Plenary Session 4:

"Development, validation and application of a CFD based wind turbine simulation model"

Gabriel Usera - UdelaR

UNIVERSIDAD DE LA REPÚBLICA URUGUAY

FACULTAD DE INGENIERIA

MFC
GRUPO DE MECÁNICA DE LOS FLUIDOS COMPUTACIONAL

SWTOMP
Small Wind Turbines Optimization and Market Promotion

Workshop
Small Wind Turbines

caffa3d.MBRi : Open Source Ongoing Development

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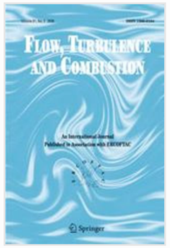
2004 … 2008



Flow, Turbulence and Combustion
October 2008, 81:471 | Cite as

A Parallel Block-Structured Finite Volume Method for Flows in Complex Geometry with Sliding Interfaces

Authors | Authors and affiliations

G. Usera, A. Vernet, J. A. Ferré

2014

Cluster Computing
June 2014, Volume 17, Issue 2, pp 231–241 | Cite as

A general purpose parallel block structured open source incompressible flow solver

Authors | Authors and affiliations

Mariana Mendina, Martin Draper, Ana Paula Kelm Soares, Gabriel Narancio, Gabriel Usera

Ann Biomed Eng. 2015 Jan;43(1):154-67. doi: 10.1007/s10439-014-1082-9. Epub 2014 Aug 13.

Accuracy and reproducibility of patient-specific hemodynamic models of stented intracranial aneurysms: report on the Virtual Intracranial Stenting Challenge 2011.

2015

Cito S[1], Geers AJ, Arroyo MP, Palero VR, Pallarés J, Vernet A, Blasco J, San Román L, Fu W, Qiao A, Janiga G, Miura Y, Ohta M, Mendina M, Usera G, Frangi AF.

Computers and Fluids 156 (2017) 200–208

Contents lists available at ScienceDirect

Computers and Fluids

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

ELSEVIER

2017

Coupled discrete element and finite volume methods for simulating loaded elastic fishnets in interaction with fluid

CrossMark

Paolo Sassi, Jorge Freiria, Paula La Paz, Mariana Mendina, Martin Draper, Gabriel Usera*
IMFIA - UdelaR - J. Herrera y Reissig 565, Montevideo, 11300, Uruguay

Tenth International Conference on Computational Fluid Dynamics (ICCFD10), Barcelona,Spain, July 9-13, 2018

ICCFD10-2018-xxxx

2018 …

A Large Eddy Simulation model for the study of wind turbine interactions and its application

M. Draper[1,*], A. Guggeri[1], M. Mendina[1], G. Usera[1], and F. Campagnolo[2]

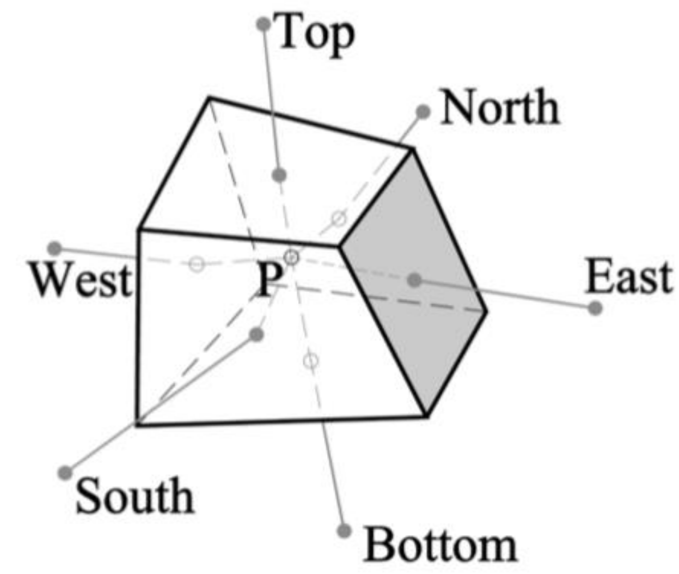
caffa3d.MBRi : Finite Volume Flow Solver

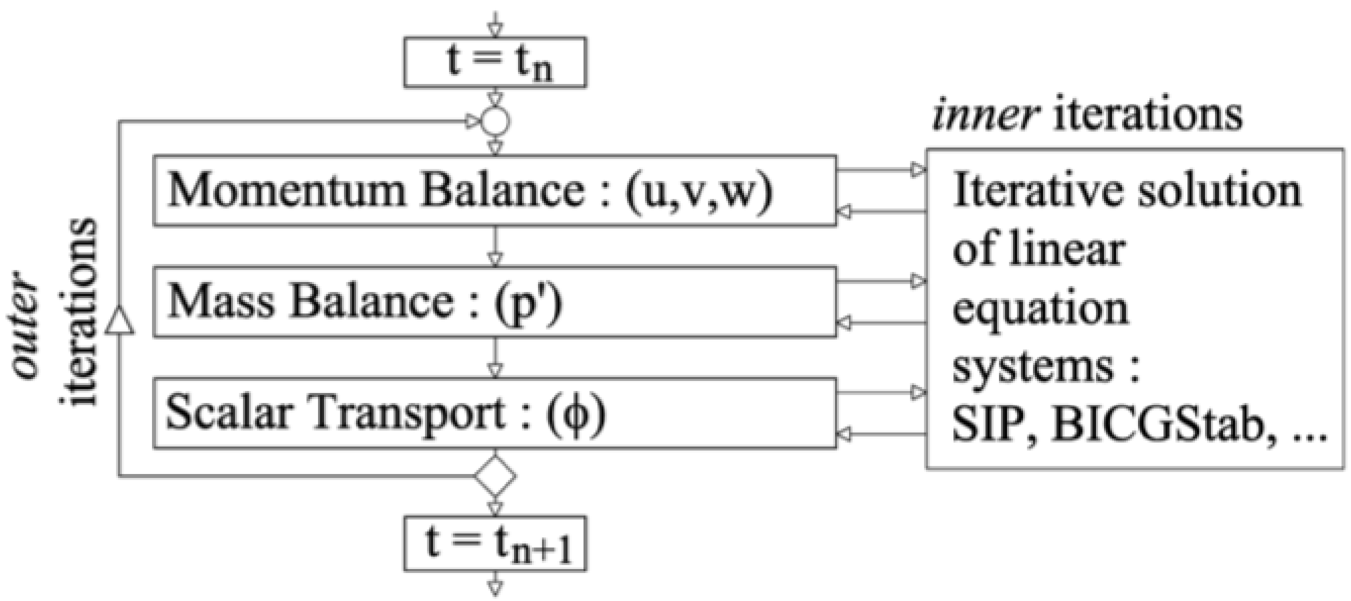
$$\int_S (\boldsymbol{v} \cdot \hat{\boldsymbol{n}}_S)\, dS = 0$$

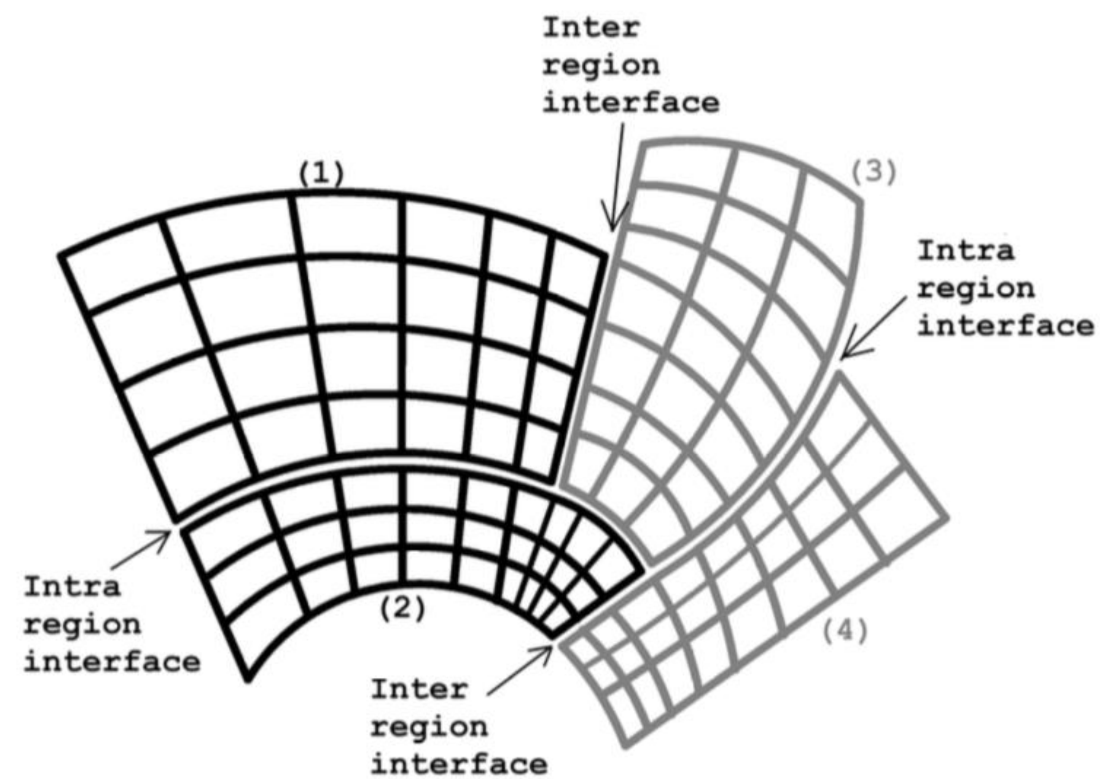
$$\int_\Omega \rho \frac{\partial u}{\partial t} d\Omega + \int_S \rho u \,(\boldsymbol{v} \cdot \hat{\boldsymbol{n}}_S)\, dS =$$

$$\int_\Omega \rho\beta\,(T - T_{ref})\, \boldsymbol{g} \cdot \hat{\boldsymbol{e}}_1 d\Omega + \int_S -p\hat{\boldsymbol{n}}_S \cdot \hat{\boldsymbol{e}}_1 dS +$$

$$\int_S (2\mu \boldsymbol{D} \cdot \hat{\boldsymbol{n}}_S) \cdot \hat{\boldsymbol{e}}_1 dS$$

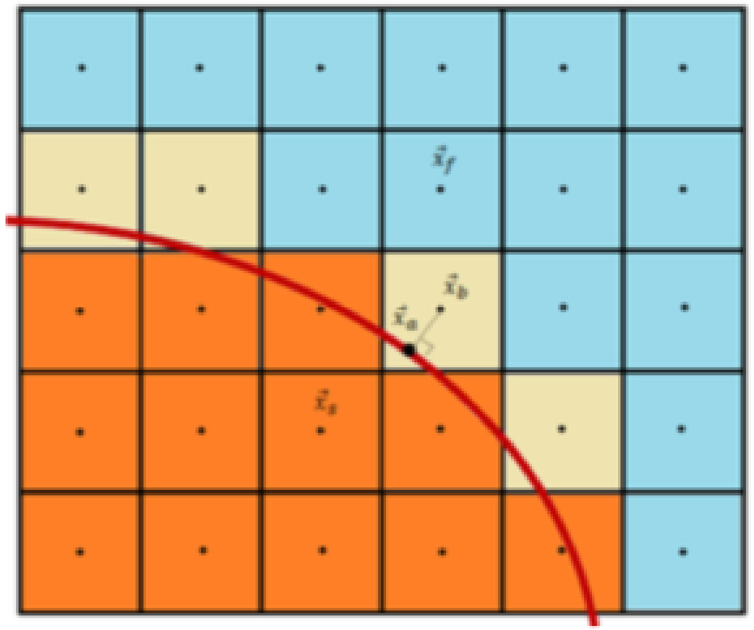






(Mendina et al, 2014)

Immersed Boundary Conditions



$$\int_{\Omega} \rho \frac{\partial \vec{\mathbf{v}}}{\partial t} \, d\Omega + \int_{S} \rho \vec{\mathbf{v}} (\vec{\mathbf{v}} \cdot \hat{\boldsymbol{n}}_S) \, dS = \int_{\Omega} \rho \beta (T - T_{ref}) \vec{\mathbf{g}} \, d\Omega$$
$$+ \int_{S} -p \hat{\boldsymbol{n}}_S \, dS + \int_{S} (2\mu \boldsymbol{D} \cdot \hat{\boldsymbol{n}}_S) \, dS + \boldsymbol{F_{imb}}$$

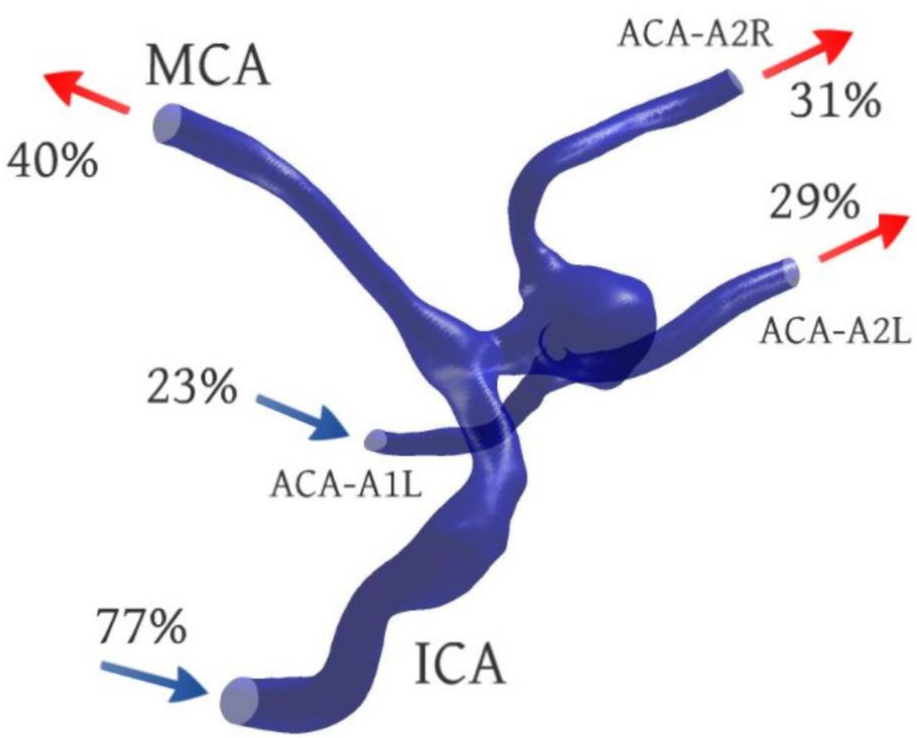
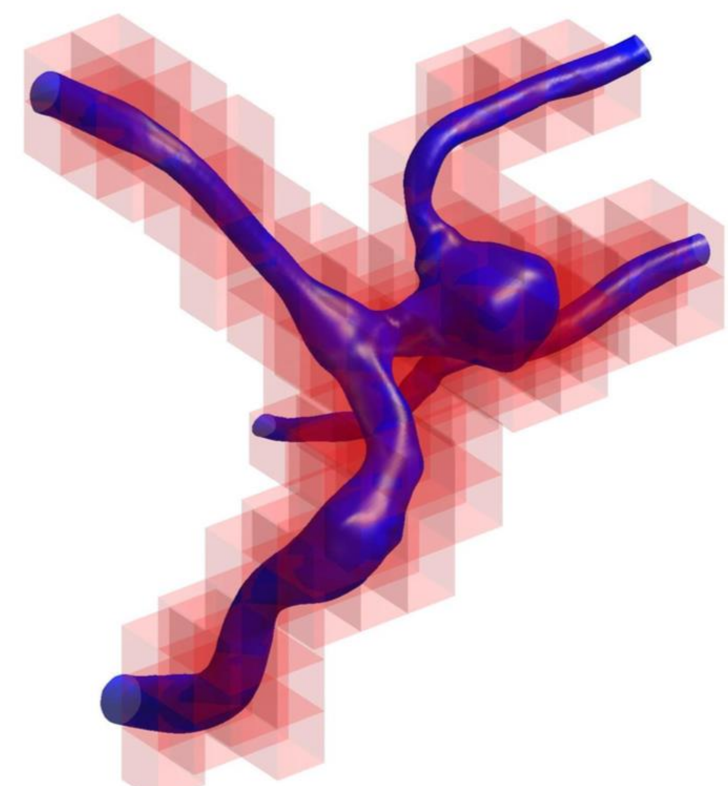


Fig. 14 Patient specific aneurysm geometry with specified flow distribution at inlets and outlets.



(Mendina et al, 2014)

Immersed Boundary Conditions

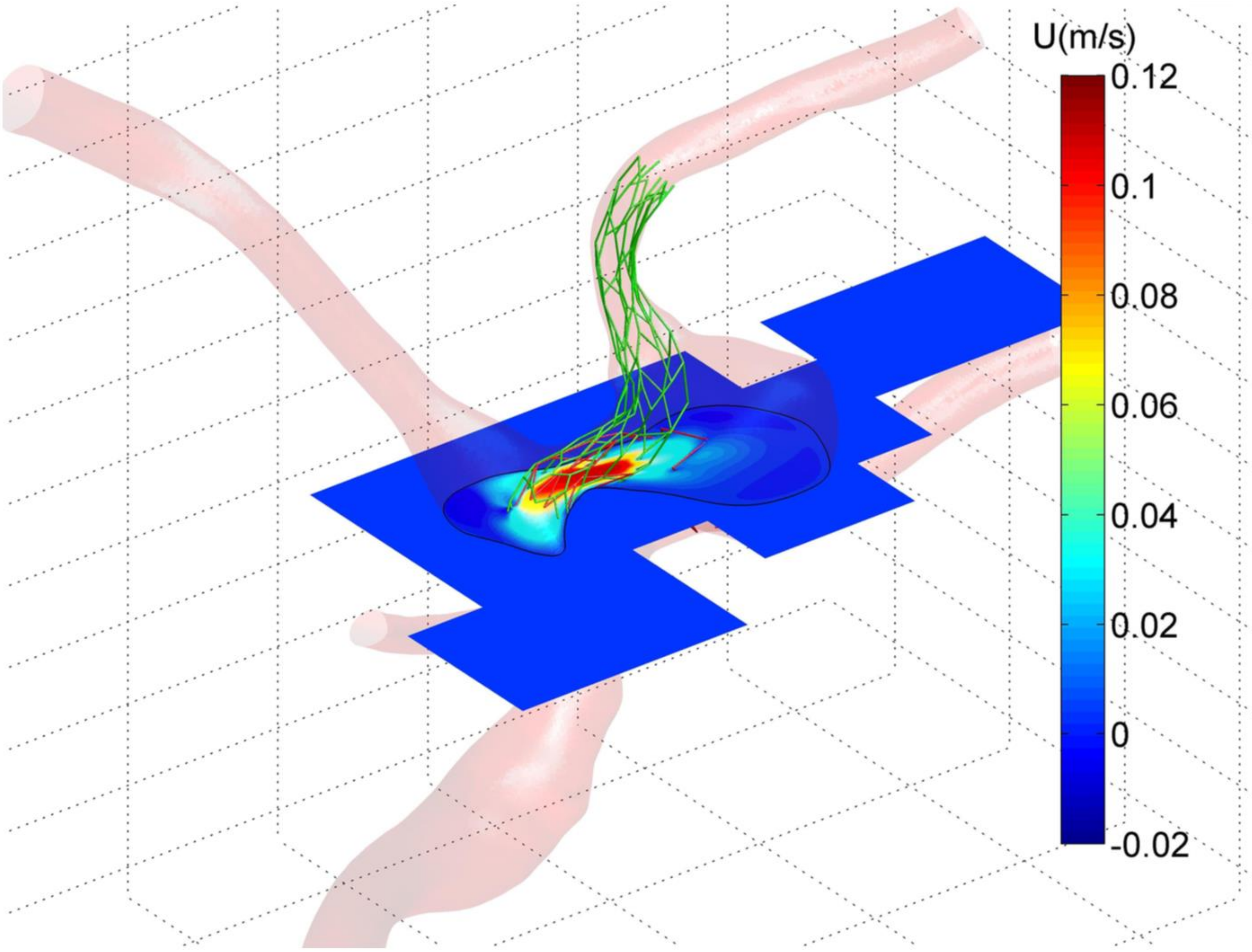
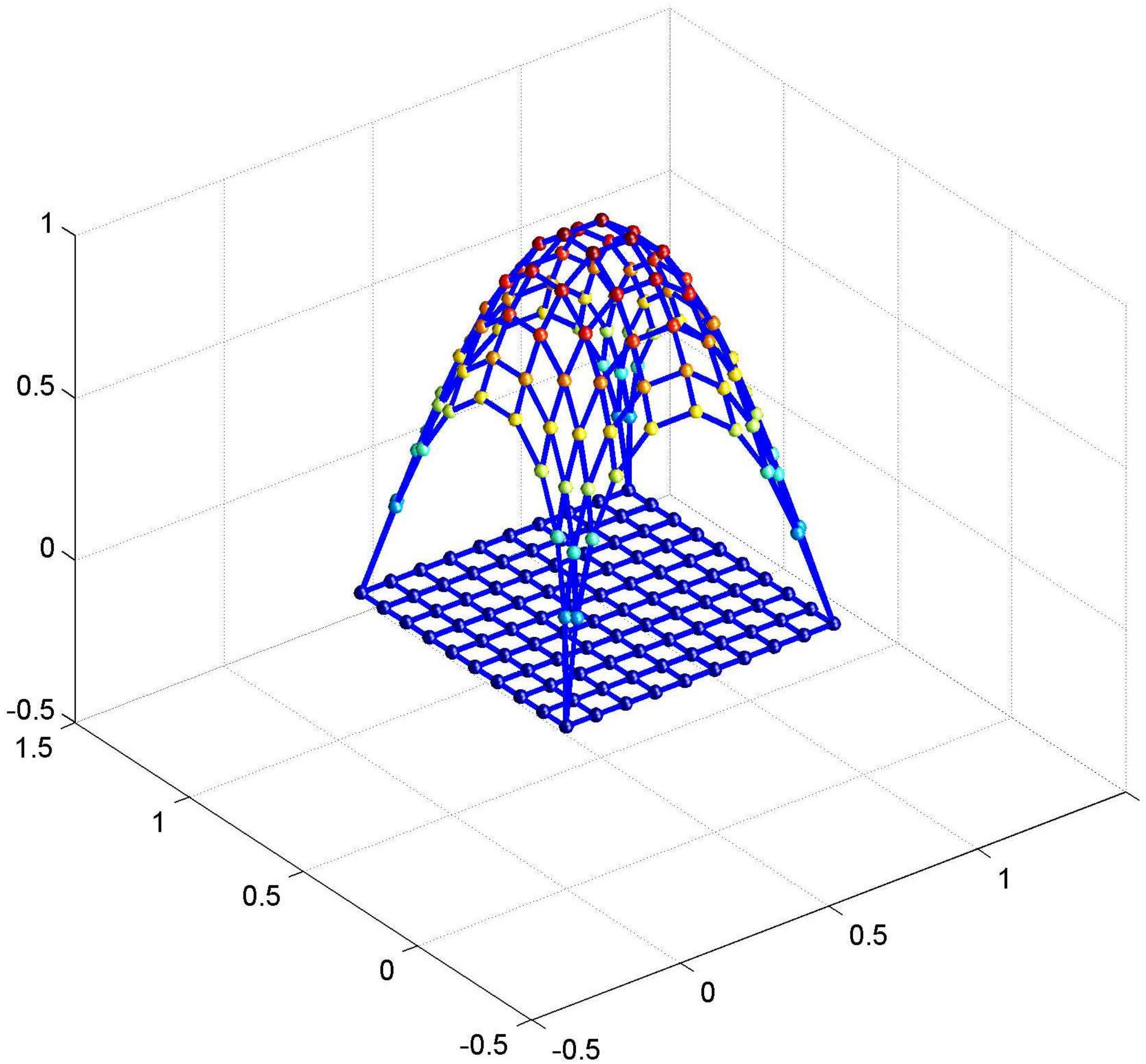


Fig. 16 Detail of flow interaction with stents.

(Mendina et al, 2014)

Multi body dynamics



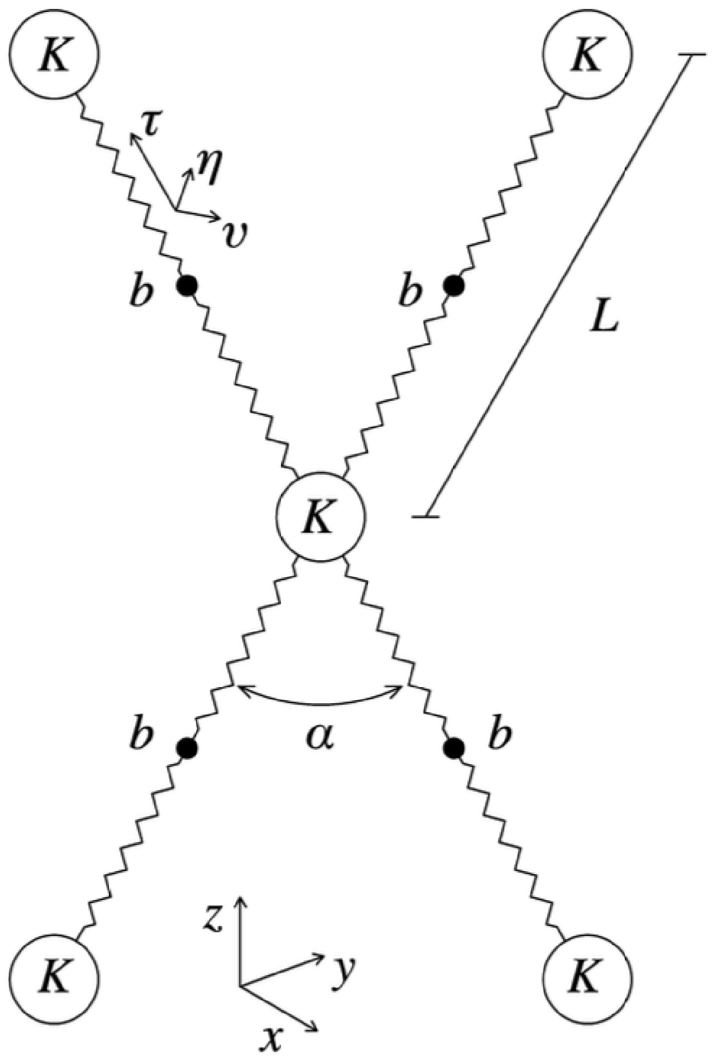


Figure 1: Sketch of the point masses and massless strings.

(Sassi et al, 2017)

Multi body dynamics

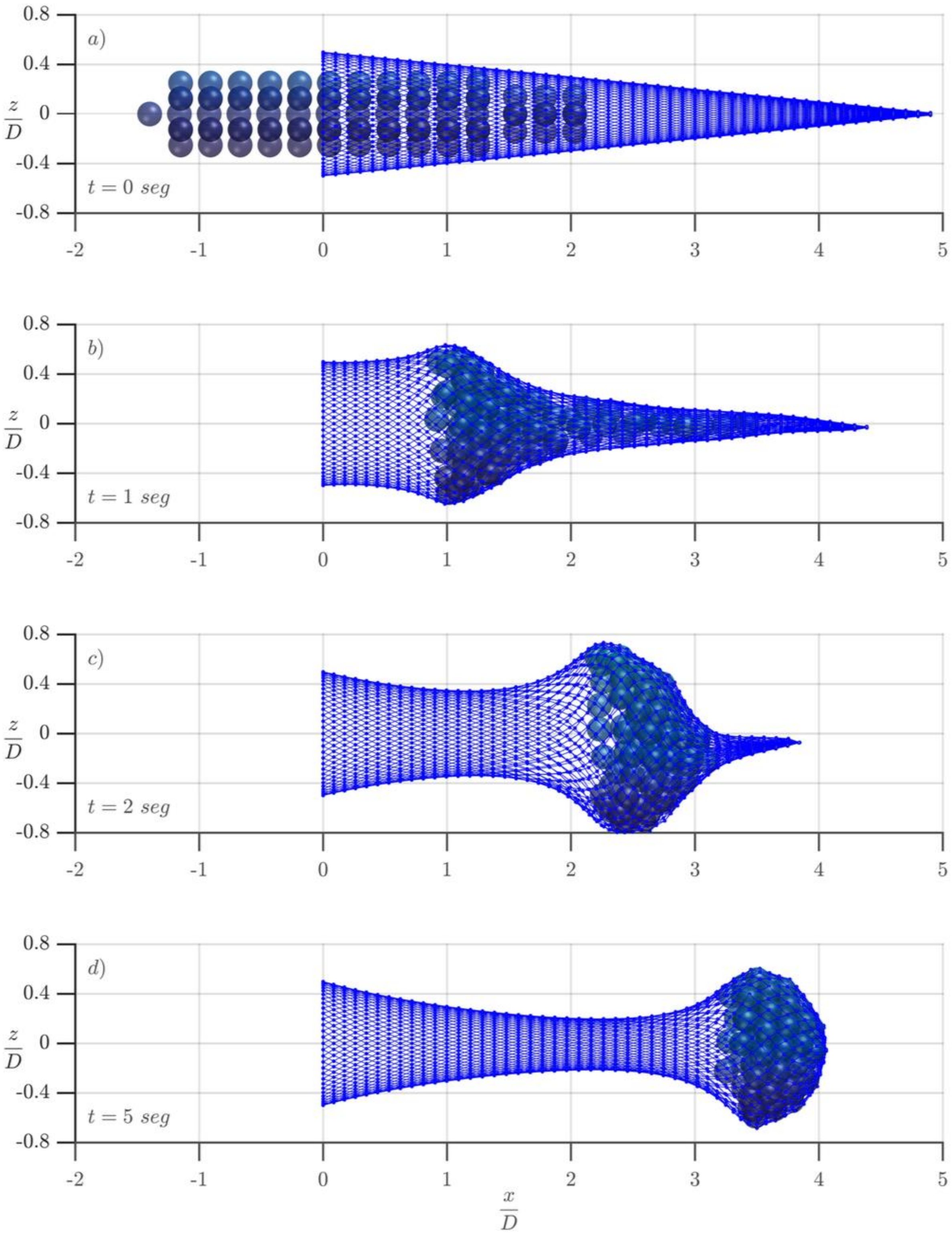


Figure 3: Evolution of the fishnet shape, at time steps t = 0 , 1.0 , 2.0 , 5.0 s, as the load is dragged into the fishnet.

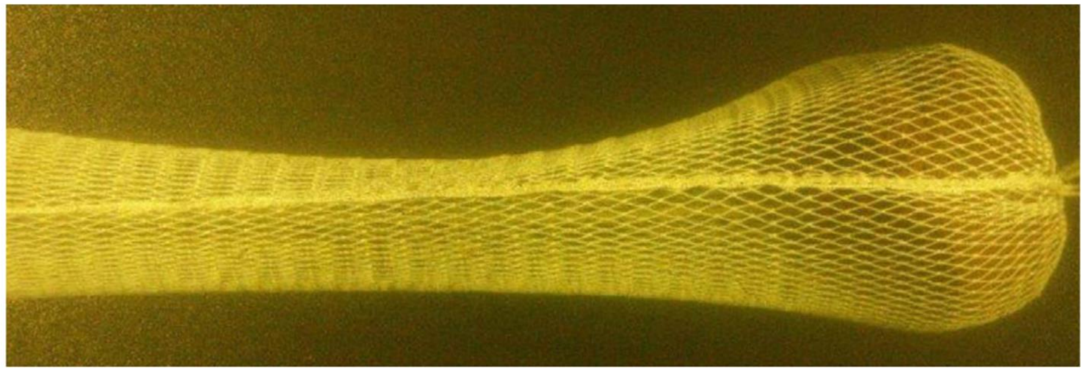


Fig. 5. Shape of the fishnet during the towing tank test.

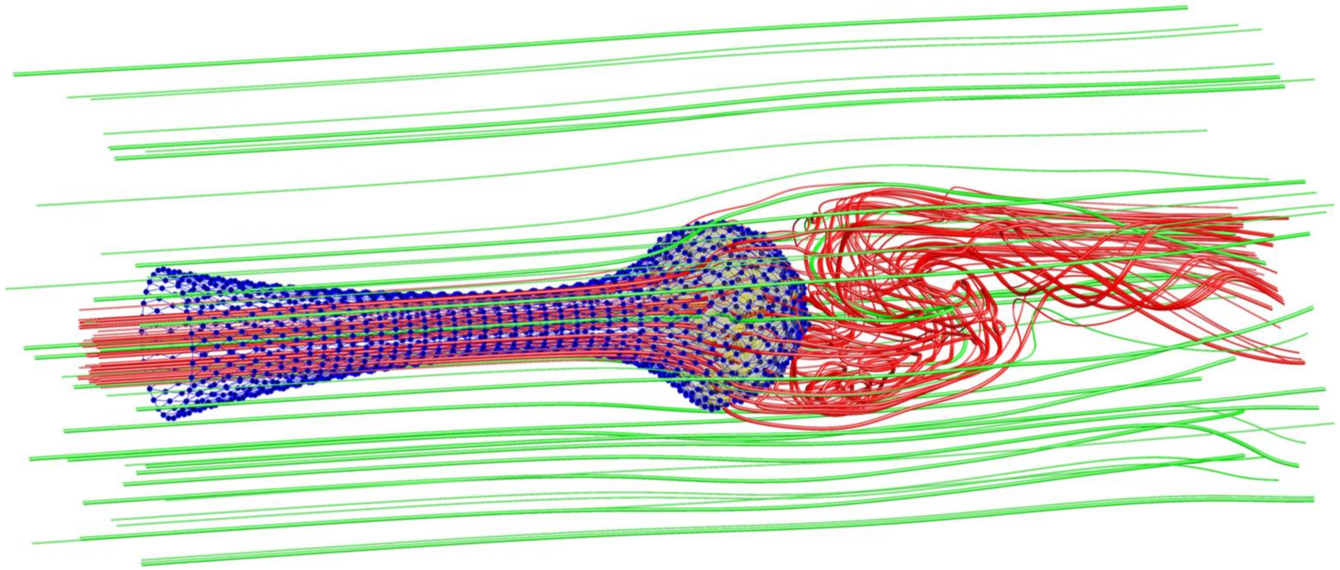
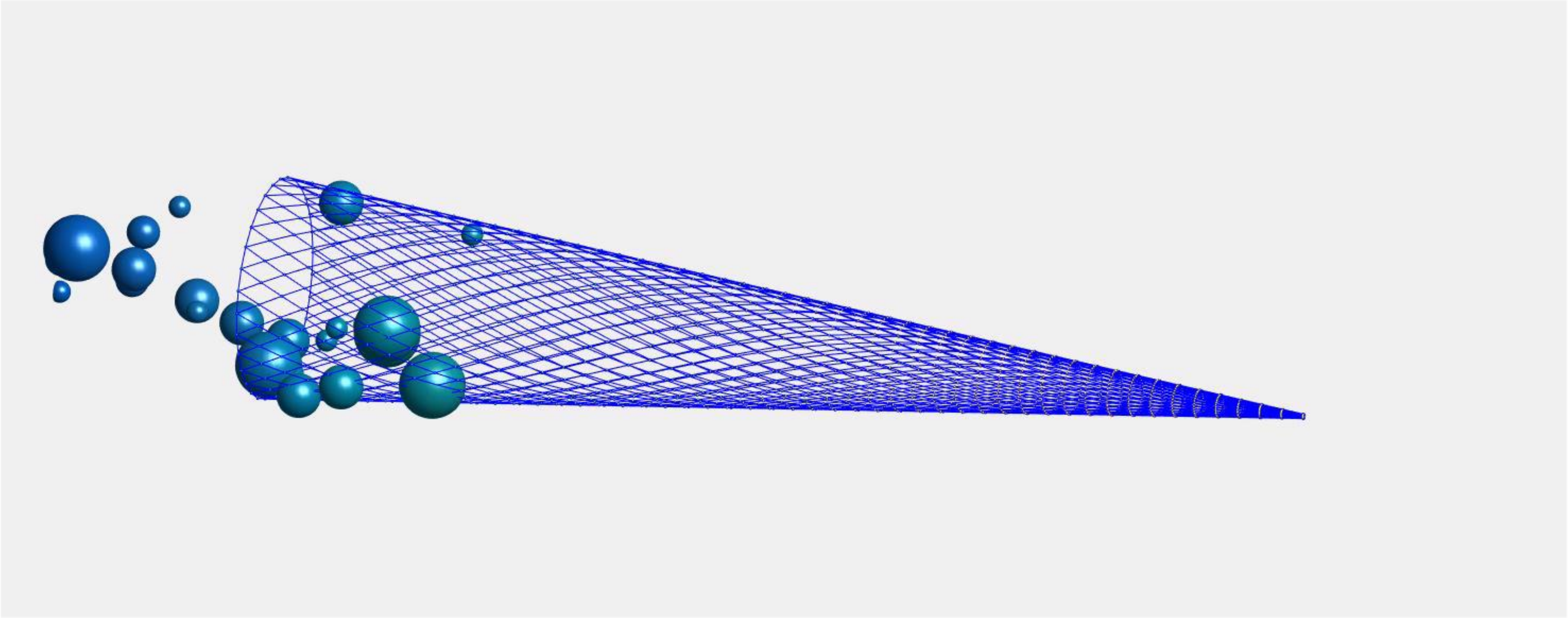


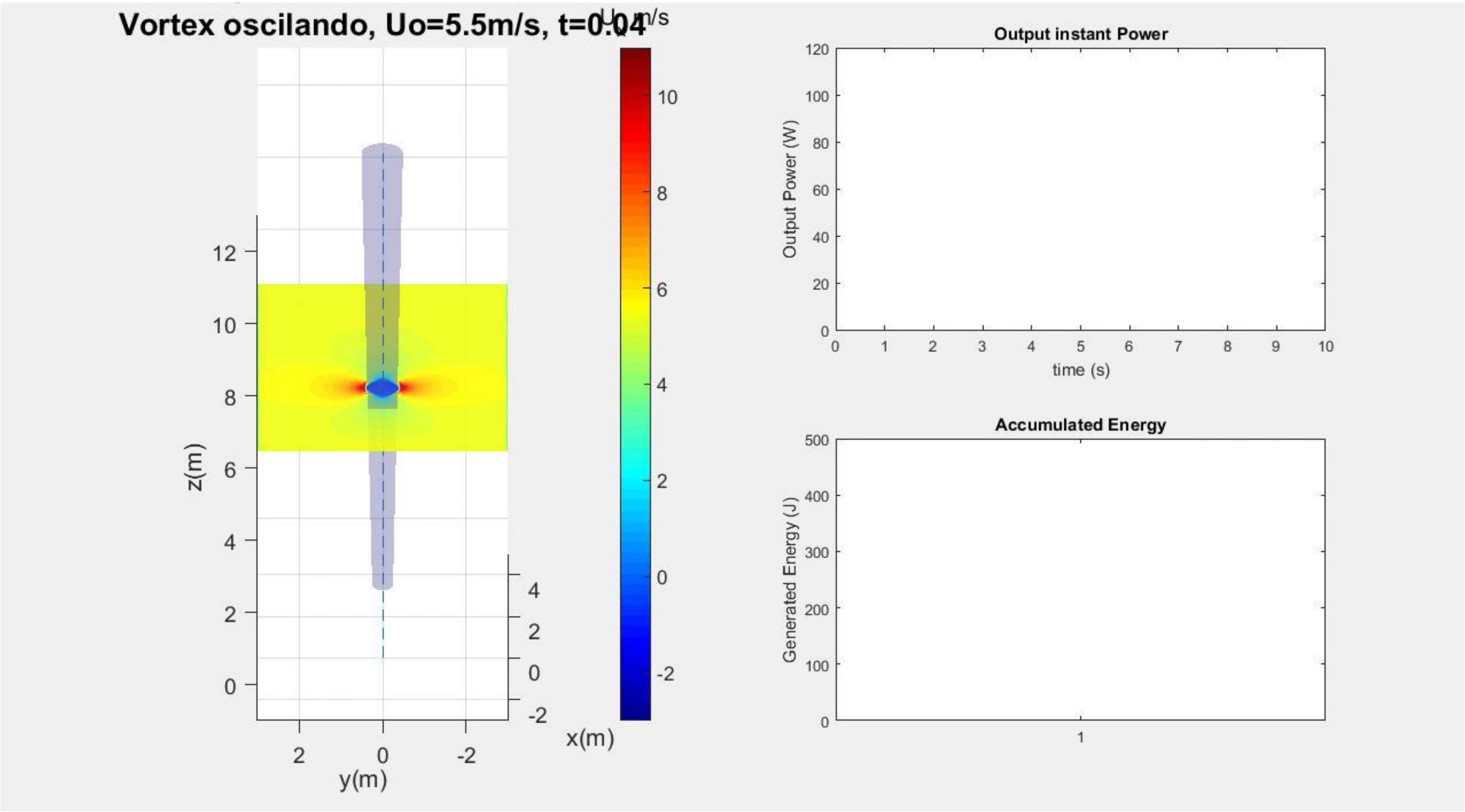
Figure 5: Stream Lines

(Sassi et al, 2017)

Loaded Fishnet Simulation



Vorticity Wind Turbine



(Sassi et al, 2018)

CFD BEM WTG model

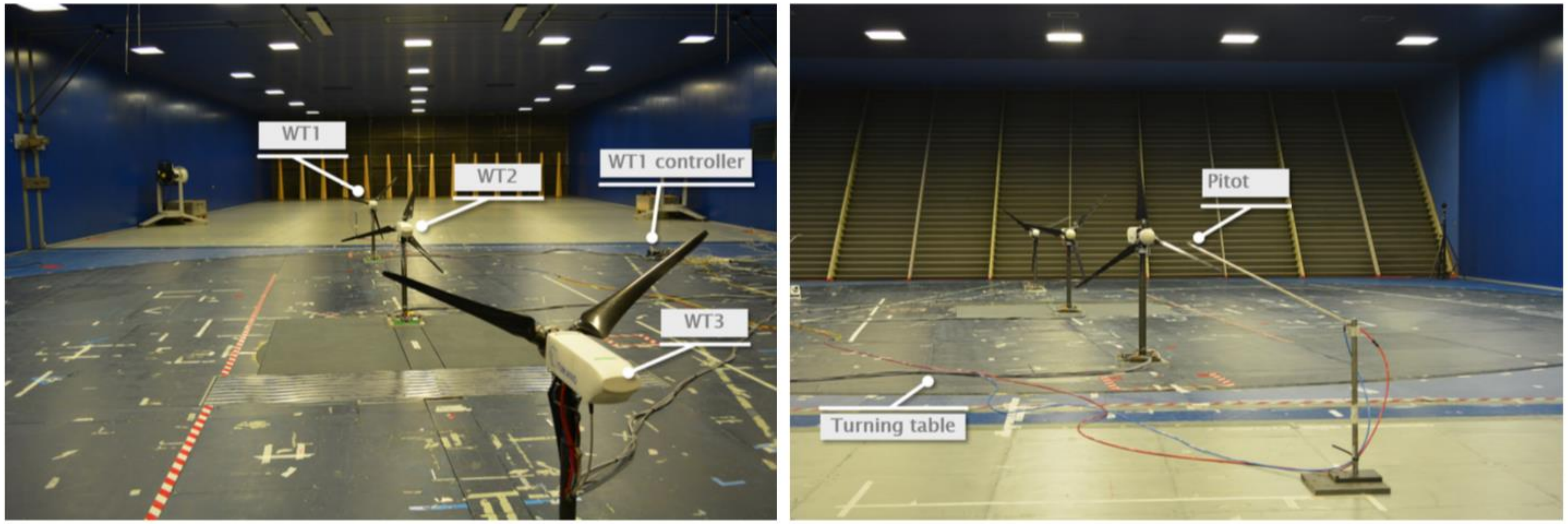


Figure 3: Wind farm layout in the wind tunnel.

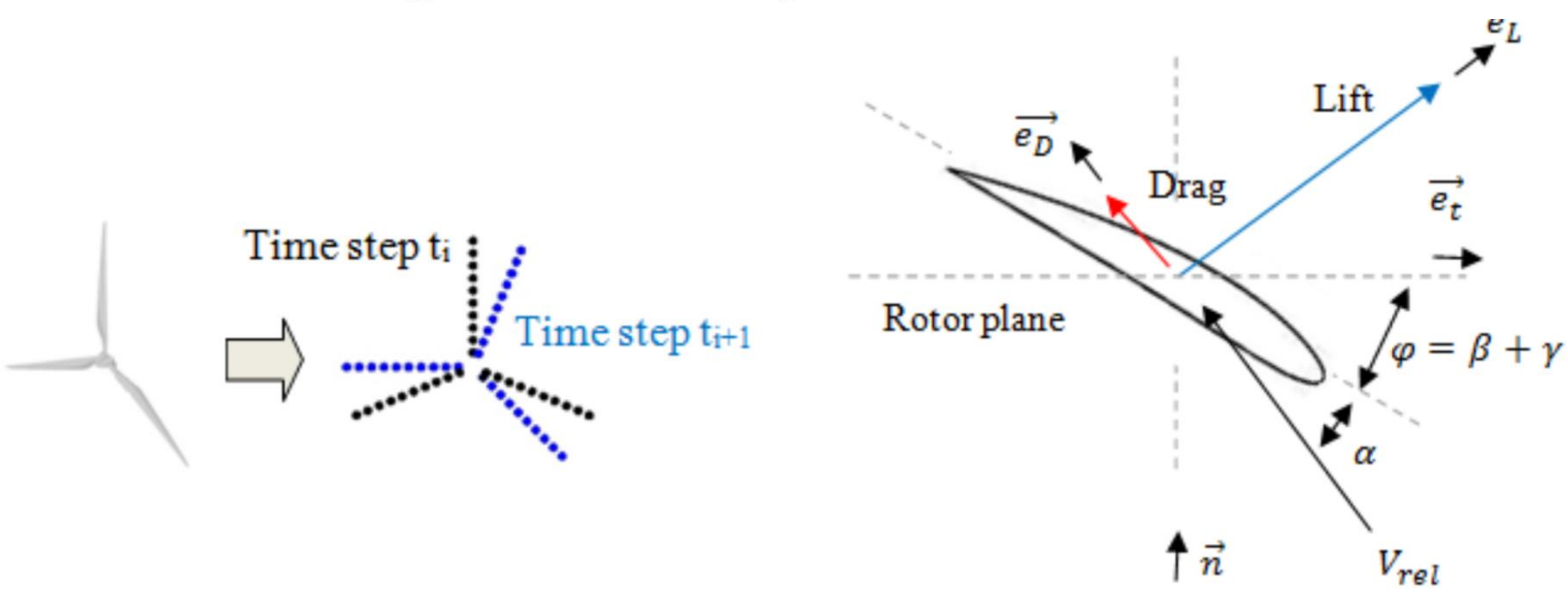
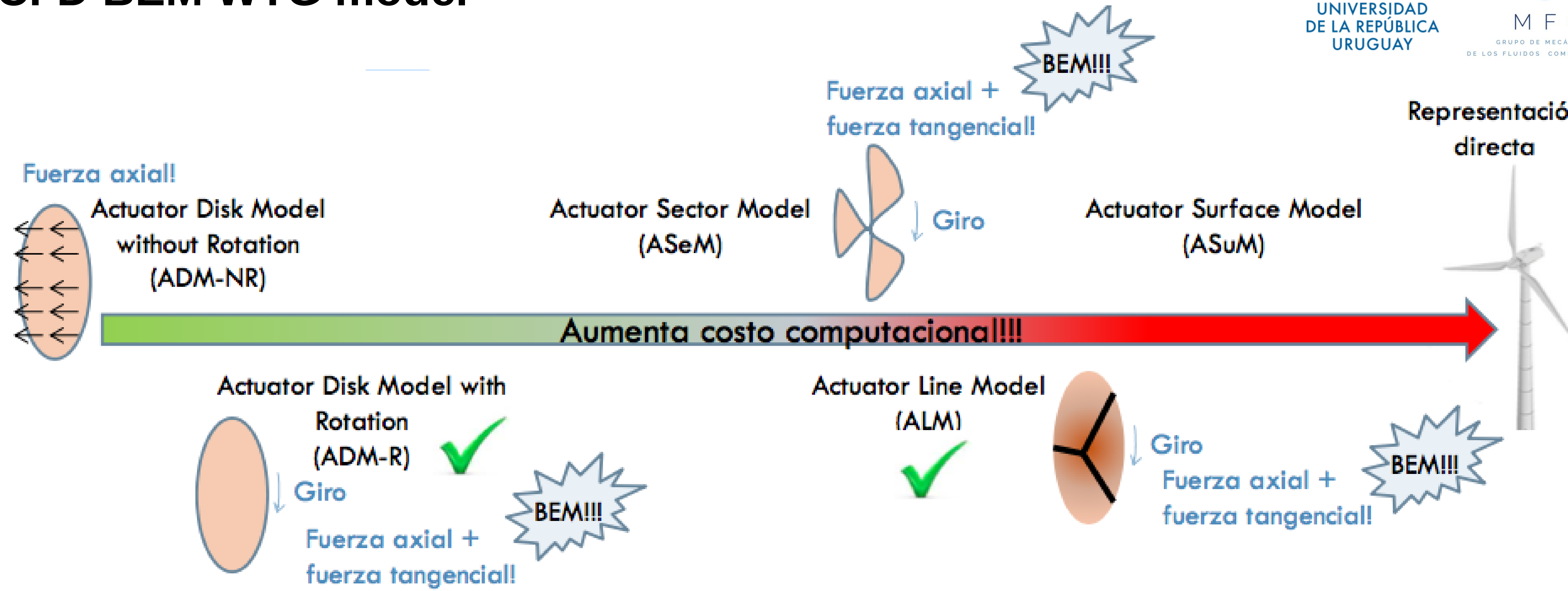


Figure 2: ALM rotor representation (left) and a cross-sectional airfoil radial section (right).

(Draper et al, 2018)

CFD BEM WTG model



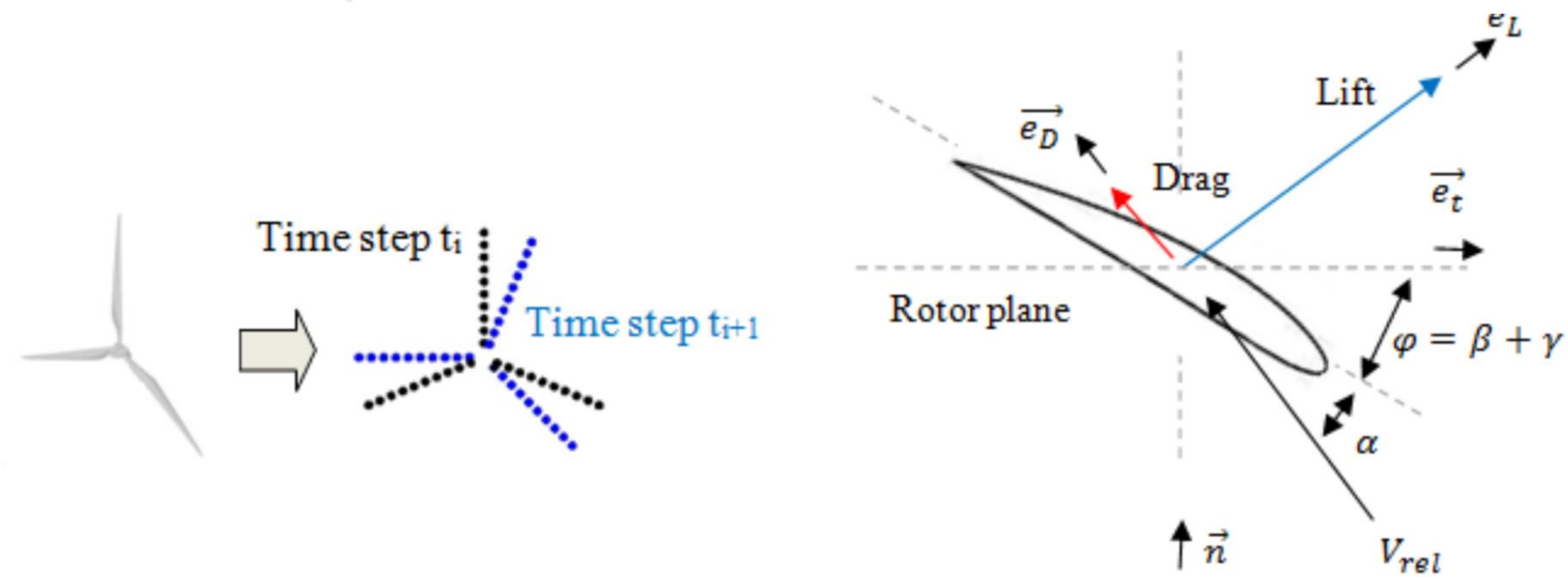


Figure 2: ALM rotor representation (left) and a cross-sectional airfoil radial section (right).

(Draper et al, 2018)

CFD BEM WTG model

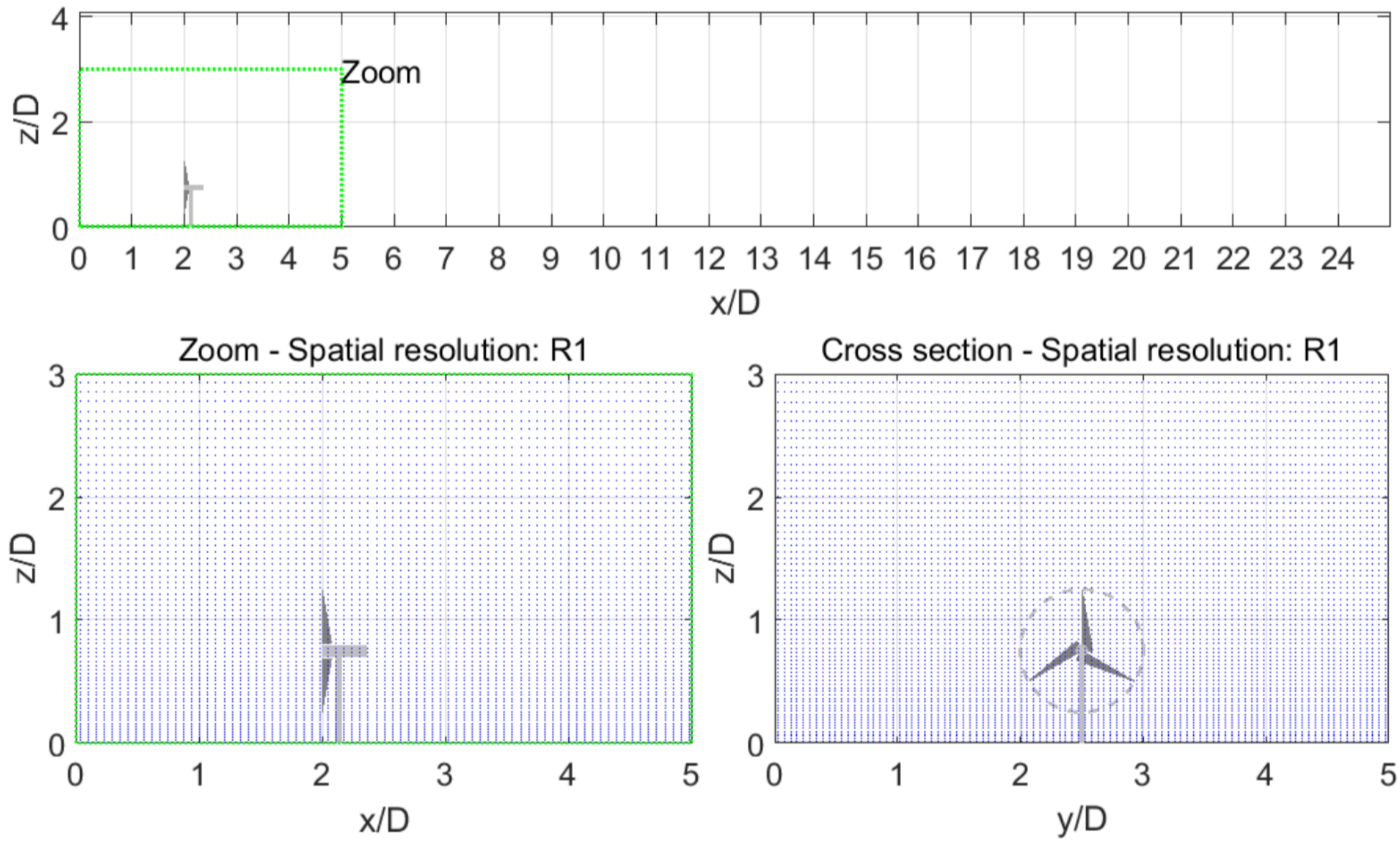


Figure 5: Side view of the computational domain (top). Spatial resolution R1: zoom view close to model wind turbine (bottom, left) and cross section (bottom, right). Blue dots represent grid node centers.

(Draper et al, 2018)

CFD BEM WTG model

Table 1: Numerical setup.

Spatial resolution	Nx	Ny	Nz	$\Delta x(m)$	$\Delta y(m)$	$z_{min}(m)$	$R/\Delta x$	$R/\Delta y$	Nz_{Rotor}
R0	256	64	64	0.107	0.086	0.035	5.1	6.4	22
R1	384	96	80	0.072	0.057	0.022	7.7	9.6	30
R2	512	128	108	0.054	0.043	0.016	10.2	12.8	40

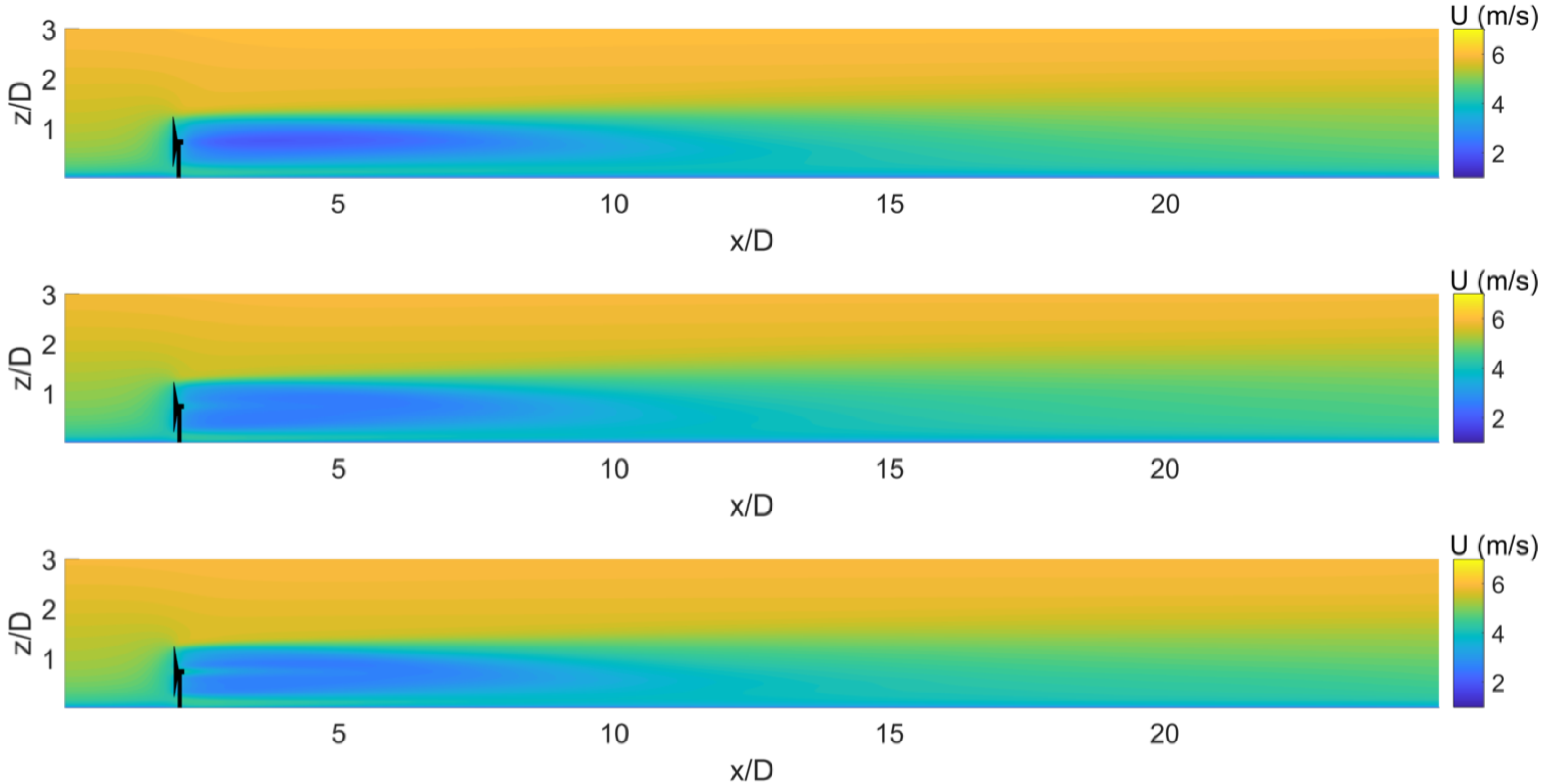


Figure 6: Mean streamwise velocity component in a plane passing through the rotor center. Top: spatial resolution R0, center: spatial resolution R1, bottom: spatial resolution R2. The model wind turbine is sketched in black.

(Draper et al, 2018)

CFD BEM WTG model

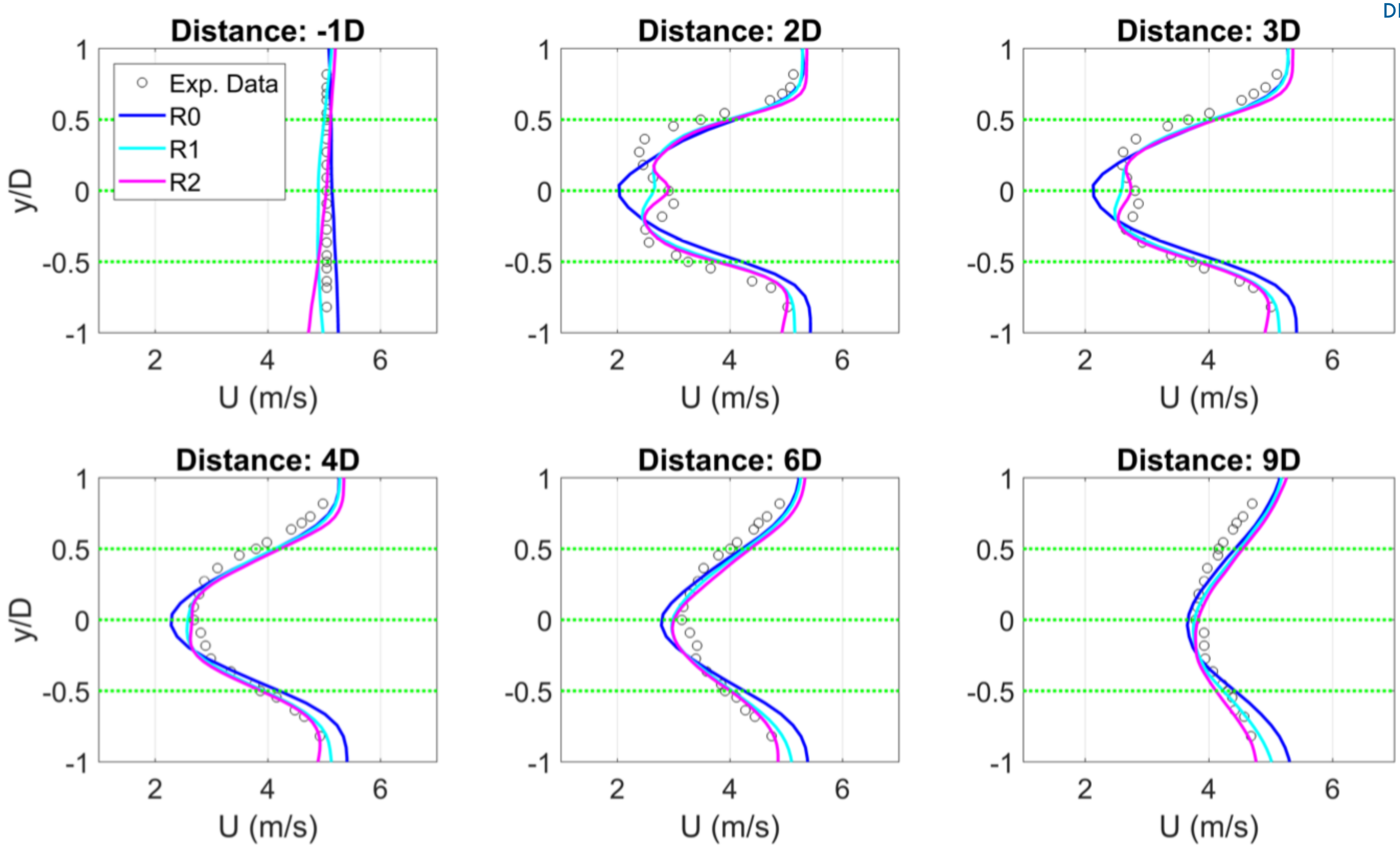


Figure 7: Mean streamwise velocity component at different locations in the wake at hub height, for the three spatial resolutions considered. Dotted green lines represent the rotor center and blade tips. Open circles represent experimental data.

Table 2: Power and thrust coefficients. Values in brackets represent the difference between experimental and simulated value.

		Cp	Ct
Exp. Data		0.453	0.788
Sim.	R0	0.451 (-0.3%)	0.717 (-9.0%)
	R1	0.428 (-5.4%)	0.716 (-9.2%)
	R2	0.414 (-8.5%)	0.699 (-11.3%)

(Draper et al, 2018)

CFD BEM WTG model

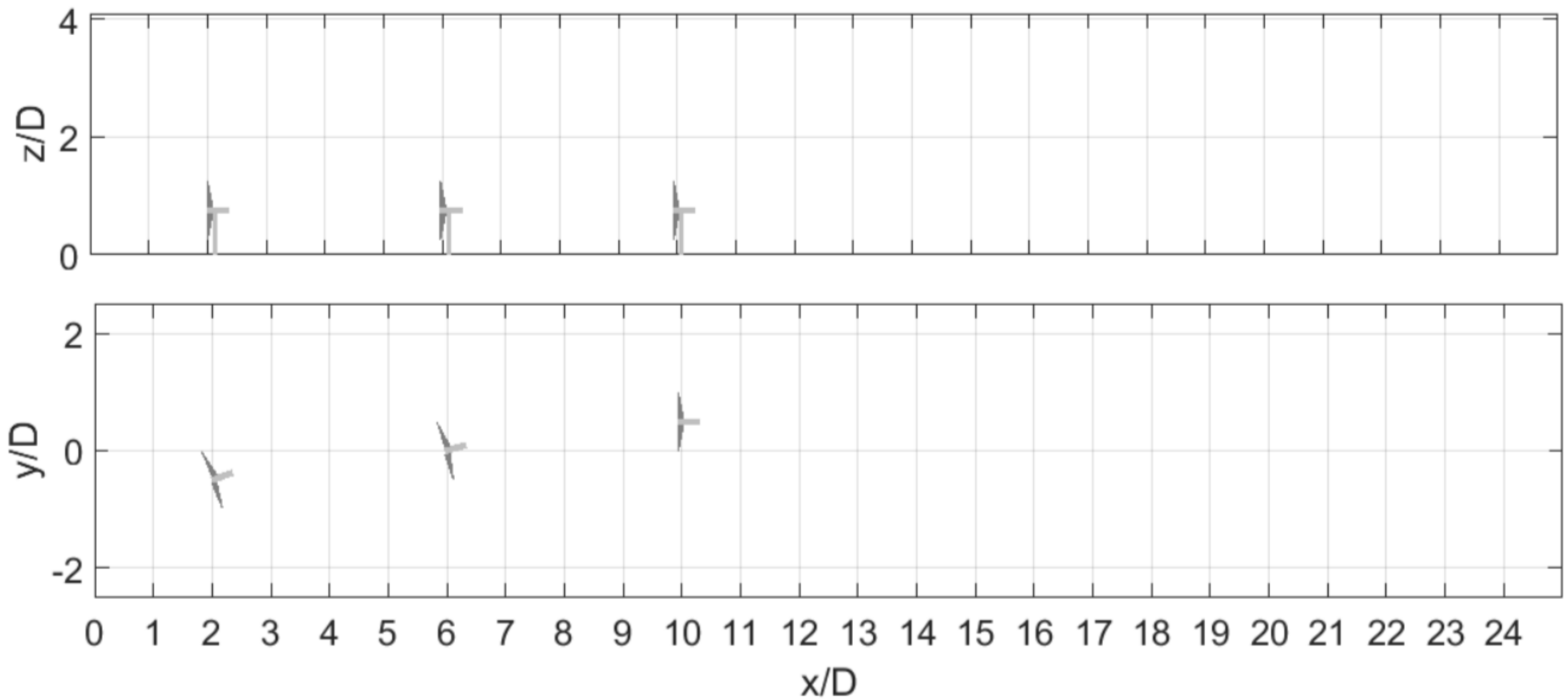


Figure 10: Computational domain showing the layout for the selected yaw setting. The wind turbine models are sketched in grey.

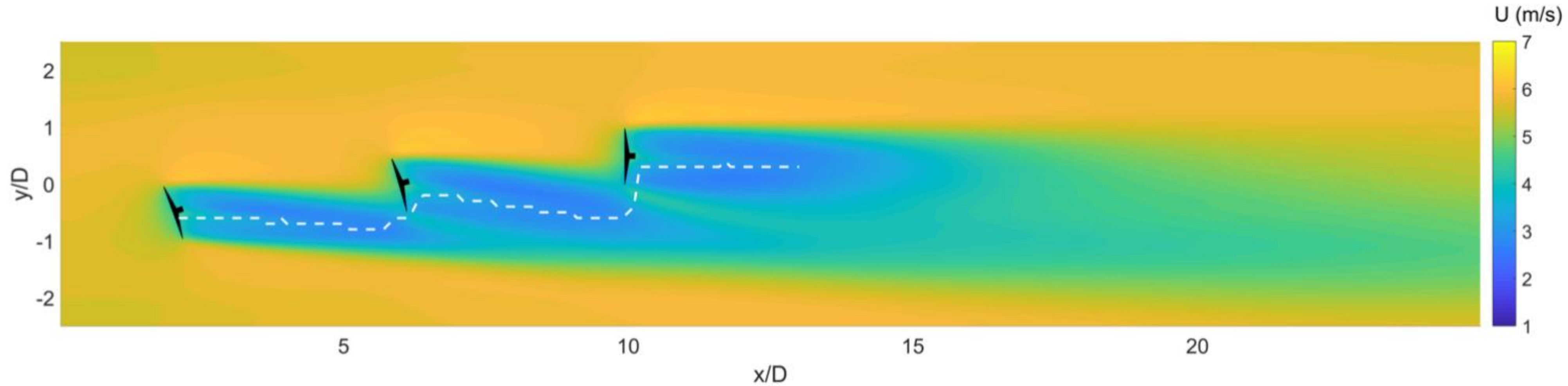


Figure 11: Mean streamwise velocity component in a horizontal plane passing 0.10 m above the rotor center. Spatial resolution R1. The model wind turbines are sketched in black. The white dash line represents the wake center computed from the experimental data by minimization of Equation 7.

(Draper et al, 2018)

CFD BEM WTG model

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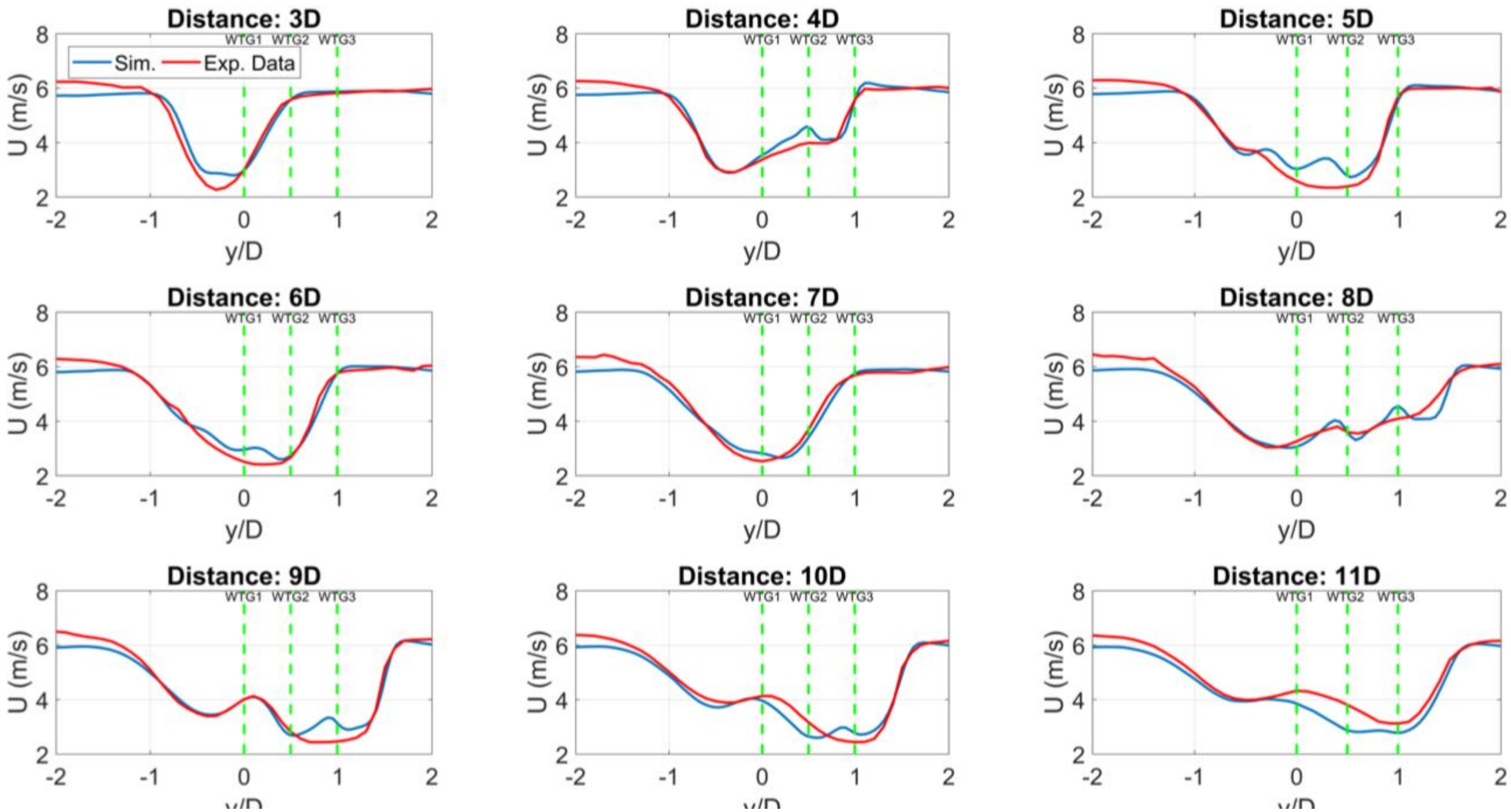

Figure 12: Mean streamwise velocity component in a horizontal plane 0.10 m above the rotor center at different locations in the wake. Spatial resolution R1. The wind turbine rotor centers are represented with green dashed lines. Distance is measured from the rotor plane of the upwind model wind turbine.

Table 3: Power coefficient of each model wind turbine.

	WTG1	WTG2	WTG3	Total
Exp. Data	0.388	0.350	0.404	1.142
Sim.	0.400	0.390	0.462	1.251
Cp diff.	3.1%	11.3%	14.4%	9.6%

(Draper et al, 2018)

CFD BEM WTG model

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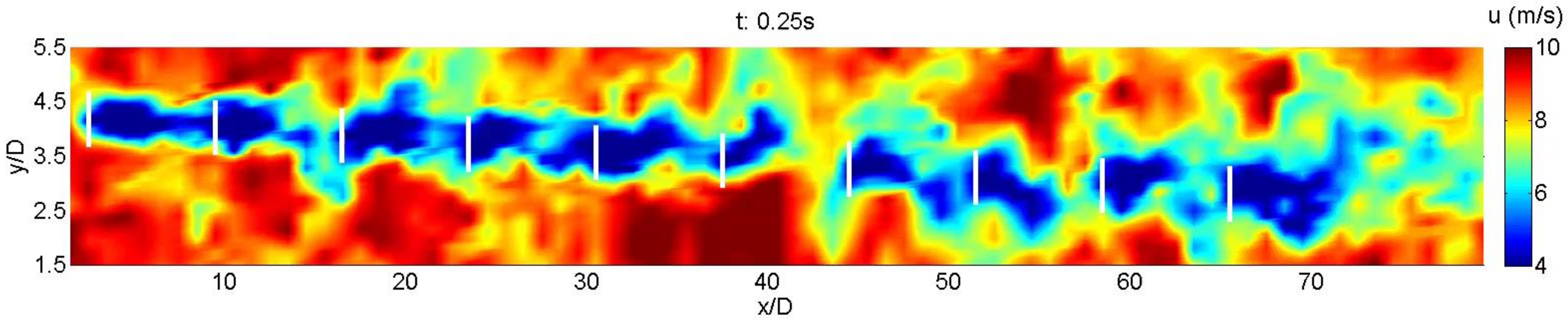
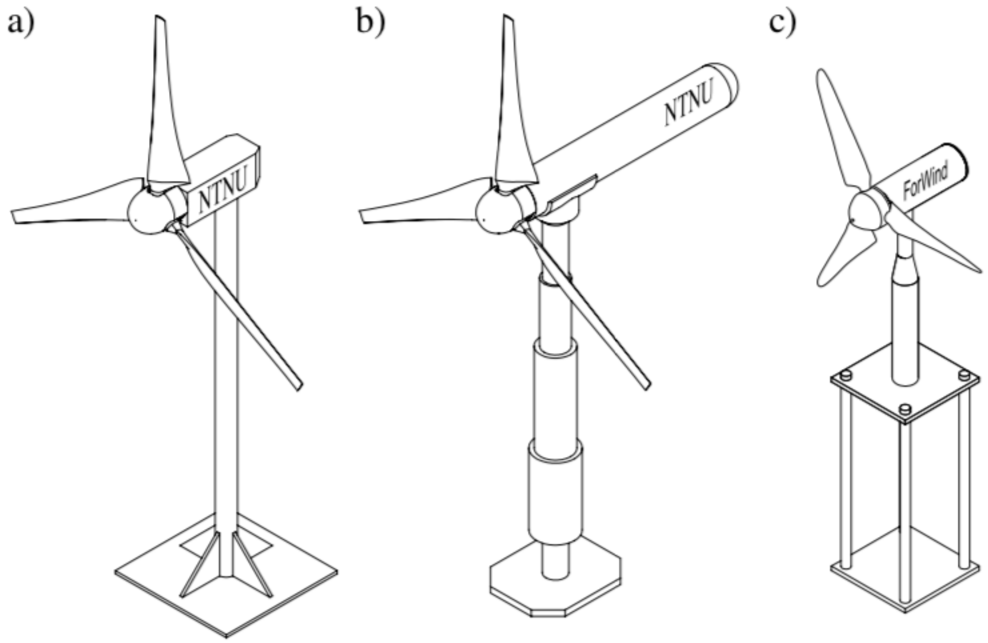
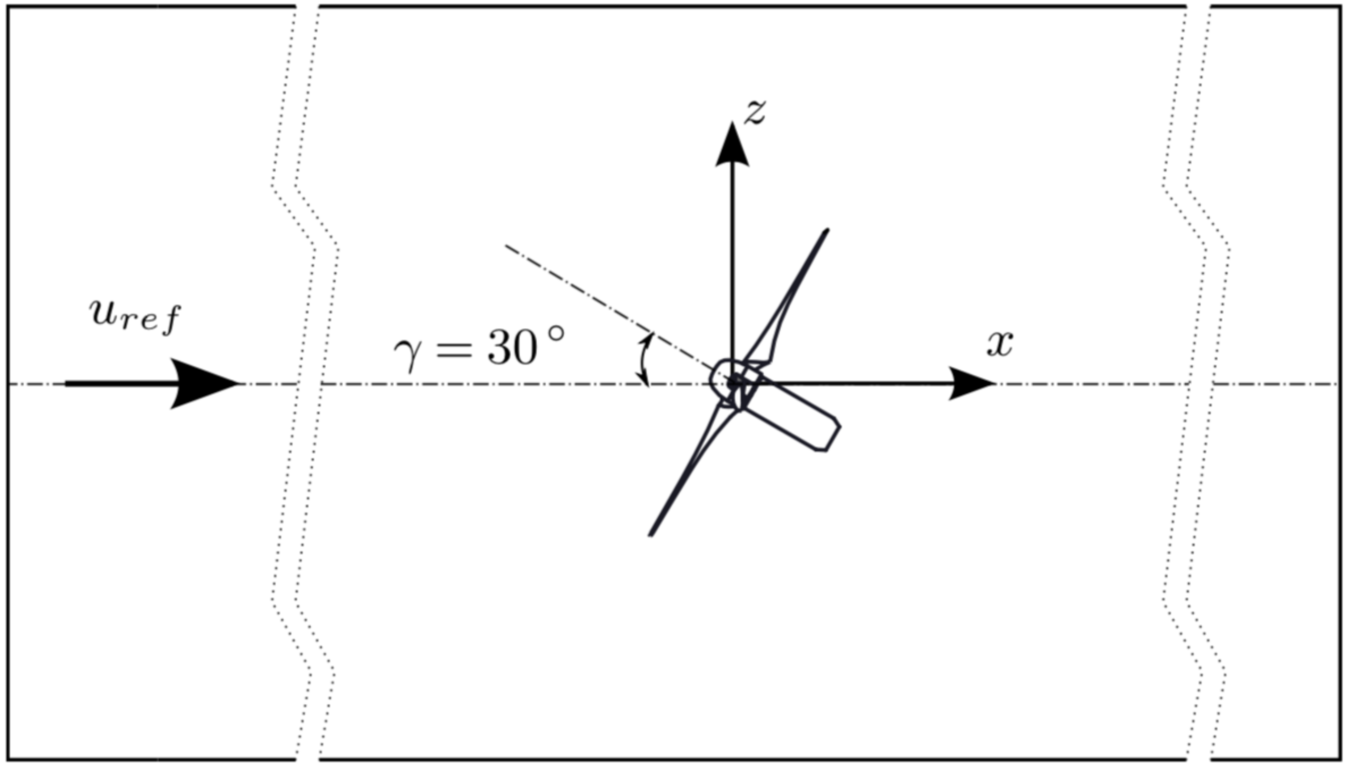


Blind Test #5 - 2017





(Mühle et al, 2018)

Blind Test #5 - 2017

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Table 2. Overview of simulation methods and parameters. Abbreviations: Improved Delayed Detached Eddy Simulation (IDDES), Large Eddy Simulation (LES), Actuator Line (ACL), Fully Resolved (FR).

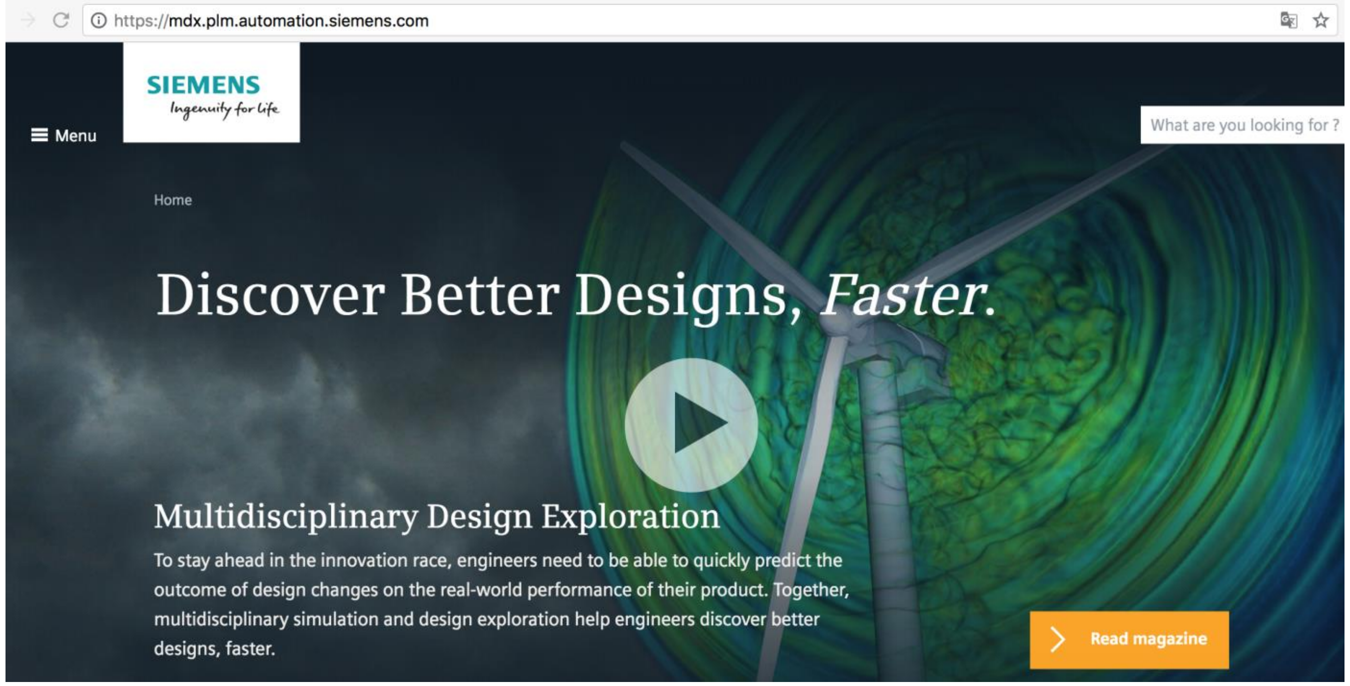
Participant	Simulation code	Flow solver type	Rotor model	Airfoil polars	Tower, nacelle	Mesh properties	Number of cells
Siemens	Star-CCM+	IDDES	FR	-	FR	Hexah./polyh.	$\approx 30.0 \cdot 10^6$
POLIMI	ALEVM	LES	ACL	X-Foil	No	Cartesian	$\approx 4.1 \cdot 10^6$
UdelaR	caffa3d	LES	ACL	X-Foil	Yes	Cartesian	$\approx 0.7 \cdot 10^6$
KTH	Nek5000	LES	ACL	Experiments	Yes	Uniform	$\approx 0.08 \cdot 10^6$

BUSINESS NEWS JANUARY 24, 2016 / 9:56 PM / 2 YEARS AGO

Siemens to buy CD-adapco for close to $1 billion: source

Liana B. Baker 3 MIN READ

(Reuters) - Siemens AG (SIEGn.DE), Europe's biggest industrial group, has agreed to buy CD-adapco, a privately held U.S. engineering software firm, for close to $1 billion in cash, according to a person familiar with the matter.



(Mühle et al, 2018)

Blind Test #5 - 2017

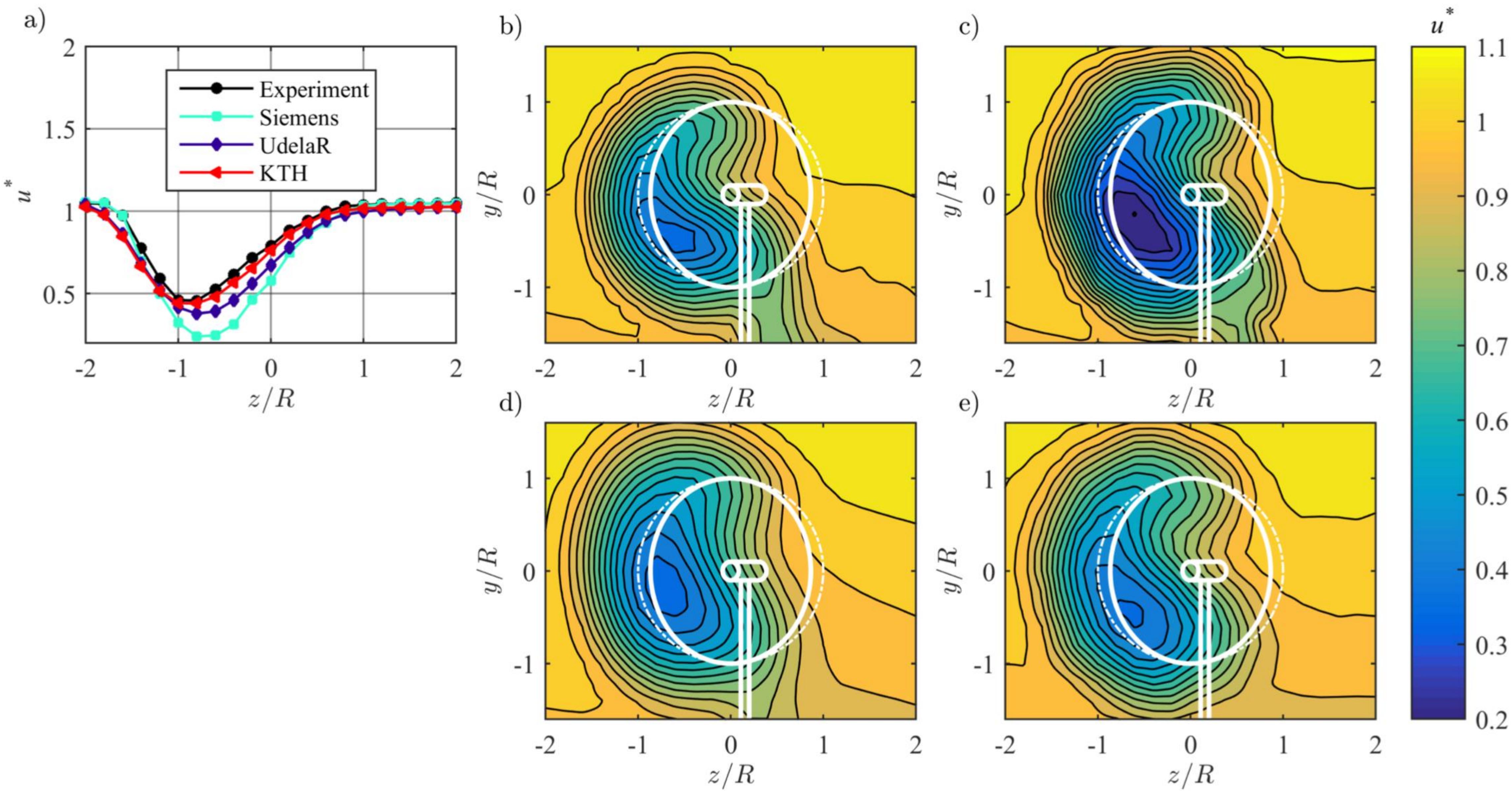


Figure 13. (a) Line plots and (b-e) contour plots for normalized streamwise mean velocity u^* in the wake 3*D* behind upstream ForWind turbine, from (b) experiments, (c) Siemens, (d) UdelaR and (e) KTH and. The white lines represent the turbine rotor, nacelle and tower, solid lines $\gamma = 30°$, dashed lines $\gamma = 0°$.

(Mühle et al, 2018)

Blind Test #5 - 2017

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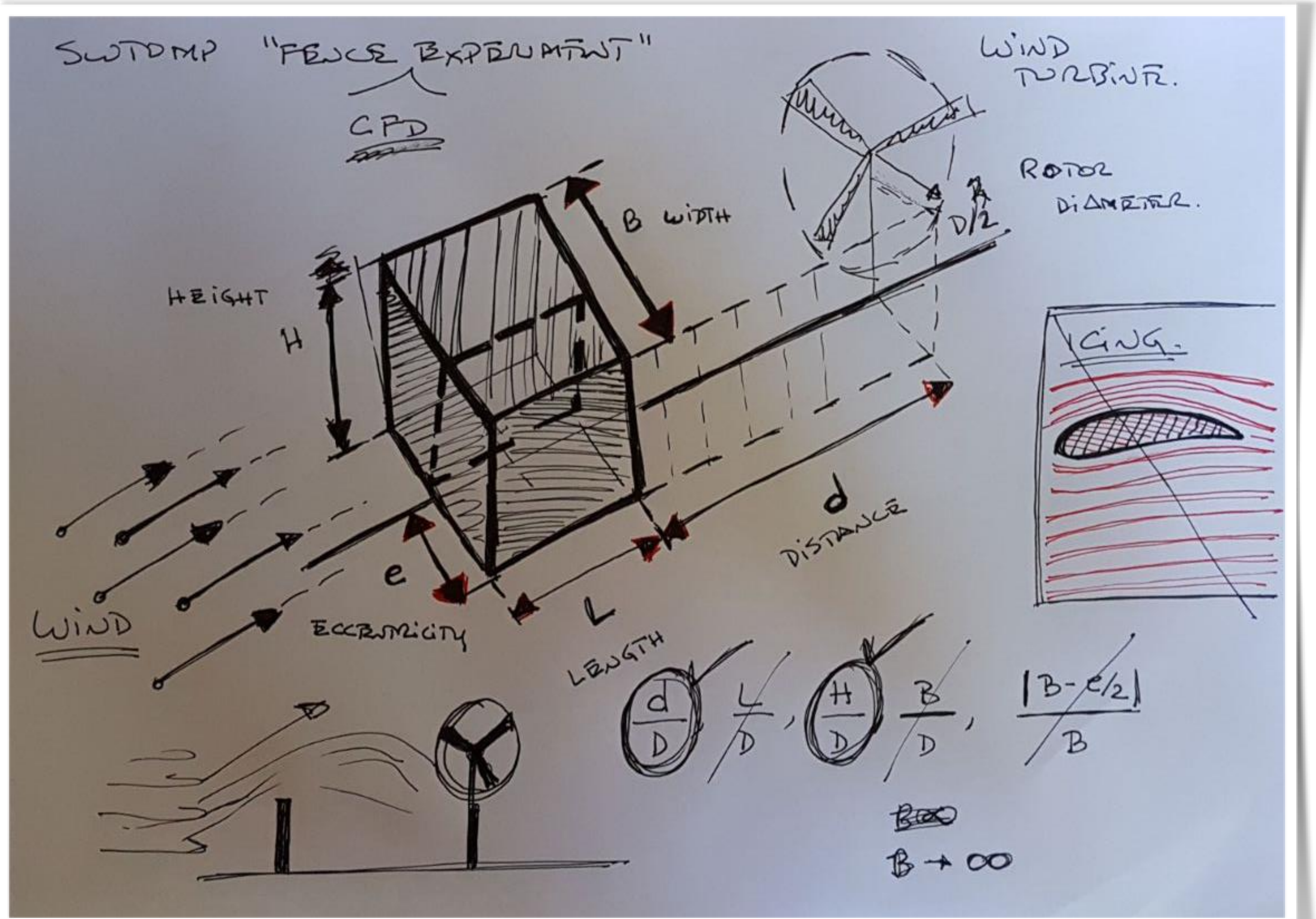
Table 6. Comparison parameters: Skew angle (ξ), wake deflection (δ) and available power in the wake ($P^*{}_{wake}$) and their differences to the measurements. Statistical performance measures: *NMSE* and *r* for u^*, v^* and k^* at 3*D* and 6*D* behind upstream ForWind turbine.

	Institution	Skew angle	Deflection (z/R)	Difference (z/R)	$P^*{}_{wake}$ [-]	Difference [%]	$NMSE_u$	r_u	r_v	$NMSE_k$	r_k
3*D*	Experiments	4.10°	-0.429		0.285						
	Siemens	3.71°	-0.388	0.041	0.141	-49.4%	0.012	0.968	0.813	0.383	0.889
	UdelaR	4.88°	-0.510	-0.082	0.207	-27.6%	0.007	0.953	0.802	0.734	0.878
	KTH	5.27°	-0.551	-0.122	0.233	-18.%	0.005	0.960	0.851	0.202	0.905
6*D*	Experiments	3.80°	-0.796		0.533						
	Siemens	3.41°	-0.714	0.082	0.430	-19.3%	0.002	0.960	0.845	0.047	0.961
	UdelaR	4.00°	-0.837	-0.041	0.540	1.2%	0.001	0.963	0.799	0.067	0.956
	KTH	4.19°	-0.878	-0.082	0.475	-11.0%	0.002	0.950	0.884	0.052	0.947

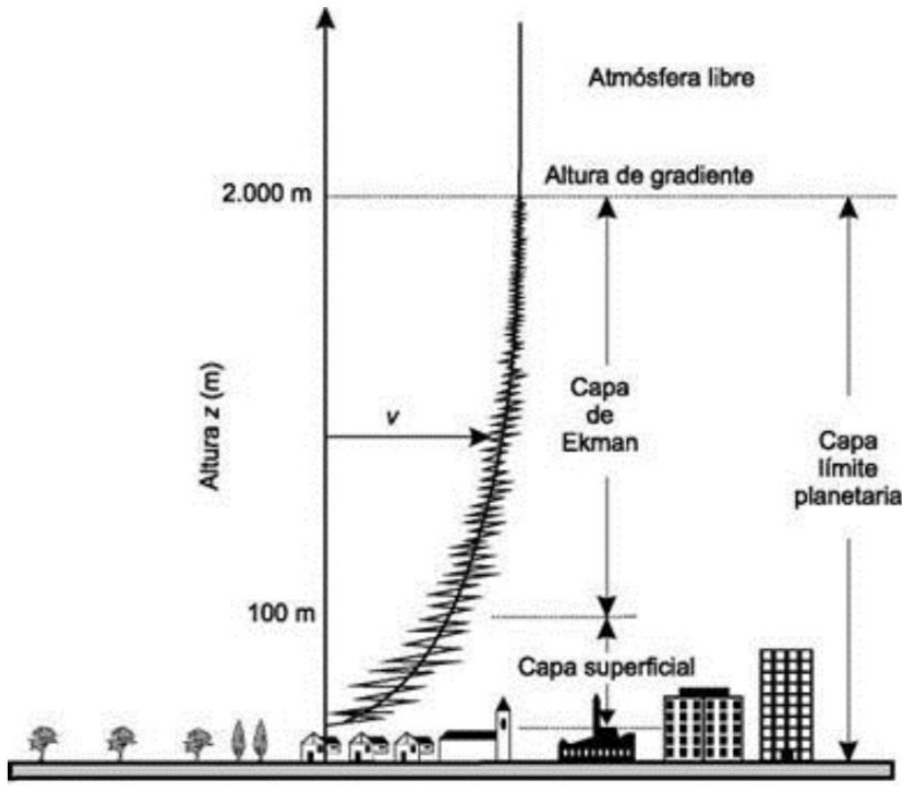
(Mühle et al, 2018)

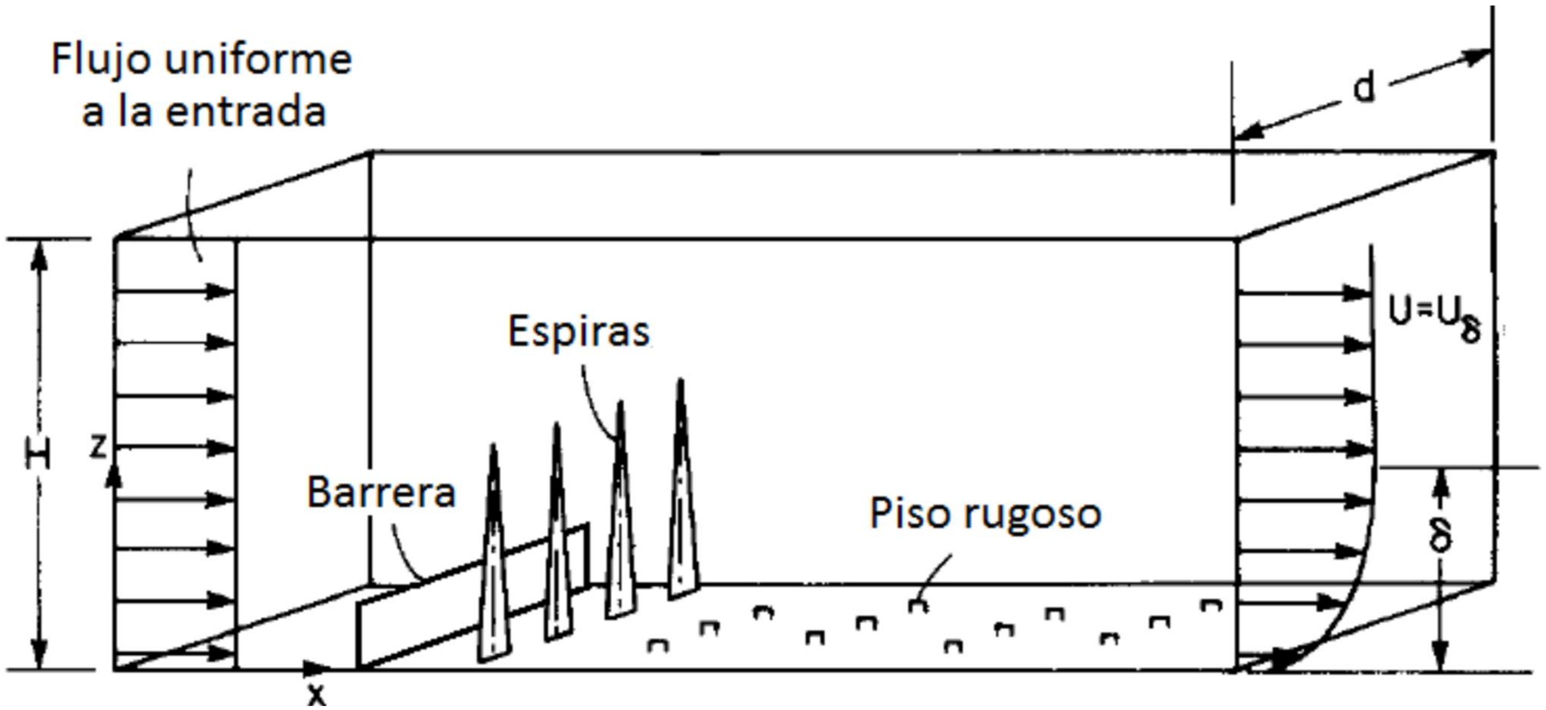
SWTOMP “Fence Experiment”, *back of the envelope idea*

-----Original Appointment-----
From: FERHAT BINGOL
Sent: Wednesday, December 13, 2017 14:43
To: FERHAT BINGOL; gusera@fing.edu.uy; timo.karlsson@vtt.fi; juand@inti.gob.ar; Carolina.Garcia2@ciemat.es; luis.cano@ciemat.es; jorge.navarro@ciemat.es
Subject: SWTOMP Project / WP2 / Online Meeting
When: Thursday, December 14, 2017 15:00-16:00 (UTC+03:00) Istanbul.
Where: https://global.gotomeeting.com/join/885803509

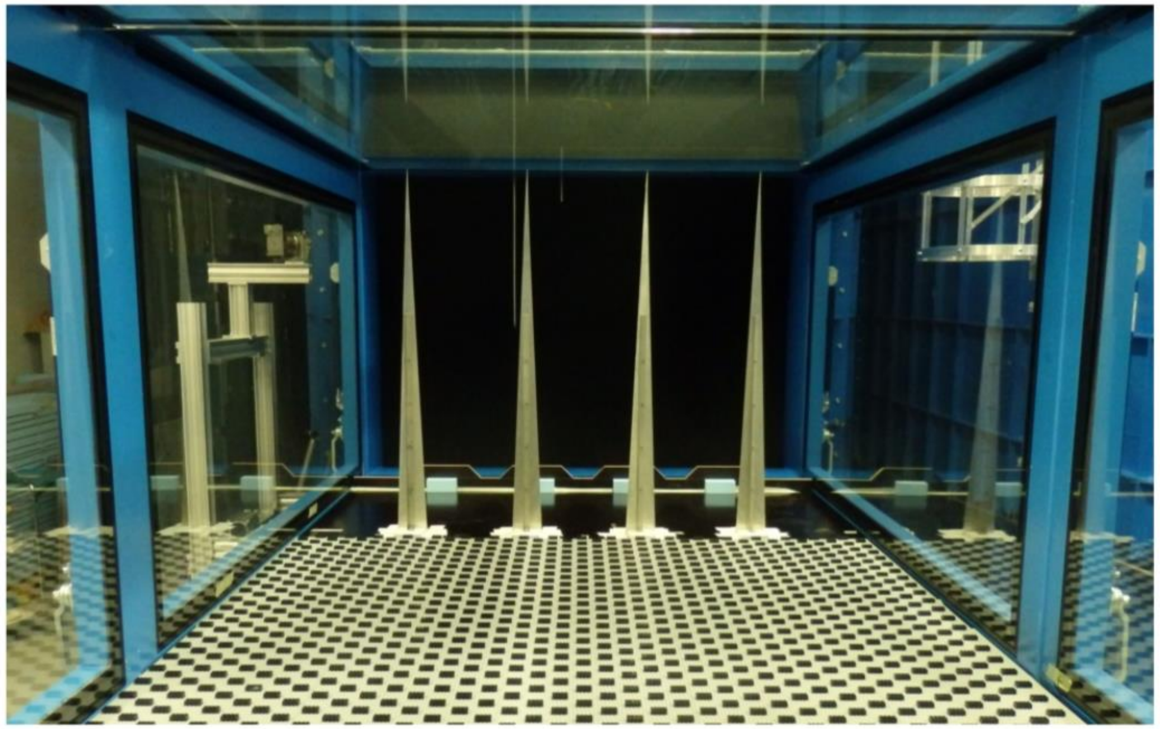


SWTOMP "Fence Experiment", ABL simulation





*"**The flow is tricked** by the barrier into believing the fetch of roughness to be longer, and by the mixing-device that the barrier is not there at all!"[Cook (1978)]*



SWTOMP “Fence Experiment”, ABL simulation

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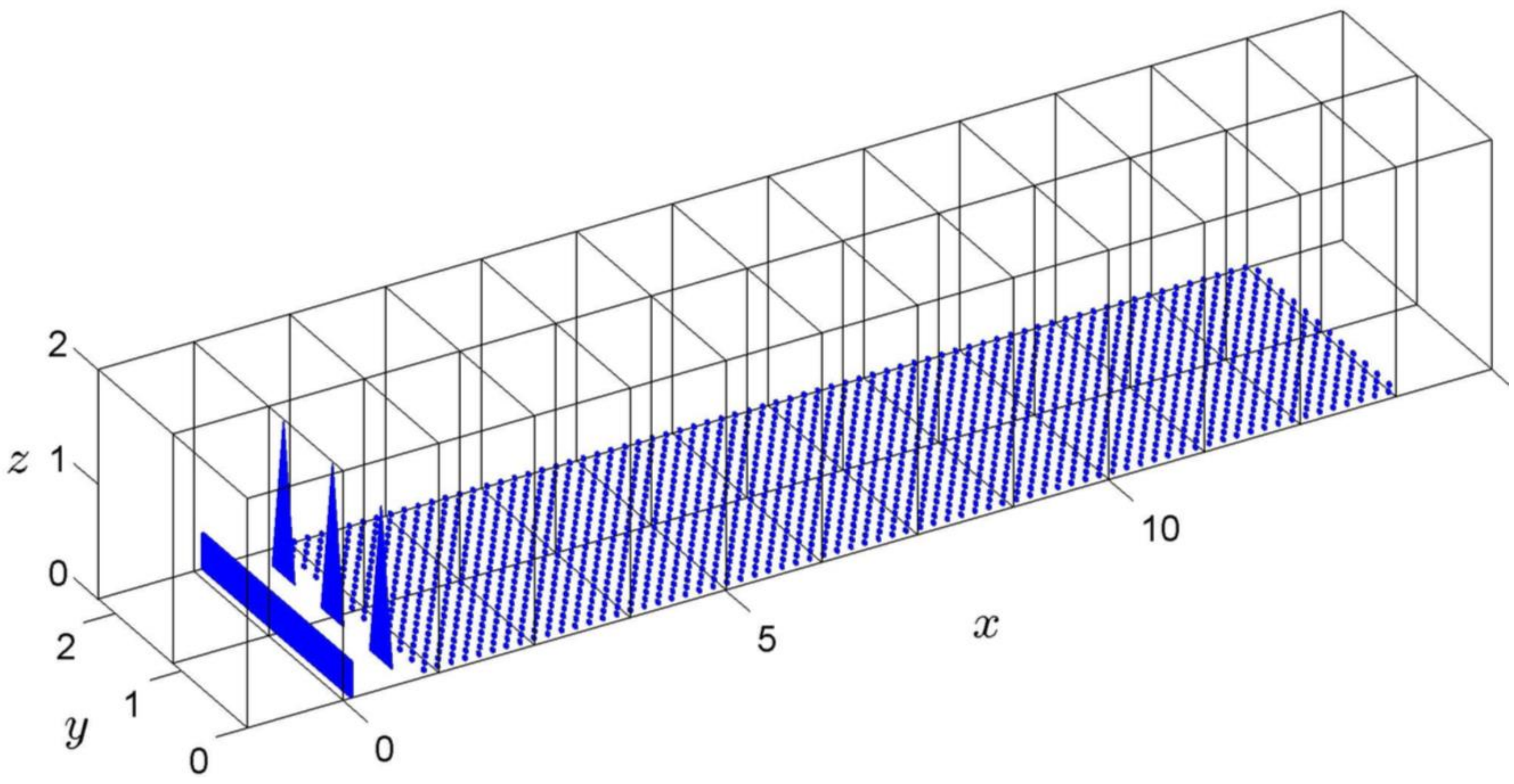
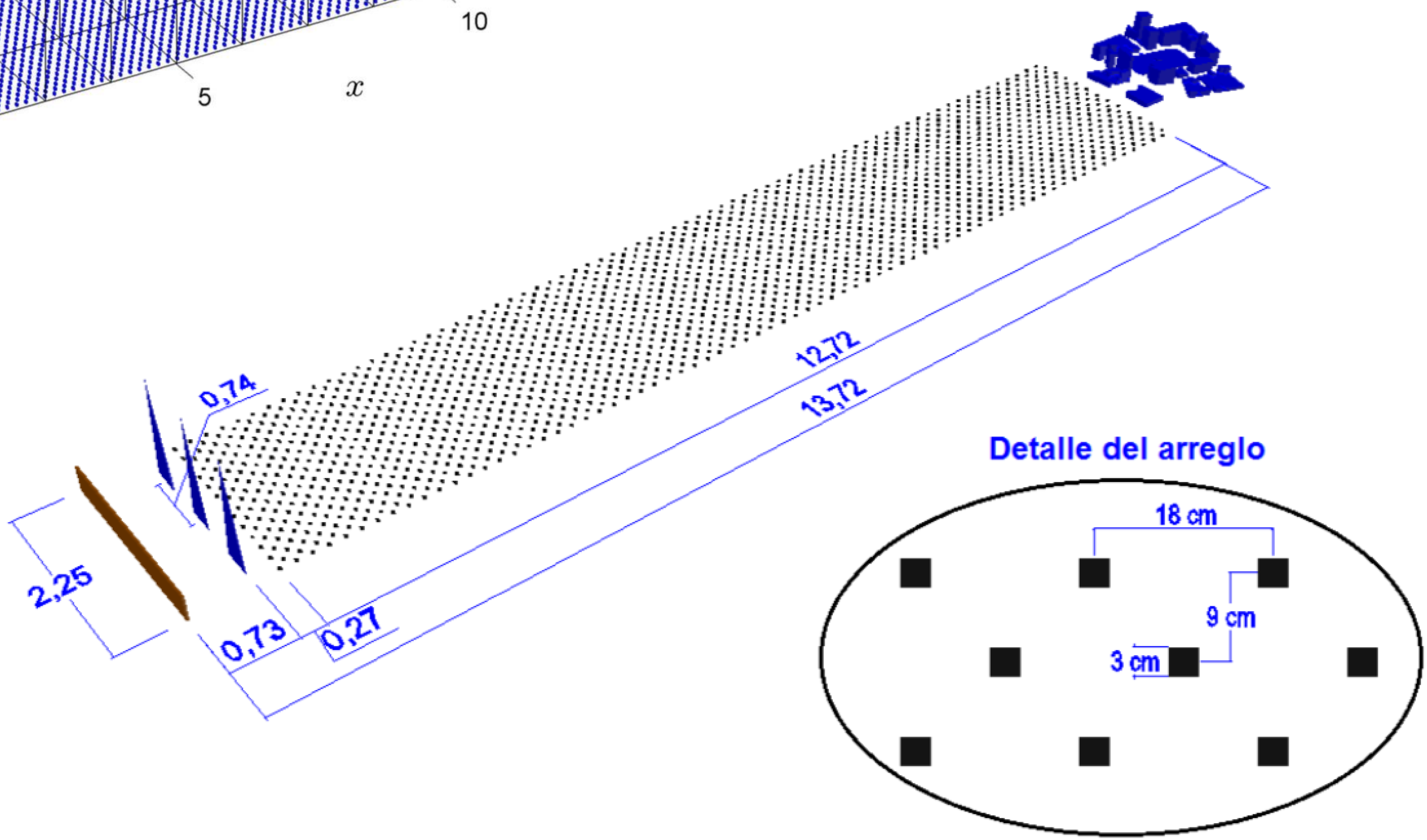
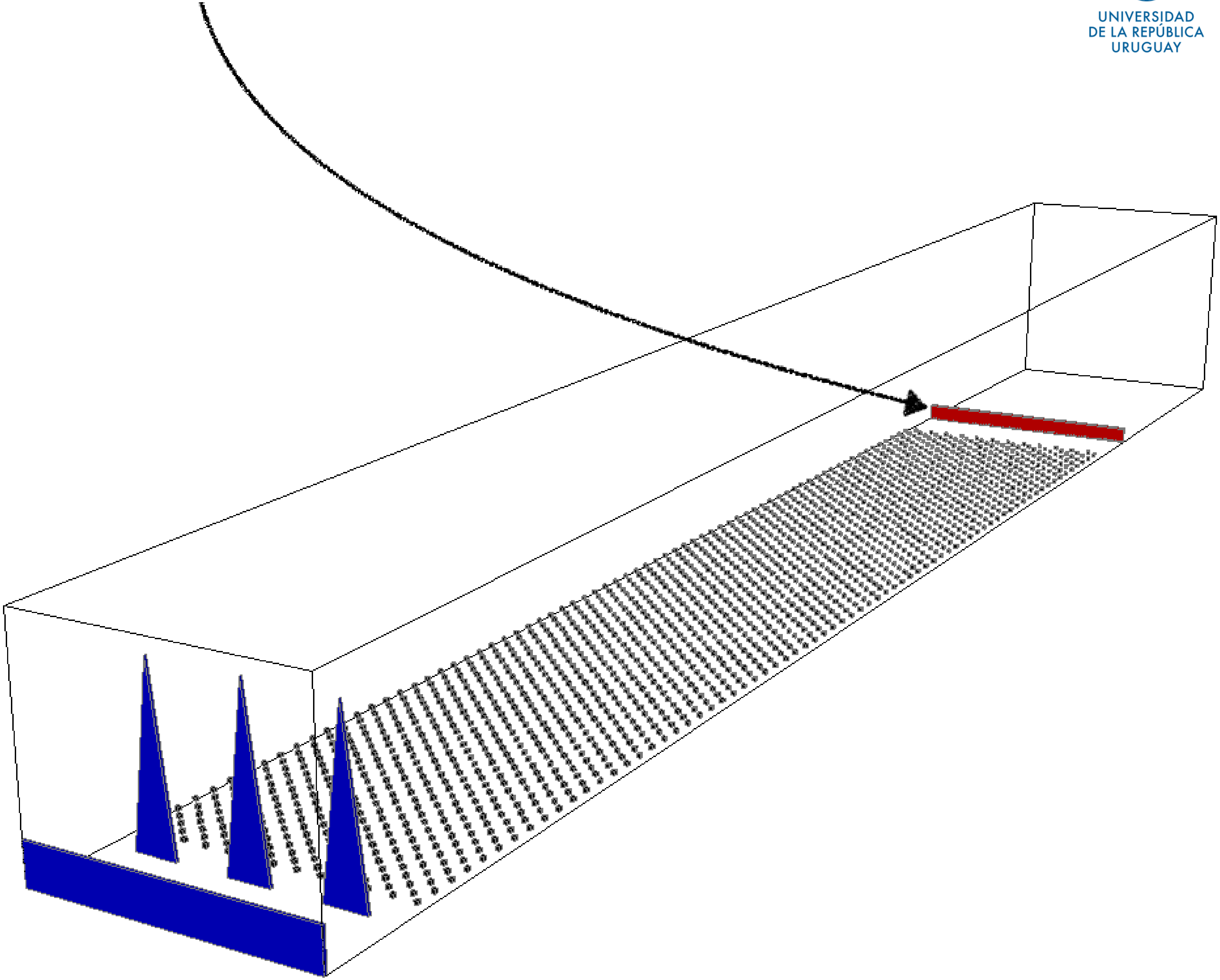
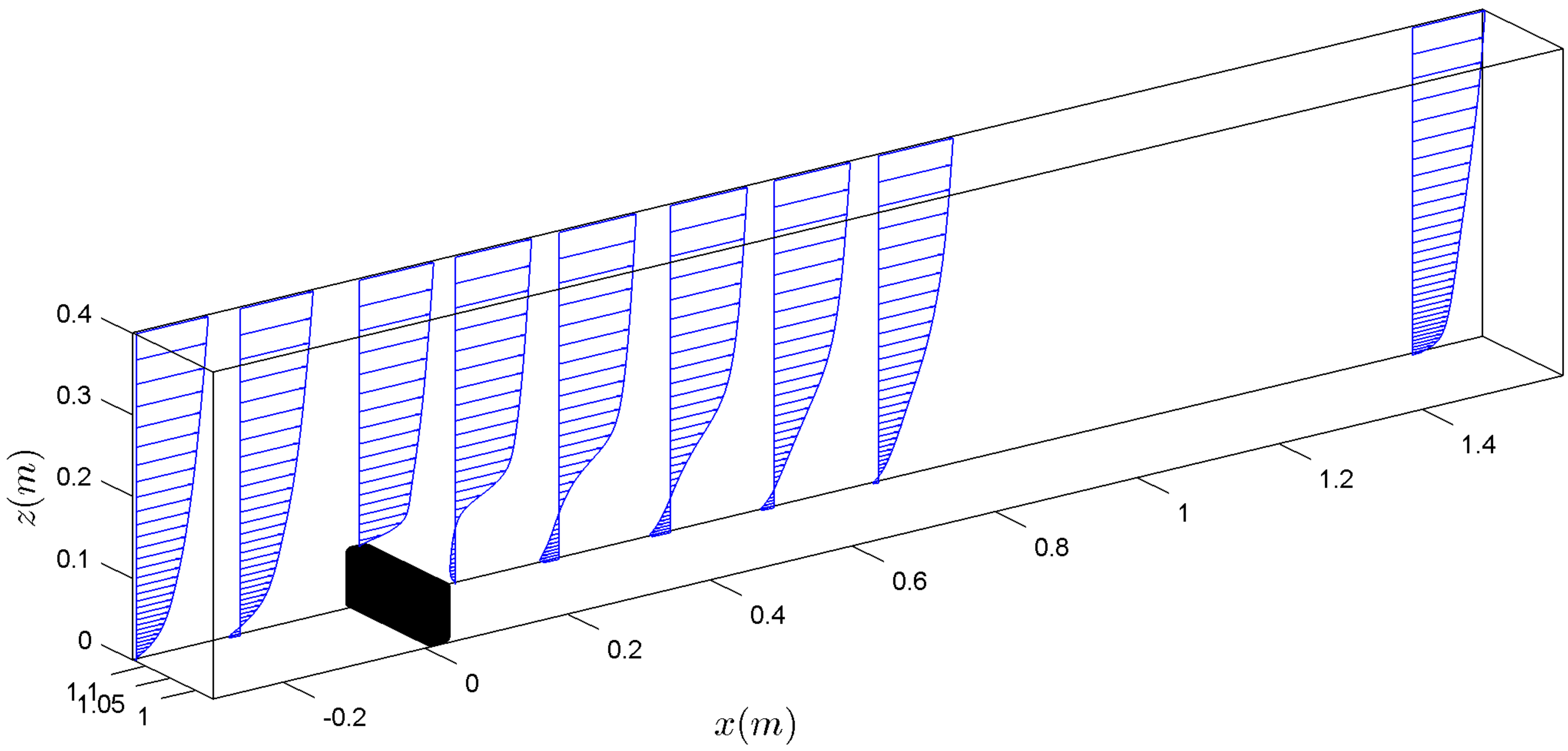




SWTOMP “Fence Experiment”, ABL simulation (1:120)



SWTOMP “Fence Experiment”, ABL simulation (1:120)



SWTOMP “Fence Experiment”, ABL simulation (1:120)

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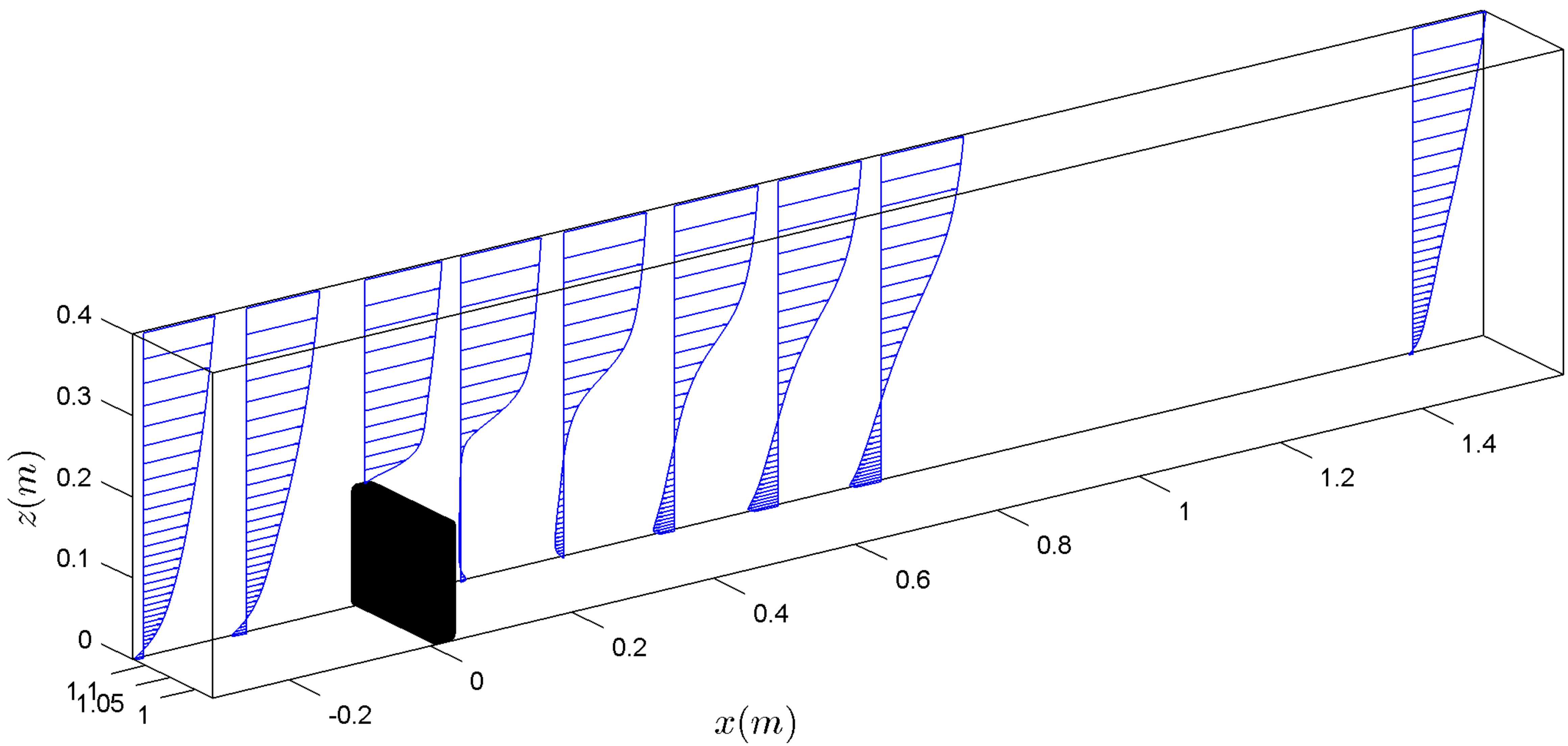
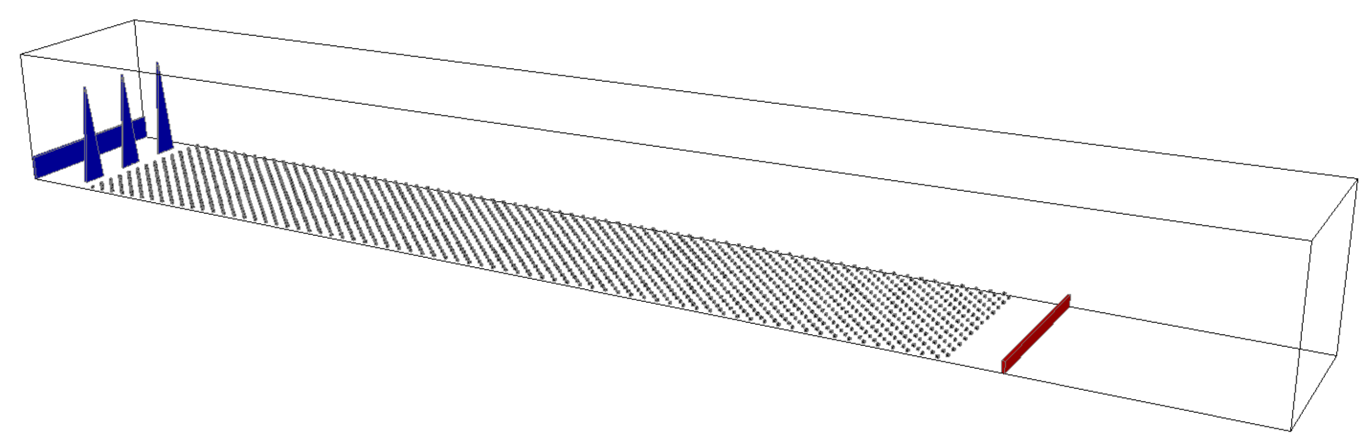
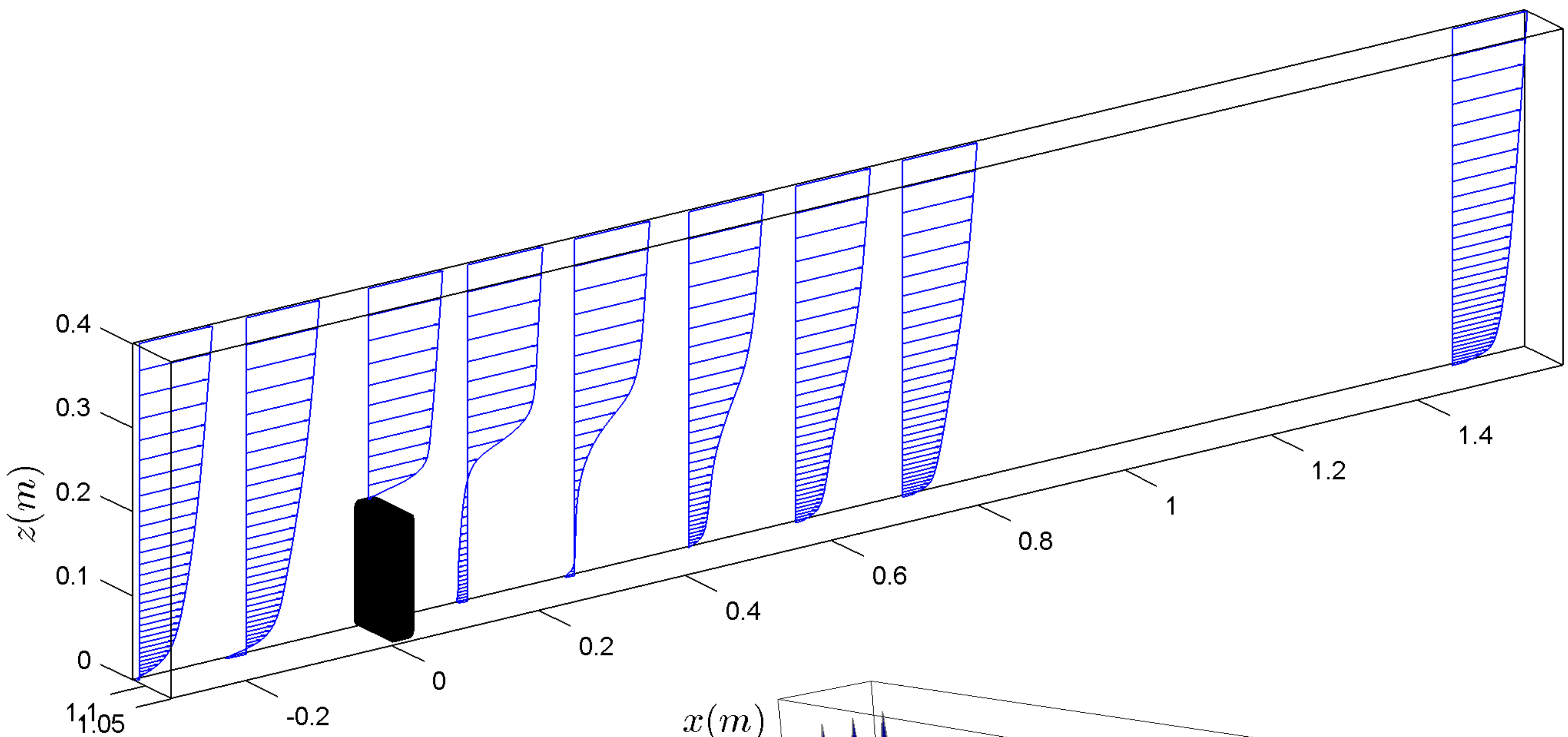
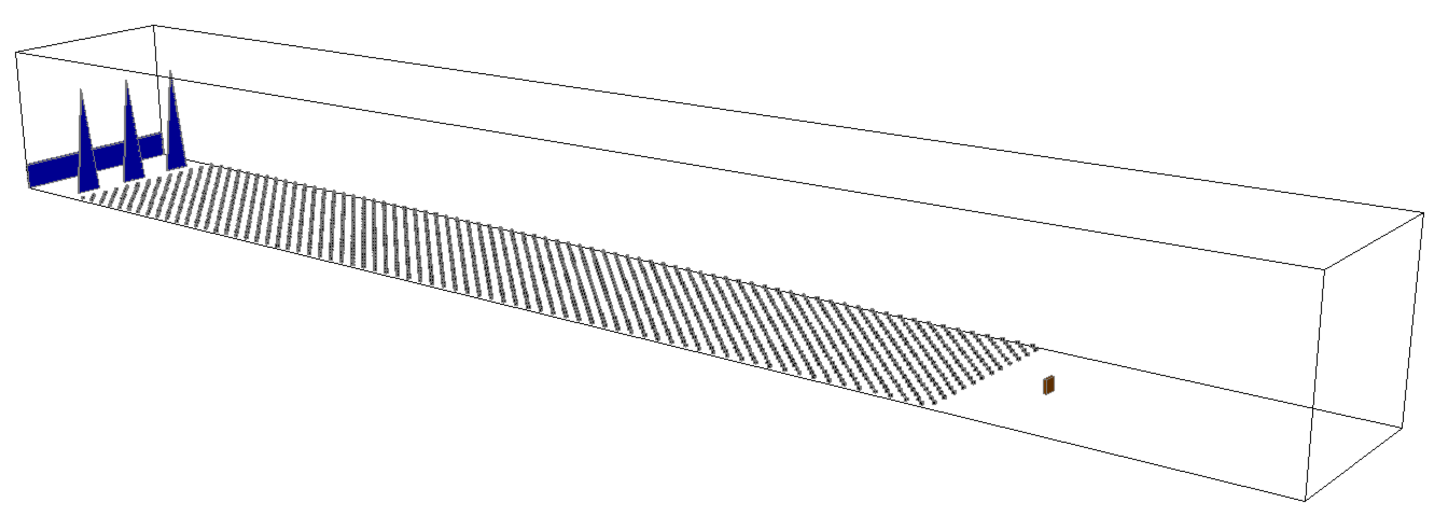


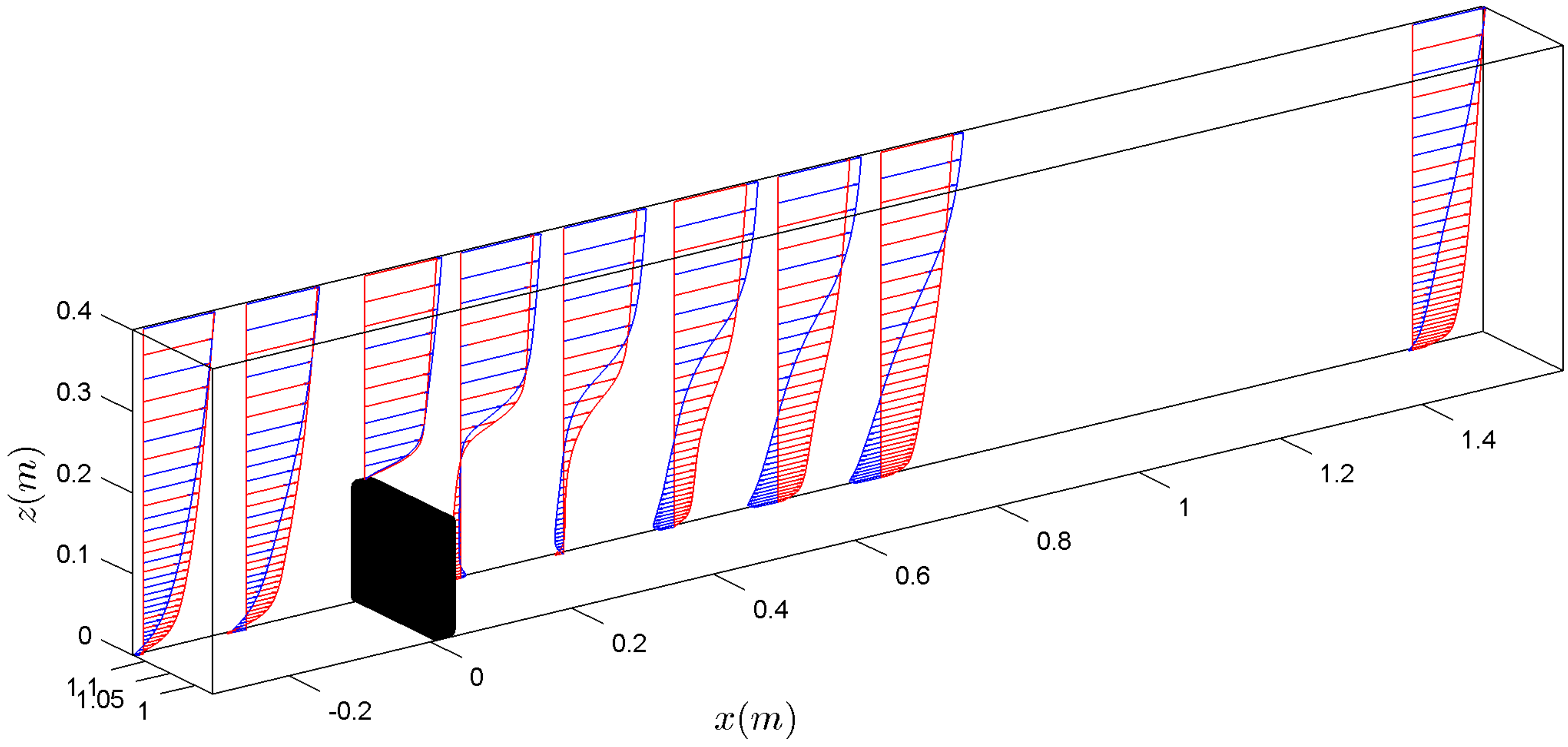


SWTOMP “Fence Experiment”, ABL simulation (1:120)





SWTOMP “Fence Experiment”, ABL simulation (1:120)



SWTOMP "Fence Experiment", ABL simulation (1:120)

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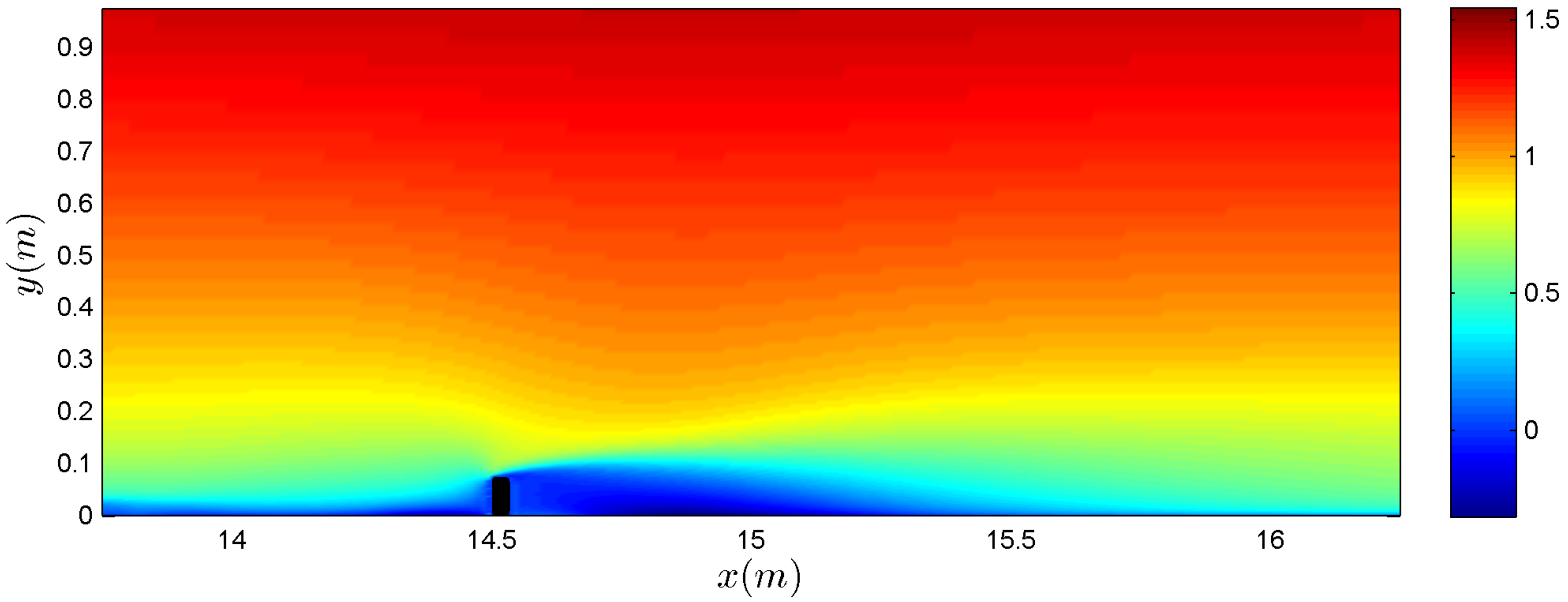
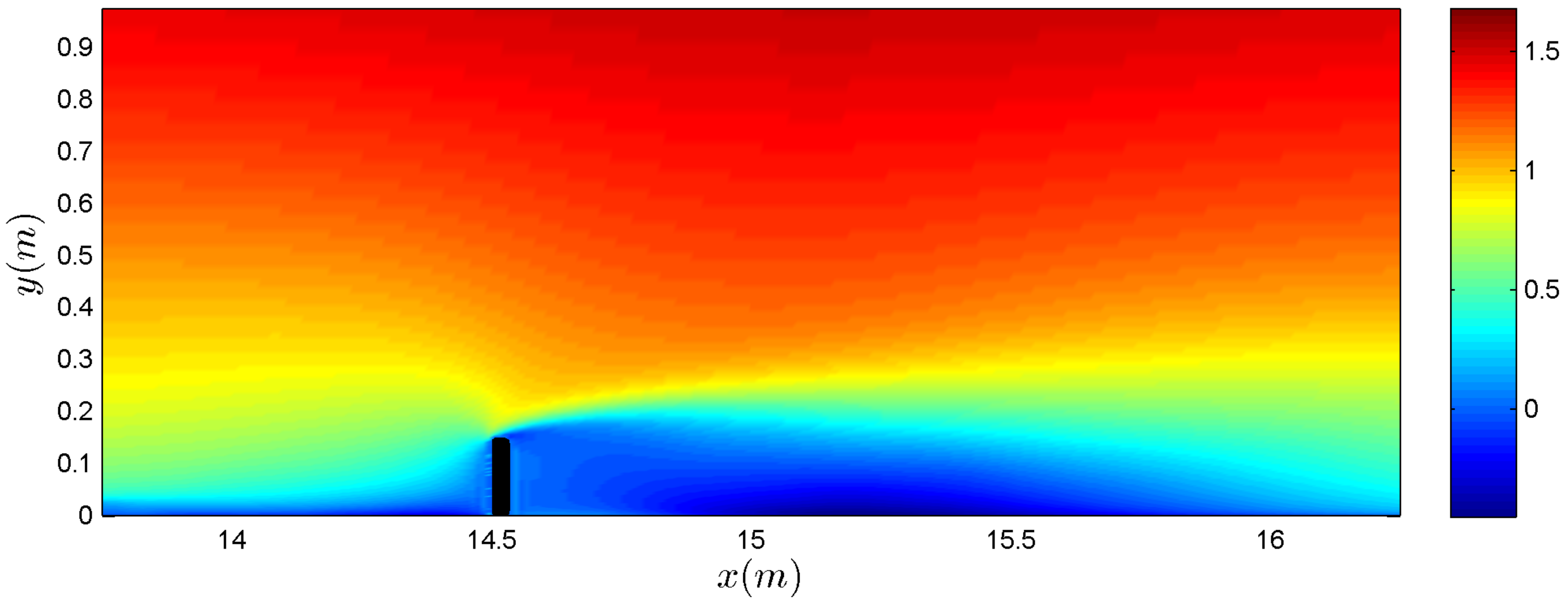
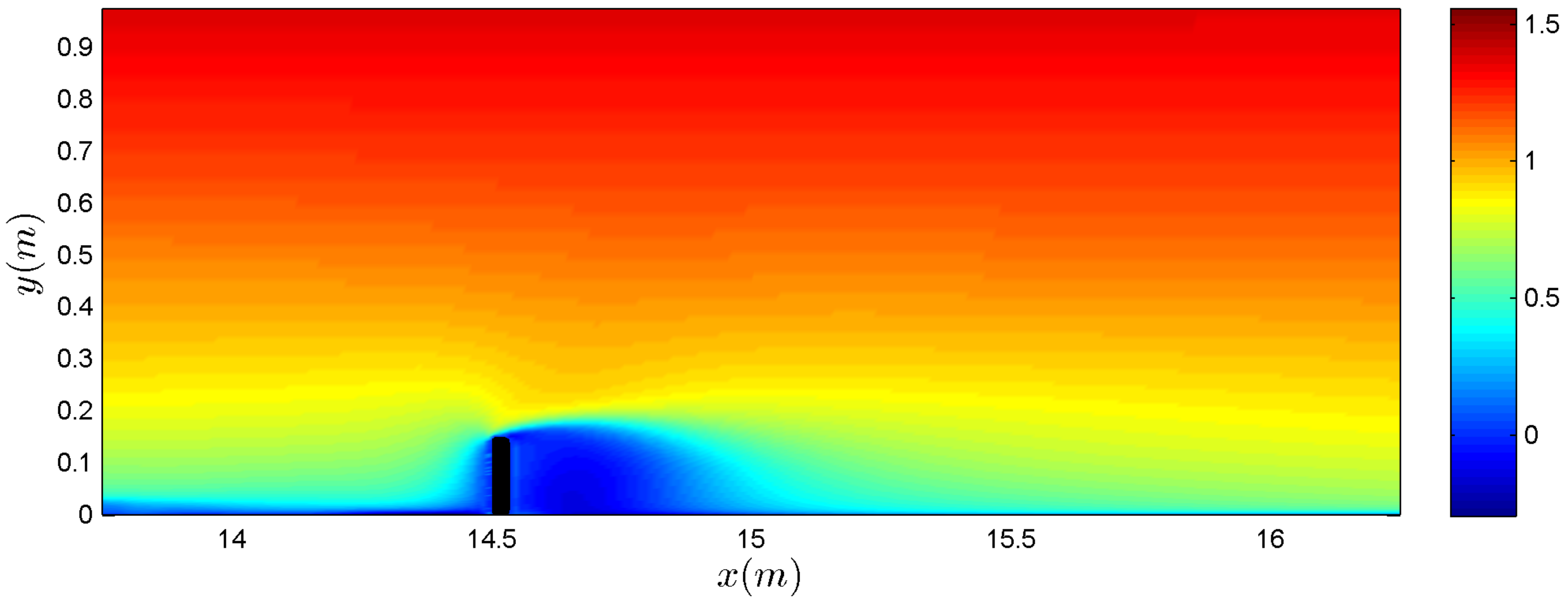


SWTOMP “Fence Experiment”, ABL simulation (1:120)



SWTOMP “Fence Experiment”, ABL simulation (1:120)



<u>Conclusions</u>

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Powerful <u>*open source*</u> finite volume based method for simulation of WTG

Capable of expansion through modularity. Massive parallelism through MPI

State of the art WTG methods on par with international research and industrial leading groups

Next steps…

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GRUPO DE MECÁNICA
DE LOS FLUIDOS COMPUTACIONAL

Complete migration to GPU - CUDA

NVIDIA®

Rotor resolved approach

Aeroelastic simulations

UTE
La energía que nos une

ADME

VENTUS

avanzamos juntos

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AGENCIA NACIONAL DE INVESTIGACIÓN E INNOVACIÓN

Gracias!!
Gracias!!

SWTOMP
Small Wind Turbines Optimization and Market Promotion
Workshop
Small Wind Turbines

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