MAXFARM

MAXimizing wind **F**arm **A**erodynamic **R**esource via advanced **M**odelling – an overview

Partners:
Imperial College
Loughborough
STFC-Rutherford Appleton
Strathclyde
Surrey

DNV GL - Energy
BMT Fluid Mechanics
Catapult Offshore Renewable Energy
Catapult Satellite Applications
Zephir LiDAR
Sgurr Energy
Zenotech
RES

Philip Hancock,

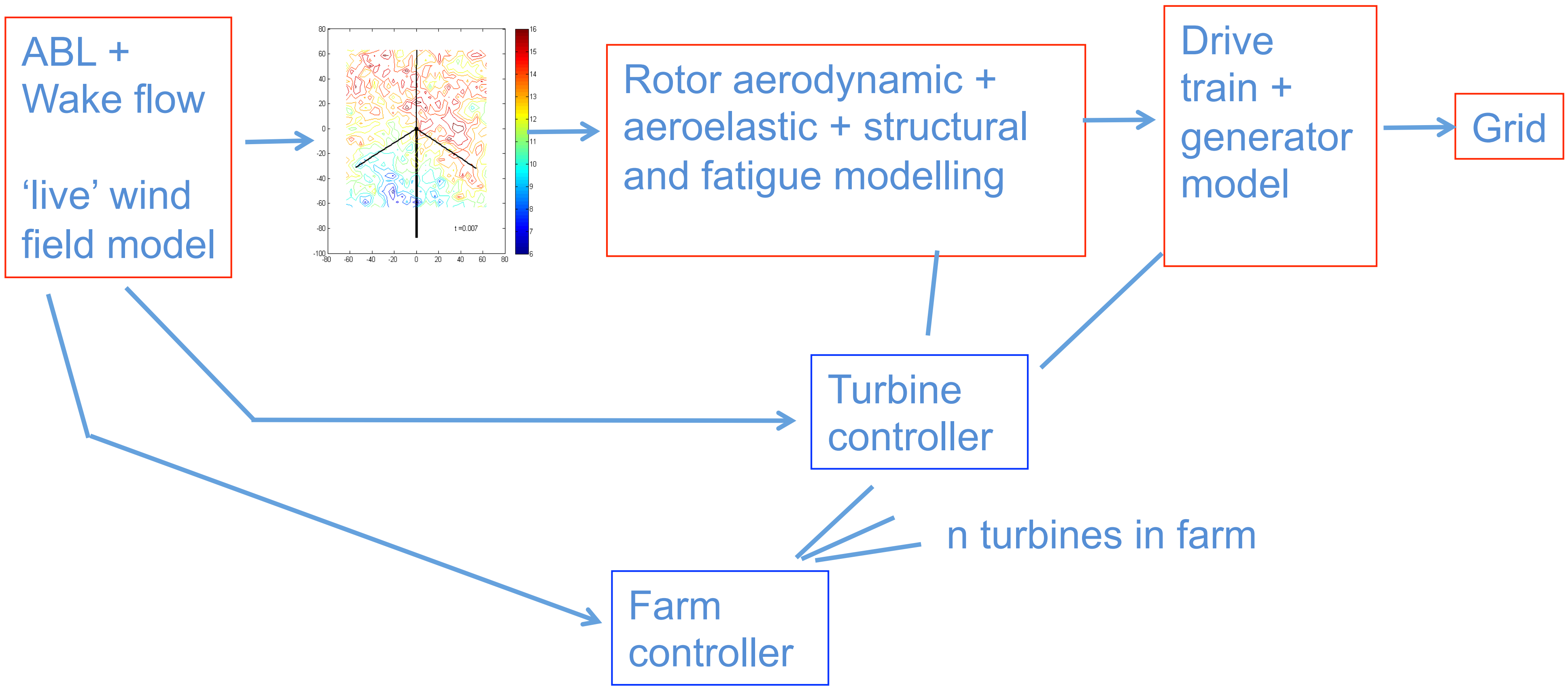
SUPERGEN General Assembly,

27th April 2017, Univ of Durham

Key Objectives

- To improve understanding and modelling of offshore wind conditions;
- To improve understanding and modelling of wake losses within and downwind of offshore wind farms;
- To improve understanding and modelling of the dynamic loading, fatigue and accumulated damage for offshore wind turbines;
- To improve turbine life and overall wind farm efficiency.

Interactions



Work Packages - outline

Work packages:

WP1: Wind conditions

WP2: Wake losses and wake-turbine inflow

WP3: Predicting loads and fatigue

WP4: Wind farm control

Key WP Interactions:

WP1: Wind conditions

WP2: Wind + wakes

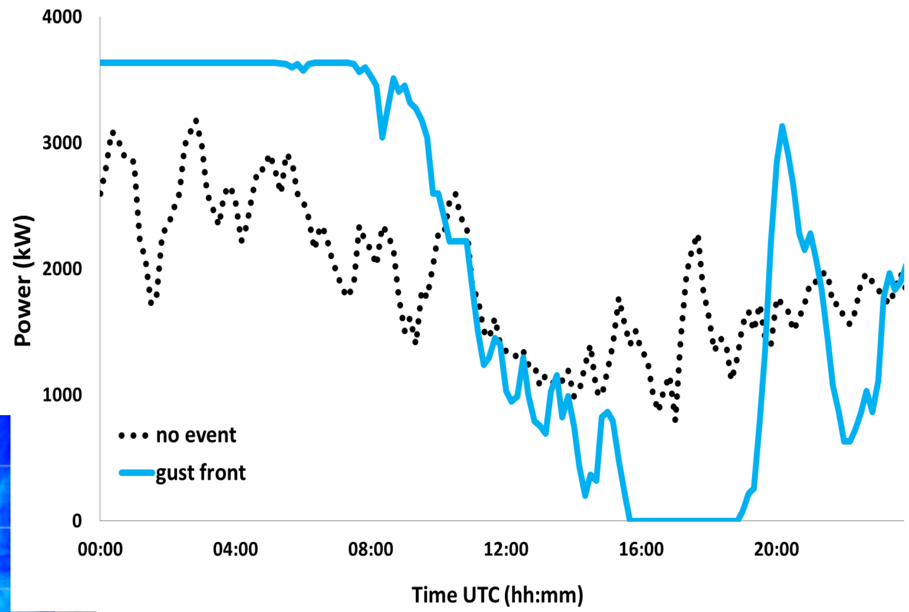
WP3: Loads & fatigue

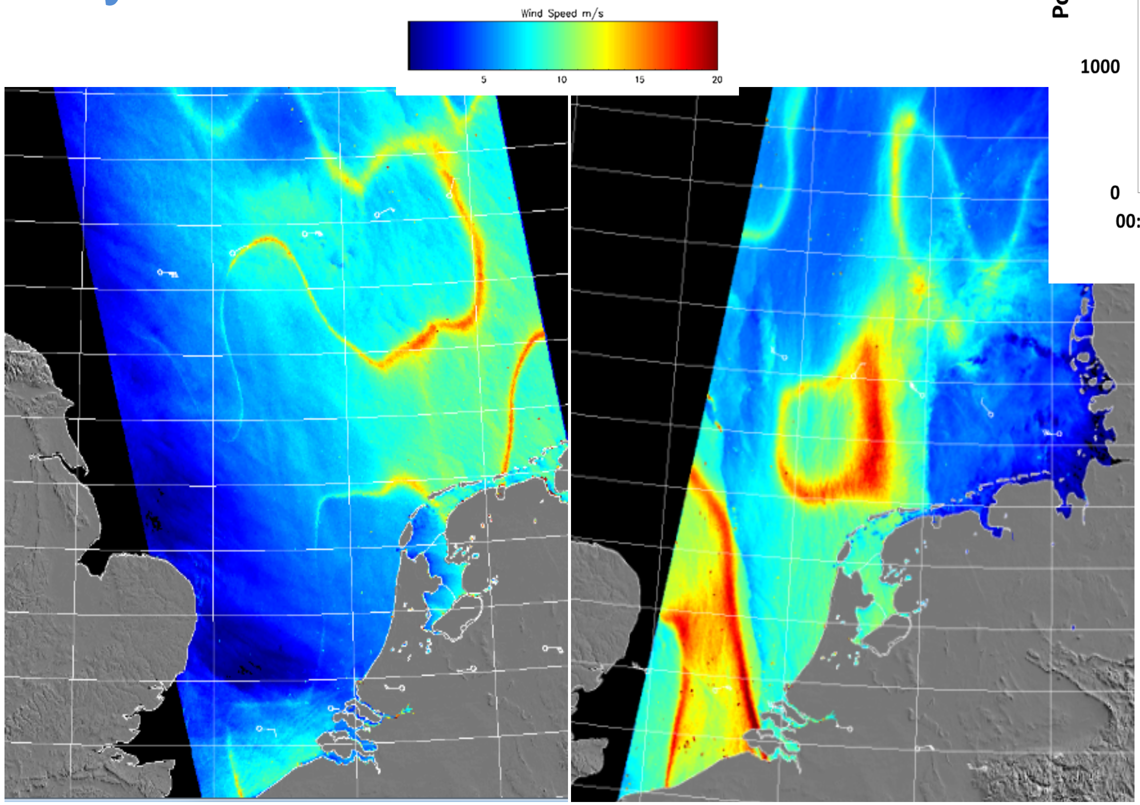
Wind + wakes (power)

WP4: Farm optimisation for power and life-time energy yield

Wind Condition Analysis (WP1.1, 1.2)

Estimated power output for a turbine at Greater Gabbard during gust front event vs. a non event day at the same location.





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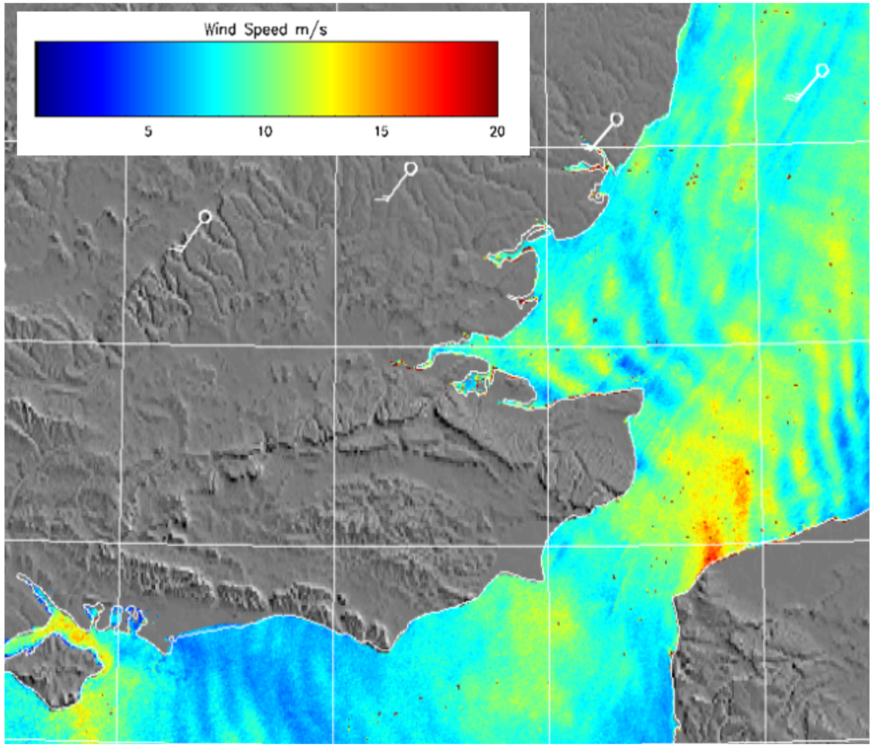
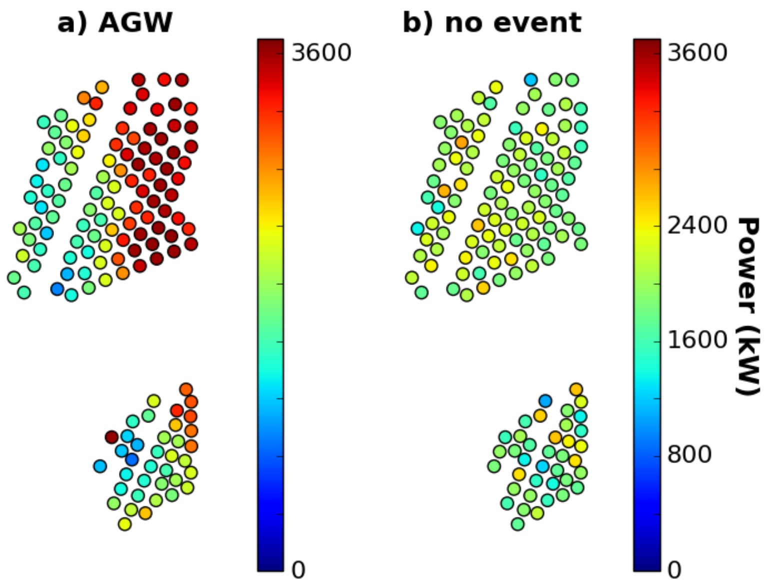
Wind Condition Analysis (WP1.1, 1.2)

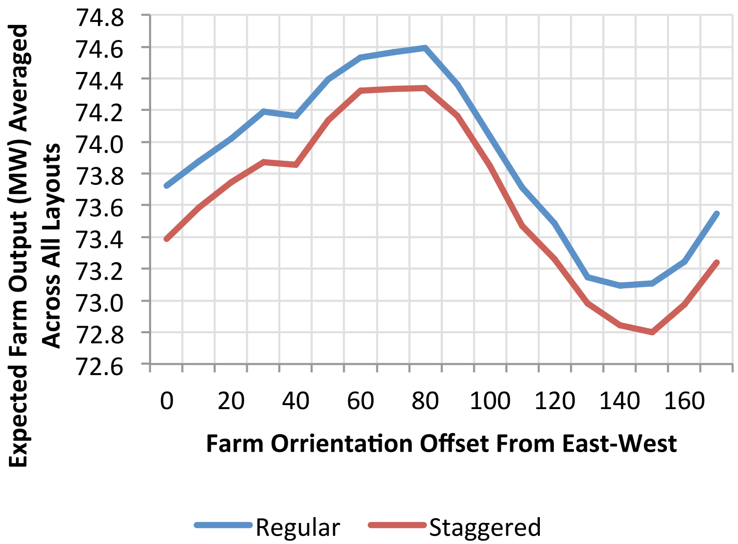
- Satellite mesoscale wind field data (provided by DTU)
- Events highlighted and compared to models
- WRF simulations to show effect on power timescales



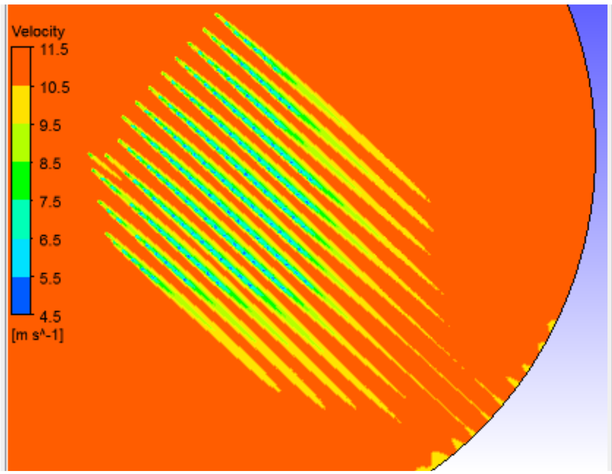


Wind Farm Analysis/Modelling (WP2.1, 2.2)

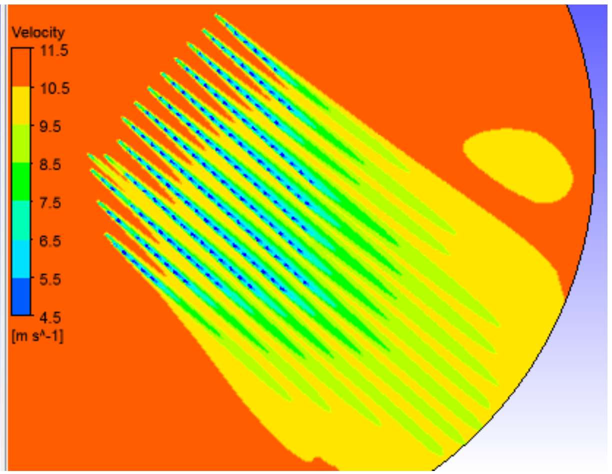
- CFD wake effects simulations of different turbine separations
- CFD wake effects of farm orientation to wind rose
- CFD effects of atmospheric stability on farm productivity (using production data from Elexon and met data from ECMWF)



Very Unstable



Stable



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Wake losses from satellite measurement

(WP2.4)

- Characterising the wakes of offshore wind farms with satellite radar data. (Synthetic Aperture Radar, SAR.)
- The radar backscatter over the sea can be related to wind speed at the surface.

- From this to compare the effects of:
  - Mean ambient wind speed
  - Location relative to shore
  - Turbine spacing
  - Atmospheric stability

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Wake losses from satellite measurement

(WP2.4)

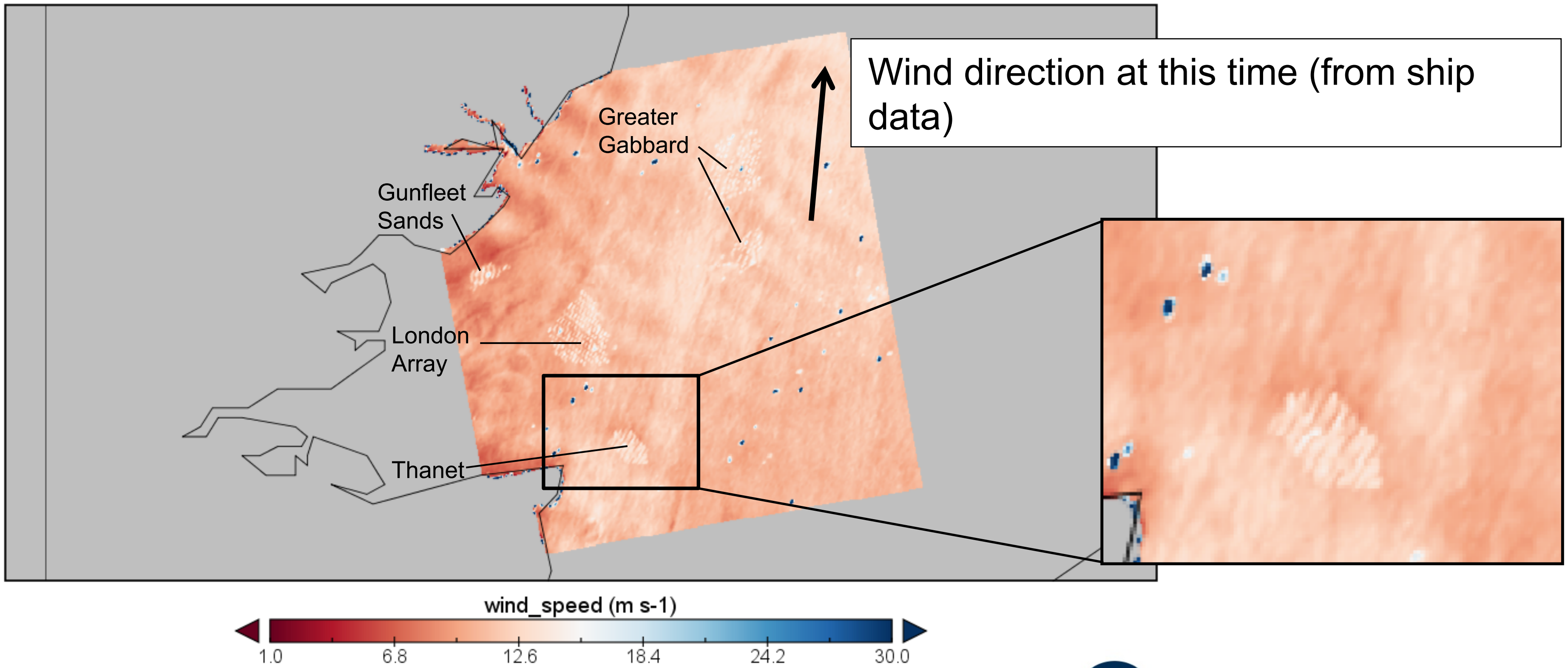
SAR Image of Thames Estuary wind farms

- Sentinel 1A on 2015-12-03
- Ascending pass
  (so flipped vertically)
- White blobs are turbines and some ships
- Wind direction approximately from South

Wake losses from satellite measurement

(WP2.4)

Wind speed around several Thames Estuary wind farms, derived from Sentinel-1 satellite data



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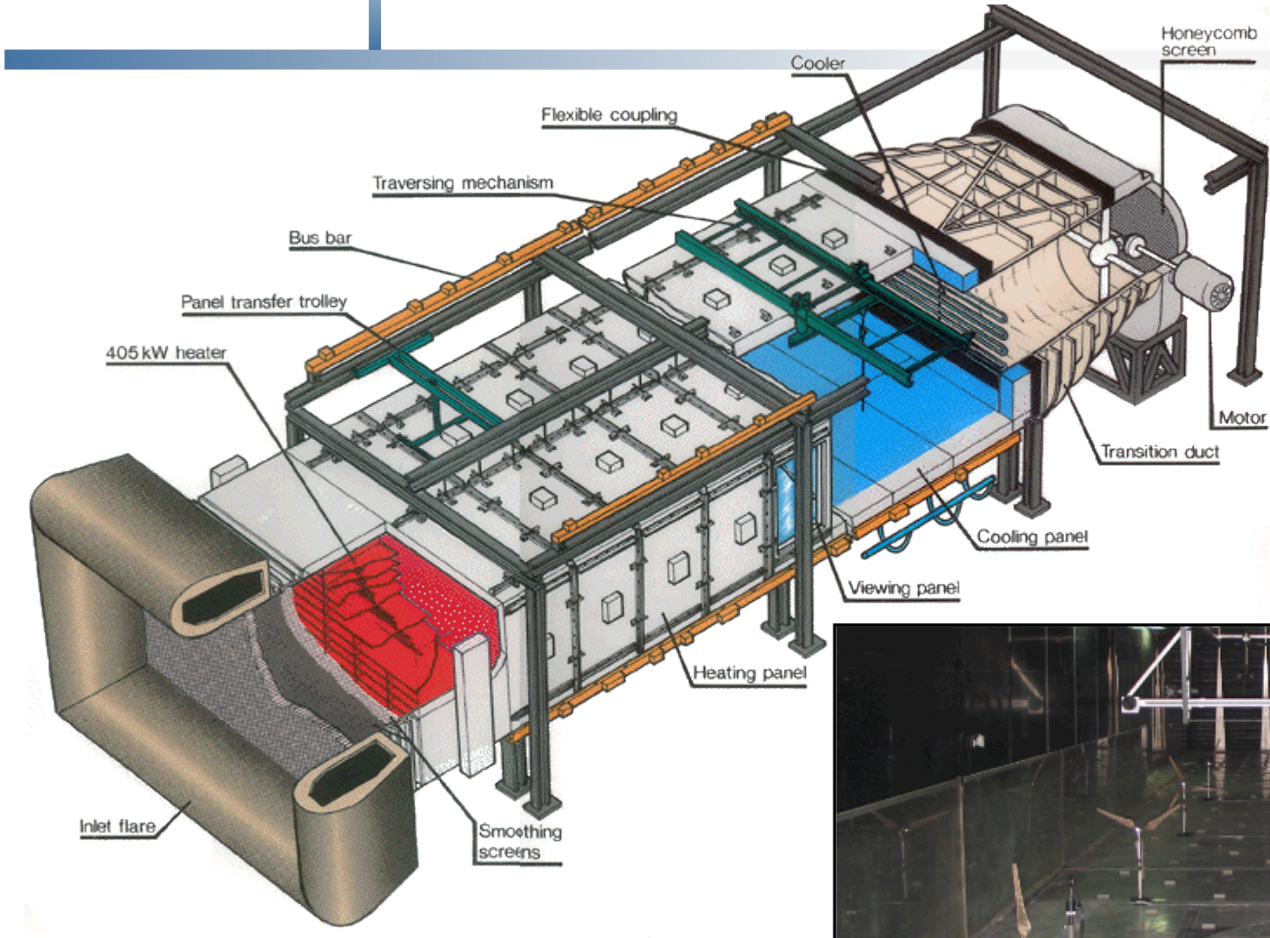
Effects of atmospheric stability (WP1.3, 2.3)

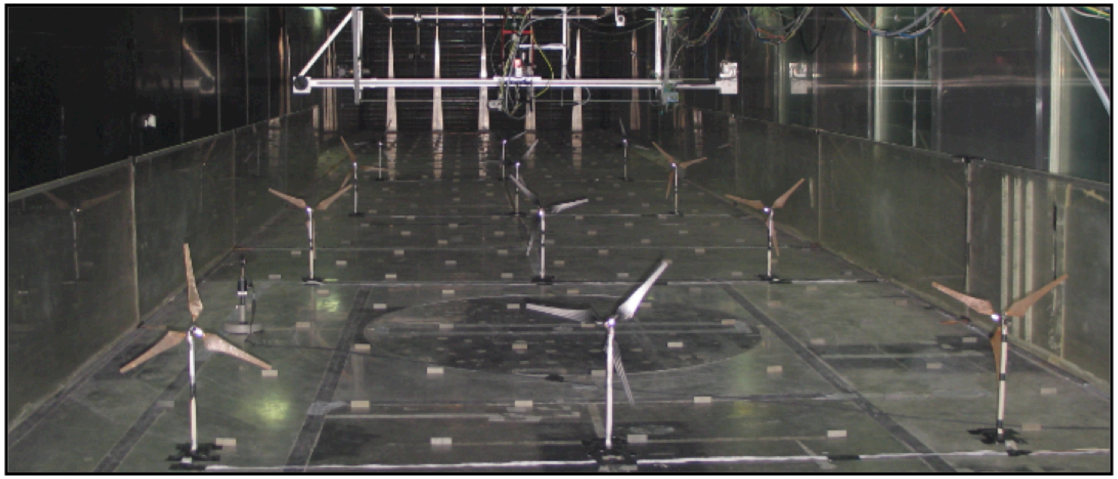


Cases:

Unstable

Stable - no inversion; with inversion

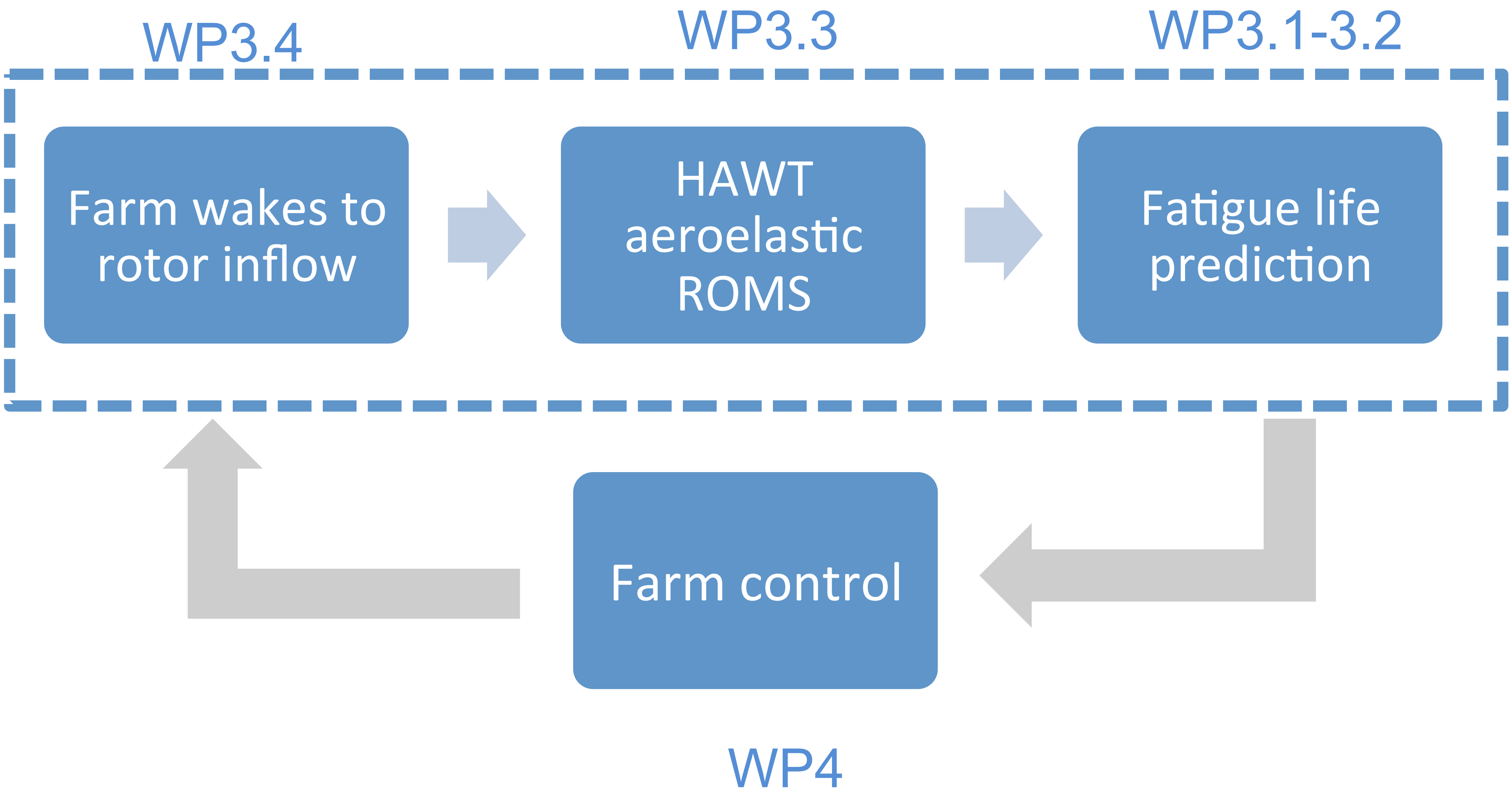
Neutral – datum cases



Predicting loads and fatigue (WP3)

- Comprehensive fatigue life prediction
- Interfacing turbine-level aeroelastic models to detailed fatigue models
- Model reduction methods for fatigue prediction from individual tower to farm-level analysis
- Integrating farm-level wake predictions with rotor inflow conditions

Goal: from conditions to fatigue



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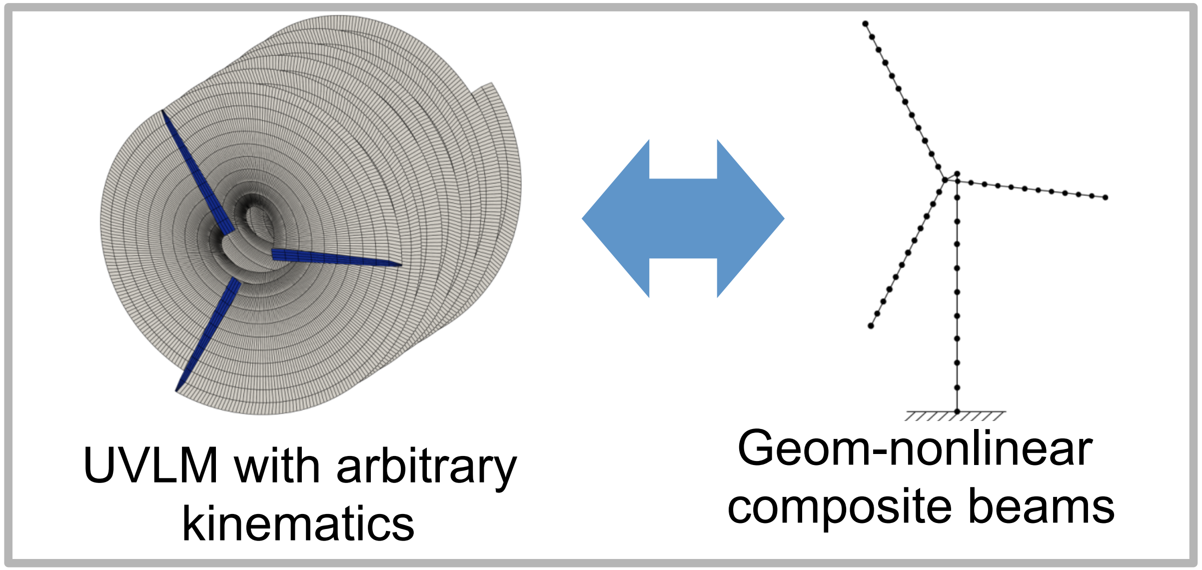
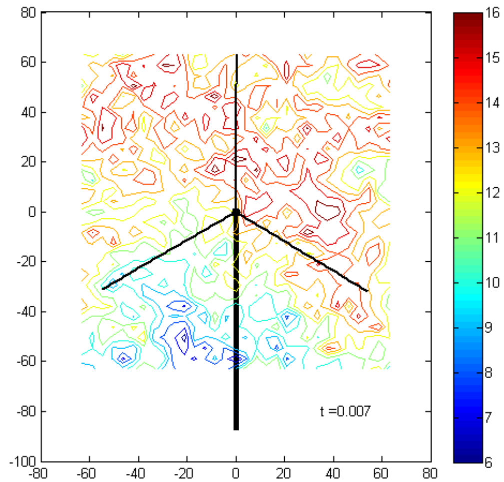
Aerodynamic-aeroelastic modelling (WP3.3)

- Baseline - In-house aeroelastic simulation framework (SHARPy)





- Time-domain, nonlinear solver
- Includes composites (aeroelastic tailoring), flaps, arbitrary inflow
- Numerically efficient (C++/Fortran), all wrapped in Python

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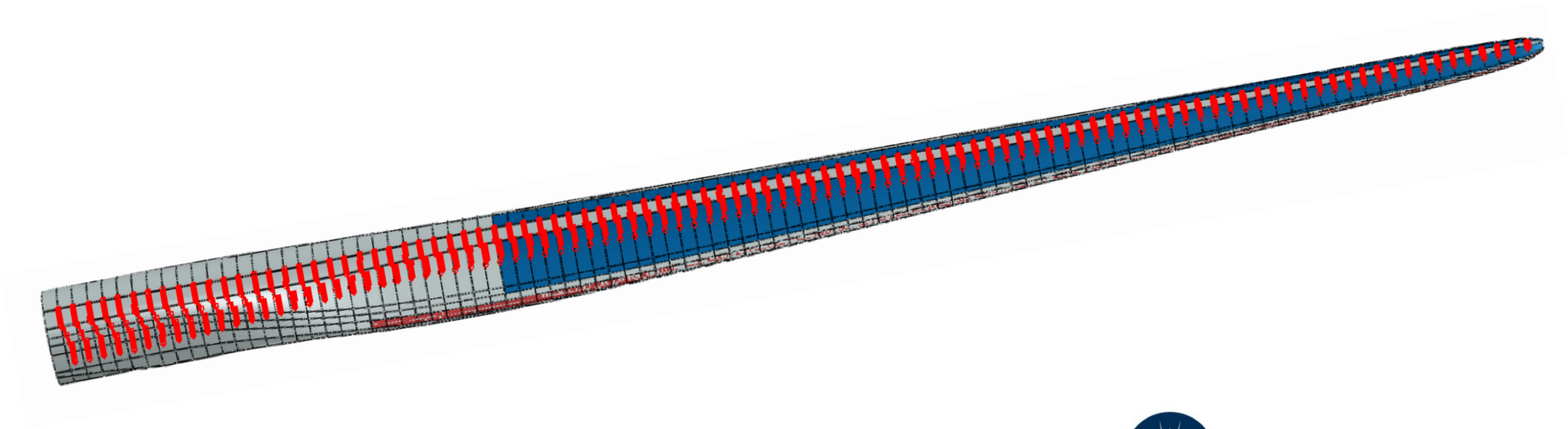
Interfacing with fatigue modelling (WP3.2)

- Based on the DTU 10 MW Reference Turbine: 90m long blades.
- DTU - Abaqus shell model and cross section meshes/data
- STFC to apply loads from the IC aeroelastic model (aerodynamic, gyroscopic, …) to Abaqus shell model of a blade.



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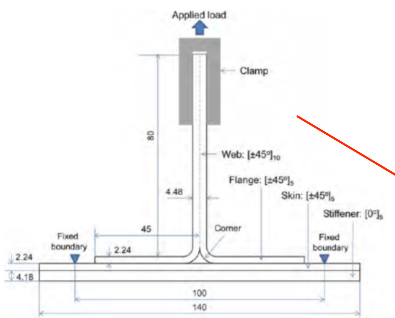
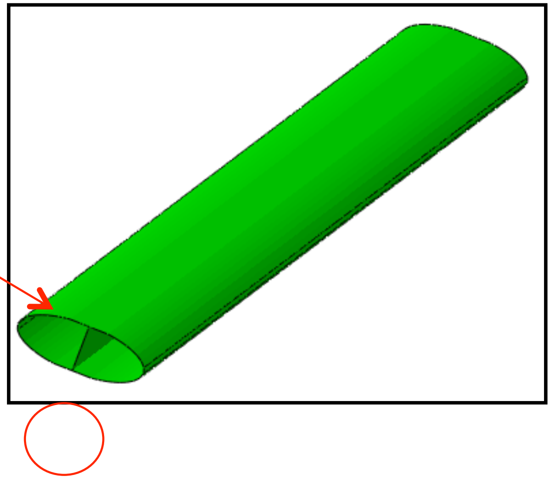
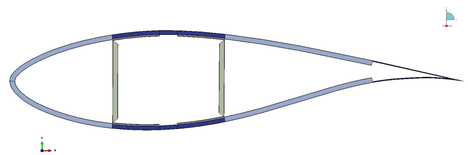
Fatigue prediction (WP3.1)

- Improve the application of damage equivalent load analysis with more detailed.
- T-joint is a fatigue critical area - work has been focused on assessing detailed stresses in this area.
- Shell models quick but not necessarily accurate – sub-models or a fine solid mesh can be computationally expensive.
- Compromise based on shell model and a series of test case sub-models (12).







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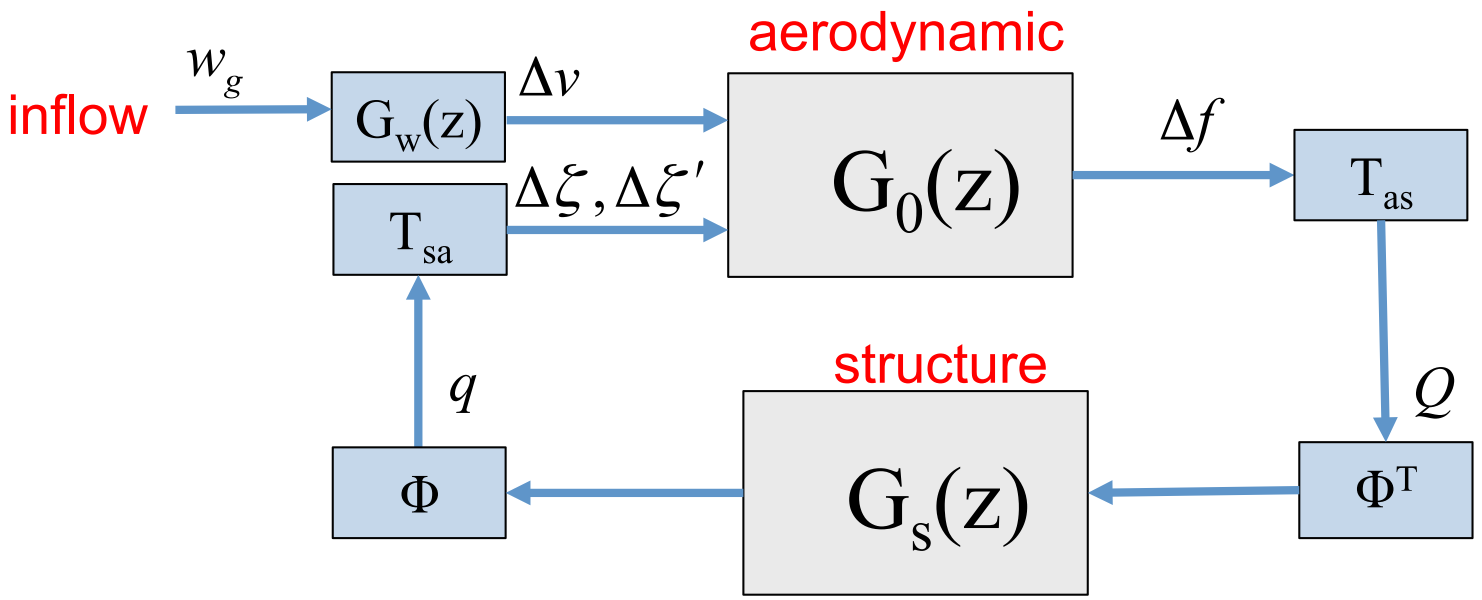
Aero-structure - model-order reduction (WP3.3)

- Reduced-order models of linearized aeroelastic system for integration in farm control:



- Input: time history on each aerodynamic panel (mapped from rotor plane)
- Output: time-history of resultant into detailed FEM for fatigue studies.

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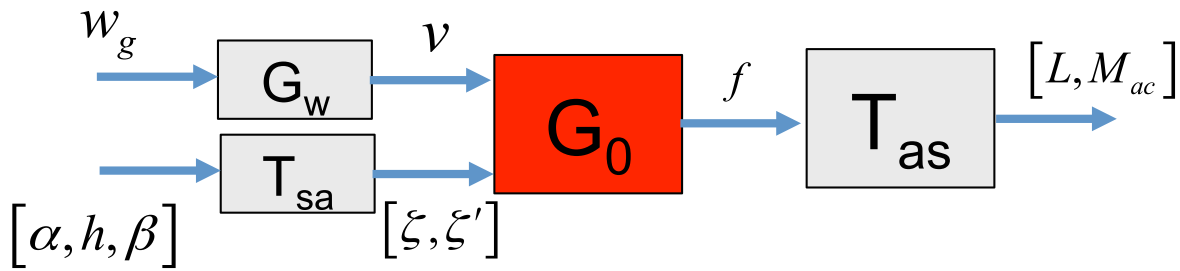
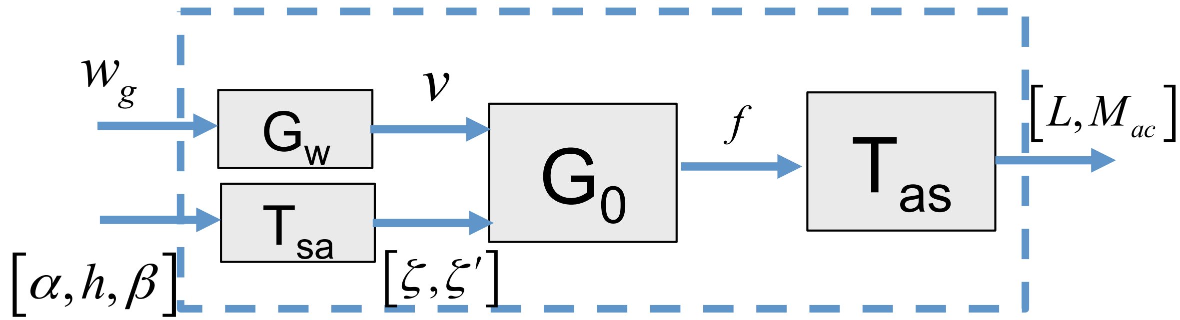
Aero-structure - model-order reduction (WP3.3)

- Reduction through balanced residualisation of discrete system
- Option 1: Balancing on general aerodynamic description, G_0

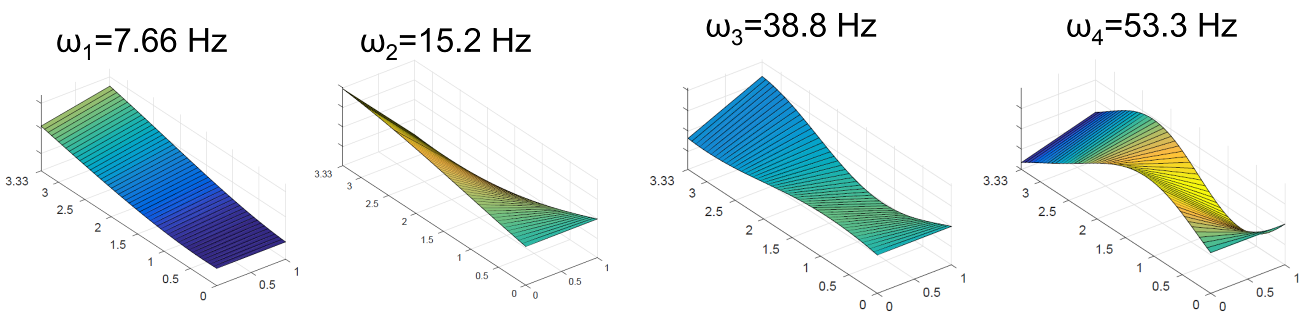


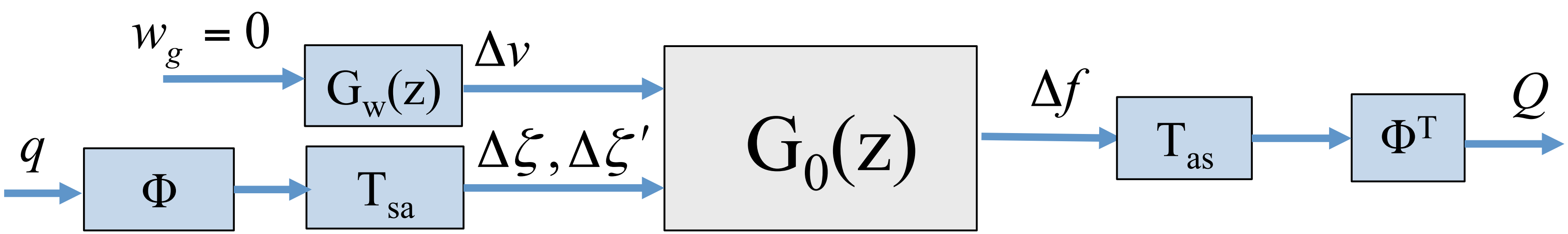
- Option 2: Balancing on problem-dependent I/O, e.g.



Unsteady aero-elasticity on a cantilever wing

- Goland wing (Goland, 1945)





- We obtain flutter behaviour after two independent operations:
  1. Compute AIC, (discrete) frequency-domain from q to Q
  2. Close the loop with structural feedback, check stability

Wind farm control (WP4.1, 4.2)

- Wind farm control objectives
  - maximise generated power
  - Provide ancillary services to grid
  - Minimise O&M costs

- Wind farm control design and analysis models are required.
  - Performance assessment is over full operating envelop.
  - Simulation should include the wind field & wakes, turbines (up to 100+) and wind farm controller.
  - Fast simulation execution times required.

Wind farm control (WP4.1, 4.2)

- Wind farm simulation has been developed
- Fast execution with following times for 600sec simulations
  - complete simulation including wind field and wind farm controller, non-optimised turbine model

Number of turbines	5	10	20
Simulation time	50secs	85secs	175secs

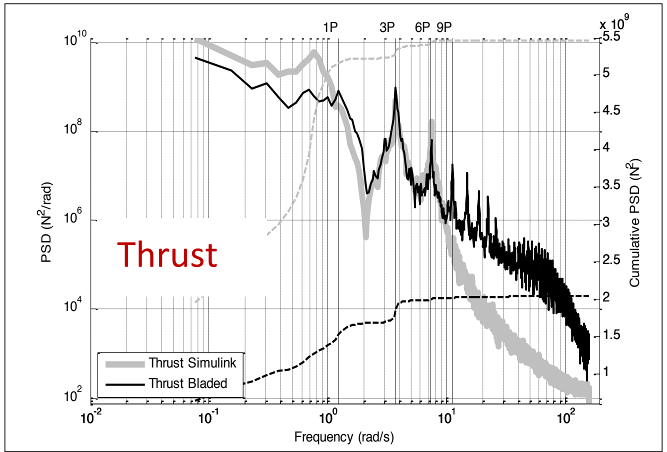
  - simulation with optimised turbine models without wind field or controller

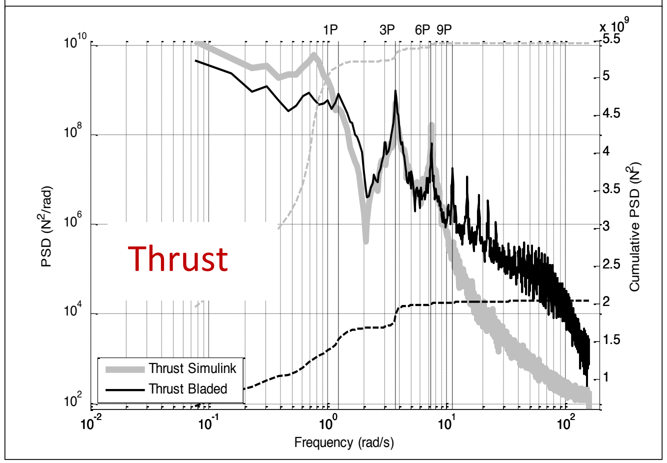
Number of turbines	100
Simulation time	300secs

- Turbine structural loads up to 6P represented.

Wind farm control (WP4.1, 4.2)

- Comparison of loads to Bladed



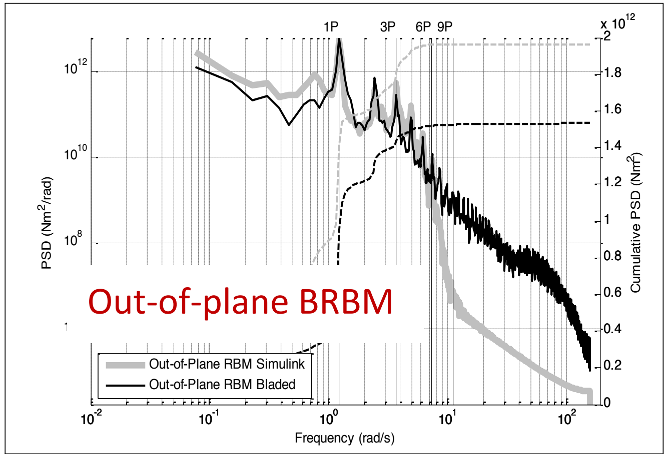


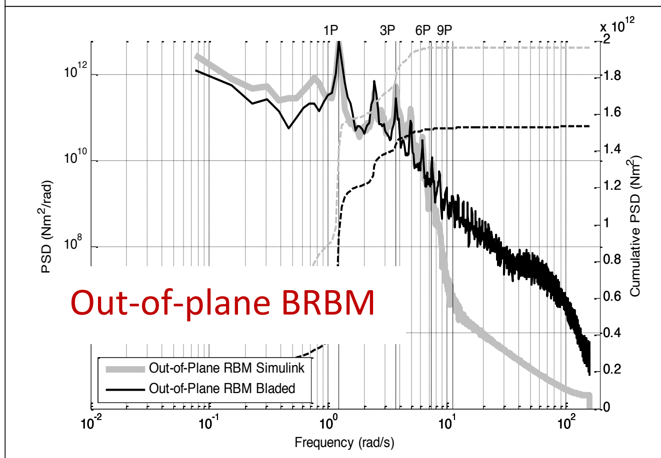
Loads with mean wind speed 8m/s

WF simulation

Bladed

Loads with mean wind speed 14m/s

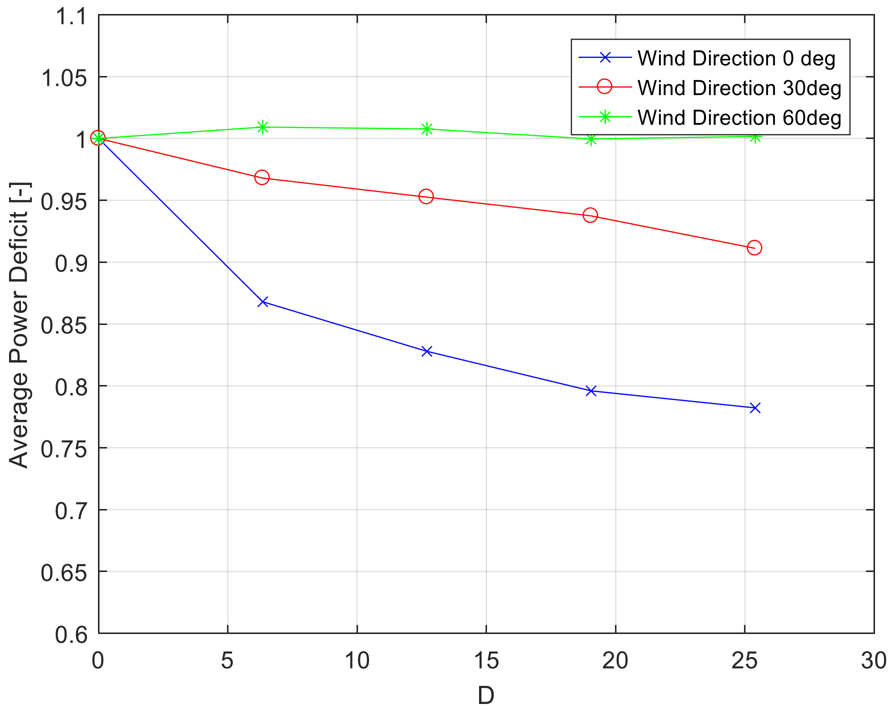




Mean wind speed ~ 14m/s Turbulence intensity ~ 10%

Wind farm control (WP4.1, 4.2)

- Average power deficits (ratios to power without wake losses).



- Farm consists of 5 x 5MW turbines
- Mean wind speed 8m/s
- Turbulence intensity 10%
- 3 wind speed directions
  - 0^0, 30^0 and 60^0
- Simulation time 600 secs
- Execution times 45 – 55

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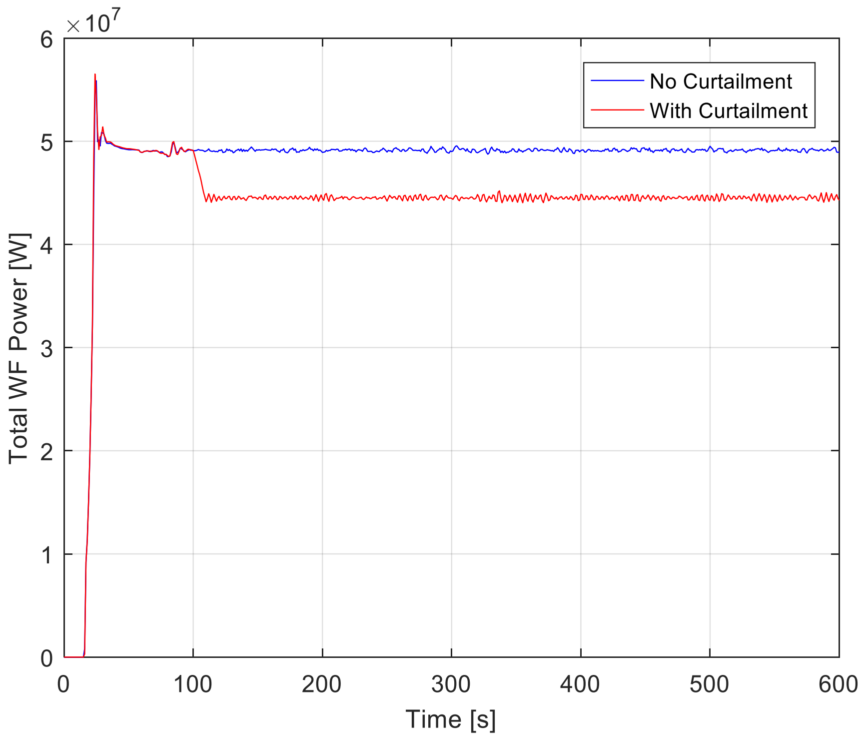
Wind farm control (WP4.1, 4.2)

- Curtailment of generated power(from 50MW to 45MW).



- Farm consists of 10 x 5MW turbines
- Mean wind speed 14m/s
- Turbulence intensity 10%
- Curtailment 5MW
- Simulation time 600 secs
- Execution times 80 – 85 secs

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Thank you