Innovative Mooring Design to Raise Yield of Floating Wind Farms in Deep Water

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BACKGROUND

There is a **unique opportunity** with floating offshore wind turbines (FOWTs) **to increase the power density** of the wind farms. Kent have explored the possibility of designing asymmetric moorings for FOWTs so the turbines move position depending on wind direction to **minimise wake losses**, maximising the power density of the farm. I.e. The turbines can **passively change position**, defined by the wind direction, seeking to minimise the interaction between upstream and downstream turbines by changing the effective spacing.

OBJECTIVES

- Investigate **asymmetric mooring systems** which allow significant translational movement perpendicular to wind direction
- Create a program which can calculate the wake losses[1,2] for turbines which **move translationally based on wind speed and wind direction**
- Propose hypothetical mooring arrangements to further **investigate the potential of innovative mooring design** to raise yield
- Run annual **energy yield calculations** for the asymmetric and hypothetical mooring arrangements
- **Compare** the results

METHODS

To conceptualise the innovative mooring solution:

- **Multi-objective design optimisation** tool (MODOT) used to drive simplified AQWA LIBRIUM model aiming to **maximise translational movement** within bounds
- LIBRIUM analyses were complete for each wind direction and wind speed to extract the translational positions of the turbines for each variable

To calculate the **energy yield**:

- A spreadsheet-based tool which iterates through each wind direction, wind speed and probability of occurrence

To configure the hypothetical solutions:

- A **binary design** was selected for its simplicity consisting of 2 possible locations for each floating turbine, with a 180^{o} window for each location dependent on axis orientation

To compare the results:

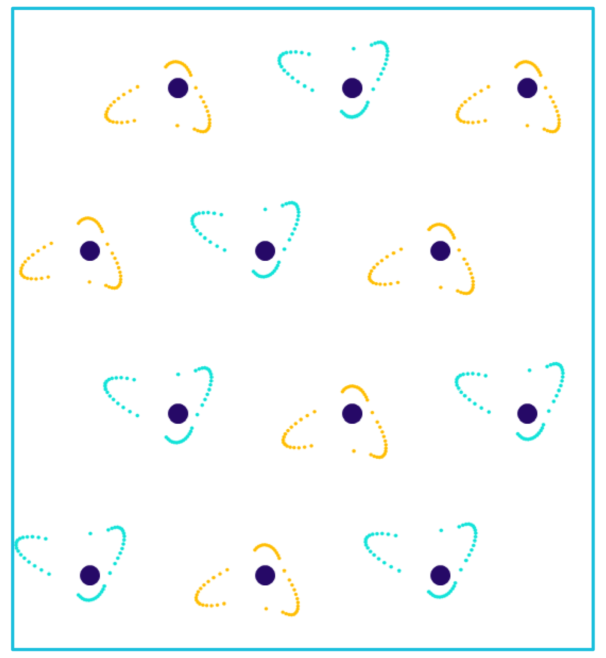
- **Annual total energy yield** is used to compare the mooring systems investigated in this study to the yield of a fixed farm

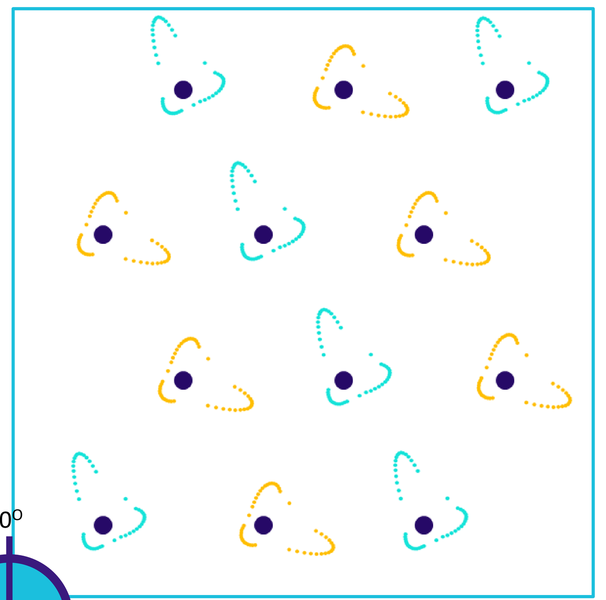
RESULTS

↑ Horns Rev 2 offshore wind farm in fog showing wake effects. Photo[3] particularly highlights the increased turbulence caused by upwind turbines. These turbines are 2.3MW.

↓ The table below shows the different mooring layouts investigated and the annual power output based on wind scatter data representative of the North Sea.

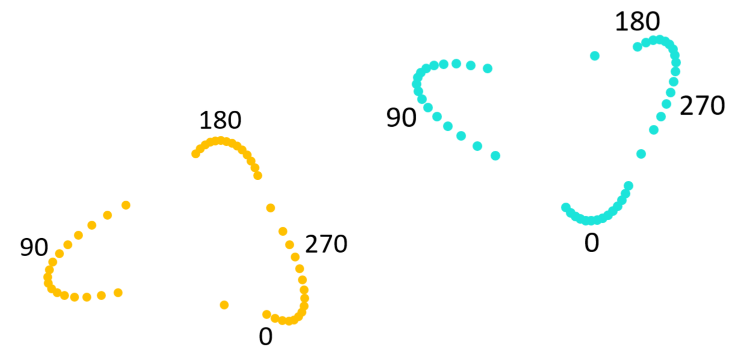
Layout	Description	Power [MWh/year]	%Increase compared to Layout 0
0	Conventional moorings	980,223	-
1a	Floating asymmetric	980,293	0.01
1b	Floating asymmetric prevailing	981,438	0.12
1c	Scaled 1b	982,908	0.27
2a	Binary design 45/45^{O}	981,112	0.09
2b	Binary design 0/180^{O}	983,220	0.31





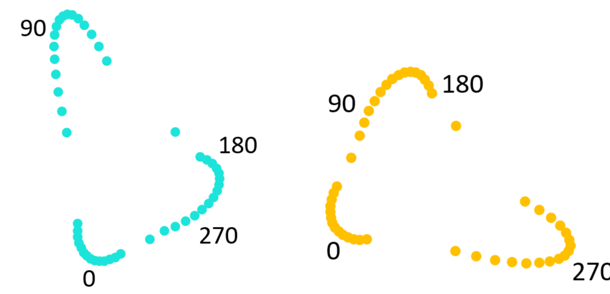
←Layout 1a:

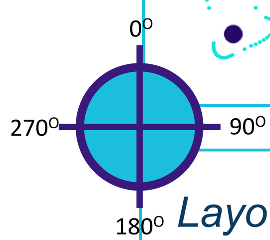
Expected to be optimised for the 0 and 270 degree directions, so minimal annual energy yield benefit due to wind scatter data used.



←Layout 1b/c:

Reorientated layout 1a for expected maximum benefit between 180 and 270 degrees.



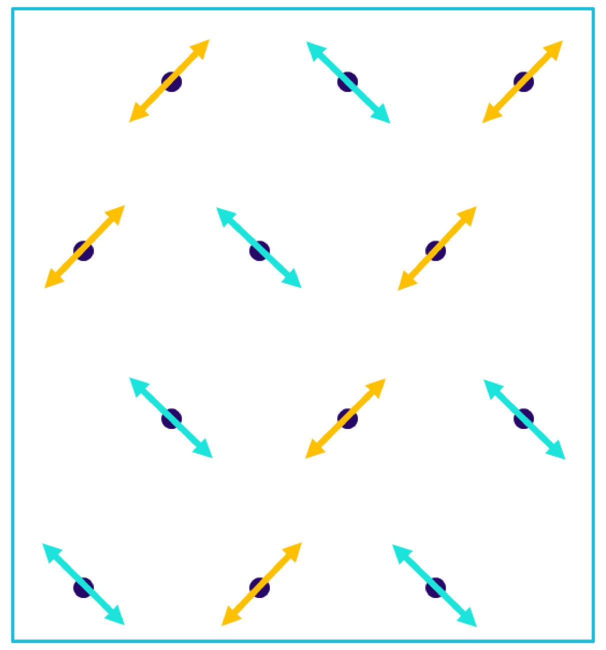


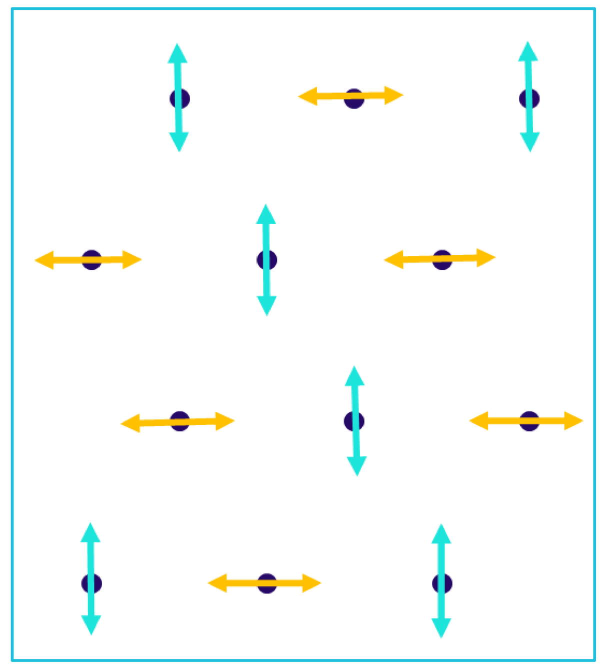
Layout 2a → (top):

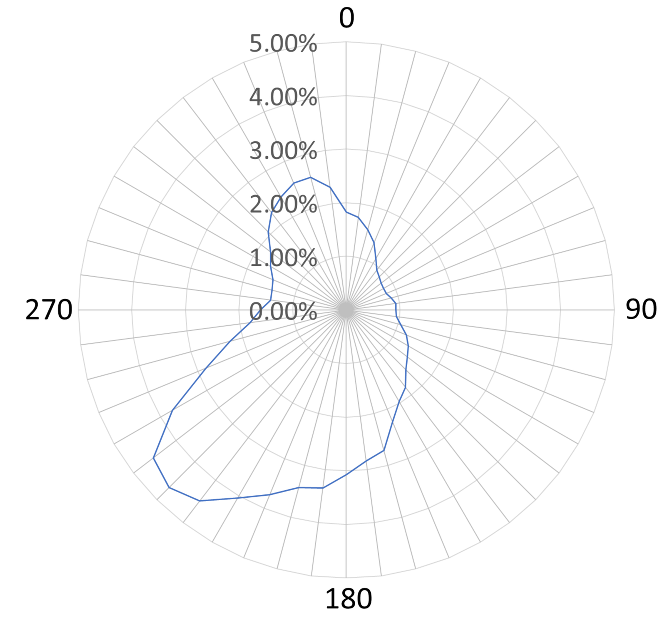
45 degree angled arrows. Turbines programmed to be positioned at either one end of the arrow head, or the other depending on which 180 degree hemisphere the wind direction is.

Layout 2b → (bottom):

0 degree angled arrows. In theory more optimal for wind scatter (below)







CONCLUSIONS

The potential benefit of designing asymmetric moorings in terms of energy yield has been investigated. A multi-objective design optimisation tool was successfully used to drive the possible mooring design for layouts 1a and 1b. A simple realistic mooring system and a hypothetical "binary" system were designed and used to in this study. The simple realistic mooring system has been modelled using springs, so taut/semi-taut moorings are most likely to work with this innovation. The orientation of the mooring systems was considered and the annual energy yield for each system was calculated based on wind turbine wake modelling.

All of the mooring layouts analysed resulted in an increase in energy yield of the farm. The most realistic moorings in Layout 1a caused the smallest energy yield increase and the hypothetical binary design in Layout 2b caused the greatest increase in energy yield of 2997MWh a year. The general trend shows that the greater offset of the moorings, the greater the energy yield of the farm. However, the greater required offsets will cause some challenges in terms of both detailed mooring design and dynamic cable layout/design.

Further optimisation could be programmed into the tool. This would orientate the whole wind farm, in addition to orientating the asymmetric moorings to result in the most optimum layout for yield. Micrositing and wake steering tools and optimisations could also be incorporated with this tool for maximum energy yield. For the results given in this part of the study, only a single wind probability distribution is considered. Different distributions would drive different mooring offsets to be beneficial to energy yield.

ACKNOWLEDGEMENTS

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REFERENCES

1 **Jensen (1983)/Katíc (1986)** – Park model and **Sanderhoff (1993)** PARK- User's Guide. A PC-program for calculation of wind turbine park performance. Risø National Laboratory. Risø-I No. 668(EN)

2 **Ishihara and Qian (2018)** A new Gaussian-based analytical wake model for wind turbines considering ambient turbulence intensities and thrust coefficient effects. Journal of Wind Engineering & Industrial Aerodynamics 177 p275-292

3 Photo of Horns Rev 2 by: **Bel Air Aviation** – Helicopter Services

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