TotalEnergies

Wind Digital Twin

Multiphysics Multifidelity and Multiscale modelling

Séminaire : Jumeaux numériques pour l'optimisation des opérations industrielles

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TotalEnergies' Offshore Wind Portfolio Worldwide

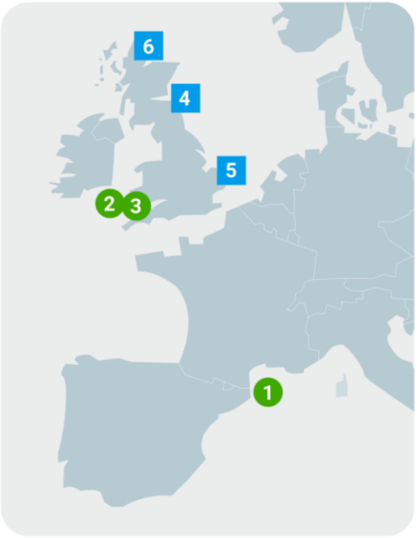
TotalEnergies

Breakdown by technology

11 gigawatts of projects in development, under construction and in production

Project location

fixed-bottom | floating



1 EolMed
Oct. 2020
- Off the coast of Port-la-Nouvelle in the Mediterranean Sea
- **30 MW** of production capacity
- Start-up: **2024**
- In partnership with **Qair**
- Accelerate the development of floating wind turbine technology

2 Valorous
Mar. 2020
- Celtic Sea
- **300 MW** of production capacity
- Start-up: **beyond 2030**

3 Erebus
Mar. 2020
- Celtic Sea
- **96 MW** of production capacity
- Start-up: **2027**
- Pioneering floating wind turbine project in the United Kingdom

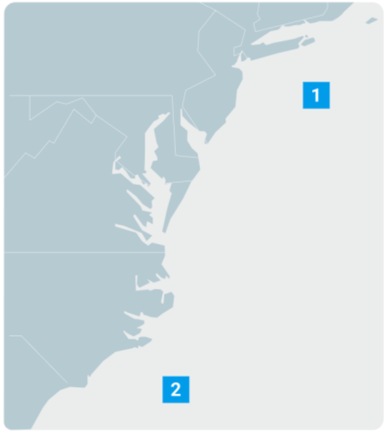
4 Seagreen
June 2020
- Off the coast of Scotland
- **1,14 GW** of production capacity
- Start-up: **August 2022**
- Scotland's largest offshore wind farm

5 Outer Dowsing
Feb. 2021
- Off the coast of Lincolnshire
- **1,5 GW** of production capacity
- Joint venture with **GIG**

6 West of Orkney
Jan. 2022
- Off the coast of the Orkney Islands
- **2 GW** of production capacity
- Start-up: **2030**
- In partnership with **GIG** and **RIDG**
- TotalEnergies' largest renewable energies development project in Europe to date

1 New York Bight
Feb. 2022
- Off the coast of New York and New Jersey
- **3 GW** of production capacity
- Start-up: **2029**
- TotalEnergies' largest renewable energies project to date

2 North Carolina
May 2022
- Carolina Long Bay
- **1 GW** of production capacity
- Start-up: **2030**
- Average annual demand of more than 300,000 homes



1 Yunlin
Apr. 2021
- Off the coast of Taiwan
- **640 MW** of production capacity
- Start-up: **November 2021**
- In partnership with **wpd**

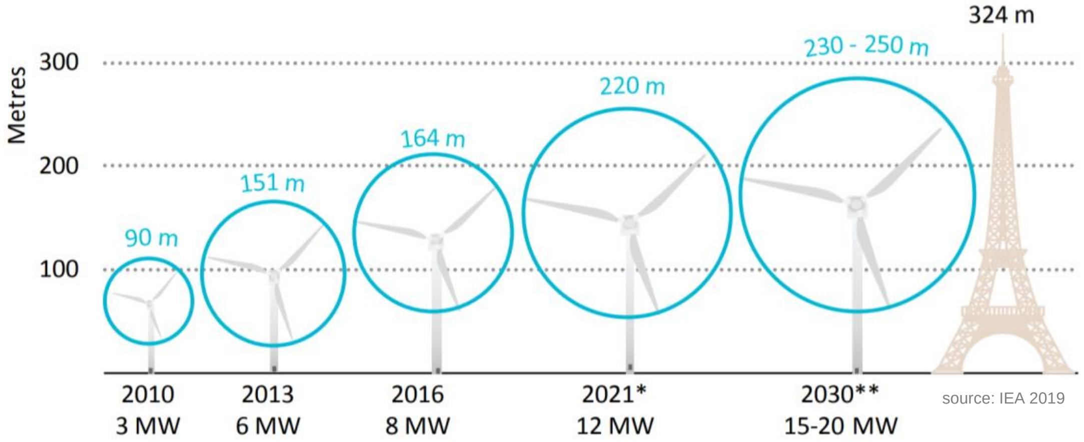
2 Bada
Sept. 2020
- South Korea
- **More than 2 GW** of potential production capacity
- Start-up: **2027**
- In partnership with **GIG**

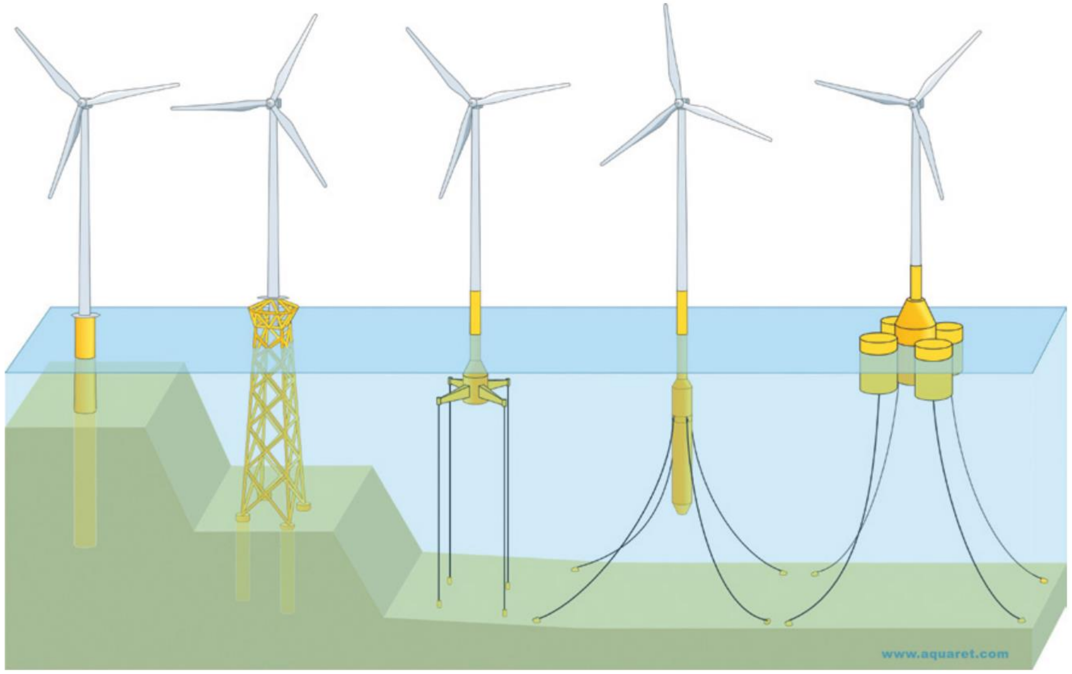
Wind Turbines – Technological Trend

TotalEnergies

- Scale-up
  - Rotor swept area increasing significantly
  - Length of blades and tower lead to new behaviour

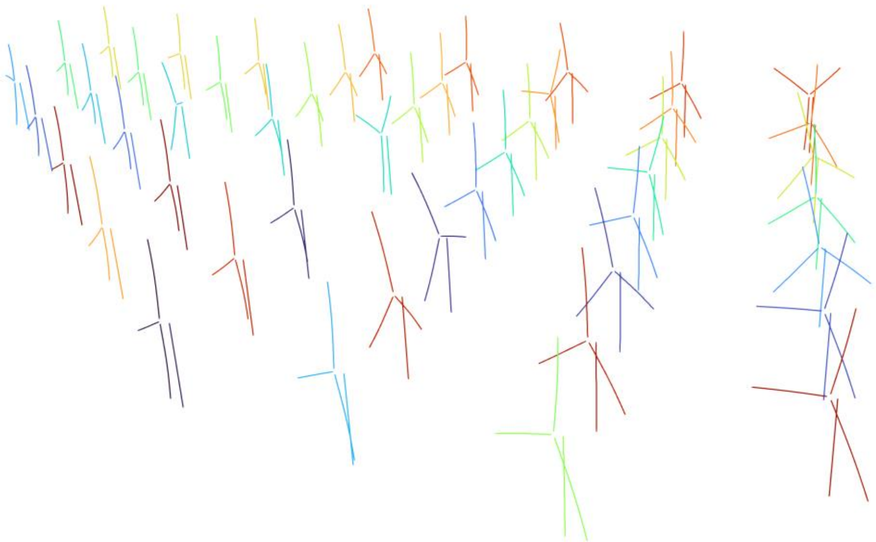
- Foundations technologies (offshore)
  - **Fixed**:
    - Types: monopile, tripod, jacket
    - Well-known technology
    - Limited in depth
  - **Floating**:
    - Types: semi-sub, TLP, spar, barge
    - Still early – no massive deployment yet
    - Unlocks deployment in deeper water
    - Uncertainties regarding mooring systems
    - Currently significantly more expensive





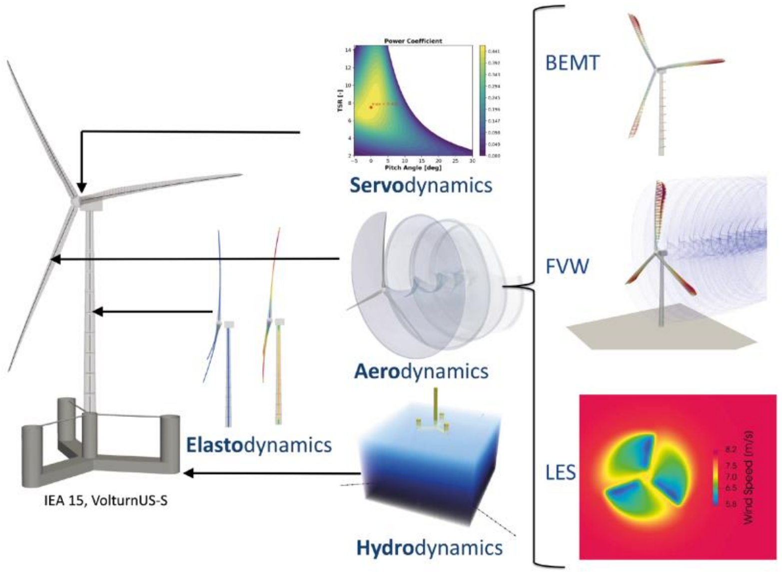
Digital Twin – A Definition for this Presentation

- Aims of the digital twin
  - **Reproduce behaviour** of physical asset numerically
    - Calibrate model to « as built » instead of « as designed », detect anomalies
  - **Anticipate behaviour** of physical asset from numerical model
    - Plan O&M, predictive maintenance (repair vs replace), reduce OPEX
  - **Evaluate model** numerically in new and/or extreme conditions
  - **Optimize** physical asset (e.g. adapting control strategies)
  - **Add new features** numerically before deploying on physical asset

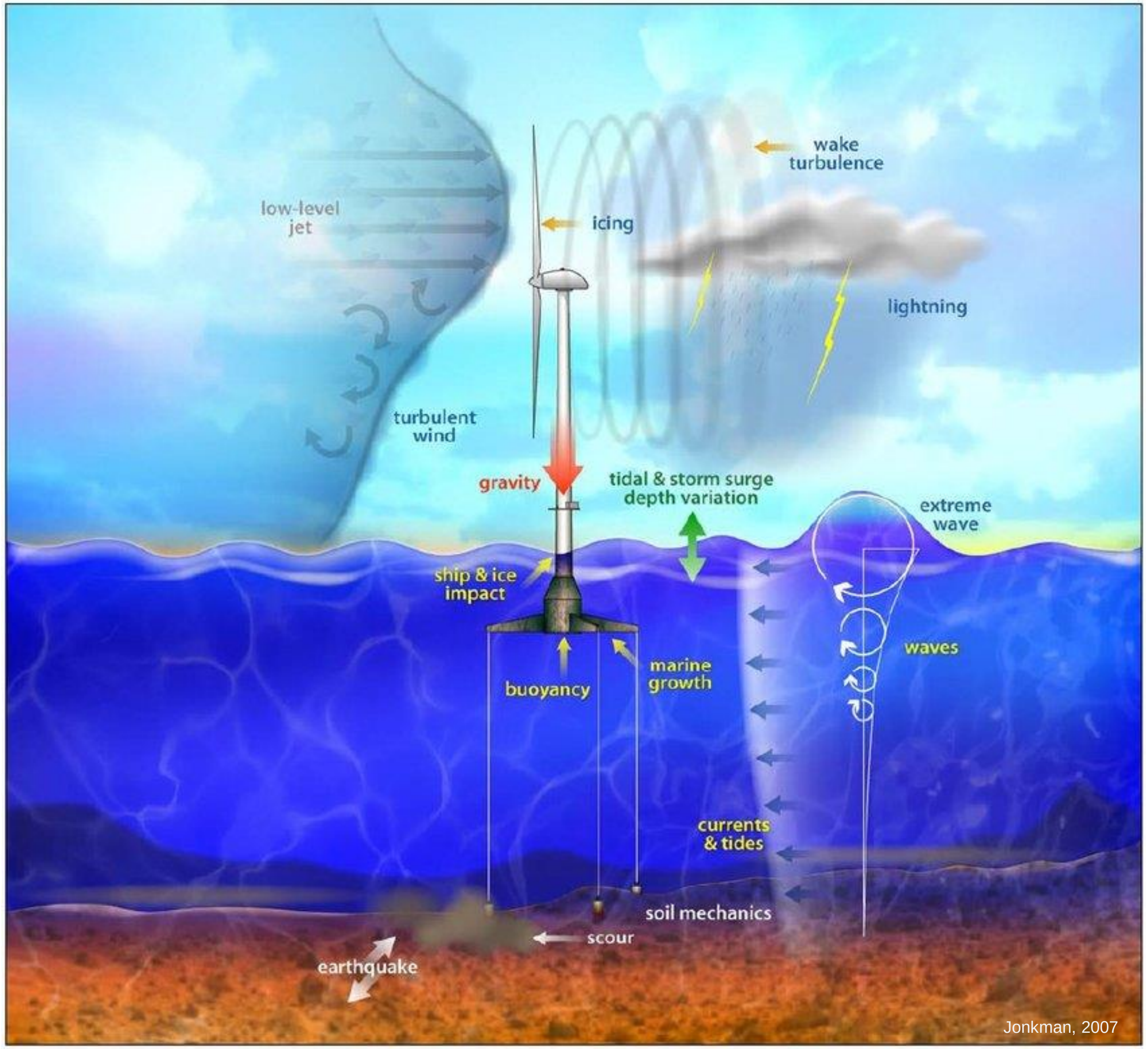


- Main aspects of digital twin
  - **Multiphysics** – physics involved and their interaction
  - **Multifidelity** – numerical accuracy in describing physics
  - **Multiscale** – component, turbine, farm, inter-farm

- Time domain, dynamic model considered



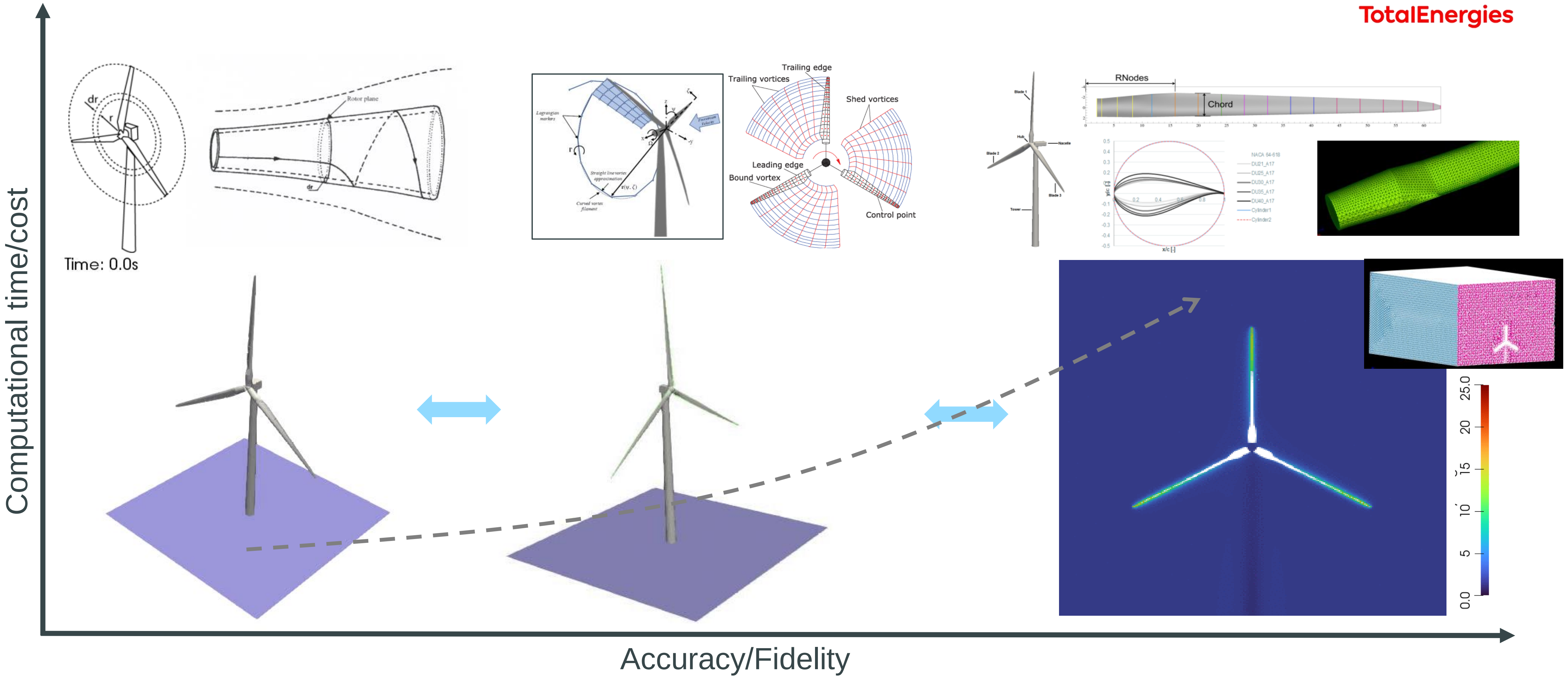
Physical Asset – Multiphysics



- Physics involved:
  - Aerodynamics
  - Elastodynamics
  - Hydrodynamics
  - Servodynamics

- Main questions:
  - How to represent each aspect individually
  - How to couple them together
  - What level of accuracy is needed
  - What scale is important

Numerical Model – Multifidelity



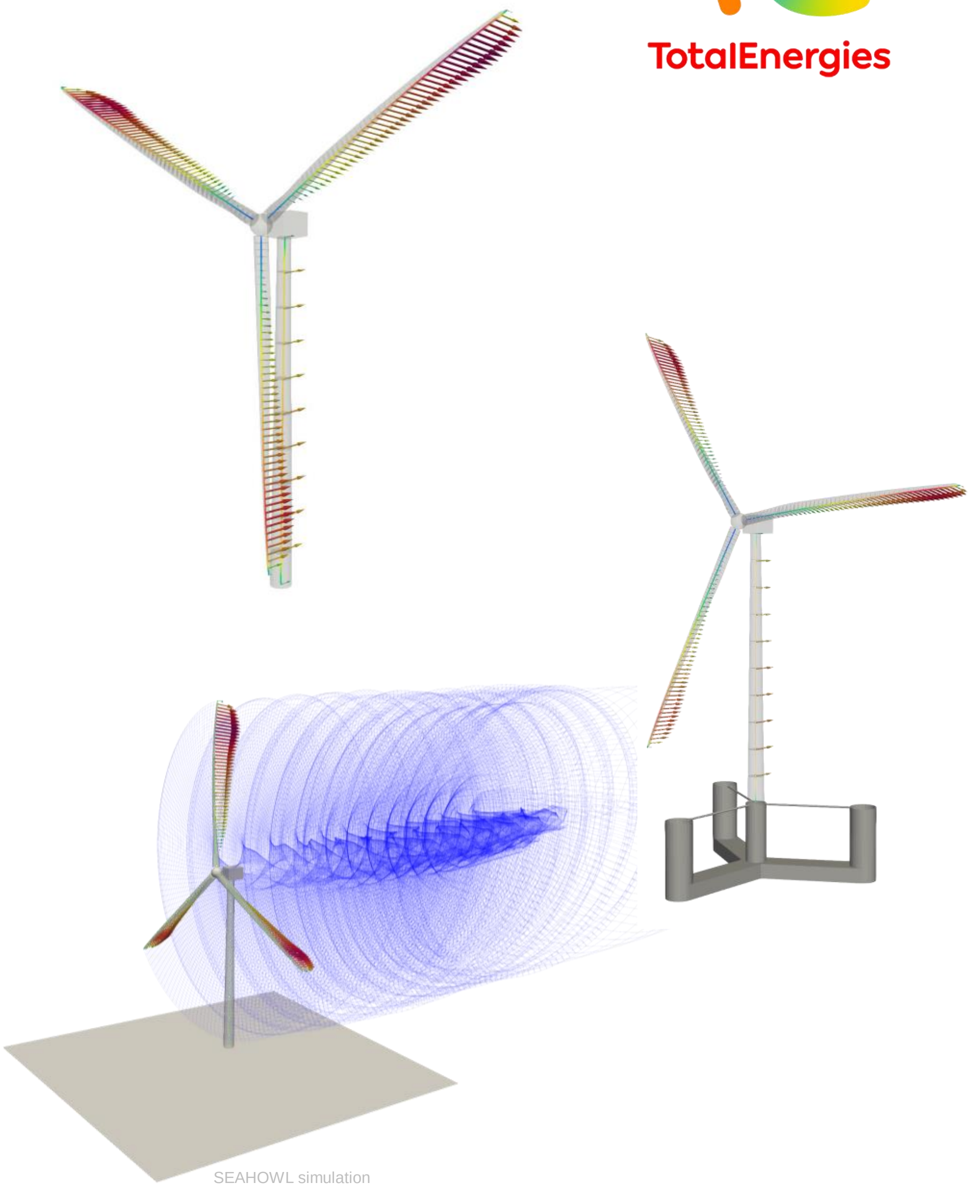
Level of fidelity is application dependent

Building a Fully Coupled Model

- Main issues with off-the-shelf tools:
  - ✗ Black box physics if not fully open source
  - ✗ Lack of flexibility/modularity
  - ✗ Not always HPC-ready
  - ✗ Hard to do fast modifications/updates

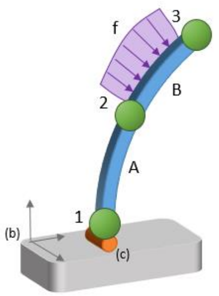
- Main reasons to build fully coupled model:
  - ✓ Total control of physics (no black box)
  - ✓ Modular/flexible framework from the ground up
  - ✓ Modern and efficient with latest available tools
  - ✓ Easier to adapt to digital twin needs

- TotalEnergies solution:
  - → **SEAHOWL**: Servo-Elasto-Aero-Hydro Offshore Wind Lab
  - → Monolithic elastodynamics (Project Chrono): multibody, FEM
  - → Internal implementations and specialized external tools

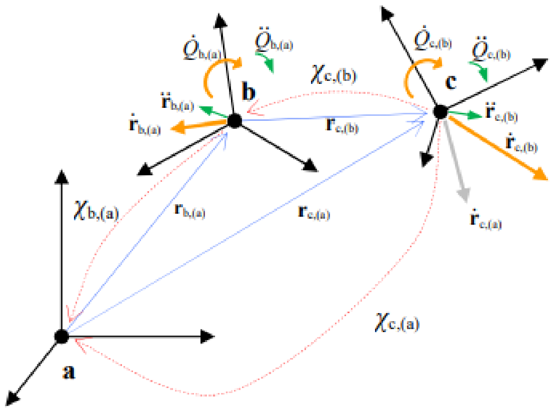


SEAHOWL simulation

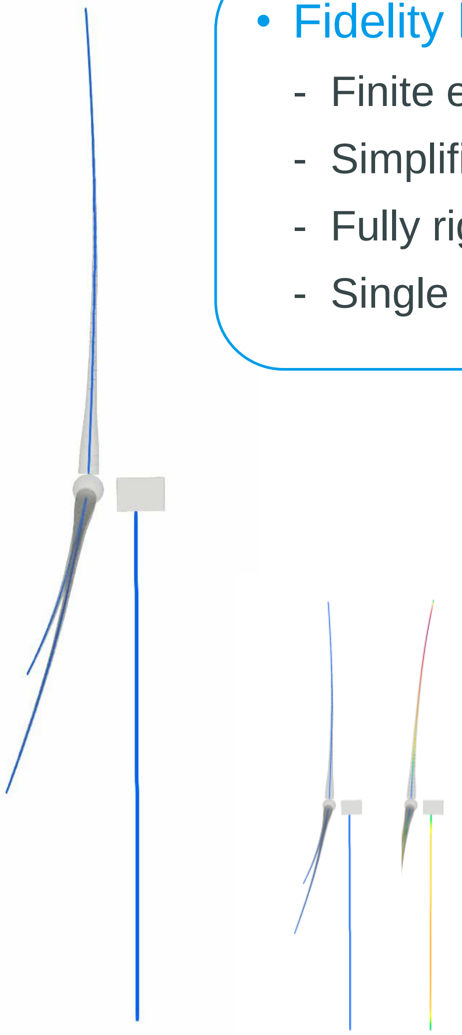
Elastodynamics



Project Chrono



- Main inputs:
  - Environmental loads
  - Controller commands
    - Generator electrical torque
    - Demanded blade pitch
- Main outputs
  - New positions of nodes/bodies
  - Total loads on components



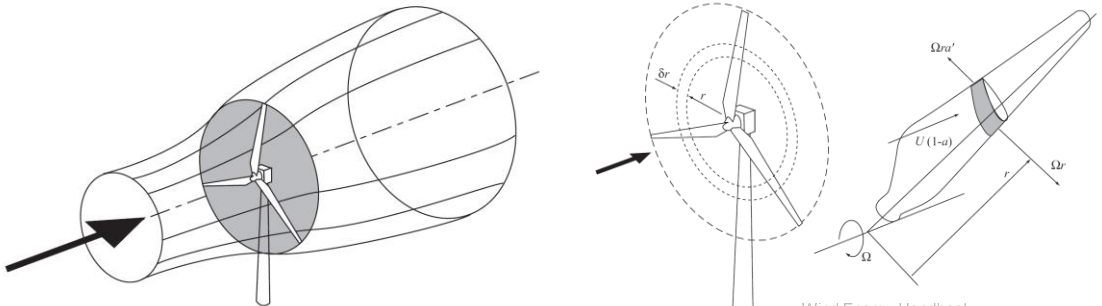
SEAHOWL simulation

- Fidelity levels (rotor):
  - Finite elements / FPM (6x6) beams
  - Simplified beams
  - Fully rigid blades
  - Single rigid body for rotor

- Identified gaps:
  - Lacking instrumentation
    - Blade root, tower base moments
  - Undetailed properties
    - Composite material of blades
    - Scantling of tower
  - Uncertainties on installation
    - Soil properties
    - Moorings/anchors positions

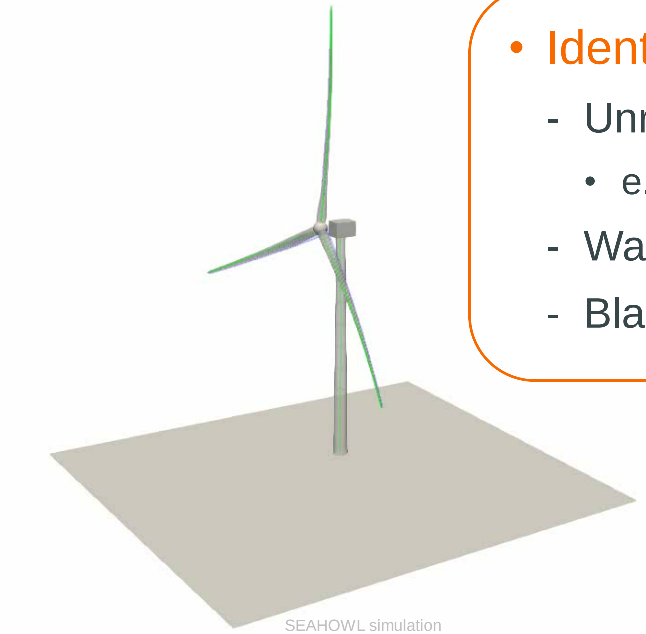
Aerodynamics

- Fidelity levels:
  - Computational Fluid Dynamics
    - Blade resolved
    - Actuator Line Method (ALM)
  - Free Vortex Method (FVM)
  - Blade Element Momentum Theory (BEMT)



Wind Energy Handbook

- Main inputs:
  - Wind velocity, direction, turbulence
  - Blades and tower nodes positions, velocities, accelerations
- Main outputs
  - Blade and tower aerodynamic loads
  - Wake (if approach produces it)

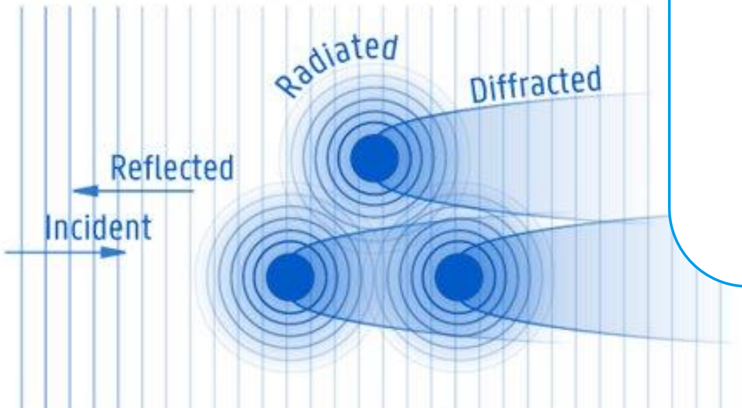


SEAHOWL simulation

- Identified gaps:
  - Unrepresentative instrumentation
    - e.g. anenometer on nacelle, behind rotor
  - Wake dynamics
  - Blade geometry (lift, drag)

Hydrodynamics

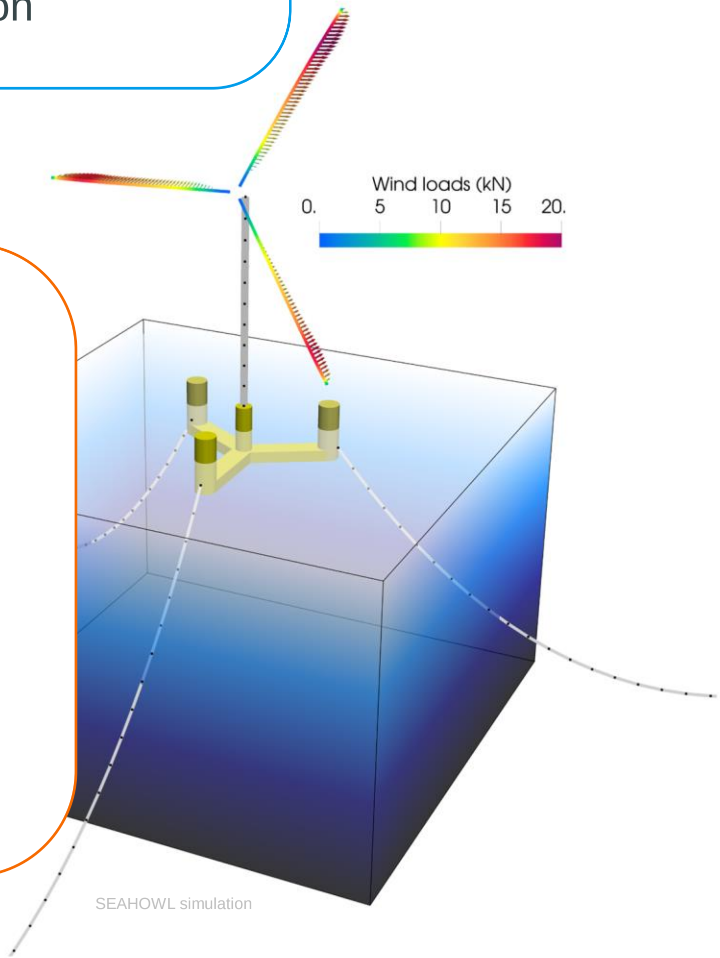
- Fidelity levels:
  - Computational Fluid Dynamics
    - Smooth Particle Hydrodynamics (SPH)
    - Finite Volume/Element Method (FVM/FEM)
  - Potential flow: Boundary Element Method
  - Strip theory: Morison's equation



Verbrugghe et al., 2017

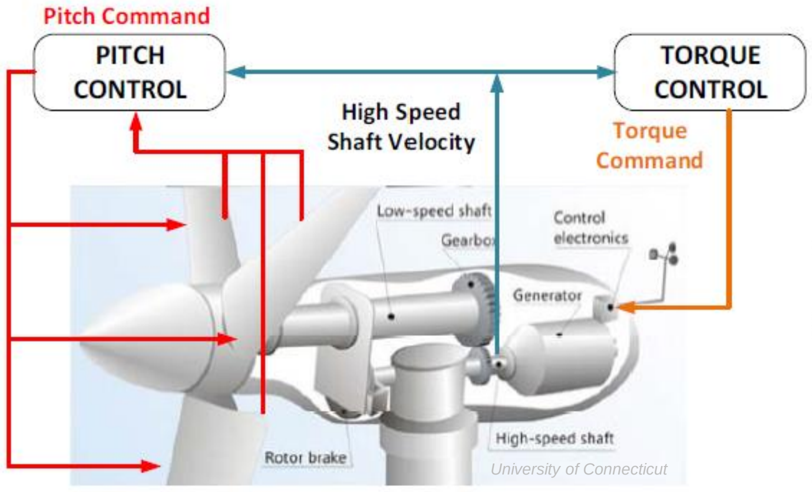
- Main inputs:
  - Sea state (Hs, Tp, direction, current)
  - Hydrodynamic database / floater geometry
  - Floater viscous damping
  - Mooring drag and added mass coeffs
- Main outputs
  - Floater hydrodynamic loads
  - Moorings hydrodynamic loads

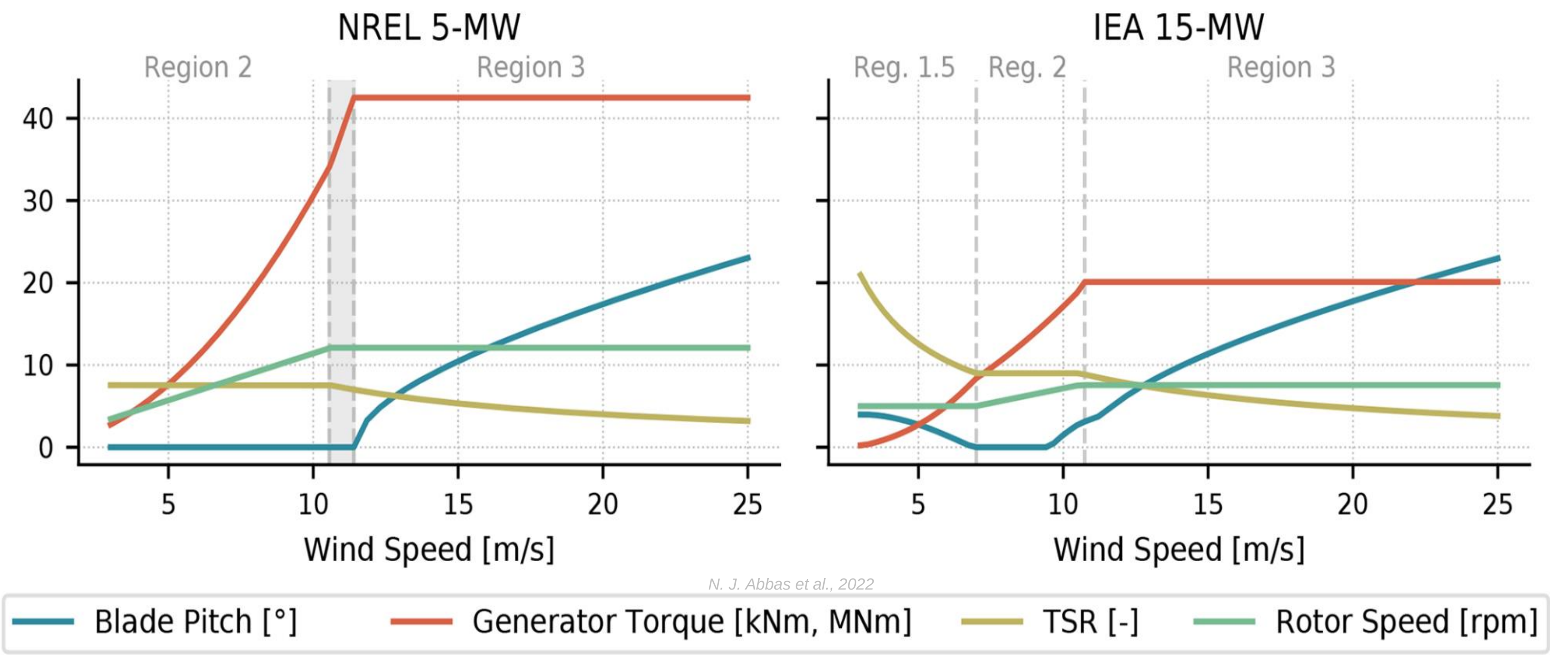
- Identified gaps:
  - Real-time data of waves / free surface elevation
  - Lacking instrumentation
    - Pressure gauges
    - Overtopping measurement
  - Uncertainties over lifetime
    - Marine growth
    - Scour (anchors)



SEAHOWL simulation

Servodynamics

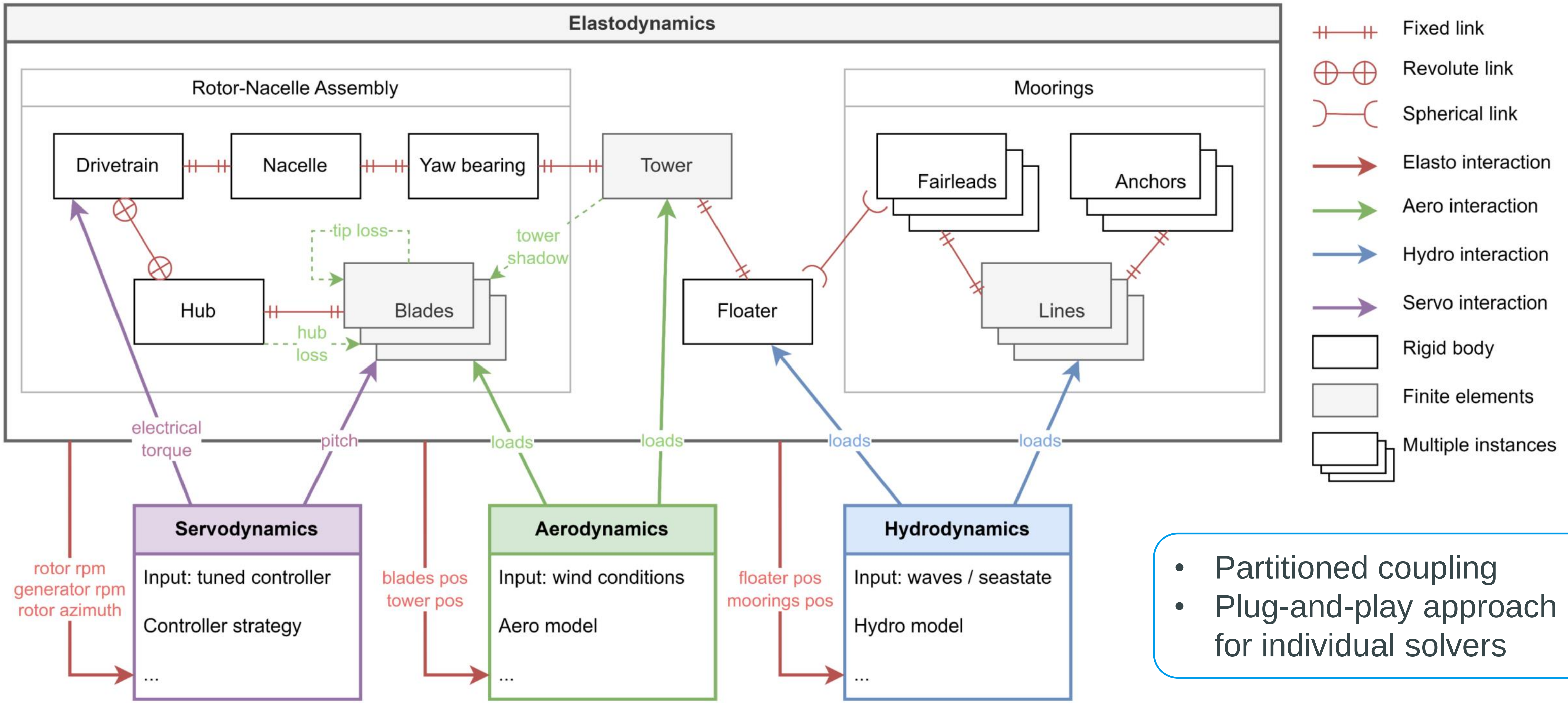




- Main inputs:
  - Rotor RPM
  - Generator RPM
  - Rotor azimuth
- Main outputs
  - Electrical torque
  - Demanded blade pitch

- Identified gaps:
  - « Black box » controller strategy

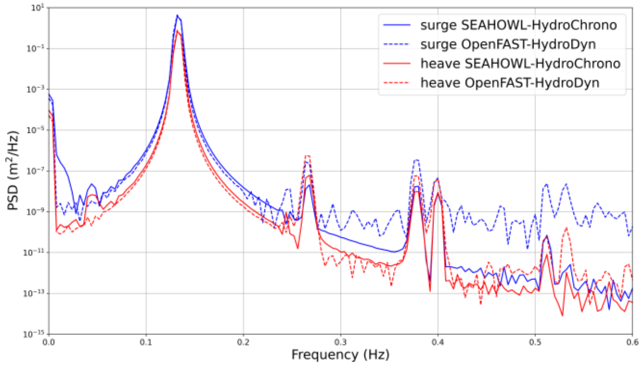
Numerical Multiphysics Workflow

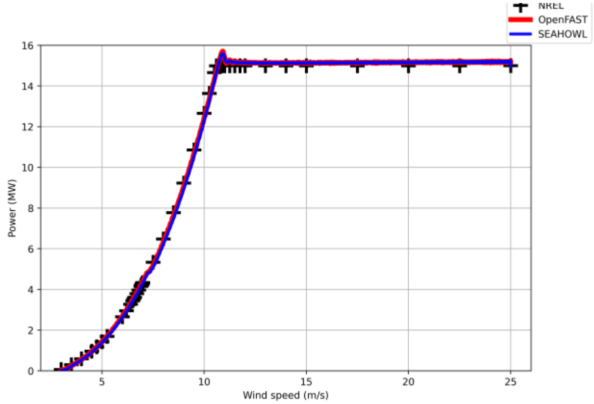


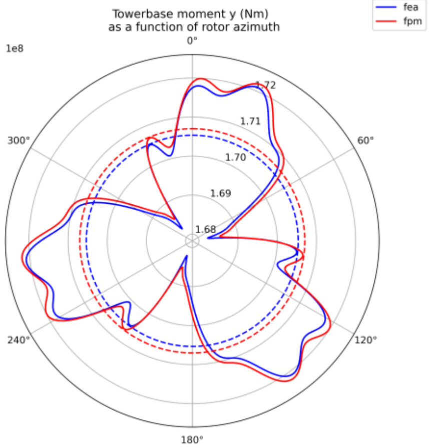
- Partitioned coupling
- Plug-and-play approach for individual solvers

Verification & Validation

- Verification: « solving the equations right »
  - Compare numerical results and/or convergence
- Validation: « solving the right equations »
  - Comparison with experiments
  - Cross-code validation
- Field data is key to validate / synchronize digital twin







- SCADA live data:
  - Quality
  - Frequency
  - Synchronisation
  - Cleaning
  - Processing
  - Communication

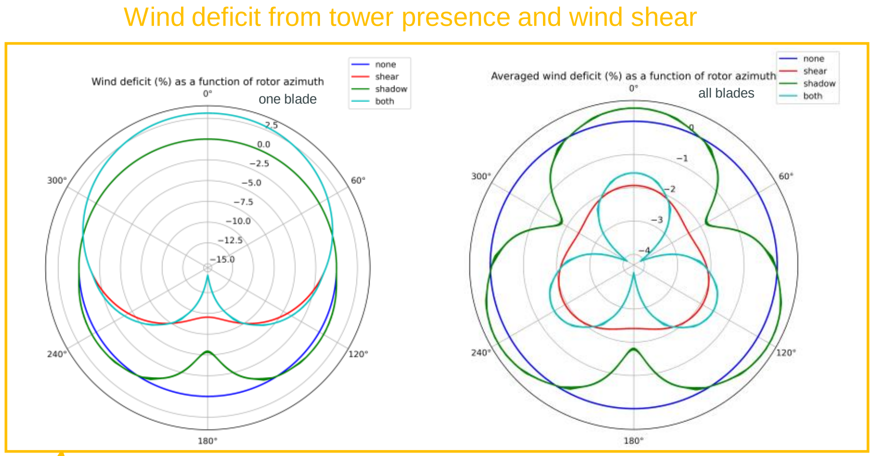
Digital to Physical Application (1/2)

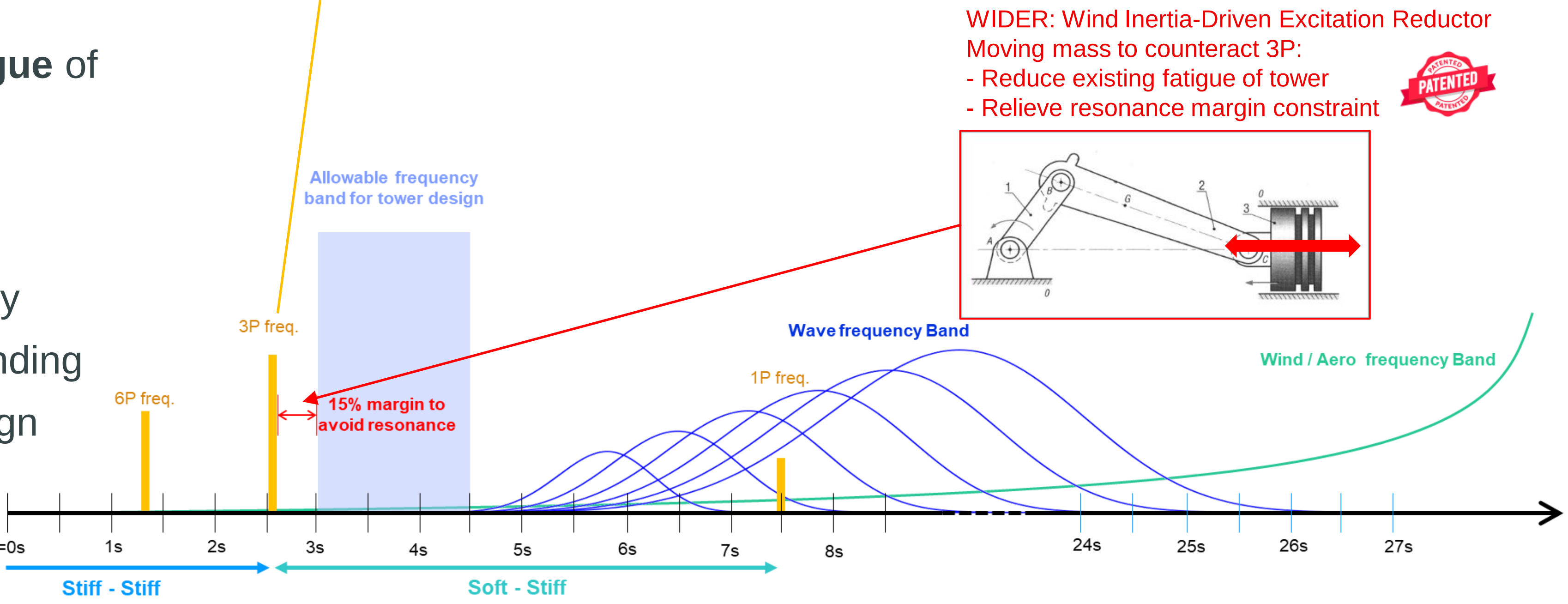
3P effect mitigation

→ Once digital twin is built, use numerical model for new features

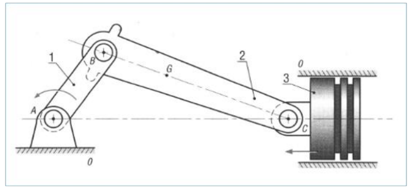
- The problem: 3P effect
  - Due to **wind shear** and passage of blade in front of tower (**tower shadow**)
  - Can contribute significantly to **fatigue** of components (blades, tower)

- Tower design constraints
  - **Soft enough** to avoid 3P frequency
  - **Stiff enough** to avoid extreme bending
  - → **Narrow frequency band** for design





Digital to Physical Application (2/2)
3P effect mitigation

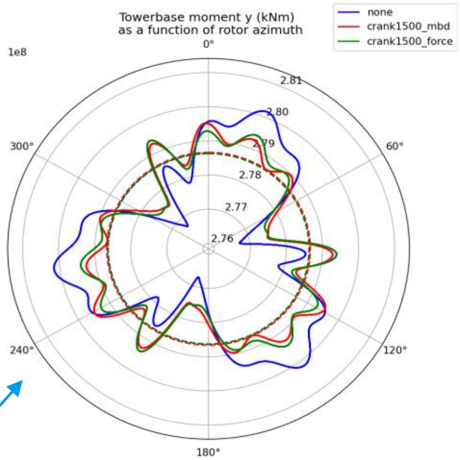


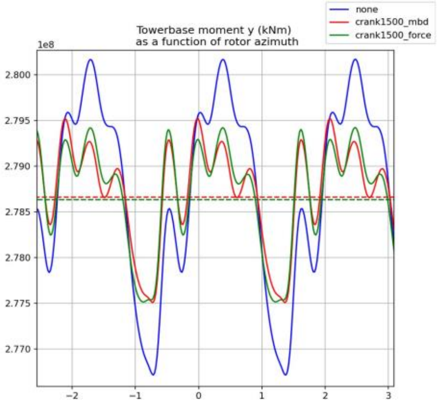
- SEAHOWL for investigating WIDER solution
  - Ease of implementation of system in multibody framework
  - Non-turbulent wind used to isolate 3P problem
  - Results produced quickly

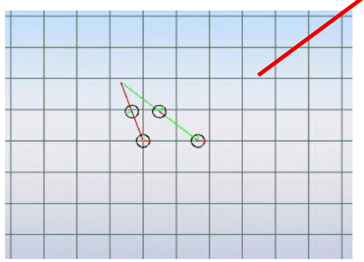
- Different implementations:
  1. Pure force (from analytical acceleration)
  2. Full multibody (crank-shaft system)

  → Sufficiently close to use pure force

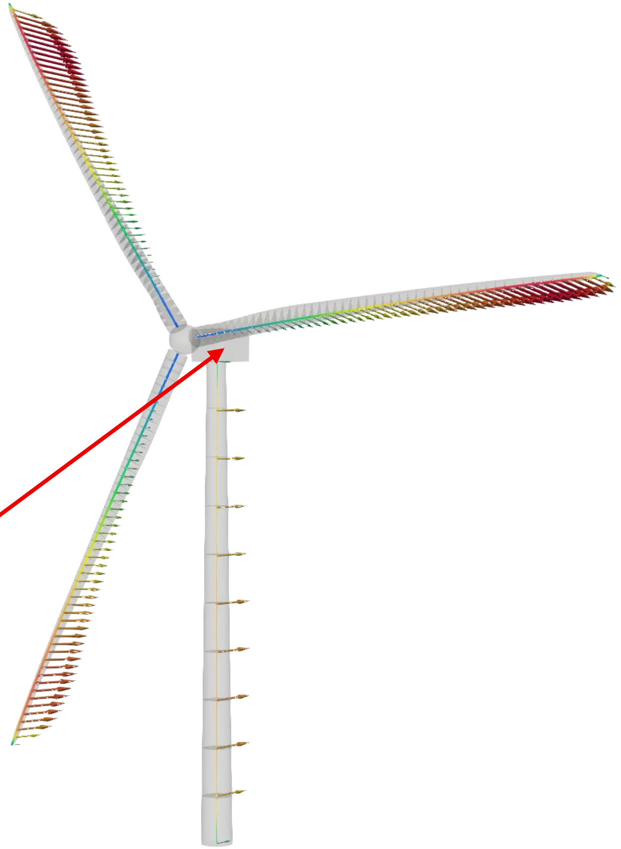
- Main findings:
  - ~40% load variation reduction due to 3P on above rated wind speed case
  - ~ 0.1% of RNA mass







WIDER crank-shaft applied to RNA with speed adapted according to rotor speed



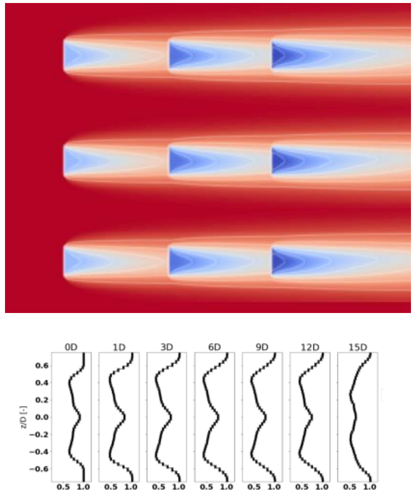
Digital concept to real device on physical asset?

Farm Scale Digital Twin

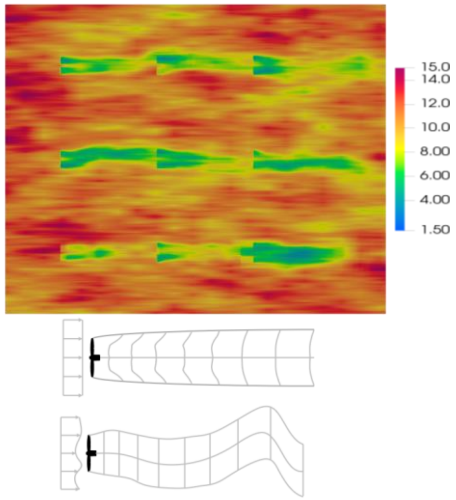
- From turbine to farm:
  - Interaction between turbines
  - Wake propagation / superposition
  - Short-term forecasting
  - Plan operation and maintenance
  - Super controller strategies

Farm Scale – Numerical Aspects

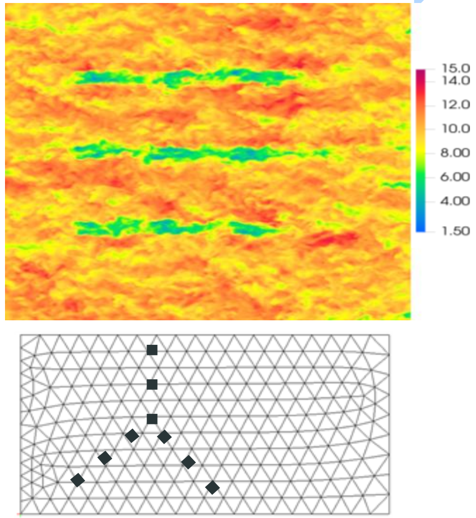
Increasing Fidelity / Increasing Computational Cost



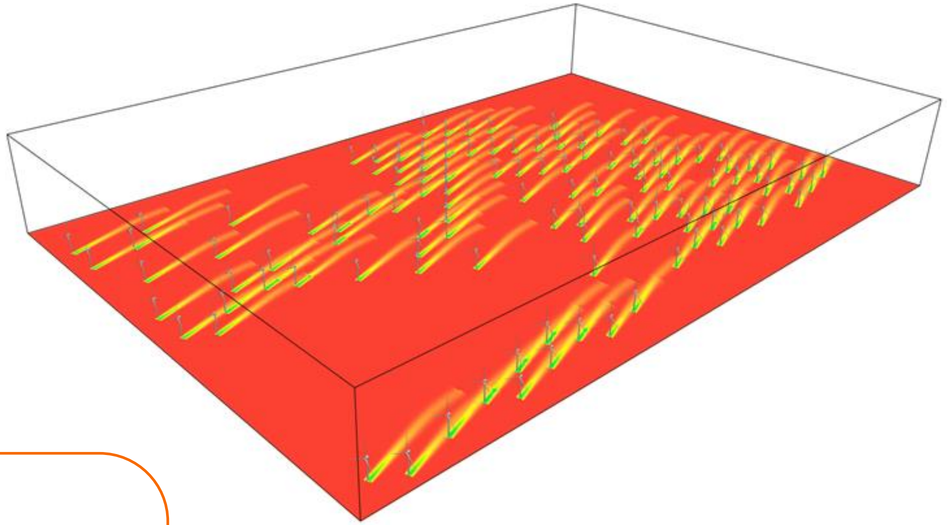
Steady-Wake



Dynamic Wake Meandering

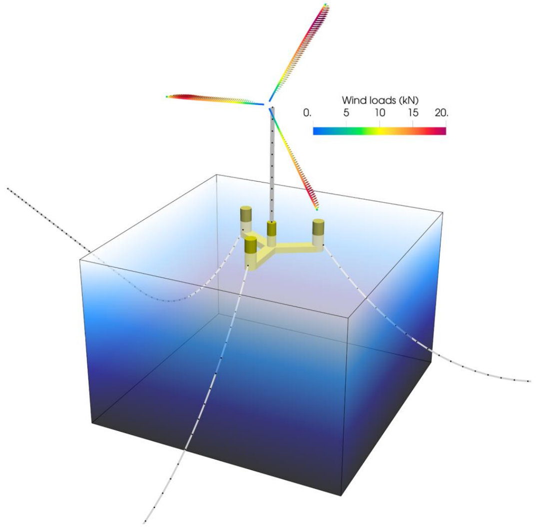


Large-Eddy Simulation



- Challenges:
  - Uncertainties on wind resource
  - High fidelity prohibitively expensive
    → Surrogate needed
  - Need to calibrate wake models

Conclusions

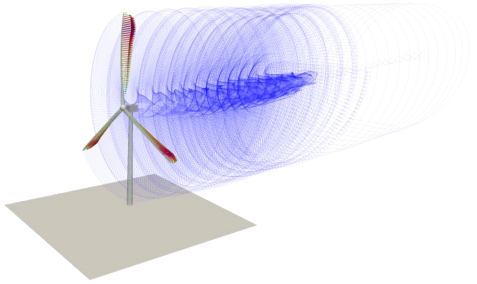


- Multiphysics multifidelity digital twin
  - Modular and flexible for innovative applications
  - Total control of physics involved (no black box)
  - Tunable trade-off of fidelity vs computational cost

  → Numerical model adjustable to digital twin aims

- Multiscale (farm, inter-farm)
  - Wake calibration requires high fidelity modelling
  - Surrogate needed for real-time or near real-time
  - Large uncertainties on wakes of physical asset

  → Investigation ongoing to improve robustness



- Data from physical asset
  - Key to validate / synchronize digital twin
  - Live data remains a challenge (quality, frequency, comm, etc)

  → Design instrumentation with digital twin in mind

- Challenges to tackle
  - Accurate geometry and material properties of physical asset
  - Adjust numerical model from « as designed » to « as built »
  - Control strategy of physical asset
  - Control strategy of farm (super controller)
  - Uncertainties of components installation (e.g. moorings)

  → Circumvent issues numerically if physical data unavailable

Merci.

Thank you.