Validation of a FAST Model of the Statoil-Hywind Demo Floating Wind Turbine

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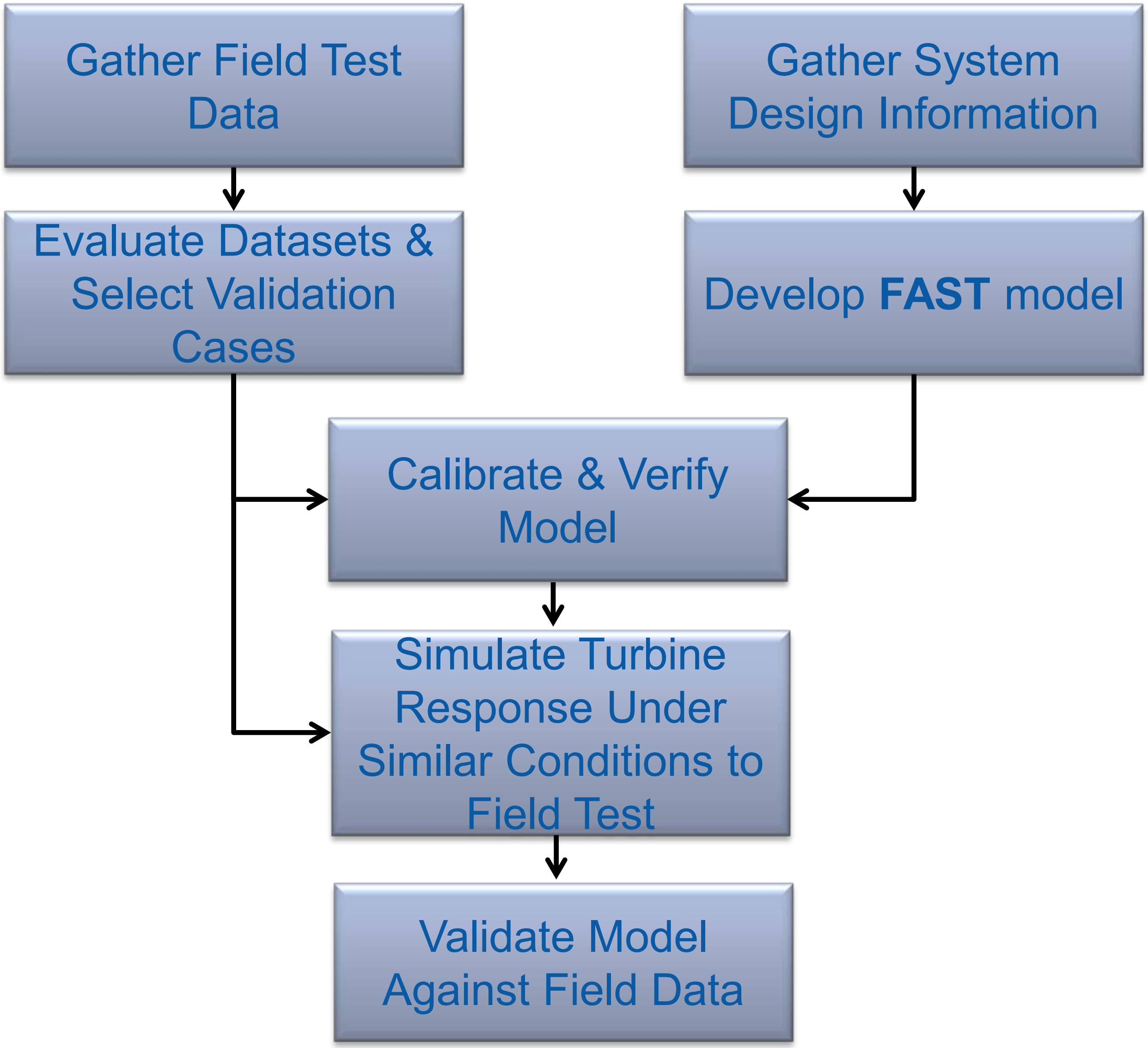
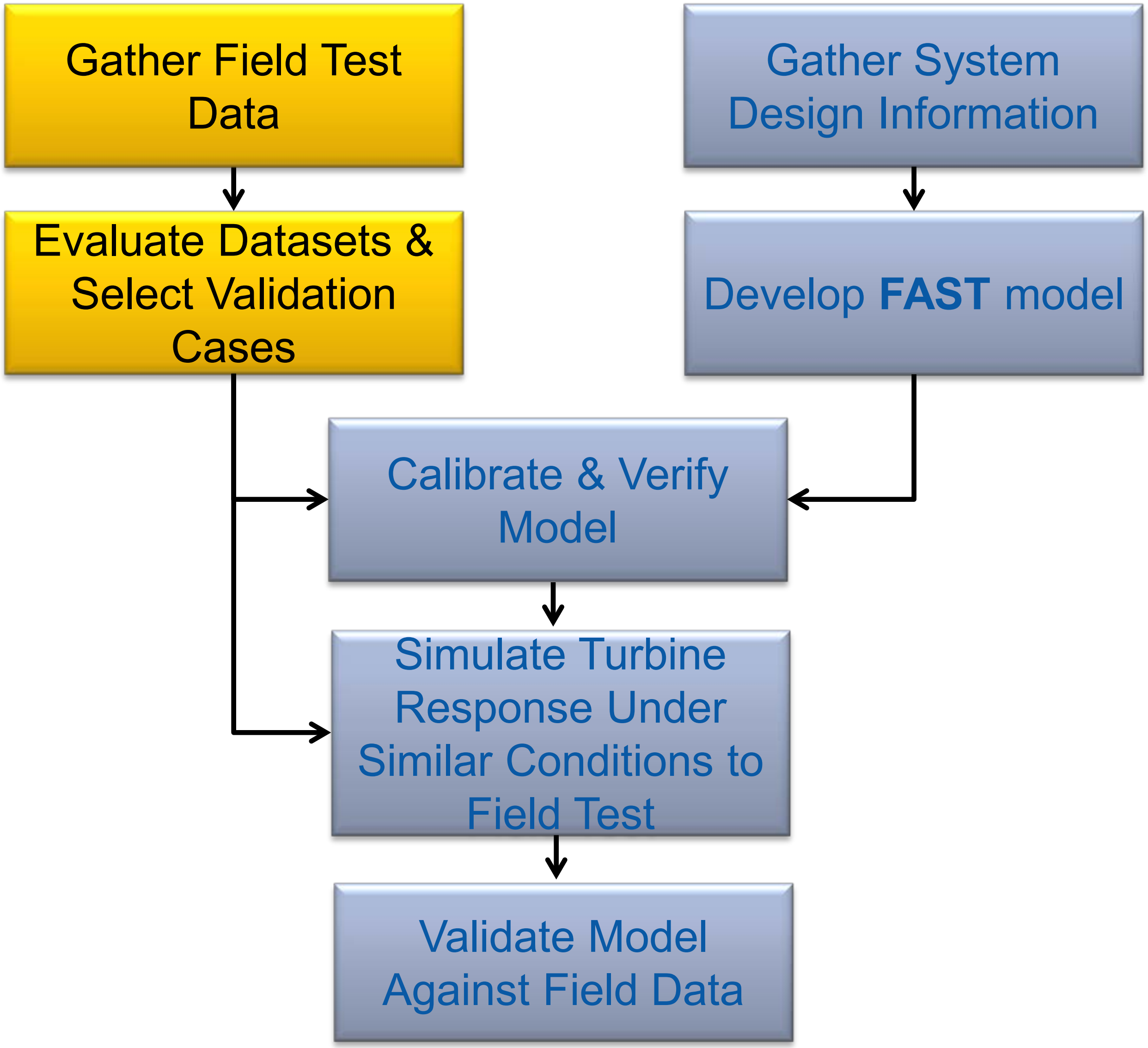
Project Overview & Objectives

- **FAST** is DOE/NREL's premier open-source wind turbine multi-physics engineering tool:
  - Turbine capability validated for land-based applications
  - FOWT capability verified in IEA Wind OC3 & OC4 projects
  - FOWT capability validated against model-scale wave-tank data
- This presentation uses Hywind Demo field data to validate & assess accuracy of **FAST** under realistic full-scale open-ocean conditions

Project Methodology



Field Data


Gather Field Test Data
Gather System Design Information
Evaluate Datasets & Select Validation Cases
Develop **FAST** model
Calibrate & Verify Model
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Field Data

Datasets Used for Validation: Statoil provided 8 time series w/ turbine operating (nothing parked/idling), each 30-60-min long, in roughly stationary environmental conditions

Case no.	Duration (min)	Mean wind speed (m/s)	Wind direction (coming from) (deg)	Significant wave height (m)	Peak-spectral wave period (s)	Peak-shape parameter (-)	Wave propagation direction (deg)	Mean current speed (m/s)	Current direction (deg)	Turbine status
1	60	4.7	151	0.88	7.0	2.2	4	0.40	138	Producing power
2	60	9.1	36	1.3	6.9	1	144	0.31	68	Producing power
3	60	9.7	15	1.4	8.6	2	146	0.32	316	Producing power
4	35	12.8	227	3.3	9.7	1.1	25	0.29	50	Producing power
5	35	13.4	252	5.2	10.3	1.74	79	0.52	89	Producing power
6	35	17.5	147	4.0	10.0	1.2	355	0.43	337	Producing power
7	35	18.3	165	2.0	6.8	2.2	353	0.38	316	Producing power
8	35	21.7	152	2.3	7.1	2	358	0.30	336	Producing power

Field Data

Measurements:

Metocean	Turbine	Tower	Platform
• Wind speed & direction • Current speed & direction profiles • Wave height & direction spectral moments	• Generator speed • LSS moments & torque • Blade pitch • Blade root moments • Nacelle yaw • Export power	• Accelerations @ tower top • Bending moments @ stations along tower	• 6 DOF motion • Geodetic position

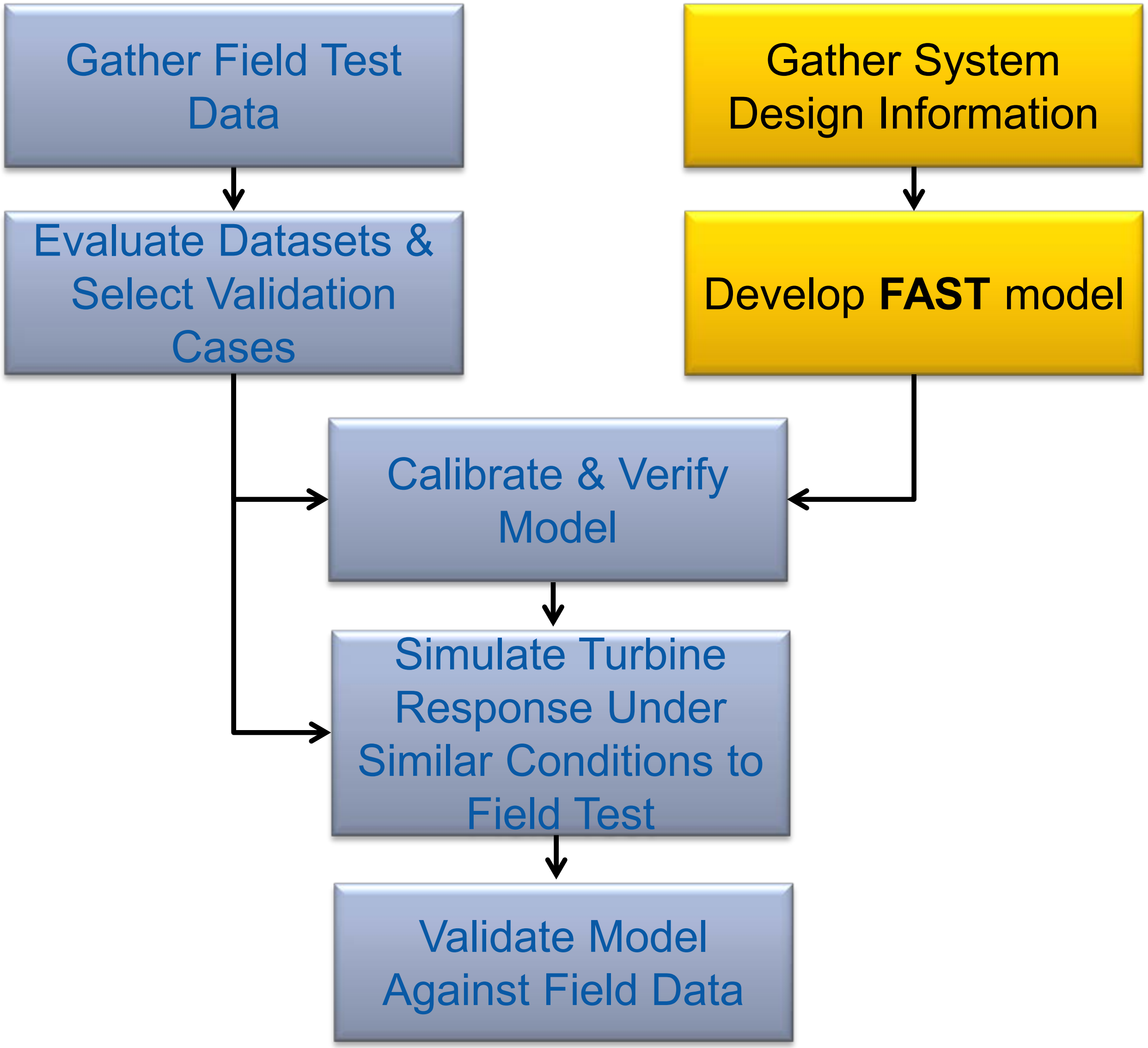
Data QA (in addition to previous QA by Statoil):

- Reviewed each measurement for continuity/gaps, noise, spikes, strange values/obvious errors, range/thresholds, etc.
- Spot-checked measured values against specifications/expected values
- Verified sample rates for consistency & against specifications
- Cross-compared similar measurements & performed correlation tests

Several channels were rejected, but majority of data was good

Measurement calibrations & uncertainties not provided (limits extent of validation possible)

Model Data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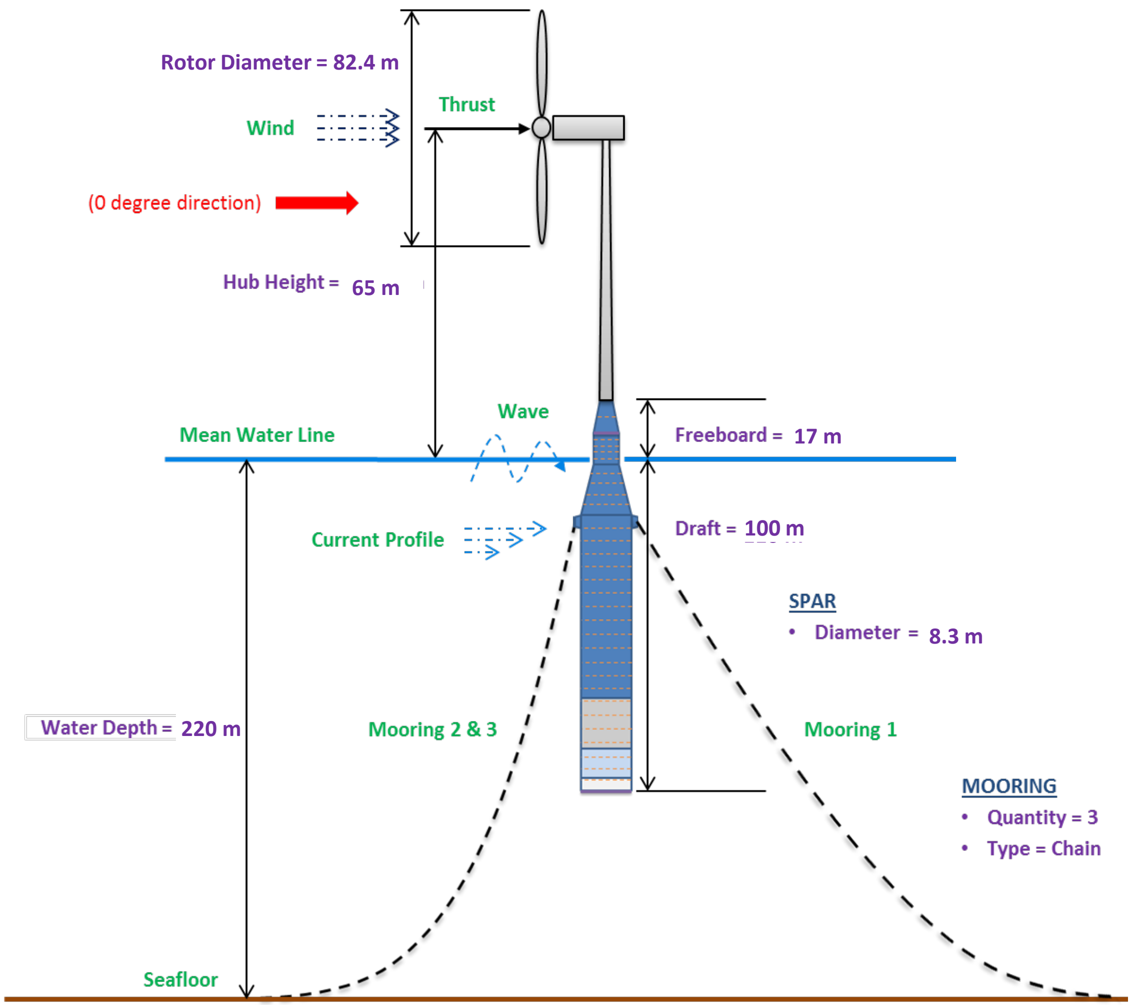
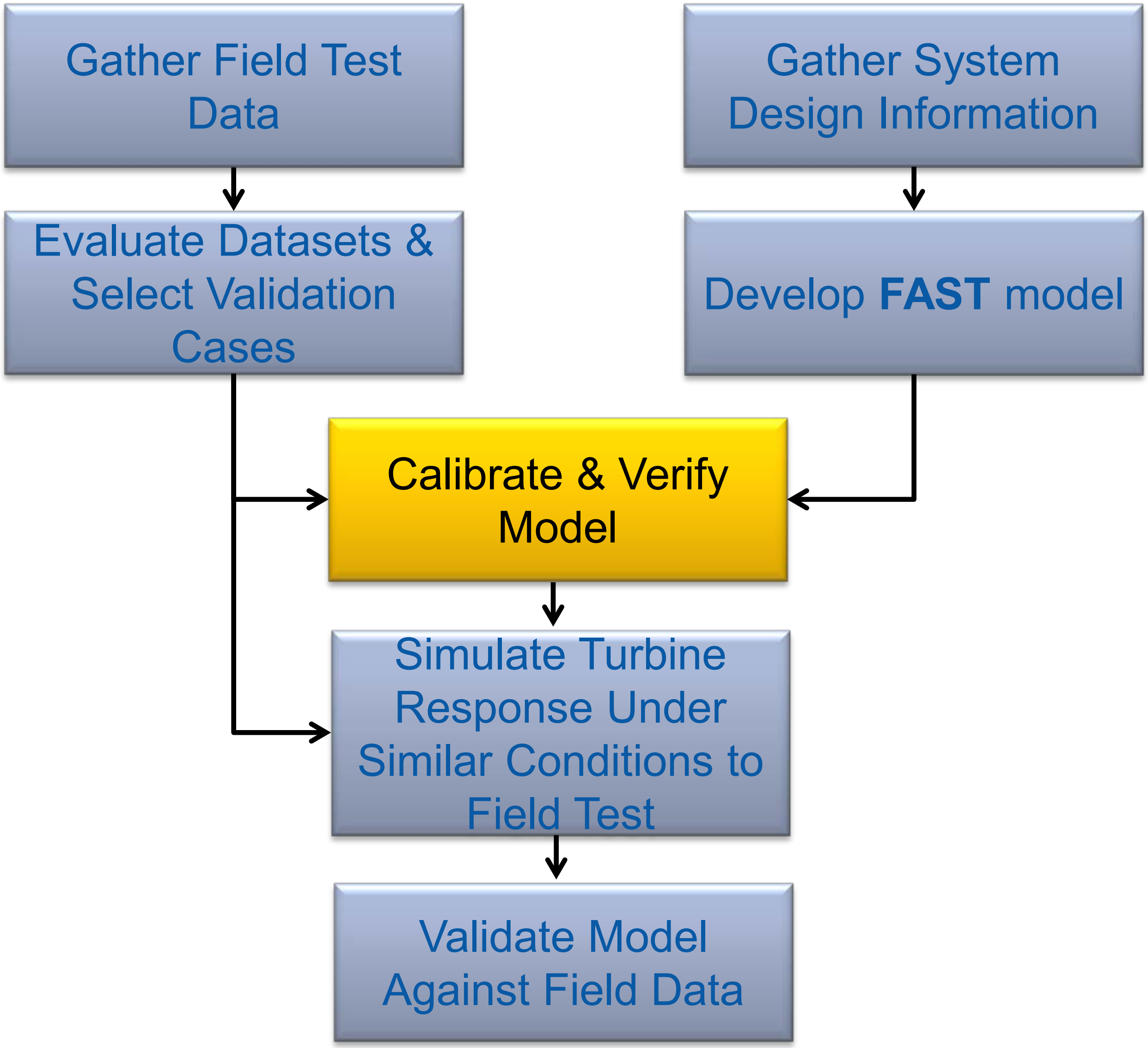
Model Data – Simplifications/Differences

FAST model built by data provided by Siemens & Statoil



- Blades simplified as straight beams
- Moorings simplified as uniform catenaries w/ equivalent mass/stiffness
- Linear yaw stiffness used to approximate restoring of mooring delta
- Approximate offshore controller mimics 2-layer Siemens-Statoil controller deployed in field
- No nacelle-yaw control
- Wind time series accurate @ hub-height; other points in field derived (**TurbSim**)
- Unidirectional wave time series developed from limited wave statistics

Calibration & Verification



Calibration – Methodology

Parameter	Change	Rationale
Blade mass	Scaled to match total mass	Simplified beam model
Tower mass	Scaled to match total mass	Simplified beam model
Mooring mass/length	Scaled to match surge/sway natural frequencies	Simplified mooring model & provided mooring details were approximate
Yaw spring	Selected to match yaw natural frequency	Simplified mooring model & provided mooring details were approximate
Spar vertical CG	Shifted to match pith/roll natural frequencies	CG not provided

Calibration – Results

Masses & Inertias (Normalized)

Parameter	Specified	Simulated
Blade Mass	1	1
Blade CoG	1	1.007
Second Mass Moment	1	0.9954
Tower-top Mass	1	1.0002
Tower Mass	1	0.993

Blade & Tower Frequencies (Normalized, Fixed/Nonspinning)

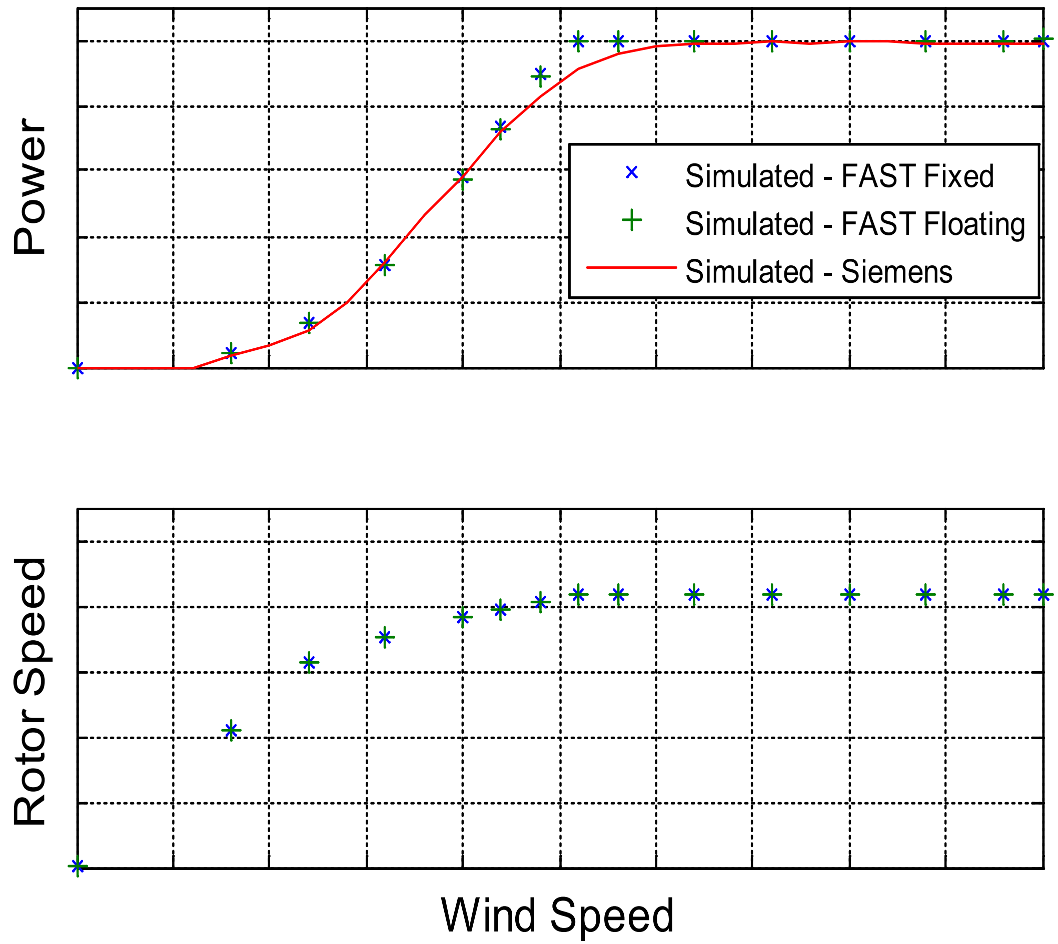
Parameter	Specified	Simulated
Flap Blade Mode 1	1	1.008
Flap Blade Mode 2	1	1.03
Edge Blade Mode 1	1	1.006
Tower Mode 1	1	0.91
Tower Mode 2	1	0.99

Spar Natural Periods (with Nonoperating Turbine)

Parameter	Measured (s)	Simulated (s)
Surge	125.0	120.0
Sway	125.0	119.5
Heave	27.5	27.8
Roll	23.9	25.6
Pitch	23.9	25.1
Yaw	6.2	7.36

Verification – Power Curve & Rotor Speed

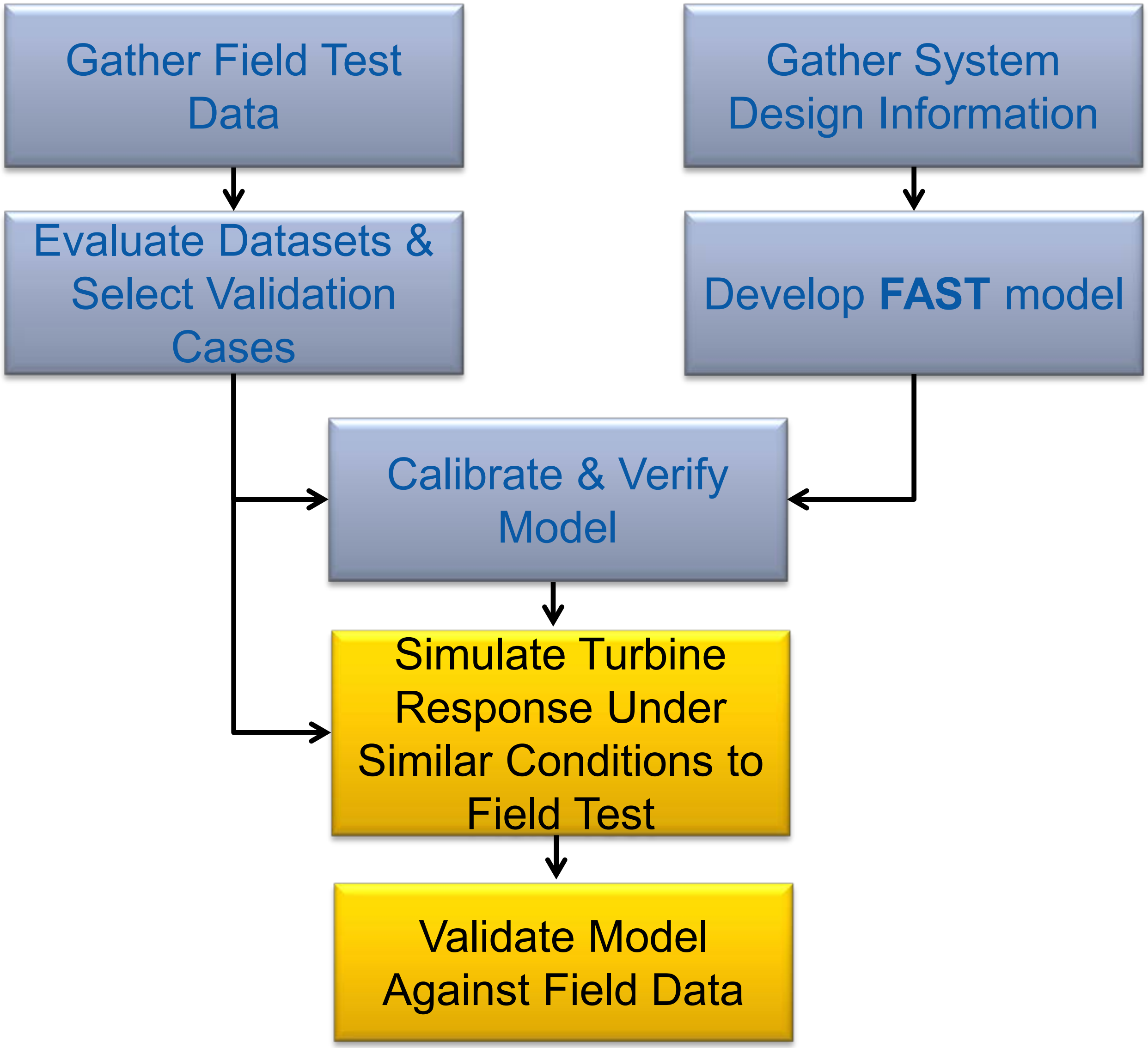
- Excellent agreement between fixed & floating model
- Good agreement between Siemens simulated land-based power curve



*Fixed **FAST** model uses Siemens' land-based controller*

*Floating **FAST** model uses approximate offshore controller*

Validation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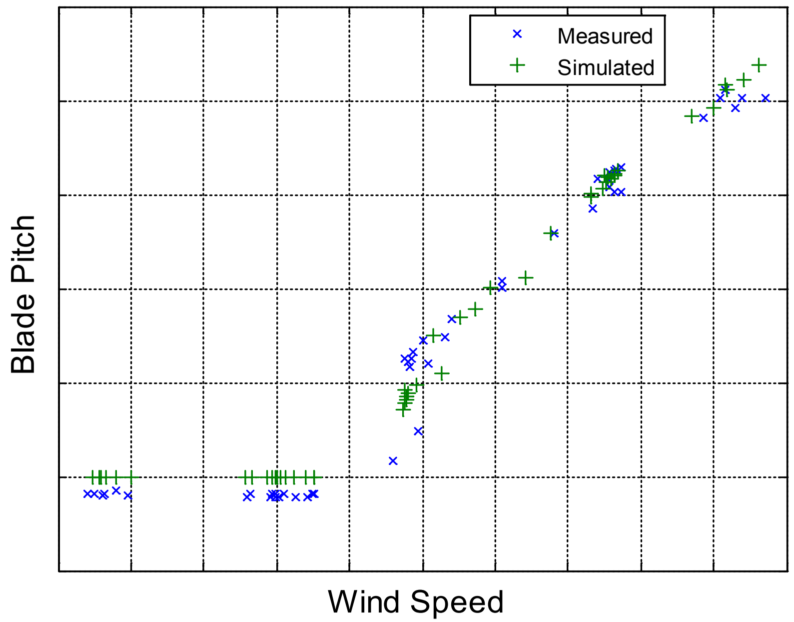
Validation – Control

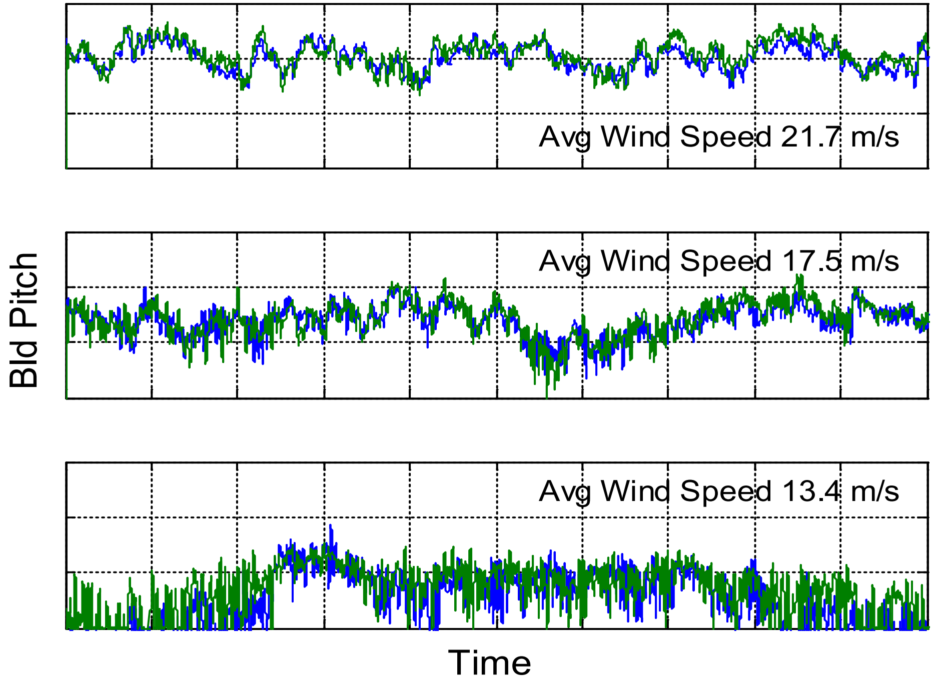
- Excellent agreement between measured & simulated blade pitch:
  - In response to rapid changes to wind speed
  - @ different mean wind speeds
  - Even though wave time series differ

*The use of **TurbSim** to reproduce measured wind time series @ hub height & statistically equivalent wind field allowed comparison of time series*

Being able to do same for waves would be useful

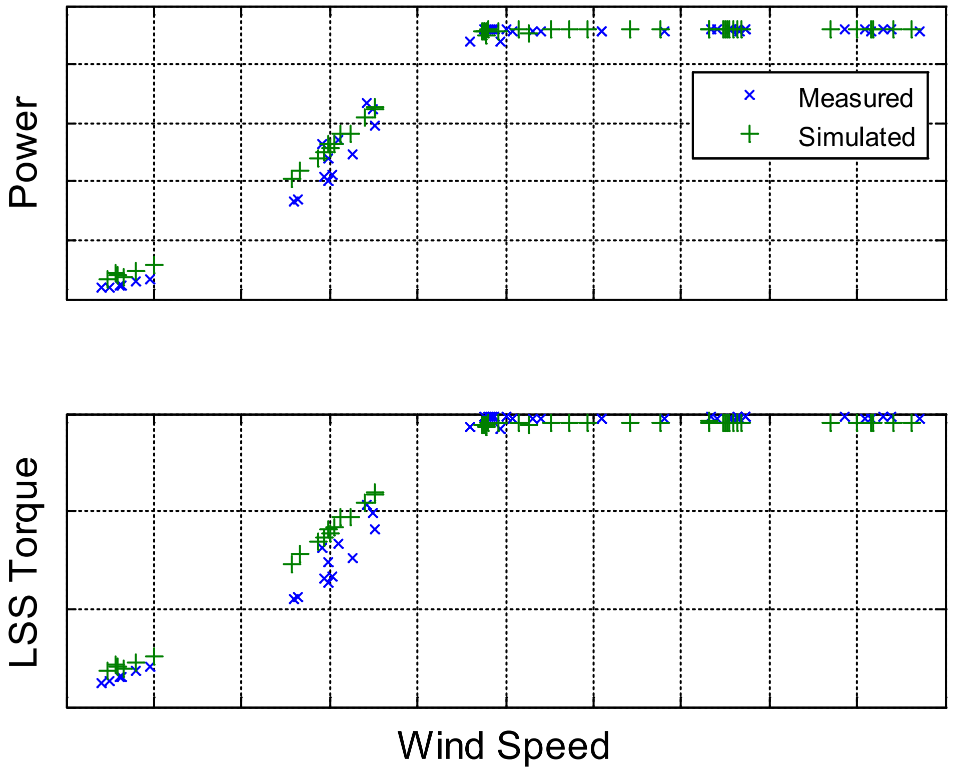


5-Min Averages



Validation – Drivetrain

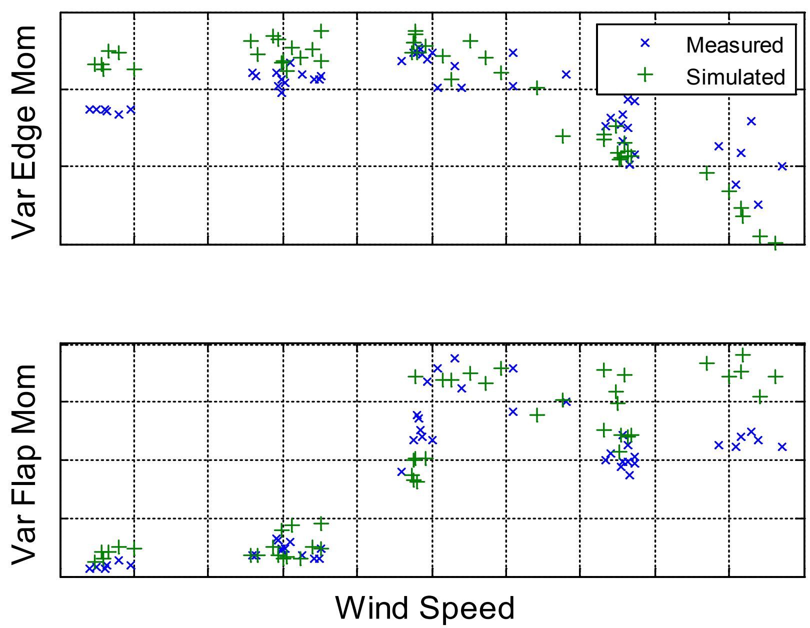
- Excellent agreement in power & torque above rated
- Model slightly over-predicts power & torque below rated, expected because:
  - Simplifications in blade model
  - Use of approximate controller
  - Use of nacelle-based wind measurements

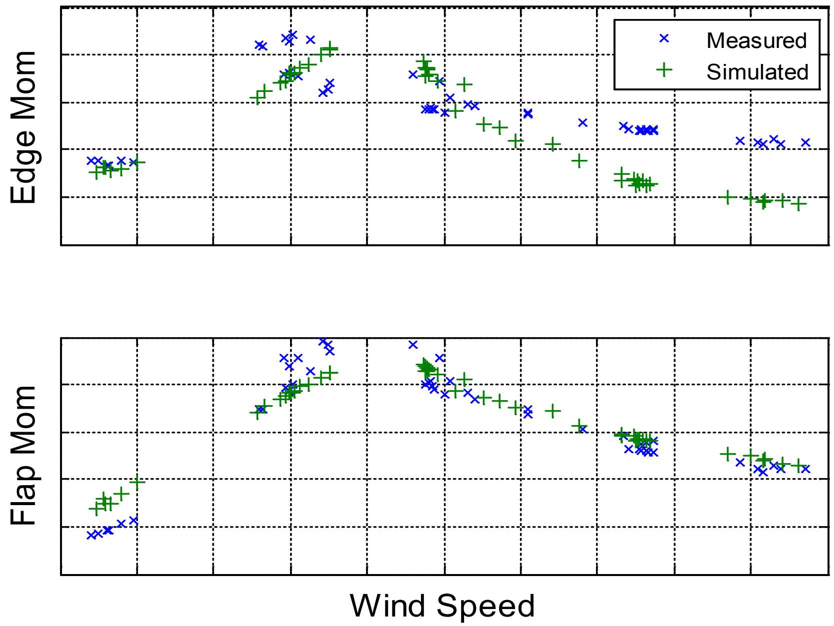


No scale factors were provided to convert measured strain to torque; a scale factor & offset (to remove signal bias) were chosen to fit measured torque with simulated values

Validation – Blade Loads

- Mean flap moments agree well
- Mean edge moments agree up until rated power, but diverge when blade is pitched:
  - Flap moment >> edge moment & difference may be due to slight misalignment of strain gauges from principle edge & flap axes

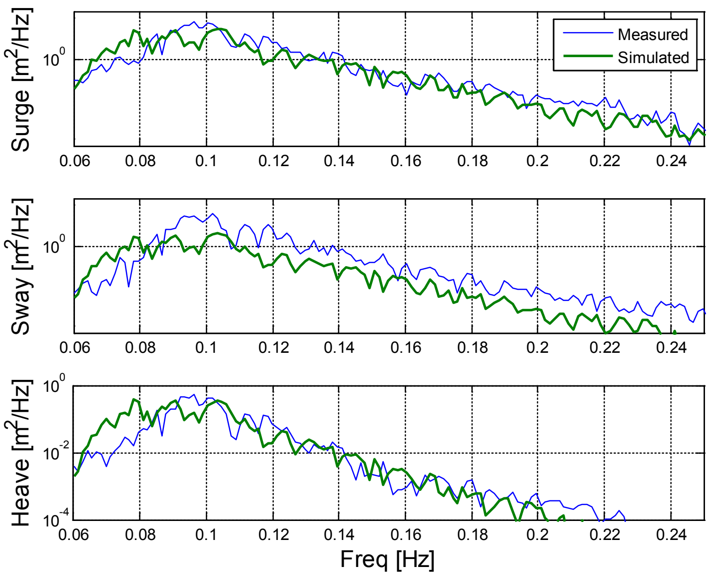


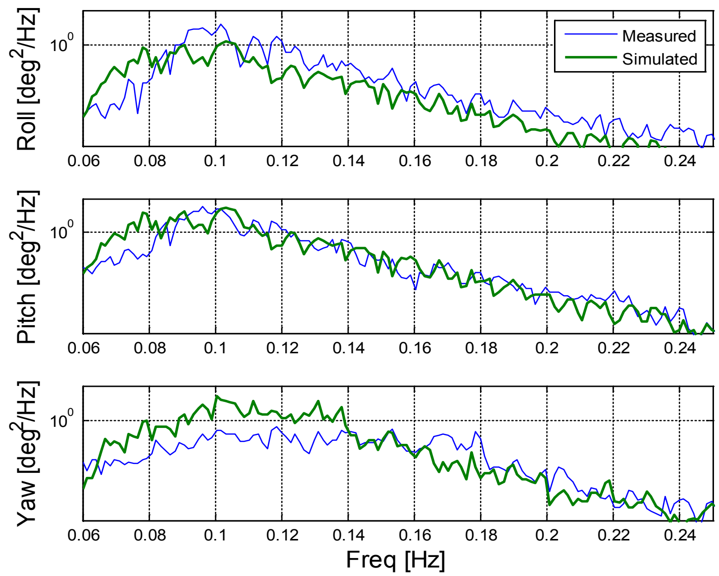


No scaling factors were provided; a scale factor & offset were chosen to fit measured & simulated 5-min average variance & mean

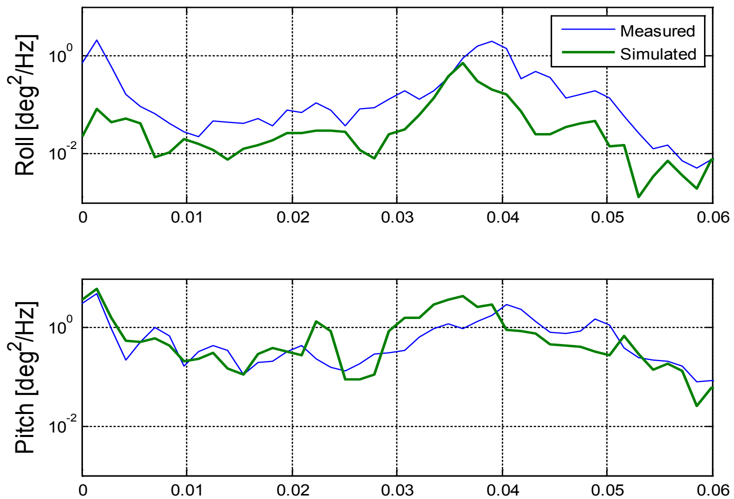
Only a comparison of general response can be made, not a direct comparisons of signal magnitude

Validation – Platform Response @ H_s = 4 m, T_p = 10 s



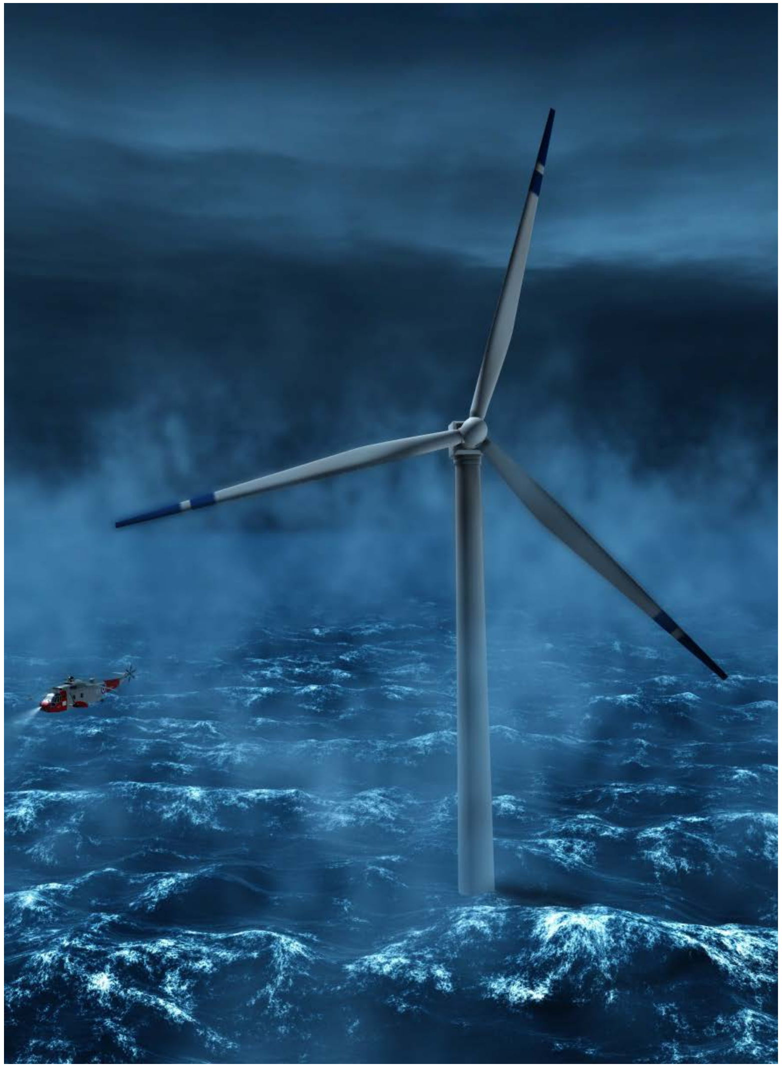


- Good agreement in surge, sway, heave, roll & pitch over all frequencies within wave-band
- More variation outside wave-band & in yaw response, likely caused by:
  - Mooring simplification
  - Spread seas
  - Different wind variation across disk



Conclusions & Outlook

- Good agreement found between measured & simulated responses
- Validation presents solid first step in checking **FAST** accuracy to model coupled FOWT response under realistic open-ocean conditions
- Next steps could involve:
  - Improvement of blade (**BeamDyn**) & mooring models (**MoorDyn**)
  - Measured wave time series
  - Measurement uncertainty quantification & model sensitivity analysis
  - Analysis of additional cases, including parked/idling under extreme conditions



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Carpe Ventum!

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