X-ROTOR

2023.01.18

X-shaped Radical Offshore Wind Turbine
for Overall Cost of Energy Reduction

VAWT support structure mass sensibility due to the aerodynamic load scaling

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Supervisor: Michael Muskulus , NTNU

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 101007135

Overview

- Introduction to X-Rotor Wind Turbine
- Design Conditions
- Design methodology
- Basic Structural Design
- Effect of load reduction

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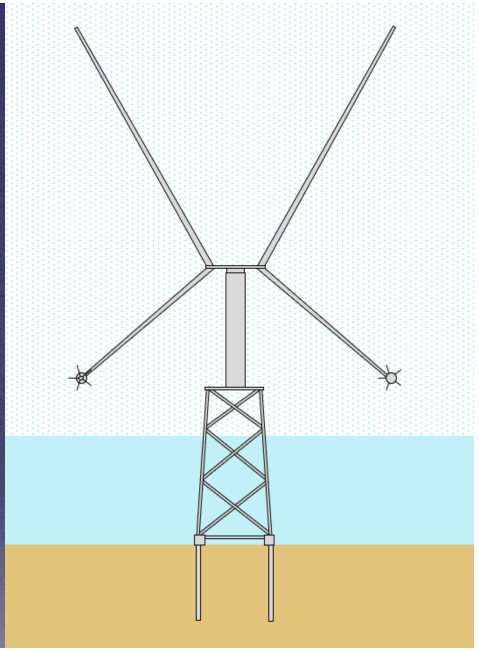
X-Rotor Wind Turbine



- WP1: Project management and coordination
- WP2: Aero-elastic code development and performance
- WP3: Control and Operational Strategy
- WP4: Design of mechanical structure & analysis
- WP5: Power take-off and conversion system design
- WP6: Cost of Energy Reduction Analysis
- WP7: Environmental and Socio-Economic Impact
- WP8: Industry Ratification and Further Development Roadmap
- WP9: Communication, Dissemination
- WP10: Ethics requirements

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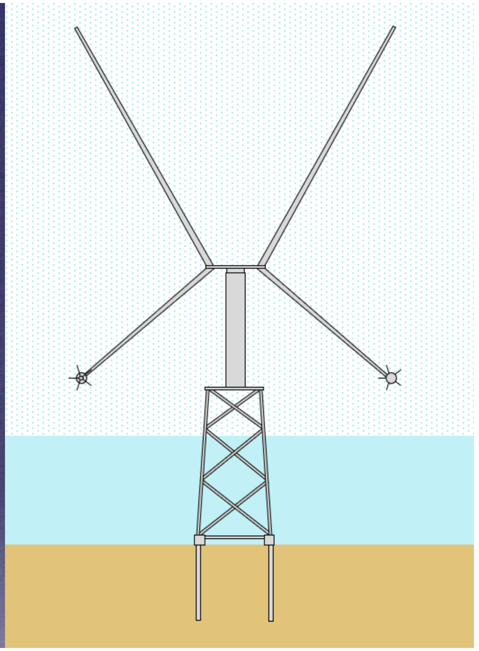

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Design conditions

- Representative North Sea environment
- $U_{70,50}$ = 36.8 m/s
- $H_{s,50}$ = 10.1 m
- Distance to shore 300 km
- Assumed 40 m water depth

Location of 18 potential European offshore sites
Li et all (2015)

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Design conditions

- Design according to DNV rules
- Primarily S355 steel considered
- Stress concentration factors according to Efthymiou
- Tentative dimensions / masses of electrical components from WP5
- Lumped load cases for basic design
- Loads from WP2

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Design methodology

- Dynamic load simulation
- Fully resolved wave loads (Morison)
- DNV rules
- Design fatigue factor DFF = 3
- Stress concentration factors (Efthymiou)

Reference: Fedem Theory Guide

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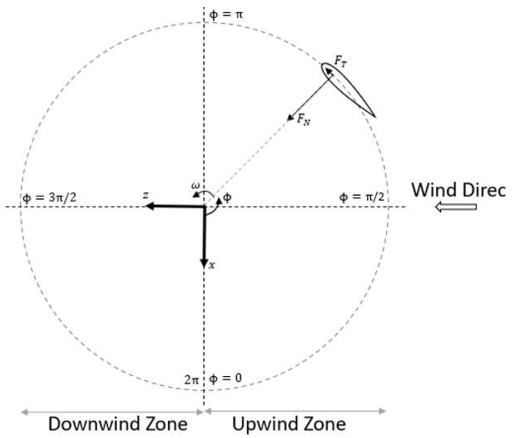
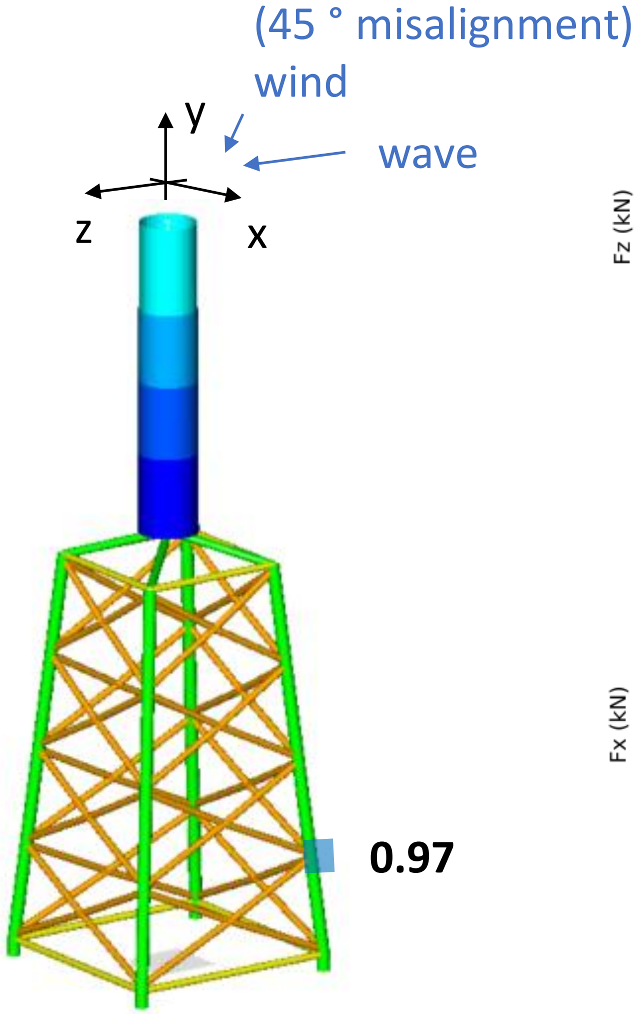
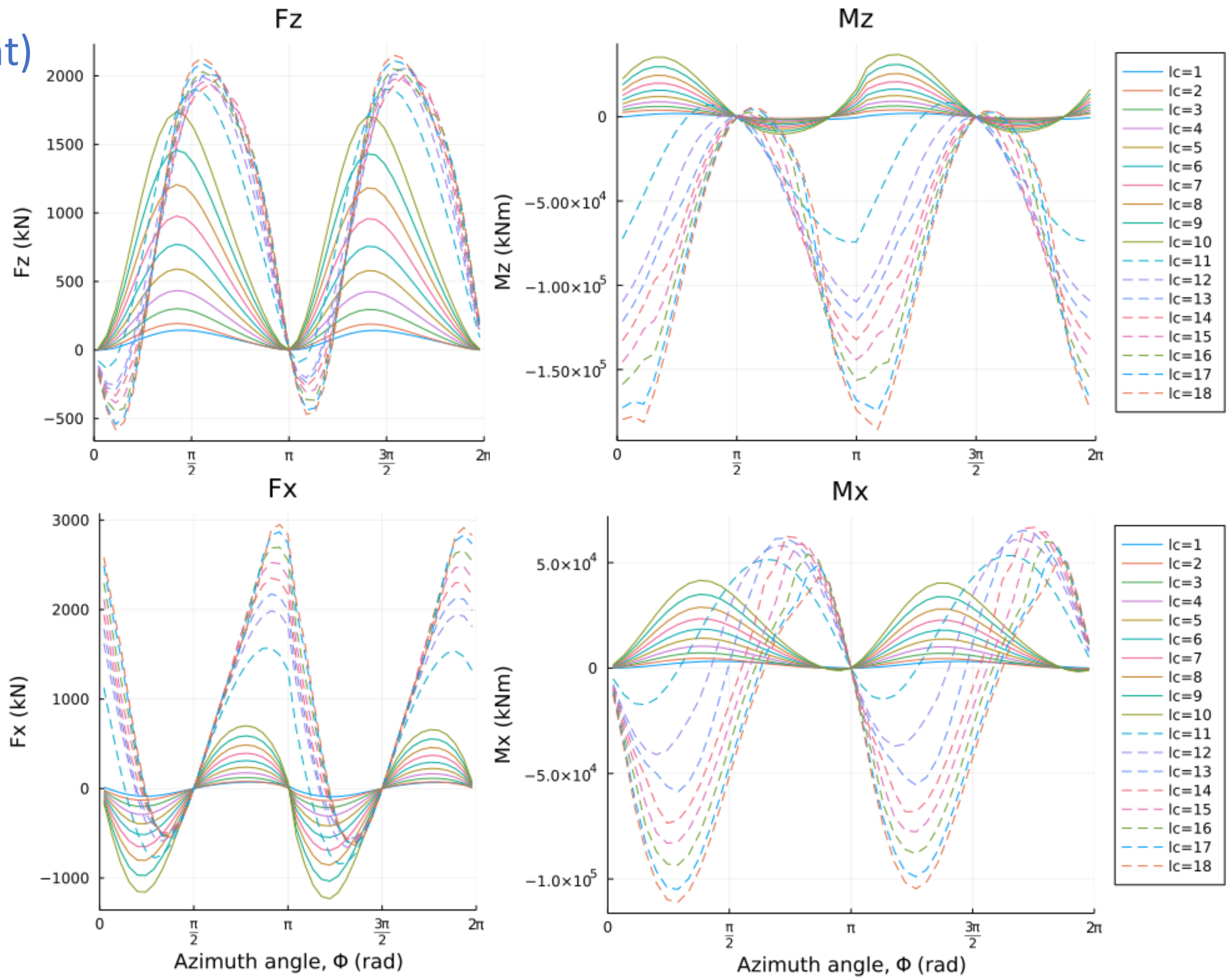
Significant fatigue loading







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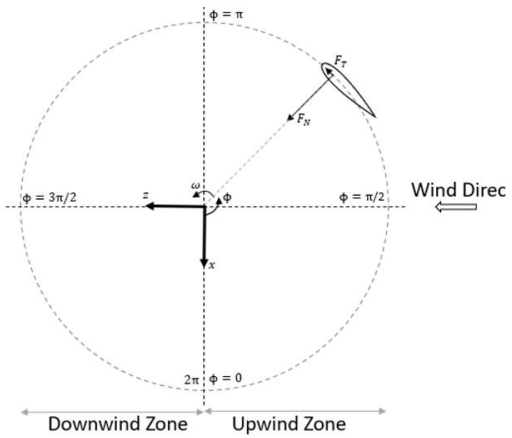
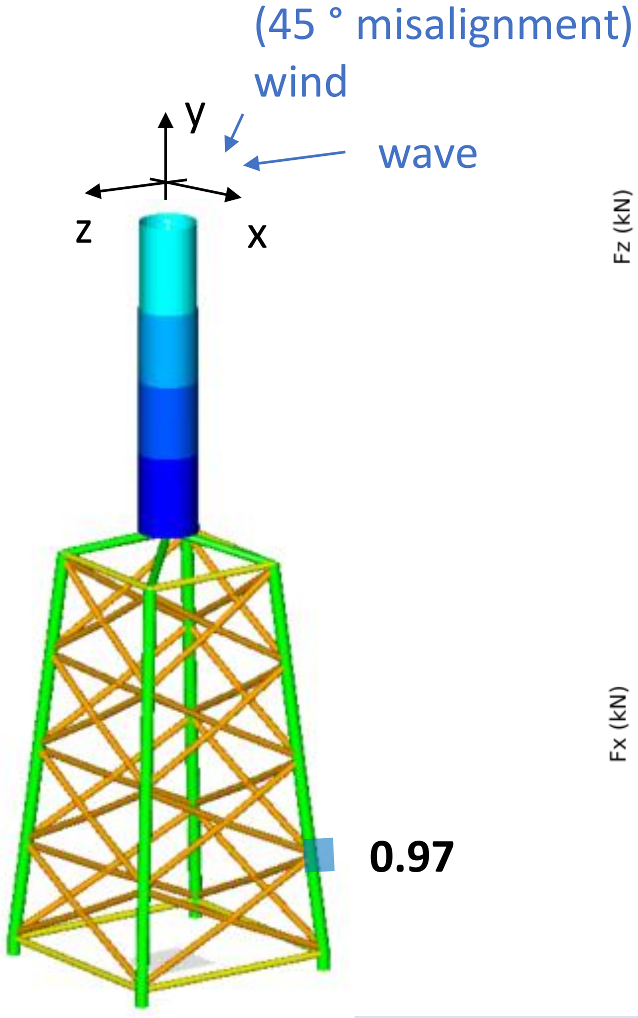
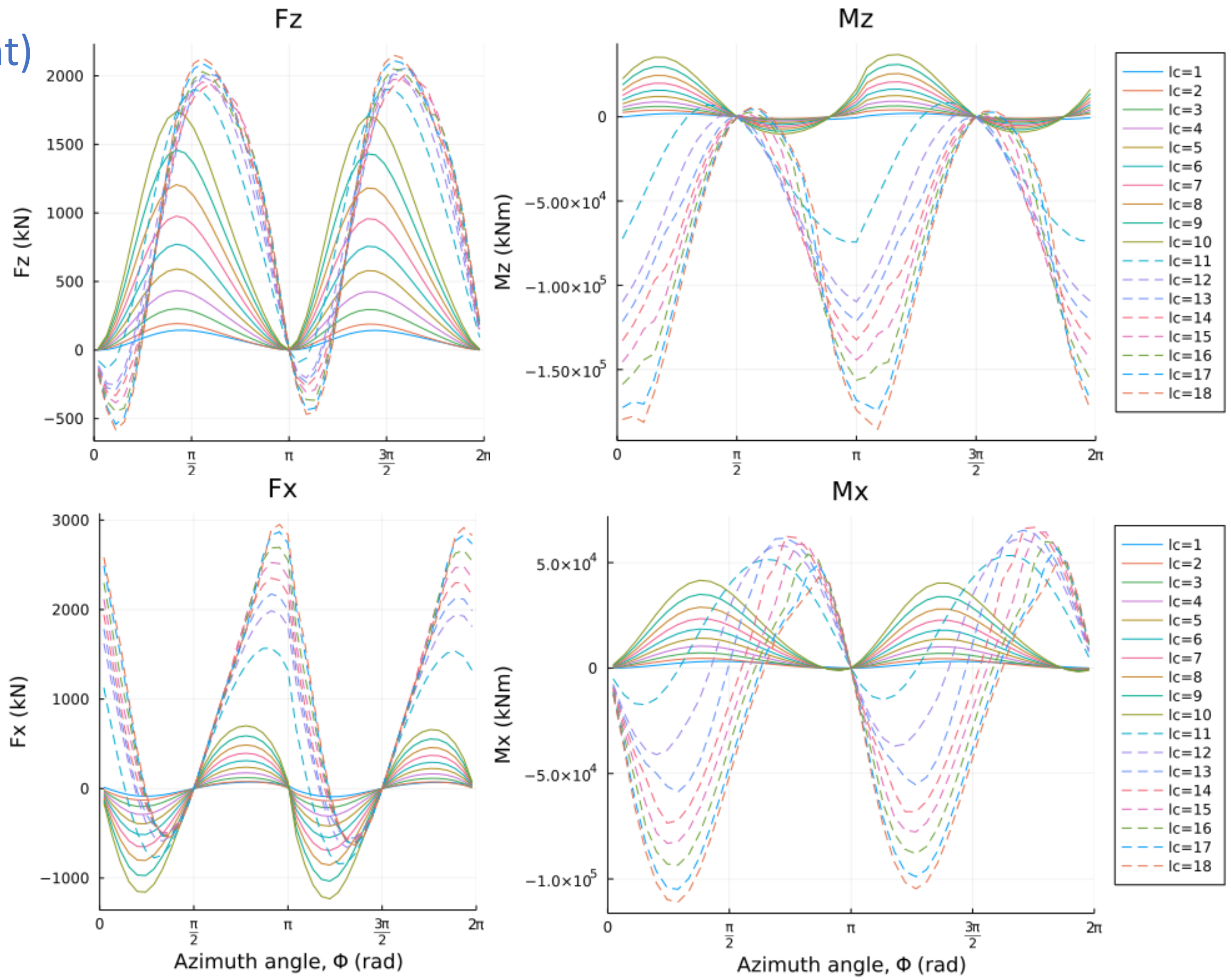
Significant fatigue loading

Sensible to control strategy!







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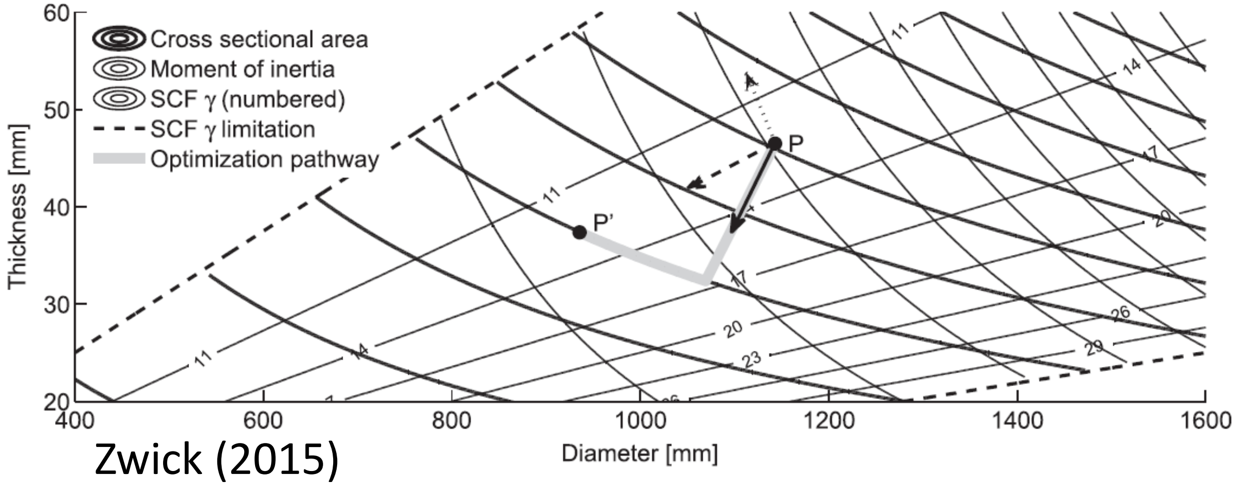
Optimization strategy

1. Increase leg diameter until feasible design
2. Keep ratio of brace diameter to leg diameter
3. Reduce D/t ratio (up to 16) to reduce both SCFs and wave loads



Zwick (2015)

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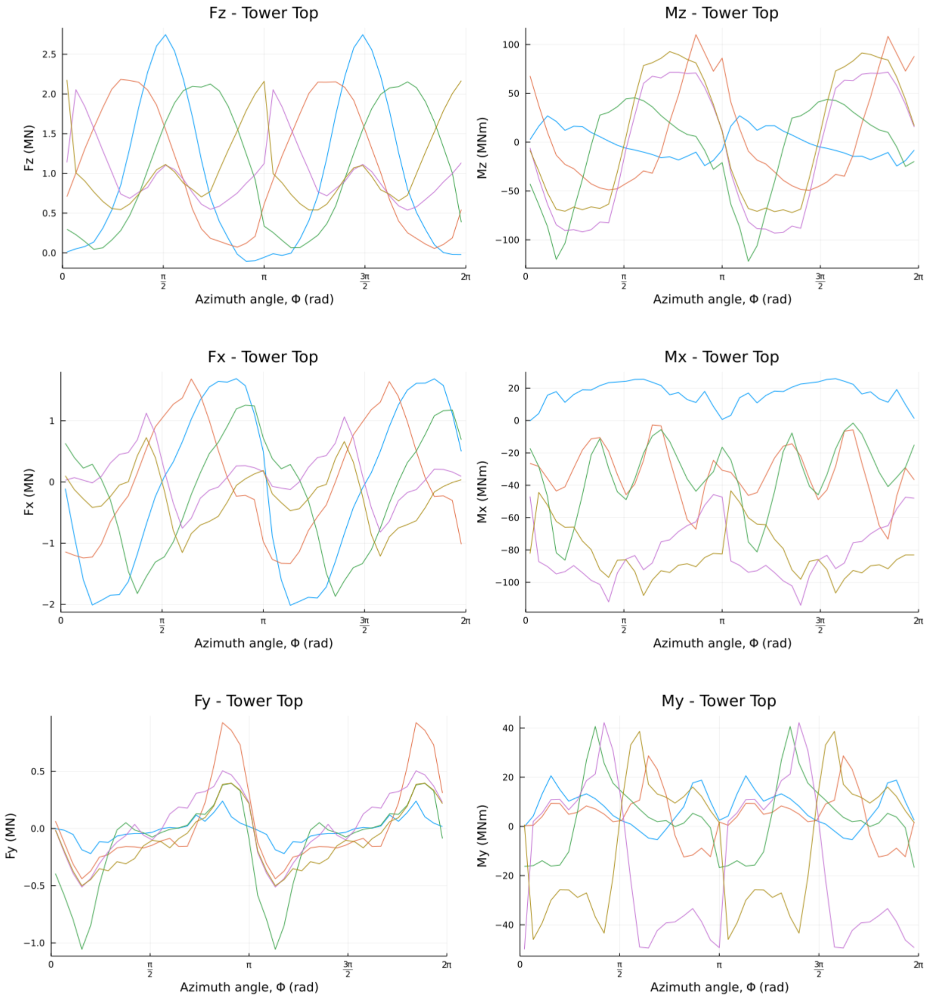
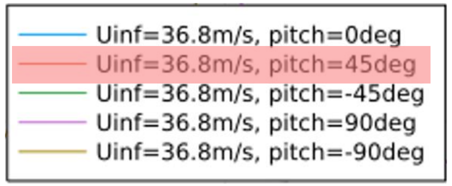
Ultimate Loads Uinf = 36.8m/s

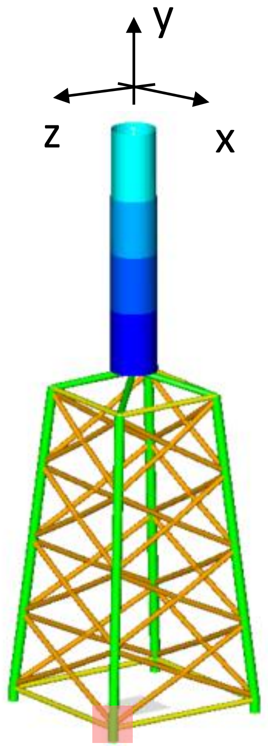


- Turbine parked in any azimuth
- Different blade flag position
- All components applied

  (no compensation from 2nd rotors)

	Max	Min
Fz (MN)	2,746	-0,105
Fx (MN)	1,689	-2,015
Fy (MN)	0,925	-1,055
Mz (MNm)	110,115	-121,962
Mx (MNm)	25,879	-114,187
My (MNm)	42,201	-49,945





188.61 MPa

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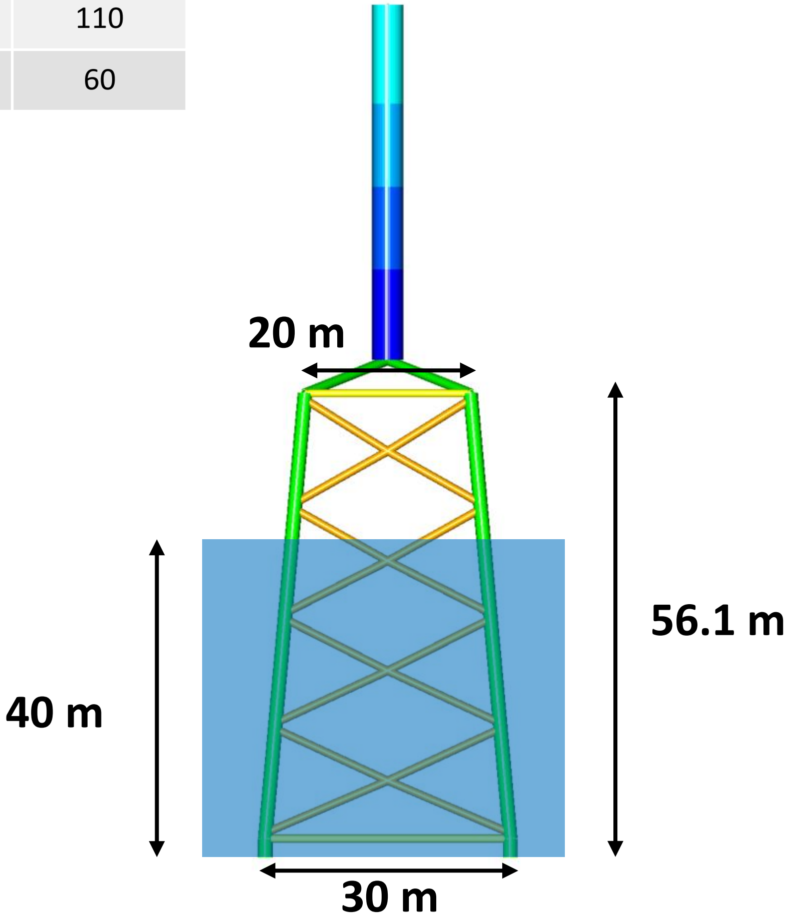
Basic structural design

- Demonstrates feasibility
- t between 60-110 mm
- SCFs generally between 2-5
- Stiff-stiff design at 1.66 Hz
- Top mass 224 tons (rotor + equipment)
- Primary steel mass **2574 tons** (excl. piles)

	Diameter (m)	Thickness (mm)
Legs	1.83	110
Braces	1.00	60



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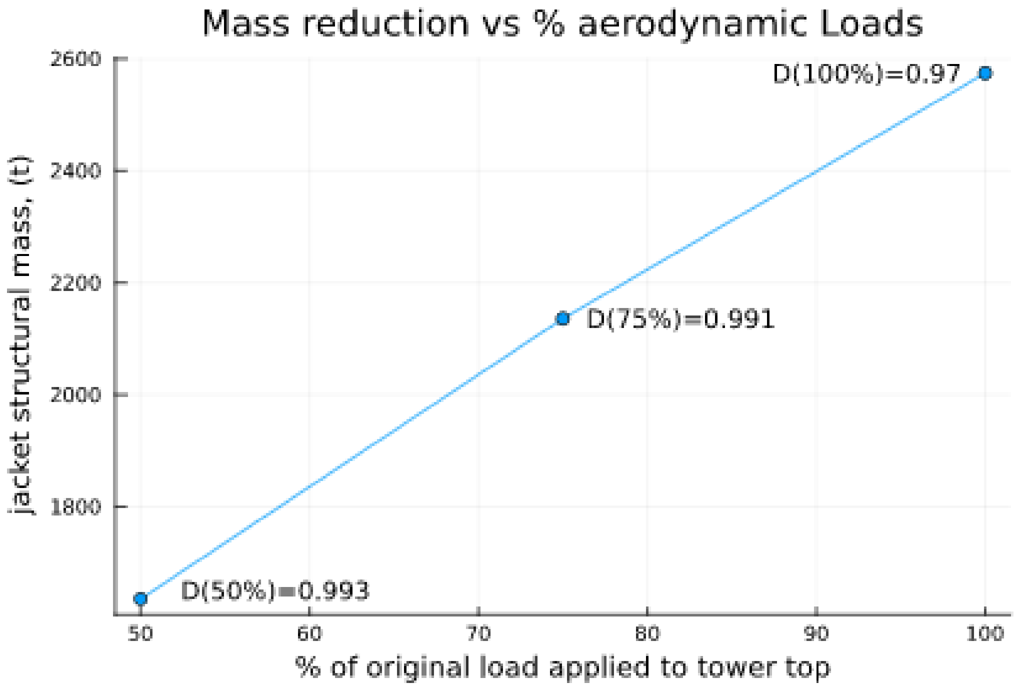
Effect of load reduction

Applied loads on the tower top were reduced to 75% and 50% of the original components

% load applied	Mass (t)
100	2574
75	2136
50	1635



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Main conclusions

- Design loads sensitive to control strategy
  - Need to optimize / update loads
- Offshore support structure feasible
  - But potentially heavy / expensive
- Still a lot of room for improvement…
  - Need for computer-aided optimization

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Next steps

- Jacket design including flexible piles
- Access the influence of blades´s centripetal and gravity loads
- Provide input to new control strategies
- Structural optimization


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X-Rotor session: Friday 9h

Friday 20 January

	7A) Societal impact and controversies Chairs: Rita V. D'Oliveira Bouman, NTNU and Lena Kitzing, DTU	**7B) Operation & Maintenance Chairs: Iver B. Sperstad, SINTEF and Jonas Kaczenski, Fraunhofer**	**7C) Side-event: XROTOR (0900-1130)**
0900	Introduction by chair	Introduction by chair	The XROTOR consortium (https://xrotor-project.eu/) invites for a side-session at Deepwind 2023. Agenda 1. Overview of the concept and operation (William Leithead / Laurence Morgan, Strathclyde) (30 minutes) 2. CFD analysis and aerodynamic models (Carlos Ferreira, Delft, & Beatriz Mendez Lopez, CENER) (30 minutes) 3. Discussion and Break (10-15 minutes depending on length of discussion) 4. Structural models (Michael Muskulus, NTNU) (20 minutes) 5. Power take-off systems (David Campos-Gaona, Strathclyde) (15 minutes) 6. Socio-economic and environmental impact (Niall Dunphy, UCC) (20 minutes) 7. Cost of energy modelling James Carroll, Strathclyde) (15 minutes) 8. Discussion and summing up (5 to 10 minutes)
0905	Whispers in the Wind: Ethical dimensions of social conflict in offshore wind - Rita V. D'Oliveira Bouman, SINTEF Ocean	The Sensitivity of Failure Definitions on Wind Turbine Failure Rate and Availability Estimates – Fraser Anderson, University of Edinburgh	
0920	Identifying and addressing societal aspects of offshore wind power in the North Sea – Tomas Moe Skjølsvold, Sara Heidenreich, NTNU	Multirotor wind turbine systems: an exploration of failure rates and failure classification – Jade McMorland, University of Strathclyde	
0935	From where the wind blows – The social dynamics of wind power opposition – Sigurd Hilmo Lundheim, NTNU	Effects of grid demand oscillations on degradation of power train system in offshore wind turbines – Farid Khazaeli Moghadam, NTNU	
0950	Just wind power? Mapping of Norwegian ownership models and decision-making processes – Kim-Andre Myhre Arntsen, NTNU	Support System for Optimised Maintenance of Horizontal Axis Wind Turbines – Arvind Keprate, OsloMet	
1005	Leveraging innovative technology to address societal interests in offshore wind farm development, Jan-Tore Horn, Vind Technologies AS	Technical modelling challenges for large idling wind turbines – Galih Bangga, DNV Services UK	
1020	Closing by chair	Closing by chair	
1030	Break		

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References

Leithead, William et al., 2019. The X-Rotor Offshore Wind Turbine Concept. Journal of physics. Conference series, 1356, p.12031. doi:10.1088/1742-6596/1356/1/012031

Li, Gao, Z., & Moan, T. (2015). Joint Distribution of Environmental Condition at Five European Offshore Sites for Design of Combined Wind and Wave Energy Devices. Journal of Offshore Mechanics and Arctic Engineering, 137(3), 31901. https://doi.org/10.1115/1.4029842

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