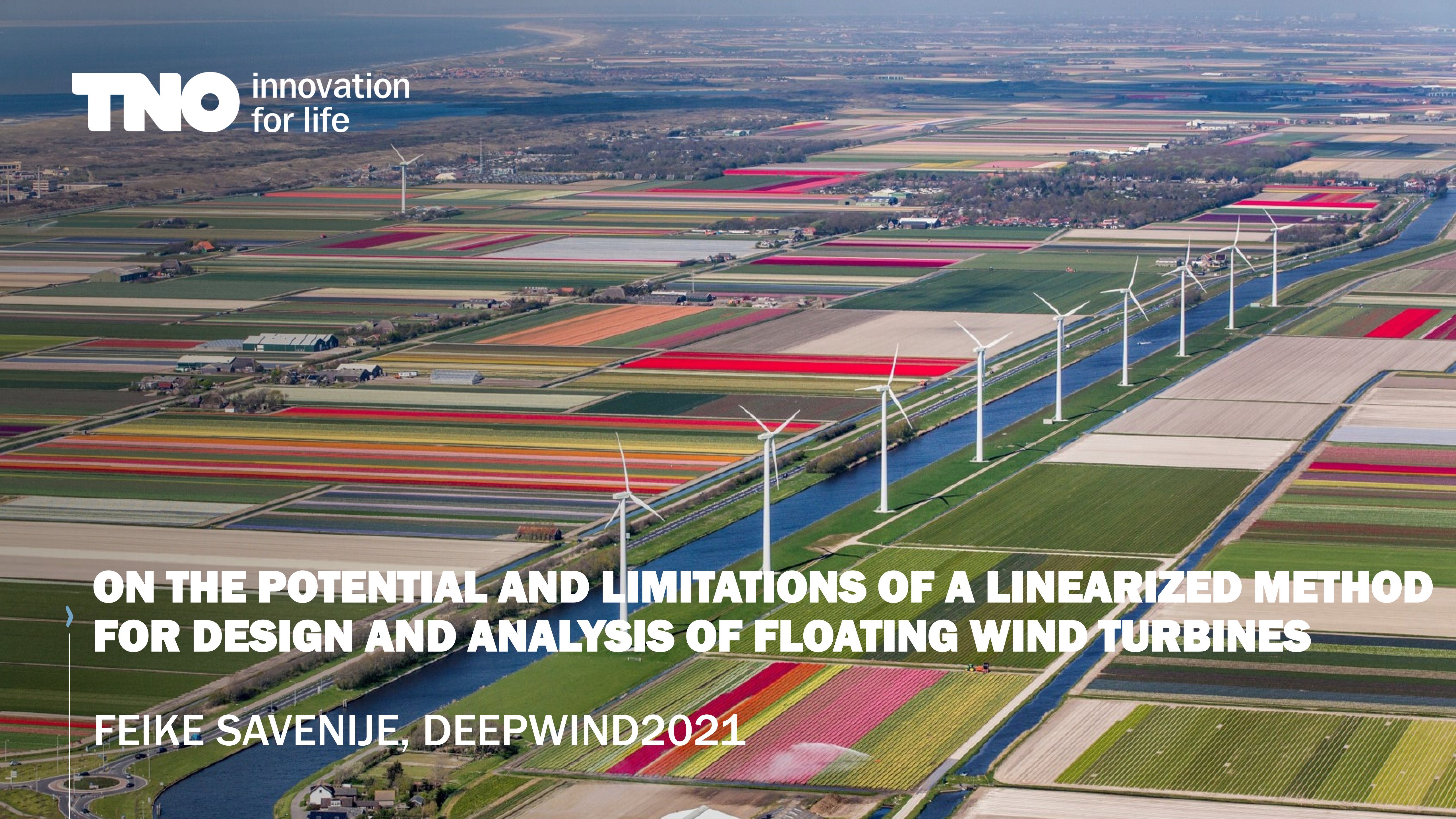

TNO innovation for life

ON THE POTENTIAL AND LIMITATIONS OF A LINEARIZED METHOD FOR DESIGN AND ANALYSIS OF FLOATING WIND TURBINES

FEIKE SAVENIJE, DEEPWIND2021


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CONTENTS

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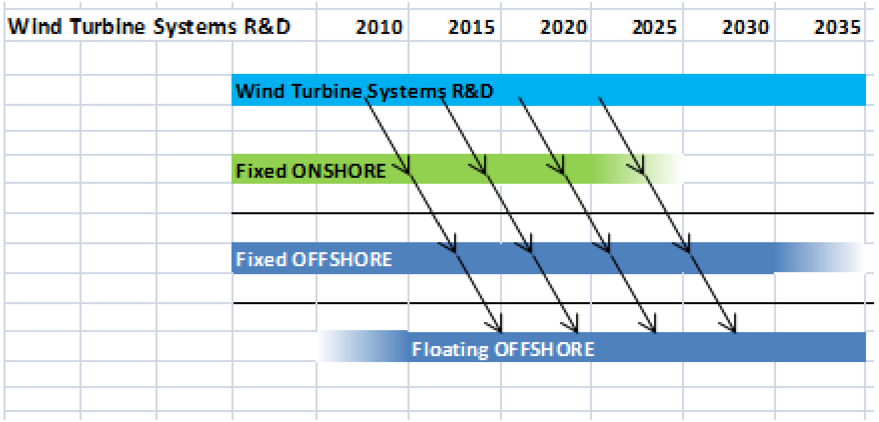
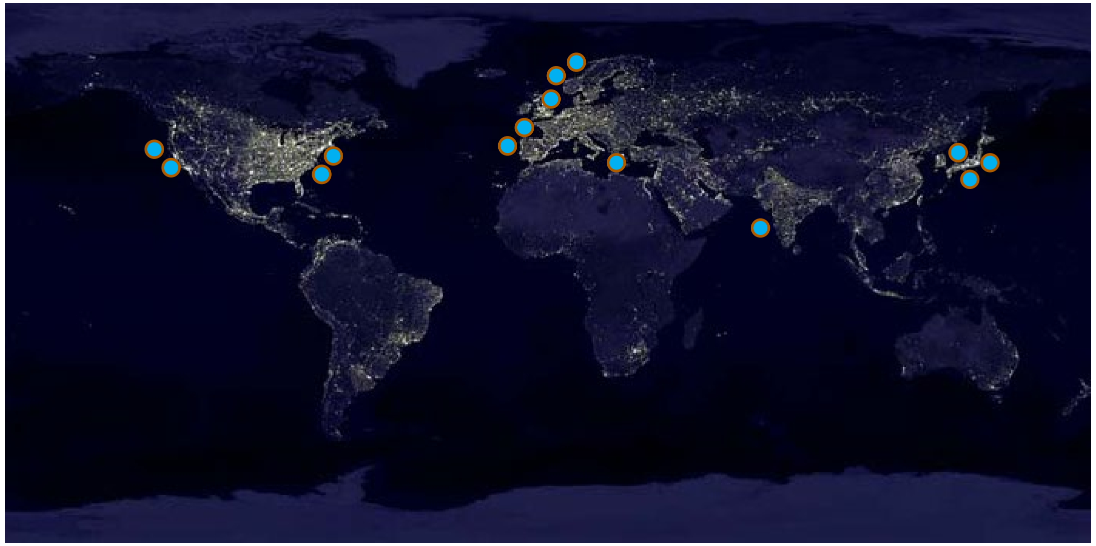
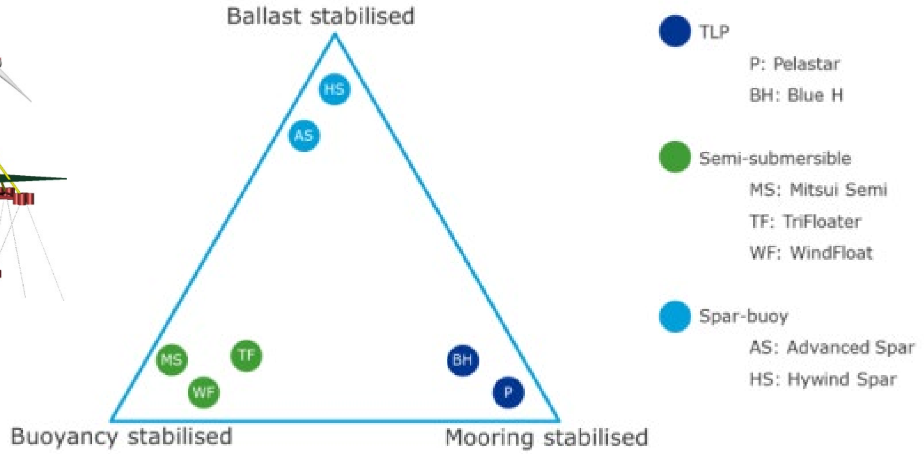
MOTIVATION
FLOATING WIND DEVELOPMENT

- Large deep water areas (also near load centers)
- EERA and Carbon Trust confirm future for floating wind
- Several demo/pilot sites operational
- Ambitious targets set by EU member states
- Need for research and development on floating wind to achieve the required cost reduction



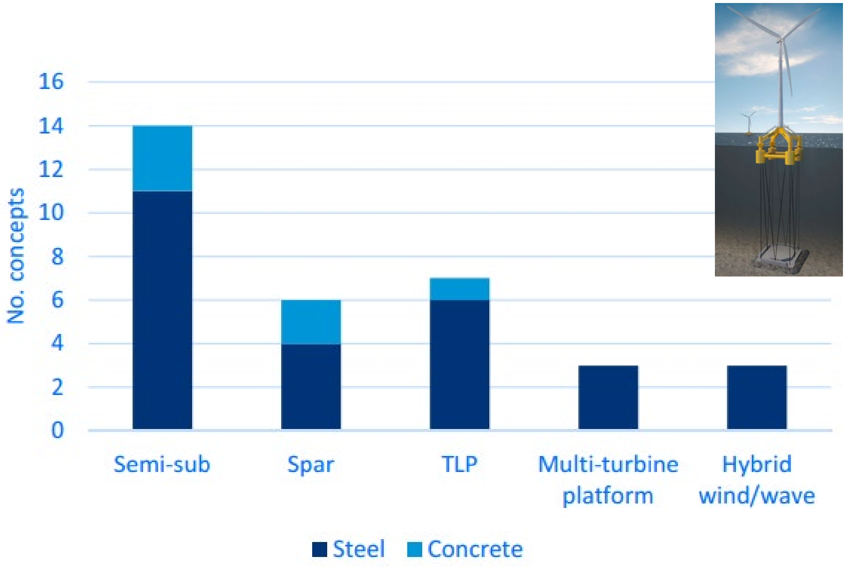


MOTIVATION
DESIGN ITERATION



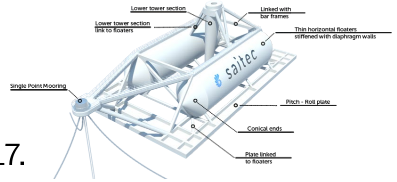
Many different concepts still in development – no clear convergence yet:

- Different stabilizing mechanisms
- Different materials
- Different mooring concepts



Floating wind turbine design iteration:

- Concept exploration
- Site specific design
  - Metocean
  - Logistics (manufacturing, installation)
- Cost reduction can lead to lighter, more flexible designs
- Design driving loads during operational design load cases (e.g. DLC16 [1])

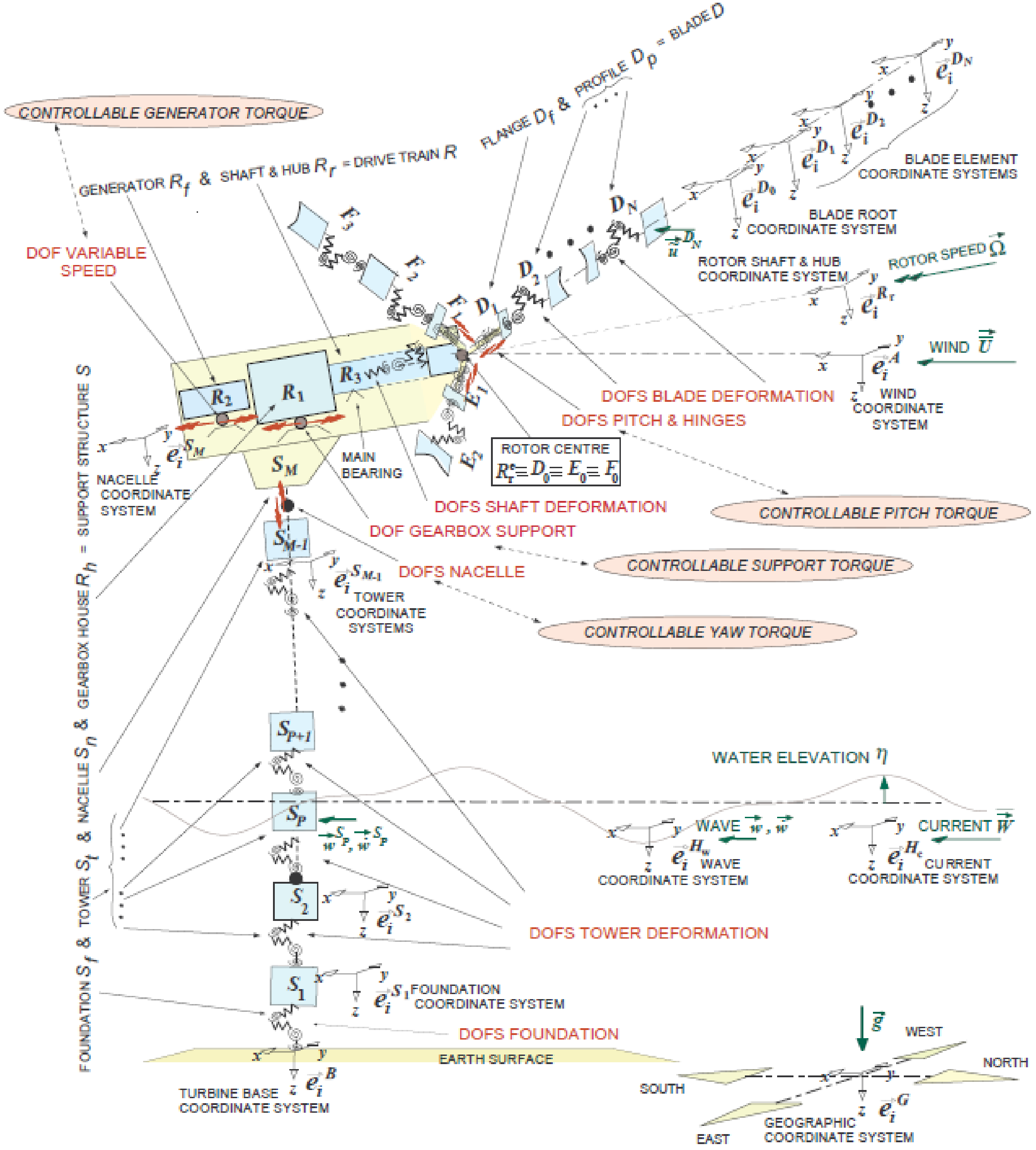


[1] J. Azcona etal; Design solutions for 10MW floating offshore wind turbines. InnWindEU project deliverable 4.3.7, 2017.

METHOD
WIND TURBINE MODEL: TURBU

TURBU model properties:

- Linear time invariant
  - Nonlinear equilibrium working point
  - Analytical linearization
  - Coleman transformation
- Modular approach
- Includes the relevant dynamics for concept design
- Model DOFs can be tuned to the application
- Laplace transform enables use in frequency and time domain



METHOD
SUPPORT STRUCTURE MODEL

Two-stage approach:

- TURBU offshore floating (rigid body global motion):
  - (Non)linear time domain hydrodynamics from panel methods (e.g. NEMOH [2])
  - Linearization (as proposed by Perez&Fossen [3])
  - Linear mooring stiffness and possible additional damping
- TURBU flexible support structure implementation:
  - Extended panel method for flexible platform modes
  - Assumption of Morison for initial inertia effect on modes
  - Beam approach for typical multi-legged platforms, covers most concepts (semi, TLP)
  - Other shapes could be included using externally derived Craig-Bampton modes/matrices

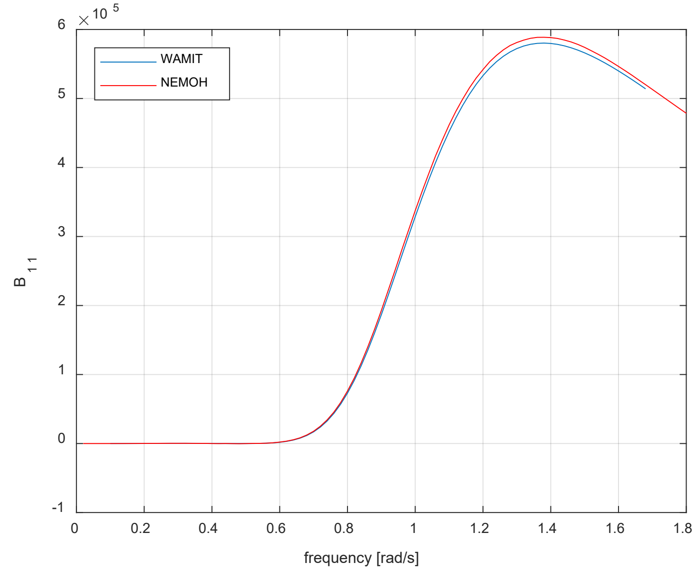
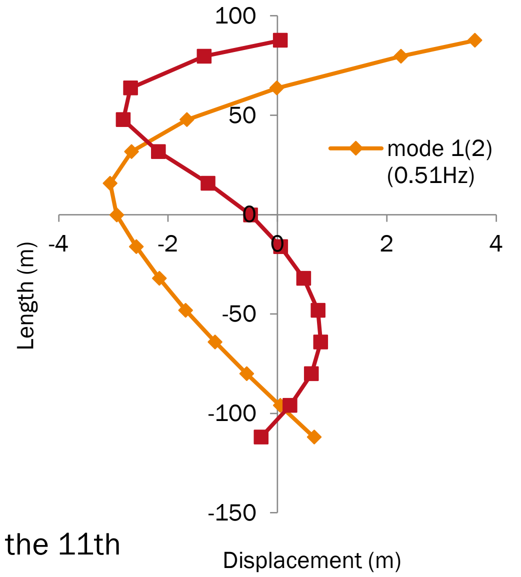


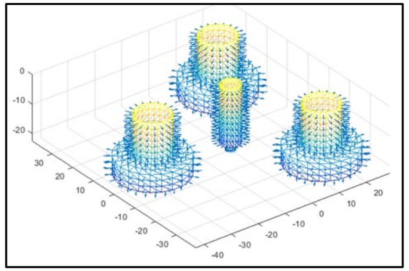
fig: hydrodynamic damping for first flexible mode

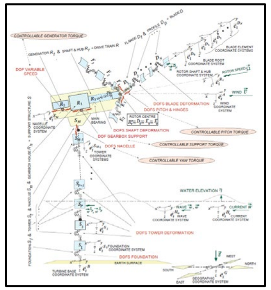


[2] A. Babarit, G. Delhommeau: Theoretical and numerical aspects of the open source BEM solver NEMOH. In Proc. of the 11th European Wave and Tidal Energy Conference, Nantes, France, 2015.

[3] T. Perez, T. Fossen; A Matlab Toolbox for Parametric Identification of Radiation-Force Models of Ships and Offshore Structures. In Modeling, Identification and Control, 30-1, 2009.

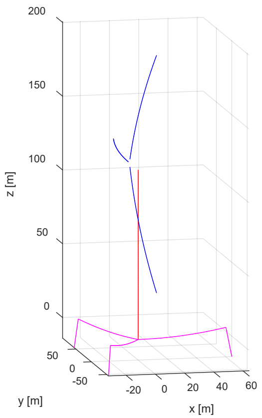
METHOD
APPROACH

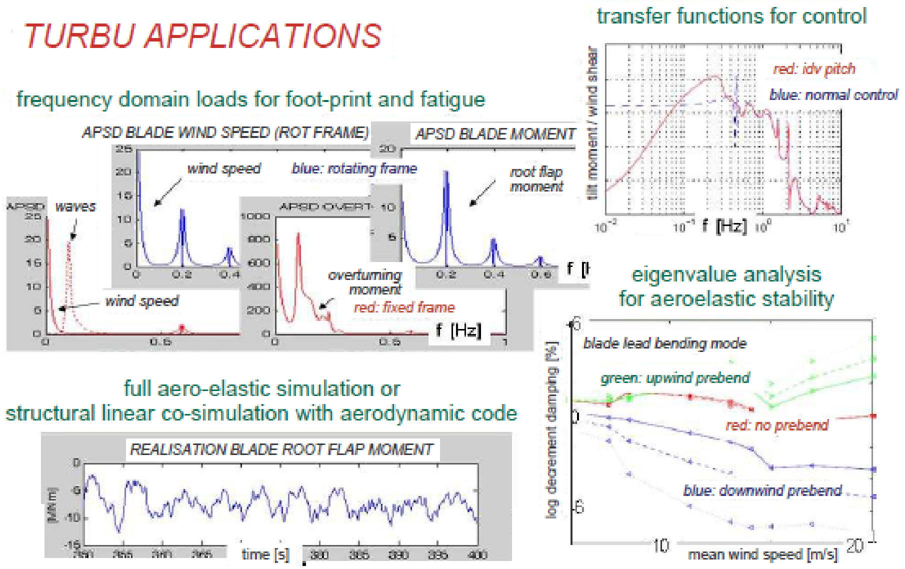




Overview of the stepwise model building approach:

1. Determine rigid body hyddata
2. Determine nonlinear equilibrium working point
3. Linearize model in working point
4. Extract flexible support structure mode shapes
5. Calculate hyddata for flexible modes
6. Link (linearized) hyddata to respective modes





POTENTIAL OF LINEAR ANALYSIS METHOD
UNDERSTANDING SYSTEM DYNAMICS

System/Modal parameters:

- Identification of instability & resonance issues
- Aero/hydro-elastic analysis

Frequency domain overview:

- Identification of instability & resonance issues
- Understanding dynamic interaction between components
- Understanding of the transfer of external loading
- Control design

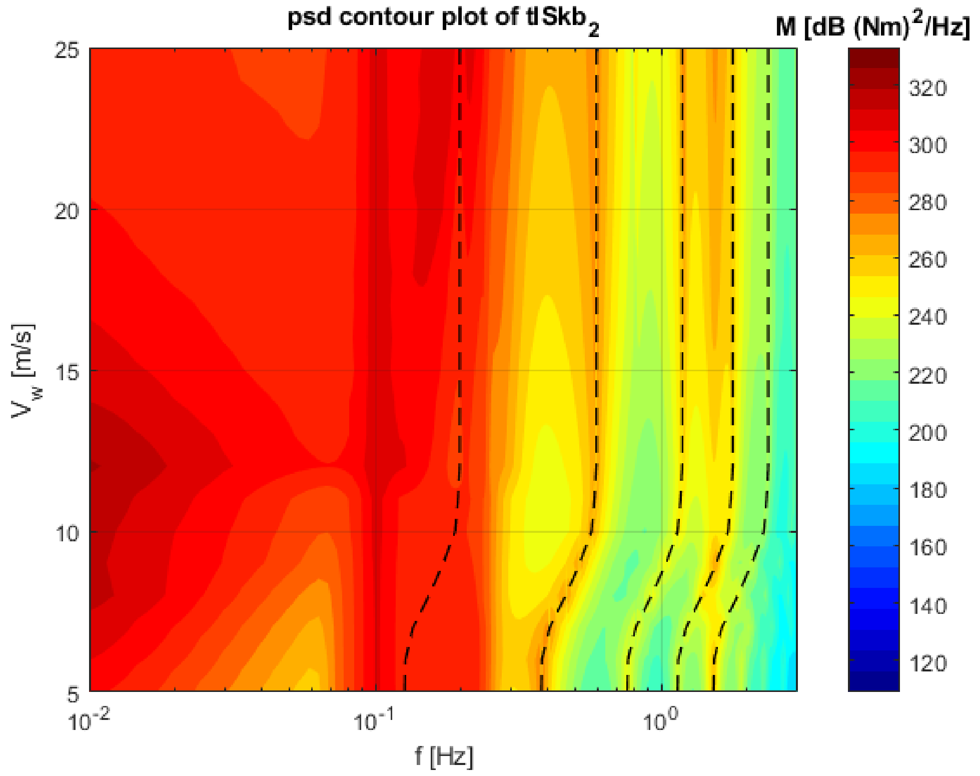


fig: collection of output spectra of fore-aft tower base bending moment accross the operating range

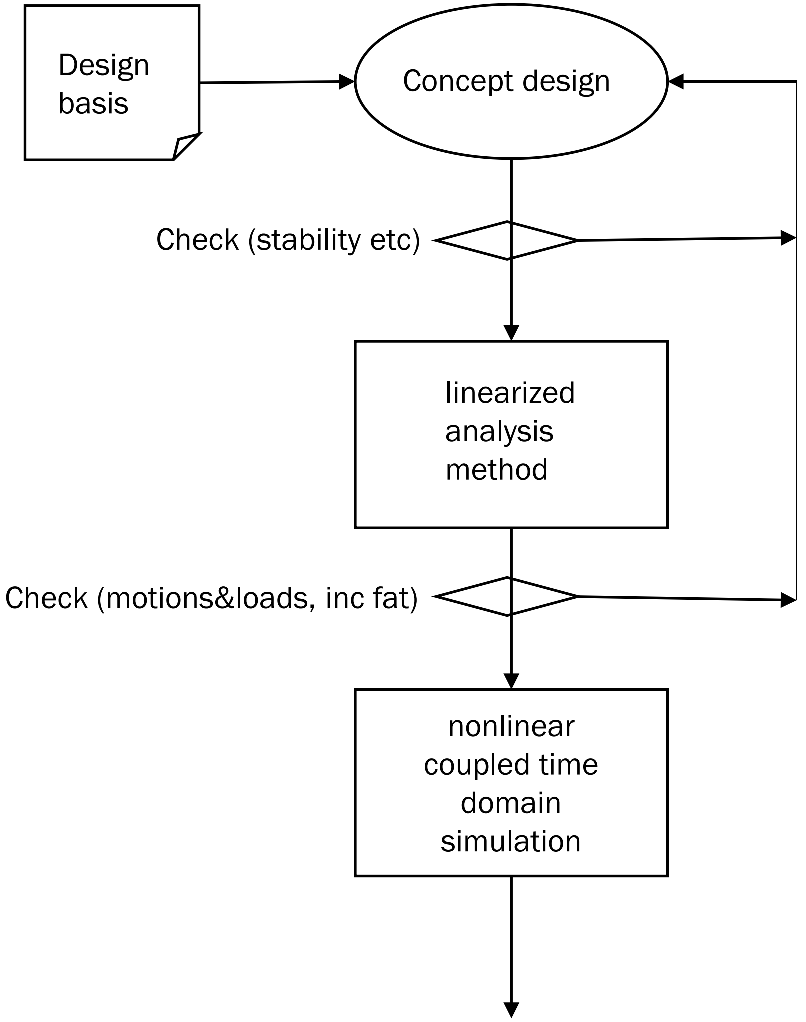
POTENTIAL OF LINEAR ANALYSIS METHOD
DESIGN ITERATION

Scoping of design driving load cases:

- Evaluation for range of metocean conditions
  - Different wind inflow conditions
  - Sea-state scatter diagram
  - Wind-Wave misalignment

Concept design iteration:

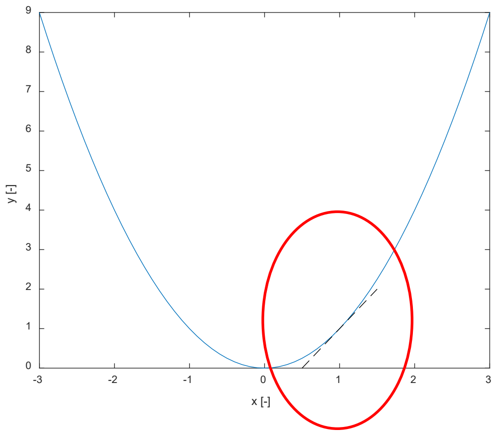
- Parameter variation for sensitivity studies
- Holistic optimization, including fatigue assessment



LIMITATIONS OF LINEAR ANALYSIS METHODS

Transient events, such as:

- Wind turbine shutdown
- Mooring tight/slack



Highly nonlinear effects:

- Viscous drag

Higher order effects, such as:

- Mooring line dynamics (be aware of possible resonance)
- Vortex Induced Vibrations

WHAT'S NEXT
FUTURE WORK

The following activities are initiated:

- Method
  - Further verification and validation (for other concepts, against measurements)
  - Introduction of second order wave loads
  - Stack of linear models for transient events
- Application
  - Optimization of lightweight concept design
  - Use of linear floating wind turbine model in digital twin setup (Kalman Filter observer approach)

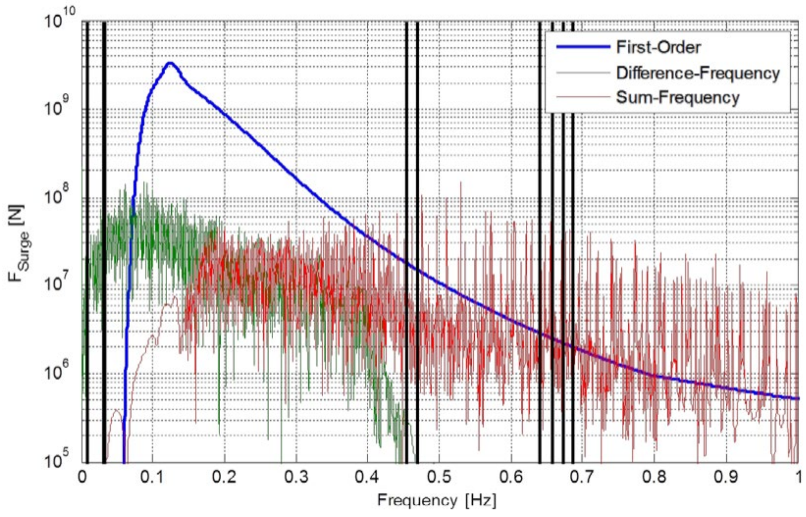


fig: second order wave forces (src: [4])

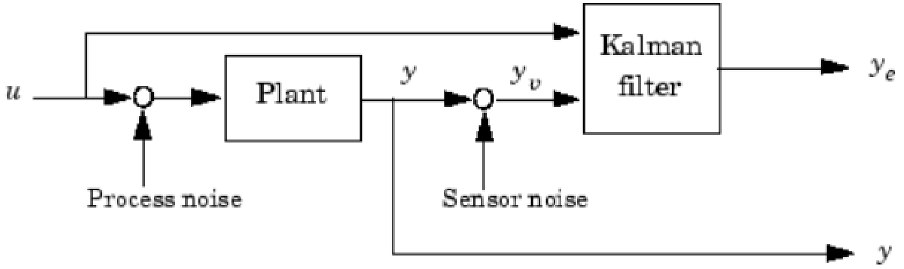


fig: Kalman Filter based observer (src: MathWorks)

[4] T. Duarte, A. Sarmento, J. Jonkman; Effects of second-order hydrodynamic forces on floating offshore wind turbines, Presented at AIAA SciTech 2014.

THANK YOU FOR YOUR ATTENTION

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