INFLUENCE OF AERODYNAMIC MODEL FIDELITY ON ROTOR LOADS DURING FLOATING OFFSHORE WIND TURBINE MOTIONS

DENIS MATHA[1,2*], LEVIN KLEIN[3], DIMITRIOS BEKIROPOULOS[3], PO WEN CHENG[2]

[1]RAMBOLL WIND, GERMANY * (PREVIOUSLY WITH [2])
[2]STUTTGART WIND ENERGY, UNIVERSITY OF STUTTGART, GERMANY
[3]INSTITUTE OF AERODYNAMICS AND GAS DYNAMICS, UNIVERSITÄT STUTTGART, GERMANY

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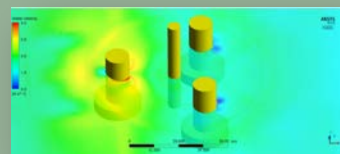
INTRODUCTION

INTRODUCTION

Accuracy / Cost

Typical Application:

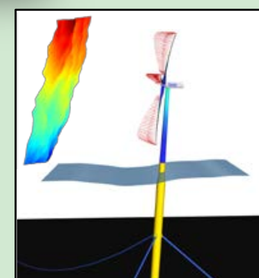
full CFD-FEM FSI methods



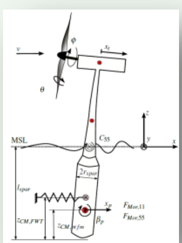
Component level / Detailed Design, validation

Navier-Stokes equations,
Continuum mechanics

State-of-the-art
Aero-servo-hydro-elastic
coupled analysis



Design validation, optimization & certification



Potential flow theory,
Newtonian/analytical mechanics

Reduced nonlinear
coupled models

Pre-design & Optimization

coupled / de-coupled

Semi-empirical methods (Morison)

Frequency domain
methods

Efficiency / Speed

INTRODUCTION

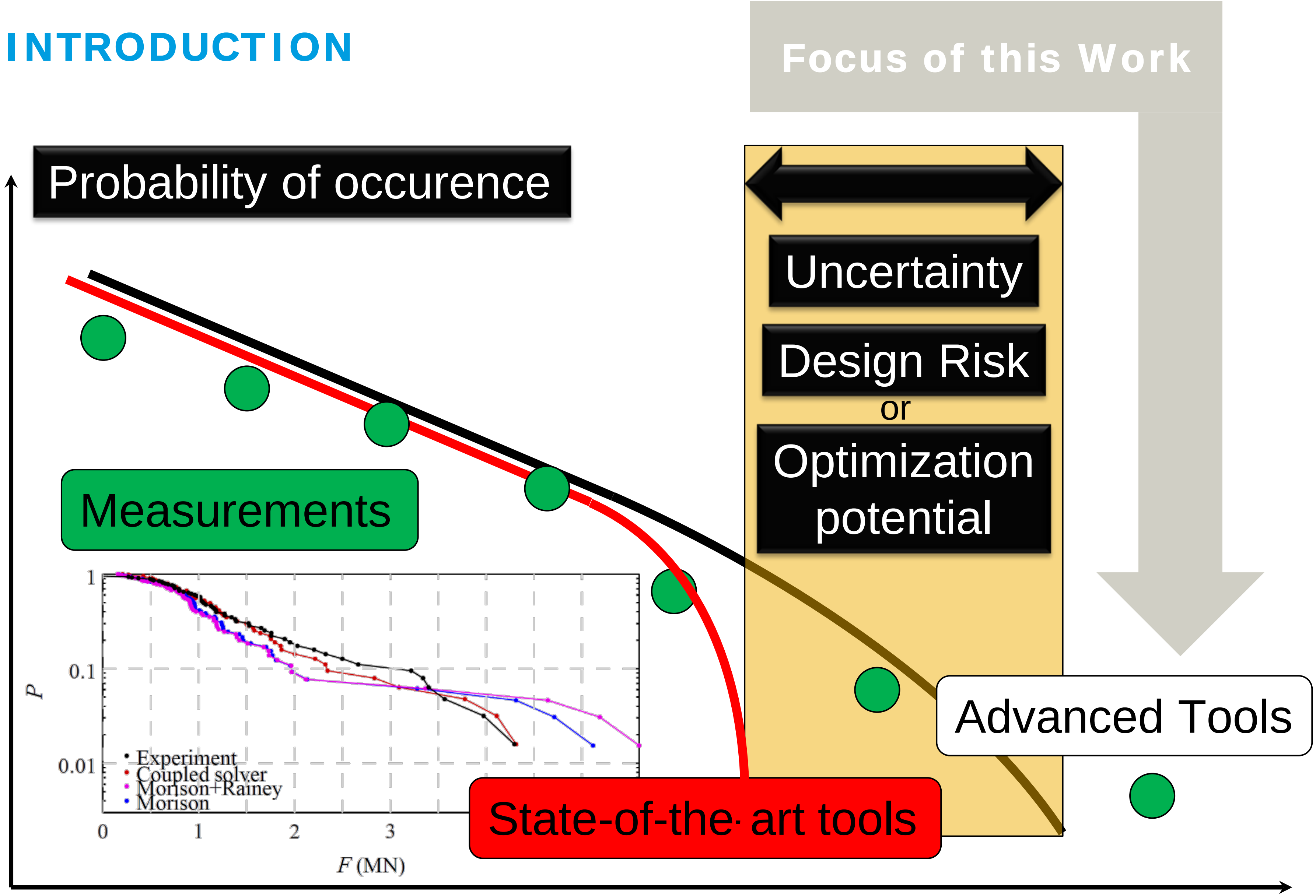


Fig. D. Matha, University of Stuttgart, SWE; idea adapted from H. Bredmose, DTU

Signe Schløer, Bo Terp Paulsen, Henrik Bredmose, OMAE2014-24684, „APPLICATION OF CFD BASED WAVE LOADS IN AEROELASTIC CALCULATIONS”

INTRODUCTION

FOWT modelling research primarily focuses on hydrodynamics and mooring line dynamics

Leading Question for this Study

- **What is the impact of Aerodynamic Model Fidelity on Rotor Loads during Floating Offshore Wind Turbine Motions?**

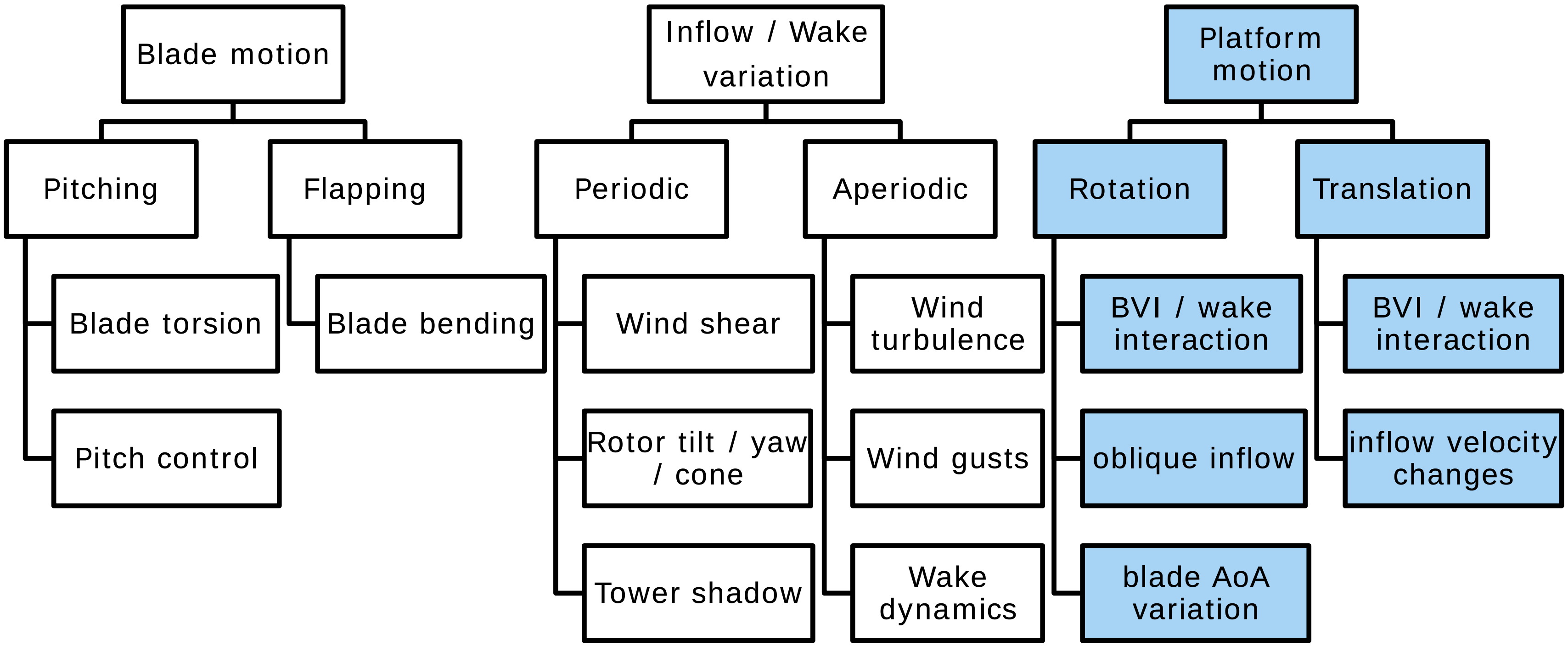
Presented work is related to

- OFFWINDTECH Project within EU KIC Framework and associated PhD projects in Stuttgart
- Similar questions related to model fidelity are also investigated in ongoing EU project, e.g. LIFES50+
- (no results from LIFES50+ are presented)

RAMBOLL Presented results were generated primarily at Stuttgart Wind Energy

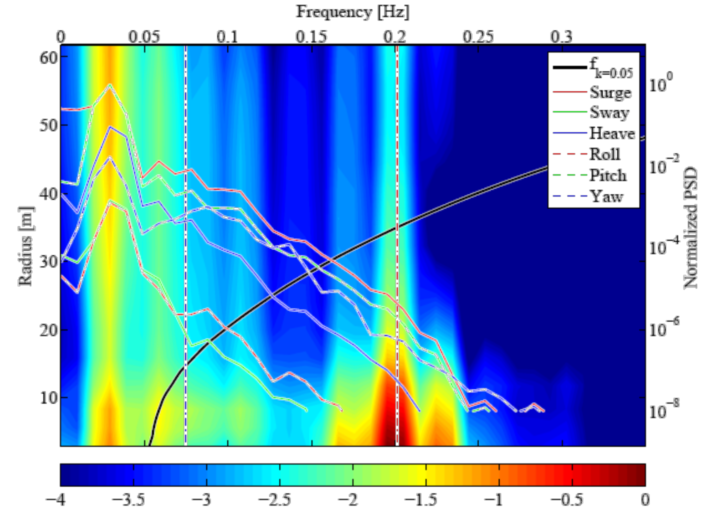
INTRODUCTION

Aerodynamic effects on a floating offshore wind turbine



INTRODUCTION

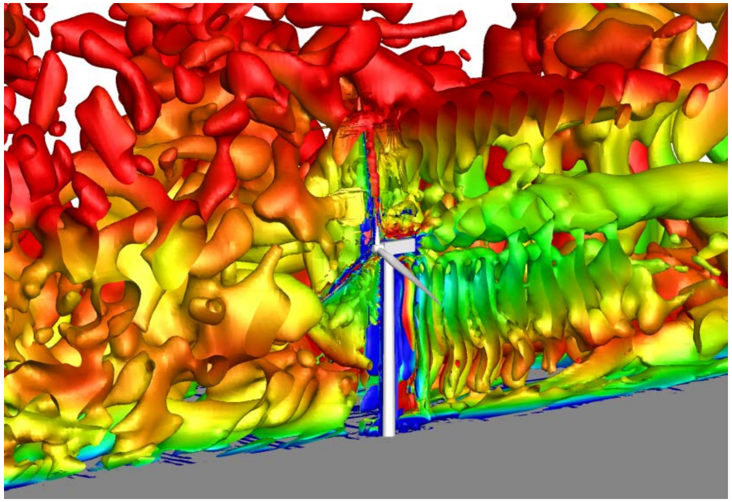
- Complex 3d viscous & rotational effects
- Complex rotor interaction with
  - tower & nacelle
  - turbulent atmospheric boundary layer
  - (half) wake
  - Structure
- Wave & wind induced platform motion
- unsteady aerodynamic effects



OC3 Hywind @ rated wind speed
Contour: normalized α PSD over radius
Curves: PSD of platform motions

Percentage of **aerodynamically unsteady (k > 0.05)** to total energy from α PSDs:

	Monopile	OC3Spar
Below Rated	0.3 %	18.0 %
Rated	1.7 %	17.9 %
Above Rated	0.1 %	17.9 %



*Thomas Sebastian, “THE AERODYNAMICS AND NEAR WAKE OF AN OFFSHORE FLOATING HORIZONTAL AXIS WIND TURBINE”, UMASS Dissertation, 2012

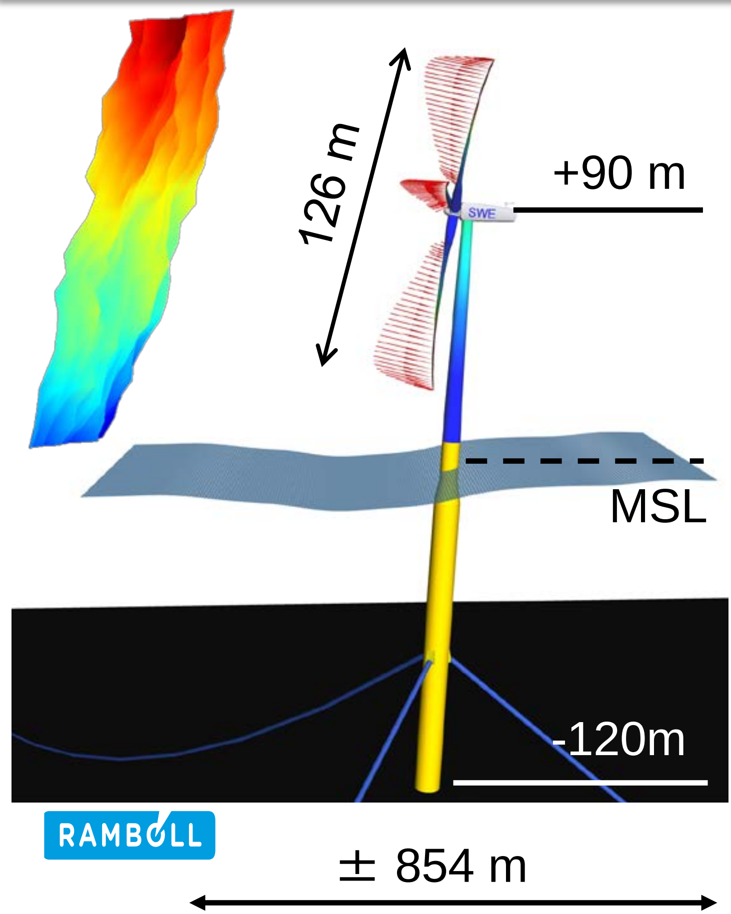
APPROACH

APPROACH
REFERENCE MODEL

Platform & Tower:

OC3 Hywind Spar Buoy

Turbine: **modified** 5MW **NREL WT**



Modification of Blades & Controller:

- Recalculated airfoil tables
  - XFOIL (panel & BL code) generated to ensure comparability with new airfoils
  - Applied Viterna extrapolation, Snel 3D corrections & DS parameters for use in BEM
- Changed aerodynamic & structural twist angle
  - Goal: At rated wind speed, a lift coefficient close to todays high performance blade designs

    $c_L > 1.1$ (from $c_L > 0.95$)
- Changed generator torque controller constant
  - Adjusted for blade modifications

APPROACH
AERODYNAMIC MODELS

BEM: Blade Element Momentum Theory

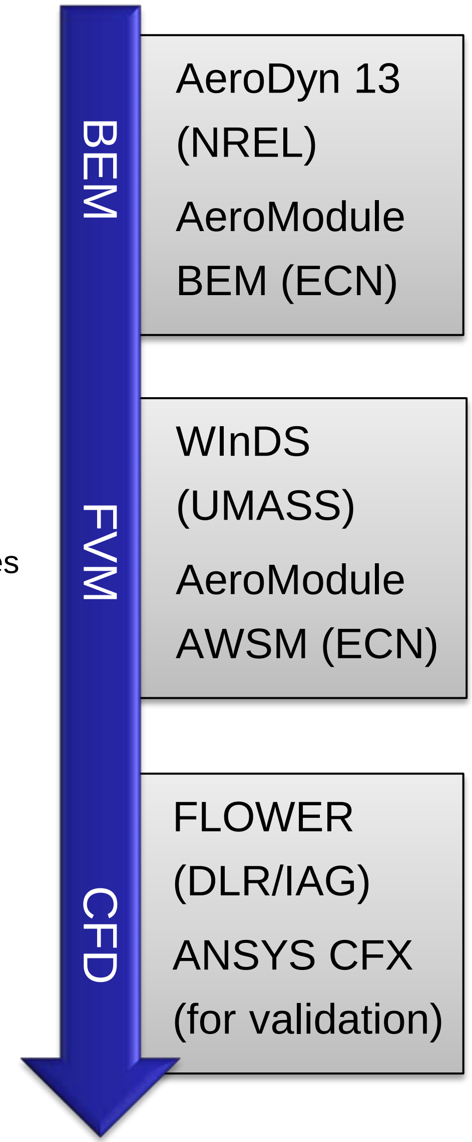
- State-of-the-art in aero-servo-hydro-elastic FOWT load simulation
- Basic idea: Balance of forces in axial (and tangential) directions from global momentum balance with Forces at the local blade element
- Encompasses various assumptions & semi-empirical correction models

LLFVWM: Lifting Line Free Wake Vortex Method (Potential Flow)

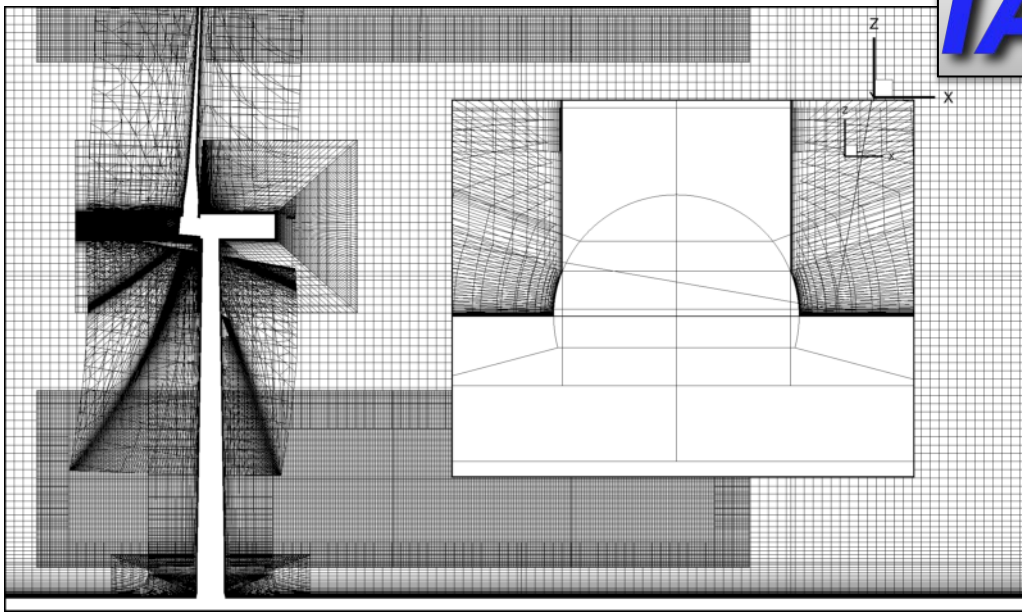
- vorticity in the volume is lumped into vortex lines
  - Blade: Lifting Line (airfoil tables req.)
  - Wake: Free surface of shed vortices
- dynamic wake effects and local blade aerodynamics are inherently represented

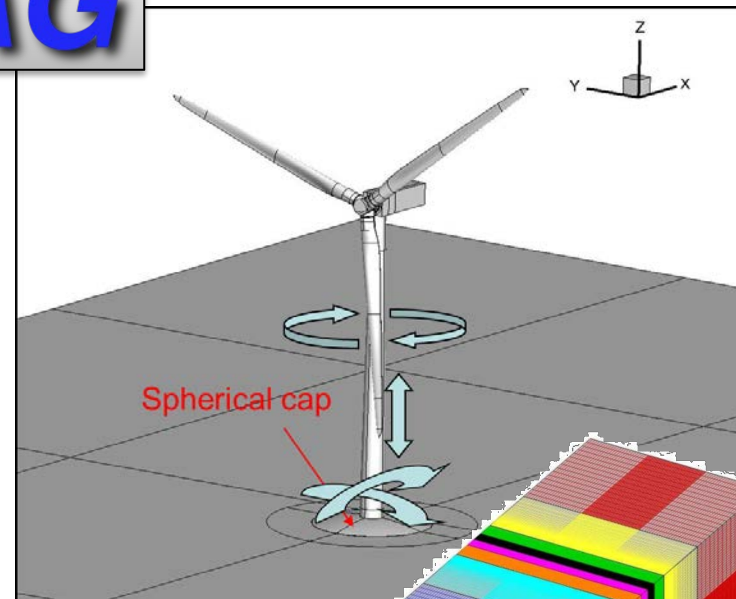
CFD: (U)RANS (Unsteady Reynolds-Averaged Navier-Stokes)

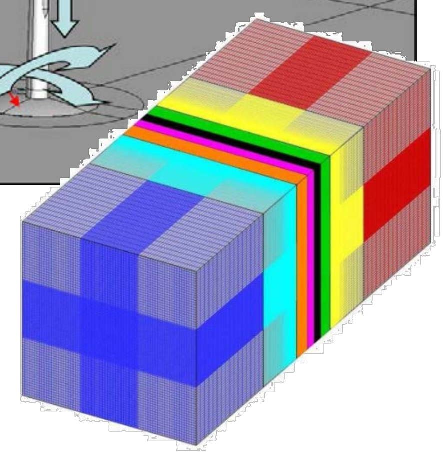
- State of the art for complex turbulent flow simulations (not yet in wind)
- Turbulence models are applied to solve the NSE

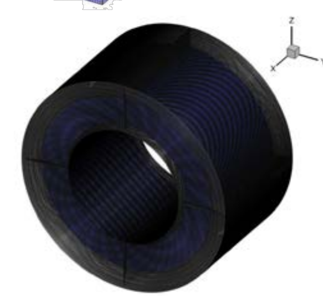


APPROACH
CFD MODEL









- Extended Block-structured Code FLOWER (DLR)
- 14 components
- CHIMERA overlapping mesh technique

- Background mesh
  - 400m x 400 m x 520 m
  - Δxyz ≈ 2 m
- Approx. 30 million cells
- 0.014s time-step size (≡1°)
- k-ω turbulence model

APPROACH
AERODYNAMIC ANALYSIS

1. Model Setup in 5 different aerodynamic codes, covering 3 methodologies using SIMPACK as structural WT model

2. Verification of baseline onshore loads

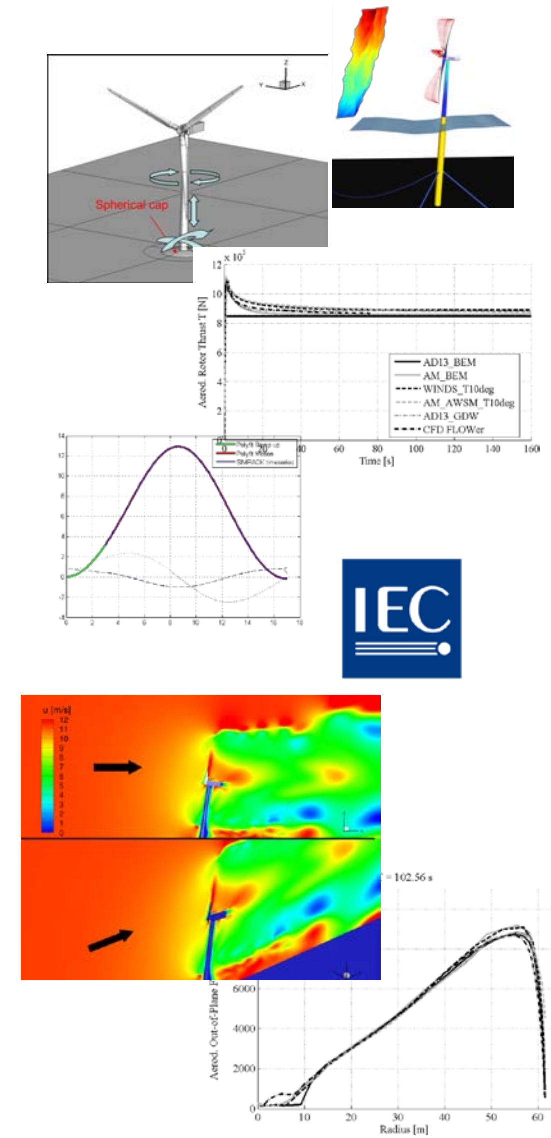
3. Selection of Floating Cases

   a) Extreme motions for CFD analyses for limited conditions

   b) IEC operating DLCs for inflow condition analysis

4. Performing load cases a) & b)

5. Analyzing extreme loads & inflow conditions



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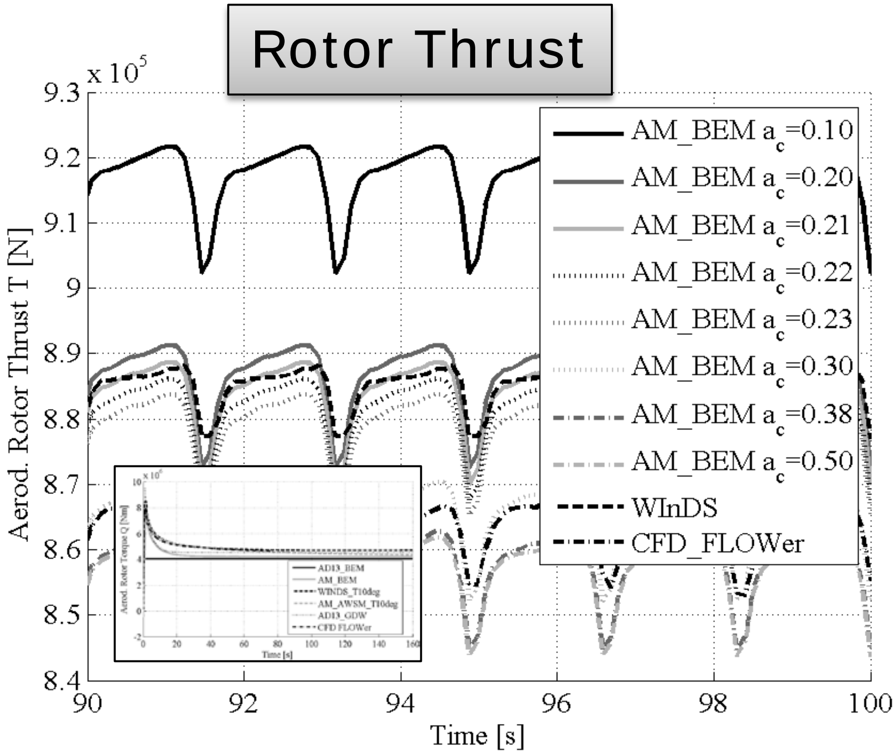
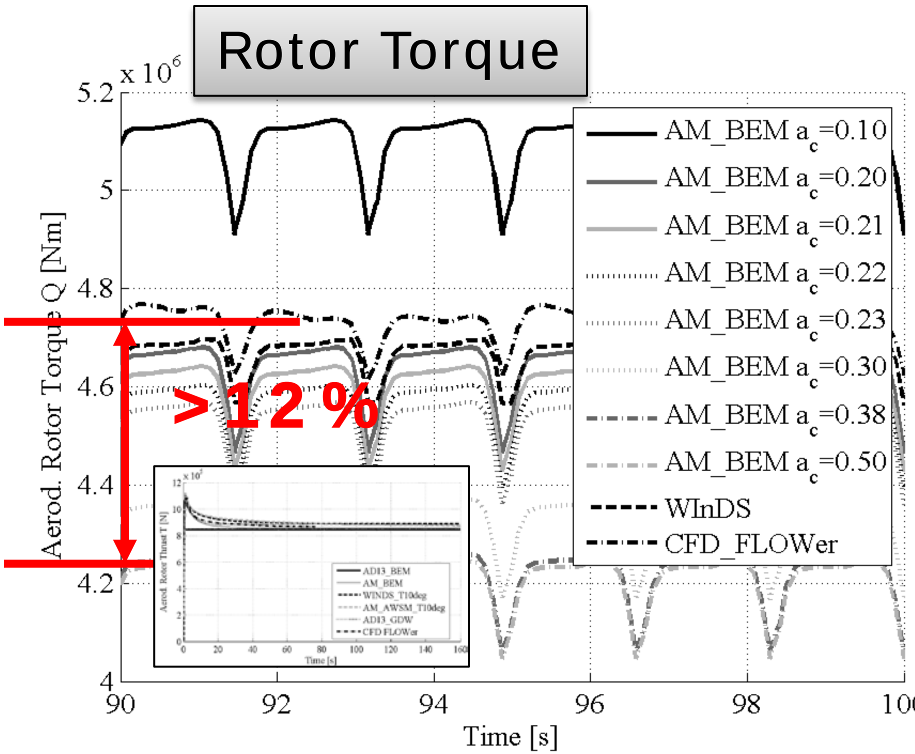
RESULTS

RESULTS
VERIFICATION OF ONSHORE LOADS





- Parametric correction model study performed to identify causes for large >12% torque deviations
- Significant influence from turbulent wake state (Glauert) correction observed due to high rotor induction level

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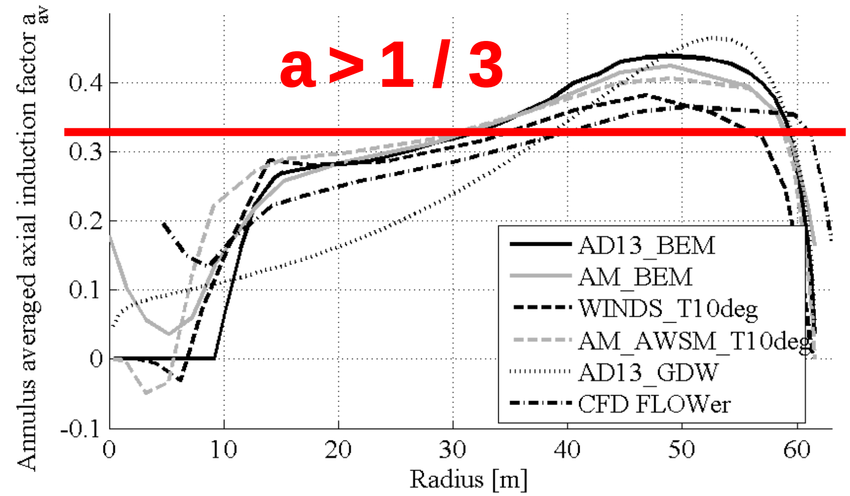
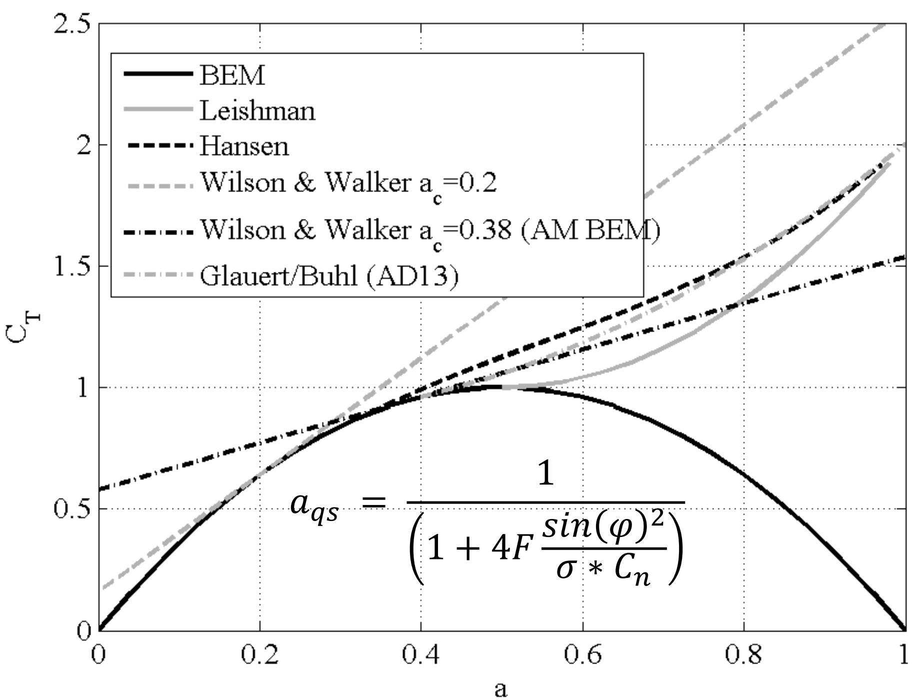
$$a_c = 0.2$$

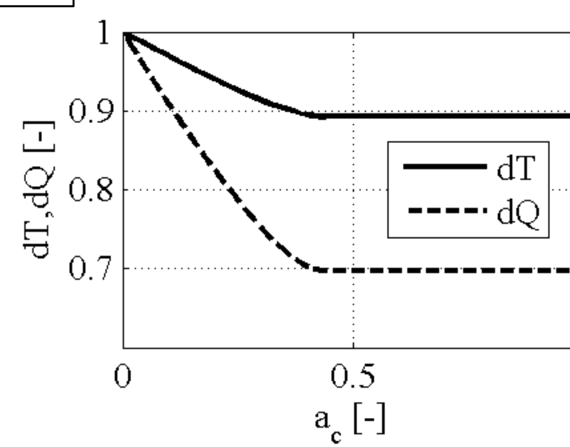
RESULTS
TURBULENT WAKE STATE CORRECTION

- Turbulent wake state correction is an empirical modification for high induction factors, where the momentum equation breaks down and predicts multiple flow directions in the wake



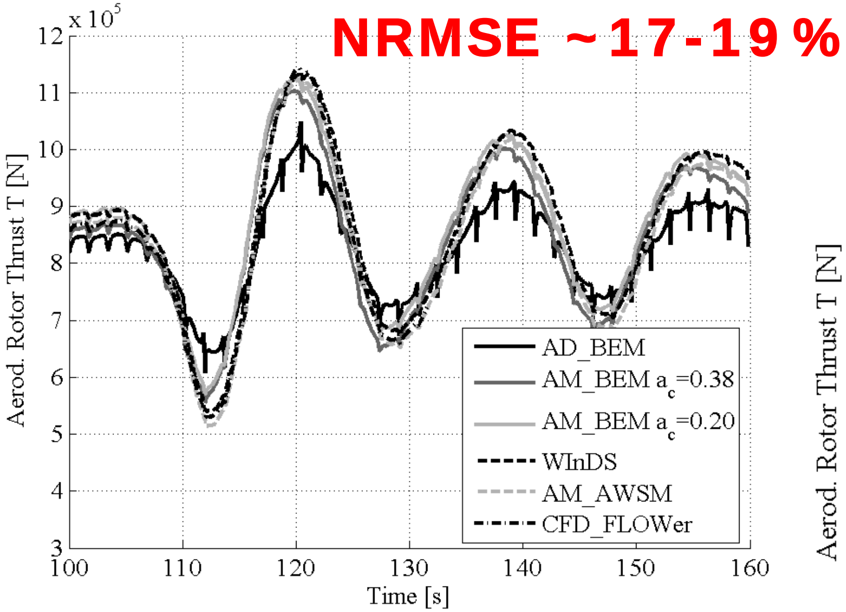
$$a = \frac{4a_c^2F - CT}{(8a_c - 4)F}$$

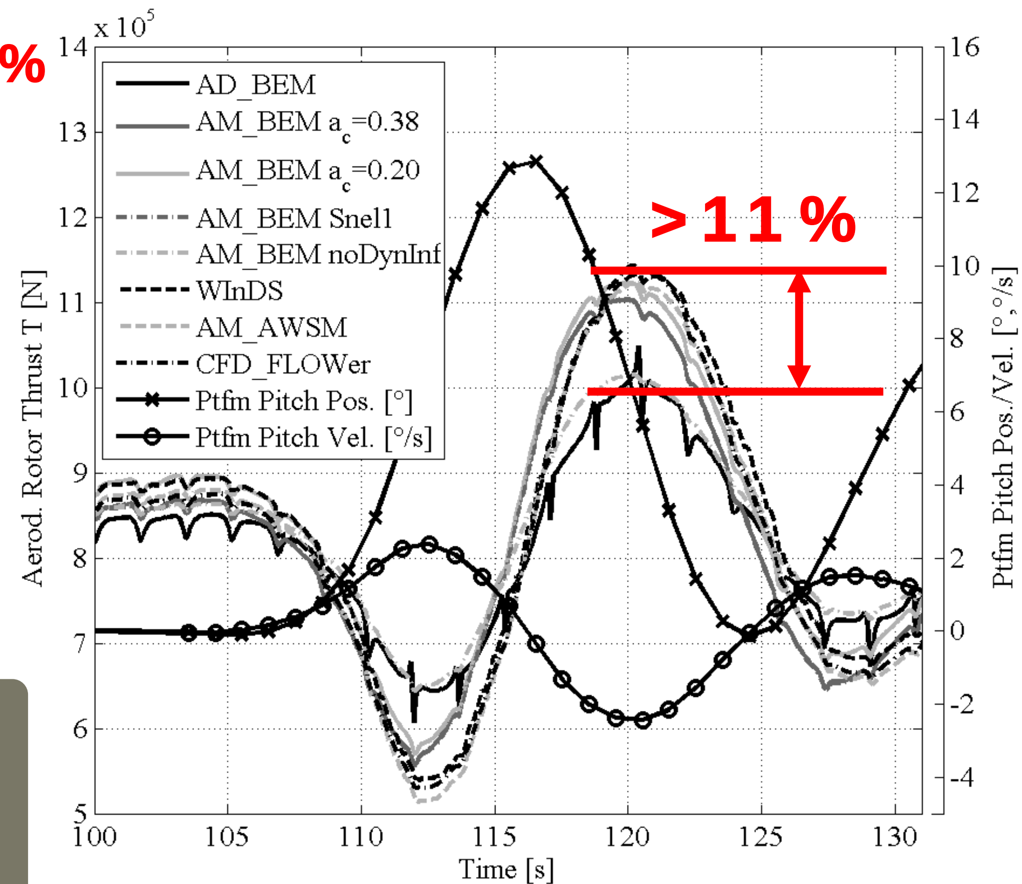




RESULTS

EXTREME MOTION ANALYSIS - THRUST





Dynamic Inflow identified as largest influence on thrust and torque differences of BEM and FVM/CFD loads
***additional pos. timeshifts**

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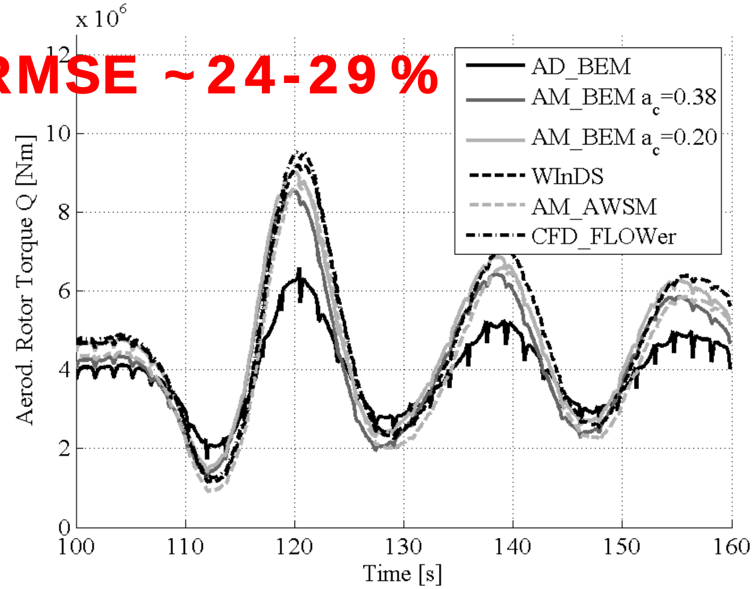
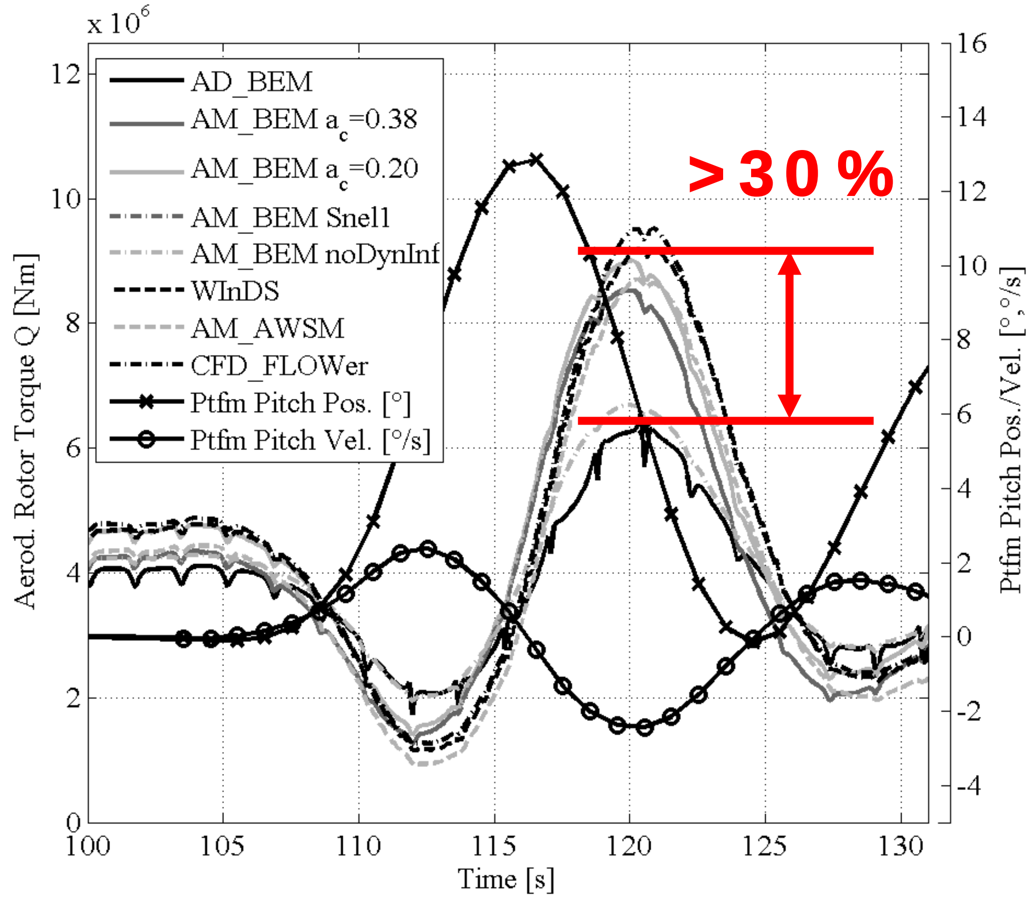
RESULTS
EXTREME MOTION ANALYSIS - TORQUE

NRMSE ~24-29%





	$NRMSE(T)$	$NRMSE(Q)$
BEM no DynIn	17-19%	24-29 %
AM BEM w. DynIn $a_c = 0.20 - 0.38$	~7%	6-10 %
FVM	1-3%	2-6 %

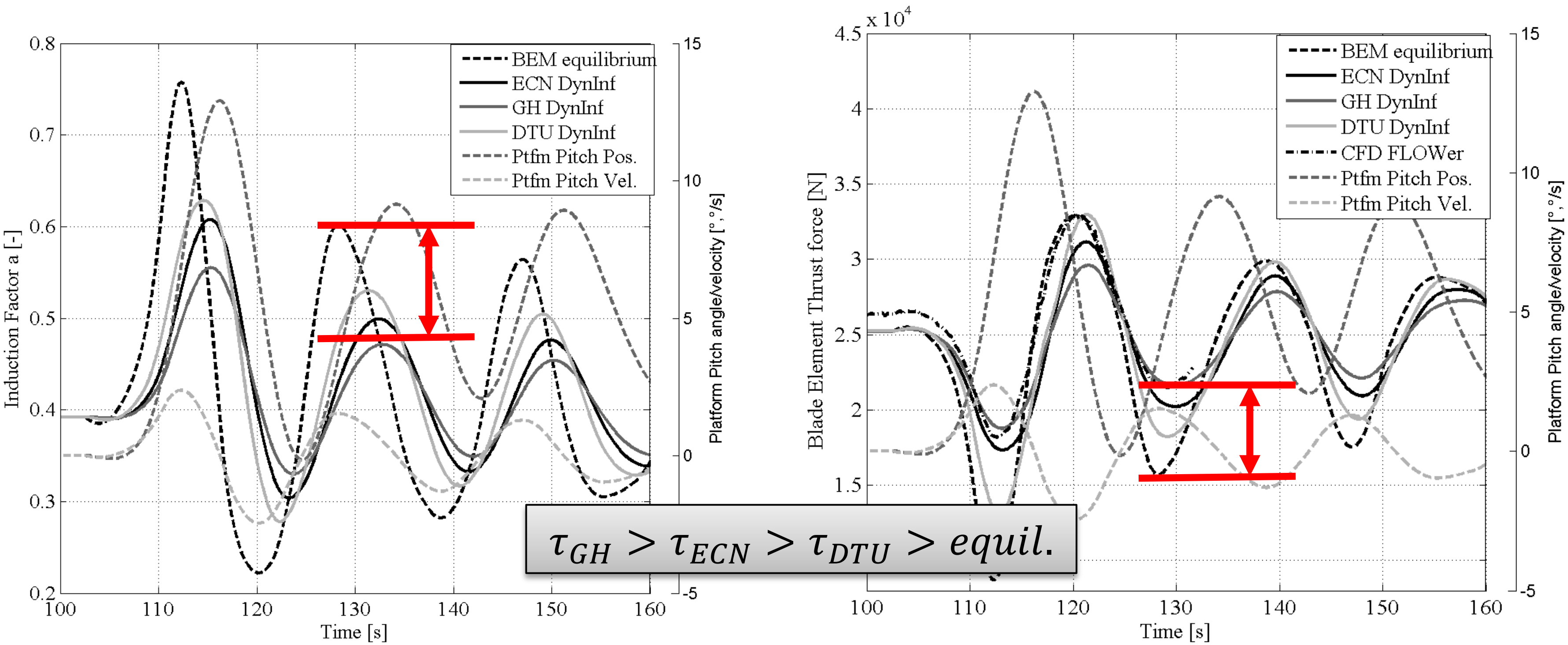
RESULTS

EXTREME MOTION ANALYSIS – DYNAMIC INFLOW

- Simple model confirms influence of Dynamic Inflow during motions
- Sensitivity to model and time constants
- Particular relevance at specific wave periods

$$L \cdot C_T = \tau \cdot \dot{a} + a$$

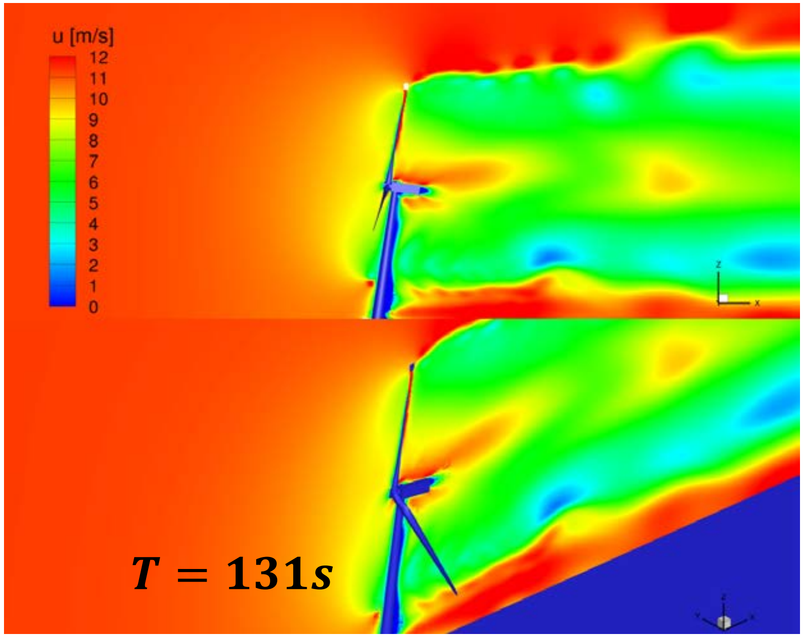
$$T_{DynInf} = \frac{D}{V_\infty} = \frac{126m}{11.3m/s} = 11.15s$$

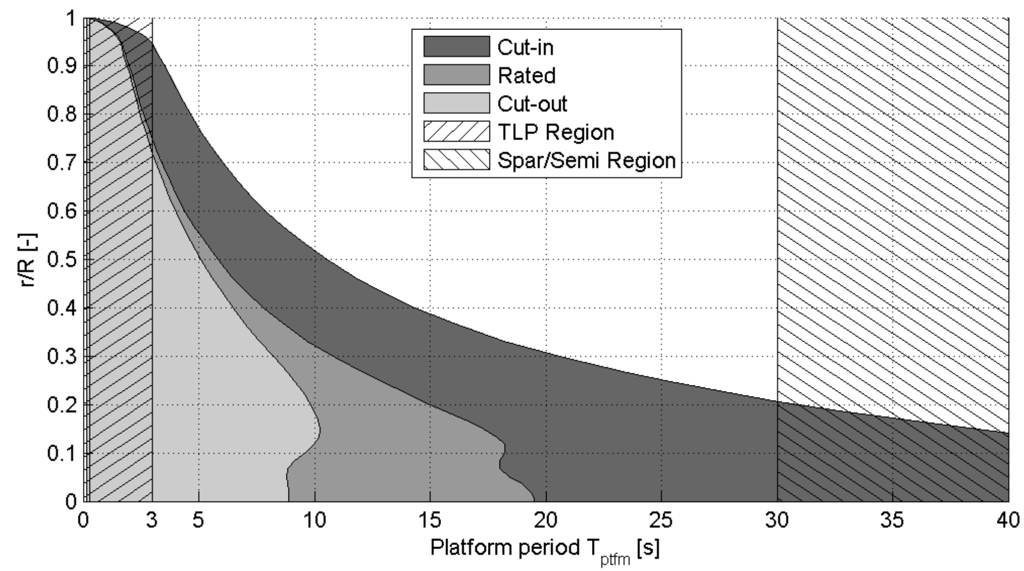


$$\tau_{GH} > \tau_{ECN} > \tau_{DTU} > equil.$$

RESULTS
FLOW FIELD ANALYSIS

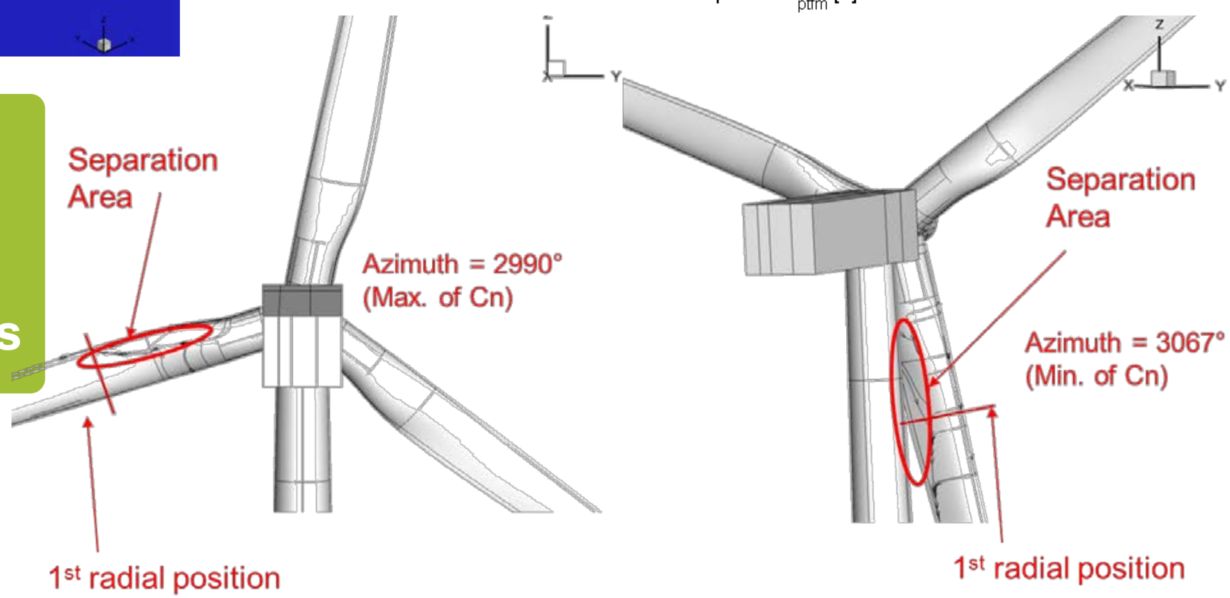
$$k_i = \frac{\omega c}{2|\vec{V}|} = \frac{\omega_{ptfm} c_i}{2\sqrt{U_\infty^2 + (r_i \Omega)^2}}.$$





FVM: Sensitive to vortex core models

CFD: Sensitive to y^+ and turbulence models



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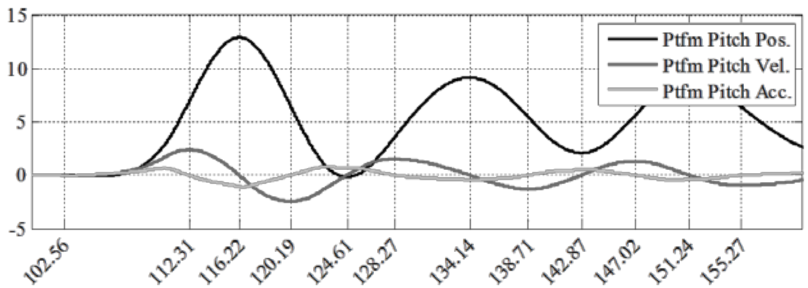
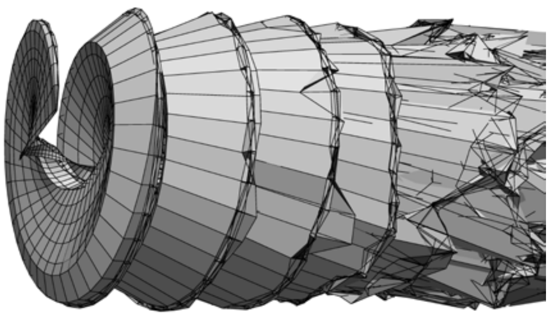
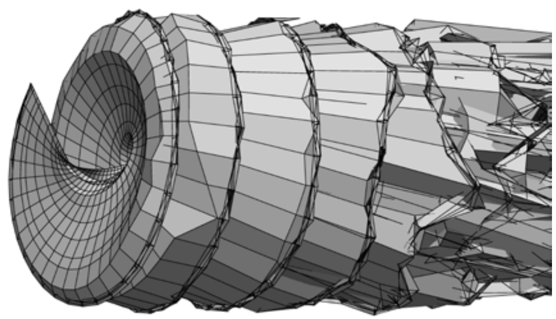
RESULTS
FLOW FIELD ANALYSIS

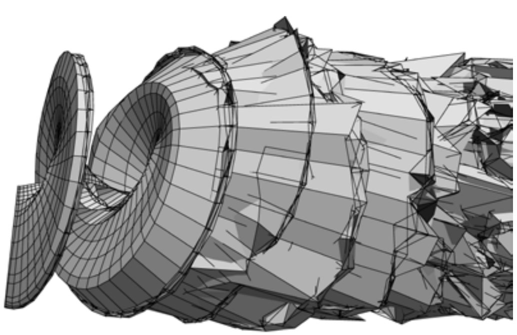




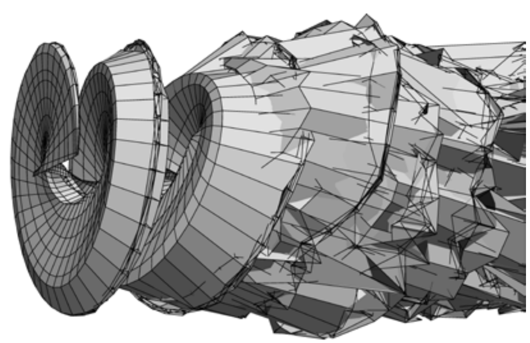
T=102.56s



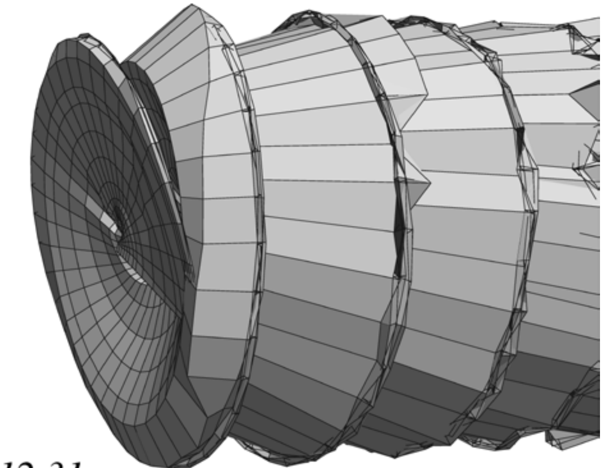
T=116.22s



T=124.61s

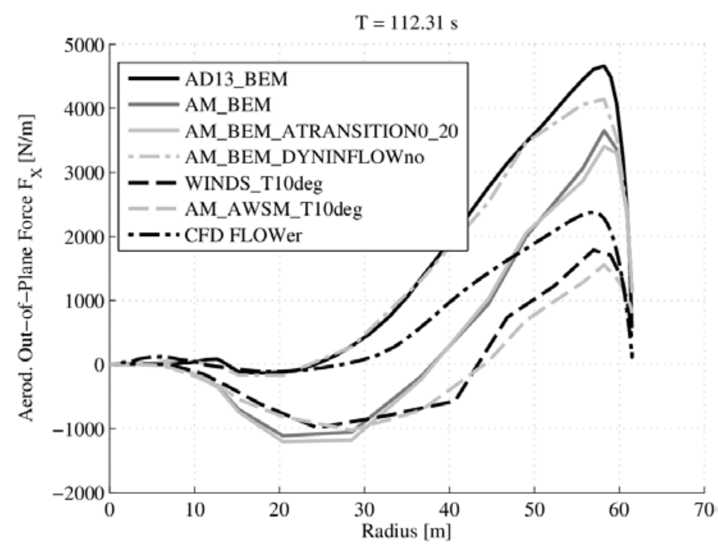


T=128.27s

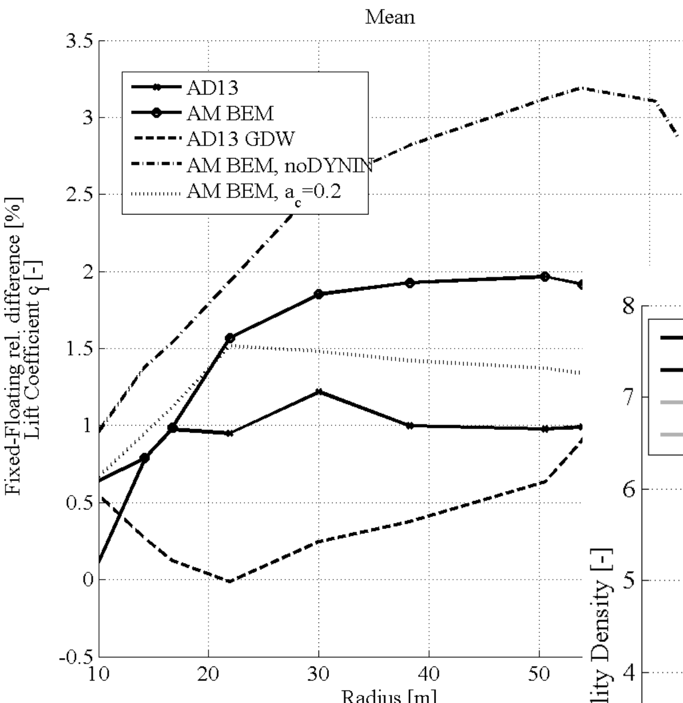


T=112.31s

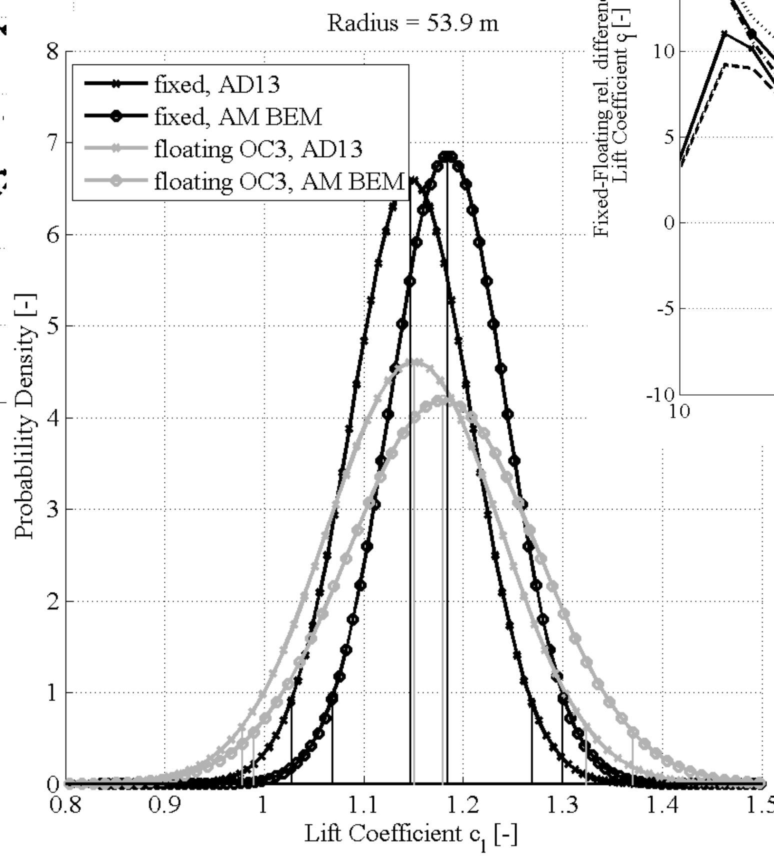
Unsteady effects
Local blade load distrib. differences:

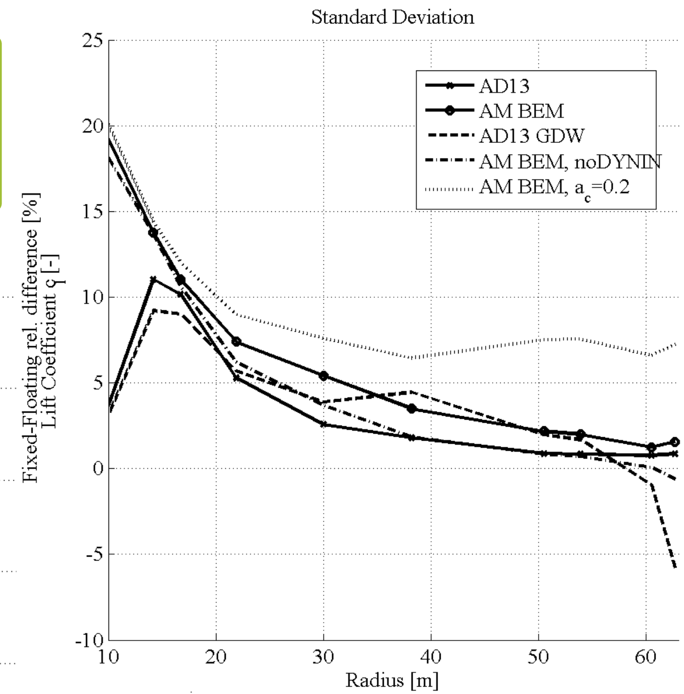


RESULTS
INFLOW CONDITIONS



IEC DLC 1.1 @ rated wind





Minor impact on design point: $c_{l,ref}, Ma_{ref}, Re_{ref}$

Larger airfoil design range: $\Delta c_l, \Delta Ma, \Delta Re$

CONCLUSION

CONCLUSION

- Study on aerodynamic model fidelity influence on FOWTs
- Models setup for BEM, FVM and CFD methods

Dynamic Inflow
with important influence on thrust and torque loads and timeshifts for FOWTs

TWS correction
is important for rotors operating at high induction levels, as likely for FOWTs

Other unsteady effects
Local blade loads influenced by flow separation & BVI

Inflow conditions
Design point not-influenced
Design range increased

- Use Dynamic Inflow models with appropriate time const.
- Critical assessment of local blade loads

CONCLUSION

Upcoming IEC 61400-3-2

"IEC 61400-3-1 clause 7.3.3 is generally applicable. The aerodynamic interaction between the airflow and the FOWT is of special importance due to their additional compliance and increased dynamic response. The interaction of potentially large translational and rotational motions of the floating sub-structure with the aerodynamic loading of the RNA and tower shall be considered, including aeroelastic effects and the ***associated global and local dynamic and unsteady aerodynamic effects (e.g. dynamic inflow, oblique inflow, skewed wake, unsteady airfoil aerodynamics including dynamic stall, blade-vortex interaction).*** *Wind loads on the floating sub-structure shall also be considered, where relevant."*

THANK YOU