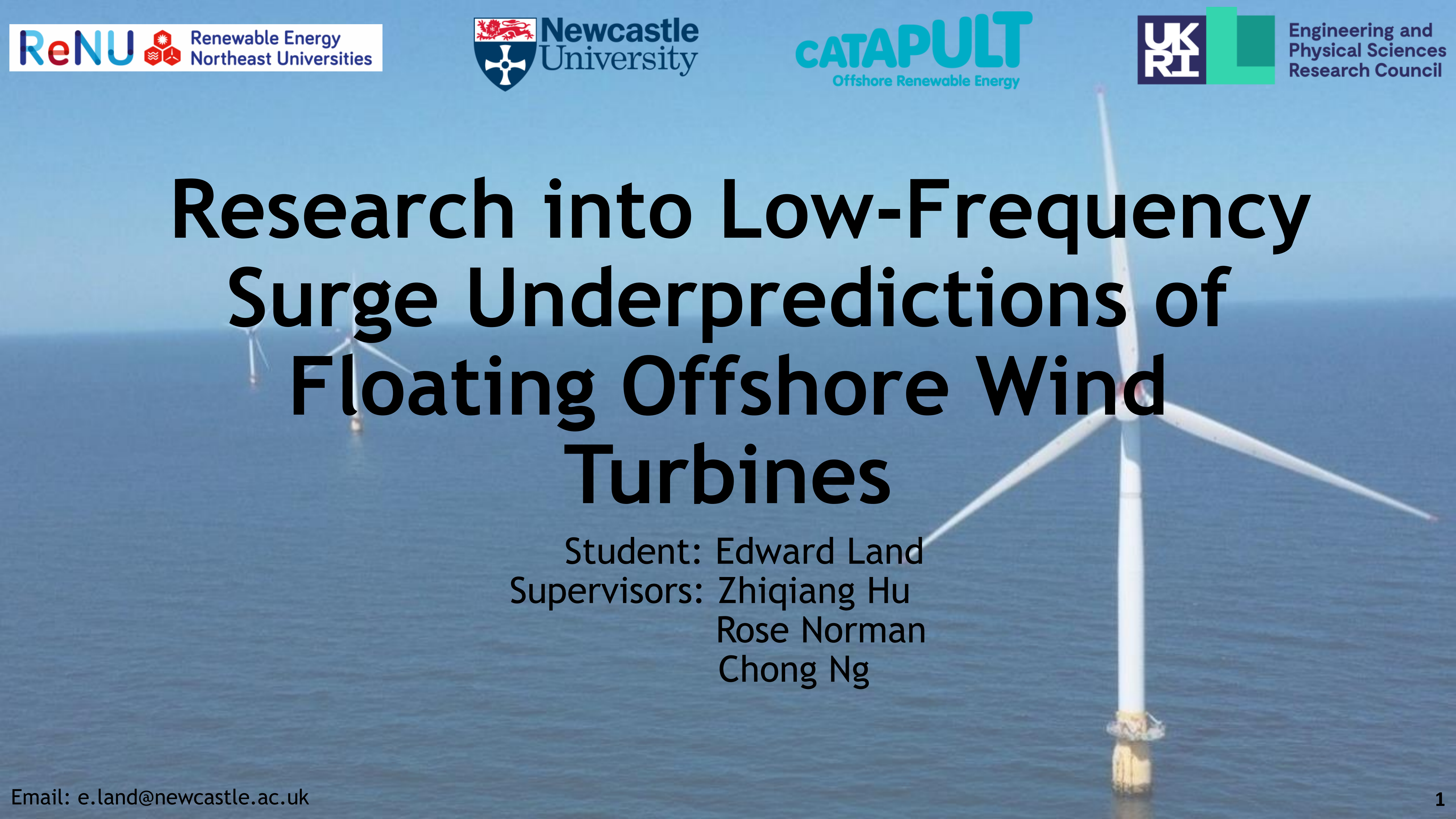

Research into Low-Frequency Surge Underpredictions of Floating Offshore Wind Turbines

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Supervisors: Zhiqiang Hu
Rose Norman
Chong Ng

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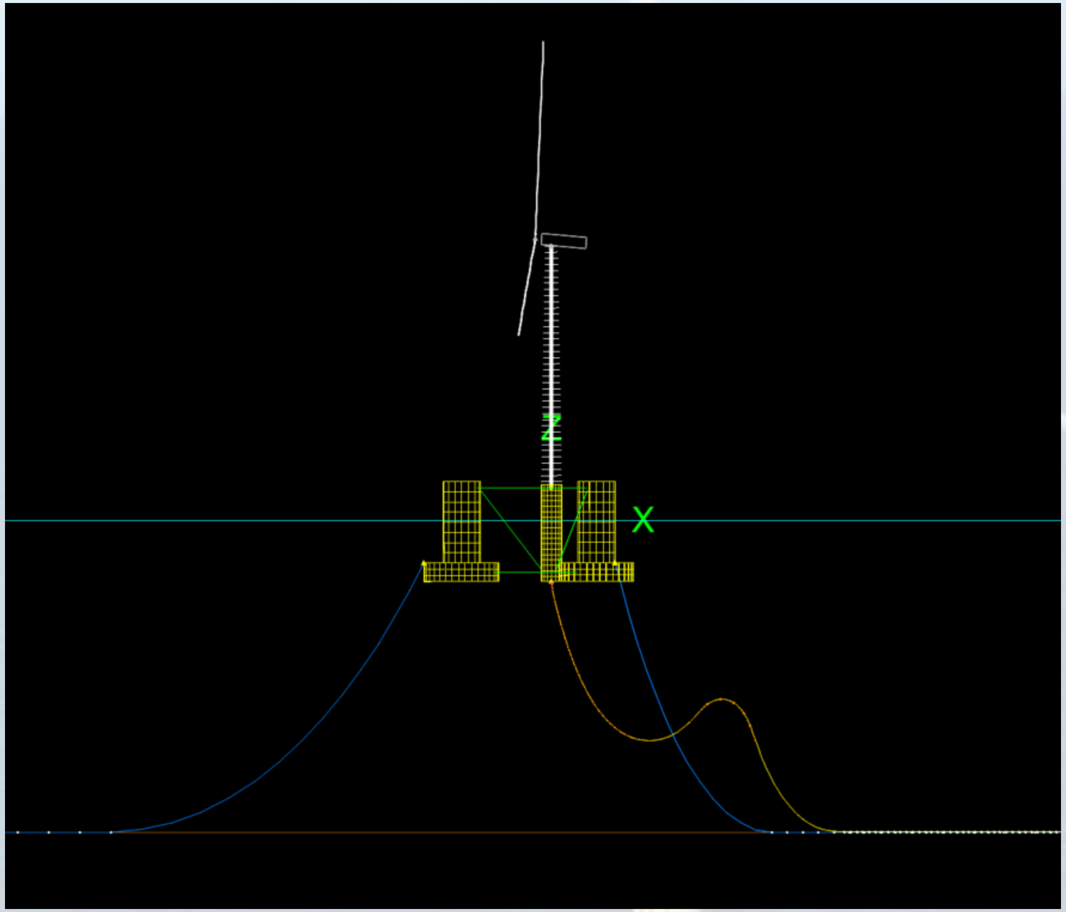
Project Overview

- Flexible Coupled Multi-Body Dynamic Research of Floating Offshore Wind Turbines (FOWT).

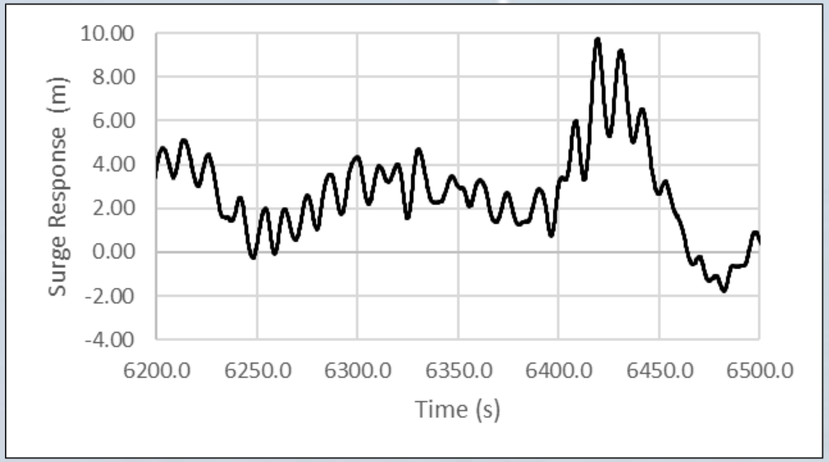
  Aims:

- To improve vessel response prediction.
- To create more cost-effective and efficient FOWTs.



FOWT model in Orcaflex

Low-frequency Motion Response



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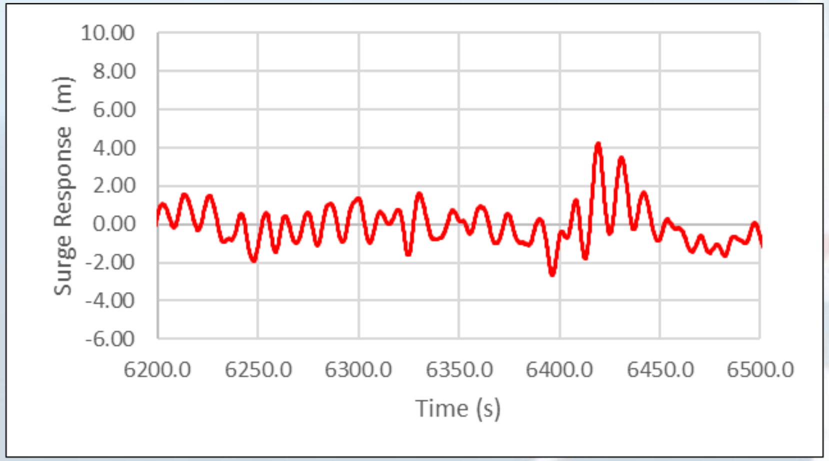
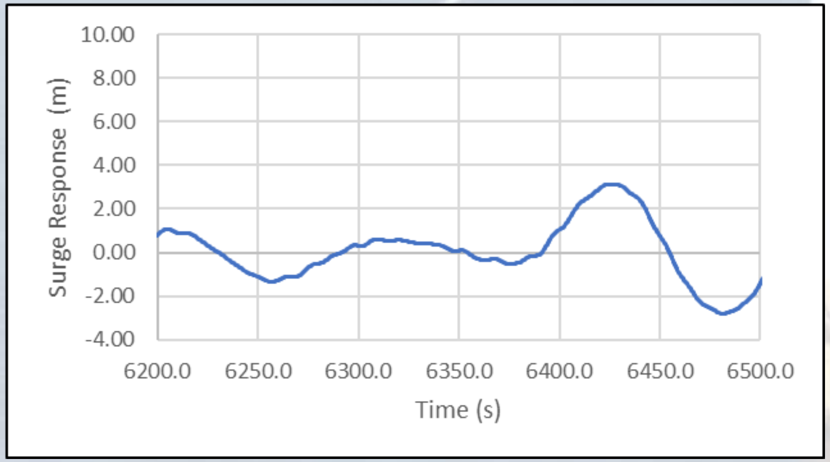


Wave-frequency response

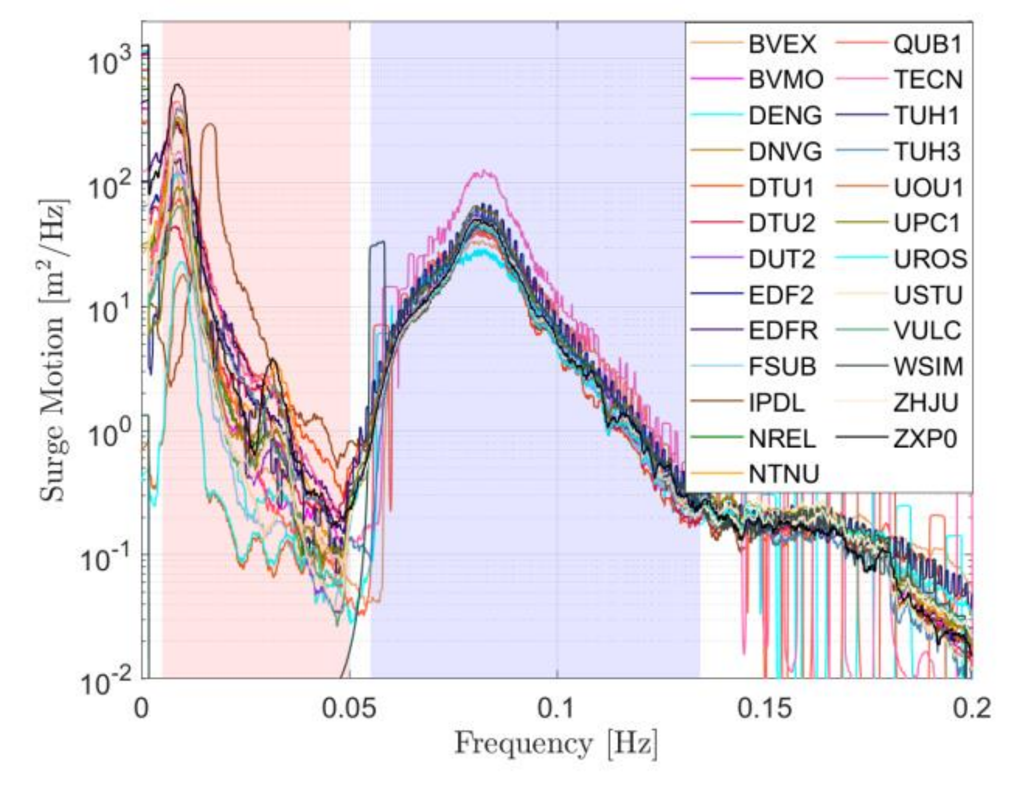
+



Low-frequency response

Low-Frequency Surge Underprediction

- Previous studies have found an underprediction of up to 20% in low-frequency loads and motions.



Surge power spectral density from [1]

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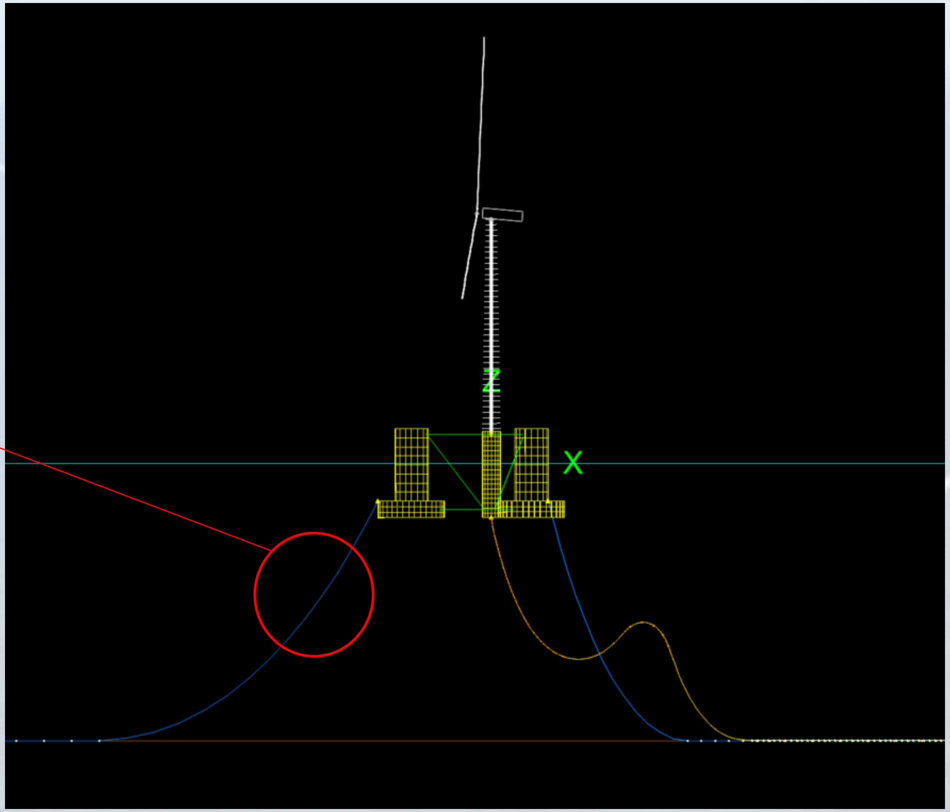
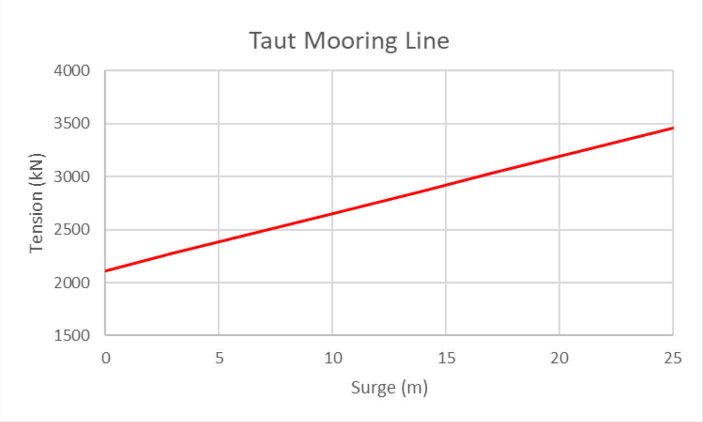
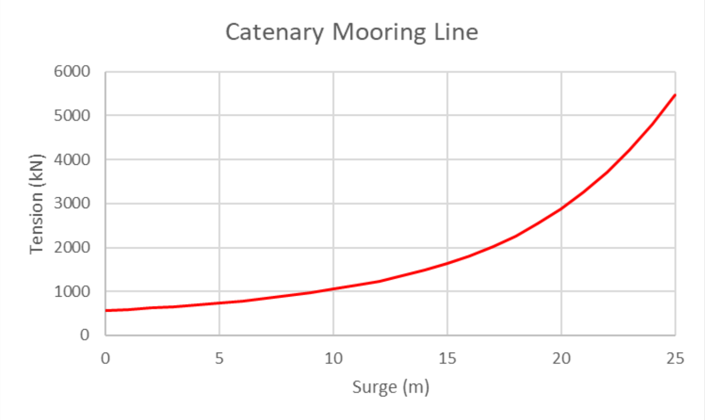
[1] Robertson, A.N., Gueydon, S., Bachynski, E., Wang, L., Jonkman, J., Alarcon, D., Amet, E., Beardsell, A., Bonnet, P., Boudet, B. and Brun, C., 2020, September. OC6 Phase I: Investigating the underprediction of low-frequency hydrodynamic loads and responses of a floating wind turbine. In *Journal of Physics: Conference Series* (Vol. 1618, No. 3, p. 032033). IOP Publishing.

Underprediction Consequences

Potential for mooring line tension to exceed design limit. Catastrophic failure in multiple offshore drilling platforms [2].



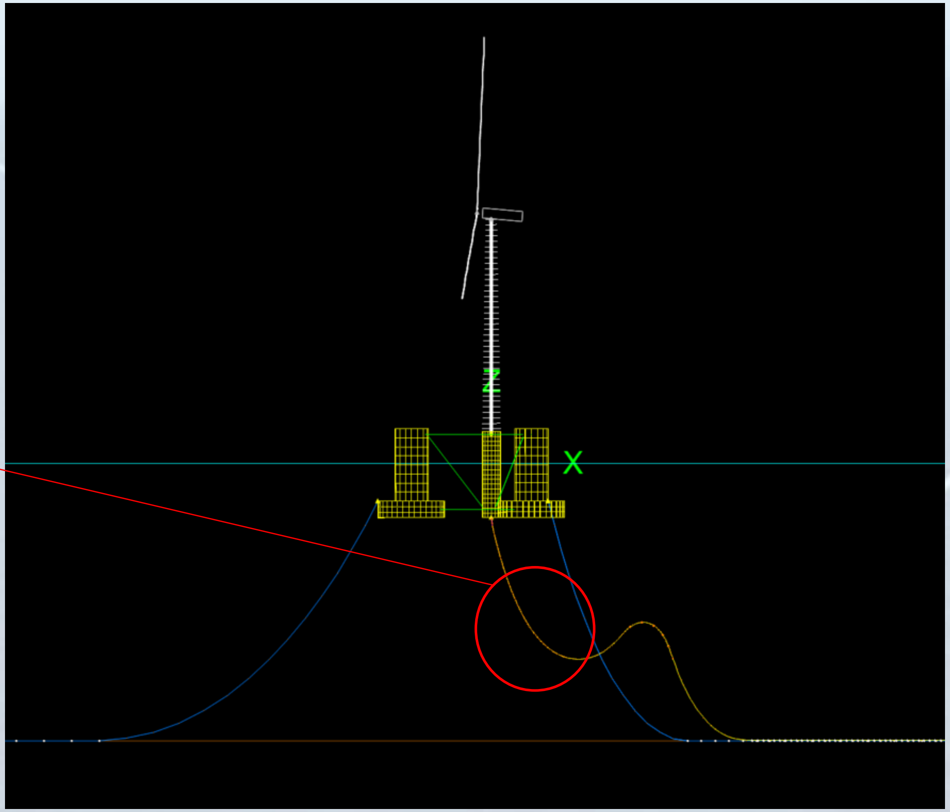


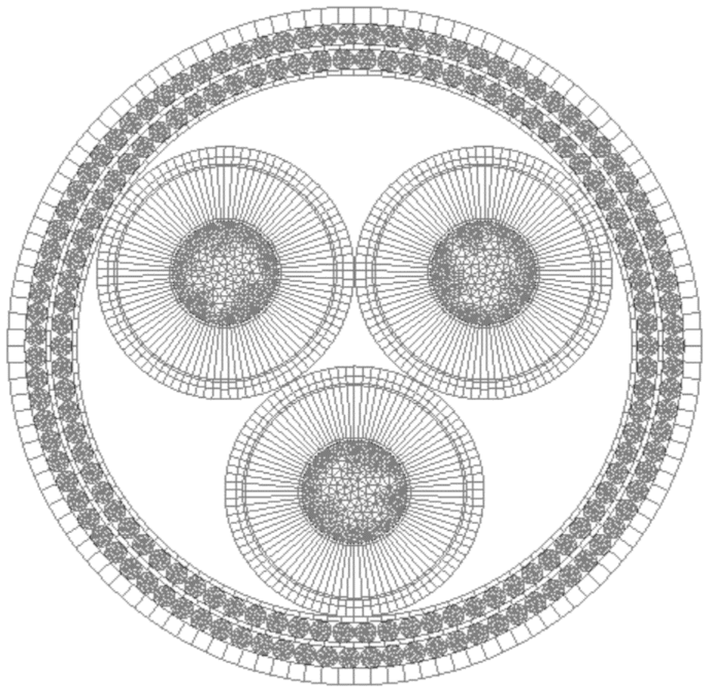


[2] STANSBERG, C. T., KAASEN, K. E., ABRAHAMSEN, B. C., NESTEGÅRD, A., SHAO, Y. & LARSEN, K. Challenges in wave force modelling for mooring design in high seas. Offshore Technology Conference, 2015. OnePetro.

Underprediction Consequences

Fatigue damage sustained by power cables from motion can increase by up to 13% [3].



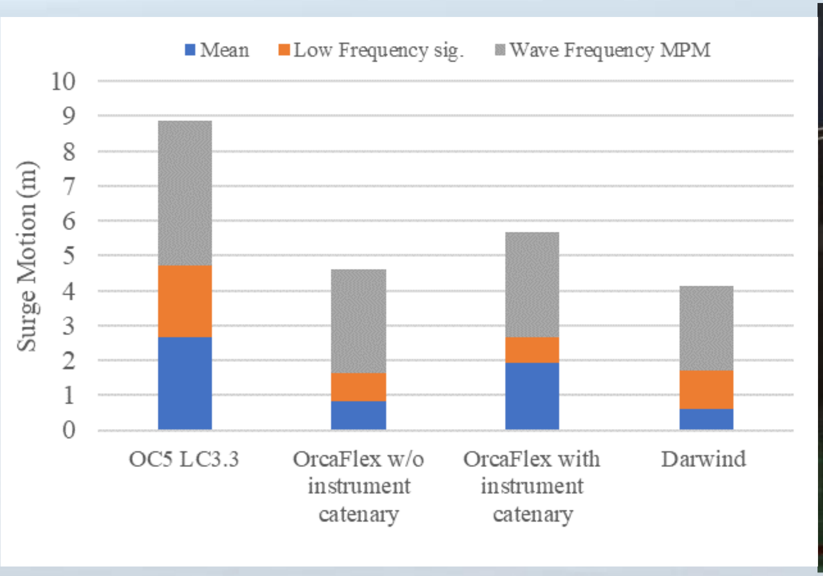


Cable cross-section modelled in UFLEX

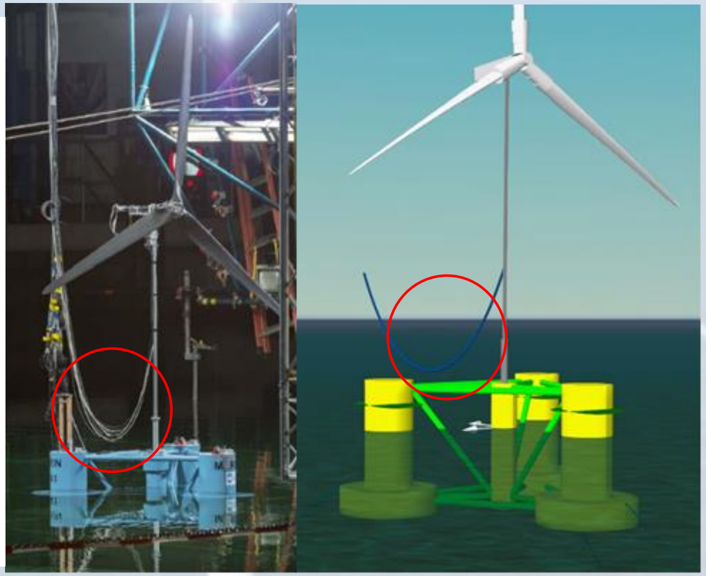
[3] LAND, E., HU, Z., HALEY, N., BRINDLEY, W. & NG, C. 2023. The effects of surge underprediction on fatigue damage of floating offshore wind turbine dynamic cables. *Advances in the Analysis and Design of Marine Structures. CRC Press.*

Low-Frequency Surge Underprediction

- Initial Testing Clearly shows the underprediction in low-frequency response shown in orange.
- Initial simulations and decay tests showed that the instrument catenary had a significant effect on the mean offset.



Initial model testing



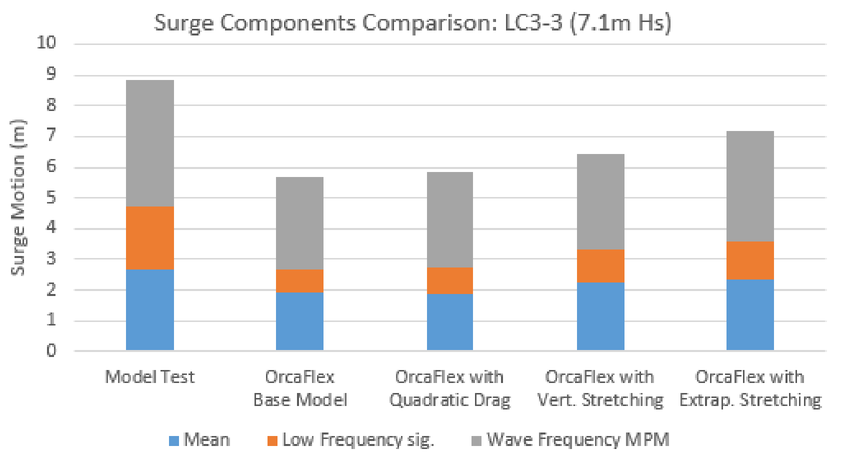
OC4 DeepCWind Experiment [4] vs OrcaFlex simulation model

[4] Helder, J.A. and Pietersma, M., 2013. UMaine-DeepCwind/OC4 Semi Floating Wind Turbine Repeat Tests. *Maritime Research Institute Netherlands: Wageningen, The Netherlands*.

Renewable Energy Northeast Universities

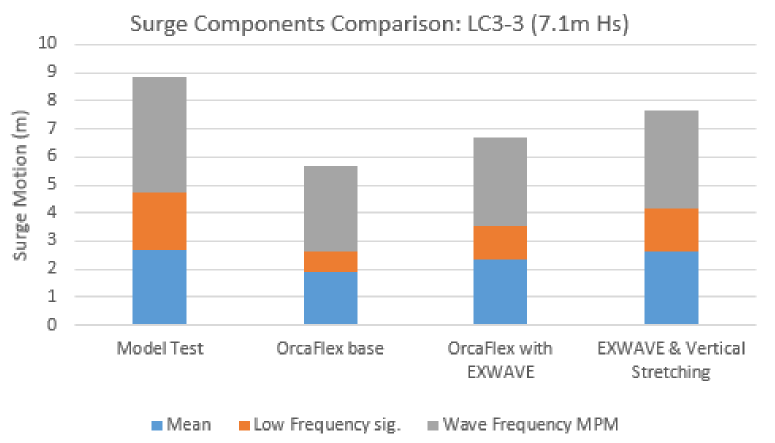
Low-Frequency Corrections

- When using wave stretching techniques, which extend wave velocity above the water line, the prediction is closer to that of the model test [5].



Effects on response when using various wave stretching techniques

- This is further improved when the quadratic transfer functions (QTFs) are corrected using the EXWAVE correction.

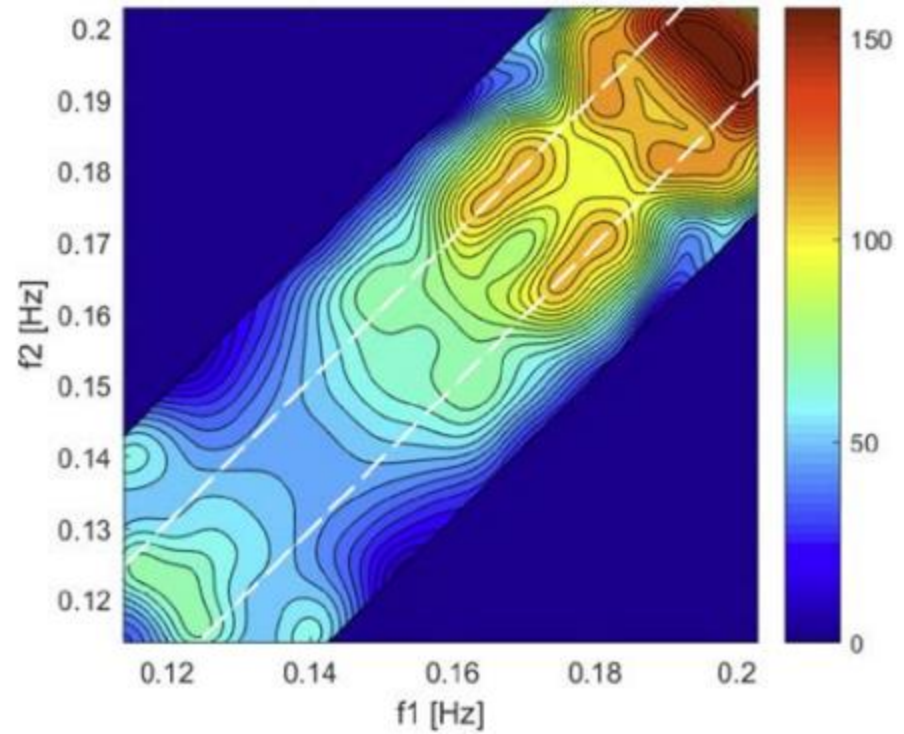


Effects on response when incorporating the EXWAVE correction

[5] LAND, E., BRINDLEY, W. & HU, Z. The Effects of Hydrodynamic and Aerodynamic Loads on the Low Frequency Responses of Floating Offshore Wind Turbines. International Conference on Offshore Mechanics and Arctic Engineering, 2022. American Society of Mechanical Engineers, V008T09A047.

Quadratic Transfer Functions (QTFs)

- Used to calculate the low-frequency forces generated from wave component pairs of frequencies f1 and f2.
- Normal generated through diffraction analysis software.



Quadratic transfer function (kNm^{-2}) from [6]

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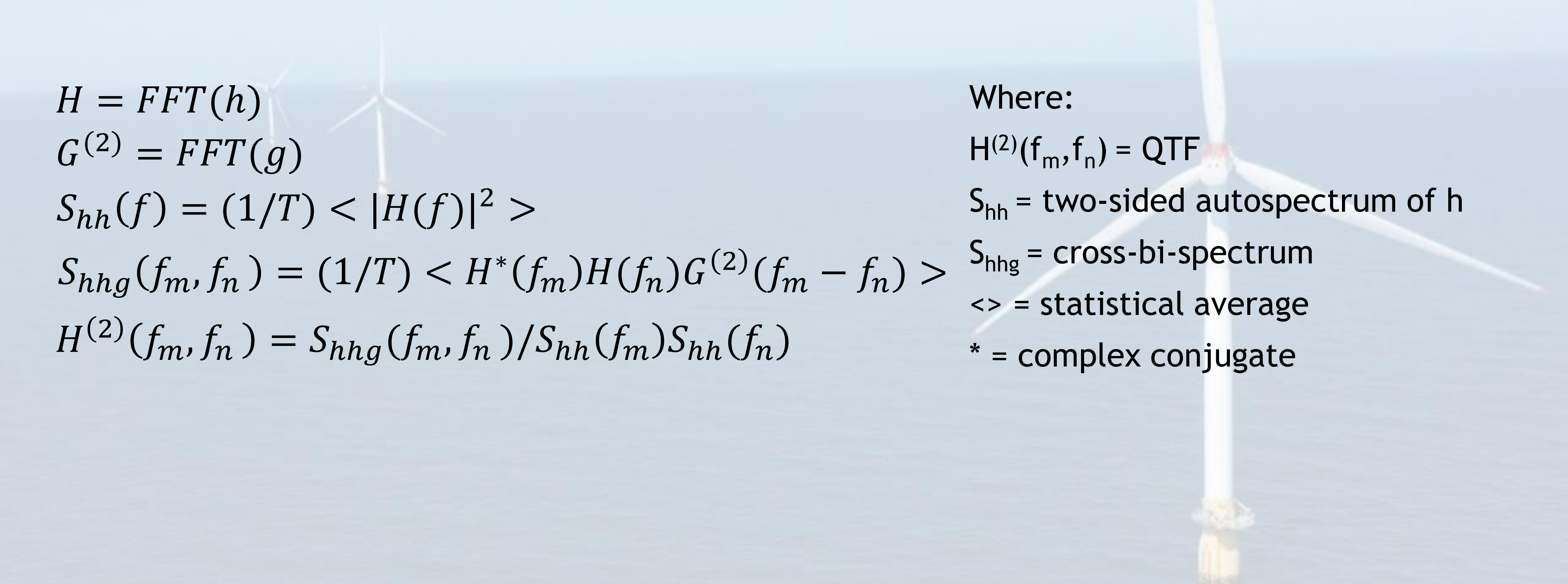
[6] Fonseca, N., Thys, M. and Berthelsen, P.A., 2021, September. Identification of wave drift force QTFs for the INO WINDMOOR floating wind turbine based on model test data and comparison with potential flow predictions. In *Journal of Physics: Conference Series* (Vol. 2018, No. 1, p. 012017). IOP Publishing.

Empirical QTF

Cross-Bi-Spectral Analysis



$$H = FFT(h)$$
$$G^{(2)} = FFT(g)$$
$$S_{hh}(f) = (1/T) < |H(f)|^2 >$$
$$S_{hhg}(f_m, f_n) = (1/T) < H^*(f_m)H(f_n)G^{(2)}(f_m - f_n) >$$
$$H^{(2)}(f_m, f_n) = S_{hhg}(f_m, f_n)/S_{hh}(f_m)S_{hh}(f_n)$$

Where:

$H^{(2)}(f_m, f_n)$ = QTF

S_{hh} = two-sided autospectrum of h

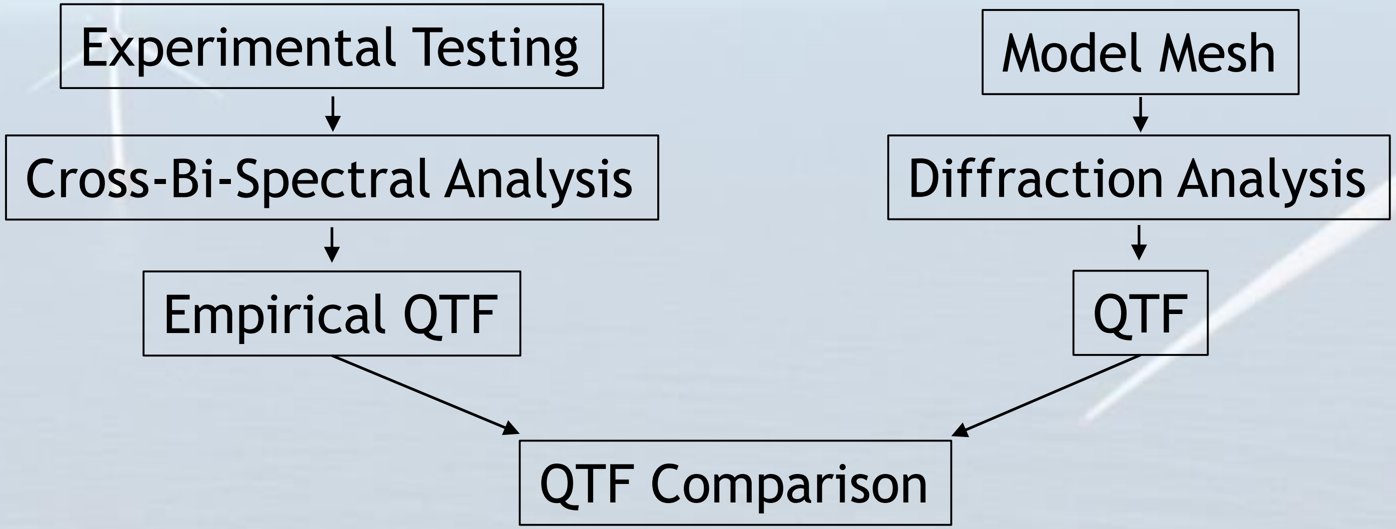
S_{hhg} = cross-bi-spectrum

<> = statistical average

* = complex conjugate

[7] STANSBERG, C. T. 1997. Linear and nonlinear system identification in model testing. *Proceedings of International Ocean and Polar Engineering Conference*, **1-9.**

Quadratic Transfer Functions (QTFs)



Experimental Testing

Cross-Bi-Spectral Analysis

Empirical QTF

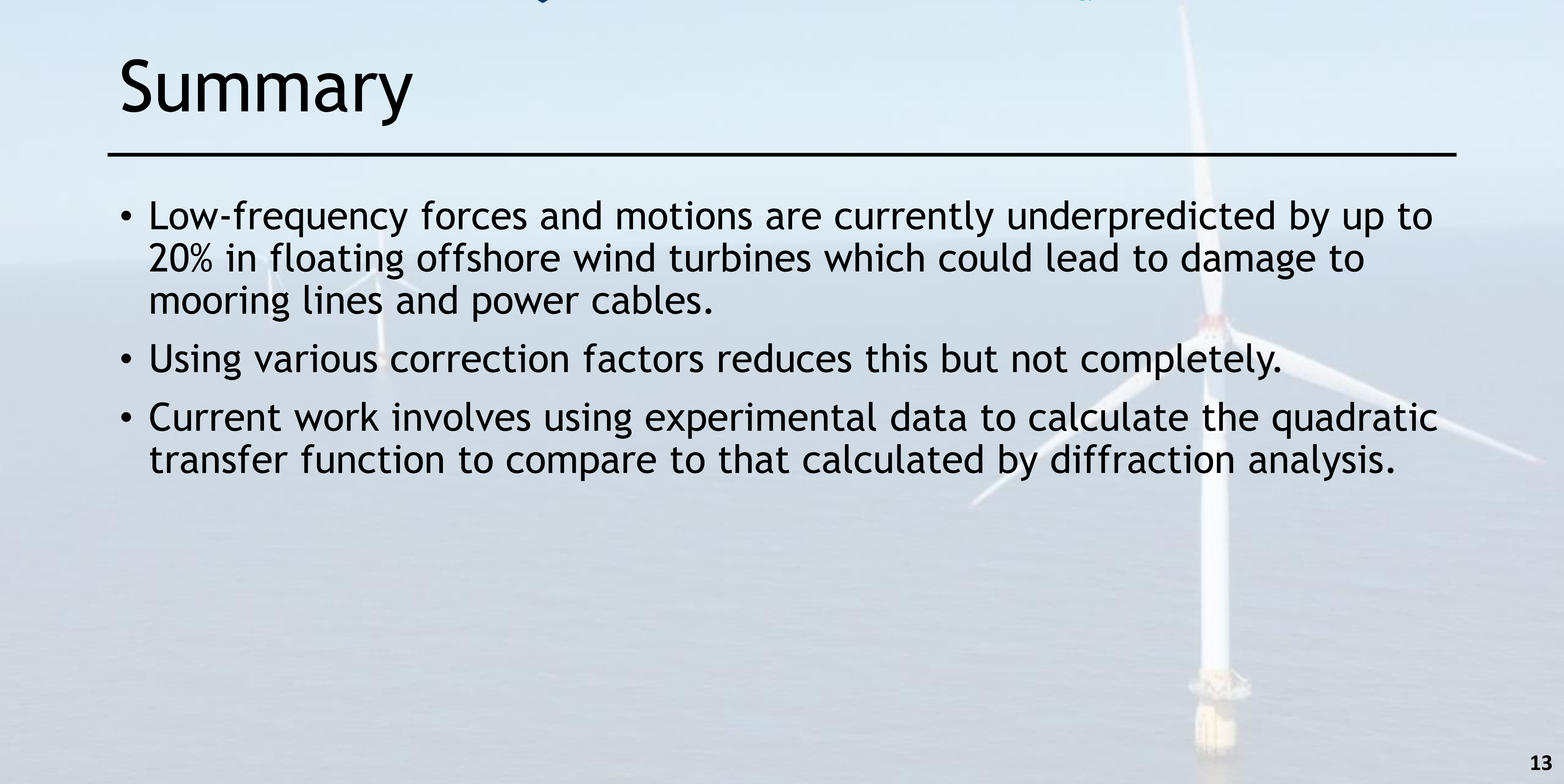
Model Mesh

Diffraction Analysis

QTF

QTF Comparison

Summary



- Low-frequency forces and motions are currently underpredicted by up to 20% in floating offshore wind turbines which could lead to damage to mooring lines and power cables.
- Using various correction factors reduces this but not completely.
- Current work involves using experimental data to calculate the quadratic transfer function to compare to that calculated by diffraction analysis.

ReNU Renewable Energy Northeast Universities

Newcastle University

CATAPULT Offshore Renewable Energy

UKRI Engineering and Physical Sciences Research Council

Thank you for Listening
Any Questions?

Email: e.land@newcastle.ac.uk

Empirical QTF

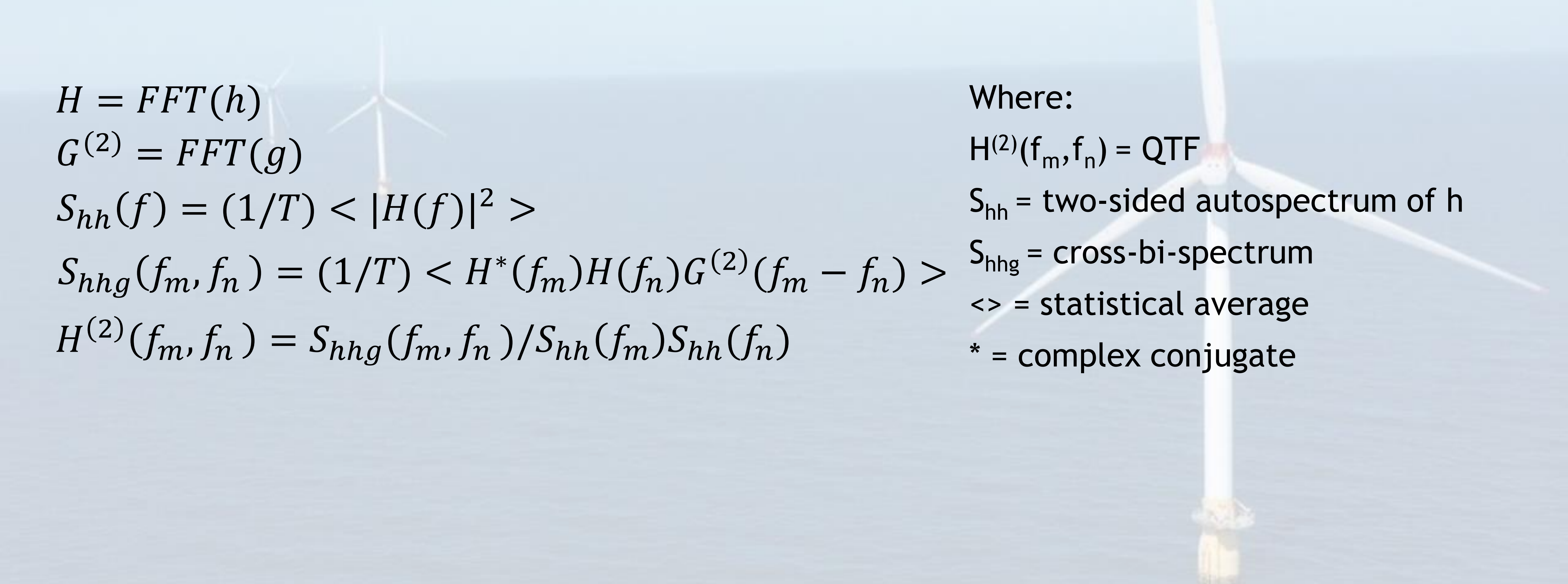
From Experiment: H (wave elevation) and X (surge motion)

$$\ddot{x}_{LF}(t) + \zeta \dot{x}_{LF}(t) + K(t) = \frac{1}{m} g(t)$$

$\ddot{x}_{LF}$ = Low-frequency surge motion
ζ = Linearised damping coefficient
K= Mooring restoring force
m = Vessel mass
g = 2nd order difference frequency wave exciting force

[7] STANSBERG, C. T. 1997. Linear and nonlinear system identification in model testing. *Proceedings of International Ocean and Polar Engineering Conference*, **1-9.**

Cross-Bi-Spectral Analysis



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