Sandia National Laboratories

NREL

Advanced Features and Recent Developments in the WEC-Sim Open-Source Design Tool

PRESENTED BY

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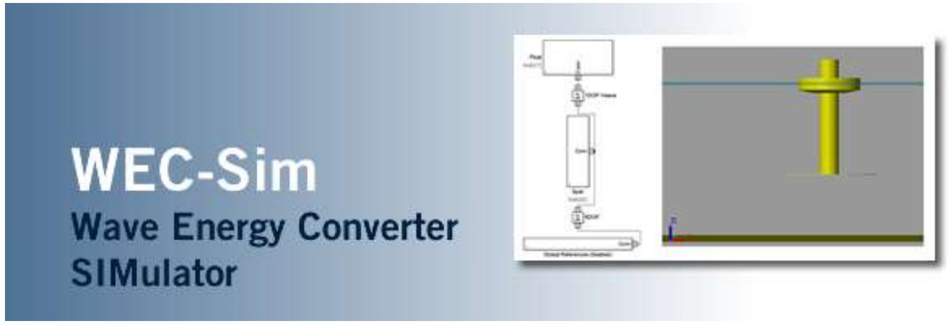
Sandia National Laboratories

WEC-Sim

What is WEC-Sim?

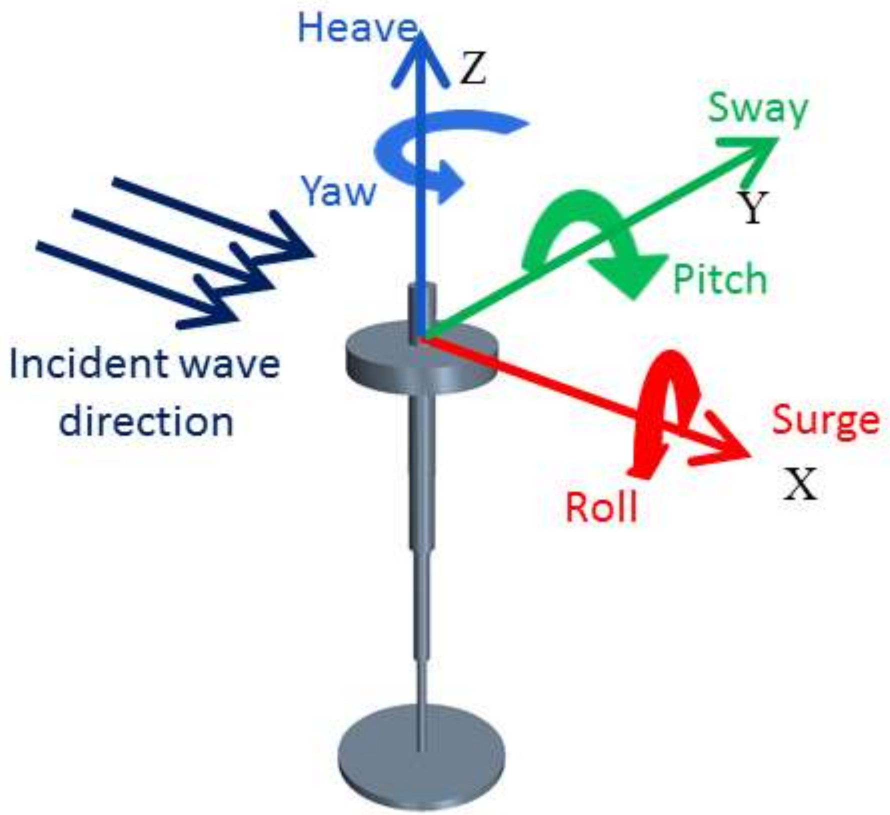
WEC-Sim (Wave Energy Converter Simulator)

- Simulates wave energy converter dynamics in operational waves
- Time-domain rigid body equation of motion solver based on Cummins' formulation
- Open source software developed in MATLAB/SIMULINK
  - Available at https://github.com/WEC-Sim/WEC-Sim
- Joint NREL/Sandia project funded by the US Department of Energy
- First Release: v1.0 in June 2014
- Current Release: v5.0.1 in Sept 2022

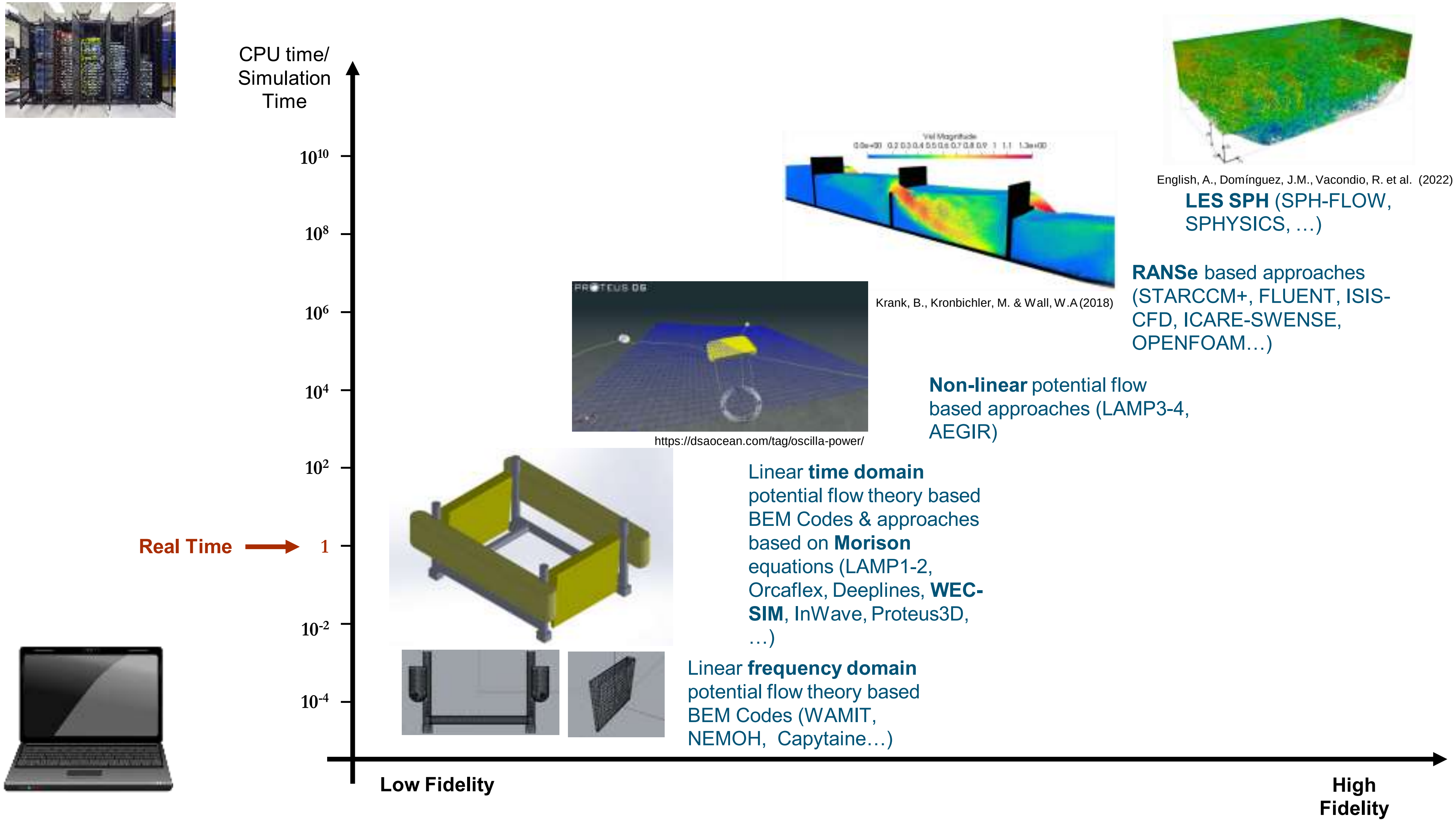


Why use WEC-Sim?

- WEC-Sim has the ability to model the dynamics of devices that are comprised of rigid bodies, power-take-off (PTO) systems, and mooring systems.
- WEC-Sim uses hydrodynamic coefficients derived from frequency-domain boundary element (BEM) simulations
- Time-domain simulations are performed by solving the governing WEC equations of motion in 6 degrees-of-freedom.

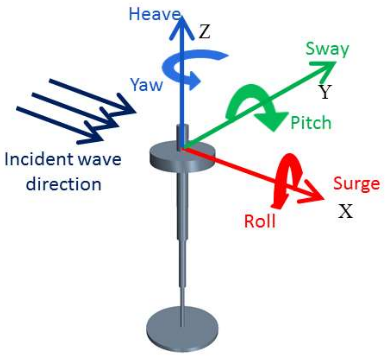


Why use WEC-Sim?



WEC-Sim Theory

- Dynamics simulated by solving time-domain equation of motion (Cummins, 1962)



$$m\ddot{x}(t) = f_{hs}(t) + f_{ex}(t) + f_{rad}(t) + f_v(t) + f_{pto}(t) + f_m(t)$$

- $f_{hs}(t)$: Hydrostatic restoring force
- $f_{ex}(t)$: Wave excitation & diffraction force (from BEM simulations)
- $f_{rad}(t)$: Radiation force: added mass and radiation damping (from BEM simulations)
- $f_v(t)$: Viscous force
- $f_{pto}(t)$: Power take-off force
- $f_m(t)$: Mooring force

- Use radiation and diffraction method and calculate the hydrodynamic forces from frequency-domain Boundary Element Method (BEM)

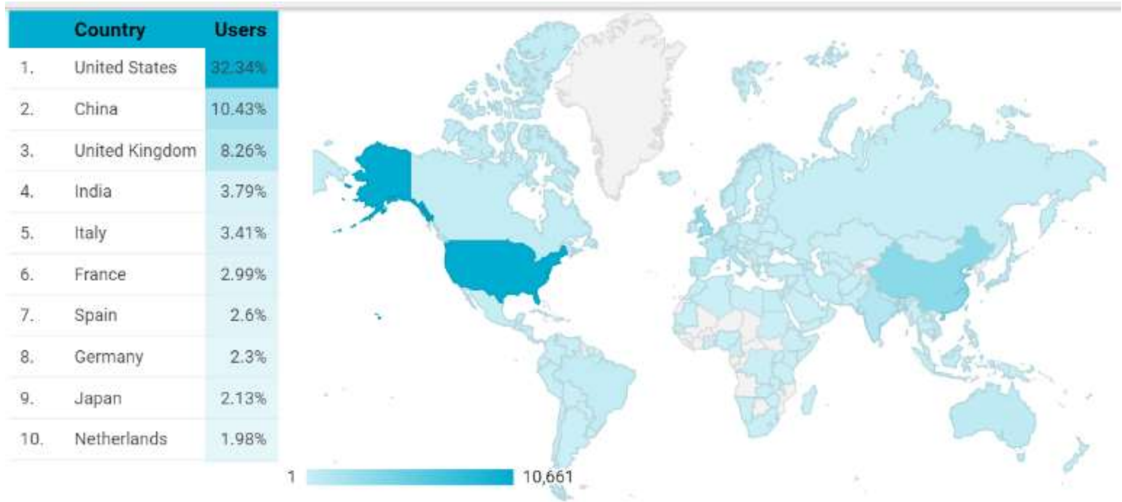
$$f_{rad}(t) = -A_{\infty}\ddot{X} - \int_0^t K(t-\tau)\dot{X}(\tau)d\tau$$

$$f_{ex}(t) = \Re\left[R_f F_X(\omega_r)e^{i(\omega_r t+\phi)}\int_0^{\infty}\sqrt{2S(\omega_r)d\omega_r}\right]$$

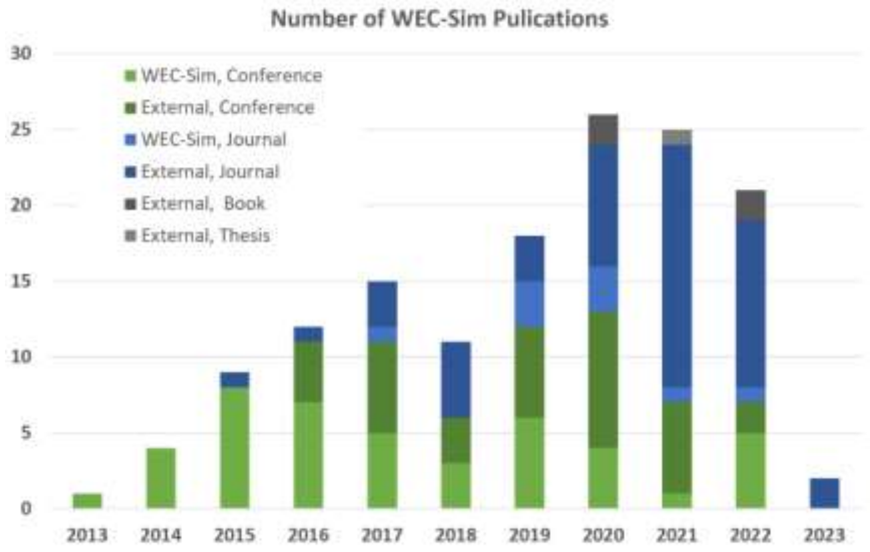
$$= \int_{-\infty}^{\infty}\eta(\tau)f_e(t-\tau)d\tau$$

WEC-Sim User Base

- Users have a crucial role for the software development and continuous improvement
- As January 2024, more than 1200 issues have been addressed and more than 1200 pull requests have been developed to improve the source code
- As of May 2023, approximately 144 scientific publications have been developed using WEC-Sim



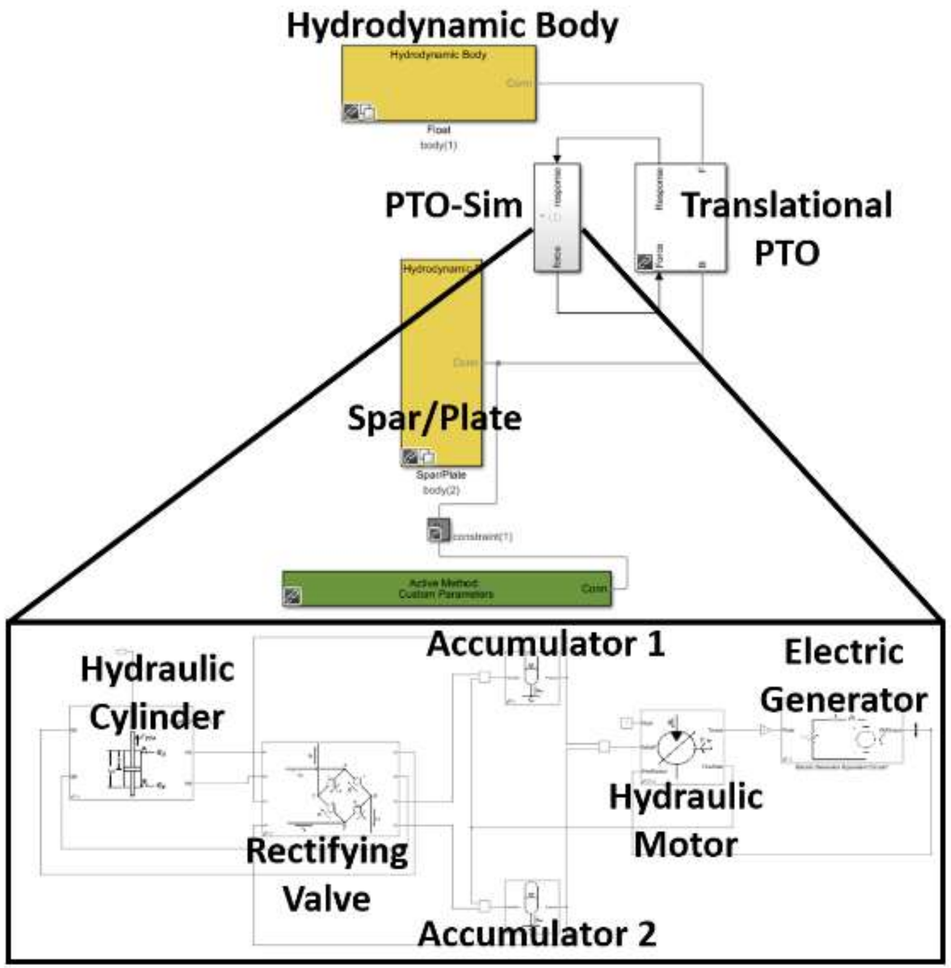
Google Analytics WEC-Sim users from November 2016 to June 2023



Number of WEC-Sim publications by year and category

WEC-Sim Recent Applications

PTO-Sim



Control Examples

Controller Application	Description
Passive (P)	Sphere with proportional (damping) control
Reactive (PI)	Sphere with proportional-integral (spring and damping) control
Latching	Sphere with latching (locking) control
Declutching	Sphere with declutching control
Model Predictive Control (MPC)	Sphere with model predictive control

Capytaine Development

Background

- Capytaine is a Python package with a Fortran core
- Based on the open-source BEM solver Nemoh
- First version of Capytaine was released in 2019

Sandia Labs and NREL funding Capytaine

- Collaboration started in April 2022
- Five new versions have been released since then
- ~60 issues have been closed
- ~130 pull requests have been merged on GitHub

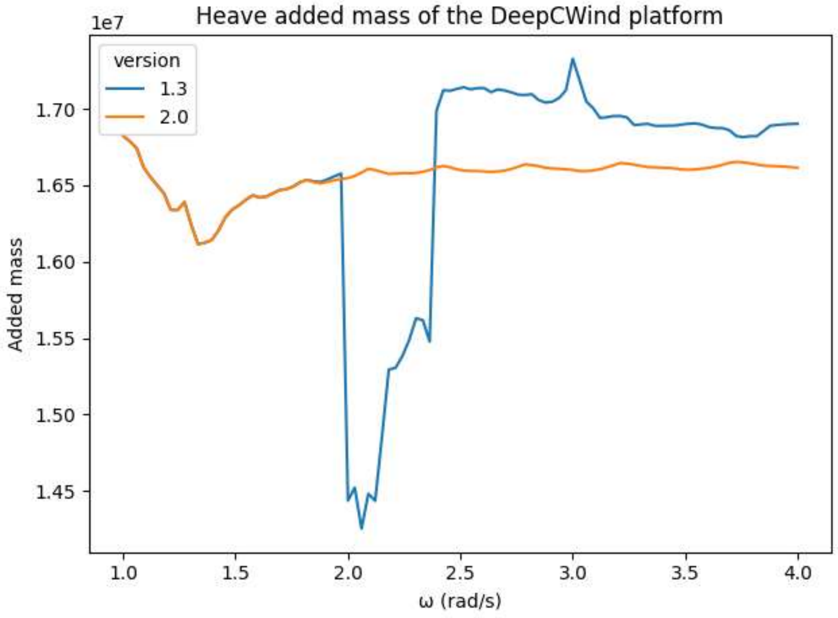
High-priority tasks for Capytaine/WEC-Sim collaboration

- Improve the precision and performance of the resolution of the radiation/diffraction problems
- Ensuring Capytaine distribution on several platforms and its long term preservation
- Supporting users and improving documentation

Capytaine Development

Improve precision for Radiation/diffraction problems

- Precision issues in high frequencies have been reported.
- The issues cause jumps in the computed hydrodynamic coefficients.



Added mass calculated with two versions of Capytaine

Source of this issue:

- Computation of the green function for panels deeper than ~1.2 wavelengths
- Most of panels had this issue for high frequencies
- This problem was solved in the latest version of Capytaine

Capytaine Development

Improvement of performance

Resolution time for a 705-panel rectangular barge with 6 degrees of freedom, 2 wave directions, and 20 frequencies, computed with a single core of a high-end CPU from 2017 (Intel Core i7-8700). All tests were run with default settings

Solver	Release date	Resolution time (infinite depth)	Resolution time (finite depth)
Capytaine v1.3	October 2021	4.9 s	13.1 s
Capytaine v1.4	July 2022	6.5 s	14.1 s
Capytaine v1.5	December 2022	3.7 s	11.1 s
Capytaine v2.0	June 2023	2.3 s	5.5 s
Nemoh v2	May 2016	36 s	56 s
Nemoh v3.0 (*)	December 2022	6 s	20 s

The Generalized Minimal Residual Method (GMRES) linear solver was replaced by a more robust direct solver

- Caching the lower-upper (LU) decomposition of the direct solver.
- Fix of a performance bug in the evaluation of the green function.

Capytaine Development

Some other updates:

- The build and packaging toolchain has been updated to follow the recent changes in the Python packaging ecosystem and to offer more installation options to users.
- Hydrostatics have been added in version 1.4.
- Exporting results to WEC-Sim has been streamlined.

Upcoming new features:

- Irregular frequency removal
- Approximate forward speed
- More accuracy and performance improvement

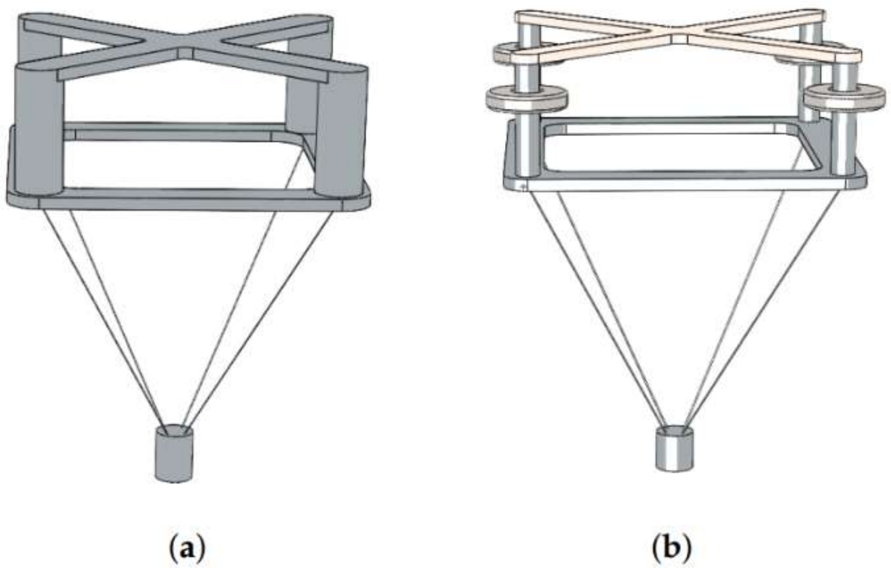
Capytaine Repository:

https://github.com/capytaine/capytaine

MOST: Matlab for Offshore wind turbine Simulation Tool

Background

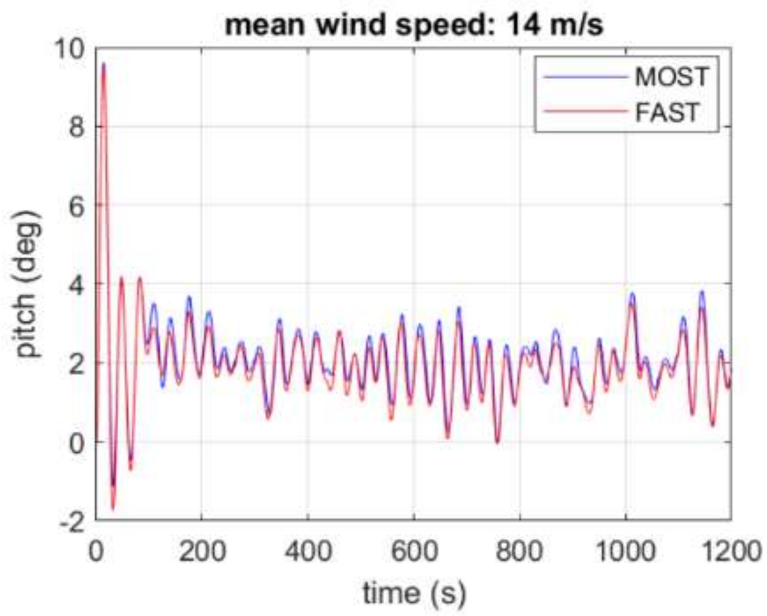
- Developed by the Politecnico di Torino
- The purpose of MOST is to simulate floating wind turbines
- MOST is integrated within the WEC-Sim environment
- The combined functionalities of MOST and WEC-Sim allows the possibility of modeling wave energy converters with wind turbine platforms or pendulum-type platforms.

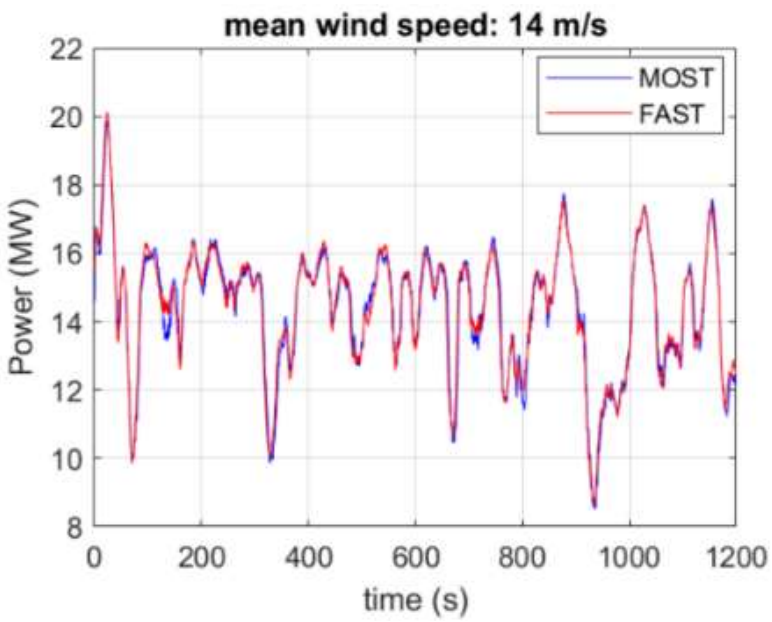


Example of hybrid concepts a) of a semisubmersible-pendulum platform and b) of a platform with integrated WEC

MOST: Matlab for Offshore wind turbine Simulation Tool

MOST has been validated using OpenFAST results:



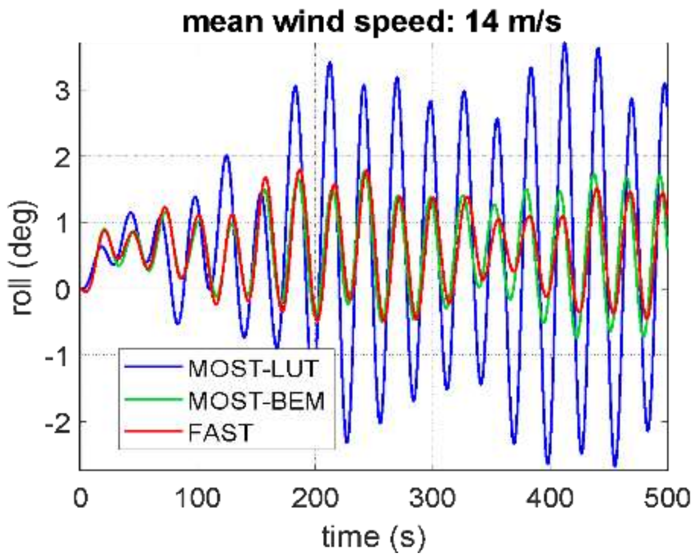


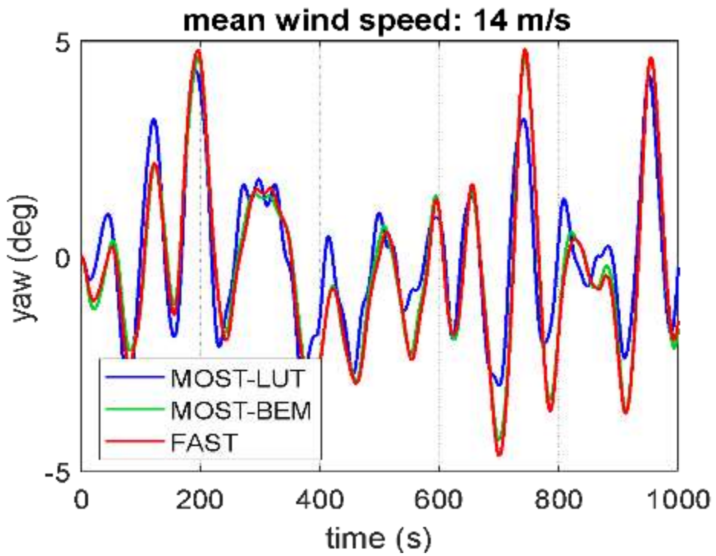
Platform pitch and power output comparison between MOST-LUT (Lookup Table) and FAST for the IEA 15 MW reference wind Turbine

- Primary distinction between MOST and OpenFast lies in their treatment of aerodynamic forces
- Aerodynamics forces in MOST are calculated using look-up tables, resulting in a speed improvement of 3 to 5 times.
- MOST is well suited for optimization studies.

MOST: Matlab for Offshore wind turbine Simulation Tool

- Next steps involve developing a model to deal with all 6 DOF
- The complete resolution of the BEM has been implemented in MOST with good results





Platform roll and yaw comparison between MOST-LUT, MOST-BEM and FAST for the IEA 15 MW wind Turbine

Thank you

For more information please visit the WEC-Sim website:

http://wec-sim.github.io/WEC-Sim

If you have questions on this presentation please reach out to any of the WEC-Sim Developers on GitHub:

https://github.com/WEC-Sim/WEC-Sim

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