风伯

FARMING THE ENVIRONMENT INTO THE GRID

BIG DATA IN OFFSHORE WIND

Mike Graham ,
Rafa Palacios.
Imperial College London.

SuperGen Wind Hub
General Assembly Conference,
Dundee, Scotland.
8th November 2018.

风伯-WIND

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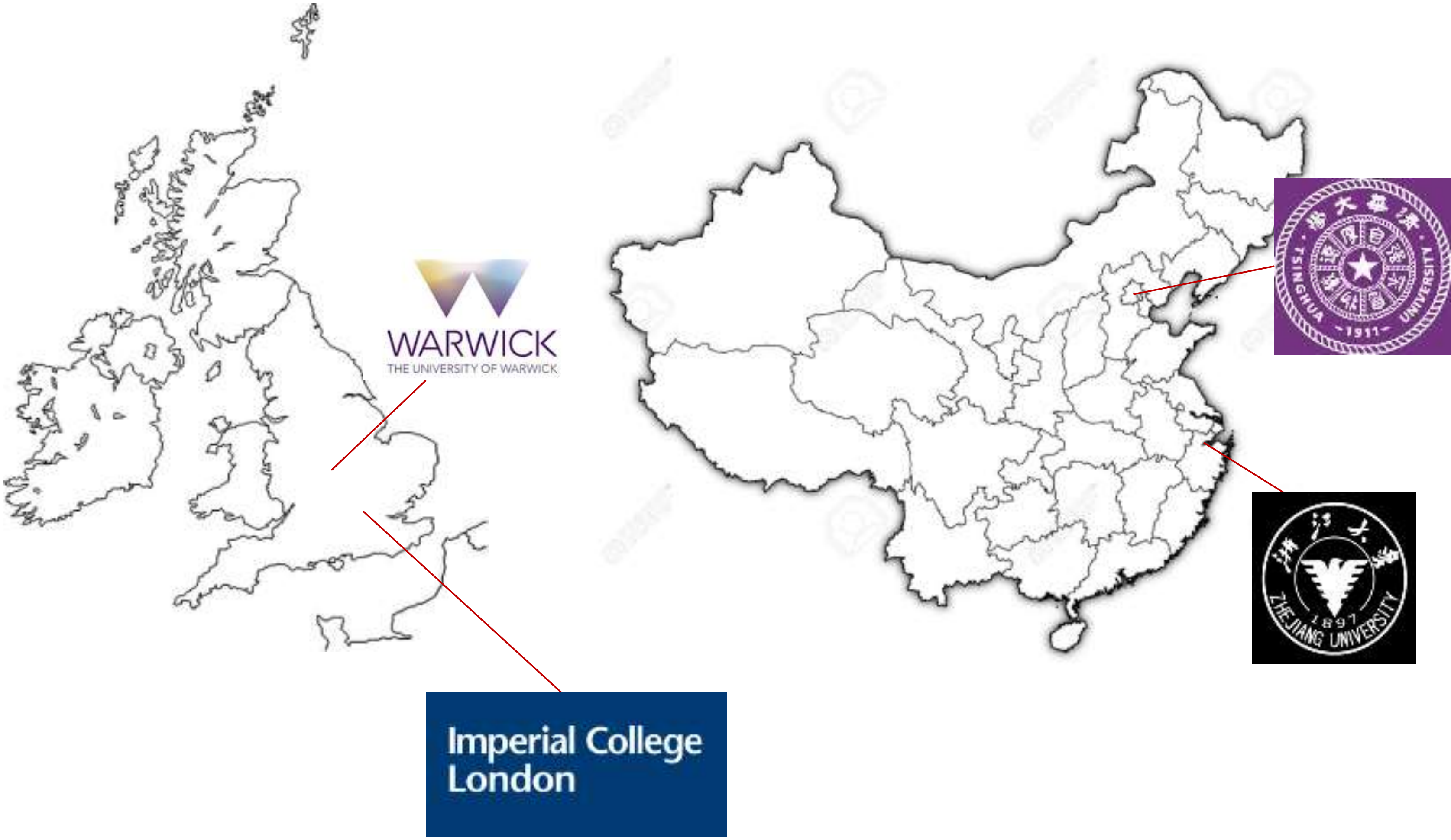
The team



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The team

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Project objectives

1. **Farm modelling** (ICL, Tsi, ZJU)
   - Very large scale simulation/optimization of offshore wind farms
   - Long-term interactions between wind farms and local environment

2. **Offshore system resilience** (UW, ICL, Tsi)
   - Sensing network to enhance grid resilience
   - Structural integrity in farm flow environment

3. **Data analytics** (UW, Tsi, ZJU)
   - Data-driven strategies for operation and control.
   - Combination of large-scale physics-based simulations and big-data analytics

4. **Validation**:
   - Comparison of simulation results with field data in Jiangsu province

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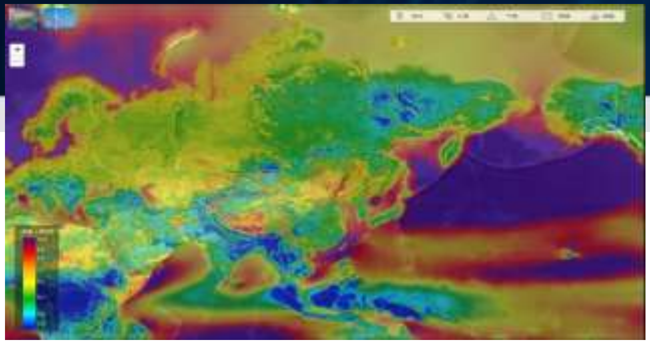
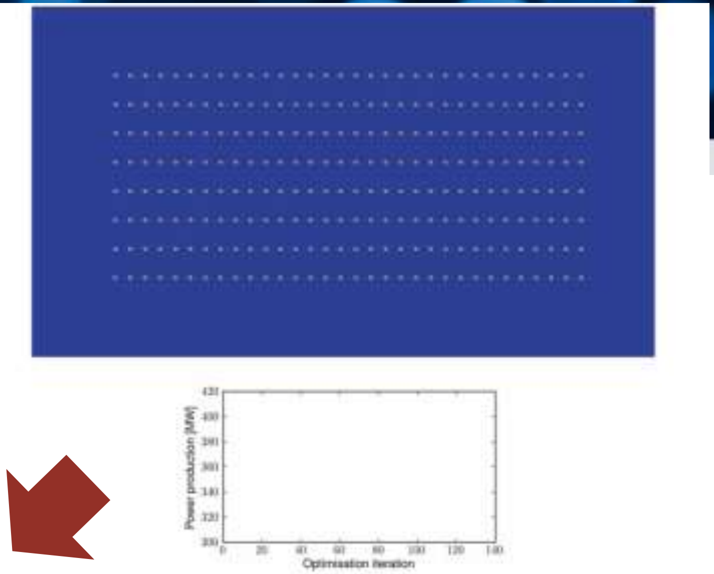
Strategy

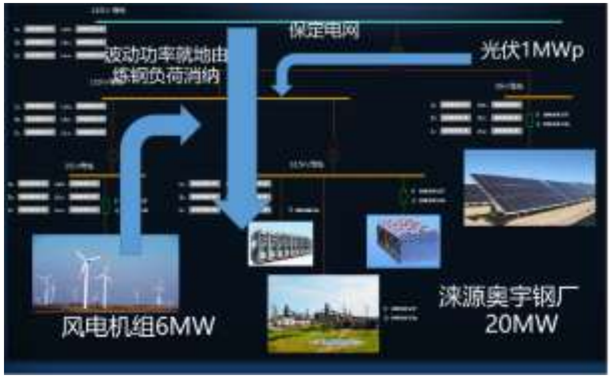


Global Wind Power (Tsi)

HAWT aeroelastic control (ICL/UW)



Array optimization (ICL)



Smart grid design (Tsi)

ICL/ZJU Joint Applied Science Data Lab (ZJU)

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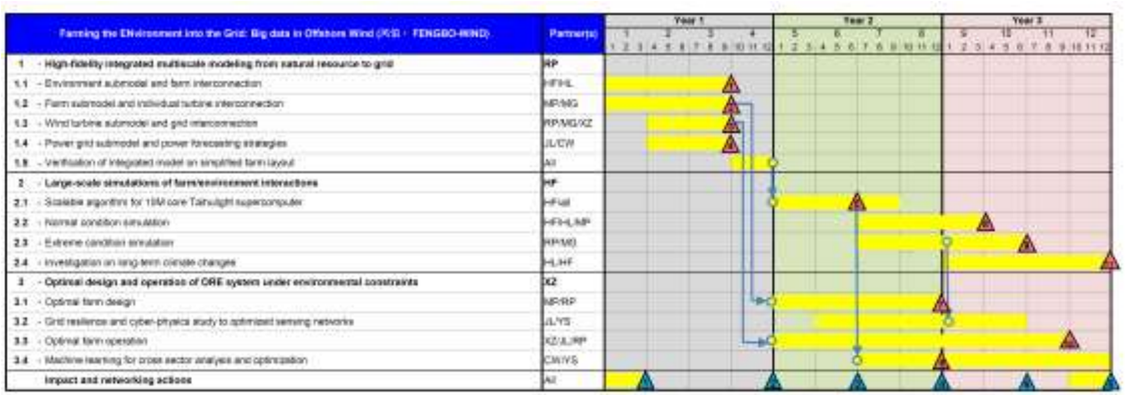
Work packages

1	**- High-fidelity integrated multiscale modeling from natural resource to grid**
1.1	- Environment submodel and farm interconnection
1.2	- Farm submodel and individual turbine interconnection
1.3	- Wind turbine submodel and grid interconnection
1.4	- Power grid submodel and power forecasting strategies
1.5	- Verification of integrated model on simplified farm layout
2	**- Large-scale simulations of farm/environment interactions**
2.1	- Scalable algorithm for 10M core Taihulight supercomputer
2.2	- Normal condition simulation
2.3	- Extreme condition simulation
2.4	- Investigation on long-term climate changes
3	**- Optimal design and operation of ORE system under environmental constraints**
3.1	- Optimal farm design
3.2	- Grid resilence and cyber-physics study to optimized sensing networks
3.3	- Optimal farm operation
3.4	- Machine learning for cross sector analysis and optimization



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Current offshore wind power plant in Jiangsu

	Name	Location	Voltage Level(V)	Number of wind turbines	Capacity(10MW)
1	龙源如海风电	Nantong	220	104	27.948
2	中水如东风电	Nantong	220	42	10
3	龙源黄海风电	Nantong	220	50	20
4	广核如海风电	Nantong	220	38	15.2
5	长江响海风电	Yancheng	220	55	20.2
6	中电二洪风电	Yancheng	220	25	10
7	广恒东台风电	Yancheng	220	50	20
8	华能如海风电	Nantong	220	46（4，5）	19.4

Total capacity on Sep 2017: 6,106 MW - Planned for 2020: 12,370 MW

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Some key past and future activities

Past:

All postdocs have been hired at UK universities

Summer school on numerical methods for ORE

5-project kick-off meeting in Oxford in April 2018

All five funded projects to start a (virtual) UK/China centre in ORE

Future

5-project meeting in Qindao in April 2019

Next FENGBO-WIND meeting in 2019/2020

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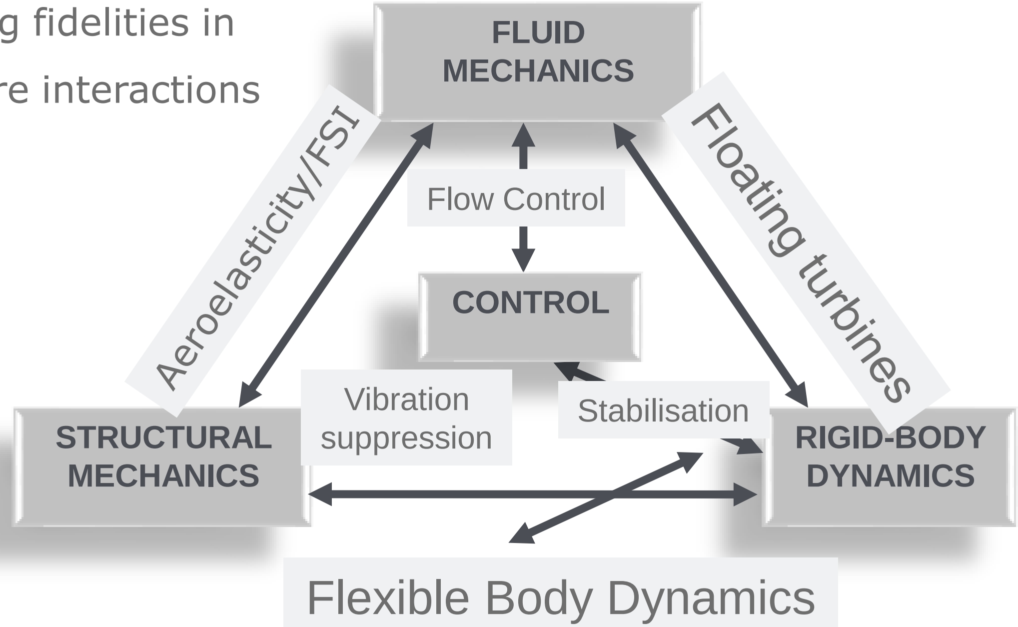
HAWT Aeroservoelastic Simulation at the Load Control and Aeroelastics Laboratory

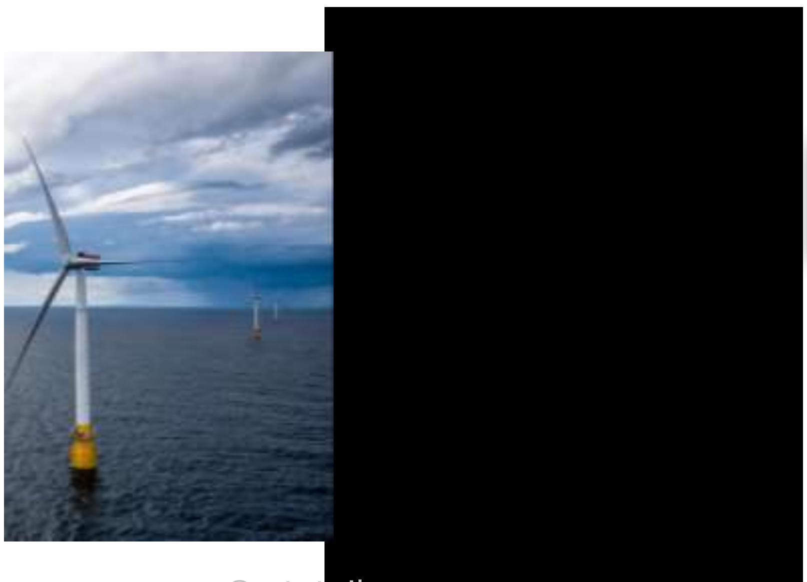
RP and MG
Department of Aeronautics

Imperial College London

Load Control and Aeroelastics Lab

- Computational work across modelling fidelities in aeroservoelasticity and fluid-structure interactions
- 2 postdocs/ 10 PhD students





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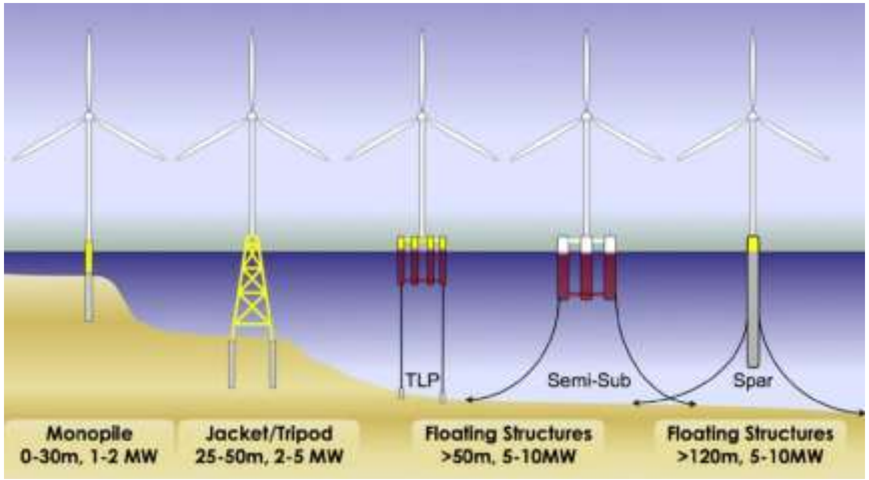
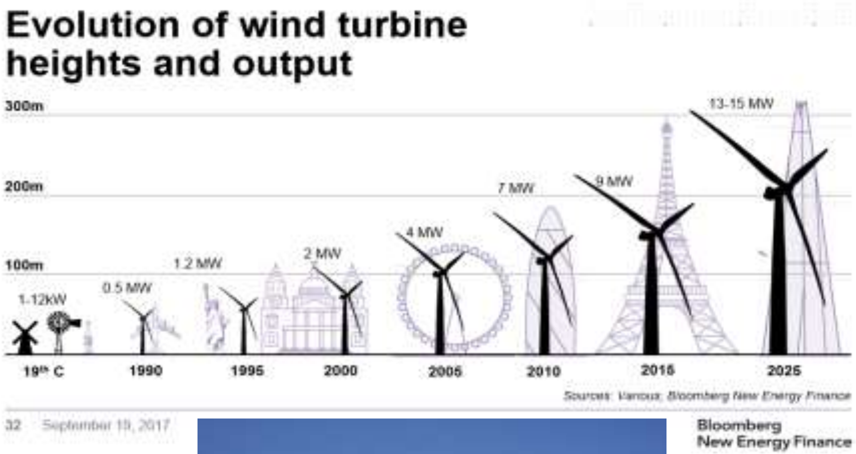
Trends in HAWT development



www.windpowerengineering.com



Larger turbines → More flexible blades and tower→ Strong aero-structure interactions

Deeper offshore → Floating turbines → Strong fluid-structure interactions

"strongly" coupled systems undergoing large deformations

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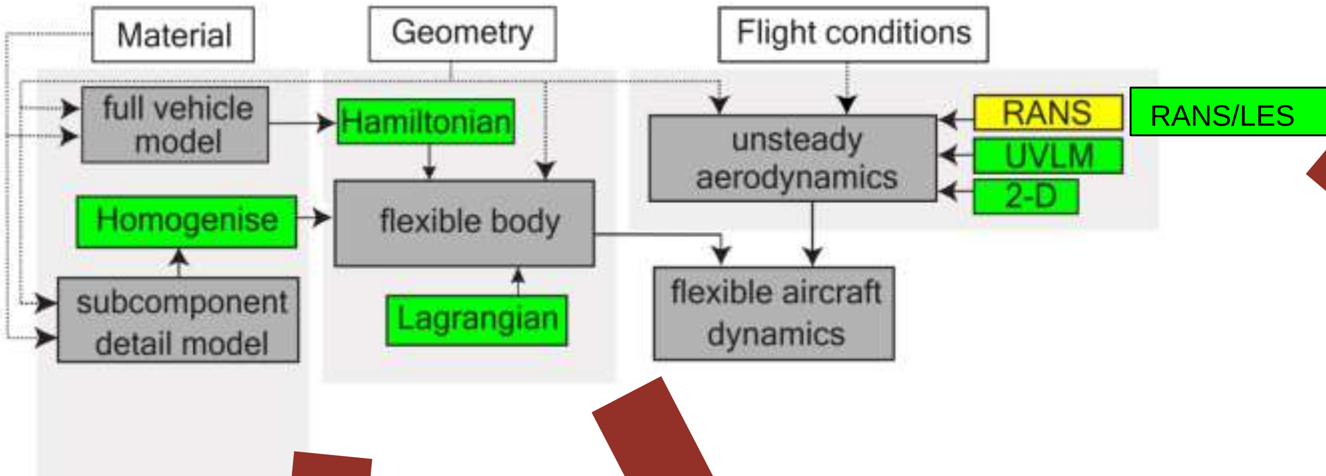
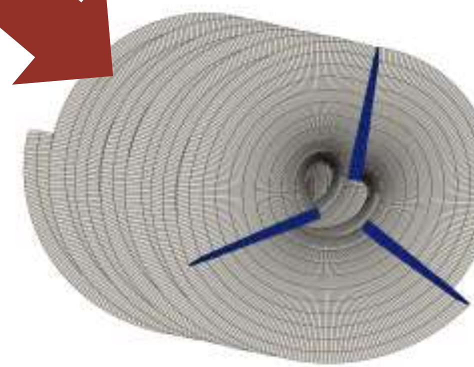
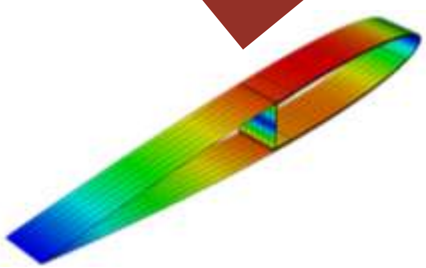
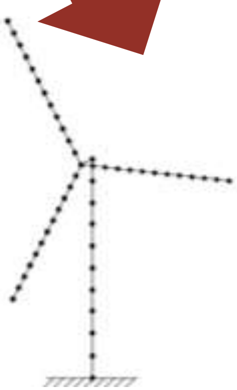
Aeroelastic simulation with highly-flexible structures

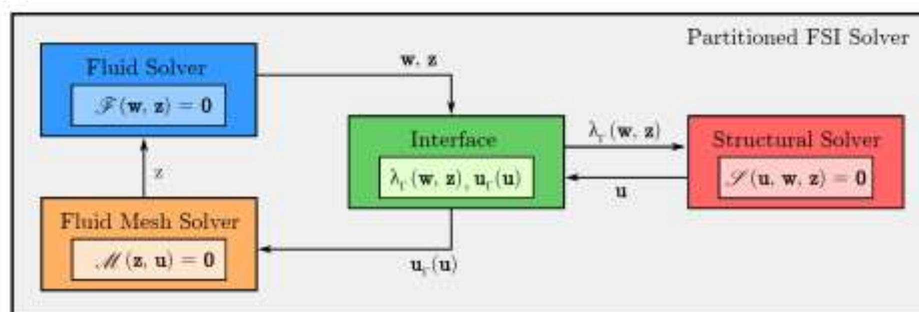
full system FEM





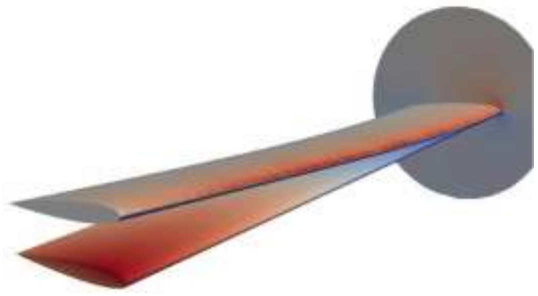






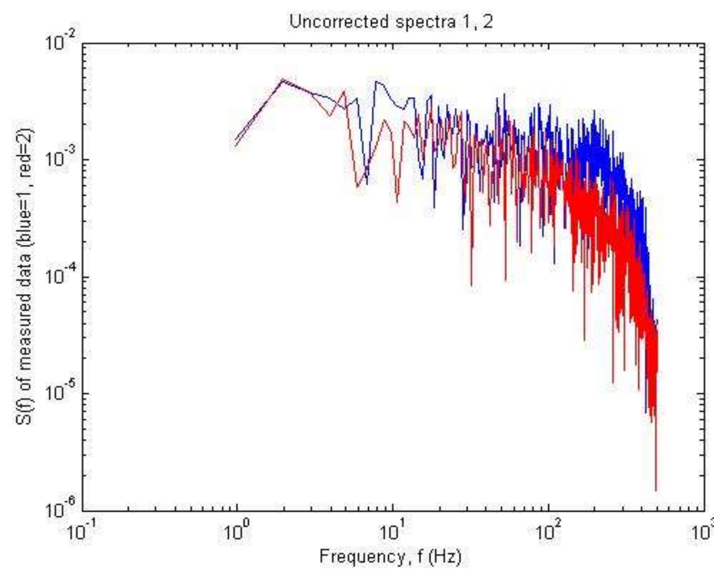
An array of tools with increasing fidelity

- SHARPy: Nonlinear composite beams + UVLM
  - Loads, control design, aeroservoelasticity
  - RPN, JMRG
- SU2: Solid FE + RANS + AD
  - Blade aero/structural design
  - RPN, Stanford, TUDelft, TU Kaiserslautern
- Win3D: Nonlinear composite beams + LES
  - RPN
  - With Dr Sylvain Laizet
- Nektar++: Solid FE + Higher-order Fluid FE
  - Separated flows and FSI
  - RPN With Prof Spencer Sherwin



Supported by experiments: (1) in air

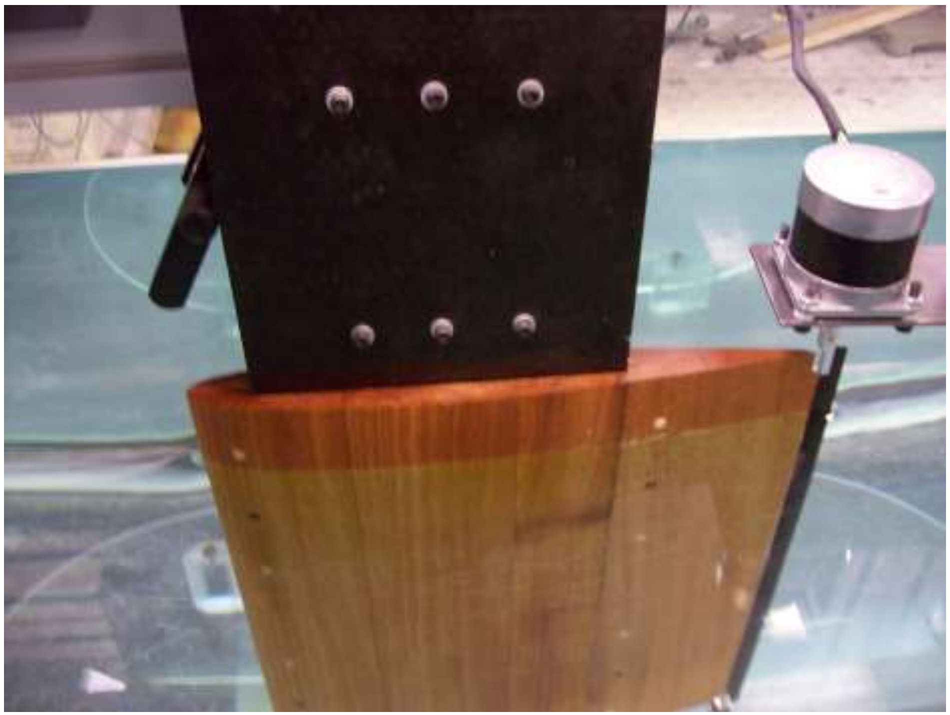
- Turbulence & rotor wake interactions (MG)

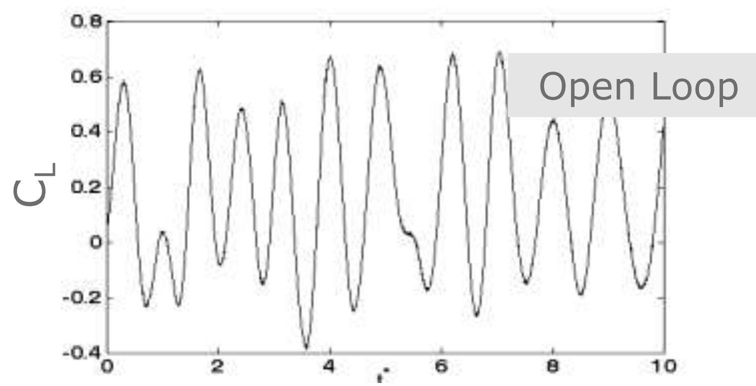


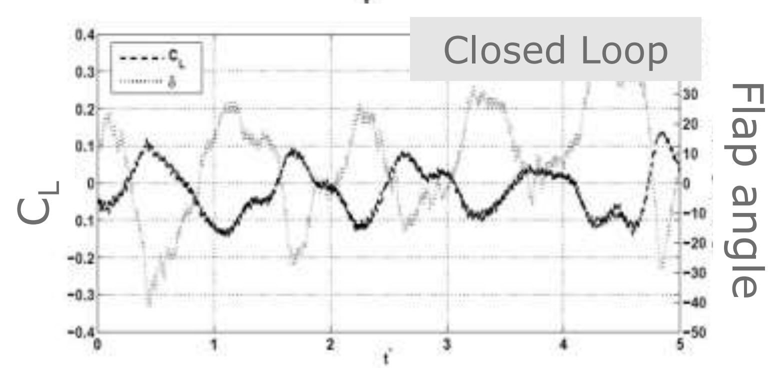
Root bending moment on
downstream rotor at 6D+0.5D offset

(2) in water.

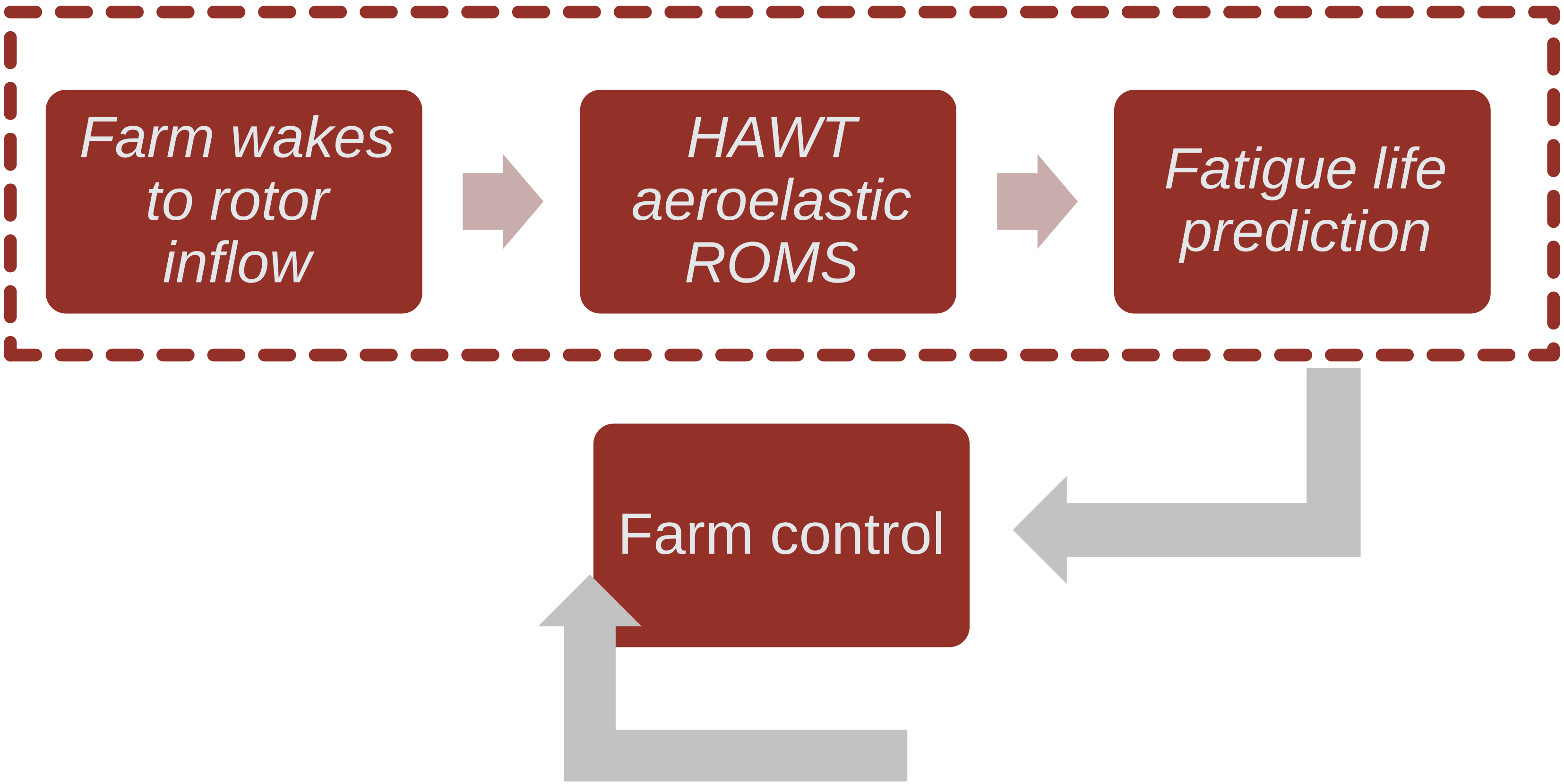
- Buffet load alleviation in water channel (MG, Mark Frederick & Eric Kerrigan)





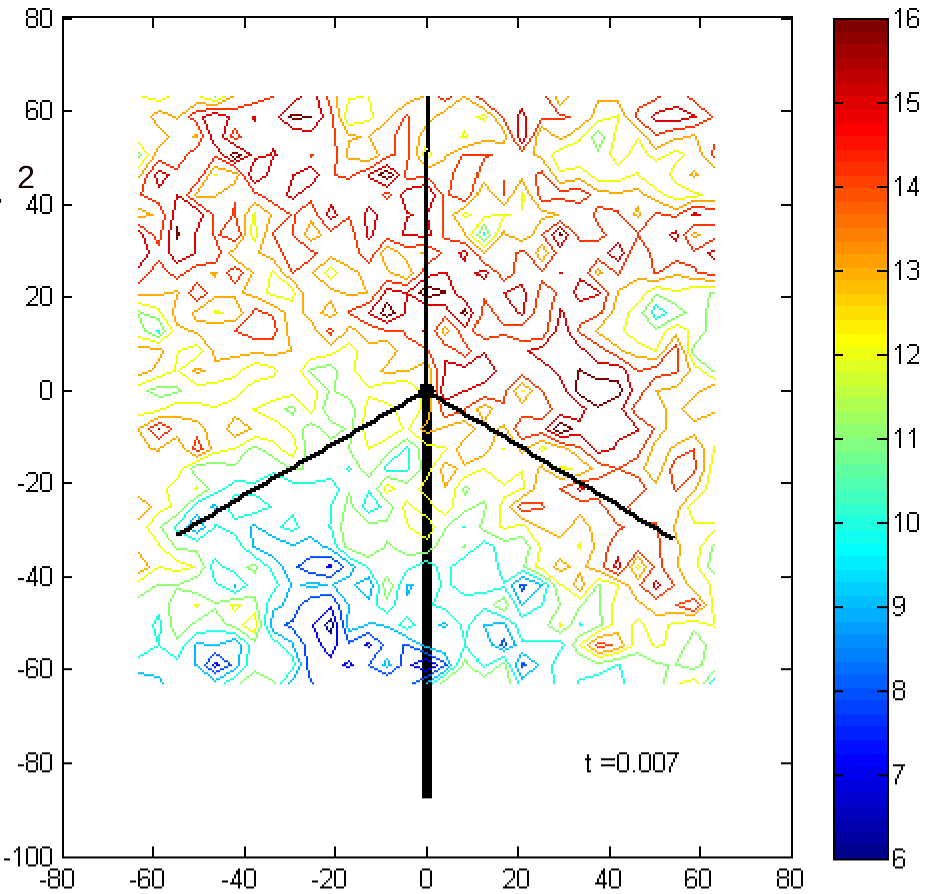


From wind conditions to fatigue



Synthetic turbulence

- **Full wind field** [1]
  - In accordance with IEC 61400-1 [2]
  - Von Karman turbulence
  - Wind shear (power law 0.2)
  - Rated conditions (11 m/s)
  - 17.5% turbulent intensity



- NREL 5MW Turbine; 6 X 600 seconds statistics

[1] Jonkman and Kilcher, NWTC Computer-Aided Engineering Tools (TurbSim)
[2] IEC 61400-1. Wind turbines-part 1: Design requirements. International Electrotechnical Commission 2006.

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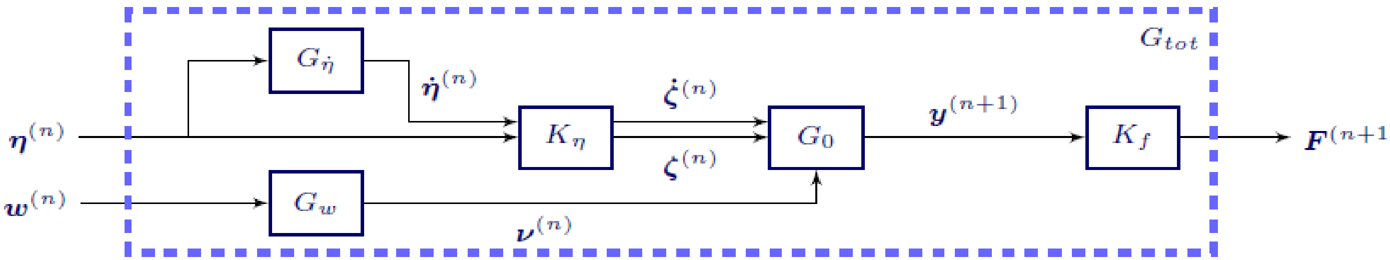
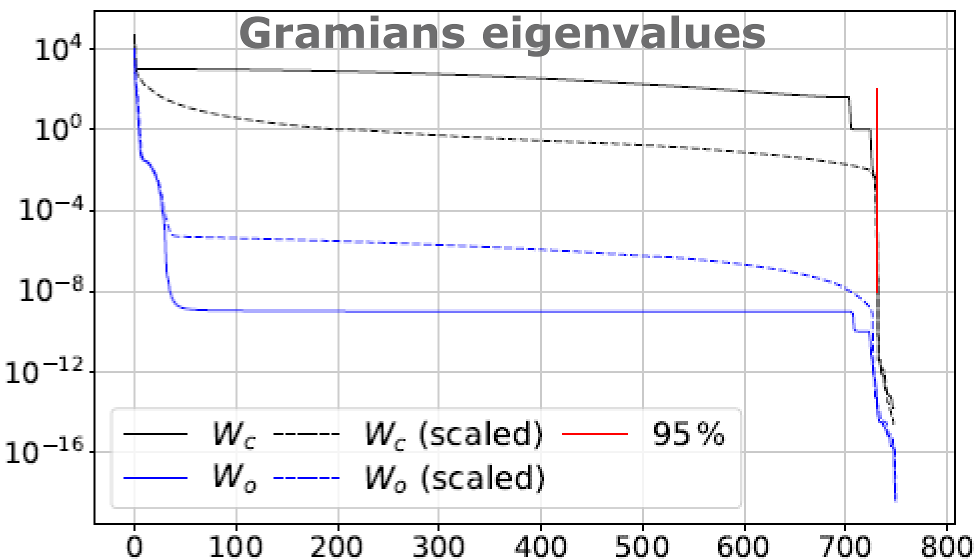
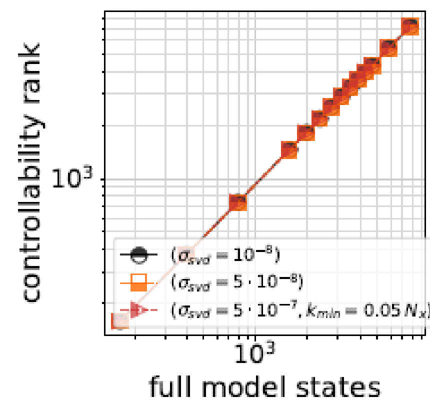
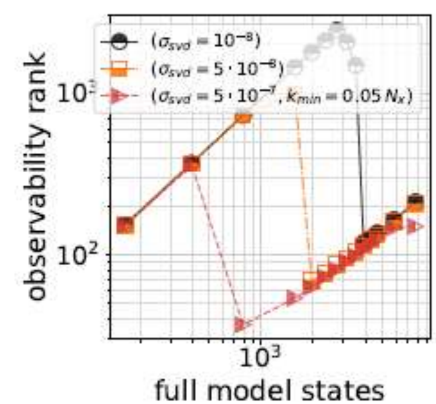
Low-rank balancing of a linearized UVLM



2. Iterative low-rank balancing







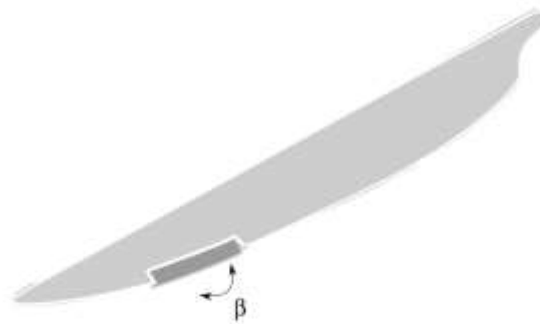
2. This + higher order time integration: **90% CPU reduction** (so far)

Closed-loop results

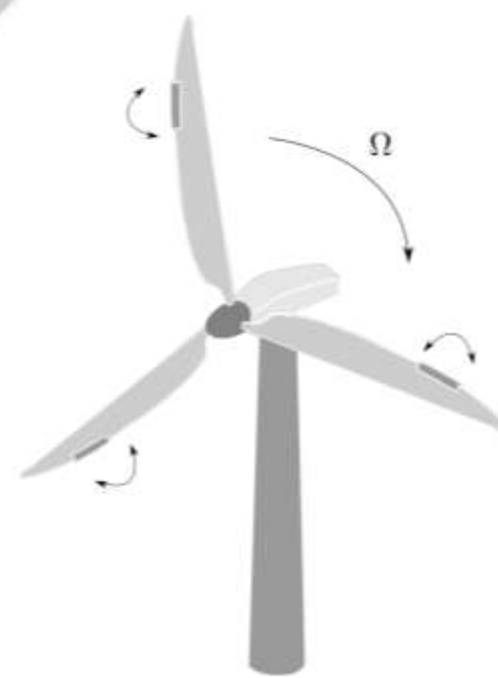
- **Active load alleviation** $|\beta| \leq 10^\circ$ and $|\dot{\beta}| \leq 100^\circ/\mathrm{s}$
  - Flaps - 10% local chord, 20% span from 0.7 - 0.9 span.
  - $\mathcal{H}_\infty$ controller designed from single rotating blade on full WT.
  - RBM feedback

% reduction rms RBM	12.9 ± 0.1
% reduction rms torsion	-97.9 ± 5.3
% reduction max RBM	12.6 ± 0.6
% reduction max torsion	-84.4 ± 17.2
% reduction DEL RBM	13.3 ± 0.89

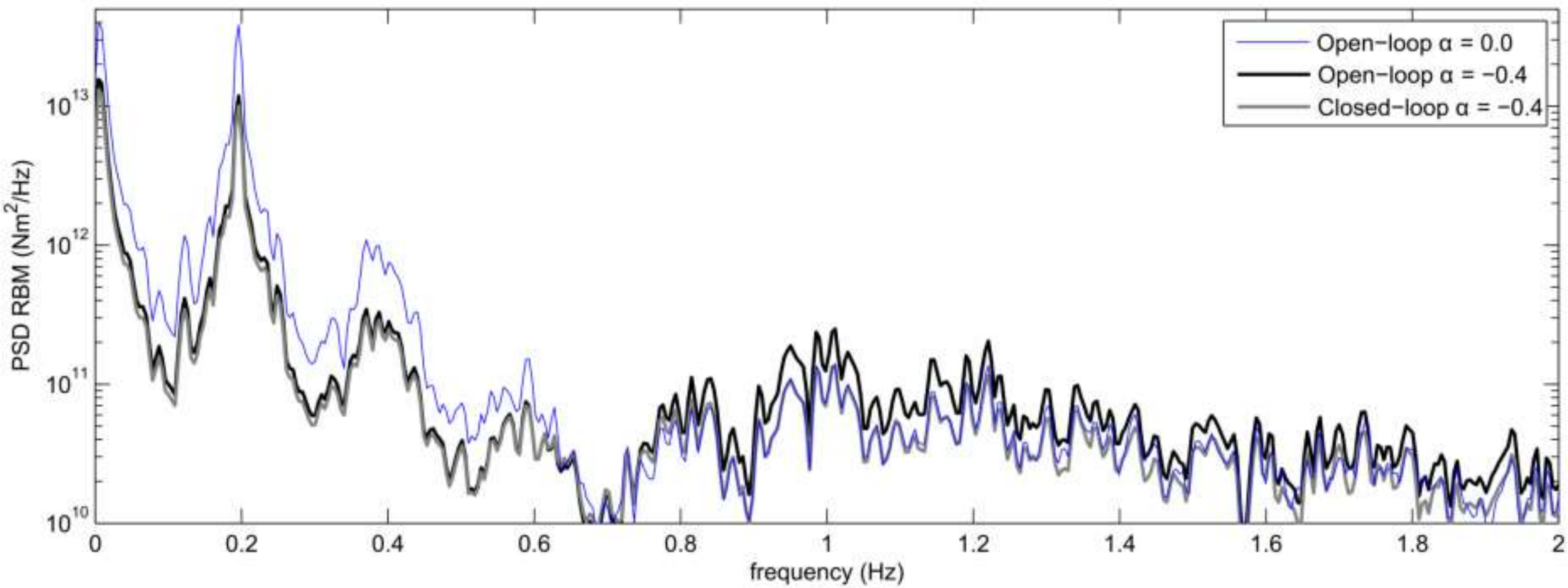
% reduction max blade tip deflection	16.0 ± 2.2
% reduction rms tower fore-aft deflection	11.1 ± 0.2
max β ($^\circ$)	9.01 ± 0.99
max $\dot{\beta}$ ($^\circ$/s)	34.9 ± 2.6



flap size of 20% span and 10% chord located at 80% span



Combined passive and active alleviation



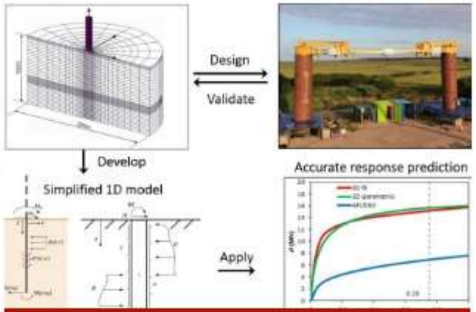
- Passive alleviation at lower frequencies
- Active methods alleviates higher frequencies

Synergistic combination of active and passive methods

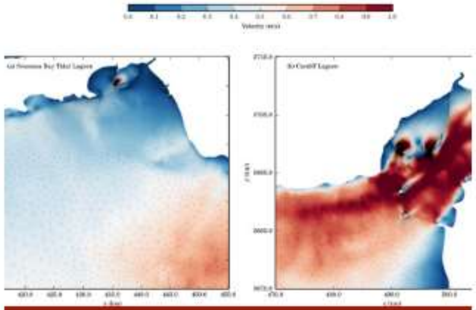
Imperial ORE Network: Research areas

Electrical: Grid Integration, Interconnects, Farm Control

Farms: Resource Mapping, Windfarm Design, Wakes, Oceanography



Geotechnics: Piles, Foundations, Soil, Geo-hazards



Hydrodynamics: Tidal Power, Wave Power and Wave Loading of Offshore Structures, Floating Structures

Operations: Monitoring, Maintenance, Non-destructive Testing

Turbines: Design and Materials, Aerodynamics, Loading and Lifetime Predictions

www.imperial.ac.uk/energy-futures-lab/research/sustainable-power/offshore-renewables

Thank You!