University of Strathclyde Engineering

Multi Rotor Solution for Large Scale Offshore Wind Power

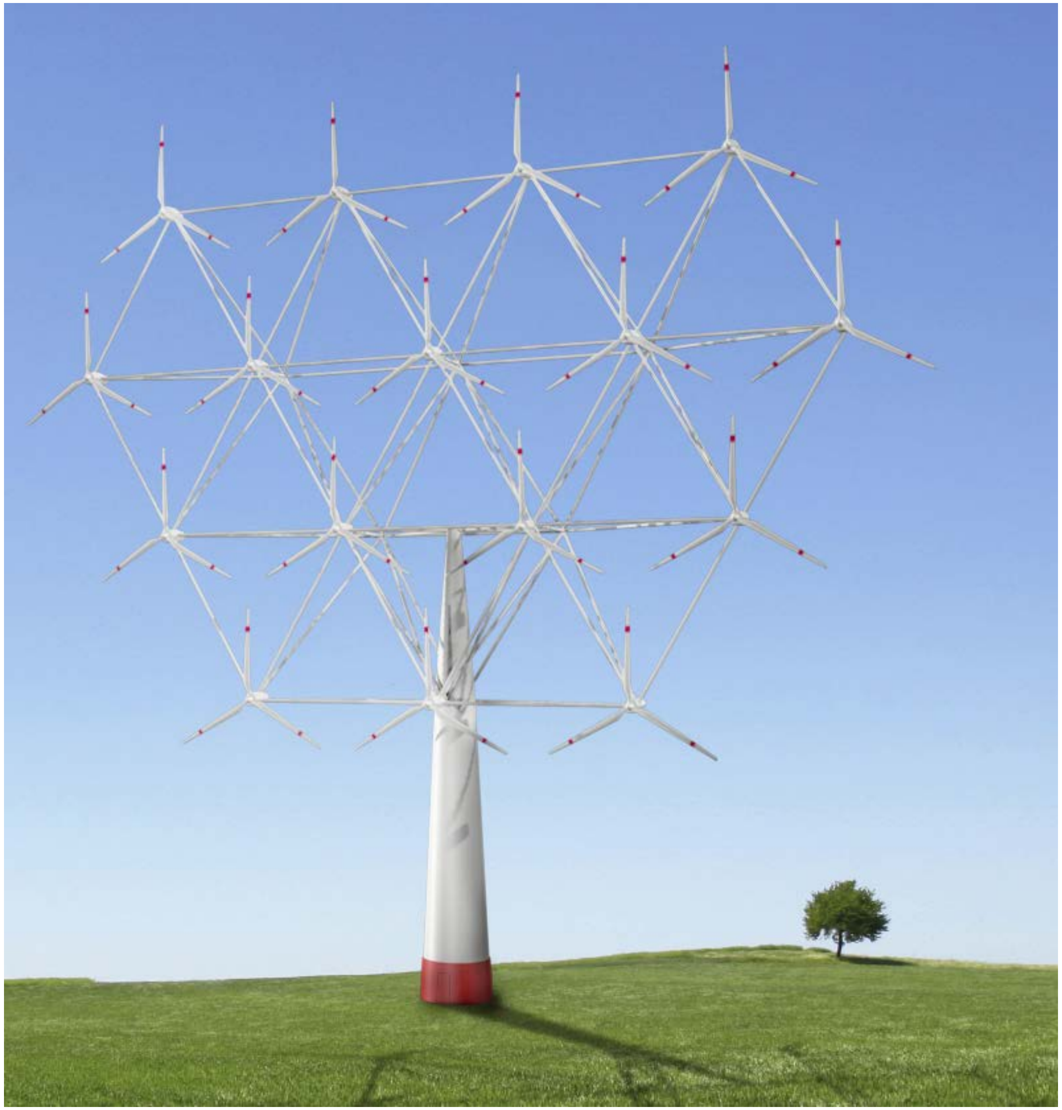
Peter Jamieson

Supergen General Assembly 2016

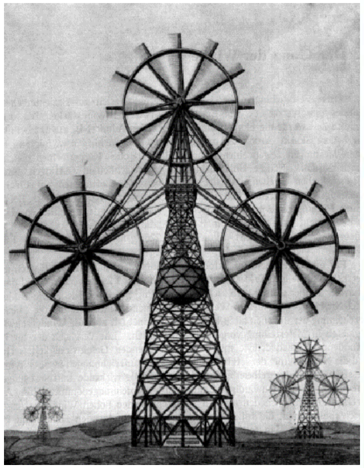
Design of Multi Rotor System

OWES

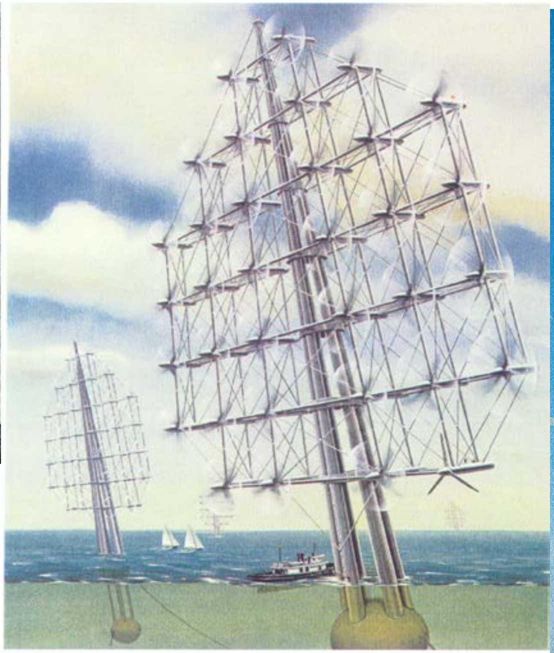
5MW system comprising 16, 312 kW wind turbines



History of Multi Rotor Systems



Honnef 1926

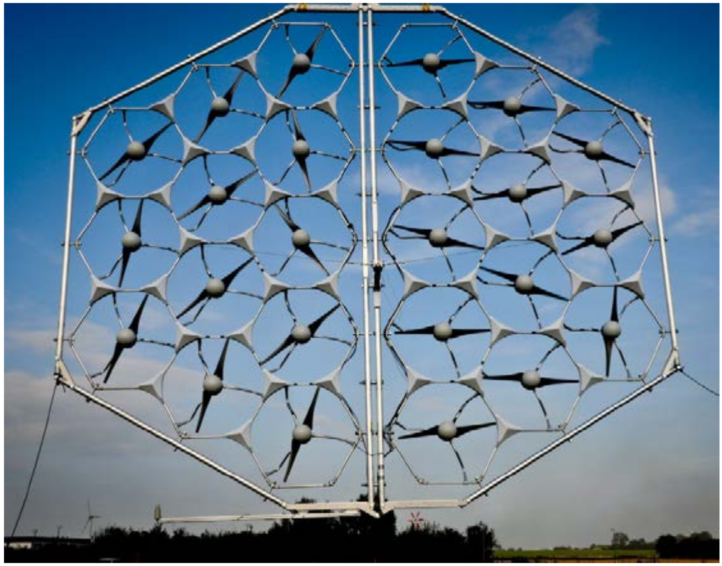


Heronemus 1976

Lagerwey 1995

Vestas 2016

MRS today



Vestas

Wind Lens Kyushu

Brose MRS

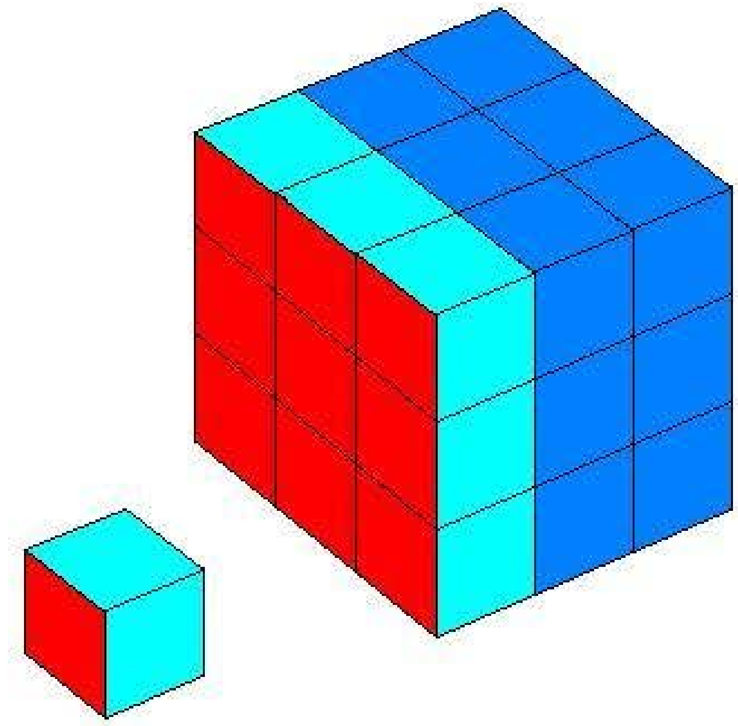
A variety of systems – different scales, different objectives but common interests in R&D progress and in growing concept credibility

Innwind.EU - 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 is without credit for predicted O&M benefit and suggested energy capture benefits of MRS

Why Multi-Rotors?



National Geographic 1976

The Multi-Rotor Scaling Argument

Equal area: $$D^2 = nd^2$$

Mass of large rotor: $$M = kD^3$$

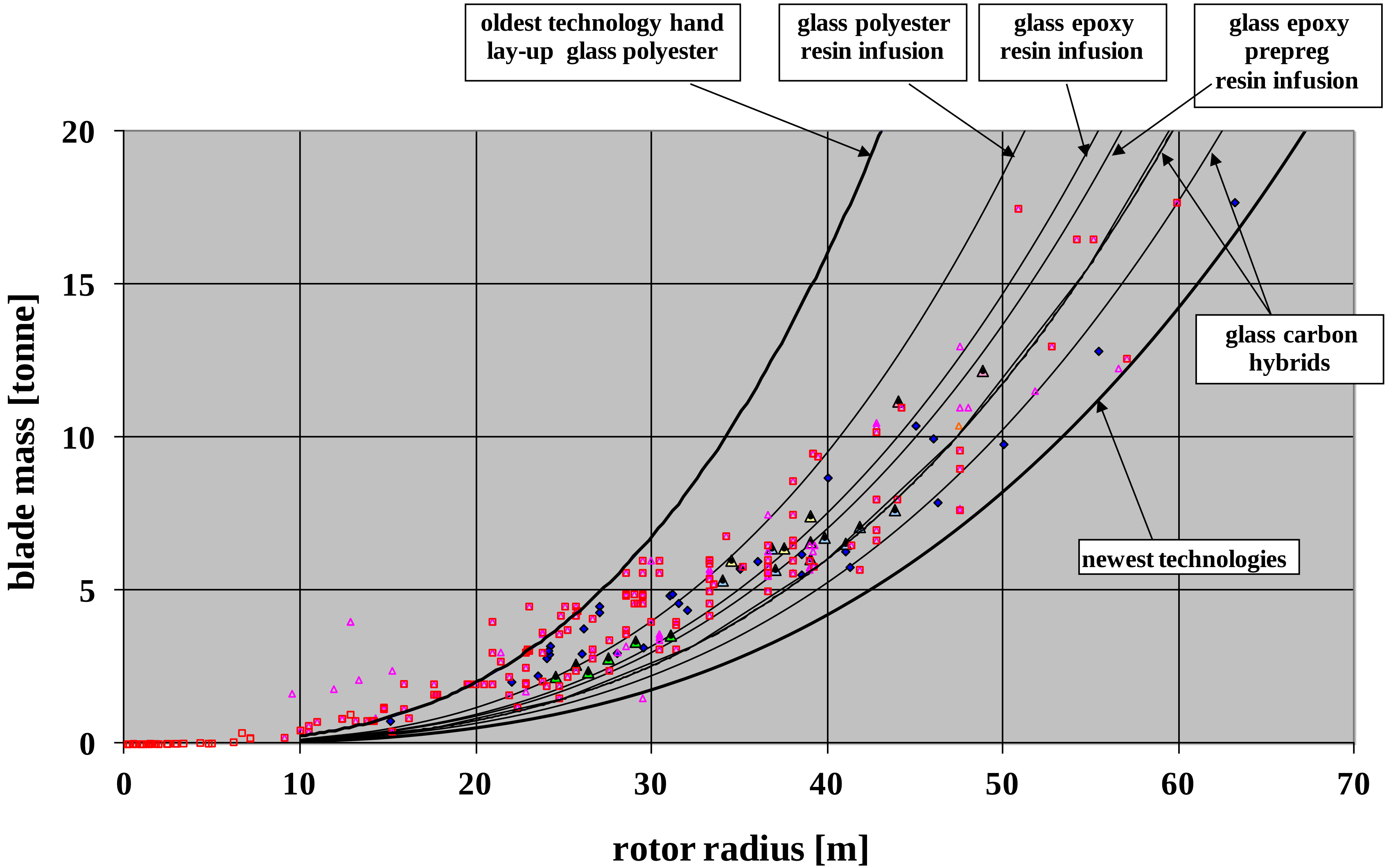
Mass of small rotor: $$m = kd^3$$

The mass ratio is: $$R = n\left\{\frac{d}{D}\right\}^3$$

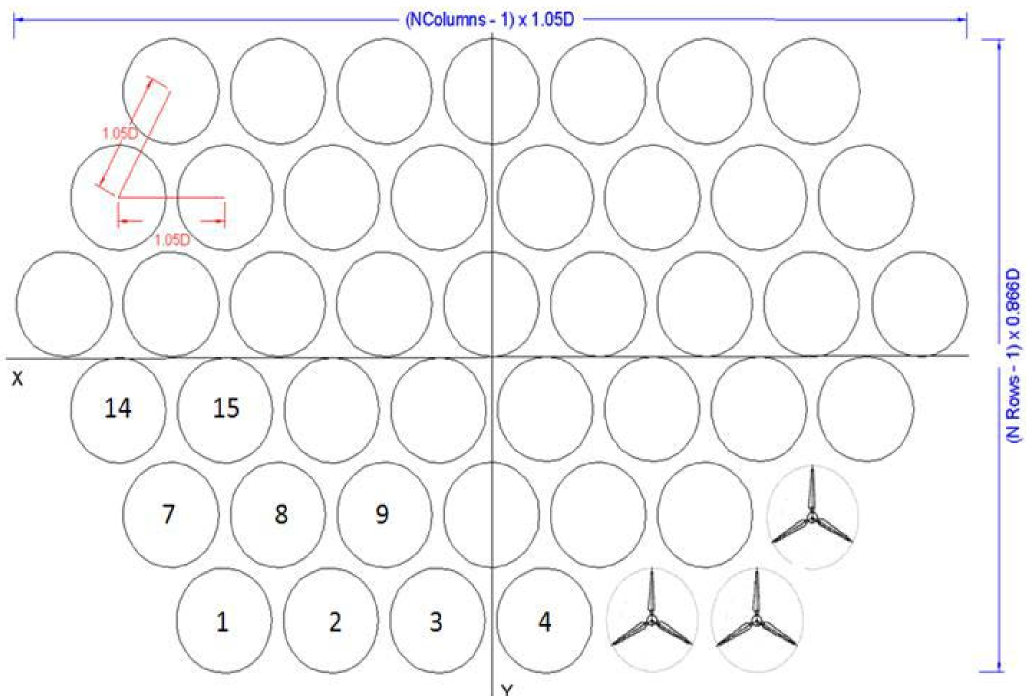
100 rotor, multi-rotor system has 1/10th
of weight and cost of rotors and drive trains compared to a single equivalent large rotor!

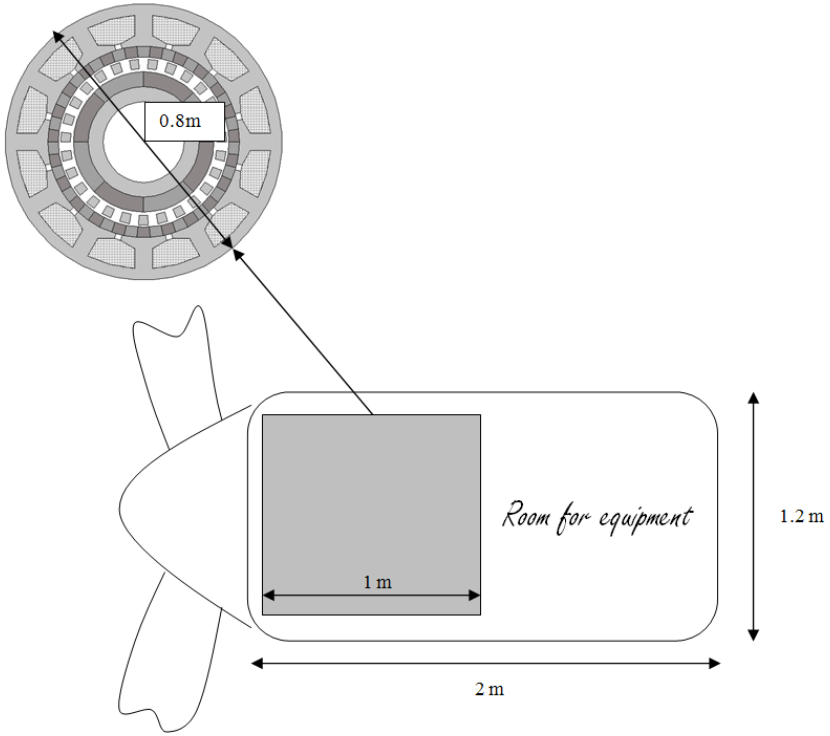
$$R = \frac{nm}{M} = \frac{1}{\sqrt{n}}$$

Is cubic scaling really true? – Yes!



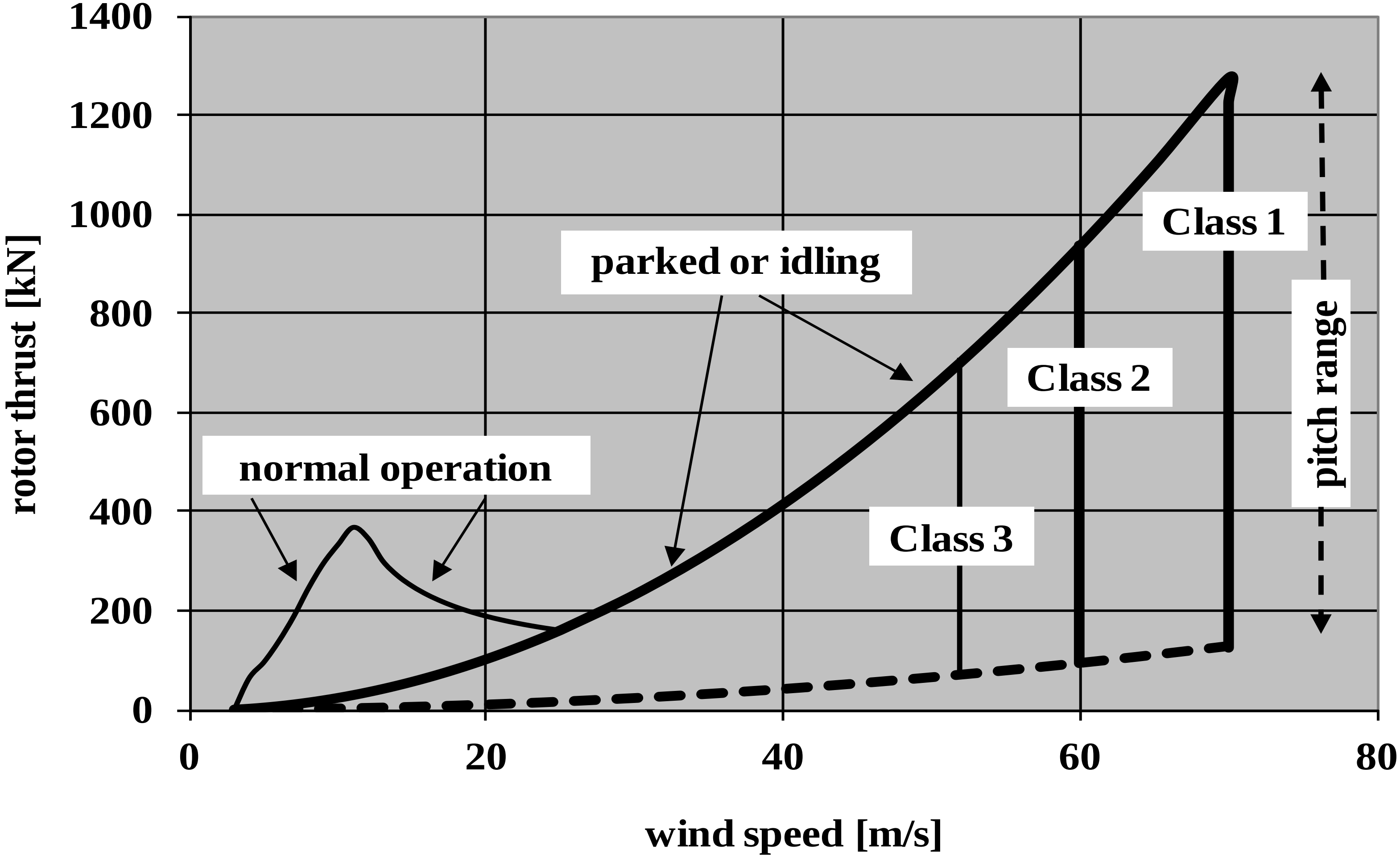
Multi rotor system definition



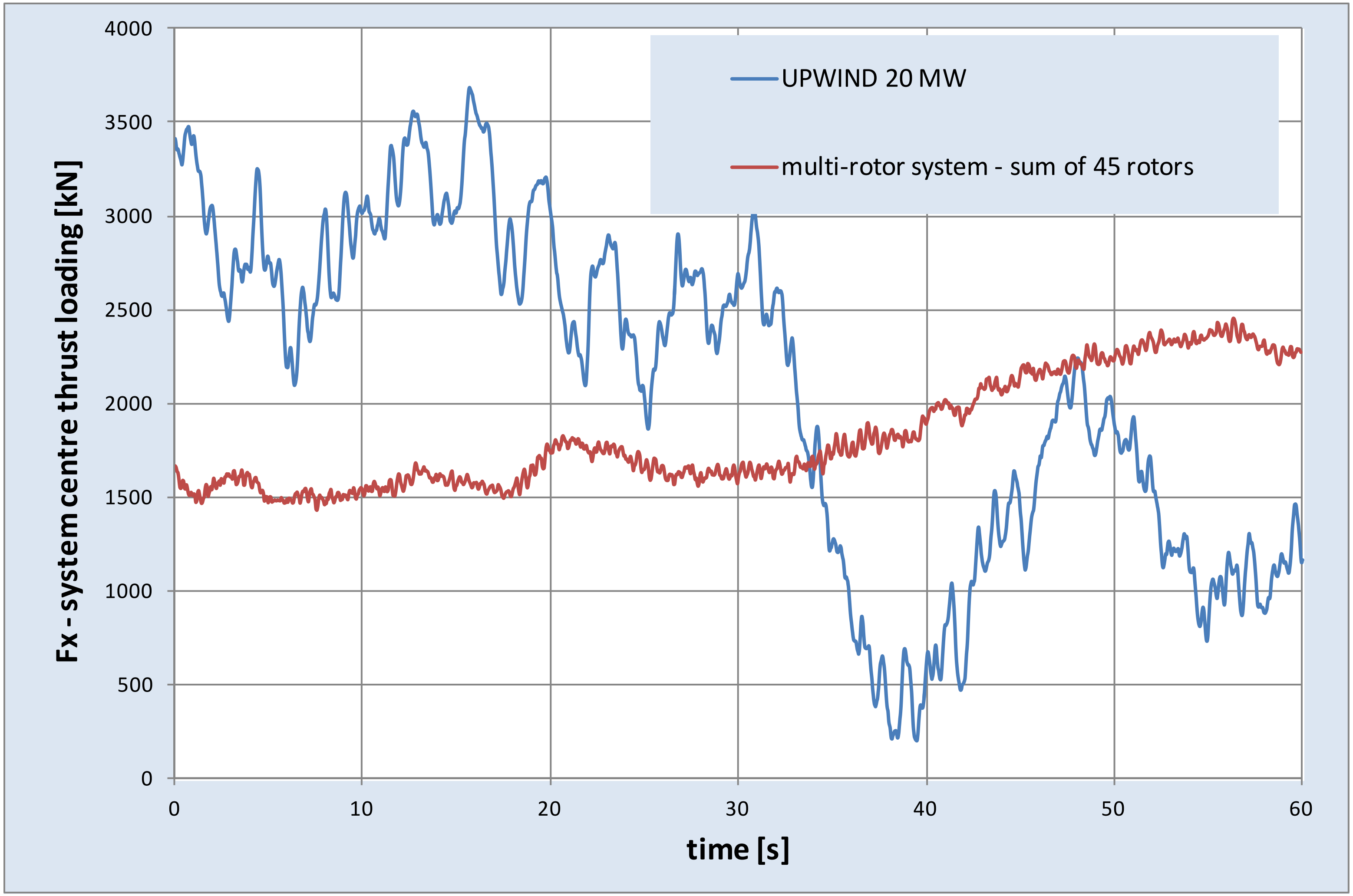


- 45 rotors each of 41 m diameter and of 444 kW rated output power comprising a net rated capacity of 20 MW
- Rotors on a triangular lattice arrangement with minimum spacing of 2.5% of diameter
- Variable speed, pitch regulated with direct drive PMG power conversion

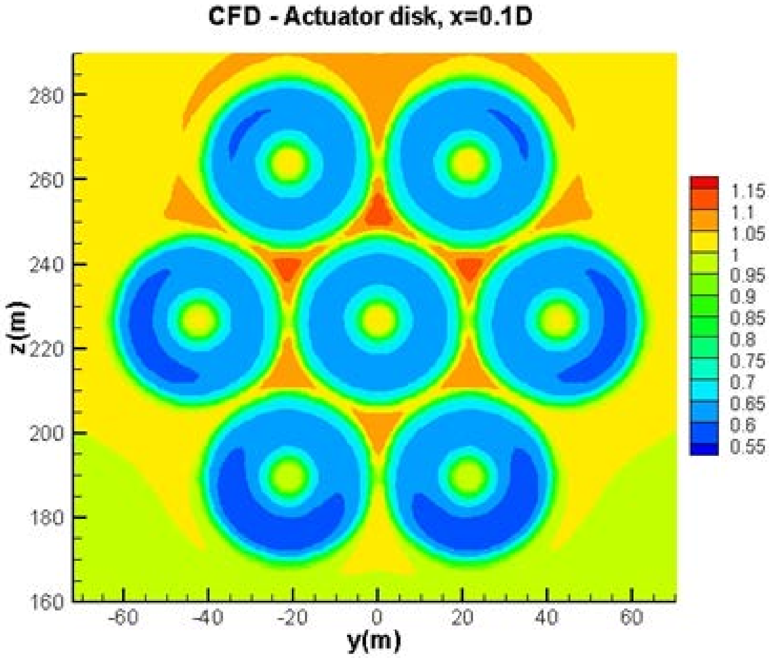
Ultimate loads comparison – rotor thrust I



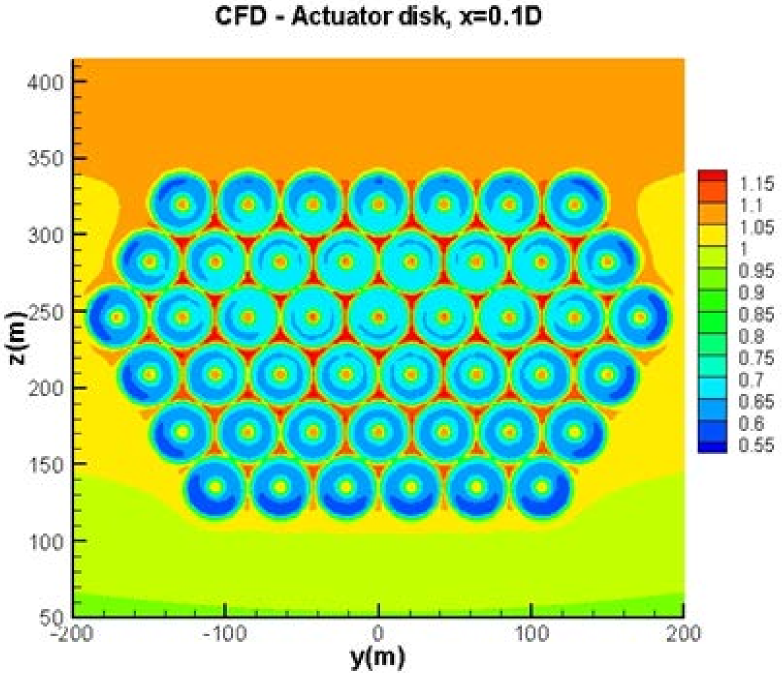
Comparison with 20 MW single rotor



Aerodynamic Evaluation

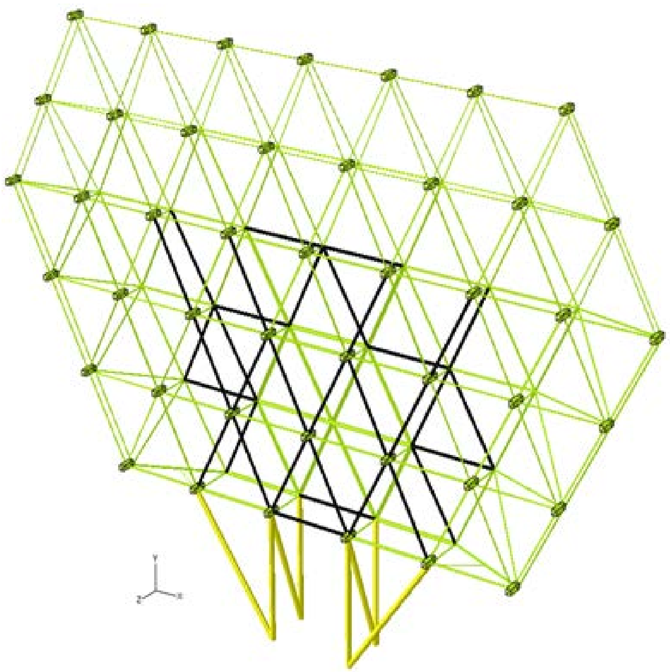


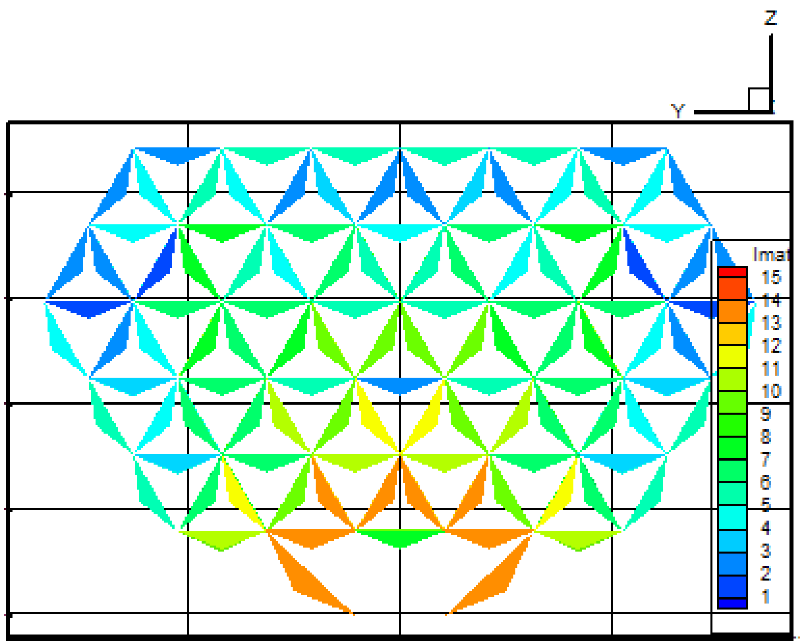
7 rotors, 2.6% power gain



45 rotors, 8.0% power gain

Multi Rotor System – Revised Structure Design (CRES)





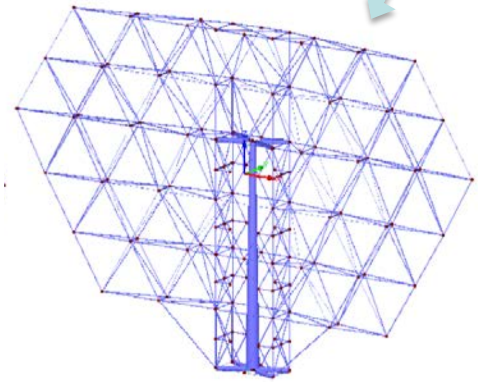
- The structure design accommodates a severe robustness criterion – overall integrity preserved according to demanded reliability criteria in event of failure of most highly stressed member

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 Task 1.4)

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

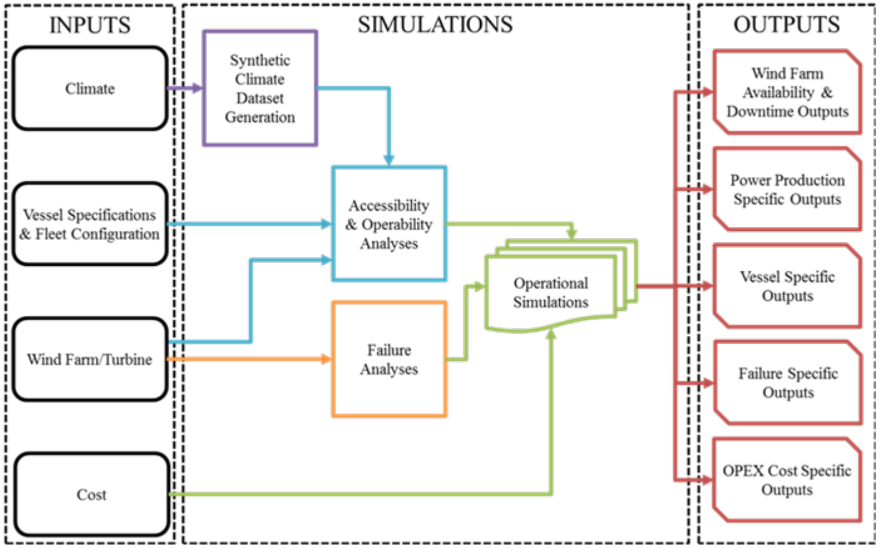
The semi-tower solution is a little more massive than the final CRES design but incorporates yawing capability

O&M of the MRS

a) O&M was broad-brushed in the initial report on advice that the focus of the present Innwind project was on CAPEX. However 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) 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 and of Gintautas (Task 13.4) was very similar for the MRS although Dinwoodie predicted lower availability of the reference wind turbine (RWT) than 97%

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.

Levelised Cost of Energy (LCOE)

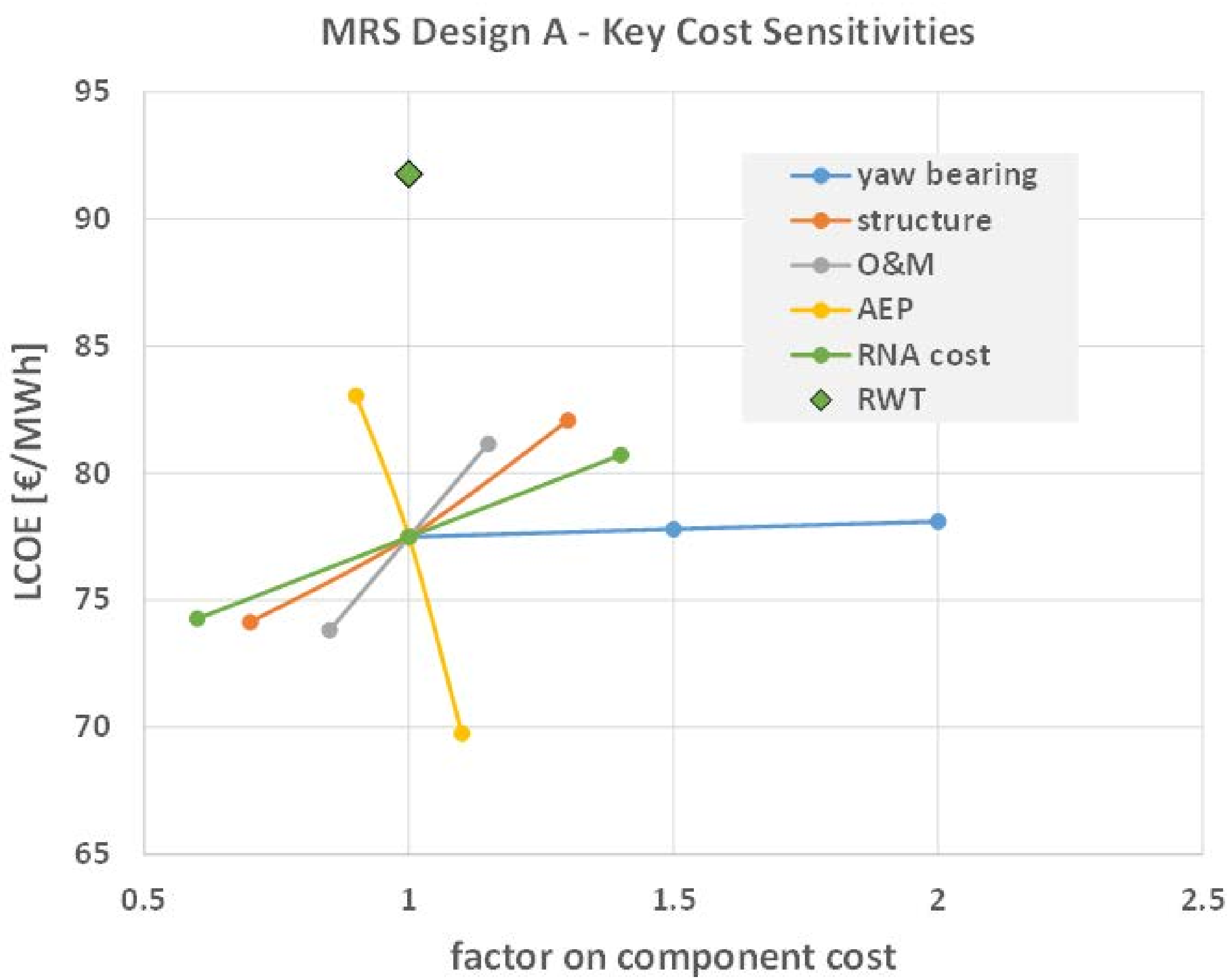
Some assumptions in the MRS base case evaluation;

- No credit for the 8% power gain predicted by NTUA nor energy gains predicted by UoS due to superior system operation in turbulent wind

- No credit in respect of O&M for enhanced reliability of the MRS turbine units compared to the RWT. Higher reliability of MRS rotor nacelle systems in production is certain for 3 main reasons
  a) Faster learning curve with factor of 20 on production quantities
  b) Much faster implementation of product development and improvement (consider 20 m new blade development v 180 m)
  c) Much reduced total cost of turbine components and hence returning cost (increasing margins on generator for example) to enhance reliability is more affordable

- No credit in O&M for the predicted 13% cost reduction

LCOE Evaluation and Sensitivity



LCOE Comparisons

LCOE Comparisons	Absolute €/kWh	Relative to offshore ref. [%]	Relative to DTU 10 MW [%]
Offshore wind reference value	**107.00**	**100.00**	
DTU 10MW	91.77	85.77	**100.00**
MRS base	77.49	72.42	84.44
MRS (1)	81.58	76.24	88.90
MRS (2)	74.31	69.45	80.97
MRS (3)	71.78	67.08	78.22
MRS (4)	75.76	70.80	82.55

1 MRS availability loss increased to 9%

2 MRS base with power credit

3 MRS base with power credit and O&M cost reduction

4 MRS base with power credit and O&M cost reduction but increased availability loss

Maybe 30 % LCOE reduction

MRS - Overview

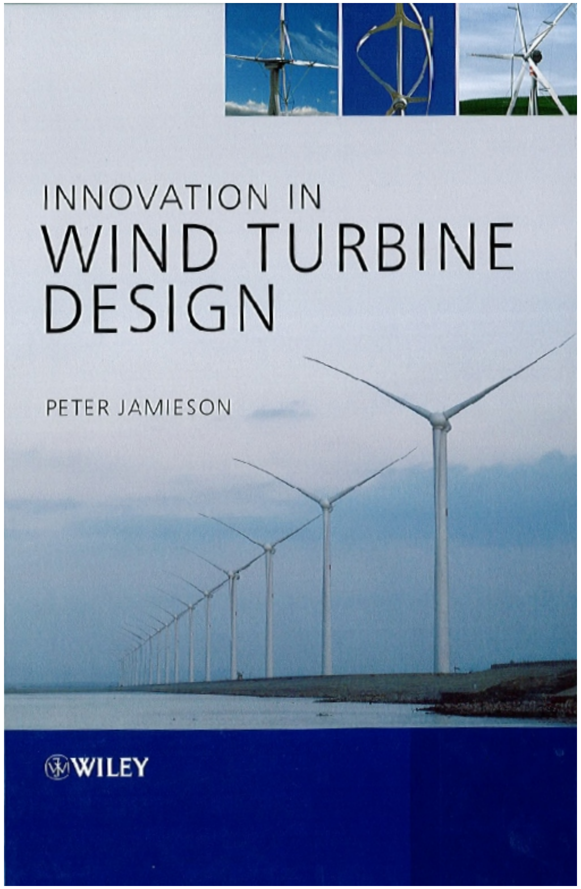
- MRS technology related LCOE reduction as suggested in the present Innwind work, reduction in LCOE from much reduced risk for investment in turbine technology and reduction ~ 80% (per installed MW of wind farm capacity) in use of composites that are difficult to re-cycle.

- As a complete system innovation (although very significantly reducing demands on turbine development) the MRS requires substantial development of aerodynamic analysis and load prediction tools and of O&M modelling and new engineering designs for yawing, for assembly and for maintenance.

- However the sensitivity studies suggest that the advantages of the MRS are quite robust and make a strong case for further research on this concept

Evaluation of Innovation

- **Benefit?**
- **Feasibility ?**
- **Cost effective?**



MRS Benefits?

a) Technology related LCOE reduction ~ 30% as in the present project
b) Further real world 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 Feasibility and Cost?

a) Very large structures but not unusual. Similar to jacket above water.
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

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!

International Workshop on MRS
at Ore Catapult, Blyth harbour, UK
October 2016

Presentations available soon at
https://ore.catapult.org.uk/