Desarrollo, validación y aplicación de un módulo CFD-BEM de aerogeneradores y su interacción con el viento

Dr. Ing. Gabriel Usera
Universidad de la República - Uruguay

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caffa3d.MBRi : desarrollo de largo plazo, de código abierto

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

2004 ... 2008

A general purpose parallel block structured open source incompressible flow solver

2014

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

2015

Computers and Fluids

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

2017

Blind test comparison on the wake behind a yawed wind turbine

Journal of Wind Engineering & Industrial Aerodynamics

2018

A Large Eddy Simulation-Actuator Line Model framework to simulate a scaled wind energy facility and its application

Aplicar Tesis Paper Nueva Capacidad

2

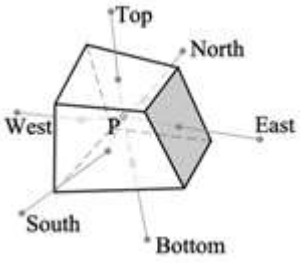
caffa3d.MBRi : solver de flujos 3D en volúmenes finitos

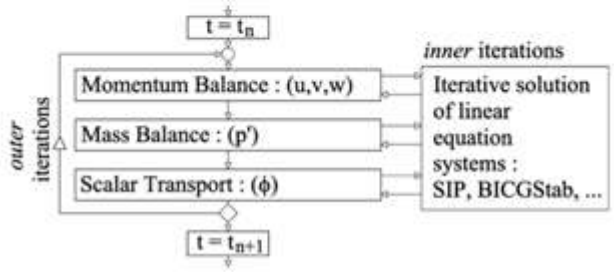
$$\int_S (\boldsymbol{v}\cdot\hat{\boldsymbol{n}}_S)\,dS = 0$$

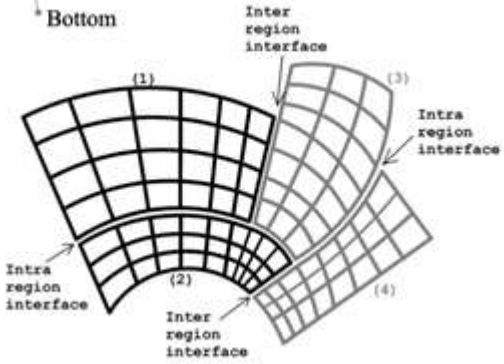
$$\int_\Omega \rho\frac{\partial u}{\partial t}d\Omega + \int_S \rho u\,(\boldsymbol{v}\cdot\hat{\boldsymbol{n}}_S)\,dS =$$

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

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



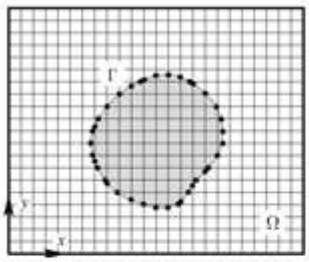




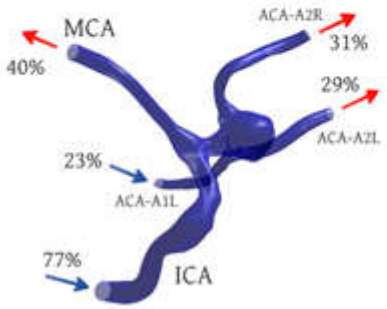
(Mendina et al, 2014)

3

Condiciones de borde inmersas



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



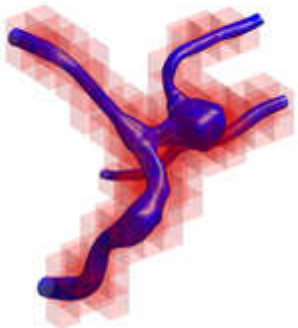


Fig. 14 Patient specific aneurysm geometry with specified flow distribution at inlets and outlets.

(Mendina et al, 2014)

4

Condiciones de borde inmersas

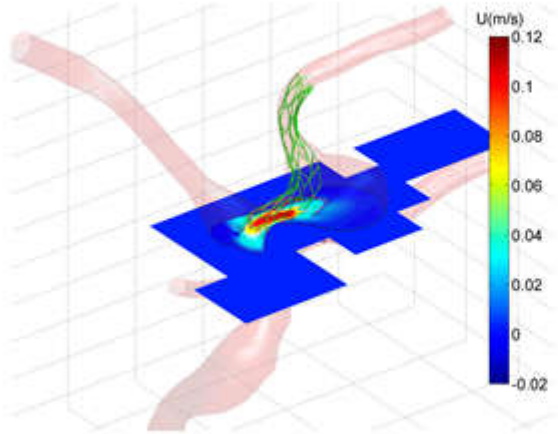


Fig. 16 Detail of flow interaction with stents.

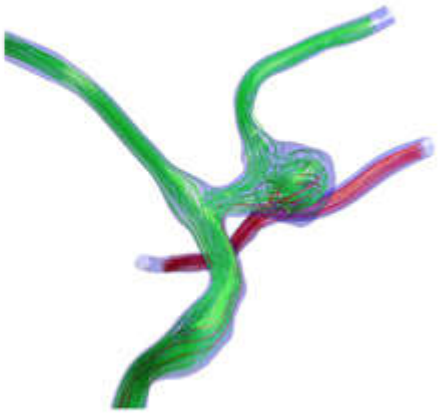


Fig. 18 Streamlines for flow coming from ICA and ACA-A1 arteries. A complex flow pattern with recirculation can be seen inside the aneurysm cavity

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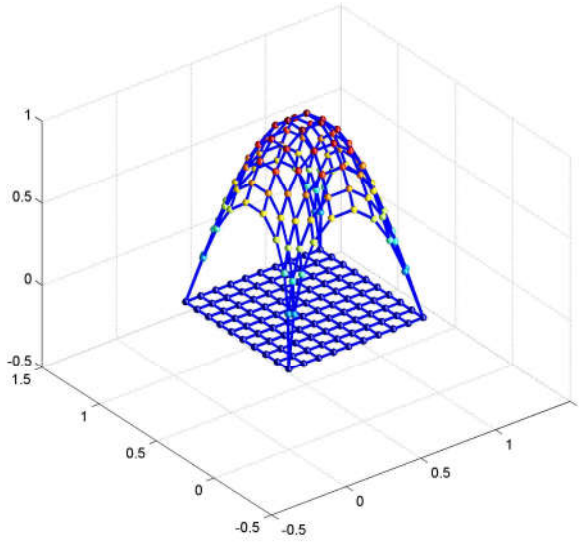
Dinámica de múltiples cuerpos (multibody dynamics)



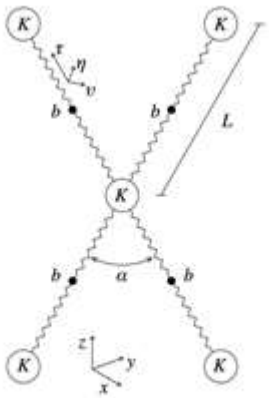


Figure 1: Sketch of the point masses and massless strings.

(Sassi et al, 2017)

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Dinámica de múltiples cuerpos (multibody dynamics)

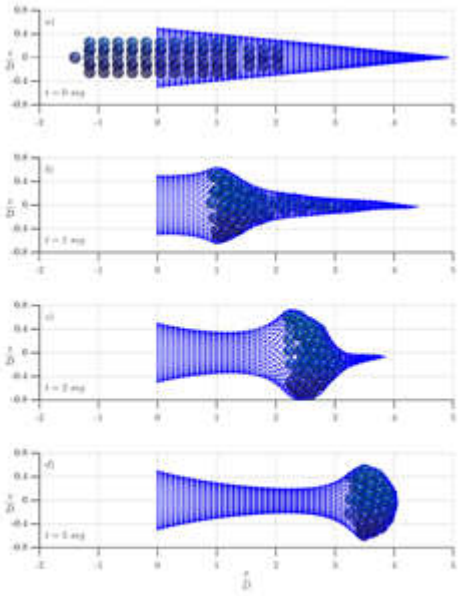
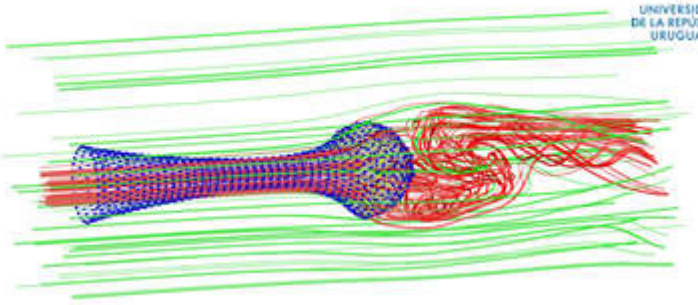


Figure 3: Evolution of the fishnet shape, at time steps $t = 0$, 1.0 , 2.0 , 5.0 s, as the load is dragged into the fishnet.



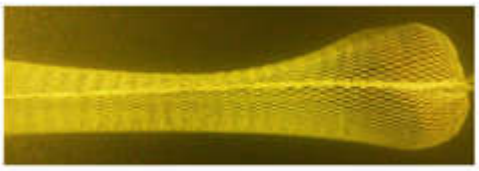


Fig. 5. Shape of the fishnet during the towing tank test.

(Sassi et al, 2017)

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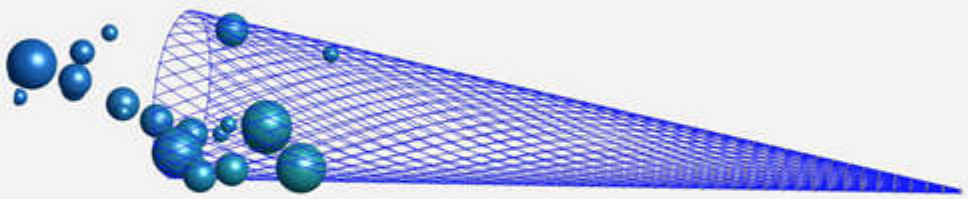
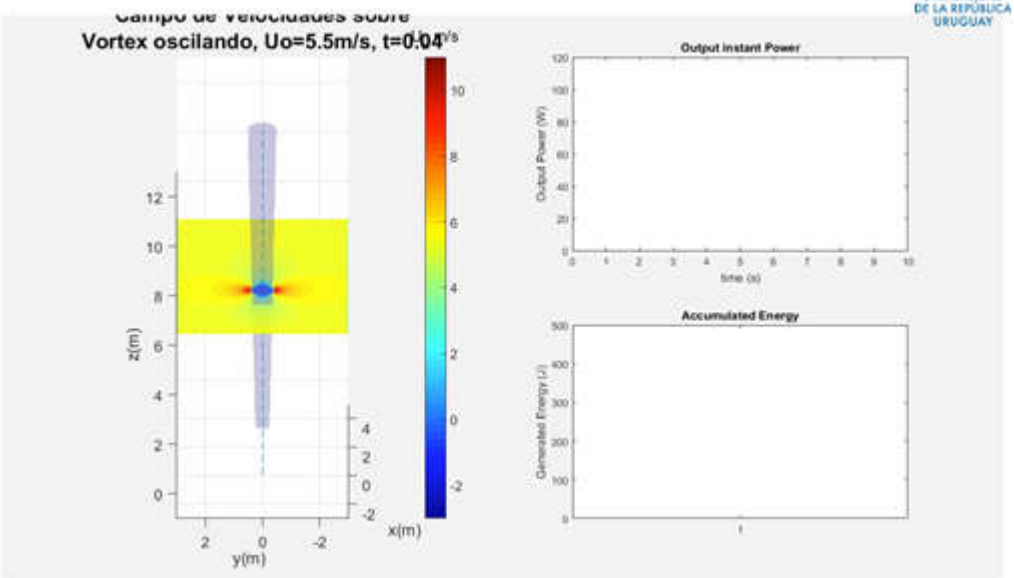
Dinámica de múltiples cuerpos (multibody dynamics)



(Sassi et al, 2017)

8

VortexBladeless : turbina sin aspas



(Sassi et al, 2018)

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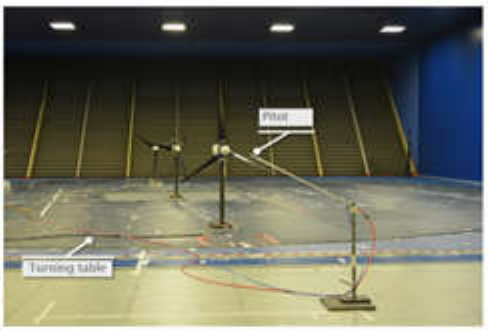
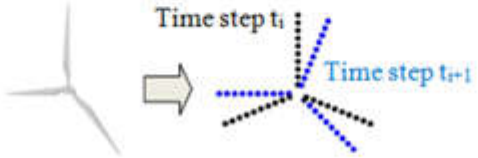
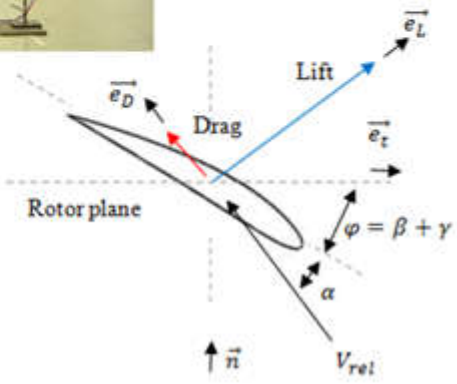
CFD-BEM en modelos a escala de turbinas eólicas



Blade
Element
Momentum Method





(Draper et al, 2018 with TUM Munich)

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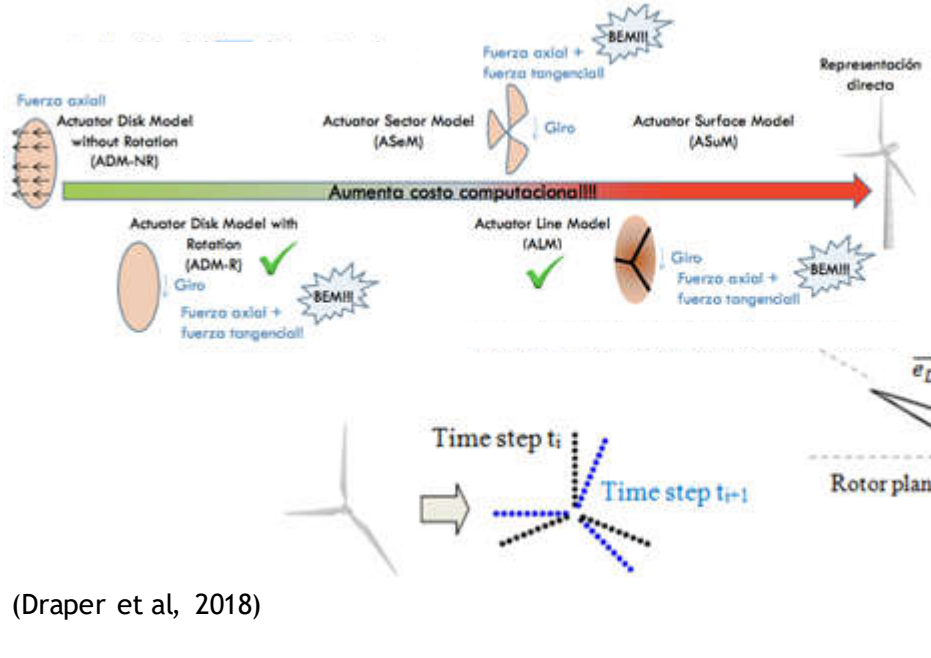
CFD-BEM: ADM , ALM y variaciones…



Blade Element Momentum Method

(Draper et al, 2018)

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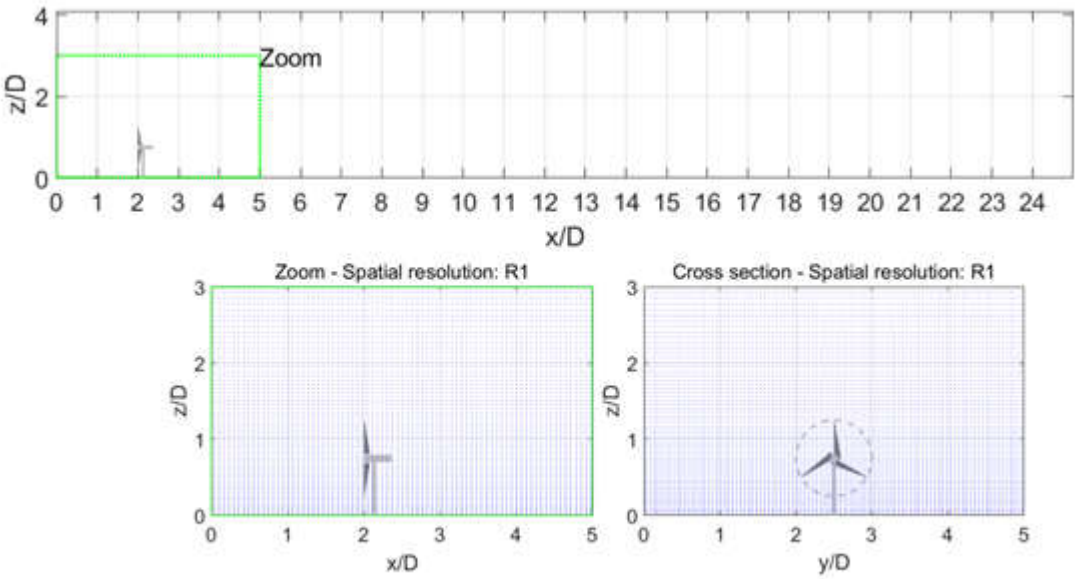
CFD-BEM: Independencia de malla



(Draper et al, 2018)

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.

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CFD-BEM: Independencia de malla

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

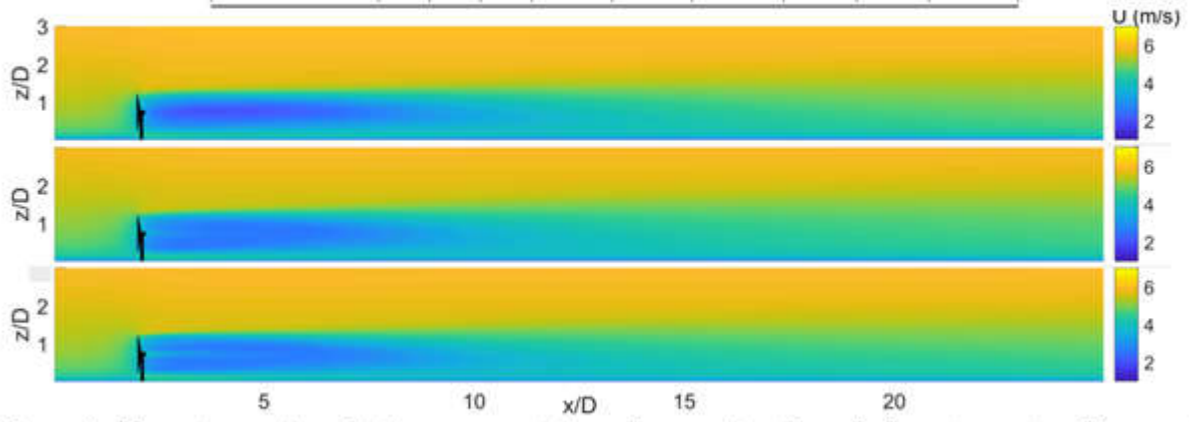

Figure 6: Mean streamwise velocity component in a plane passing through the rotor center. Top: spatial resolution R0, center: spatial resolution R1, bottom: spatial resolution R2. The model wind turbine is sketched in black.

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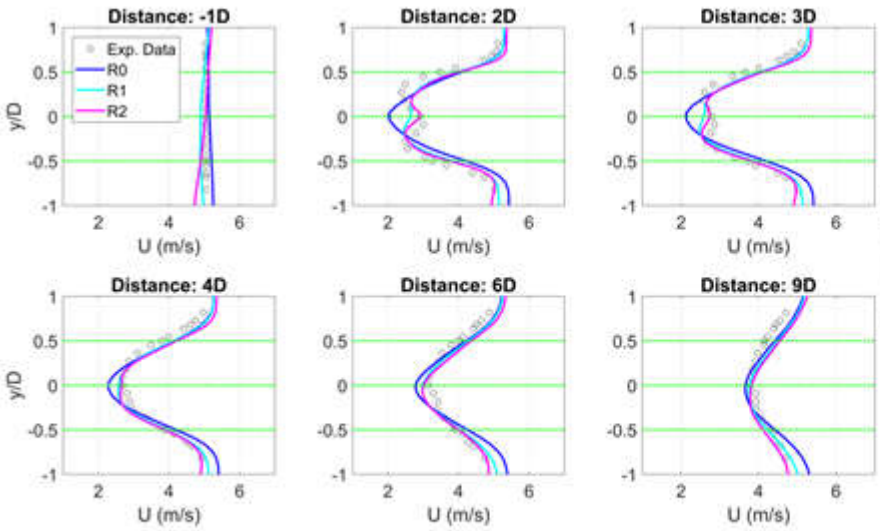
CFD-BEM: Independencia de malla



		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%)

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.

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CFD-BEM: Control de estelas por yawing

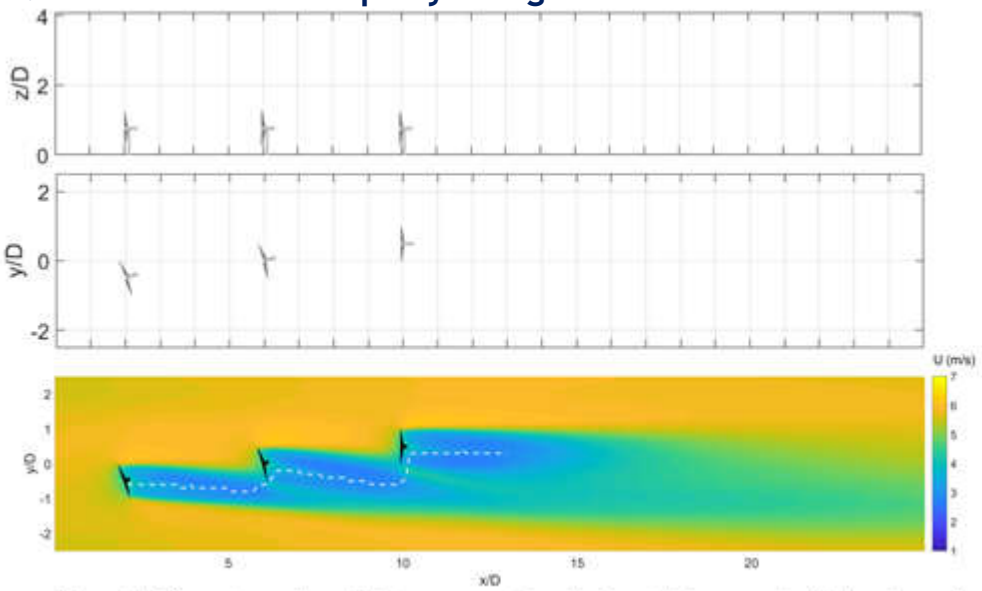

Figure 11: Mean streamwise velocity component in a horizontal plane passing 0.10 m above the rotor center. Spatial resolution R1. The model wind turbines are sketched in black. The white dash line represents the wake center computed from the experimental data by minimization of Equation 7.

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CFD-BEM: Control de estelas por yawing

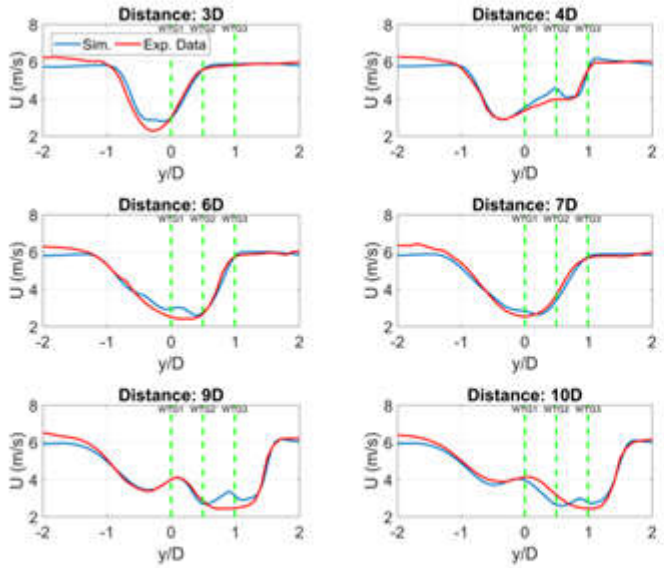

Table 3: Power coefficient of each model wind turbine.

	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%

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.

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CFD-BEM: Horns Rev -> 80 x Vestas V80 2.0 MW

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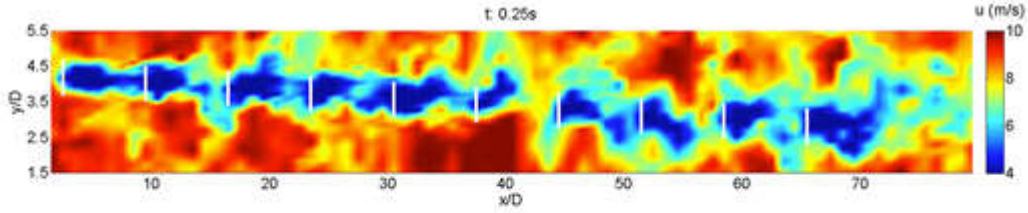
CFD-BEM: Horns Rev -> 80 x Vestas V80 2.0 MW



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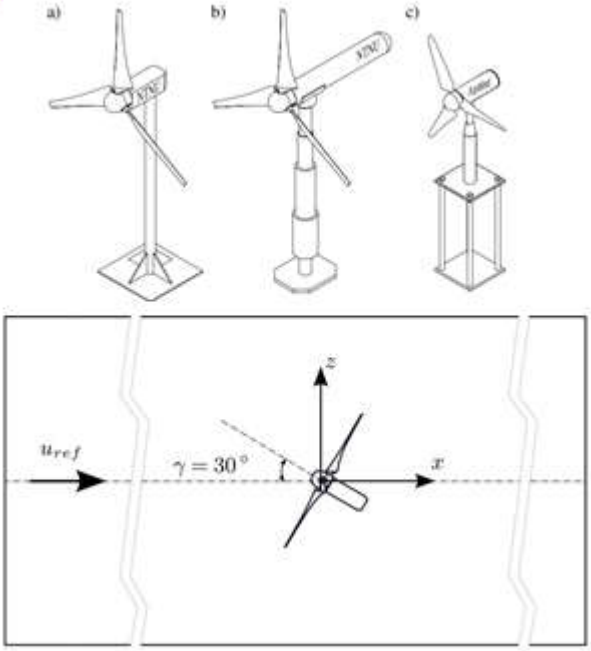
CFD-BEM: Blind Test #5 - 2017



(Mühle et al., 2018)

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CFD-BEM: Blind Test #5 - 2017

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

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

Liana B. Baker

(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)

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CFD-BEM: Blind Test #5 - 2017

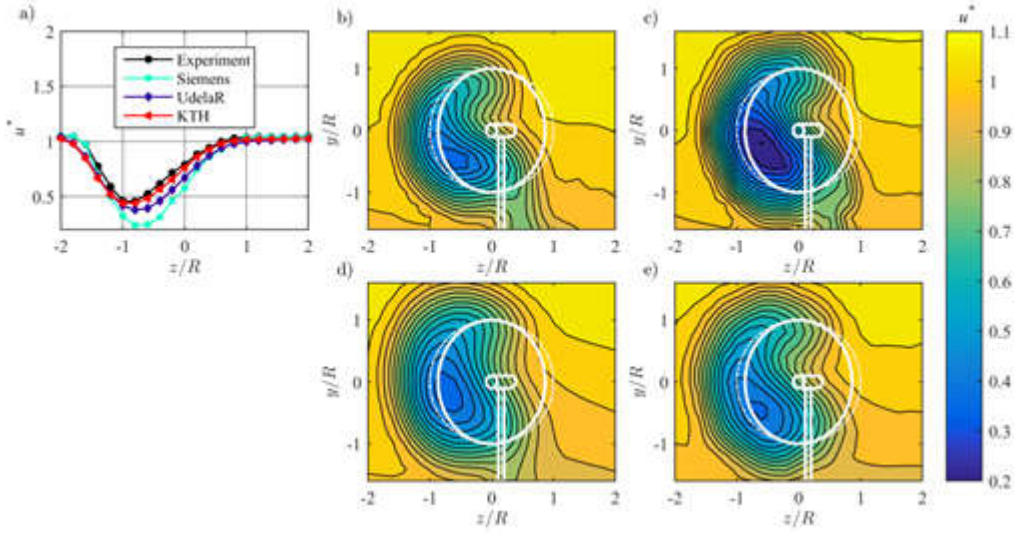

Figure 13. (a) Line plots and (b-e) contour plots for normalized streamwise mean velocity u^* in the wake $3D$ behind upstream ForWind turbine, from (b) experiments, (c) Siemens, (d) UdelaR and (e) KTH and. The white lines represent the turbine rotor, nacelle and tower, solid lines $\gamma = 30°$, dashed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

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CFD-BEM: Blind Test #5 - 2017

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 $3D$ and $6D$ 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
$3D$	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
$6D$	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

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CFD-BEM: 'Libertad' 7.7 MW Onshore Wind Farm (4 x Vestas V100)

Figure 1. Libertad wind farm location (left) and layout (right)

(Guggeri et al, 2018)

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CFD-BEM: 'Libertad' 7.7 MW Onshore Wind Farm (4 x Vestas V100)

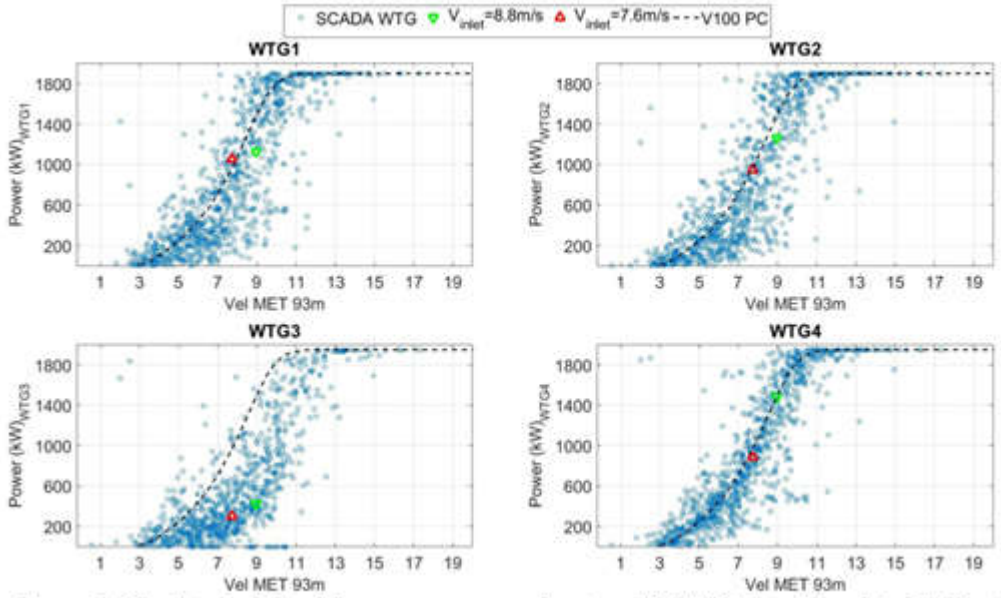

Figure 7. Simulated wind turbines mean power and scattered SCADA data filtered (wind direction 150°+/-2.5°), for two inflow conditions.

(Guggeri et al, 2018)

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Conclusiones

Modelo CFD-BEM basado en volúmenes finitos, validado para la simulación de WTG

Estructura modular expansible del modelo con paralelismo masivo basado en MPI

Métodos al nivel del estado del arte internacional en modelado de WTG methods, comparado con otros grupos de investigación y de la industria.

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Próximos pasos

Completar la migración a GPU - CUDA : CHAMAN

Enfoque de "Rotor Resolved"

Simulaciones aeroelásticas

… impulsando Spin-Off universitaria de "nicho" en CFD …
Buscando socios estratégicos !!

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UNIVERSIDAD DE LA REPÚBLICA URUGUAY

FACULTAD DE INGENIERIA

M F C

Gracias por su atención.

Gabriel Usera
Profesor Titular - UdelaR
gusera@fing.edu.uy

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