bert Blocken - Yasin Toparlar - Thomas Andrianne
Pressure coefficient (-)
<-0.15
-0.10
-0.05
0.00
0.05
0.10
>0.15
AnyGIF.org

QUESTION 5

Different professional cyclists use very different hill descent positions indicating there is no consensus on which is best. Which hill descent position is most aerodynamic?

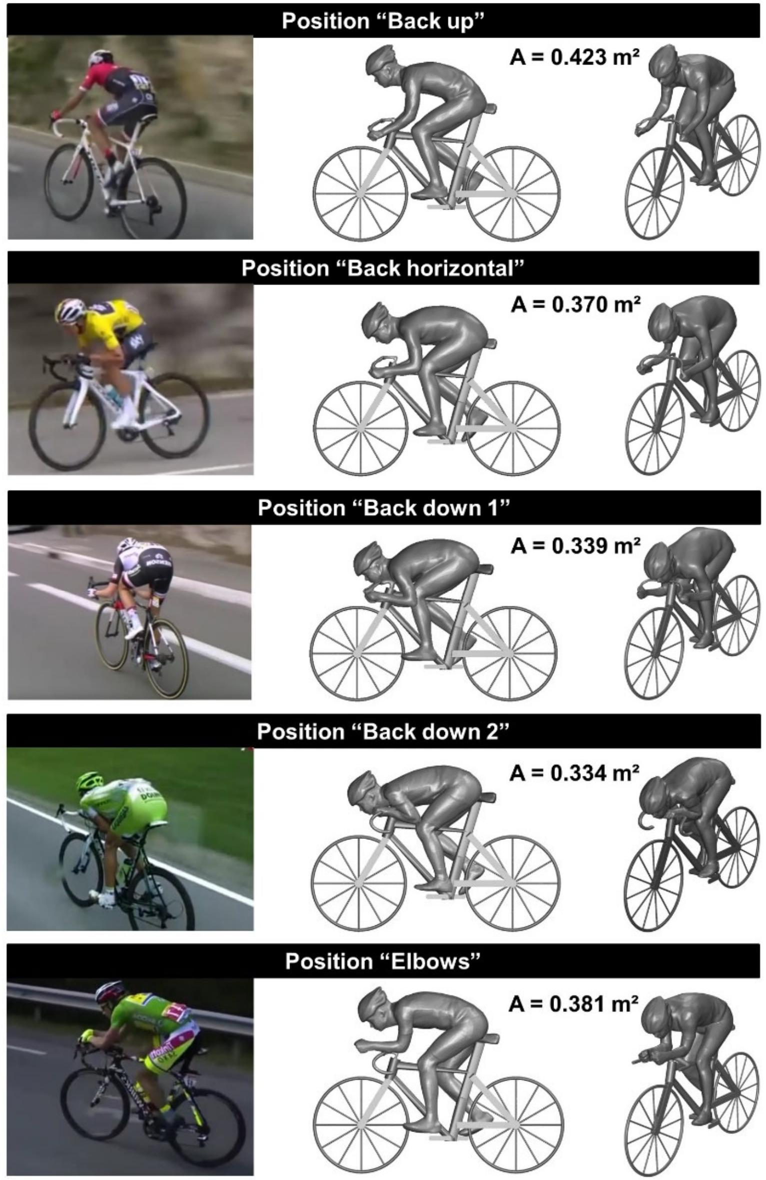


QUESTION 5

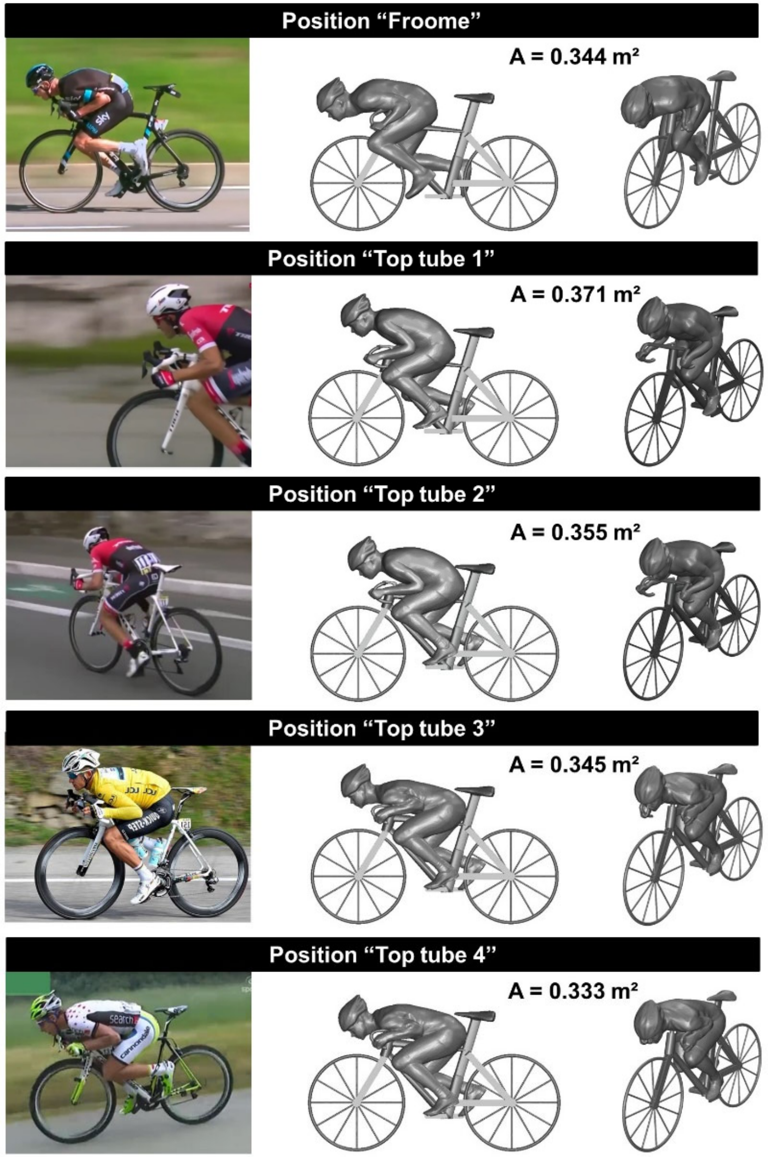


Which cyclist hill descent position is really superior? Froome, Pantani, Nibali or Sagan? The scientific answer. Part 2.

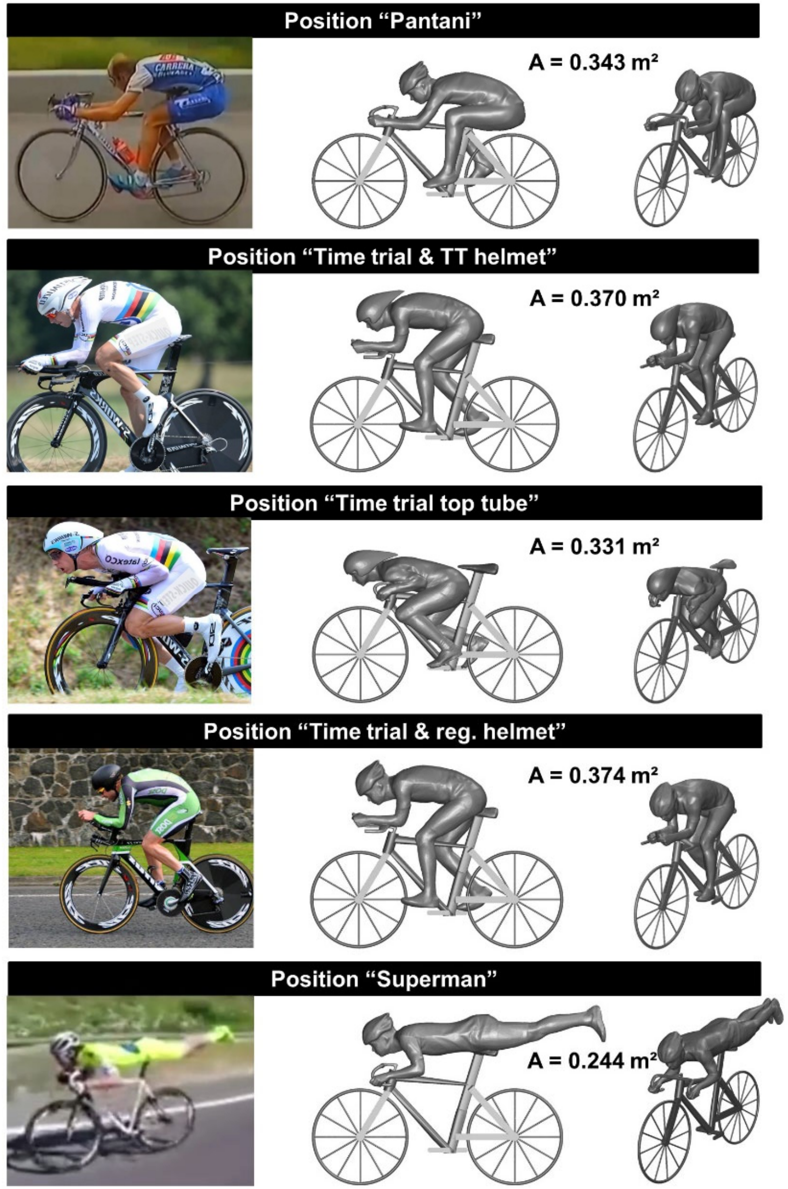
CFD simulations: More geometries

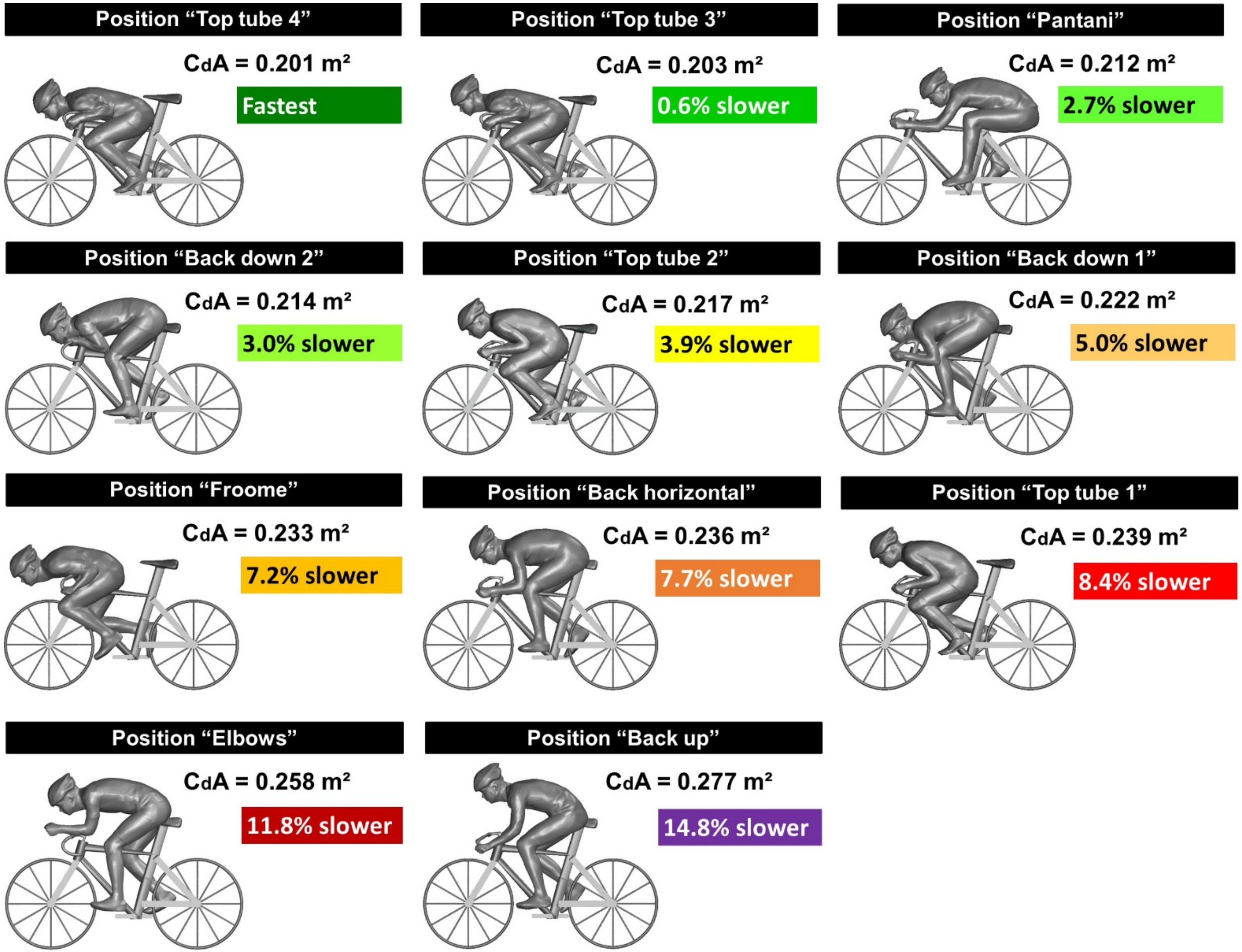


CFD simulations: More geometries



CFD simulations: More geometries





Position “Top tube 4”
$C_dA = 0.201$ m^2
Fastest
Position “Top tube 3”
$C_dA = 0.203$ m^2
0.6% slower
Position “Pantani”
$C_dA = 0.212$ m^2
2.7% slower
Position “Back down 2”
$C_dA = 0.214$ m^2
3.0% slower
Position “Top tube 2”
$C_dA = 0.217$ m^2
3.9% slower
Position “Back down 1”
$C_dA = 0.222$ m^2
5.0% slower
Position “Froome”
$C_dA = 0.233$ m^2
7.2% slower
Position “Back horizontal”
$C_dA = 0.236$ m^2
7.7% slower
Position “Top tube 1”
$C_dA = 0.239$ m^2
8.4% slower
Position “Elbows”
$C_dA = 0.258$ m^2
11.8% slower
Position “Back up”
$C_dA = 0.277$ m^2
14.8% slower

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Peter Sagan

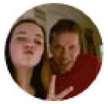
May 9, 2017 ·

Interesting study by TU Eindhoven, KU Leuven, Université de Liège and ANSYS, Inc. on the aerodynamic performance of different hill descent positions. It seems mine isn't that bad... I am practicing it around Lake Tahoe ahead of the Amgen Tour of California (photo by Chris Auld / RIDE 100%) Visit California

LINKEDIN.COM

Which cyclist hill descent position is really superior? Froom…

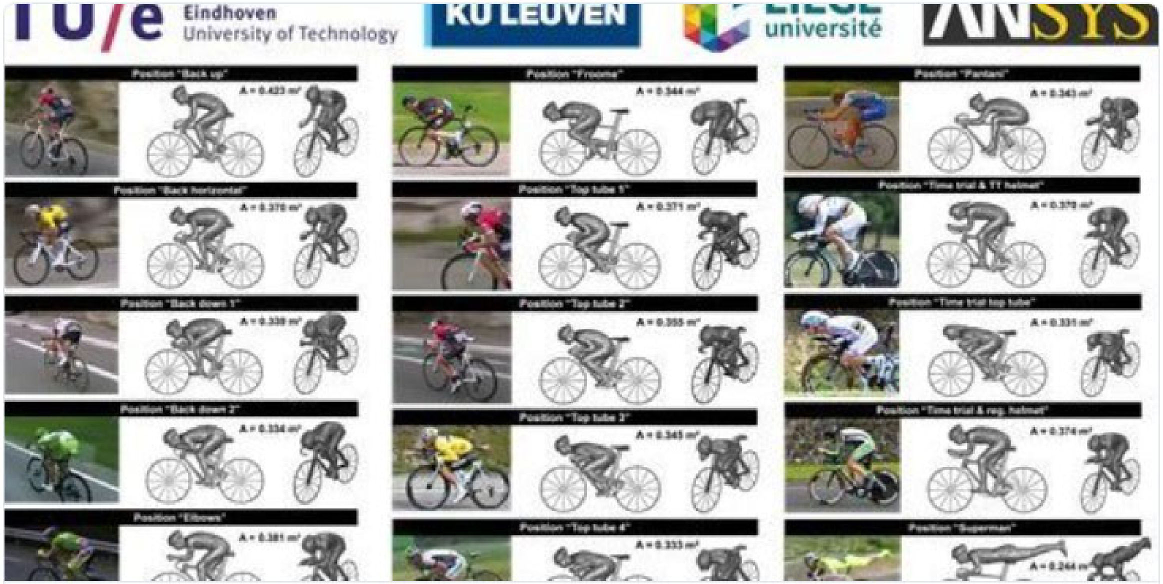
Executive summary The fact that different professional cyclists use very dif…



Peter Wardenier
@peterwardo

Following

@BertBlocken It seems @chrisfroome has changed to (close to) a 'top tube 4' bicycle position during the Finestre downhill (stage 19, '@giroditalia)? Watch this: bit.ly/2kuSk9S. Has he been studying your scientific work bit.ly/2tMfri9 ?

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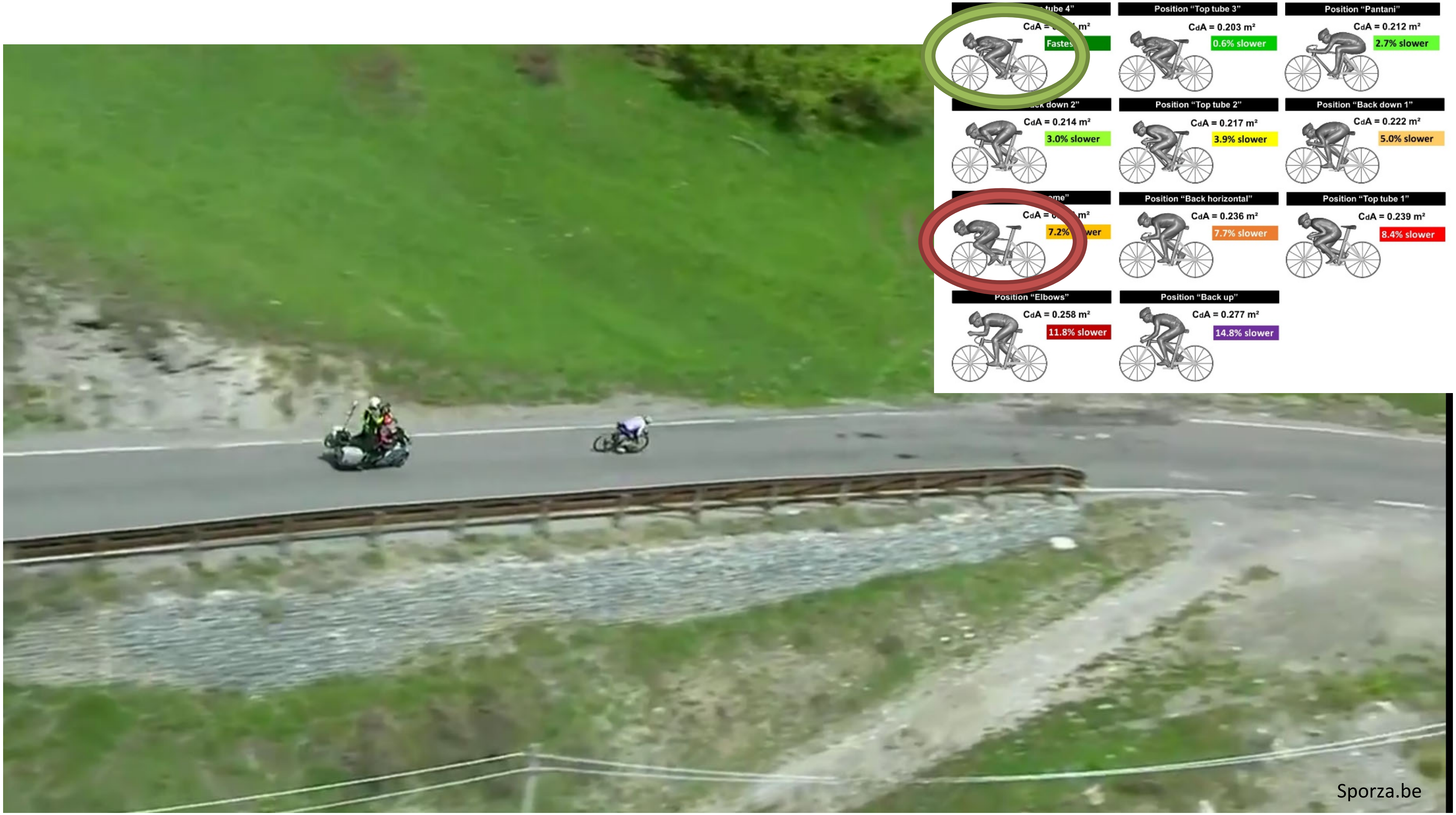
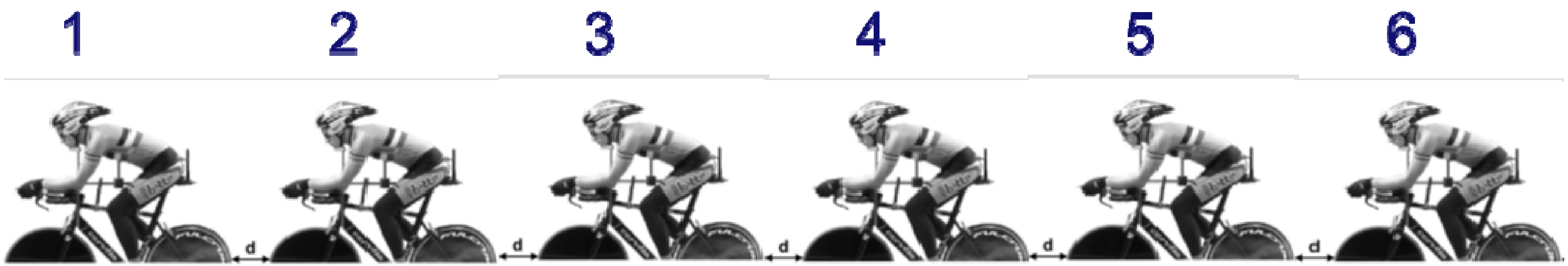

Position “Top tube 3”
CdA = 0.203 m²
0.6% slower
Position “Pantani”
CdA = 0.212 m²
2.7% slower
CdA = 0.214 m²
3.0% slower
Position “Top tube 2”
CdA = 0.217 m²
3.9% slower
Position “Back down 1”
CdA = 0.222 m²
5.0% slower
7.2%
Position “Back horizontal”
CdA = 0.236 m²
7.7% slower
Position “Top tube 1”
CdA = 0.239 m²
8.4% slower
Position “Elbows”
CdA = 0.258 m²
11.8% slower
Position “Back up”
CdA = 0.277 m²
14.8% slower
Sporza.be

QUESTION 6

Team time trial: Which cyclist has the lowest air resistance?

Six cyclists (same body geometry) are riding behind each other in a team time trial in zero-wind conditions. Which position has the lowest aerodynamic resistance?

A) Position 2
B) Position 3
C) Position 4
D) Position 5
E) Position 6




THE PELOTON PROJECT
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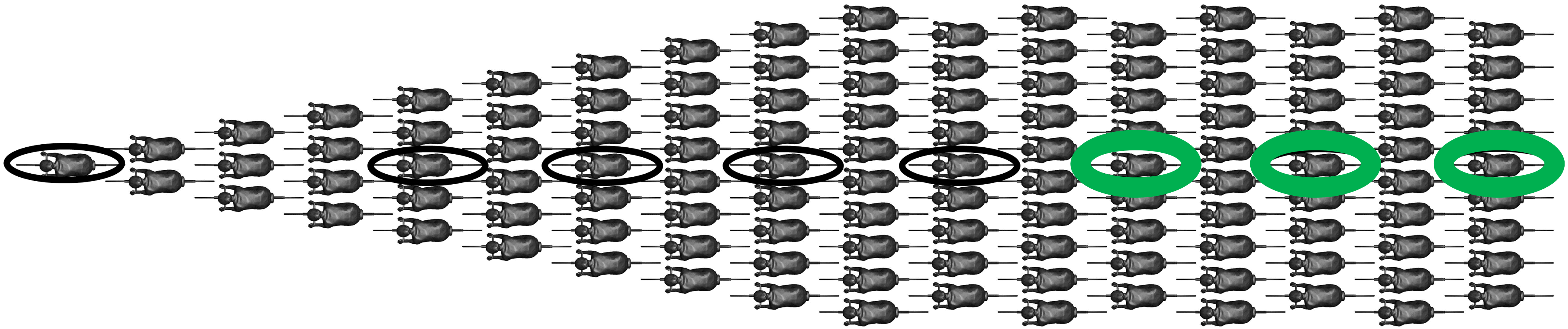
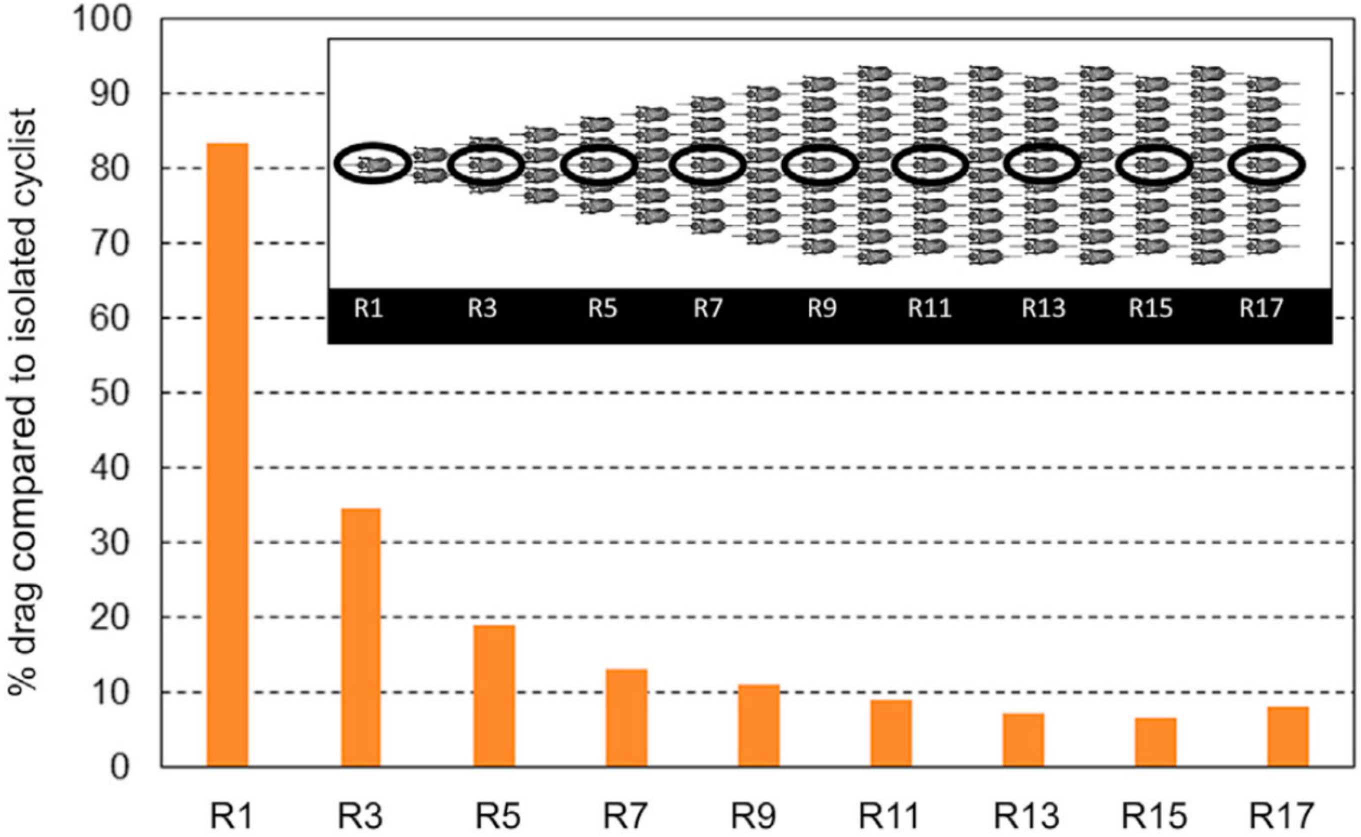
ANSYS
CRAY THE SUPERCOMPUTER COMPANY
KU LEUVEN
LIÈGE université
CUSTOMCOMPANY CREATING FINE GIFTS & AWARDS
FLEXFORM
TENAX BEELDENGIETERIJ

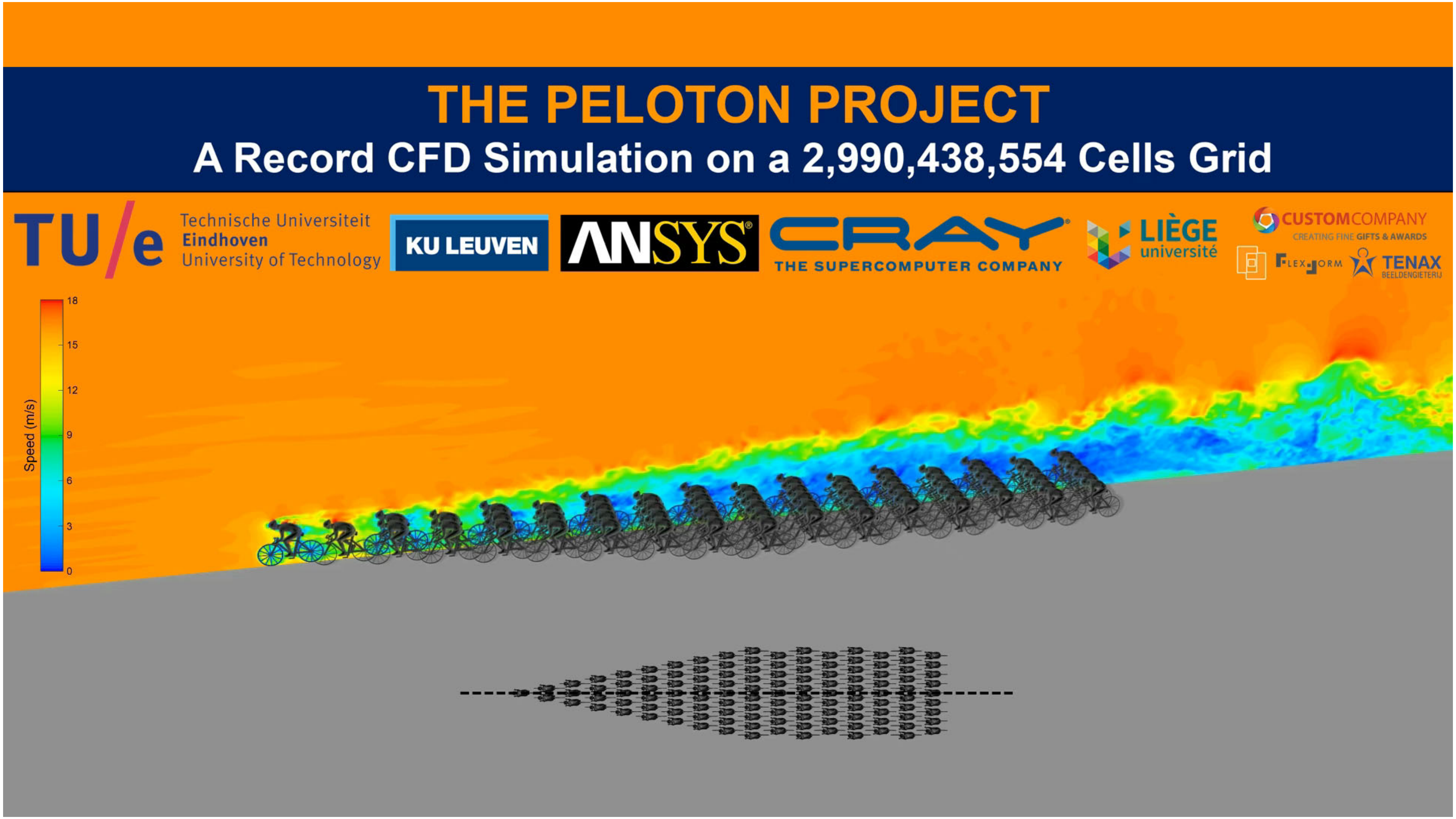
QUESTION 7

Peloton: Which cyclist has the lowest air resistance?



Drag in cycling pelotons




THE PELOTON PROJECT
A Record CFD Simulation on a 2,990,438,554 Cells Grid
TU/e Technische Universiteit Eindhoven University of Technology
KU LEUVEN
ANSYS
CRAY
THE SUPERCOMPUTER COMPANY
LIÈGE université
CUSTOMCOMPANY
CREATING FINE GIFTS & AWARDS
FLEXFORM
TENAX
BEELDENGIETERIJ
Speed (m/s)
18
15
12
9
6
3
0

THE PELOTON PROJECT

A Record CFD Simulation on a 2,990,438,554 Cells Grid

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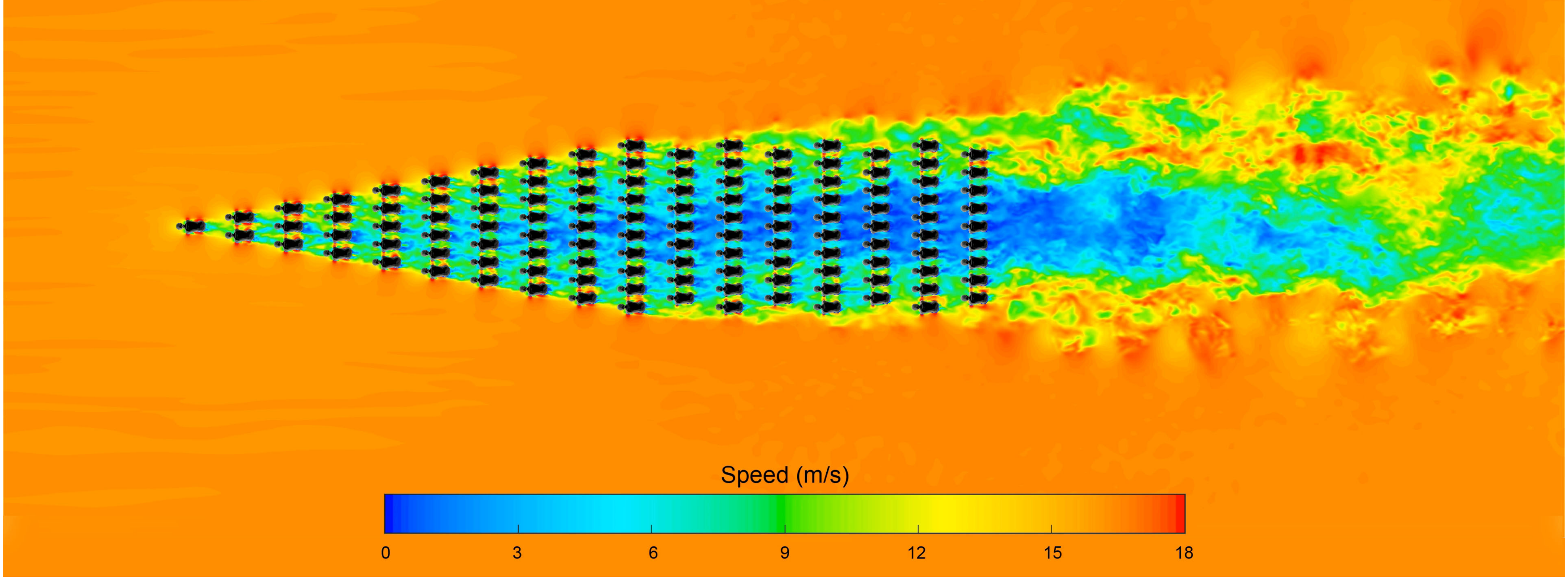
CUSTOMCOMPANY CREATING FINE GIFTS & AWARDS

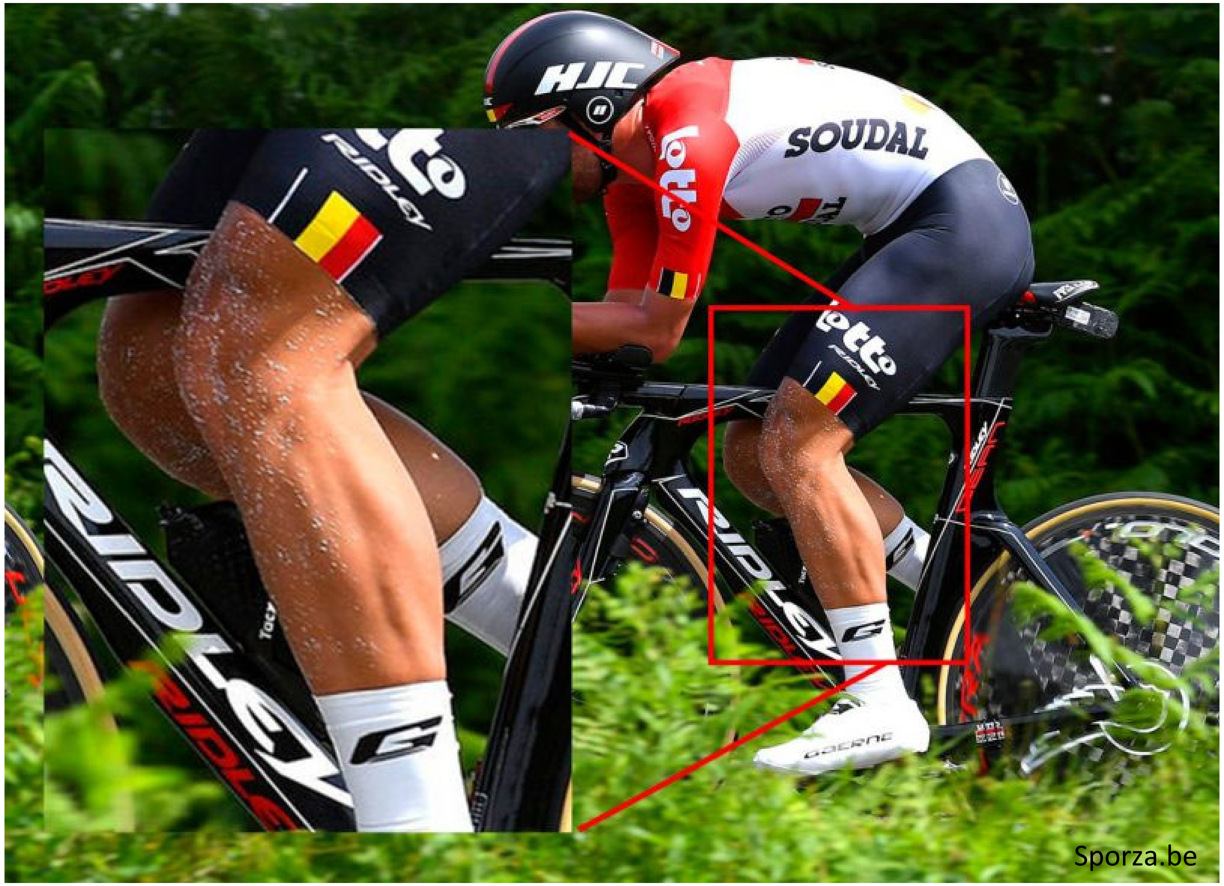
FLEXFORM

TENAX BEELDENGIETERIJ



QUESTION 8

What is the effect of the so-called speed gel?



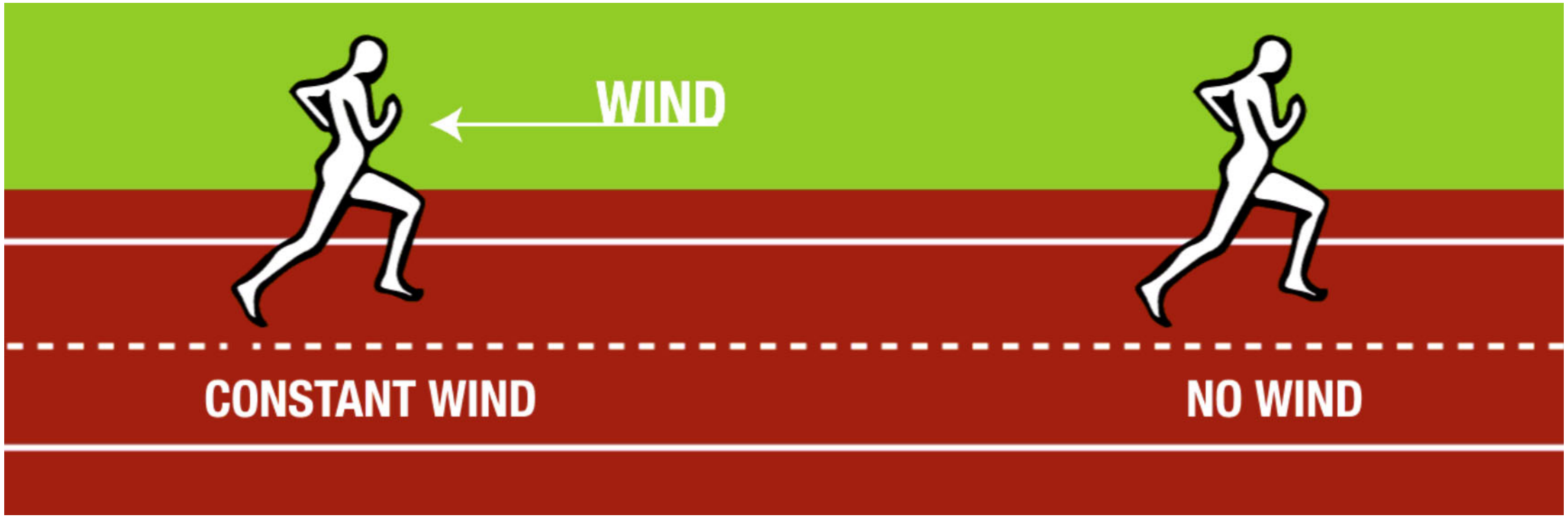
Cyclist will go:

A. Faster
B. Equally fast
C. Slower

QUESTION 9

What is fastest?

A) 400 m lap without wind
B) 400 m lap with 200 m head wind and 200 m tail wind of the same magnitude



QUESTION 9

Wind effects on running (e.g. 100 m sprint) (Mureika 2001)

$$f_d = \frac{1}{2}\rho\left(1 - \frac{1}{4}\exp[-\sigma t^2]\right)\frac{AC_d}{M}[u(t) - u_w]^2$$

Example:

$u(t) = 10$ m/s

Tailwind: $u_w = 2$ m/s → $[u(t)-u_w]^2 = 8^2 = 64$

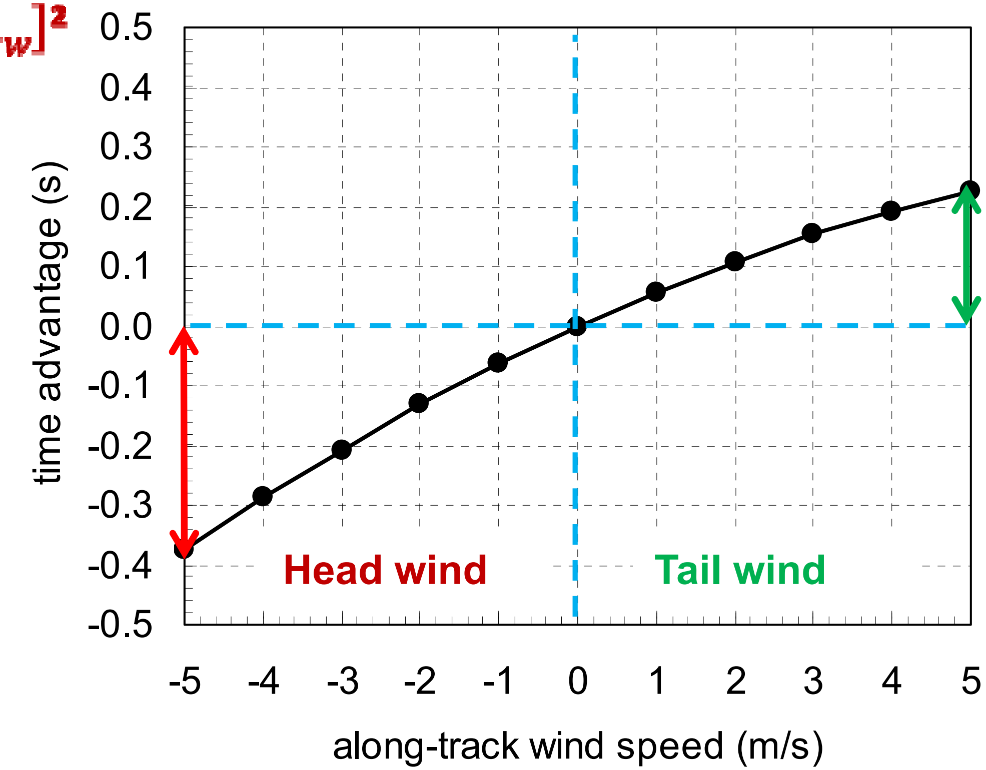
Headwind: $u_w = -2$ m/s → $[u(t)-u_w]^2 = 12^2 = 144$

QUESTION 9

Wind effects on running (e.g. 100 m sprint) (Mureika 2001)

$$f_d = \frac{1}{2}\rho\left(1 - \frac{1}{4}\exp[-\sigma t^2]\right)\frac{AC_d}{M}[u(t) - u_w]^2$$

Negative effect of head wind is larger than positive effect of tail wind!



100 m sprint aerodynamics

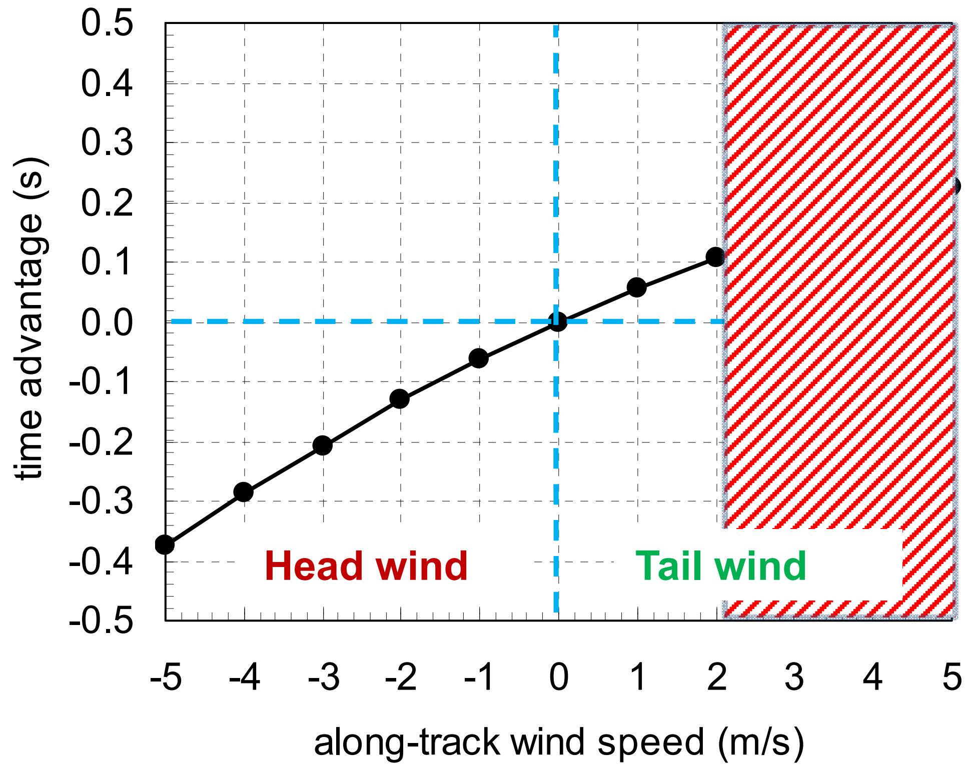
Wind assistance

IAAF rules (now: World Athletics)

At the 1936 Congress of the IAAF it was agreed that for **official recognition** of records, the assisting wind velocity must be **2 m/s or less**.

Consequences:

- Head wind can **hamper** exceptional performances
- Top “legal” performances are often achieved **with tail wind** (below 2 m/s)
- Equipment **malfunctioning** can contaminate record tables



100 m sprint aerodynamics

Simplification of mathematical-physical model (Pritchard 1993, Mureika 2001)

$$t_0 \approx t_w \left[1.03 - 0.03\left(1 - u_w \frac{t_w}{100}\right)^2\right]$$

100 m sprint aerodynamics

Some examples

Top “legal” performances are often achieved **with tail wind** (below 2 m/s)

Rank	Competitor	Mark (s)	Wind (m/s)	Venue	Corr.	Corr. rank
		t_w (s)			t_0 (s)	
1	Usain BOLT	9.58	0.9	Berlin	9.63	1
2	Usain BOLT	9.63	1.5	London	9.71	4
3	Usain BOLT	9.69	0.0	Beijing	9.69	3
3	Tyson GAY	9.69	2.0	Shanghai	9.79	7
3	Yohan BLAKE	9.69	-0.1	Lausanne	9.68	2
4	Tyson GAY	9.71	0.9	Berlin	9.76	6
5	Usain BOLT	9.72	1.7	New York City	9.81	8
5	Asafa POWELL	9.72	0.2	Lausanne	9.73	5
6	Asafa POWELL	9.74	1.7	Rieti	9.83	9

100 m sprint aerodynamics

Some examples

Equipment **malfunctioning** can contaminate record tables

Rank	Competitor	Mark (s)
		t_w (s)
1	Florence GRIFFITH-JOYNER	10.49
2	Florence GRIFFITH-JOYNER	10.61
3	Florence GRIFFITH-JOYNER	10.62
4	Carmelita JETER	10.64
5	Marion JONES	10.65 A
6	Carmelita JETER	10.67
7	Florence GRIFFITH-JOYNER	10.70
7	Marion JONES	10.70
7	Carmelita JETER	10.70

100 m sprint aerodynamics

Some examples

Equipment **malfunctioning** can contaminate record tables

Rank	Competitor	Mark (s)	Wind (m/s)	Venue	Corr.
		t_w (s)			t_0 (s)
1	Florence GRIFFITH-JOYNER	10.49	0.0	Indianapolis	10.49
2	Florence GRIFFITH-JOYNER	10.61	1.2	Indianapolis	10.69
3	Florence GRIFFITH-JOYNER	10.62	1.0	Seoul	10.68
4	Carmelita JETER	10.64	1.2	Shanghai	10.72
5	Marion JONES	10.65 A	1.1	Johannesburg	10.72 A
6	Carmelita JETER	10.67	-0.1	Thessaloniki	10.66
7	Florence GRIFFITH-JOYNER	10.70	1.6	Indianapolis	10.80
7	Marion JONES	10.70	-0.1	Sevilla	10.69
7	Carmelita JETER	10.70	2.0	Eugene	10.82

100 m sprint aerodynamics

Some examples

Equipment **malfunctioning** can contaminate record tables

→ Common belief that the current WR by the late Florence Griffith-Joyner was **strongly wind-assisted** due to equipment malfunctioning.

→ Achieved at 1988 U.S. Olympic Trials in Indianapolis
- → 10.60 s in the heats (wind-assisted)
- → **10.49 s** in quarterfinals (0.0 m/s measured!)
- → 10.70 s in semifinals (wind-assisted)
- → 10.61 in final

100 m sprint aerodynamics

Some examples

Equipment **malfunctioning** can contaminate record tables

→ Concerns:

- → 0.0 m/s as a reading **on a very windy day** immediately raised suspicion
- → Triple jump in the same stadium next to the runway: **only 3 of the 46** measurable jumps were wind-legal (i.e. u_w <= 2 m/s).
- → Triple jump wind-indicator gave **+4.3 m/s** just before the first of the three 100 m quarterfinals
- → Second quarterfinal **also** had a measured **0.0 m/s**
- → Third quarterfinal had **+5.0 m/s**

100 m sprint aerodynamics

Some examples

Equipment **malfunctioning** can contaminate record tables

→ Based on the study of wind effects on 100 m sprint times, Nick Linthorne* demonstrated that the actual wind reading for this first quarterfinal was incorrect, and should have been **+5.5** (+/- 0.5) m/s.

Rank	Competitor	Mark (s) t_w (s)	Wind (m/s)	Venue	Corr. t_0 (s)	Corr. rank
1	Florence GRIFFITH-JOYNER	10.49	**5.5**	Indianapolis	10.75	5
2	Florence GRIFFITH-JOYNER	10.61	1.2	Indianapolis	10.69	3
3	Florence GRIFFITH-JOYNER	10.62	1.0	Seoul	10.68	2
4	Carmelita JETER	10.64	1.2	Shanghai	10.72	4
5	Marion JONES	10.65 A	1.1	Johannesburg	10.72 A	4
6	Carmelita JETER	10.67	-0.1	Thessaloniki	10.66	1
7	Florence GRIFFITH-JOYNER	10.70	1.6	Indianapolis	10.80	6
7	Marion JONES	10.70	-0.1	Sevilla	10.69	3
7	Carmelita JETER	10.70	2.0	Eugene	10.82	7

100 m sprint aerodynamics

Some examples

Equipment **malfunctioning** can contaminate record tables

→ Based on the study of wind effects on 100 m sprint times, Nick Linthorne* demonstrated that the actual wind reading for this first quarterfinal was incorrect, and should have been **+5.5** (+/- 0.5) m/s.

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7	Florence GRIFFITH-JOYNER	10.70	1.6	Indianapolis	10.80	6
7	Marion JONES	10.70	-0.1	Sevilla	10.69	3
7	Carmelita JETER	10.70	2.0	Eugene	10.82	7

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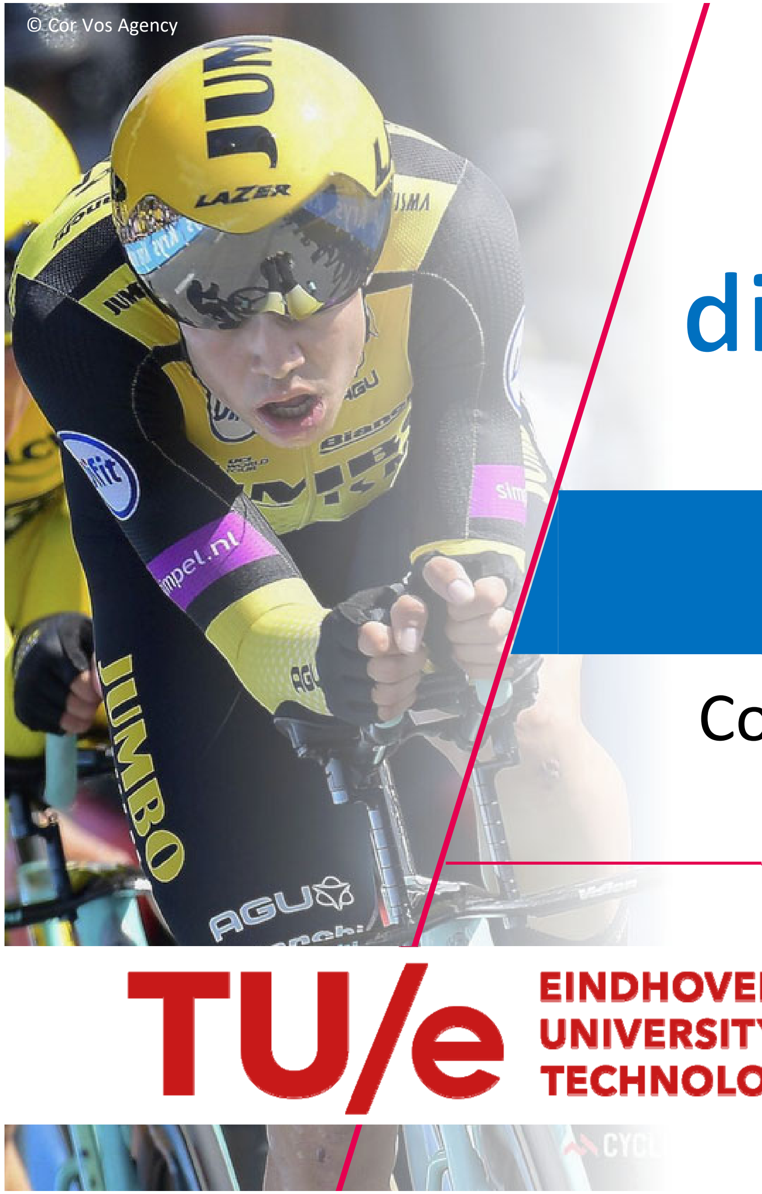
APOLOGY
ADVERTISEMENT

Tweede seizoen “Wereldrecord” op Canvas:

Op maandag, **21u20**:

1. Verspringen (Mike Powell)
2. Zevenkamp (Jackie Joyner-Kersee)
3. **Alpe d’Huez (Marco Pantani)**
4. Schansspringen (Stefan Kraft)
5. Gymnastiek (Nadia Comaneci)
6. **Speerwerpen (Jan Zelezny)**
7. 400 meter (Wayde van Niekerk)

Terug te zien op “VRT NU”



Wind engineering ten dienste van sport en steden

Dank u

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