

Unblocking critical design challenges of pre-commercial floating wind turbines

Mikel Iribas-Latour

representing

R&D TEAM at Wind Energy Department



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01 Offshore thoughts 15 years ago

02 Offshore design challenges

03 Available solutions

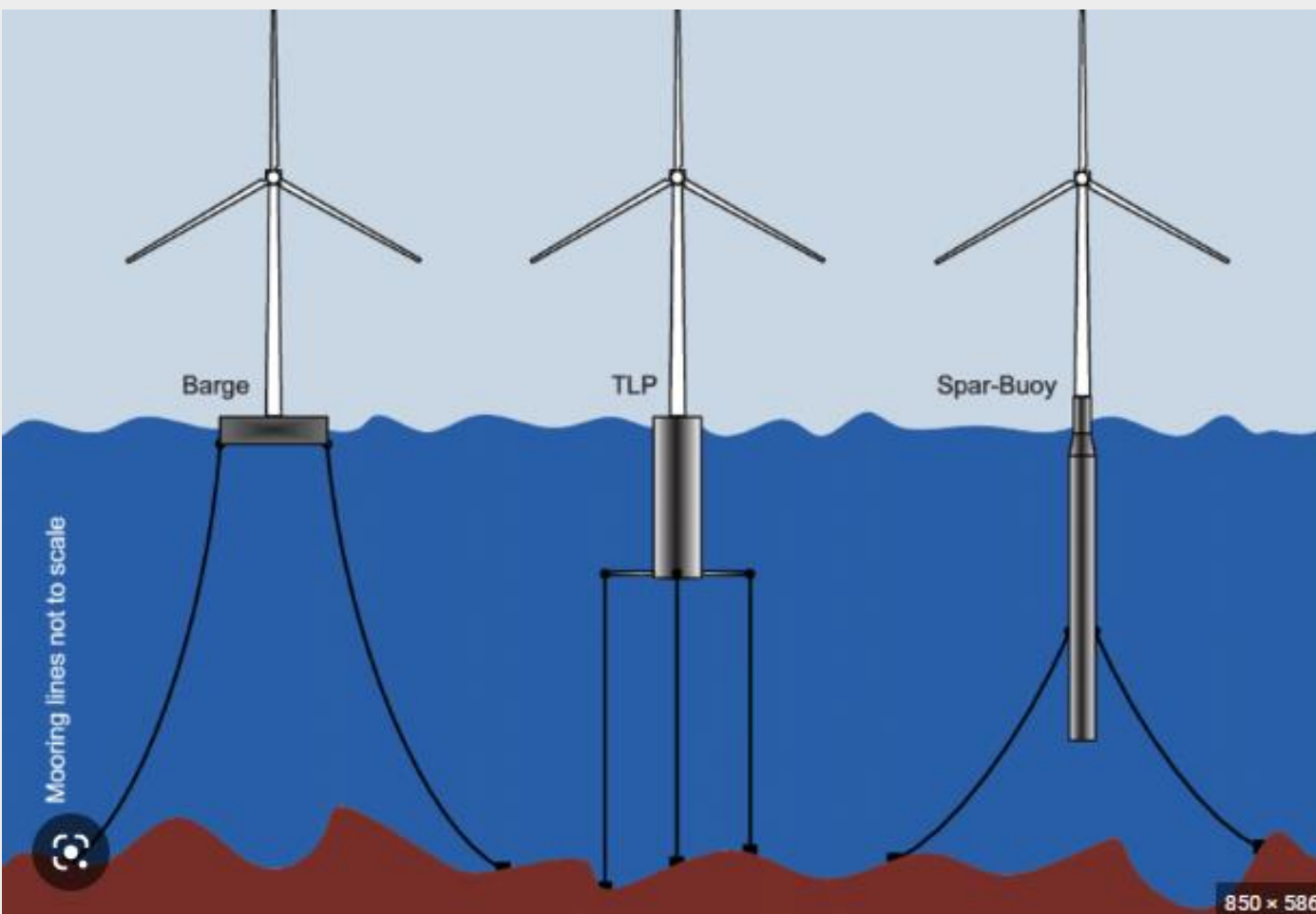
04 CENER's solution

- Unique approach
- Aerodynamic multi-complexity solution
- Hydrodynamic multi-complexity solution
- Control retrievers and FOWT co-design

05 Future challenges & conclusions

15 years ago...

Floating offshore Wind Turbine (FOWT) concepts foreseen 15 years ago:



Numerical Models:

- **Aerodynamics:**
 - BEM theory
- **Hydrodynamics:**
 - Potential theory
 - Morison

under small displacements assumptions
- **Control:**
 - Onshore control with minor changes



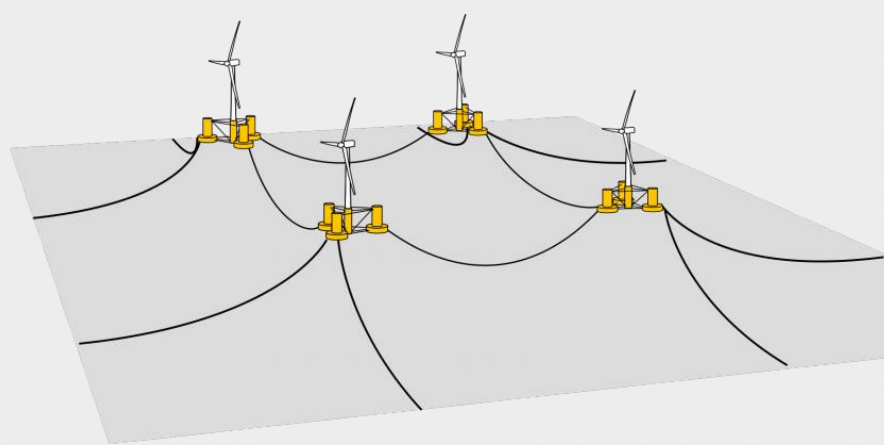
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Nowadays



FLOATING CONCEPTS: from common needs, to specific problems

	Hydrodynamics	Scale Tank Tests	FOWT Co-Design	Structural design – Fatigue	Stability analysis	Certification	Industrialization
Semi-submersible	●	●	●	●	●	●	●
TLP	●	●	●	●	●	●	●
Spar	●	●	●	●	●	●	●
Single Point Mooring	●	●	●	●	●	●	●
Multi-Wind Turbine	●	●	●	●	●	●	●

● Low level of pain

● Medium Level of pain

● High Level of pain



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Nowadays challenges

Approach to commercialization requires a step forward on: engineering technologies and processes

Reliable tools for FOWT and FO wind farms designs

- Power production
- Loads estimation: fatigue and extreme loads

More accurate and integrated tools

- Estimation of hydrodynamic parameters by CFD/scale testing
- Multi-fidelity tools, validated, integrated, common interfaces, accepted...

Sequential design vs co-designs

- Floater and Wind Turbines co-design
- Control co-design
 - Warranty the dynamic stability
 - Increase power production while reducing loads

Manufacturing & logistics:

- How, how many, who and where are we manufacturing, installing & O&M?
- Some numbers:
 - 10GW → 700 FOWT → 700 floaters → **700 months of manufacturing**
 - For 2 WT-floaters → 350 floaters → **350 months of manufacturing**



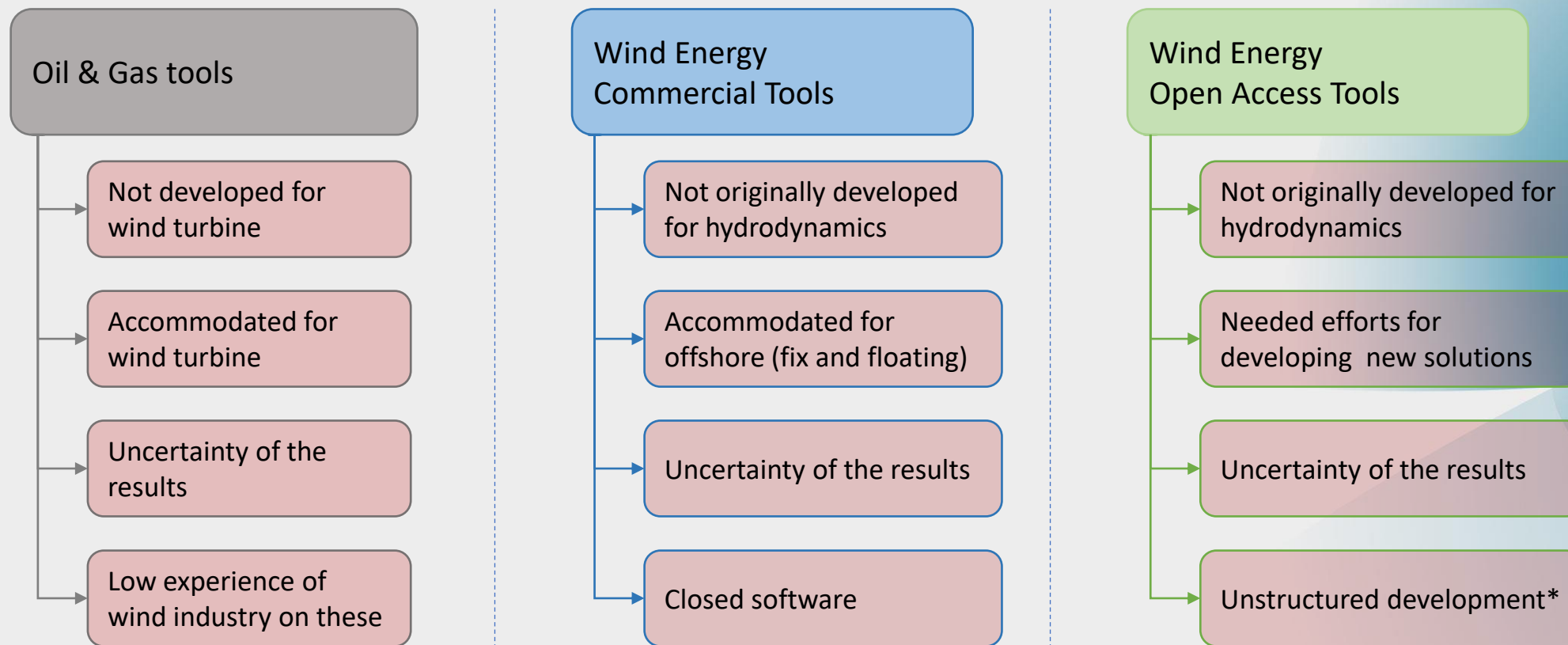
Nowadays challenges

Reliable and integrated tools for co-design

Existing floater designs demand numerical tools for supporting these technologies :

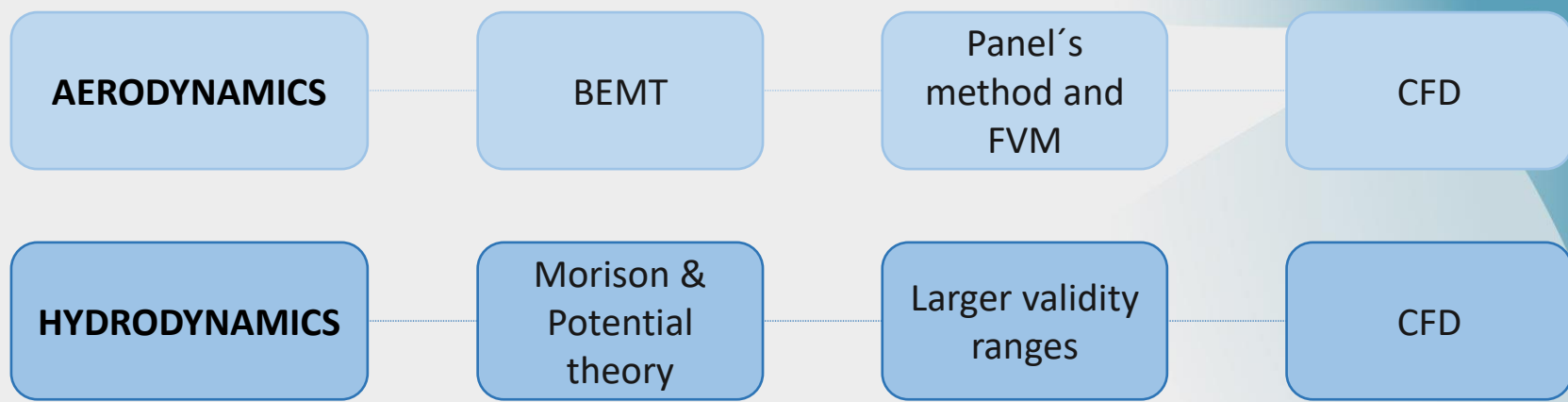
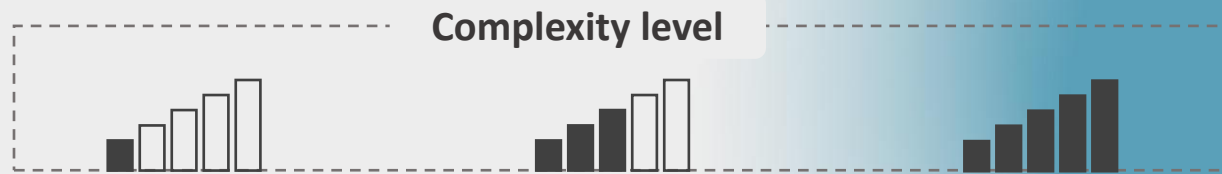
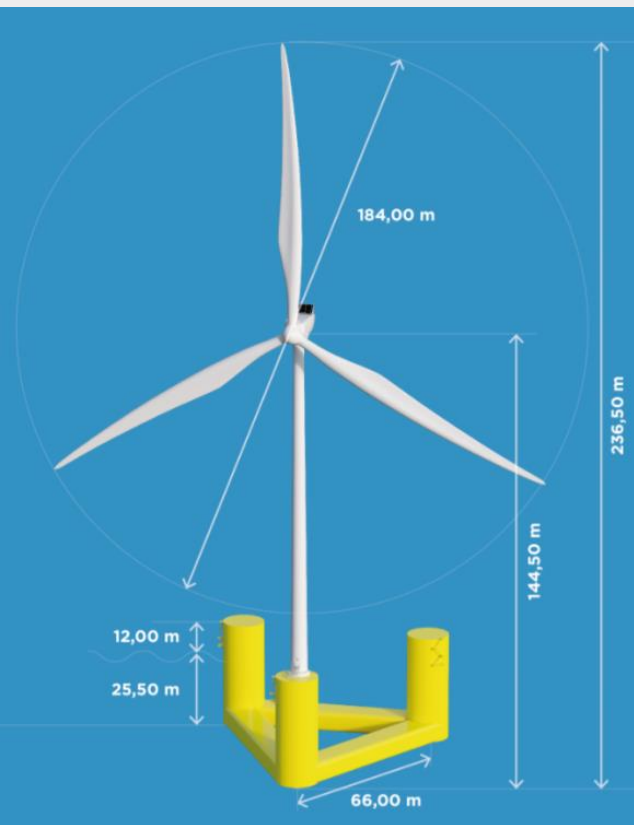
- **Wake interactions**
 - Self wake
 - Nearby wakes
- **Hydrodynamics & aerodynamics able to deal with**
 - High displacements
 - High yaw misalignment (from wind and waves & currents) for SPM
 - Complex situations, designs and configurations
- **Multibody models**
 - Shared floater
 - Shared mooring and/or anchor
 - Floaters with Several bodies
- **New control solutions for specific floater designs**
 - Weathervaning
 - Multi-WT floaters
 - Advanced controllers
- **FOWT co-design**

FOWT dynamic simulation tools: background, strengths, but also pains

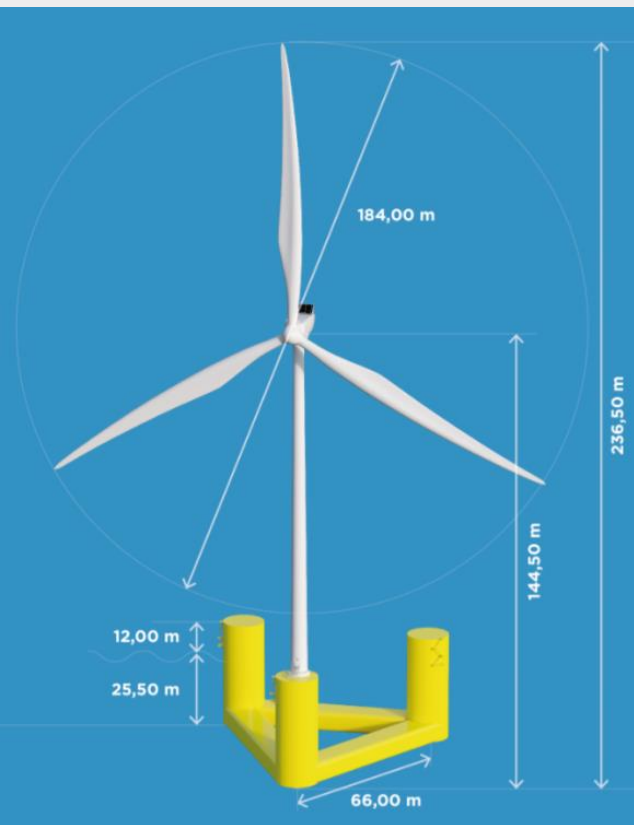


Different tools & Different environments & Different license & Different capabilities
NON-INTEGRATED, NOT-UNIQUE SOLUTION

CENER's vision to unlock the floating offshore

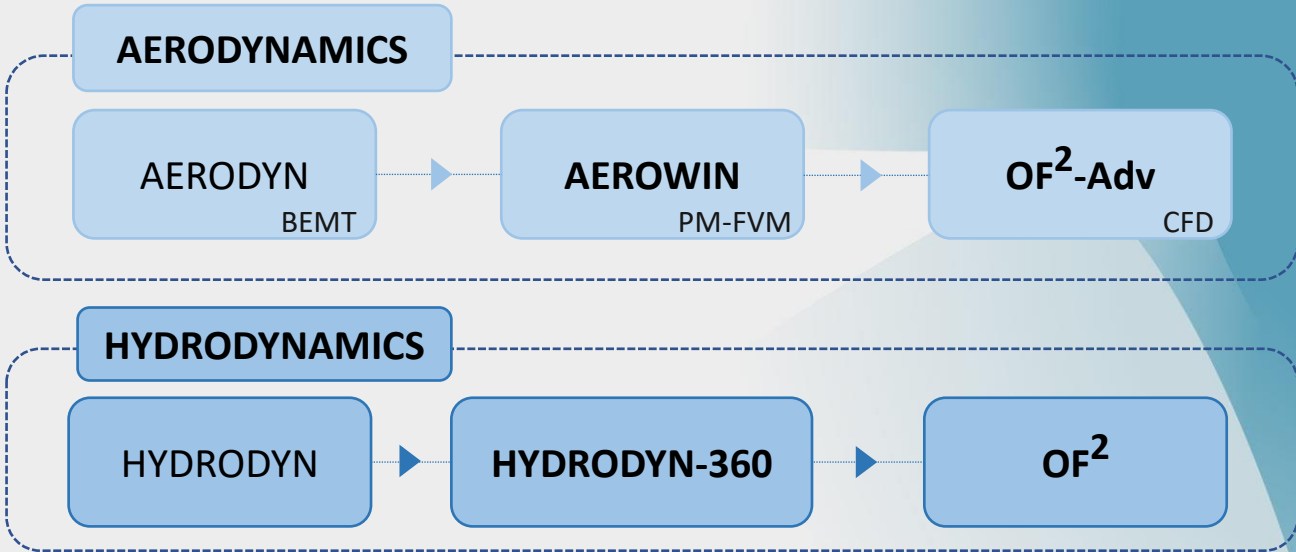
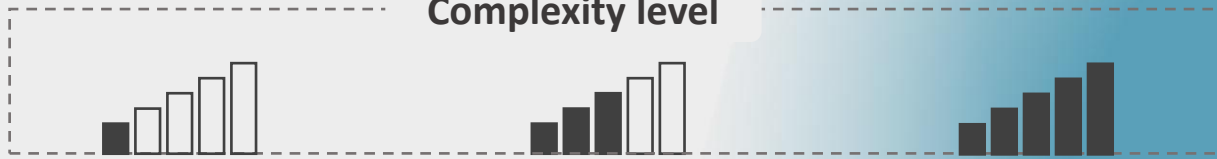


CENER'S INTEGRATED & UNIQUE Multi-Fidelity solution



MULTIBODY

MUST
(Based on **OpenFAST**)



Same tool & Same environment & Multi fidelity integrated capabilities

INTEGRATED UNIQUE SOLUTION



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CENER'S INTEGRATED & UNIQUE Multi-Fidelity solution – the framework

MULTIBODY

Most impactful applications :

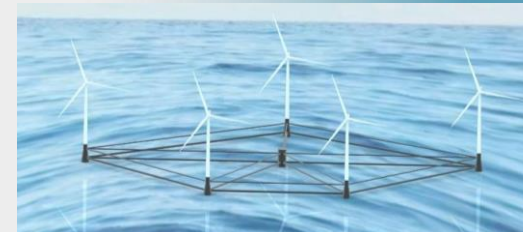
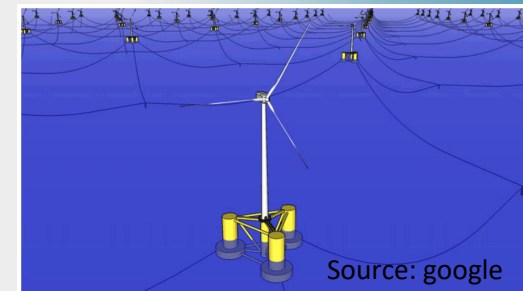
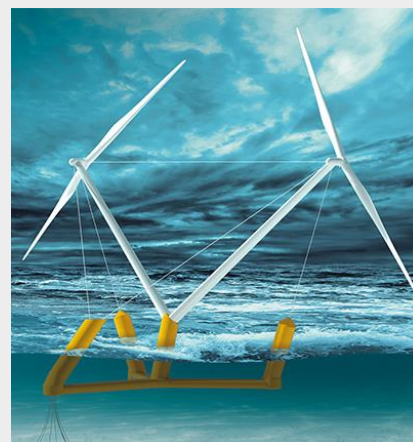
- Structural coupling
- Aerodynamic multi-fidelity coupled
- Hydrodynamic multi-fidelity coupled



Multi Wind Turbine Aerolastic Tool - MUST (Based on OpenFAST)

In the future commercially driven:

- Shared mooring
- Shared anchors



CENER'S INTEGRATED & UNIQUE Multi-Fidelity solution – the framework

MUST
(Based on OpenFAST)

CocoLib

WT1
controller

WT2
controller

CocoDyn

Module in MUST to facilitate the communication between CocoLib and the control libraries of the individual turbines

CocoLib (.dll/.so)

Coordinated controller library for wind turbines over the same floater.

- Higher hierarchical control level
- Aware of the whole system status
- Provides dynamic solutions for multiple purposes



Aerodynamic needs beyond wake interactions

AERODYNAMICS

	Stall and Unsteady Aerodynamics [SUA]	Complex Wake Conditions [CWC]
Wind Turbine concepts and designs		
Large rotors (slender blades, thick airfoils, ...)	●	
Multi-rotor & Multi-WTs *		●
Floating offshore WTs	●	●
Aerodynamic control devices *	●	●
Wind Turbine Operating conditions		
Parked or Idling conditions	●	
Dynamic wake conditions		●
Yaw misalignment		●
Partial wake interaction	●	●

AERODYN

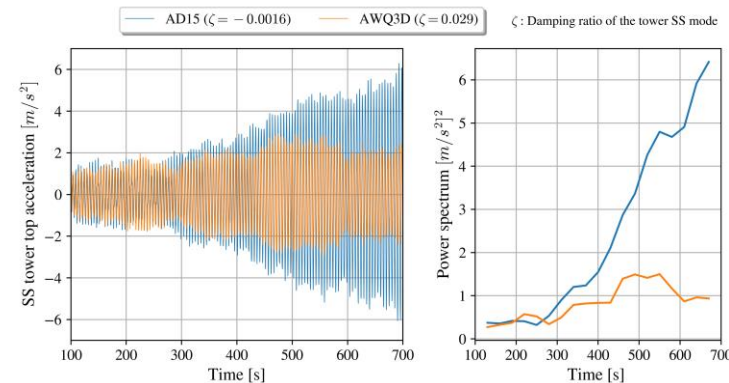
BEMT

AEROWIN

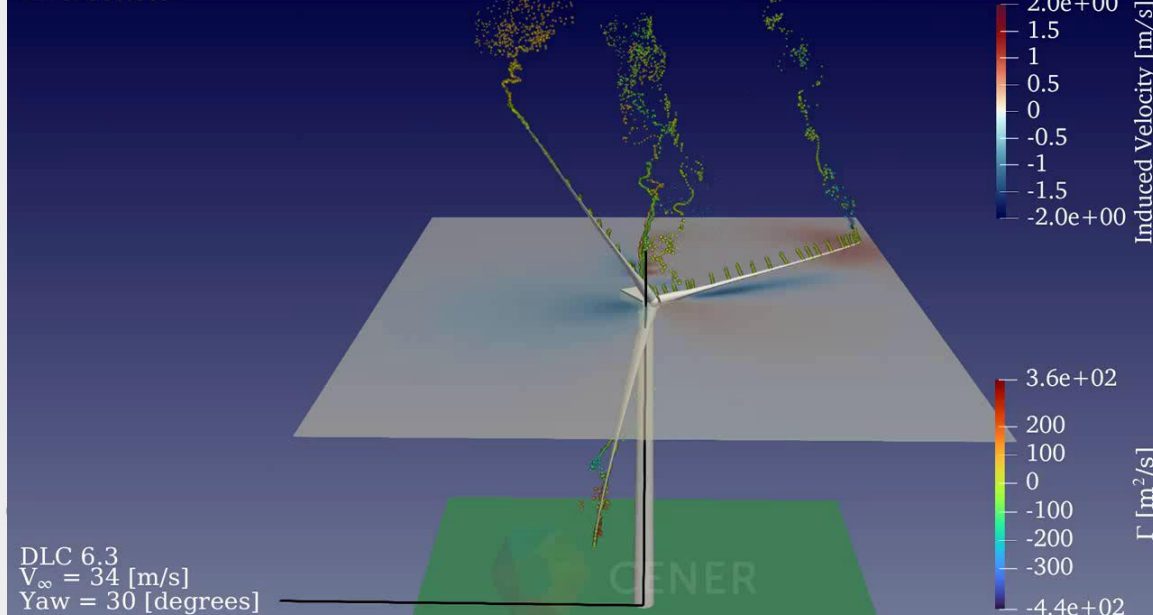
PM-FVM

OF²-Adv

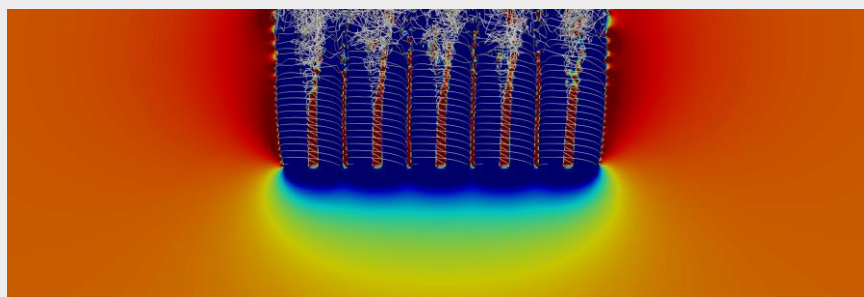
Tower SS (side-side) dynamics with different aerodynamic codes



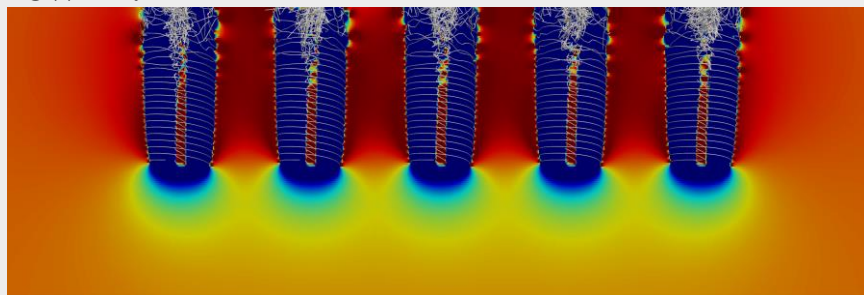
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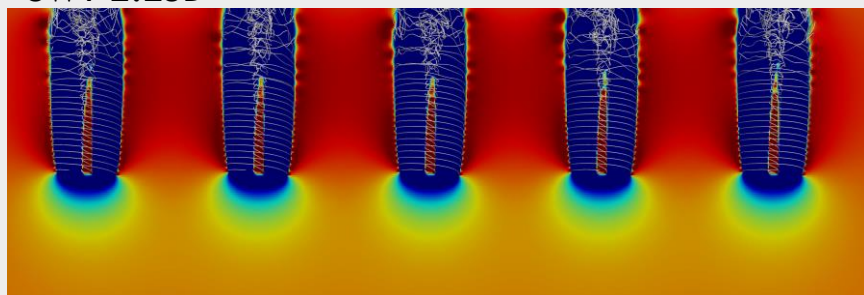
Examples of application: Multi wind turbine simulation tool, not only offshore



5WT 1.1D

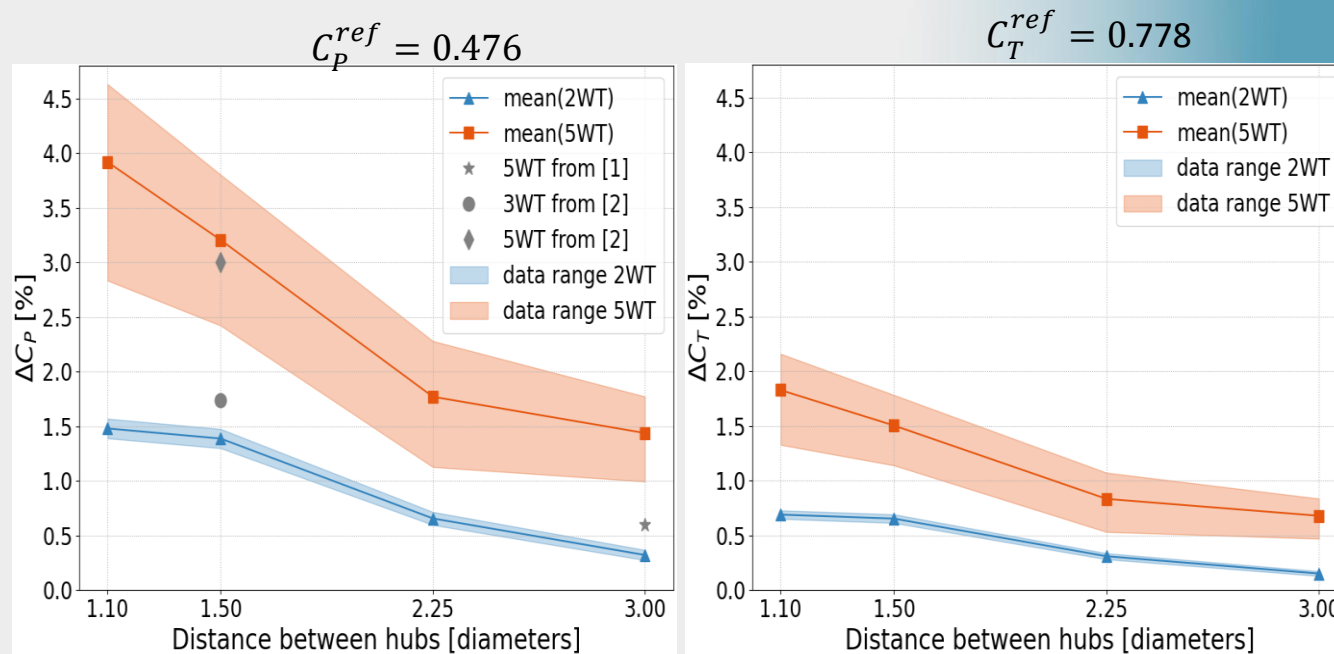


5WT 2.25D

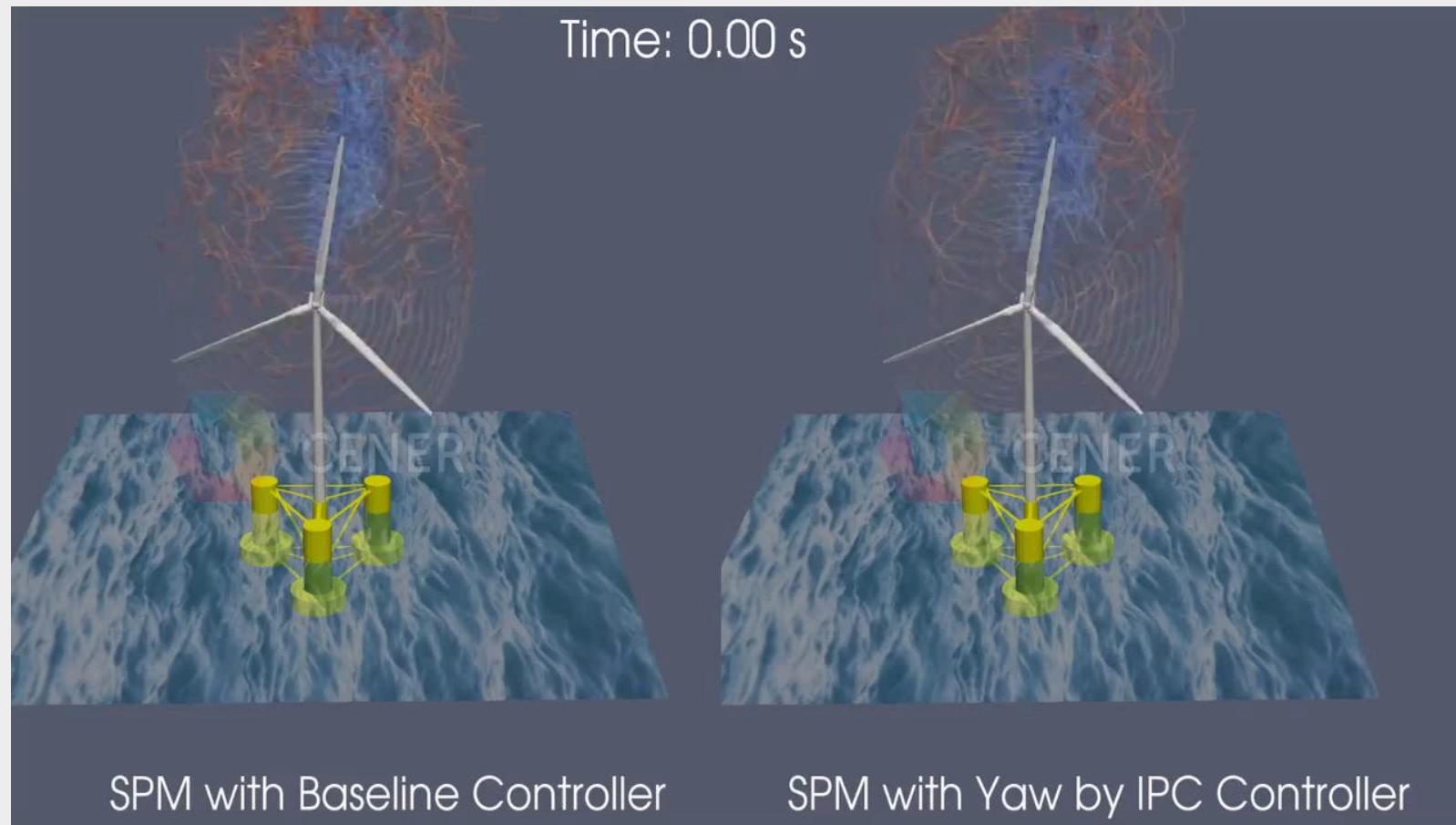


5WT 3D

- New tools, new capabilities ...
- Closer wind turbines:
 - up to 4% more C_p
 - while C_t increases less than 2%



Examples of application: Single Point Mooring floaters



SPM configuration

No mooring stiffness in yaw



Floating platform drift in yaw direction



Yaw by IP-Control

Adequate to mitigate the yaw drift
Already tested in several SPM floaters

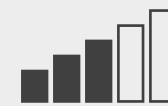


Evolution from HydroDyn to HydroDyn-360

HYDRODYNAMICS



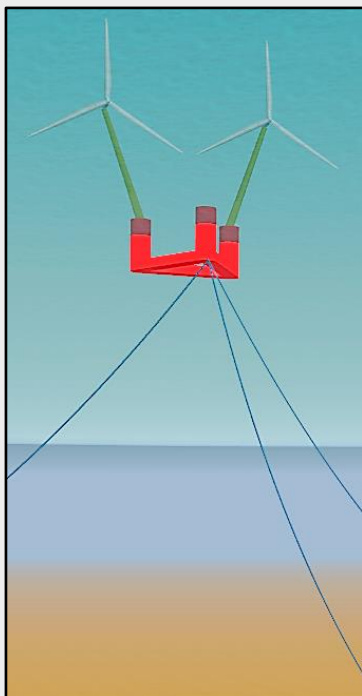
HydroDyn



HydroDyn-360



OF²



HydroDyn Forces



- ➖ Small displacements assumed
- ➖ Force, modulus and direction, does not consider changes in the wave-platform orientation
- ➖ Limitations for cases with large displacements such as SPM or mooring failure

HydroDyn-360 Forces



- ➕ Wave excitation forces (linear and 2nd order) with the relative position between platform and wave.
- ➕ Morison forces projected with the relative position between platform and wave.
- ➕ Applicable for cases such as SPM or mooring failure



Design and hydrodynamic characterization of floating platforms cenerFOAM

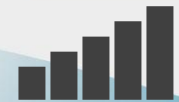
HYDRODYNAMICS



HydroDyn



HydroDyn-360



OF²

cenerFoam

Tool to design and optimize floating platform hydrodynamics by CFD

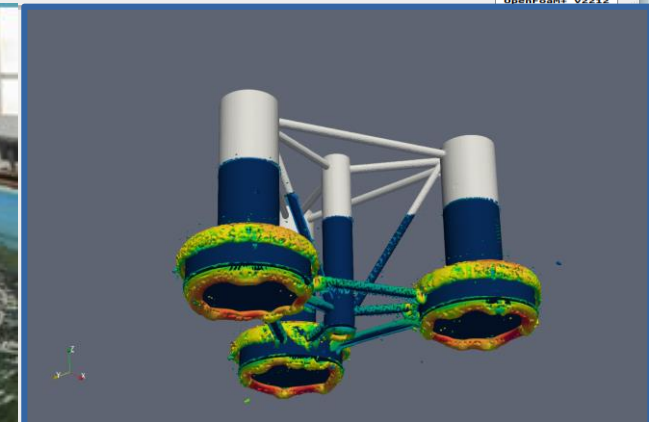
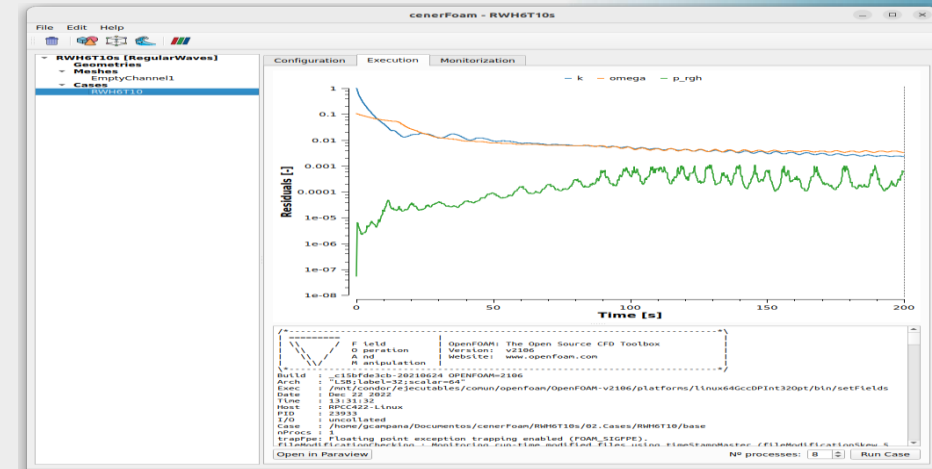
Test simulated with the tool:

- Forced displacement
- Free decay
- Regular waves
- Irregular waves
- Bi-chromatic waves
- Weathervaning

Virtualizing SiL experiments

Virtualized Tests

- Forced displacement
- Free decay
- Weathervaning
- Regular waves
- Irregular waves
- Bi-chromatic waves
- But DLCs...??



OpenFoam - OpenFast, the result is the tool OF²

HYDRODYNAMICS

HydroDyn

HydroDyn-360

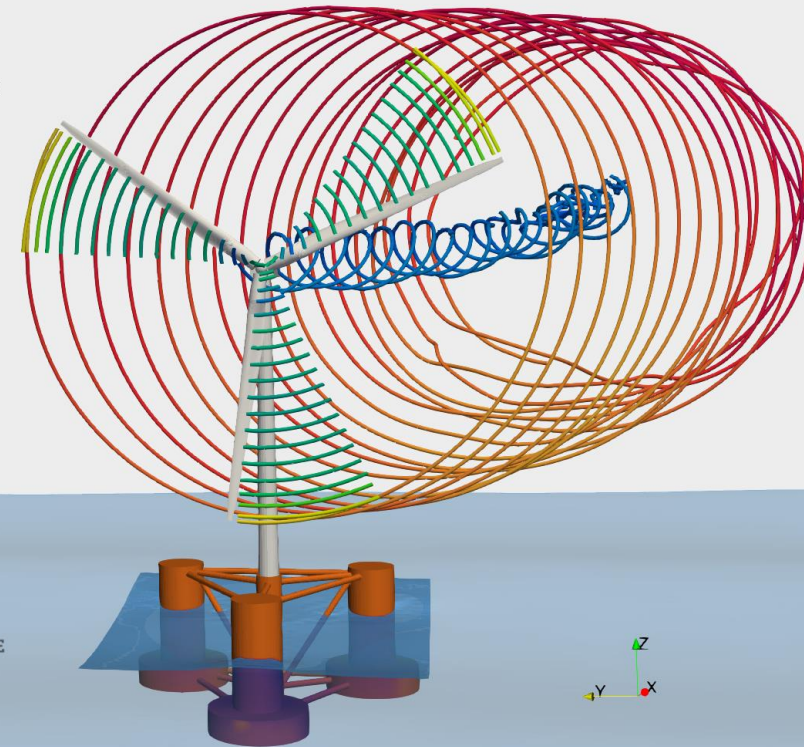
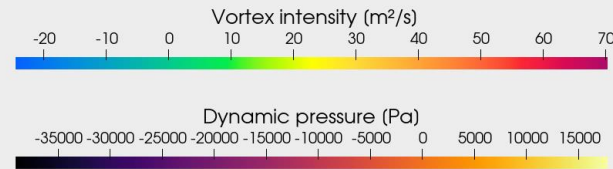
OF²

To overcome viscosity and computation effort, **OF²**

- Platform hydrodynamics CFD modelling
- WT through MUST or OpenFast

Time effort example:

to simulate in 19h a 600s case of the OC4 platform + NREL 5MW assembly under steady uniform wind condition and regular wave



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Challenges ahead & Conclusions

Floating offshore wind turbine technologies

- Great differences in terms of TRL for over 50 concepts worldwide
- Specific but also common needs for all of the concepts
- FOWT co-design is mandatory for massive development
- Unsolved challenges
 - Low track record world wide yet
 - Reliability & validation of floaters and tools
 - LCOE reduction
 - FOWT transportation, commissioning,...
 - Industrialization, circularity, O&M,...
 - Manufacturing & logistics
 - Social acceptance...





Mikel Iribas

On behalf of

R&D TEAM at Wind Energy Department

Wind Energy Engineering Manager

Tel.: +34 948 25 28 00

Email: miribas@cener.com

CENER, Ciudad de la Innovación, 7

31621 Sarriguren, Spain

www.cener.com



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