University of Strathclyde Engineering

Multi Rotor Solution for Large Scale Offshore Wind Power

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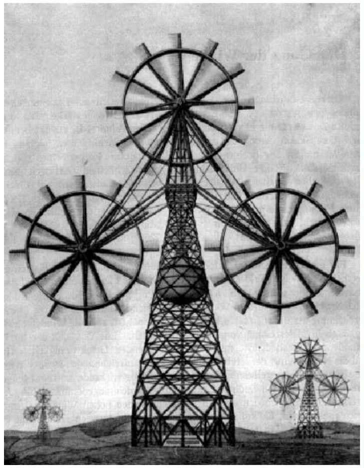
Deepwind, Trondheim 2017

History of Multi Rotor Systems



Honnef 1926

Heronemus 1976

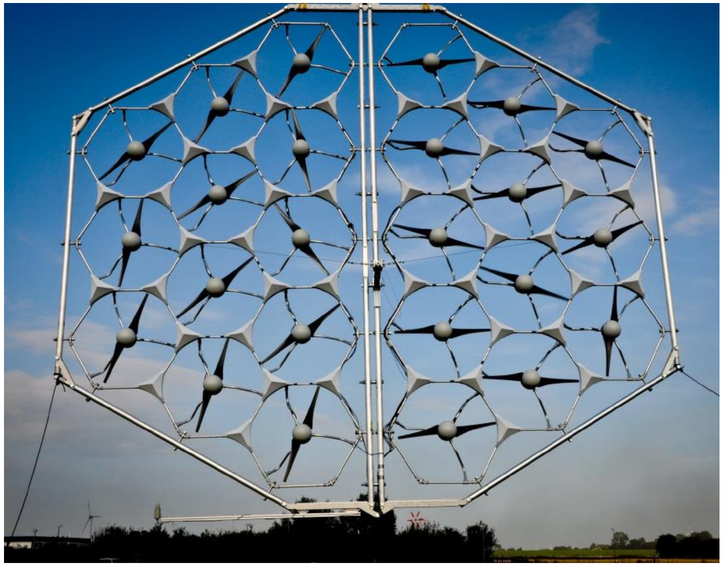
Lagerwey 1995

Vestas 2016

MRS today

Vestas

Wind Lens Kyushu



Brose MRS

A variety of systems – different scales, different design objectives but common interests in R&D progress and growing concept credibility

Innwind.eu - Partners Roles

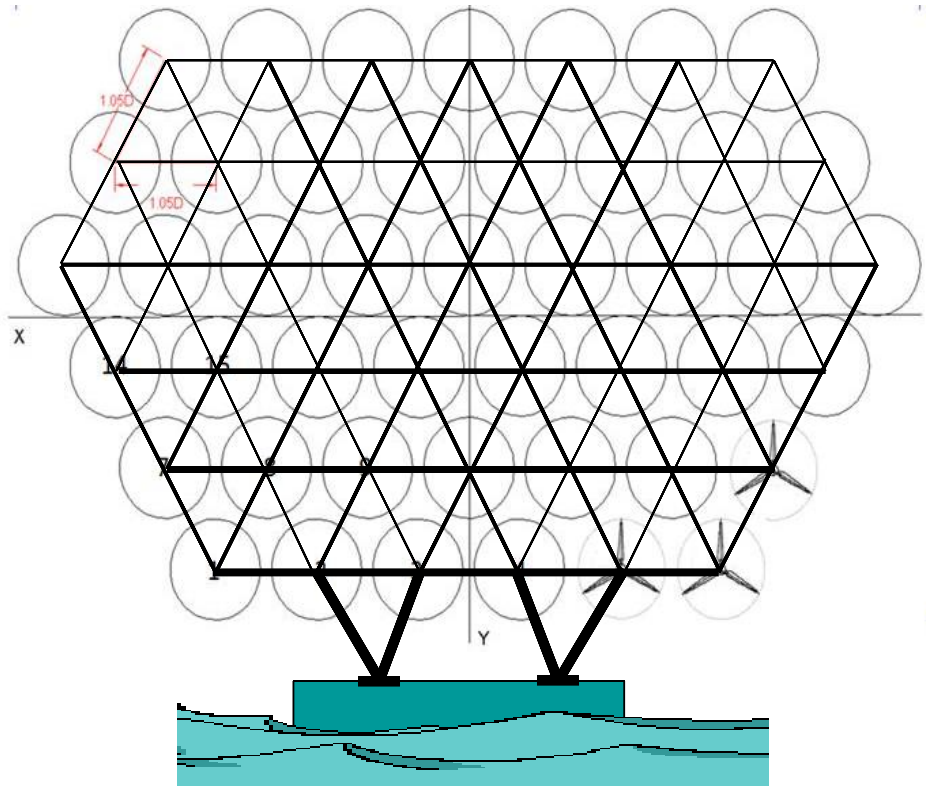
SU - Technical coordination, concept design, load calculation using:

GLGH (Now DNV GL Energy) - Bladed for 45 rotors.

CRES – support structure and floater

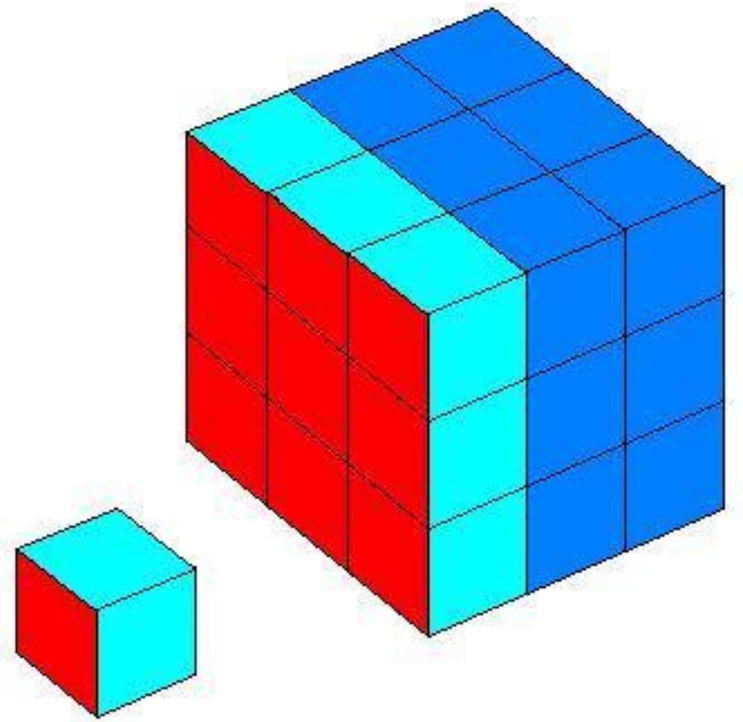
NTUA – validation of aerodynamics: rotor interaction, structure blockage.

Multi Rotor System Concept



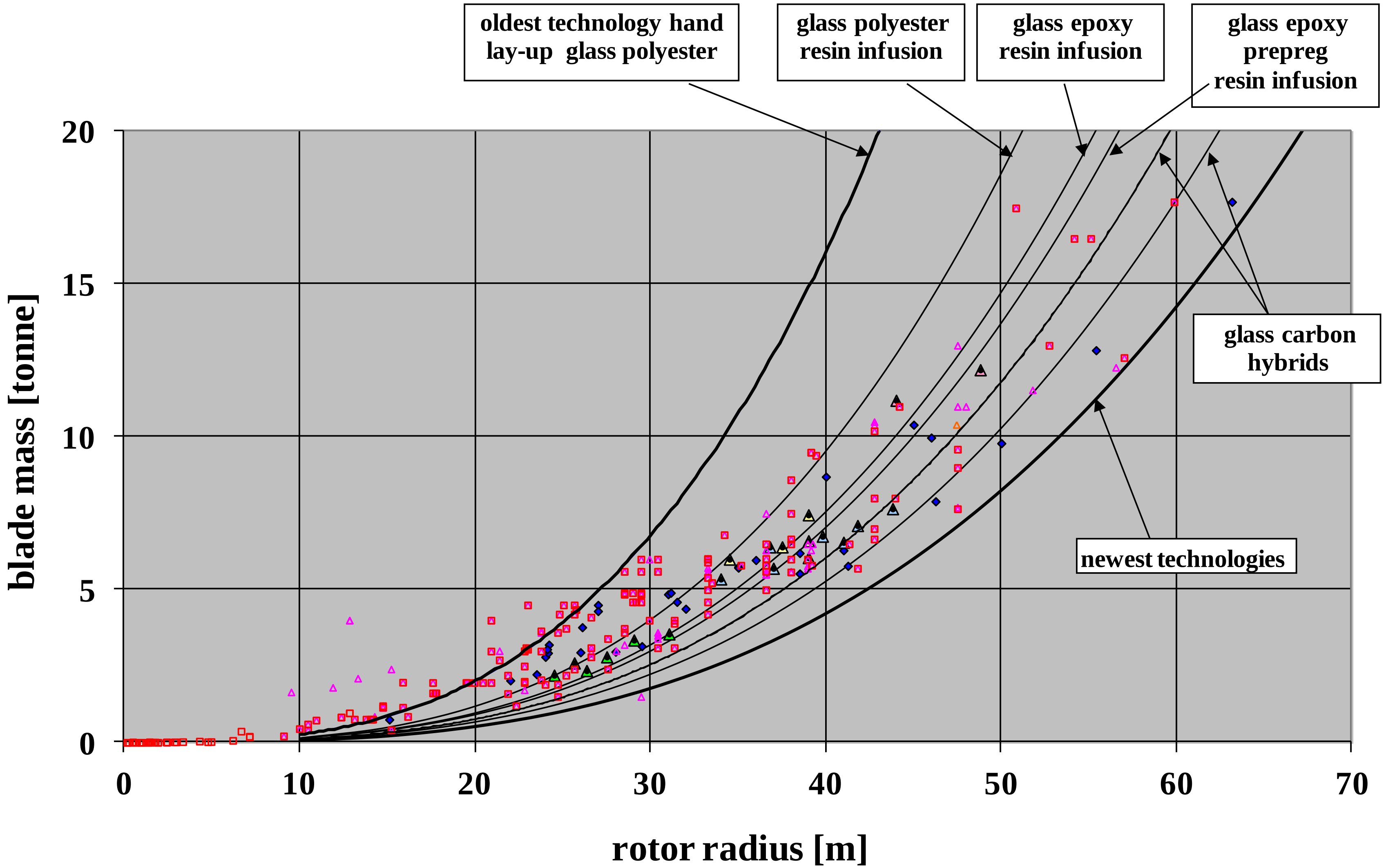
- 45 rotors each of 41 m diameter and of 444 kW rated output power comprising a net rated capacity of 20 MW
- Rotors on a triangular lattice arrangement with minimum spacing of 2.5% of diameter
- Variable speed, pitch regulated with direct drive PMG power conversion
- Jacket foundation for comparability with DTU 10 MW reference design although floating system could be advantageous

Why Multi-Rotors?



National Geographic 1976

Is cubic scaling really true? – Yes!



MRS Issues

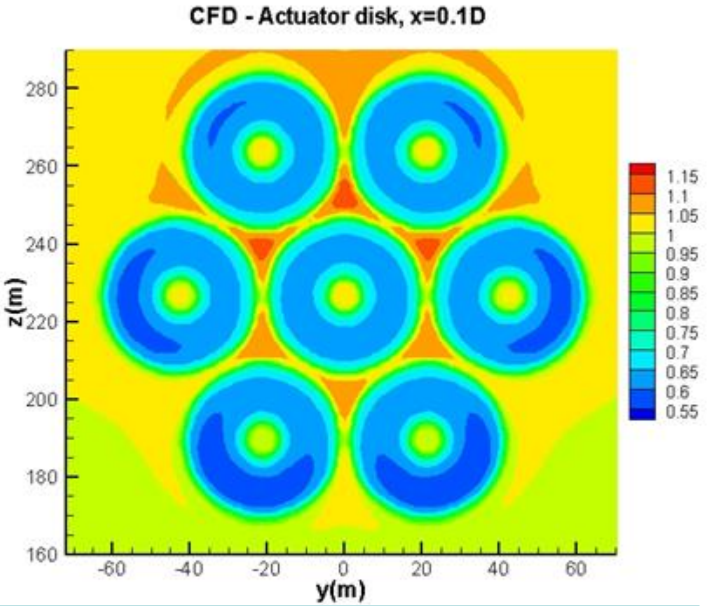
a) Aerodynamic interaction of and array of closely spaced rotors

b) Mass and cost of support structure

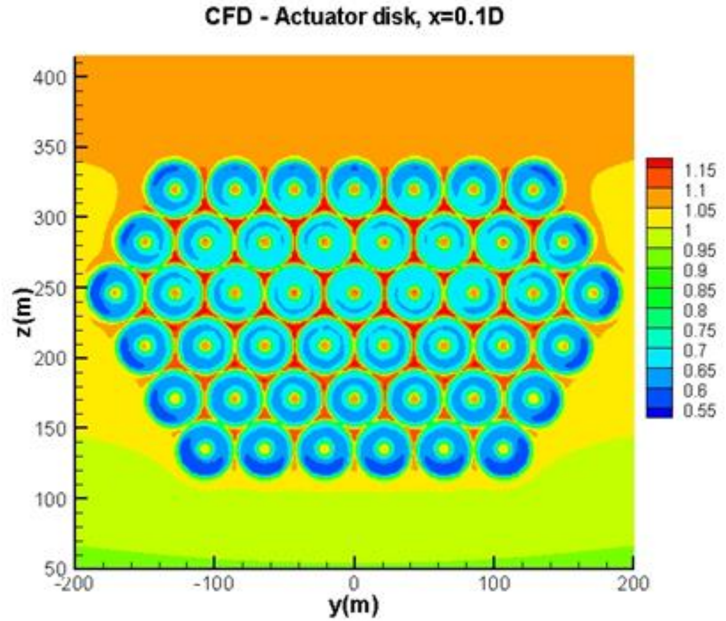
c) Feasibility and cost of system yawing

d) Reliability with much greater total part count

Aerodynamic Evaluation (NTUA)



7 rotors, 2.6% power gain

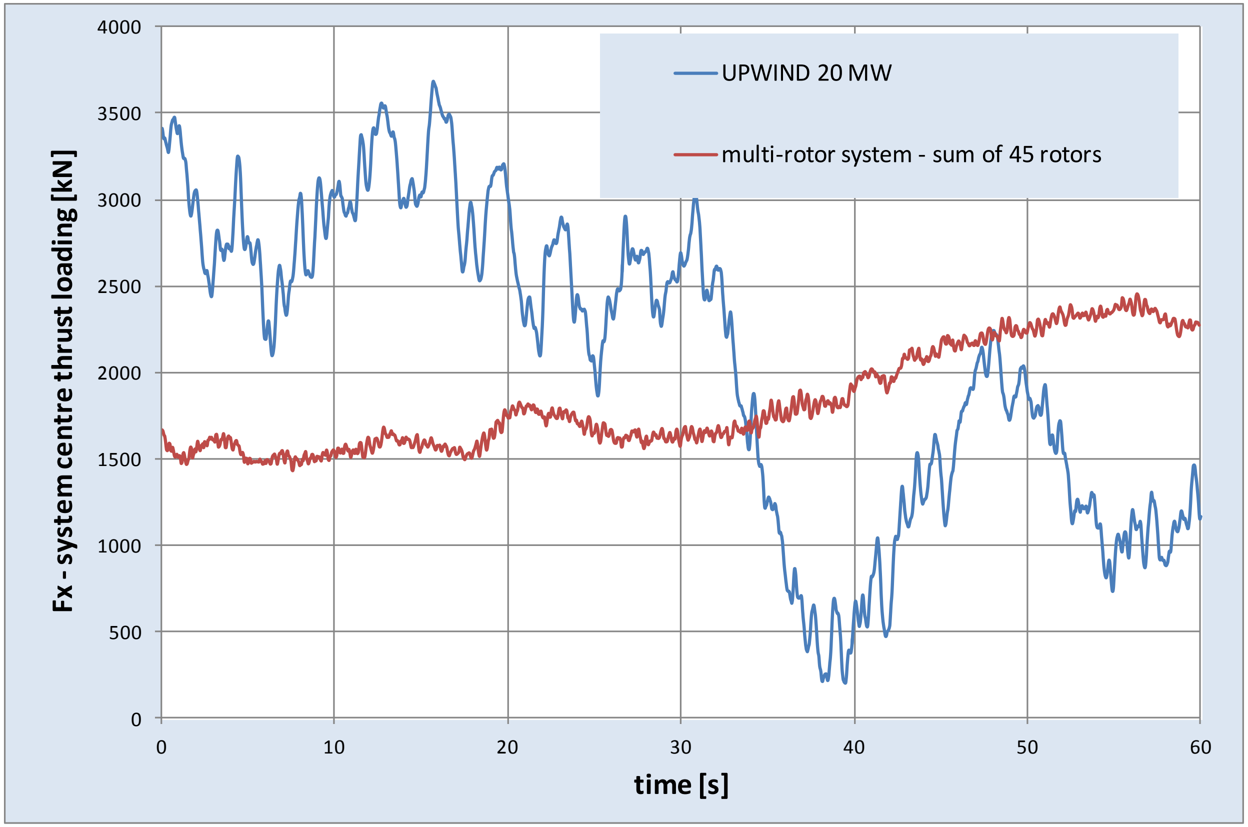


45 rotors, 8.0% power gain

In the above the rotors are actuator discs. NTUA repeated the analysis using a vortex code (blades individually represented) with similar overall results.

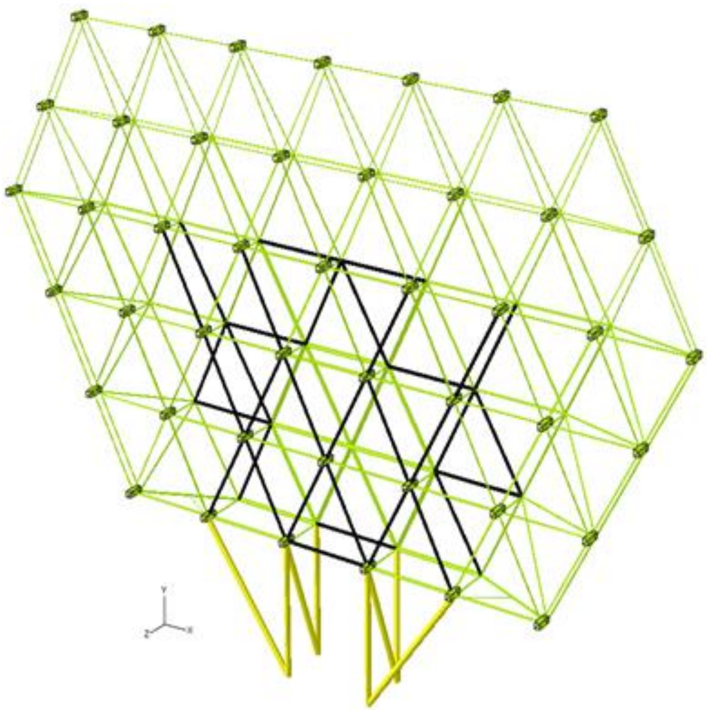
In a separate study of the University of Strathclyde it was shown that the MRS would outperform a large rotor in turbulent wind conditions due to the small rotors having intrinsically faster dynamic response.

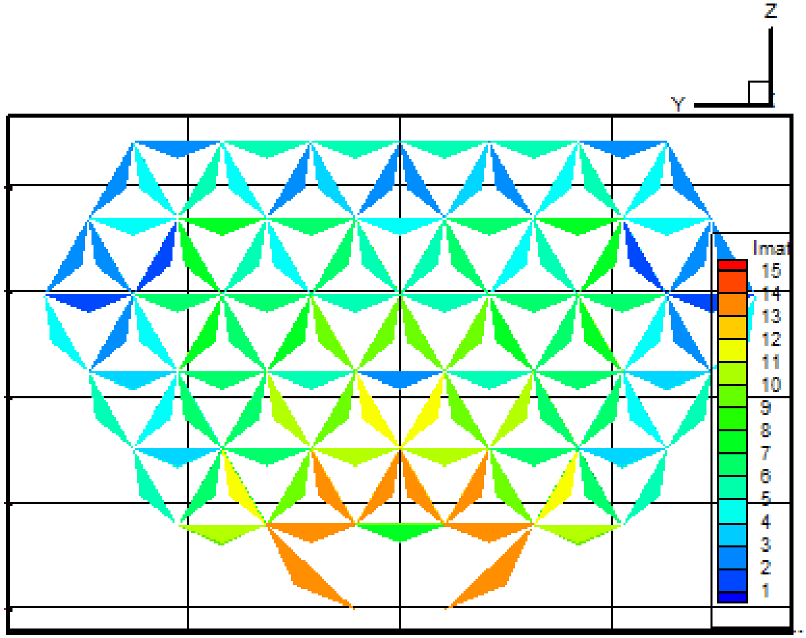
Comparison with 20 MW single rotor



Loads were derived using a specially extended form of DNV GL Bladed software which could deal with independent operation of 45 rotors in a turbulent wind field. Time series of the 6 load components at each rotor centre were used as input for the support structure design.

Multi Rotor System –Structure Design (CRES)





The structure design accommodates a severe robustness criterion – overall integrity is preserved according to demanded reliability criteria in event of failure of most highly stressed member

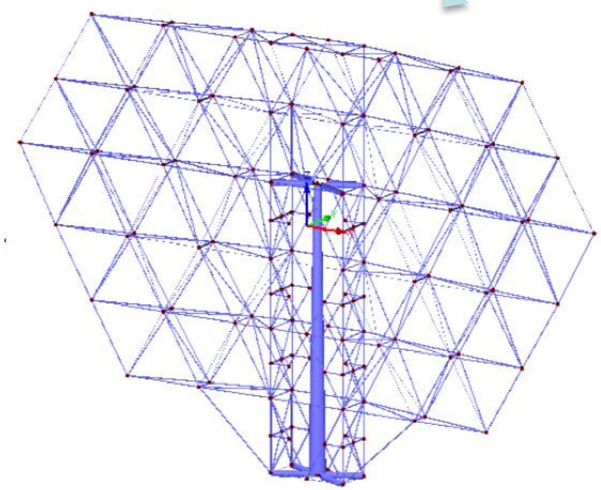
Yaw System Design

- Development of a yaw system specification
- Evaluation of bearing arrangements and loads
- Effects of structure aerodynamic drag on yaw stability
- Feasibility of yawing operation using differential control of rotor thrusts via blade pitch control (work in Innwind Task 1.4 ongoing in the PhD of Ewan McMahon of the University of Strathclyde)

Yaw System Design – twin bearings

Concept illustration at 5 MW scale

Design for 20 MW MRS developed by HAW Hamburg using RSTAB, a commercial analysis program for 3D beam structures. Prior to developing solutions with yawing capability, as a validation, they first evaluated the CRES design for DLC 1.3 with similar results for system mass.



	Semi-tower design	Reference design
	Mass [t]t	Mass [t]
Yaw Bearing connection top	390	-
Yaw Bearing connection bottom	17	-
Yaw bearings	78	
Tower	1520	-
Space Frame with rotor nacelle assemblies	1850	3760
Overall support structure	3855	3760

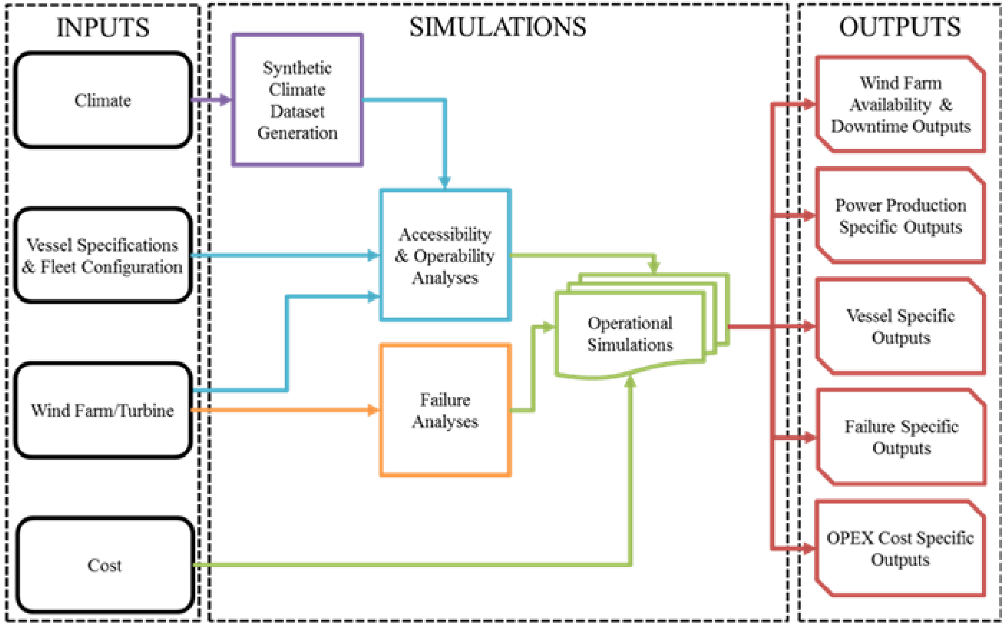
The semi-tower solution is a little more massive than the final CRES design but incorporates yawing capability. The overall structure weight and cost benefits from the frame being "hung" on the bearings with more members in tension compared to a base supported structure

O&M of the MRS

a) The MRS is significantly different from conventional technology in O&M aspects.

b) A detailed O&M model for cost optimisation of conventional wind farms (Dinwoodie, PhD thesis) was adapted to capture some of the most significant differences of the MRS

c) This was supported by work on availability and production (but excluding cost impacts) by DTU in Task 1.34 which highlighted availability penalties if all turbines required to be shut down during maintenance.



O&M Results

a) In respect of availability, the O&M modelling of Dinwoodie (Strathclyde) and of Gintautas (DTU, Task 13.4) was very similar for the MRS although Dinwoodie predicted lower availability of the DTU reference wind turbine (RWT) than the 97% assumed in Innwind

b) The Dinwoodie model predicted similar O&M costs as were attributed to the RWT in the Task 1.2 cost model and all results (O&M cost) of the UoS model were subsequently scaled by a factor so that agreement with the RWT was exact.

c) A 13% reduction in O&M cost was predicted for the MRS strongly related to the avoidance of using jack-up vessels for any level of rotor system failure.

MRS Feasibility and Cost?

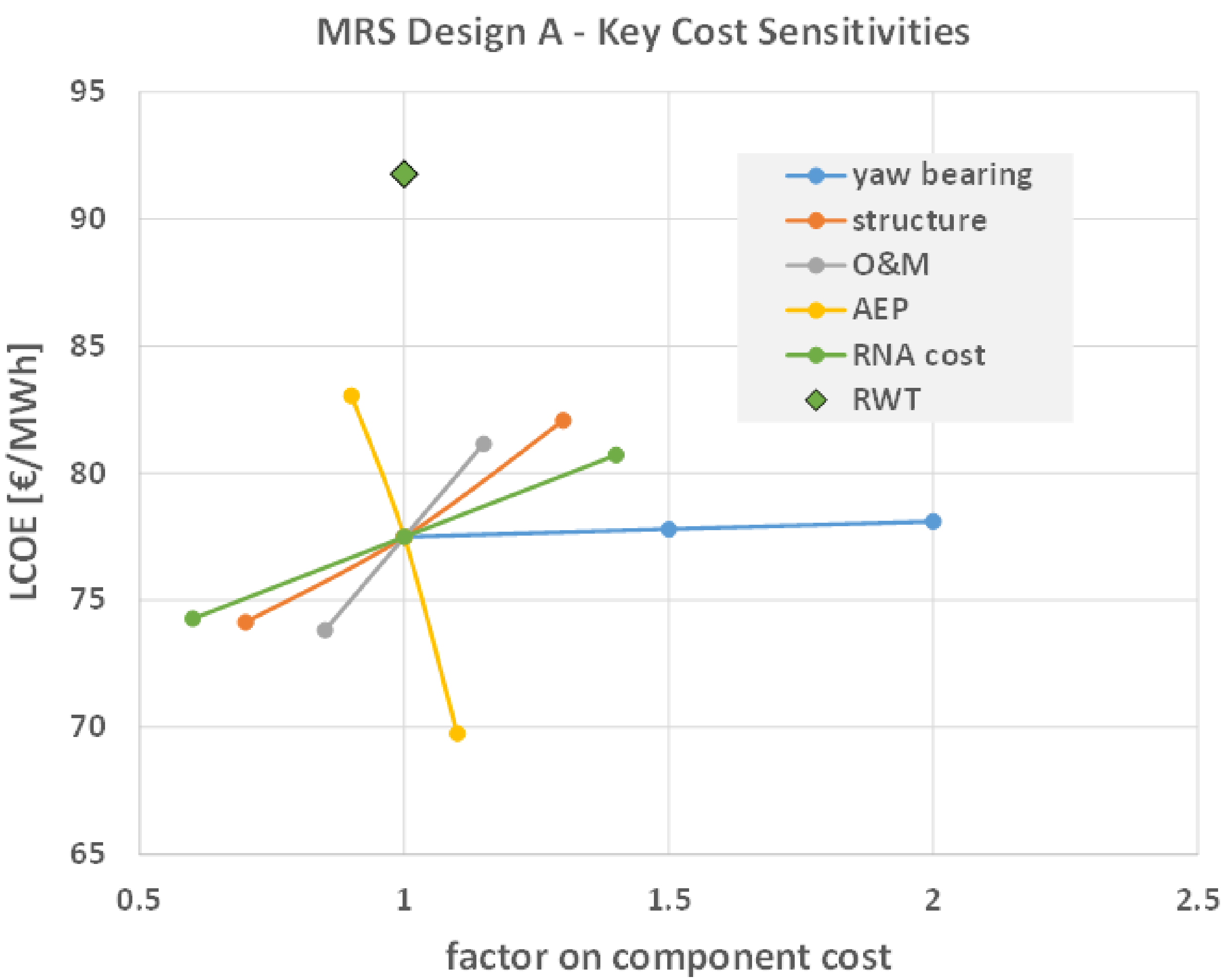
a) Very large structure but not unusual. Similar to jacket above water. Lattice structure in this and many other applications is the most efficient in total weight of materials.

b) System yawing – somewhat new challenge, definitely feasible and looks to be quite affordable

c) Aerodynamic interactions – apparently not adverse maybe even beneficial

d) Reliability with much greater total part count? Offset by reduced impact of single rotor failures, improved unit reliability and overall maintenance strategy. Potential for advantage rather than penalty in O&M costs

LCOE Evaluation and Sensitivity



PI Assessment of Innwind Innovations

LCOE Impact	%
MRS	-16.0
Low Induction Rotor	-6.0
Advanced Two Bladed Rotor	-7.6
Smart Rotor with Flaps	-0.5
Carbon Truss Blade Structure	-0.6
Bend-Twist Coupled Rotor	-0.8
Superconducting Generator	-0.4
PDD (Magnomatics) Generator	-3.2

This evaluation employing a common independent LCOE evaluation method for all innovations is without credit for predicted O&M benefit and suggested energy capture benefits of MRS

MRS Benefits?

a) Technology related LCOE reduction ~ 30% as in the present project (this is relative to current offshore LCOE)
b) Further substantial LCOE reduction from greatly reduced commercial risk related to turbine technology
c) Shortening of production and development cycles accelerating turbine cost reduction and reliability improvement
d) Potentially much larger unit capacities than conventional technology reducing the number of offshore sites per installed MW
e) Savings, perhaps ~ 80% reduction, in the use of non-recyclable glass-resin products per installed MW
f) Faster market implementation

MRS – the Vision for Large Scale

- ~ 50 % reduction in cost of energy from offshore wind
- roughly half (~25%) direct technology impacts as suggested in Innwind
- the rest from commercial and industrial benefits

MRS – The next steps?

- Enhanced and specially adapted modelling tools for aerodynamics, loads and O&M especially
- Detailed designs for fixed bed and floating offshore systems with specific attention to assembly, installation, maintenance and operational logistics
- Prototype design and testing

Thank you for your attention!