Limiting wave conditions for the safe maintenance of floating wind turbines.

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Introduction & Background

A recent Carbon Trust report has estimated that 10.7GW of floating wind could be feasible by 2030 and 70GW by 2040 [1].

The recently released offshore wind sites available for leasing in Scotland include a number of deep water sites, suitable for floating wind.

However there are still many unanswered O&M questions for floating wind – including how limited are maintenance operations by floating turbine motions?

[1] Carbon Trust 2020 *Floating Wind Joint Industry Project: Phase II summary report*

Maintenance Activities for Offshore Turbines

- Minor repair
- Major repair
- Major replacement

All of these require wind turbine technicians working within the turbine nacelle which is subject to motion.

Motion Limits for Technician Working

Research by Scheu et al [2] investigating the allowable motion for technician working on floating offshore wind turbines.

Guidance for floating wind is limited, however there is guidance available from other industries. For example guidance from Nordforsk.

Limiting Criteria	RMS Vertical Acceleration	RMS Lateral Acceleration	RMS Roll
Limiting Value	0.05g	0.04g	2.5°

Table 1. Limiting motion criteria for technician working from the Nordforsk guidance discussed by Scheu et al [2].

[2] Scheu M, Matha D, Schwarzkopf M and Kolios A 2018 Human exposure to motion during maintenance on floating offshore wind turbines *Ocean Eng.* **165** 293-306

Our Questions

How big is the wave induced structural motion of a floating wind turbine over a range of wave conditions considered suitable for maintenance operations?

Under which wave conditions does this motion exceed the motion limits for safe and effective technician working?

Our Approach

The approach taken was to calculate the wind turbine nacelle motion using a statistical frequency-domain analysis and compare this to the technician working limits from Scheu et al [2].

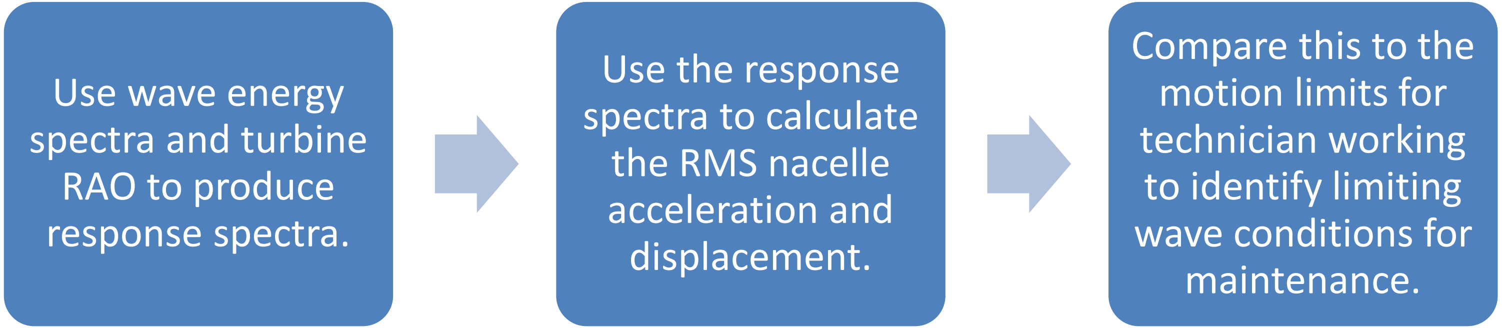


Figure 1. Overview of steps taken to determine limiting wave conditions for technician working.

Turbine: UMaine 15MW Reference Semi-submersible

IEA 15MW reference turbine supported on UMaine VolturnUS-S semi-submersible reference platform recently published by NREL [3]:

- 150m hub height, 20,093t total mass
- Includes lots of hydrodynamic data

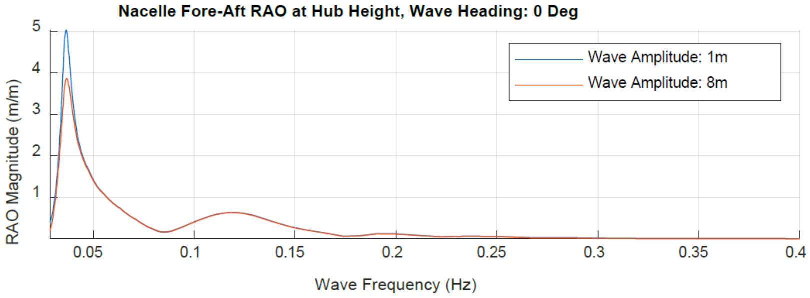


Figure 2. Turbine nacelle fore-aft RAO taken from [3].

Figure 3. UMaine 15MW reference platform [3].

[3] Allen, C. et al *Definition of the UMaine VolturnUS-S Reference Platform Developed for the IEA Wind 15-Megawatt Offshore Reference Wind Turbine.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-76773.

Frequency-domain analysis

Floating structures (including non-operational turbines) can be represented accurately as a linear-system in the frequency domain.

Wave energy spectrum → Floating turbine structural and hydrodynamic properties – **response amplitude operator.** → Turbine motion response spectrum

Some very good publications on frequency-domain analysis of floating turbines [5], [6].

[5] Pegalajar-Jurado A, Borg M and Bredmose H 2018 An efficient frequency-domain model for quick load analysis of floating offshore wind turbines *Wind Energy Sci.* **3** 693-712

[6] Guanche R, Martini M, Jurado A and Losada I 2016 Walk-to-work accessibility assessment for floating offshore wind turbines *Ocean Eng.* **116** 216-25

Method – wave energy spectrum and RAO

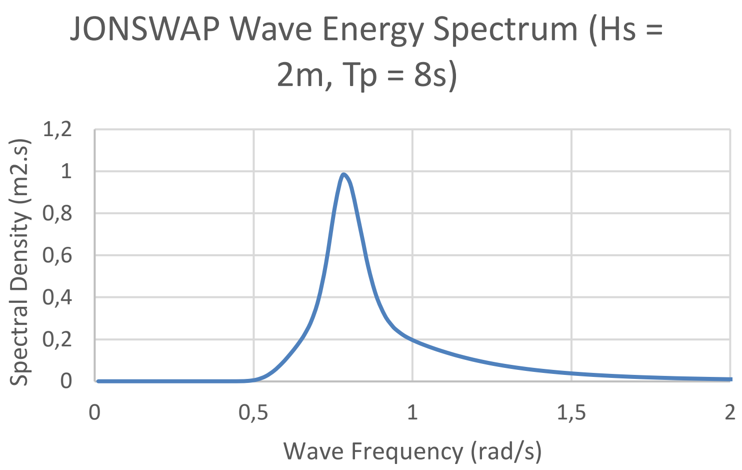


Figure 5. JONSWAP wave energy spectrum example.

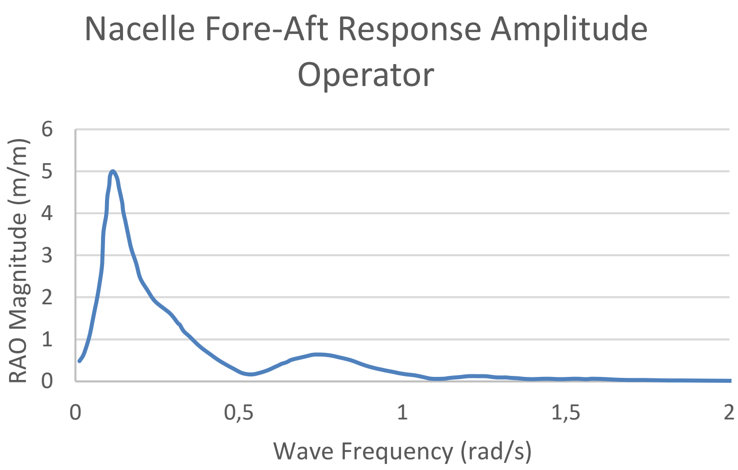


Figure 6. Turbine nacelle fore-aft RAO extracted from [3].

$$S_R(\omega) = RAO^2 * S_W(\omega)$$

Method – response spectrum & motion

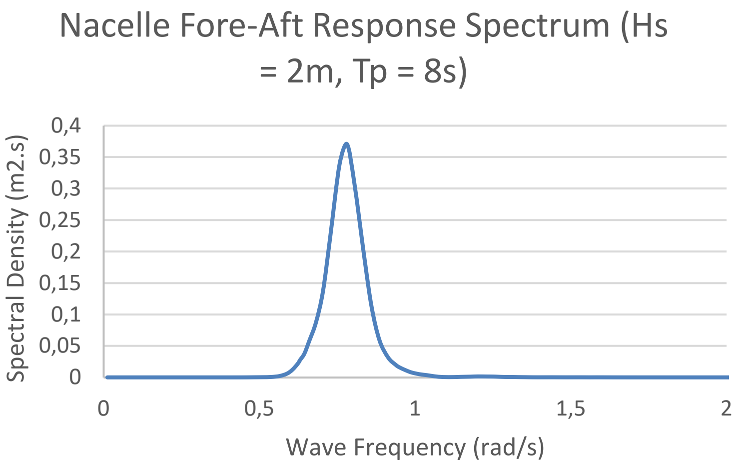


Figure 7. Motion response spectrum example.

$$Amplitude_{RMS} = \sqrt{\int_0^\infty S_R(\omega).d\omega}$$

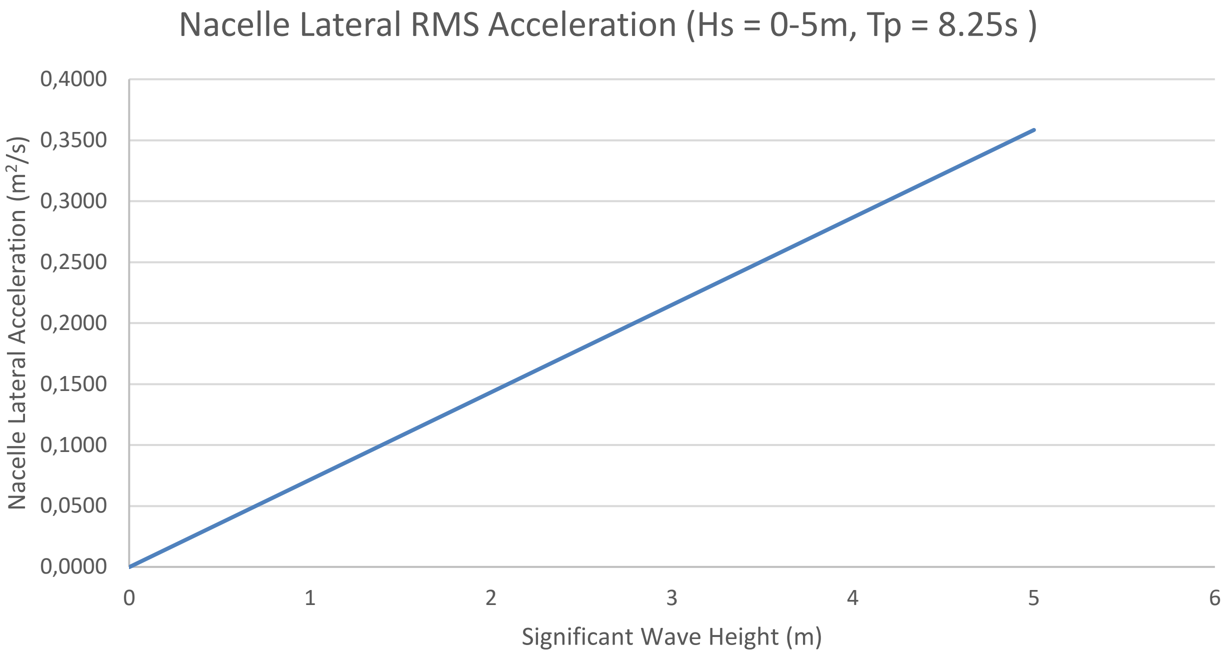
$$Acceleration_{RMS} = \sqrt{\int_0^\infty |\omega|^4.S_R(\omega).d\omega}$$

Method – limiting conditions

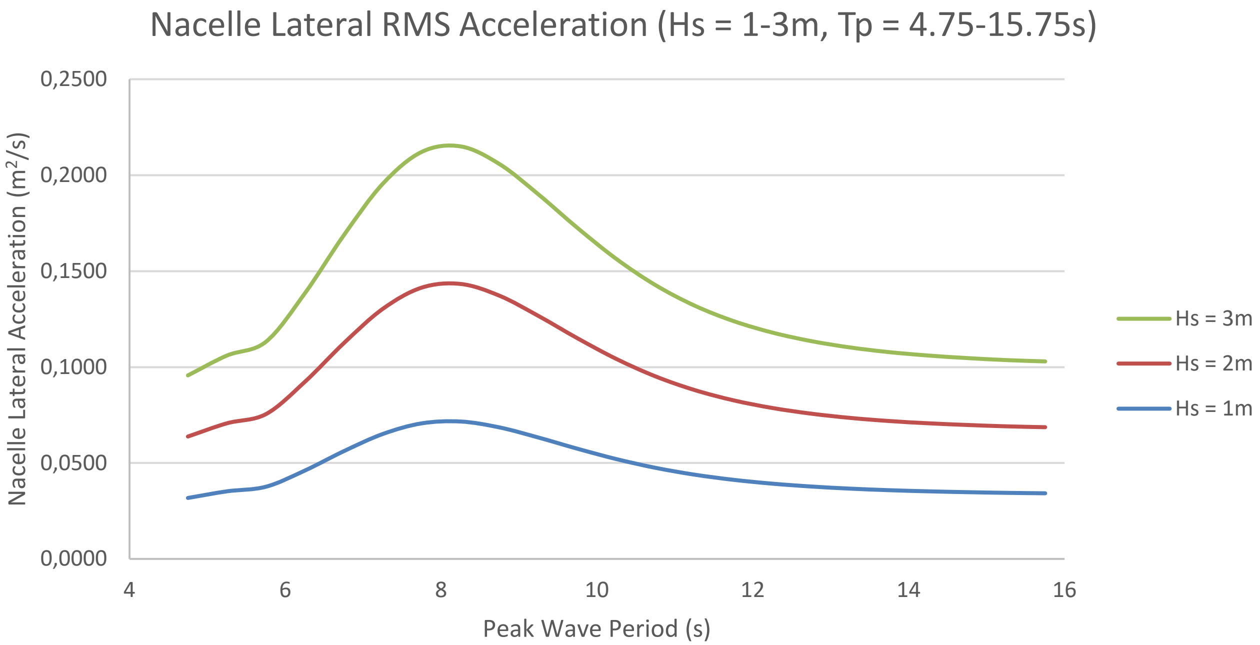
RMS values of nacelle lateral acceleration, vertical acceleration and pitch amplitude were calculated over a range of significant wave height (Hs) and peak wave period combinations (Tp).

Motion is compared to the technician working motion limits to identify under which conditions these limits are exceeded.

Results: Lateral RMS acceleration with varying Hs

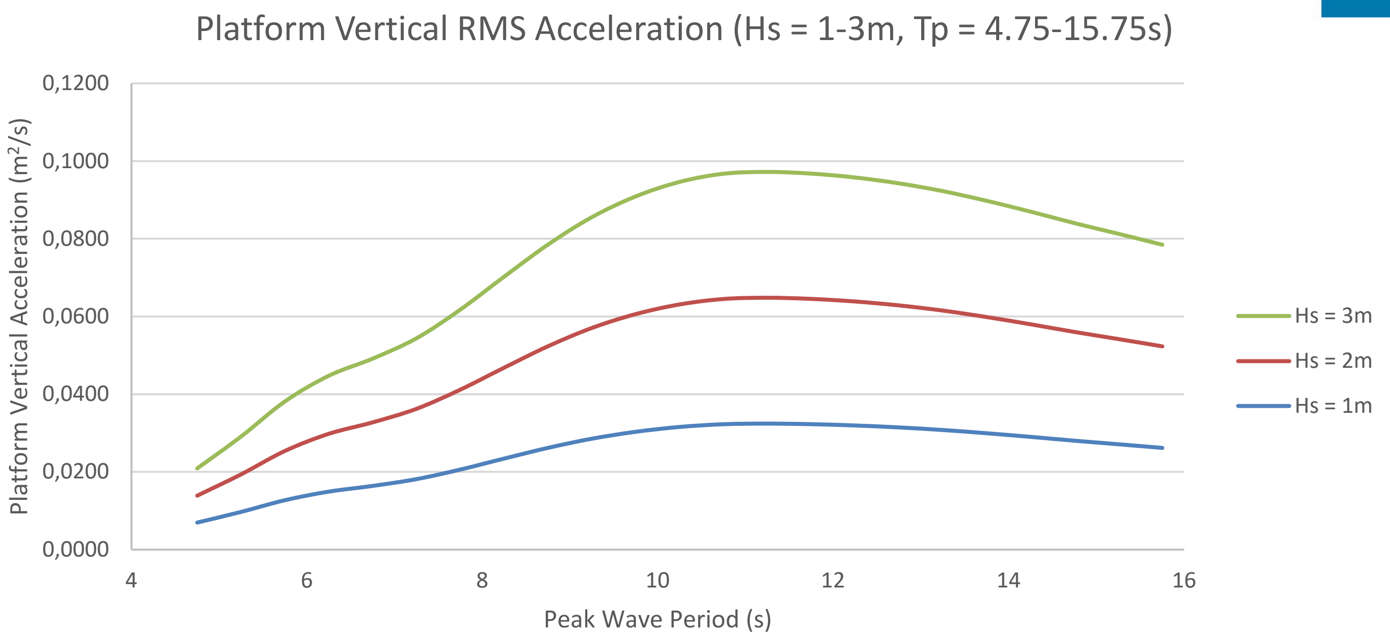


Results: Lateral RMS acceleration with varying Tp



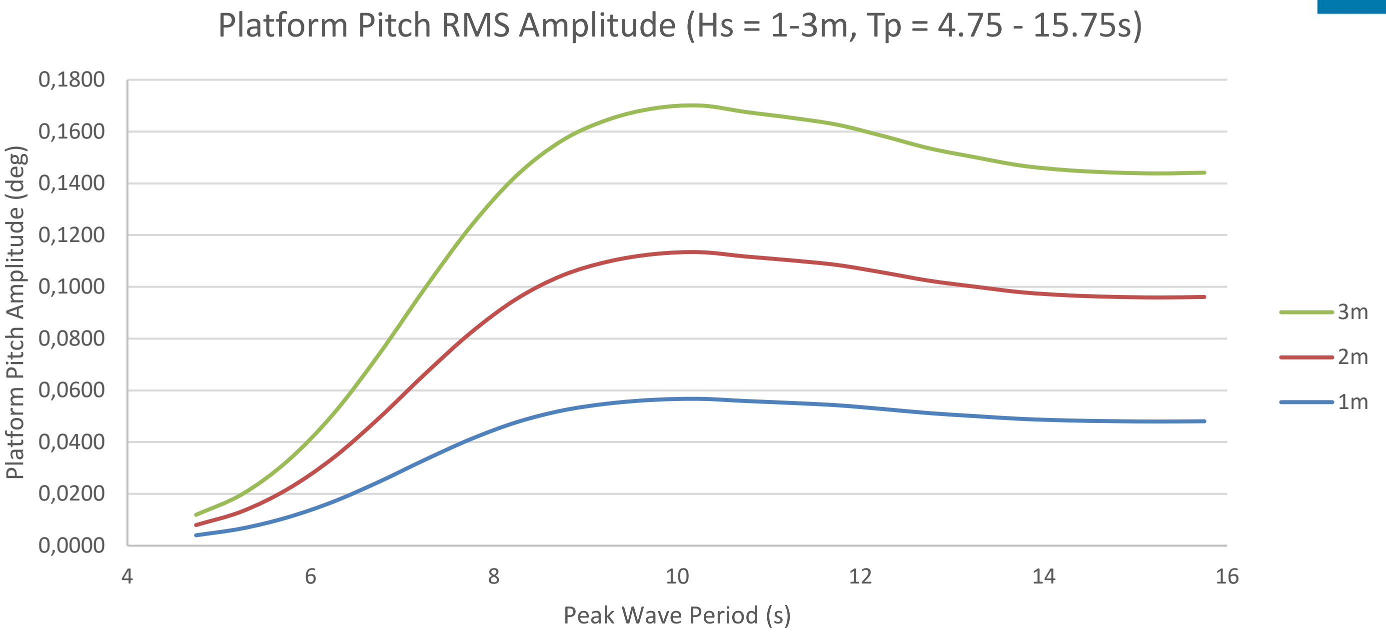
At no combination of Hs and Tp was the nacelle lateral RMS acceleration limit of $0.39m^2/s$ exceeded.

Results: Vertical RMS acceleration with varying Tp



At no combination of Hs and Tp was the platform vertical RMS acceleration (assumed to be equal to the nacelle vertical acceleration) limit of 0.49m^2/s exceeded.

Results: Pitch RMS amplitude with varying Tp



At no combination of Hs and Tp was the platform pitch RMS amplitude (assumed to be equal to the nacelle pitch amplitude) limit of 2.5° exceeded.

Findings from Analysis

Using the approach outlined, the calculated motion for the IEA 15MW reference turbine with UMaine reference platform did not exceed the motion limits for safe and effective technician working over the range of wave conditions judged likely for maintenance tasks. Nacelle lateral RMS acceleration is the closest to being exceeded.

Note that this analysis was only completed for 0 degrees wave heading - motion will be affected by direction. This analysis is also highly dependent of the platform type, size, design, etc.

Shows clearly the influence of wave period, as well as wave height, on floating wind turbine motion.

Next Steps

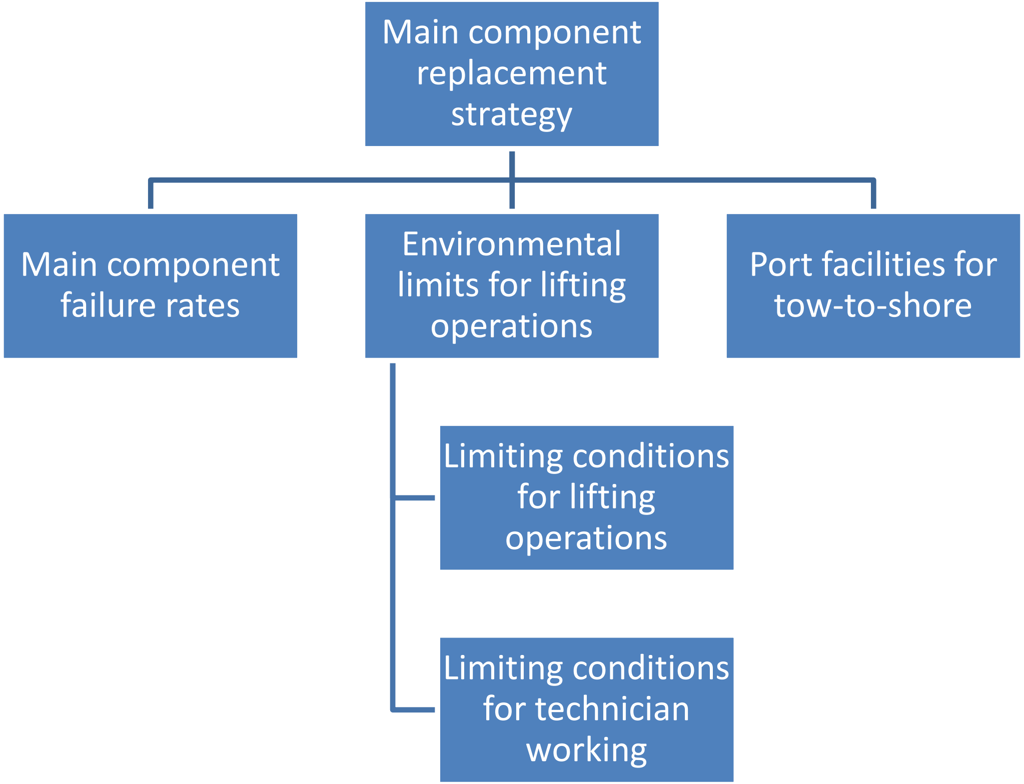


Figure 8. Overview of overall research areas and where presented work fits in.

Conclusions

Statistical frequency-domain analysis of 15MW floating reference turbine to determine when motion limits for technician working are exceeded.

It was found that the limits considered were not exceeded under the conditions assessed using this approach. But wave period does significantly influence turbine motion.

We will use these findings in future work modelling floating wind maintenance strategies.

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