Global Blockage Offshore/Onshore - Reality or Myth?

Jan-Åke Dahlberg, (former) Vattenfall Wind Power
Antonio Segalini, KTH Mechanics

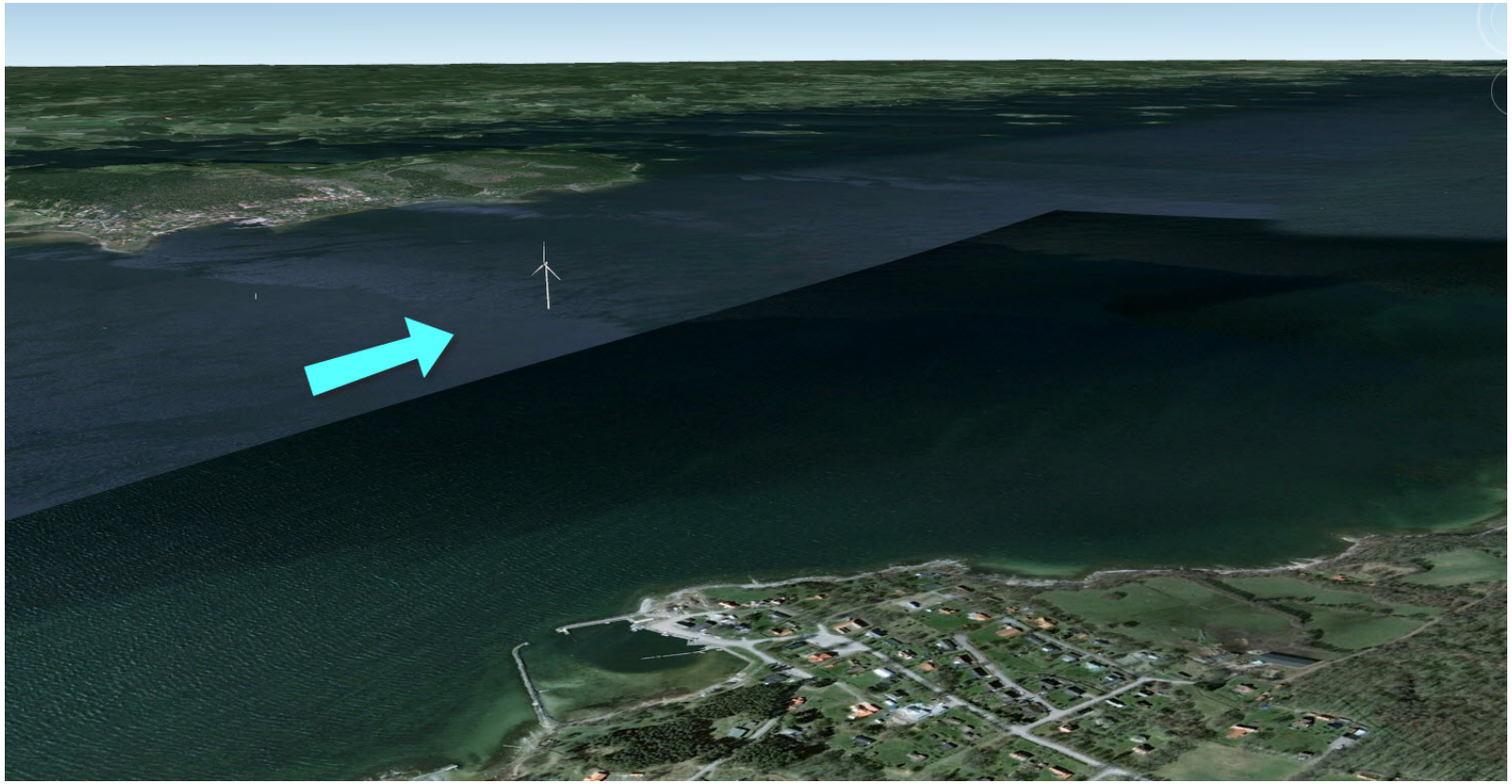
Global Turbine Array Effects

Global Blockage

Large wind farms cause a momentum loss in the flow and reduce the speed of the approaching wind. This phenomenon, called global blockage, is similar to the wind speed reduction that takes place when the wind is approaching the coast, with high roughness, from the open sea with low roughness.

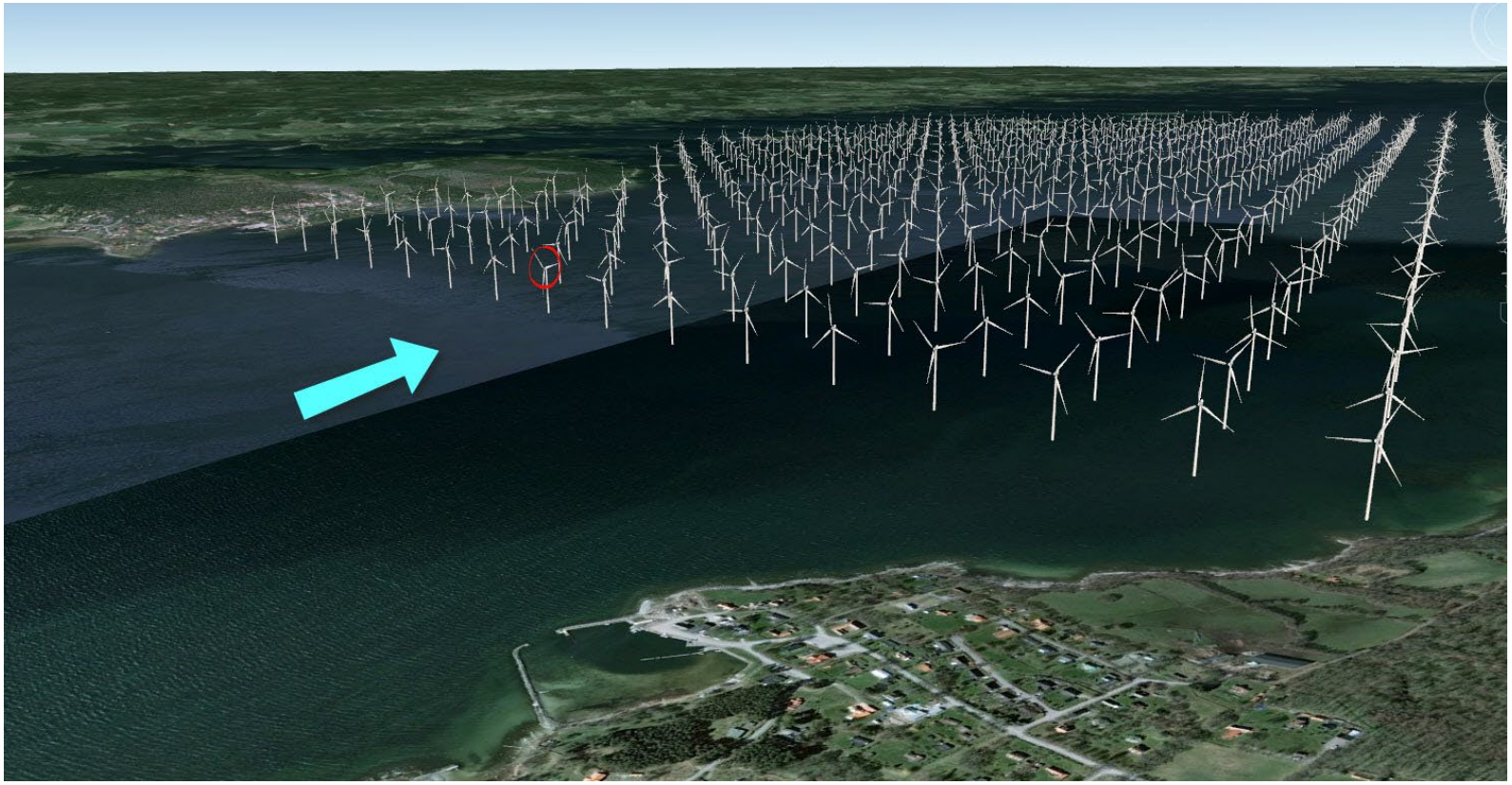
Global Turbine Array Effects

- One single turbine

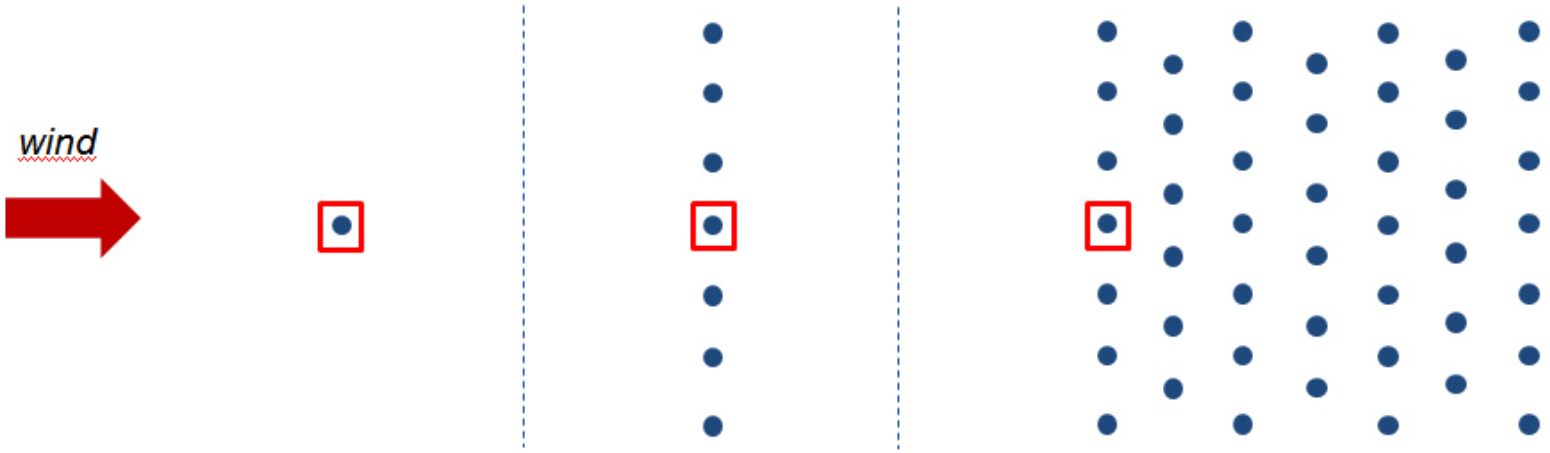


Global Turbine Array Effects

- A large Wind Farm



Global Turbine Array Effects



How can we assess blockage effects ?

Researcher in the field of wind energy since 1975

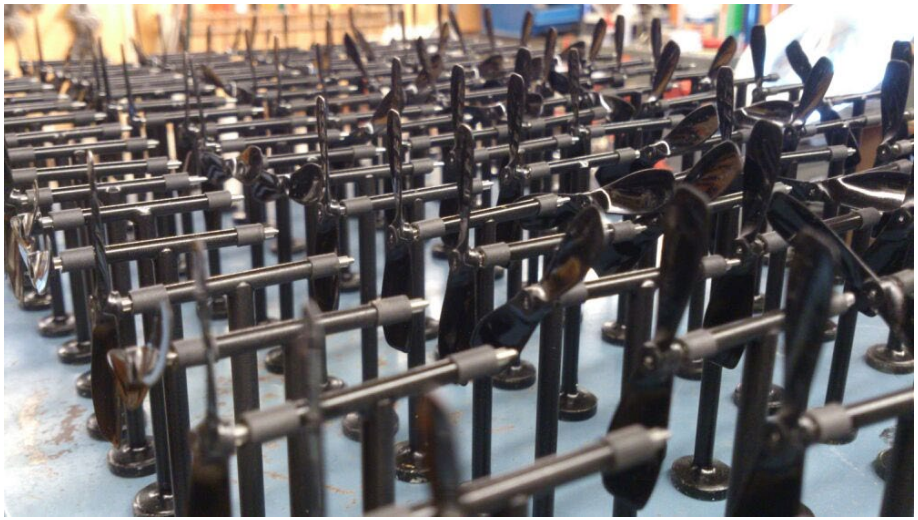
Vast experience from experiments in wind tunnels

It seemed natural to use these skills to investigate the blockage phenomenon by experiments in wind tunnels

Pros: Very well controlled conditions
Repeatable
Fast
Low cost

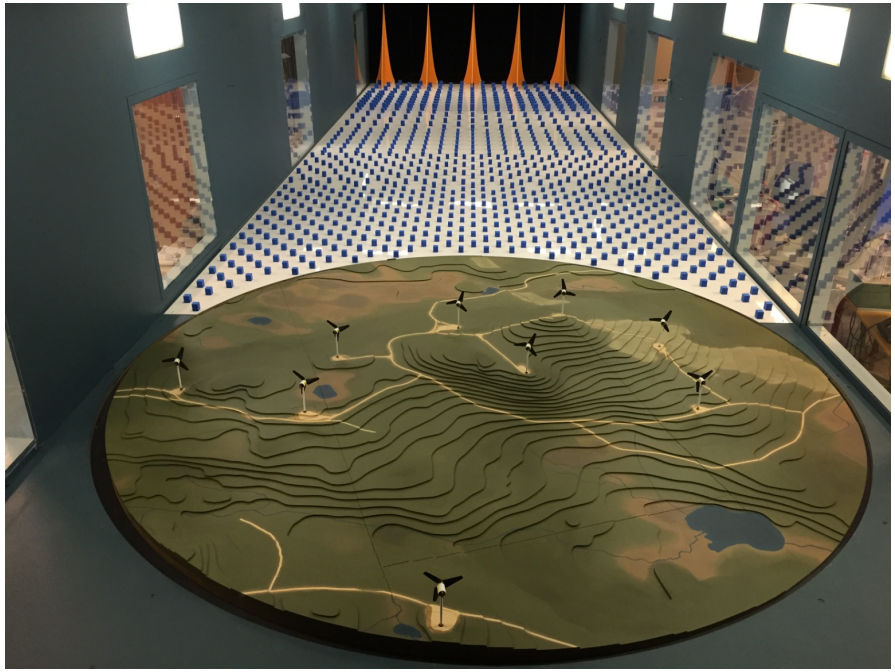
Cons: Scale effects ?

Wind turbine models



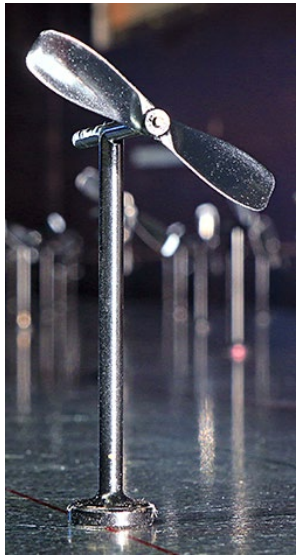
300 wind turbine models were produced and tested in Gävle wind tunnel 2013

Gävle Wind tunnel



Width: 3 m, Height: 1.5 m, Length: 11 m

Test turbines

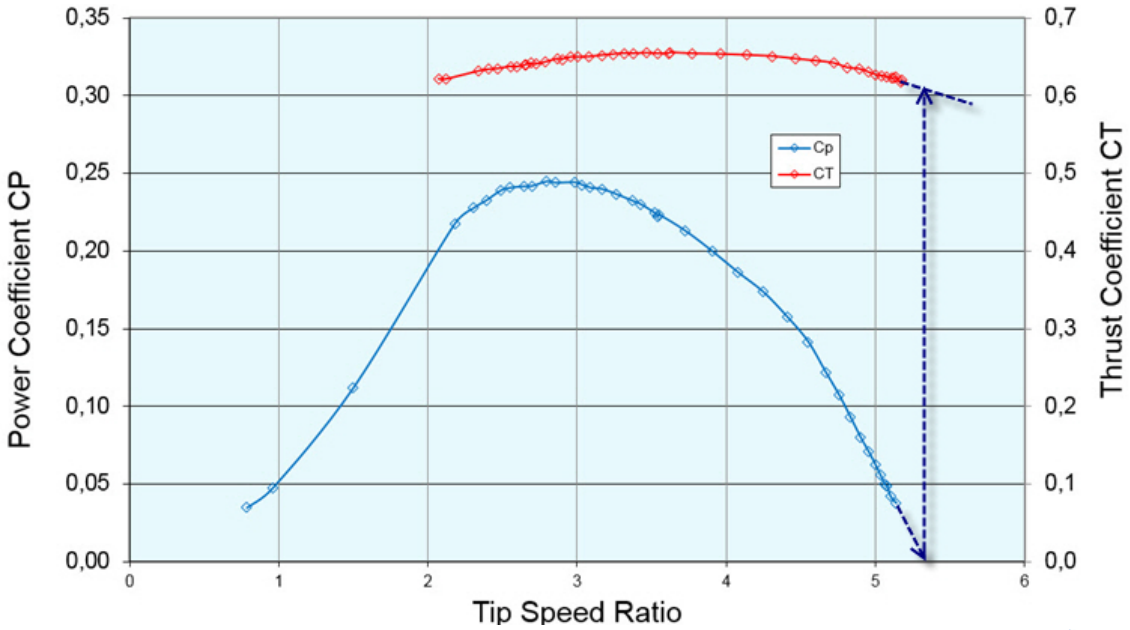


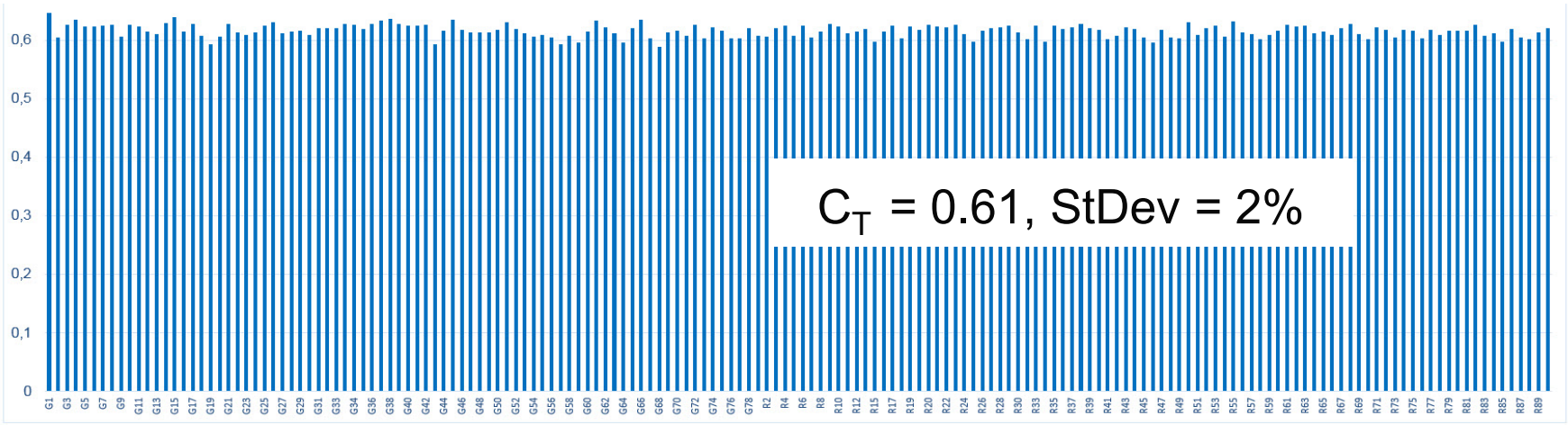
Diameter 45 mm

Hub height 60 mm

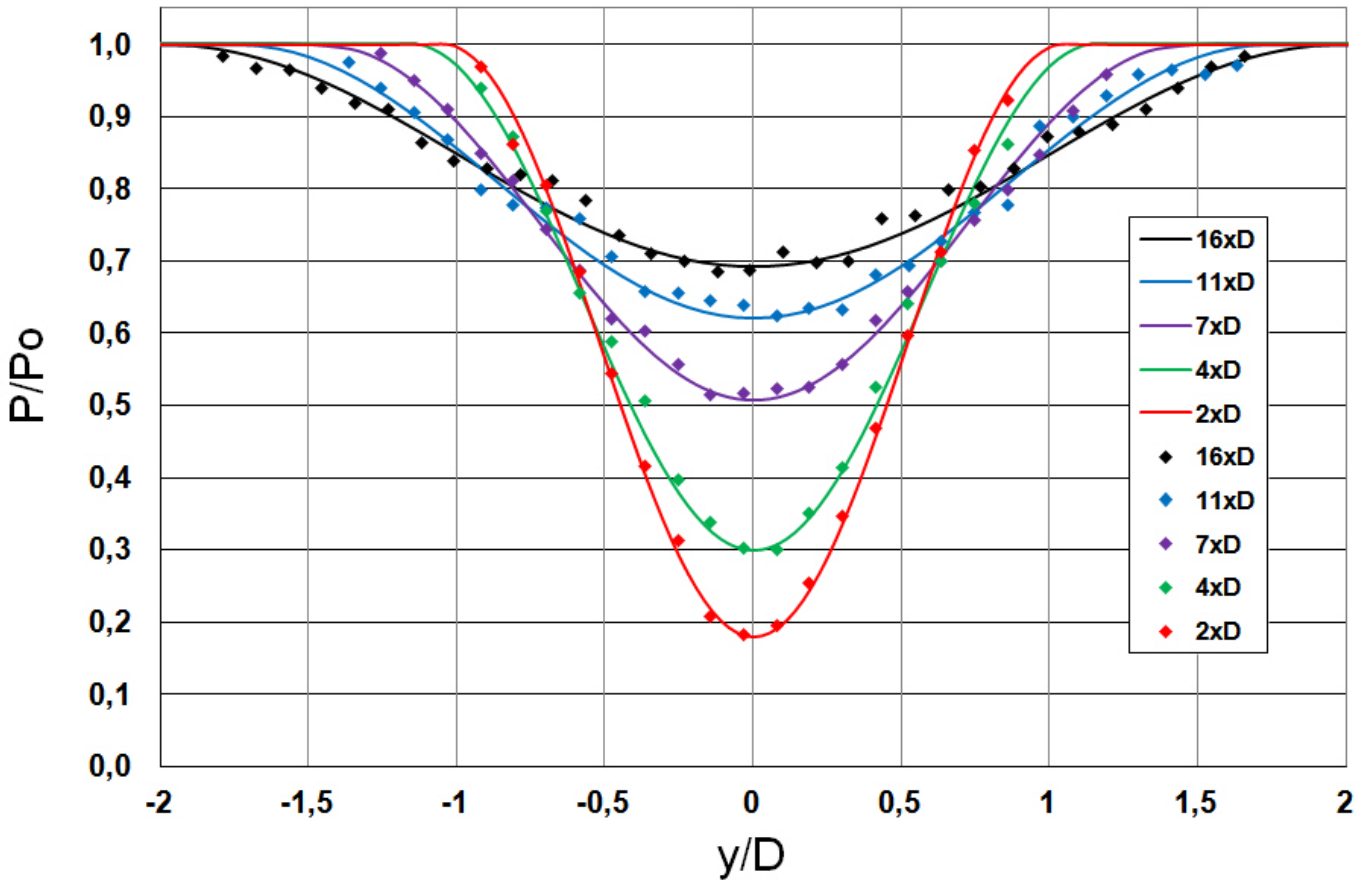
C_T=0.61 (meas.)

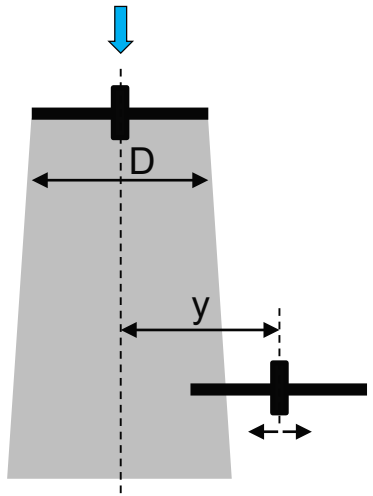
C_P=0 (free)

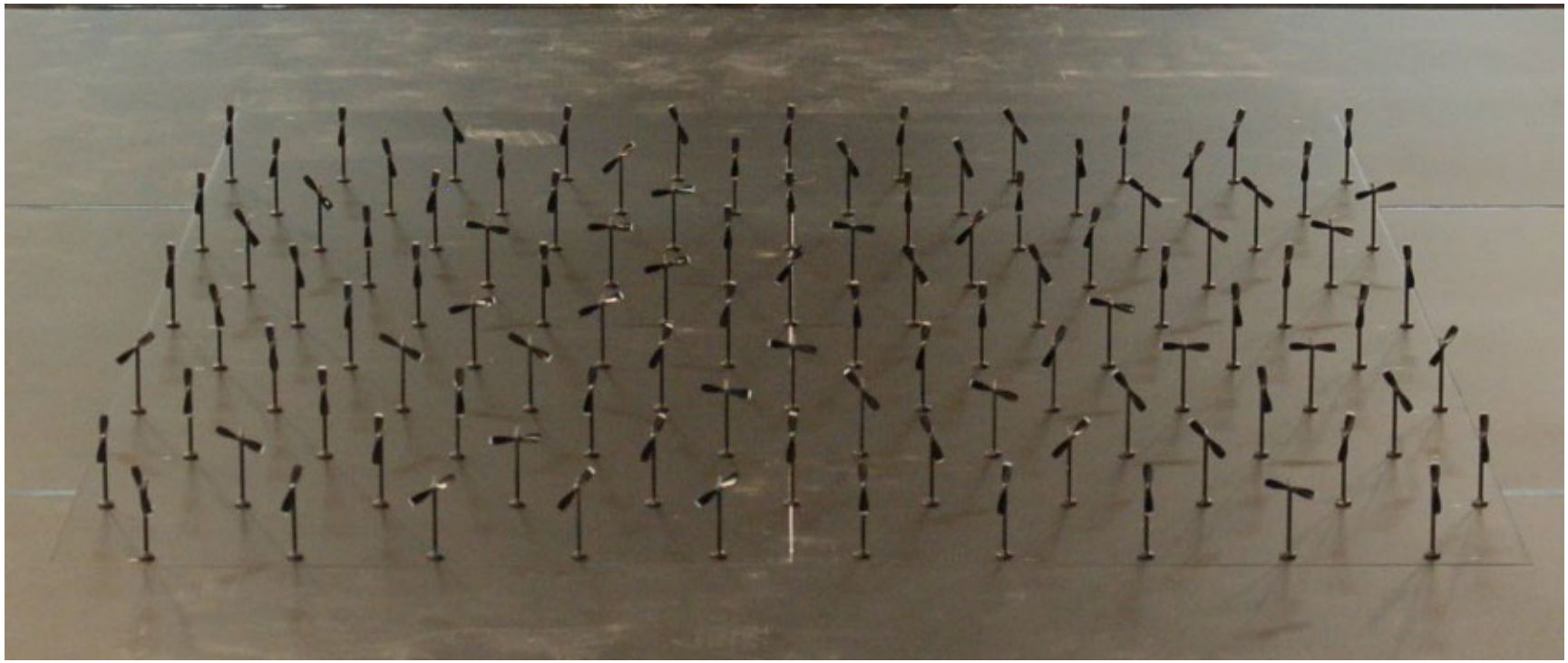




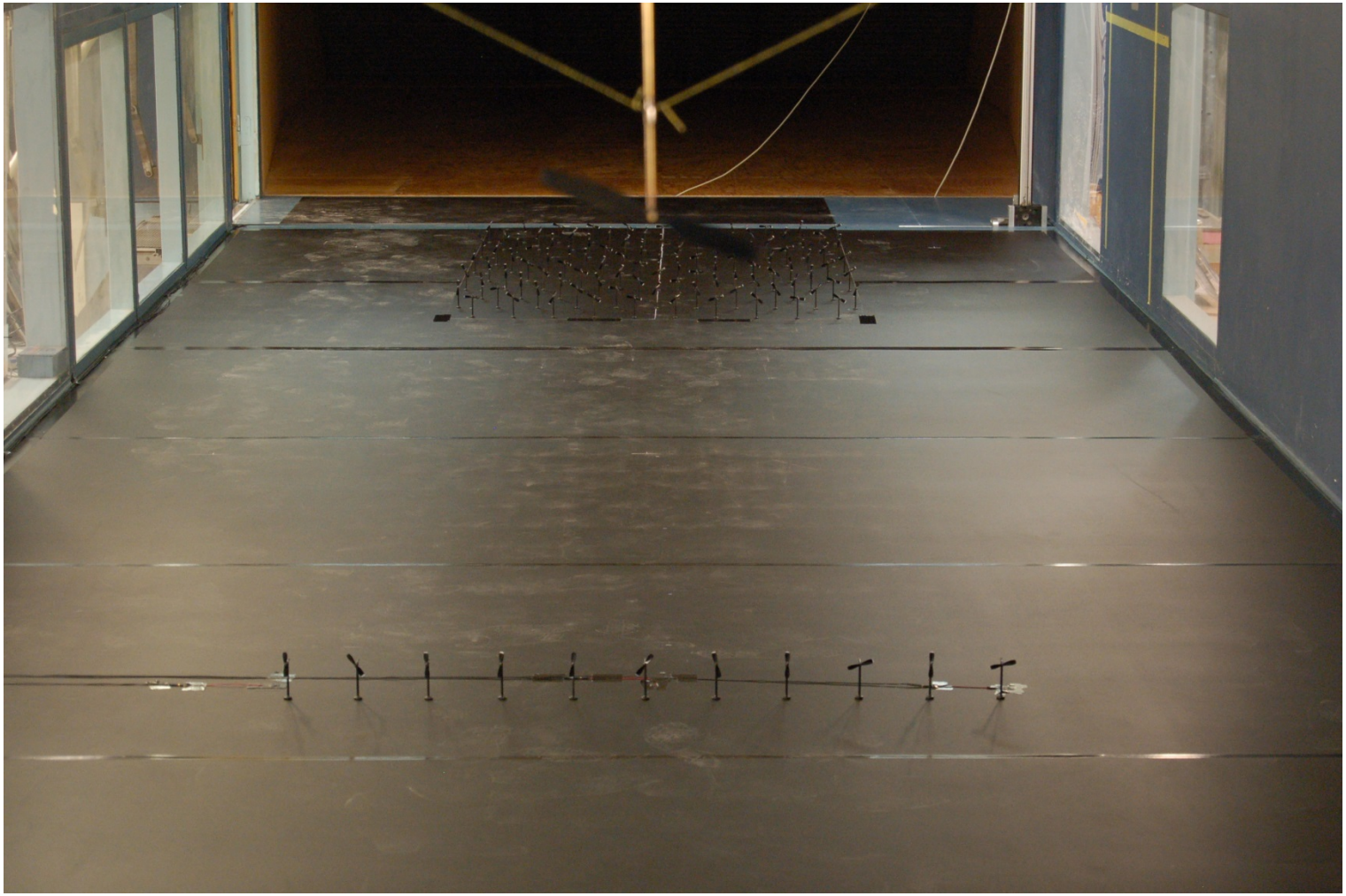
Measured Power Wakes

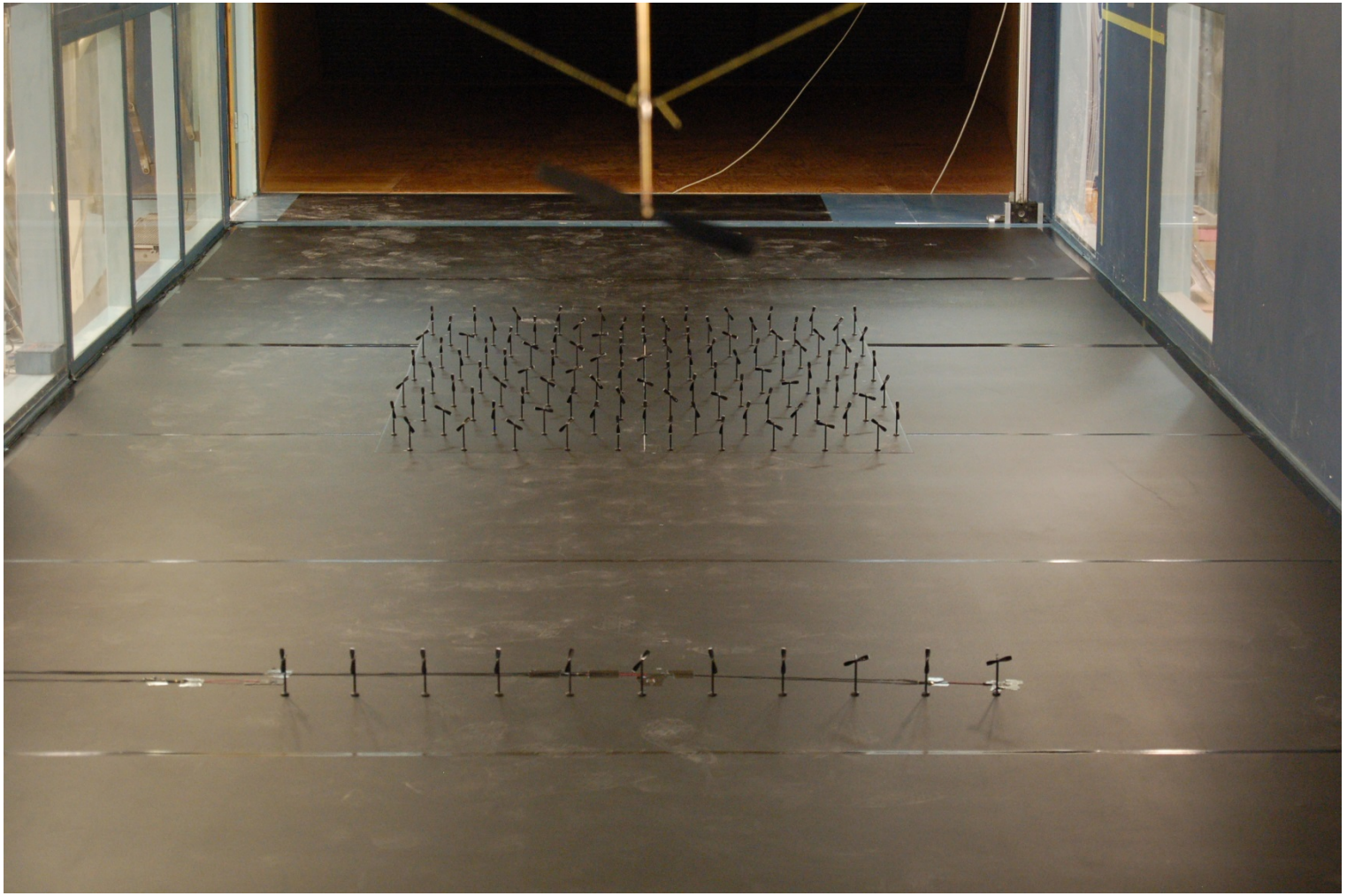


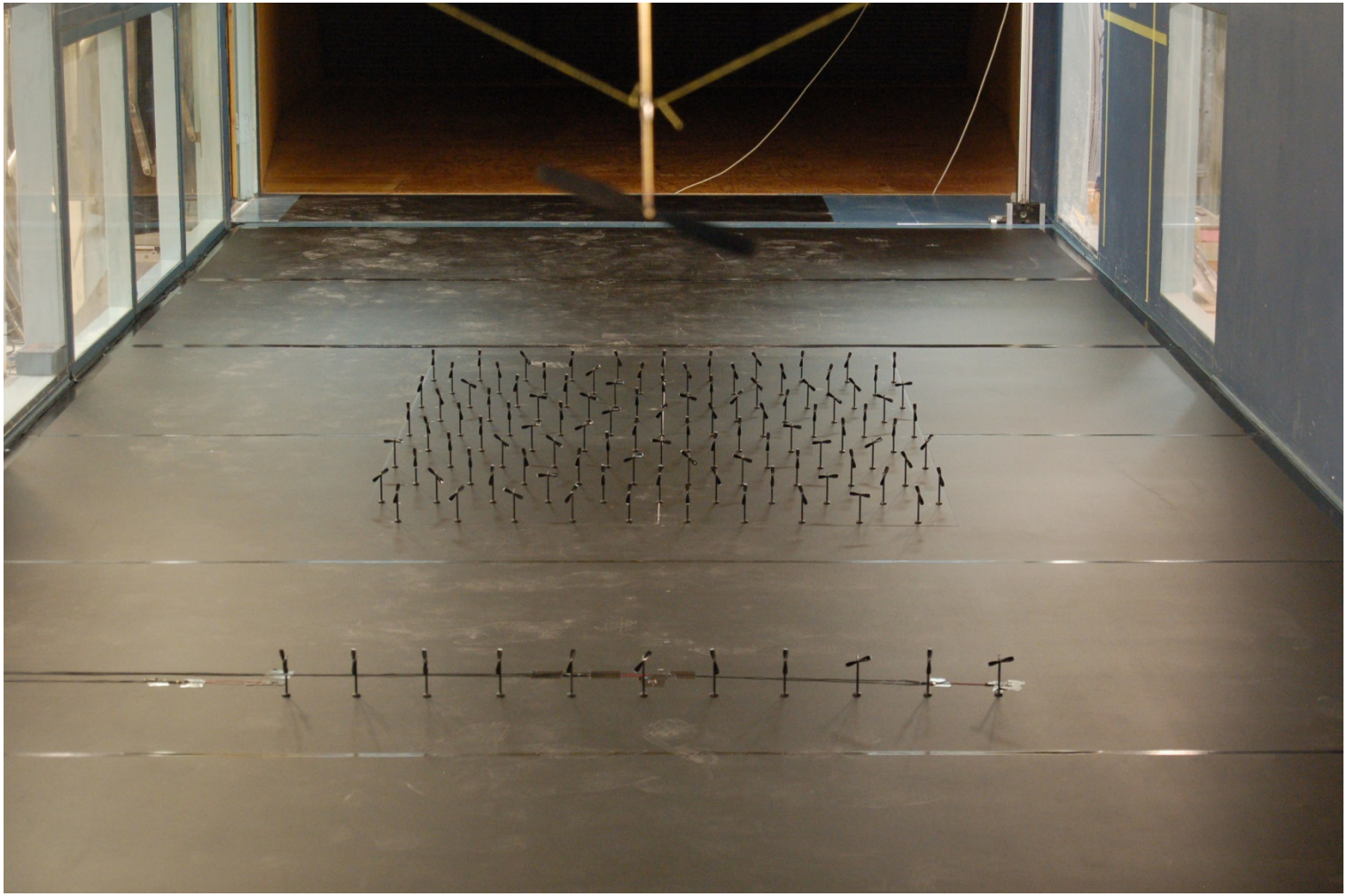


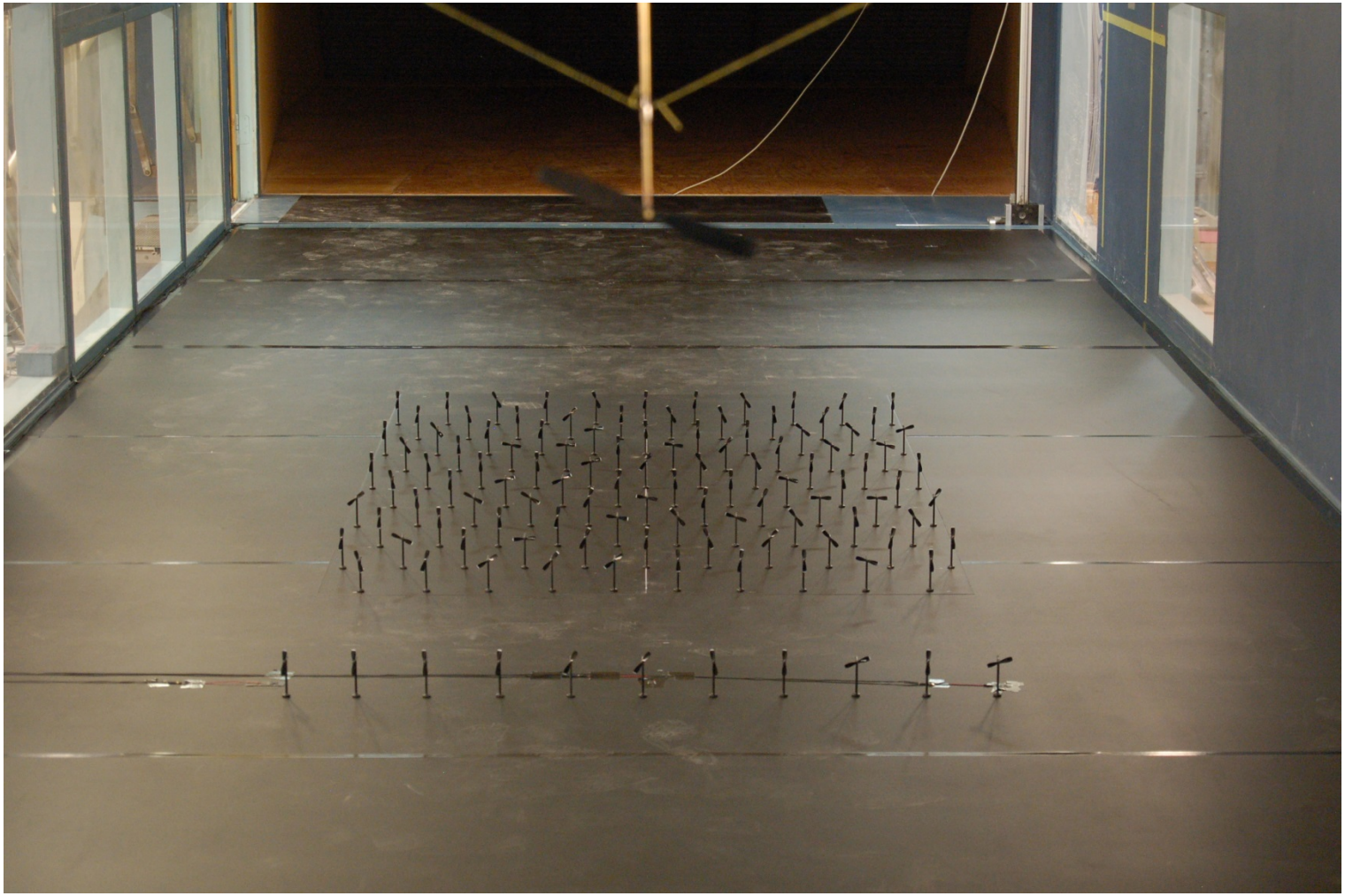


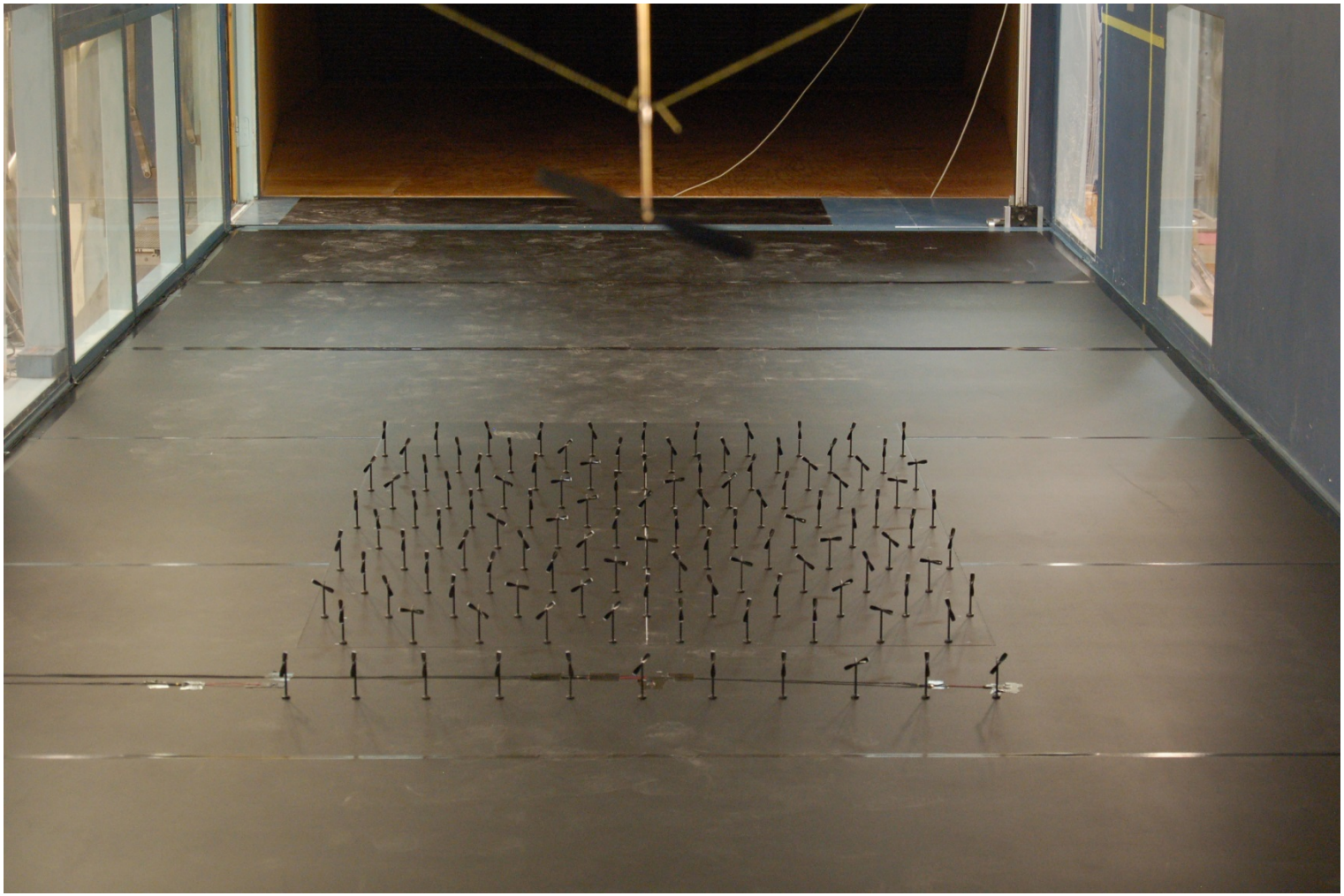
Rubéns test

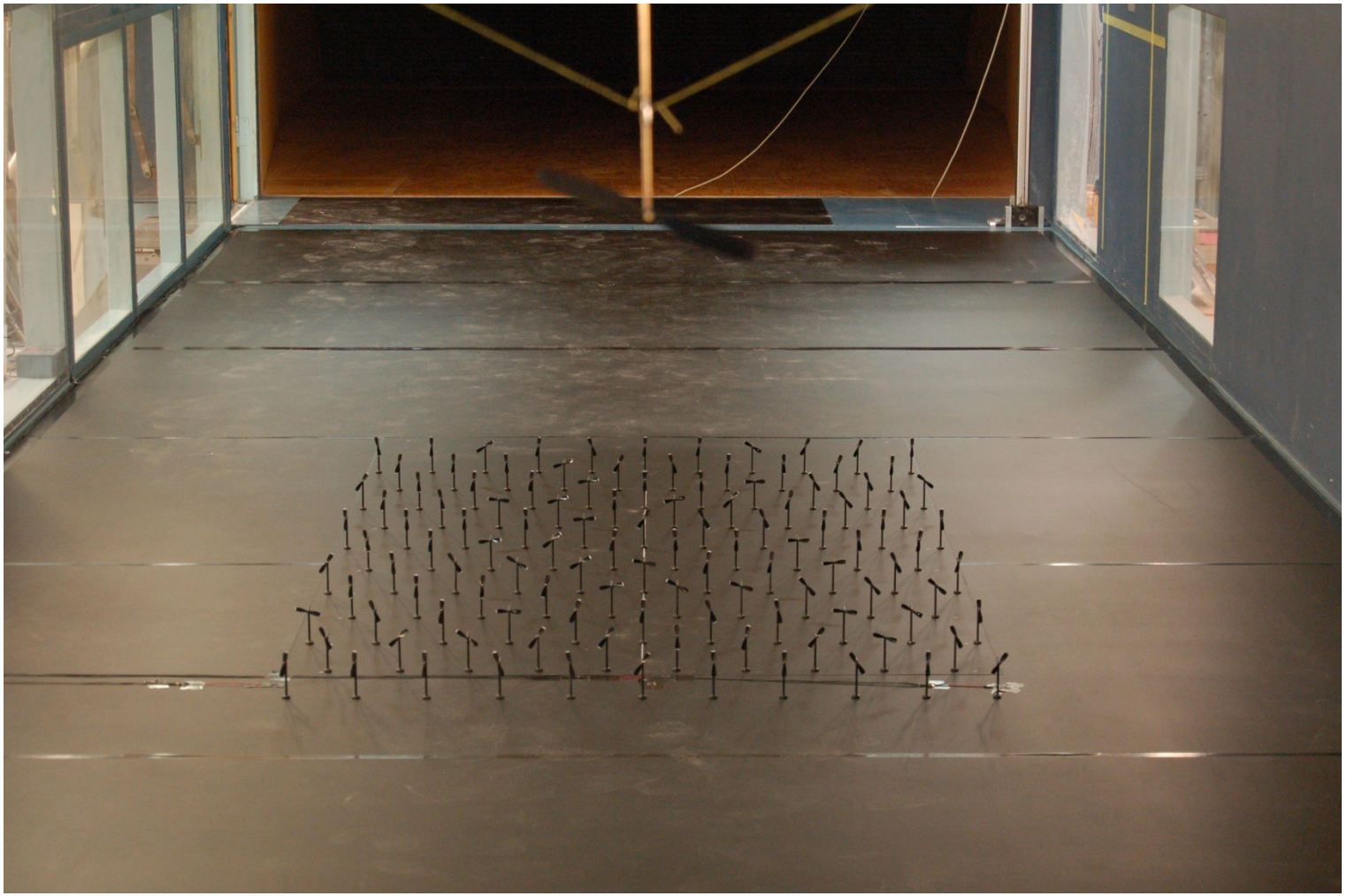


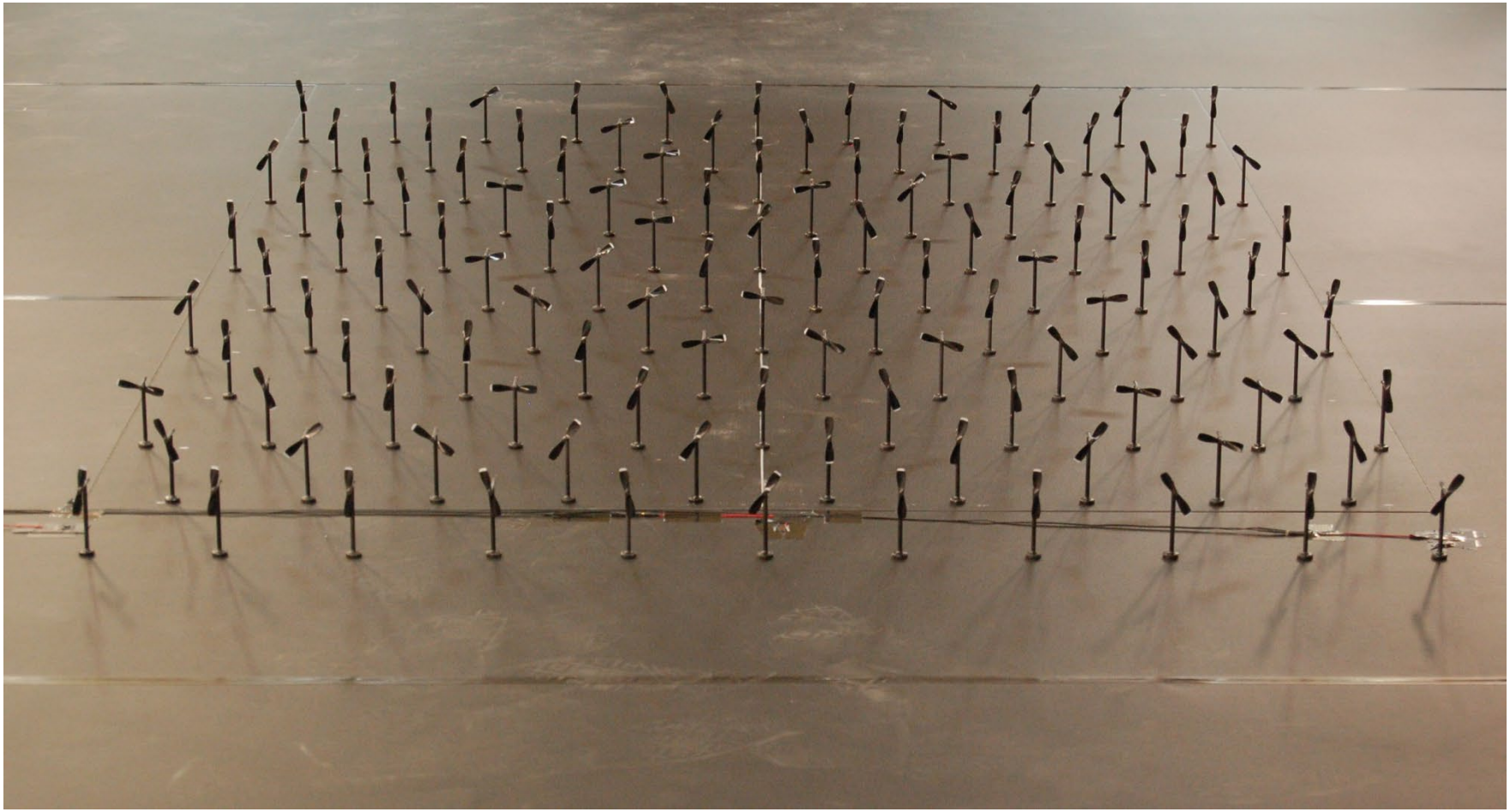


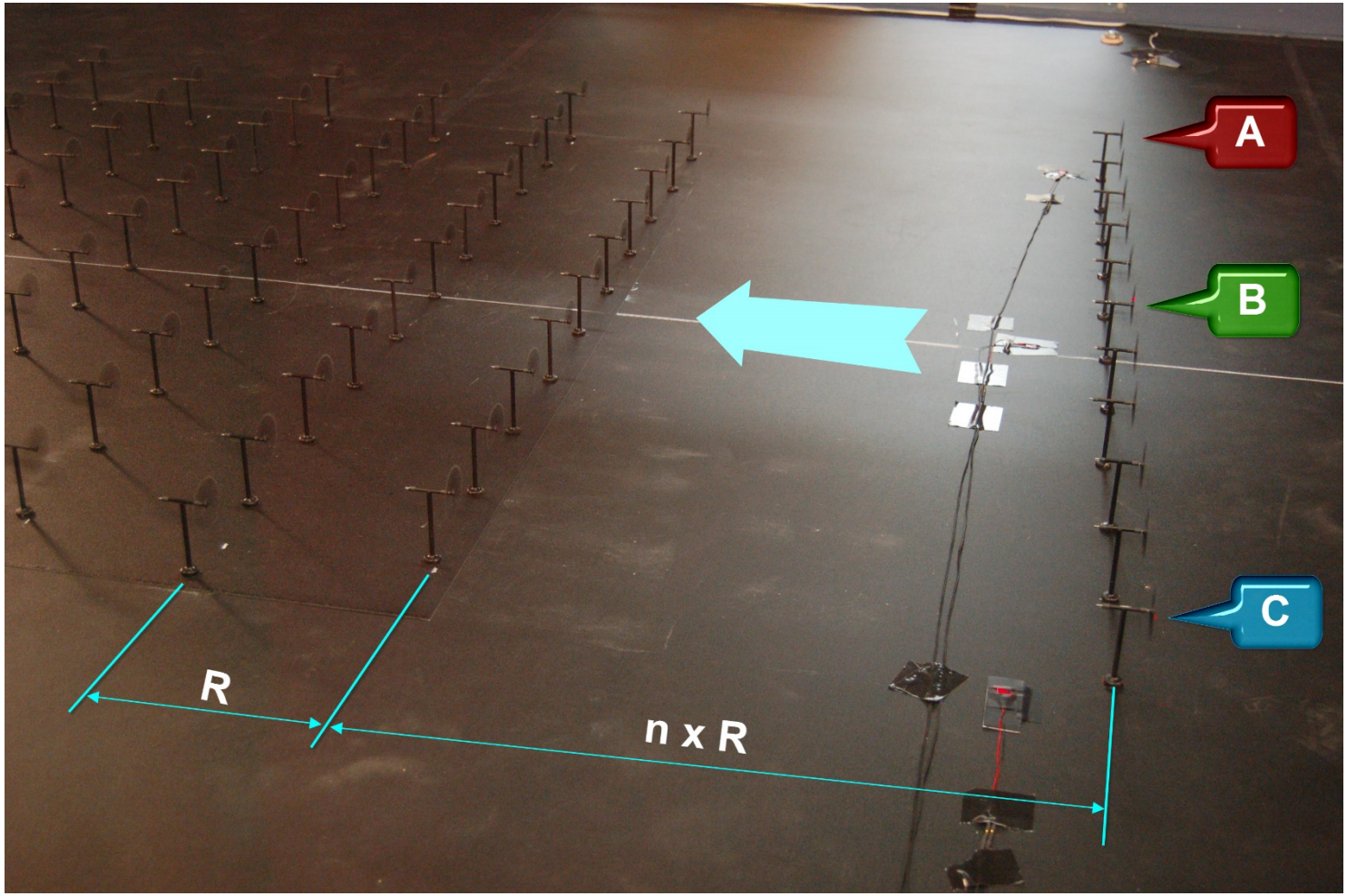




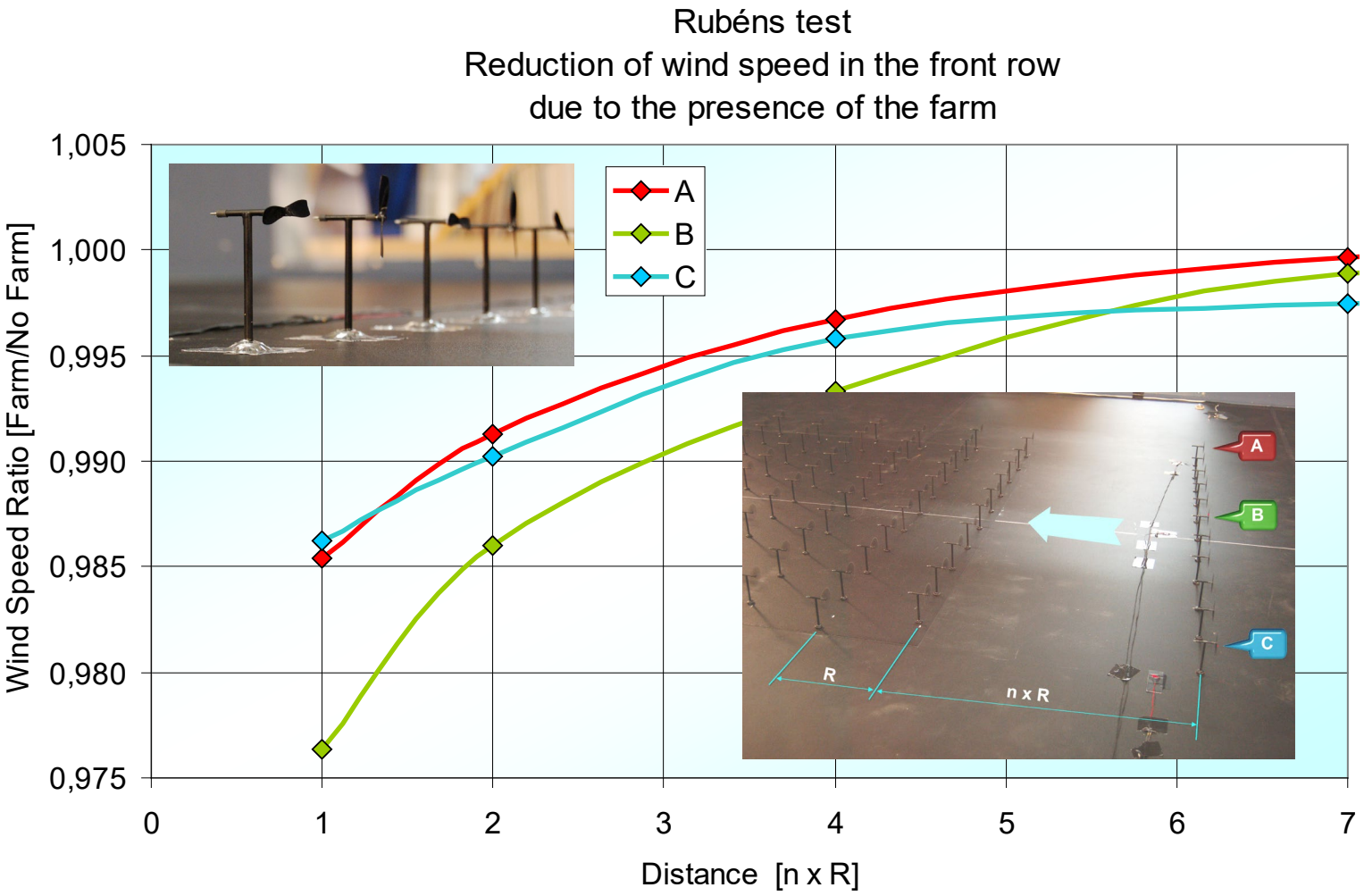







A
B
C
R
n x R

Global Turbine Array Effects



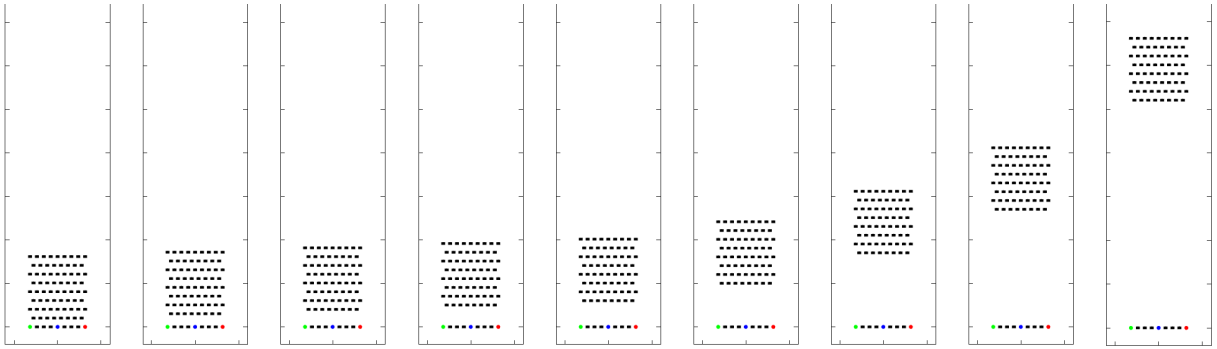
These tests were repeated, 2018, in a more systematic way in MTL windtunnel at KTH

Performed experiments

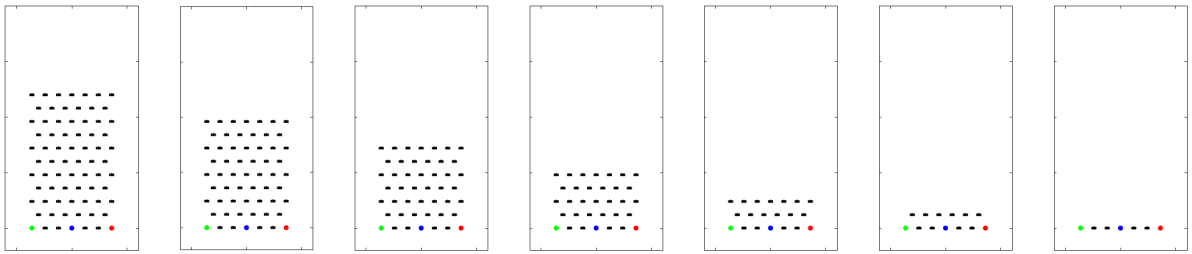
N_{tot}	N_{rows}	S_x/D	$N_{turb,1st}$	S_y/D
59	9	2.24	7	2.33
46	7	3.00	7	2.33
33	5	4.51	7	2.33
77	9	2.24	9	1.76
60	7	3.00	9	1.76
43	5	4.51	9	1.76
41	9	2.24	5	3.51
32	7	3.00	5	3.51
23	5	4.51	5	3.51
72	11	3.33	7	2.33
72	11	4.00	7	2.33
72	11	2.67	7	2.33
72	11	2.67	7	2.00
72	11	3.33	7	2.00
72	11	4.00	7	2.00
72	11	2.67	7	2.67
72	11	3.33	7	2.67
72	11	4.00	7	2.67
72(*)	11	3.33	7	2.33
72(*)	11	4.00	7	2.33
98(*)	15	2.67	7	2.33
98(*)	15	2.67	7	2.00
72(*)	11	3.33	7	2.00
72(*)	11	4.00	7	2.00
72(*)	11	2.67	7	2.67
72(*)	11	3.33	7	2.67
72(*)	11	4.00	7	2.67

85 wind farm layouts were investigated

The farm downstream was moved (Δx changed)



N_{rows} was changed from the maximum to 1 only

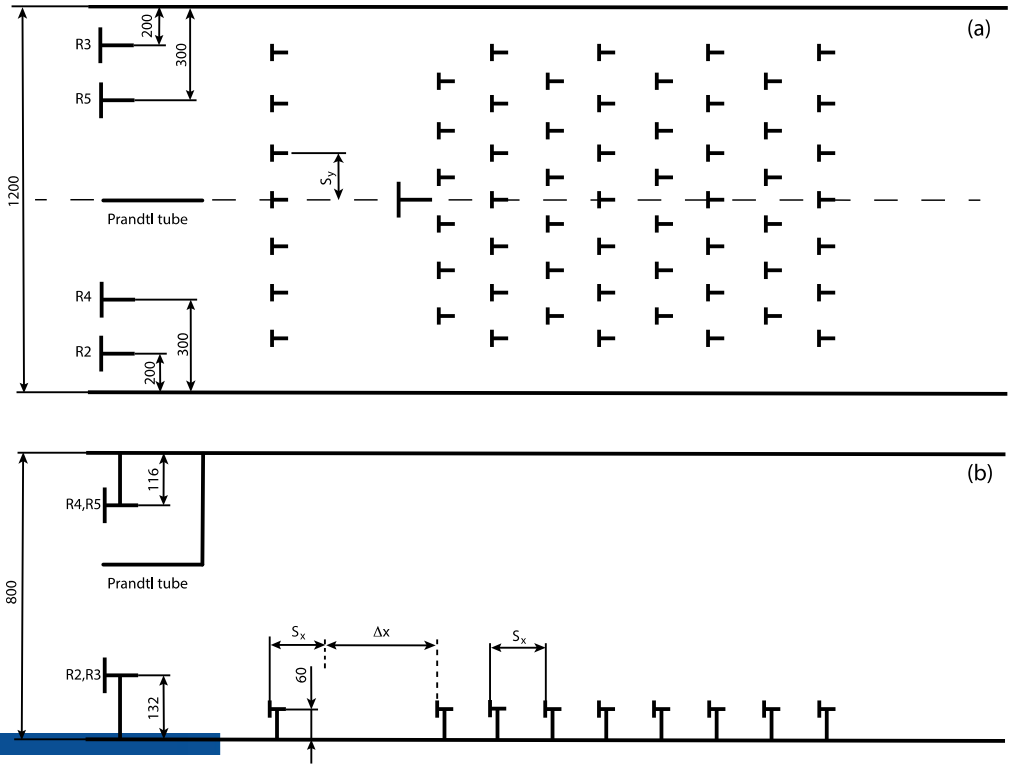


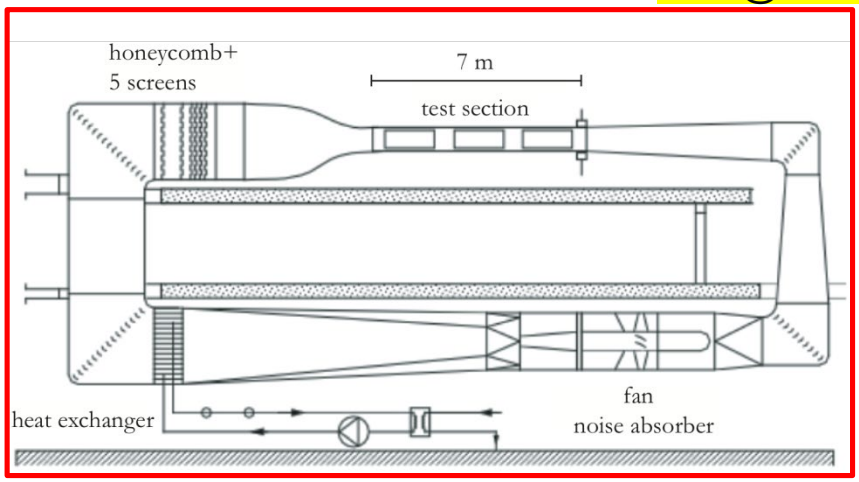
Experimental setup

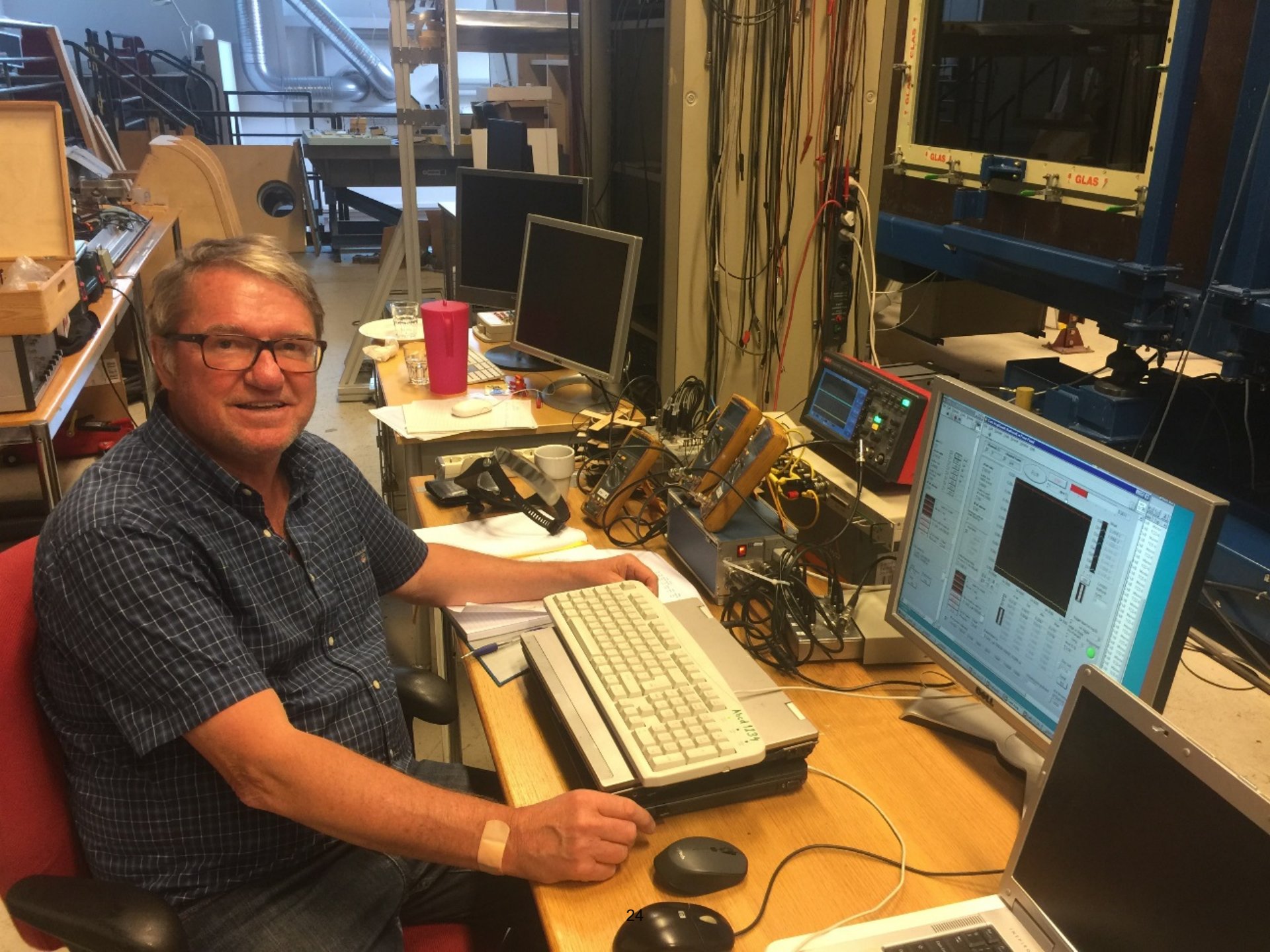
- 3 monitored turbines in the first row
- 4 monitored propeller anemometers at the test-section inlet
- Homogeneous incoming flow

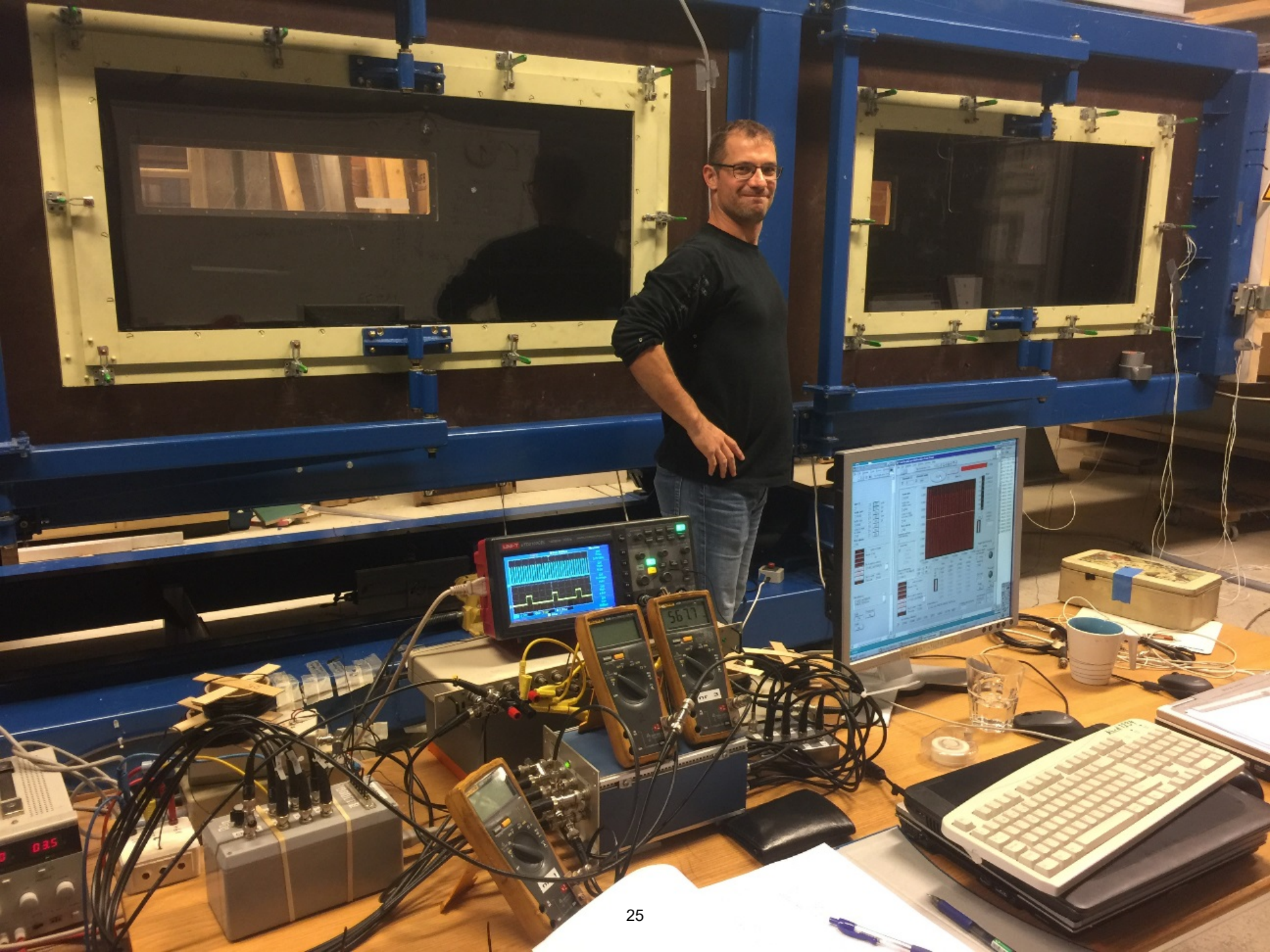
Only the RPM were measured by means of a laser and photodiode

MTL @ KTH





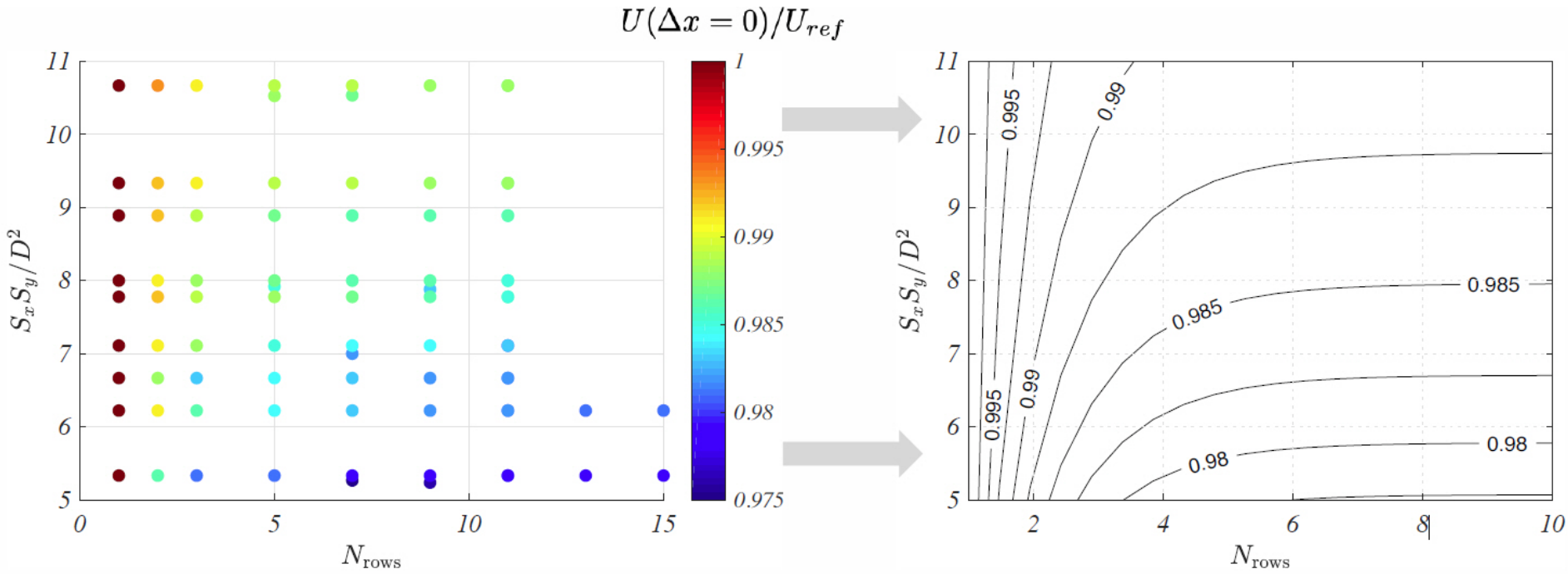

GLAS
GLAS




NYC
industry
LIMITED EDITION


T3

Collection of results from 85 farm configurations

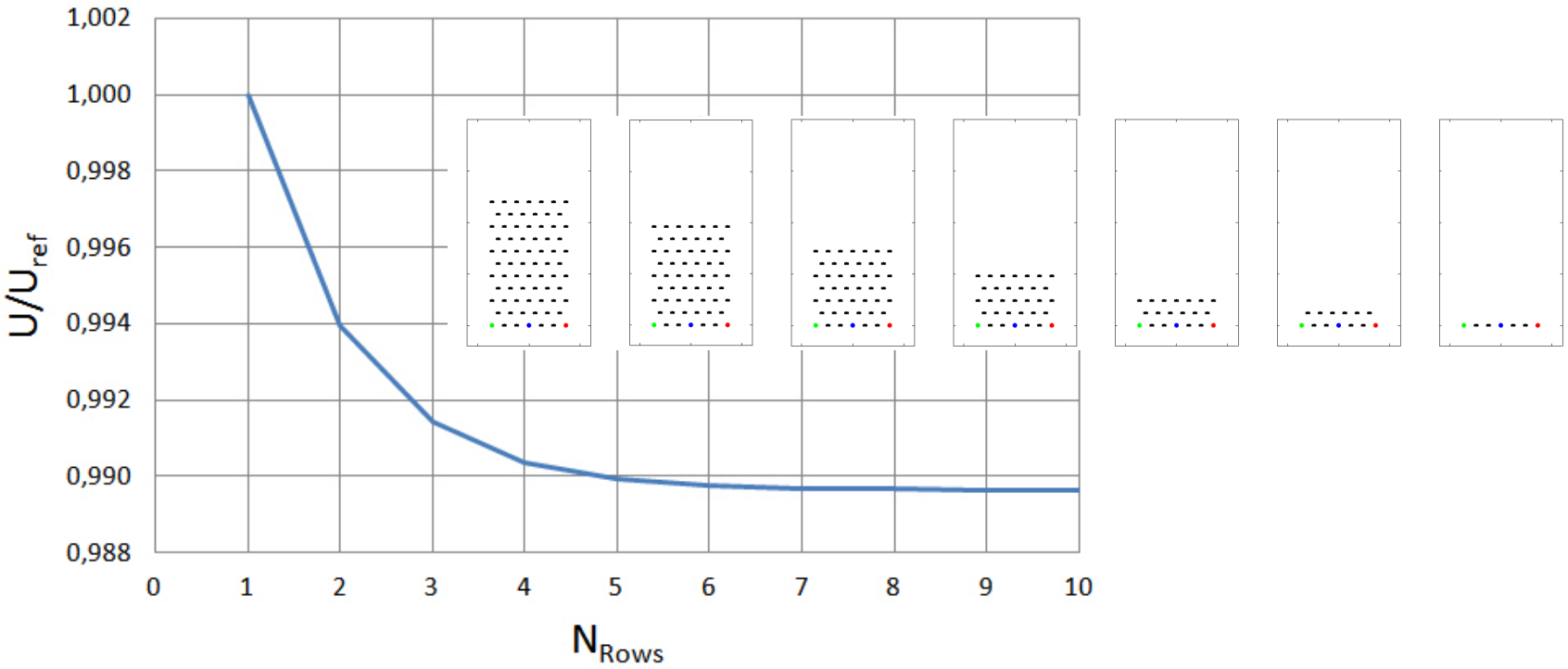


- From each experiment it was possible to determine the speed reduction of the first row for the given farm density and number of rows
- An empirical formula that fits the data is given by

$$U\left(\Delta x = 0\right) = U_{\text{ref}}\left\{1 - 0.097\left(\frac{S_x S_y}{D^2}\right)^{-0.9}\left[1 - \exp\left(0.88 - 0.88 N_{\text{rows}}\right)\right]\right\}$$

Collection of results from 85 farm configurations

$$U\left(\Delta x = 0\right) = U_{\text{ref}} \left\{ 1 - 0.097 \left(\frac{S_x S_y}{D^2} \right)^{-0.9} \left[1 - \exp\left(0.88 - 0.88 N_{\text{rows}}\right) \right] \right\}$$



Similar layouts different Blockage levels ?

	Gävle Wind Tunnel	KTH MTL Wind Tunnel
Turbulence intensity as measured by the center turbine in the first row	3%	0.15%
Velocity reduction due to Blockge for the center turbine in the first row	2.3%	1.2%

Turbulence ?

ORFEUS

STandUP for WIND

A FLOW SOLVER FOR WIND-FARM PLANNING AND BLOCKAGE ASSESSMENT

ORFEUS developed by:

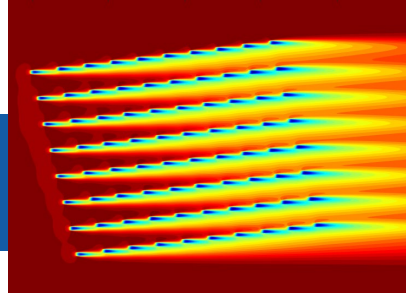
Antonio Segalini, PhD

KTH Royal Institute of Technology

segalini@mech.kth.se

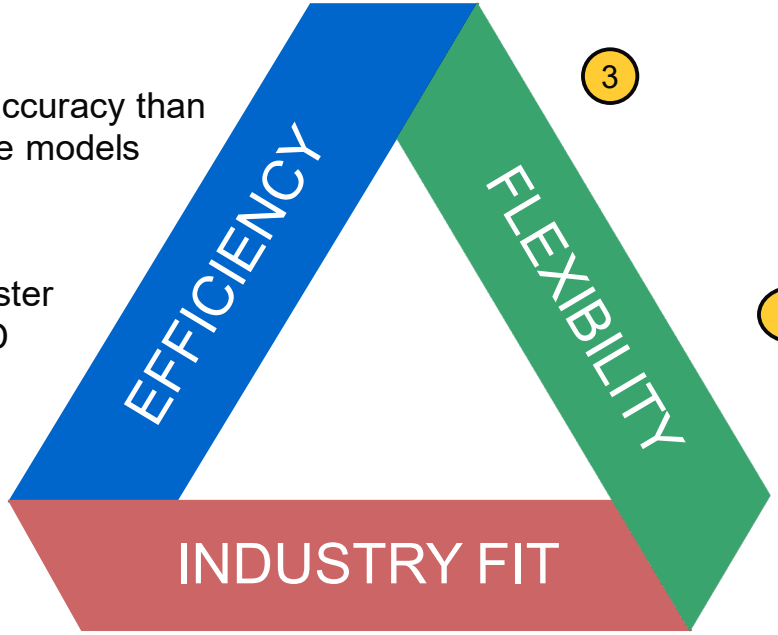
+46 (0)73 35 93 370

ORFEUS

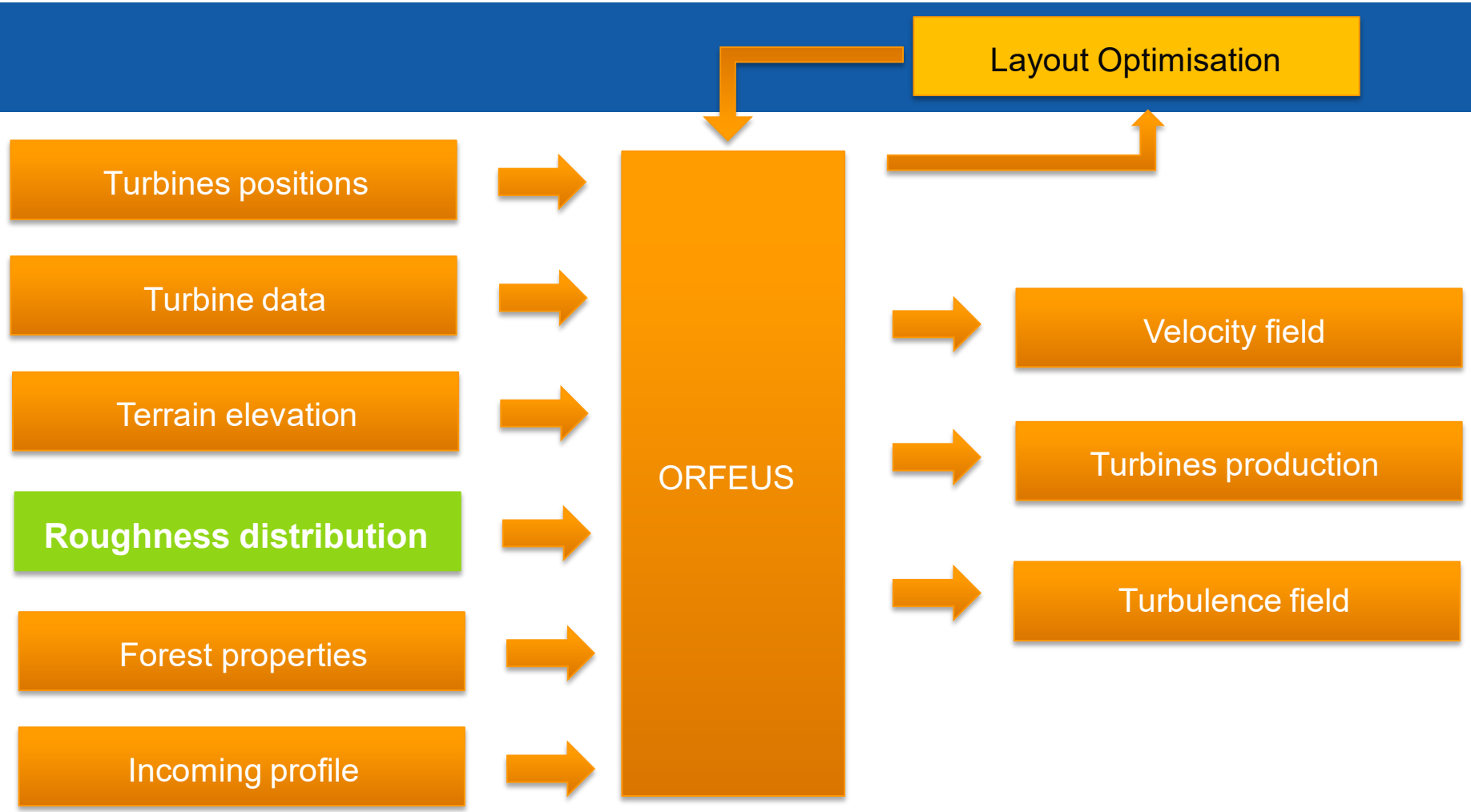


- Alternative to other CFD software to assess flow features of interest, e.g.
  - farm blockage
  - wakes interaction
  - yaw misalignment

1. Higher accuracy than wake models
2. More than 20 times faster than traditional CFD
3. Actuator disk model
4. Ability to include
   - Complex terrains
   - Forests
   - Atmospheric stratification
   - Yawed turbines
5. Improved planning for wind farms



For additional information contact Antonio Segalini (segalini@mech.kth.se)



- Spectral solver of linearized flow equations -> fast and accurate
- Turbines simulated as actuator disks -> no wake models

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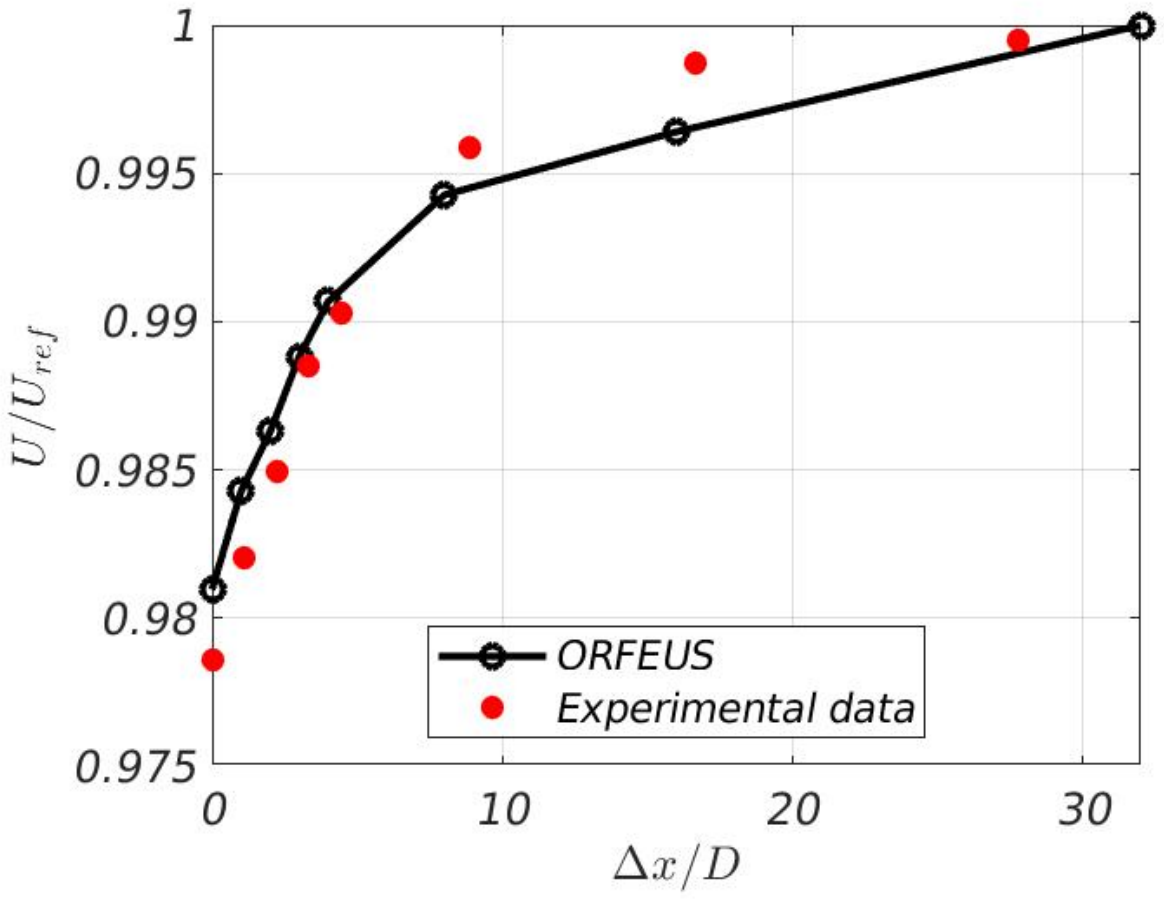
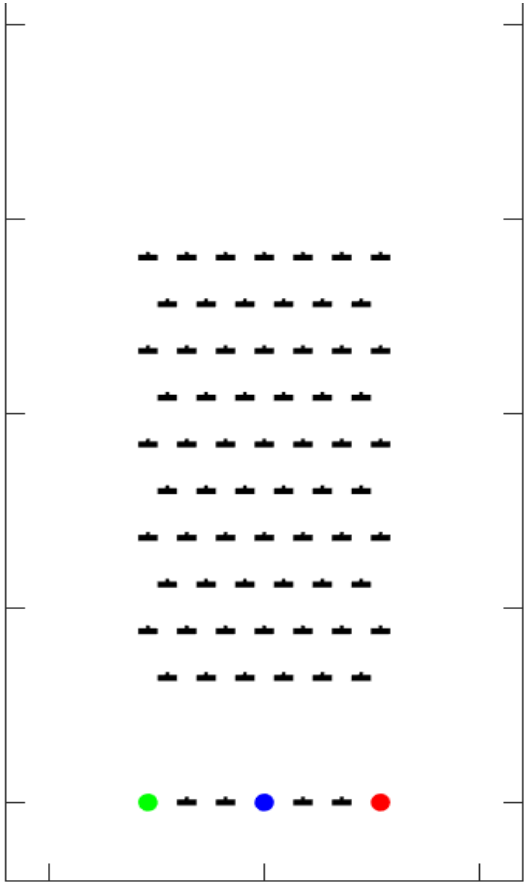
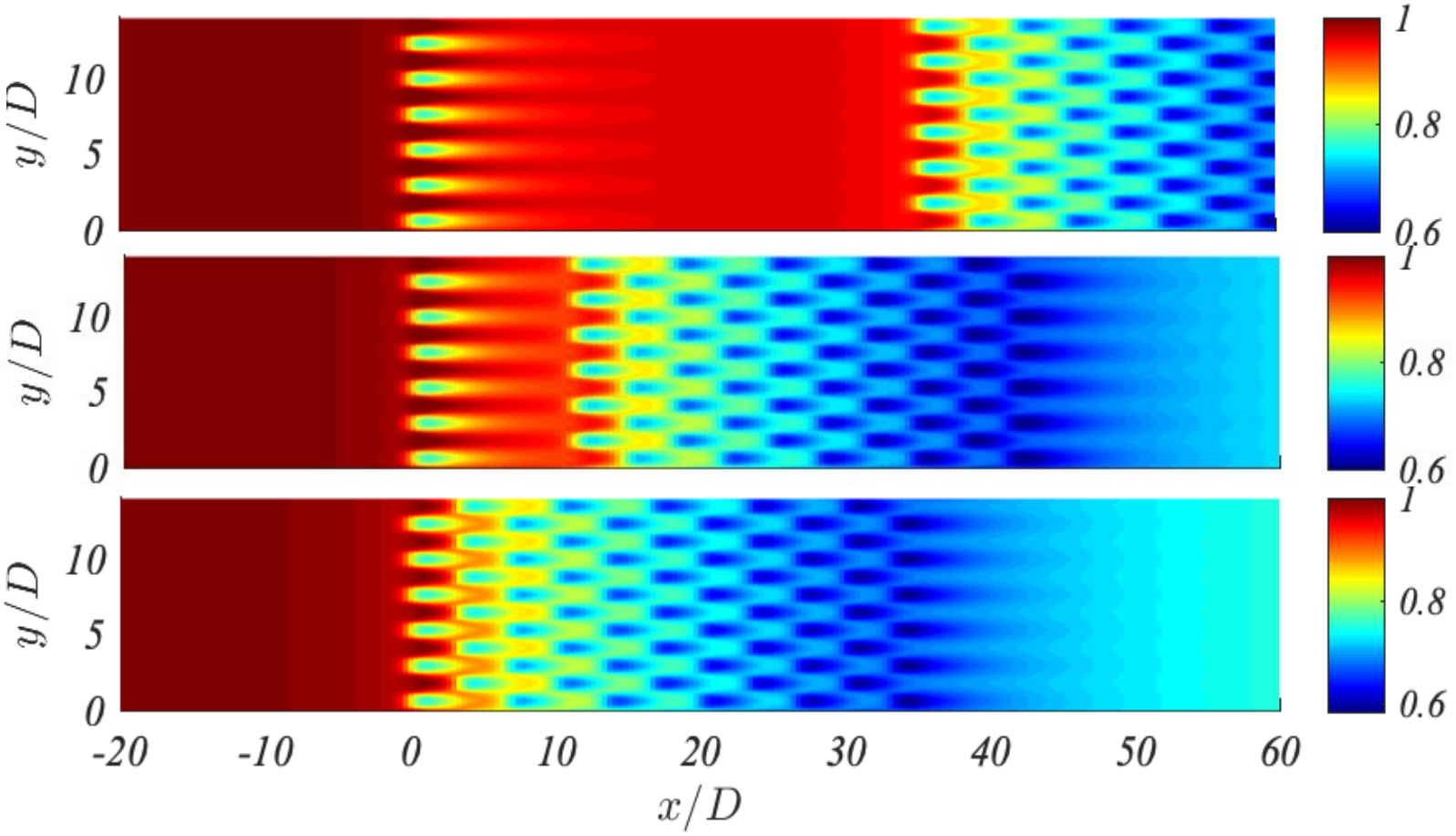
ORFEUS simulations and comparison with measurements



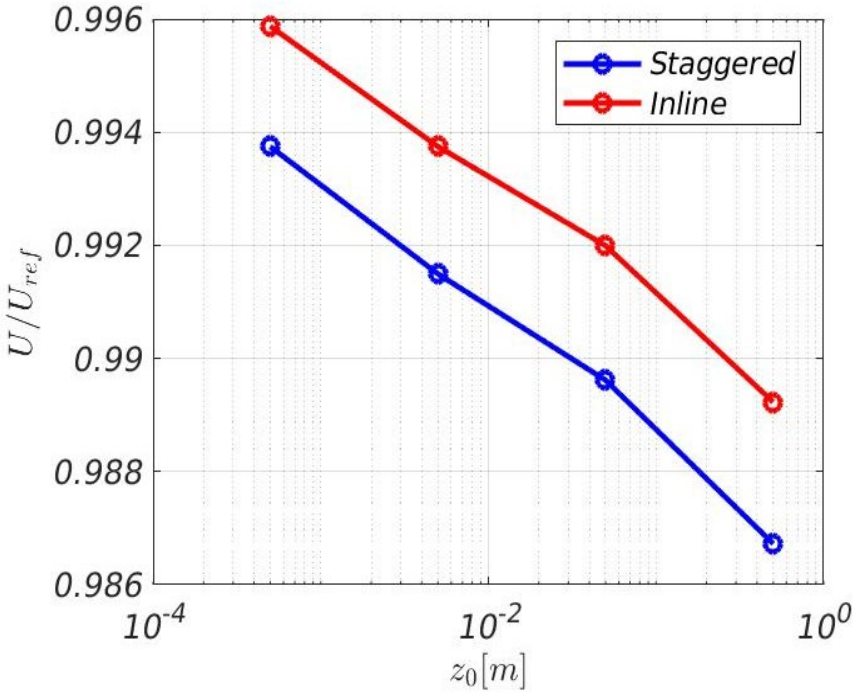


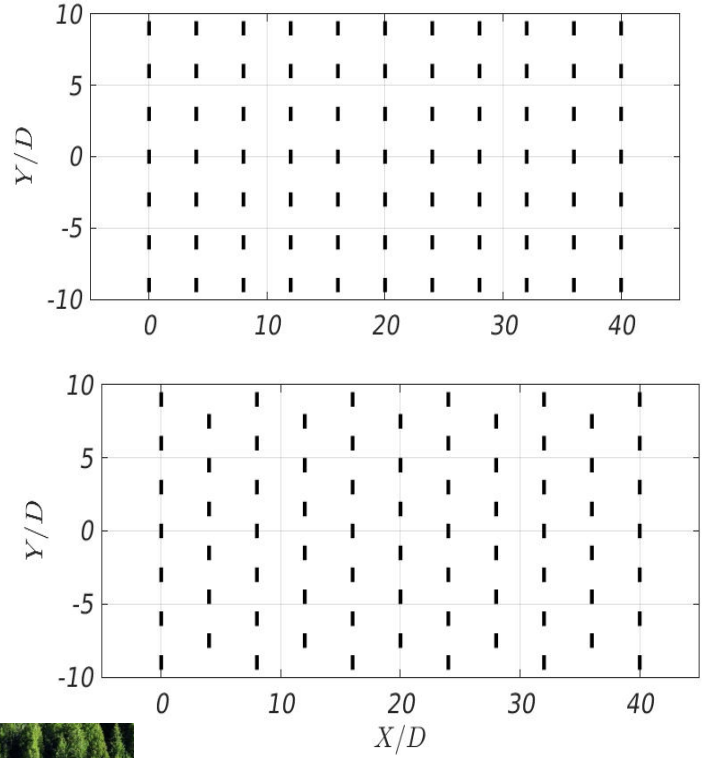
K72-7-90-11-120

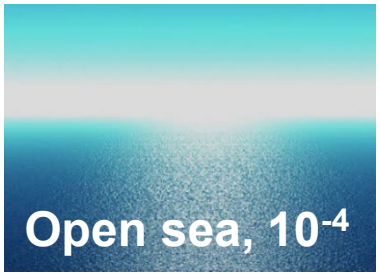
- ORFEUS simulations of tested layout



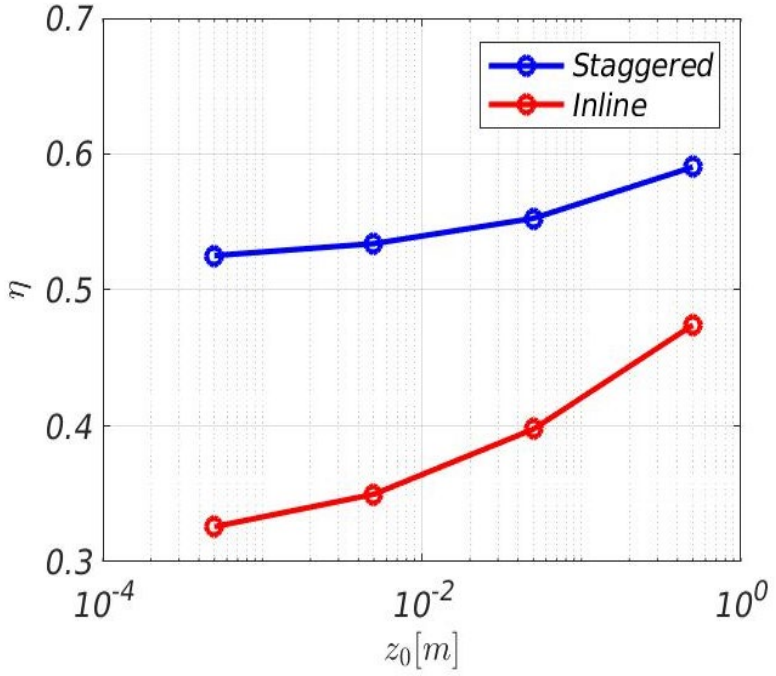
Effect of roughness, Inline/staggered, Diam=93m (Sx=4D, Sy=3D)

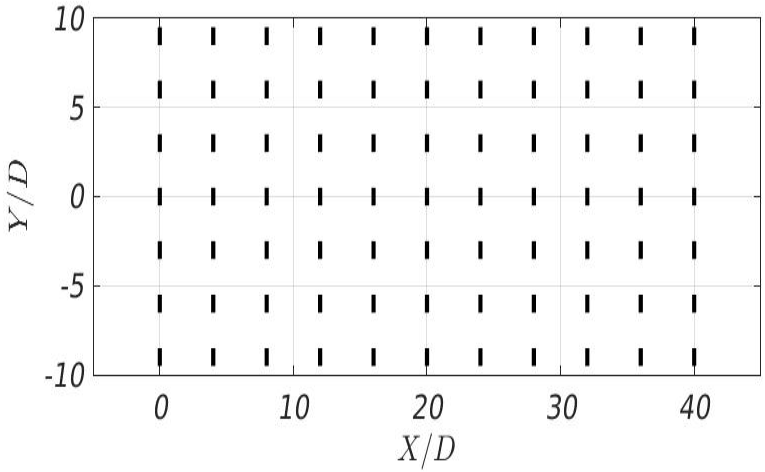


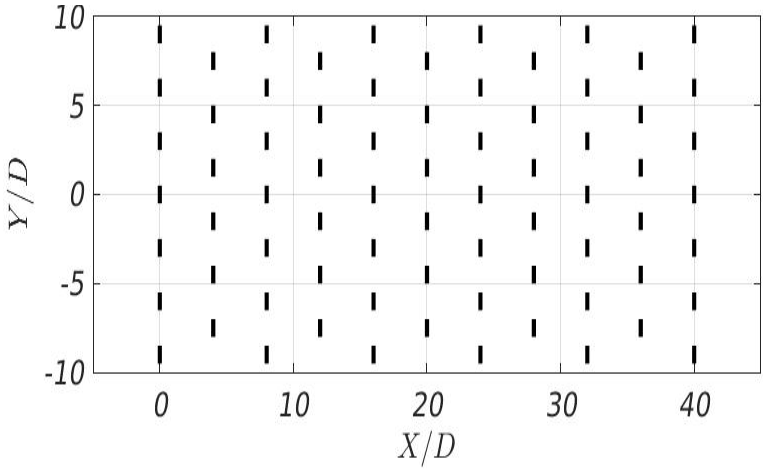




Effect of roughness, Inline/staggered, Diam=93m (Sx=4D, Sy=3D) (Array efficiency)



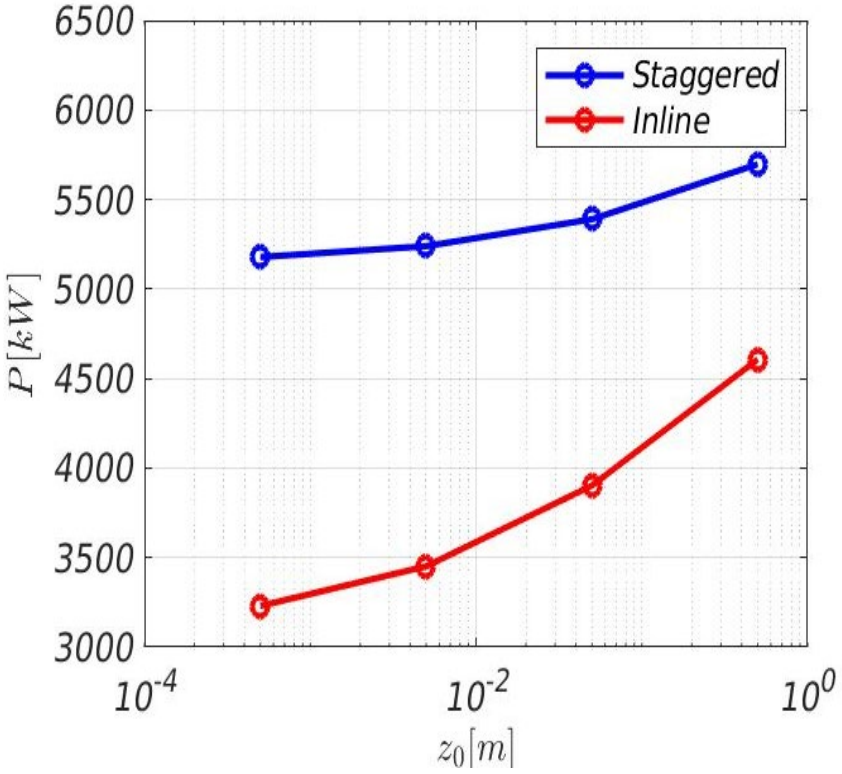




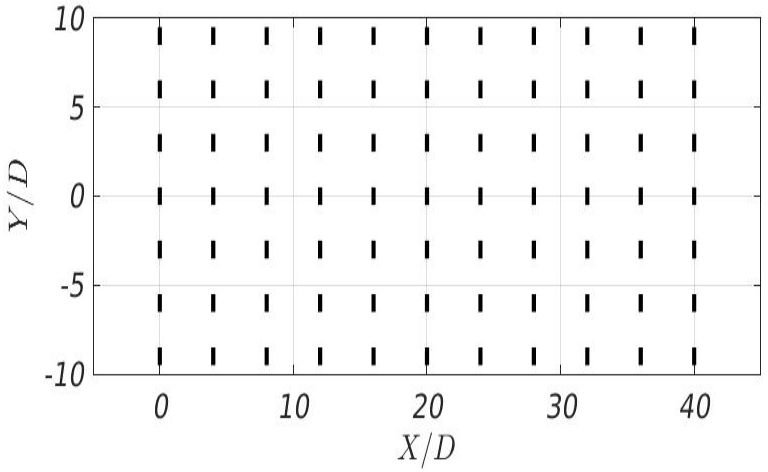
Normalized with 1:st turbine => no block

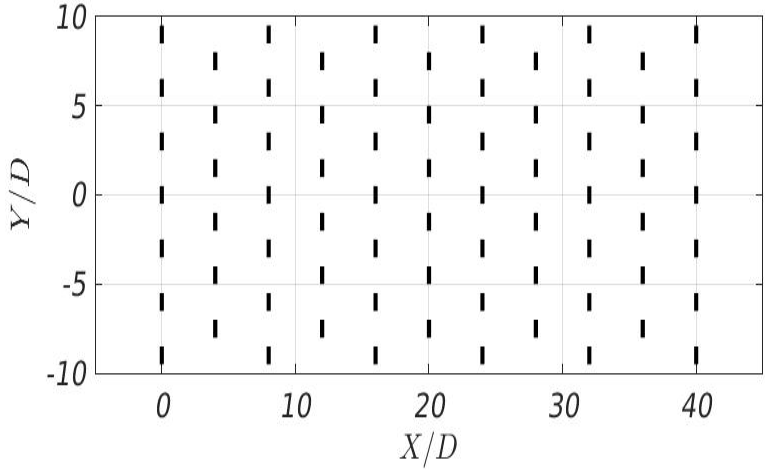
$$\eta = \frac{1}{N_t P_1} \sum_{i=1}^{N_t} P_i$$

Effect of roughness, Inline /staggered, Diam=93m (Sx=4D, Sy=3D) (POWER)

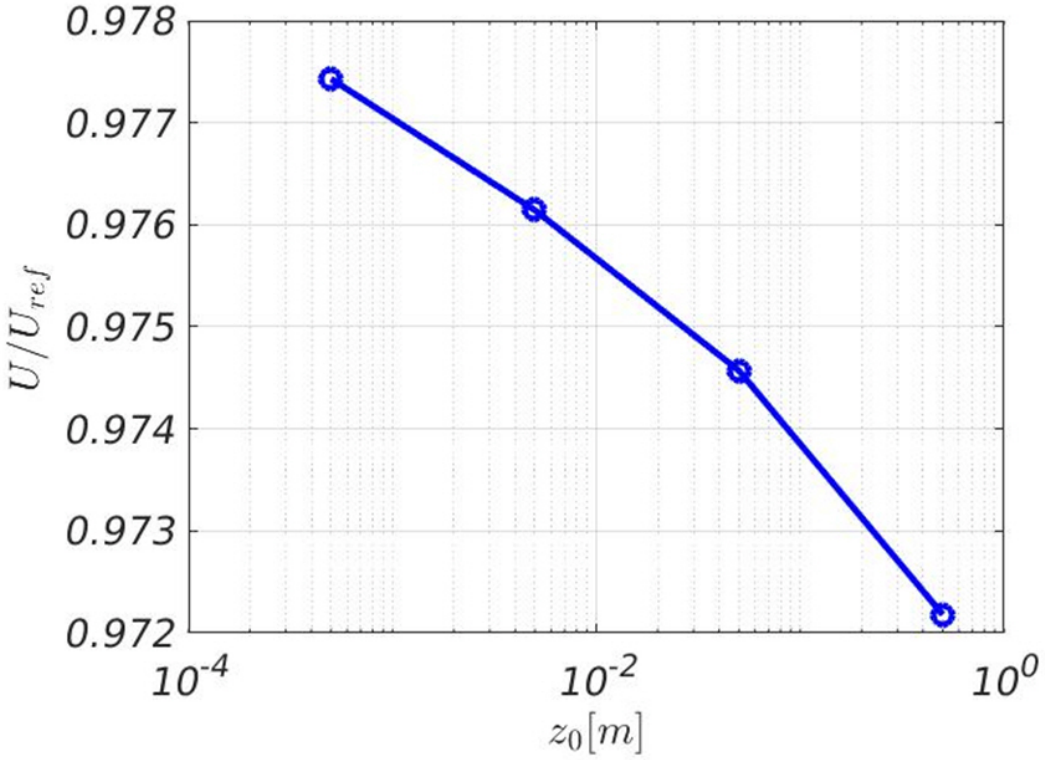


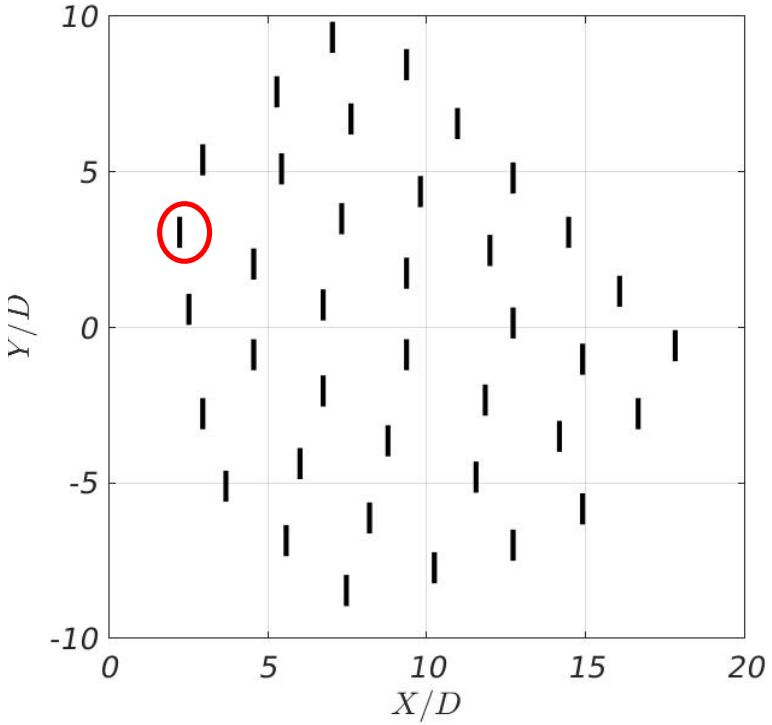
Wake and blockage effects included





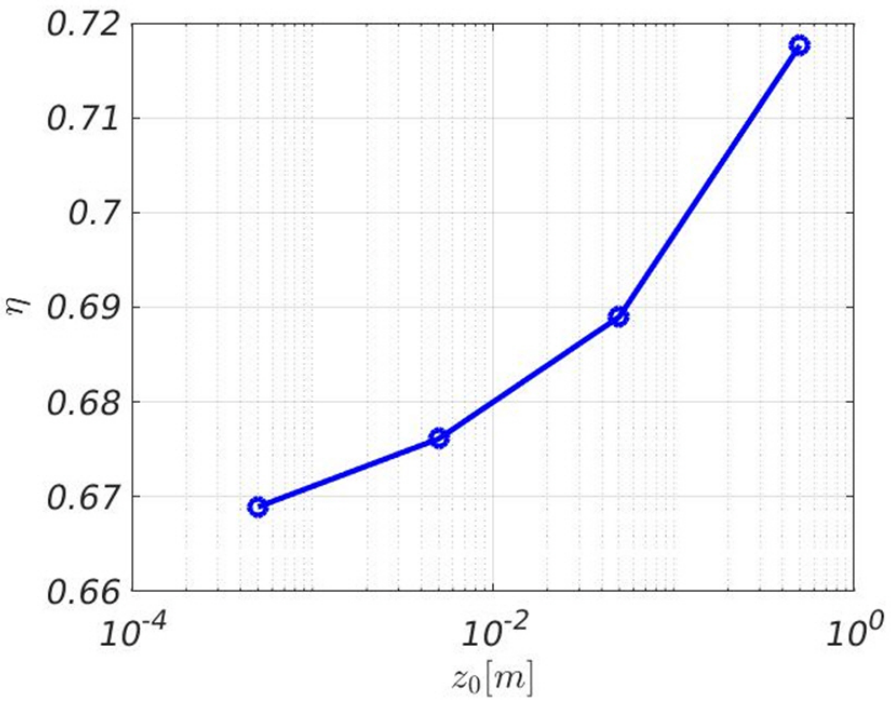
Arbitrary near circular layout (2.3 MW, D=93m)



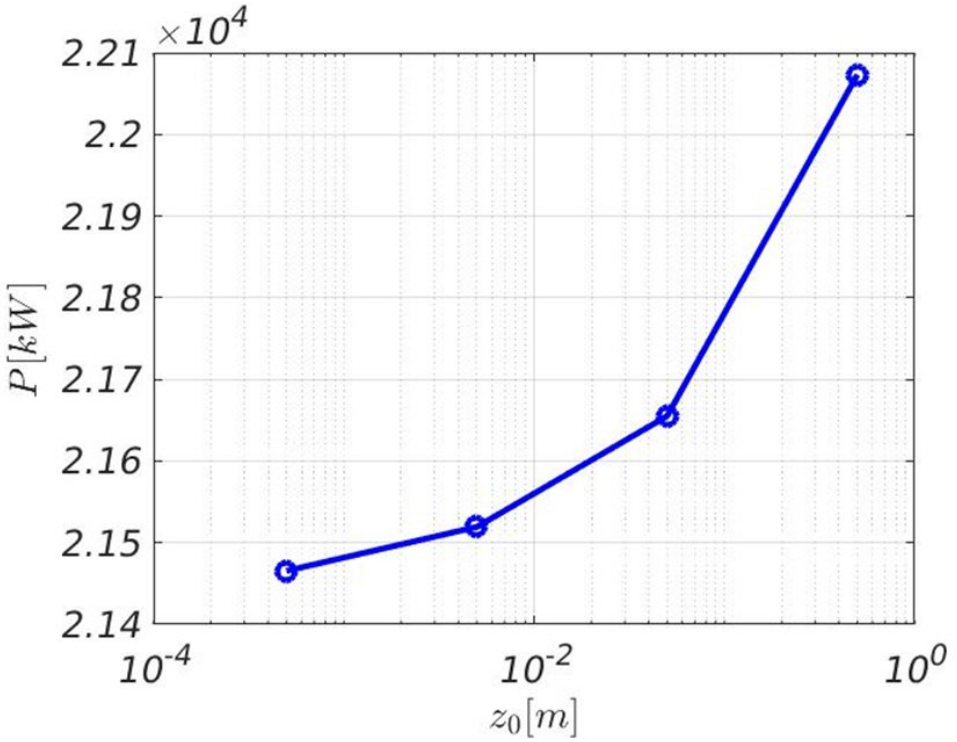


Arbitrary near circular layout (2.3 MW, D=93m)

Array efficiency



Power

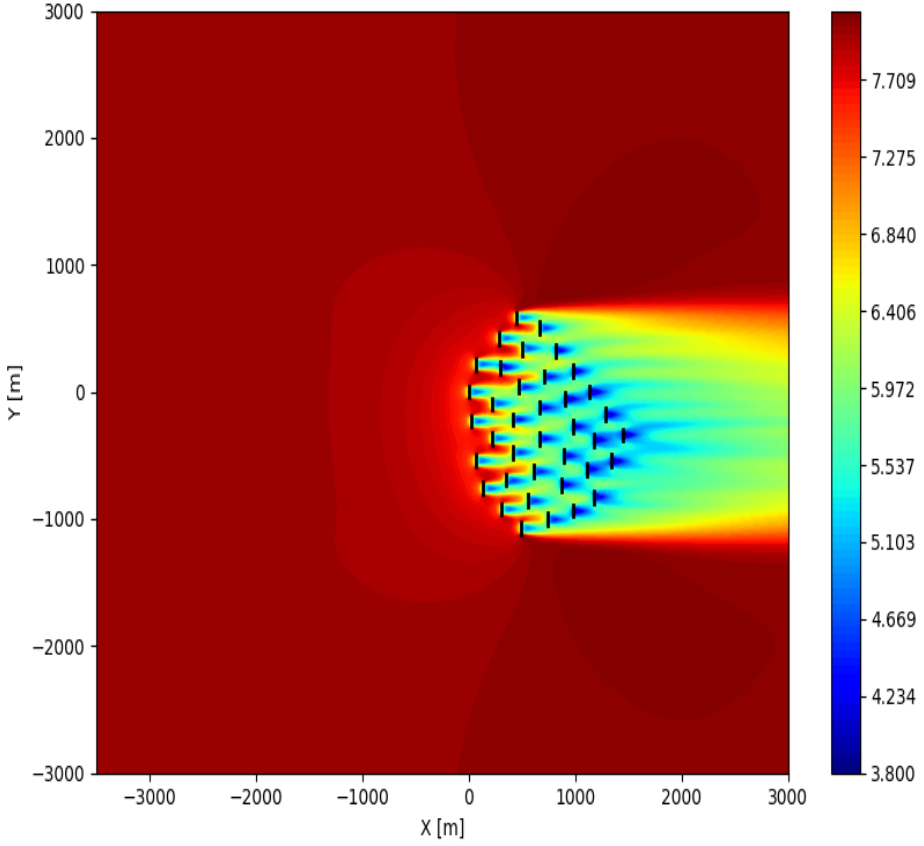


Wake and blockage effects included

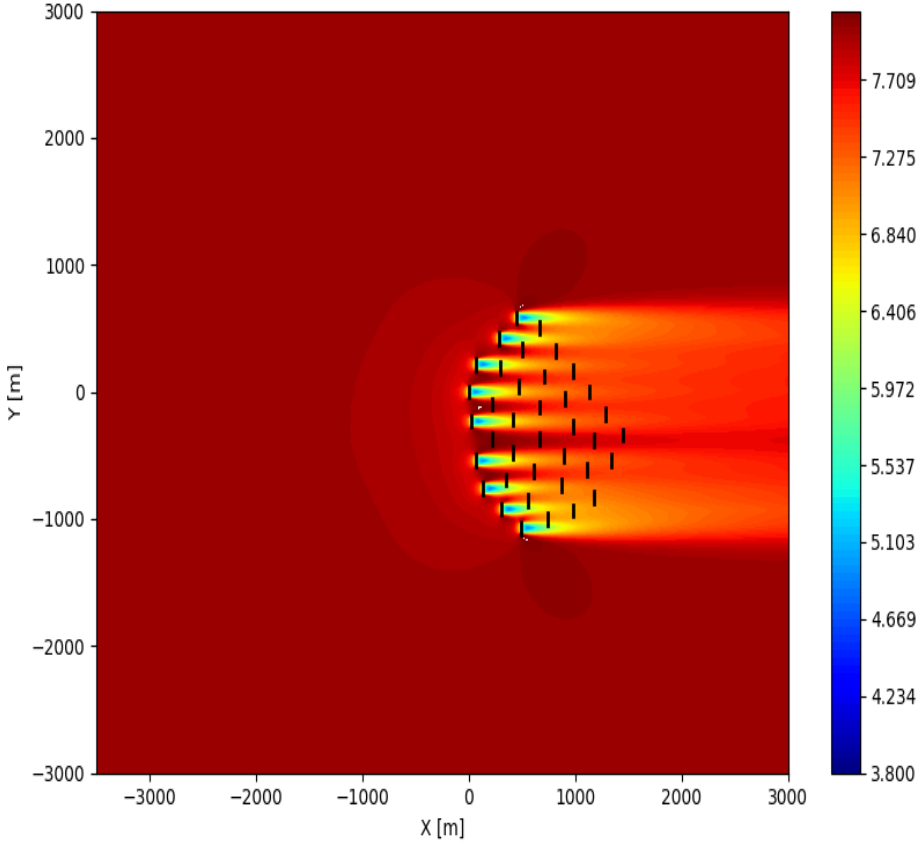
Arbitrary near circular layout (2.3 MW, D=93m)

Hub height velocity

All turbines



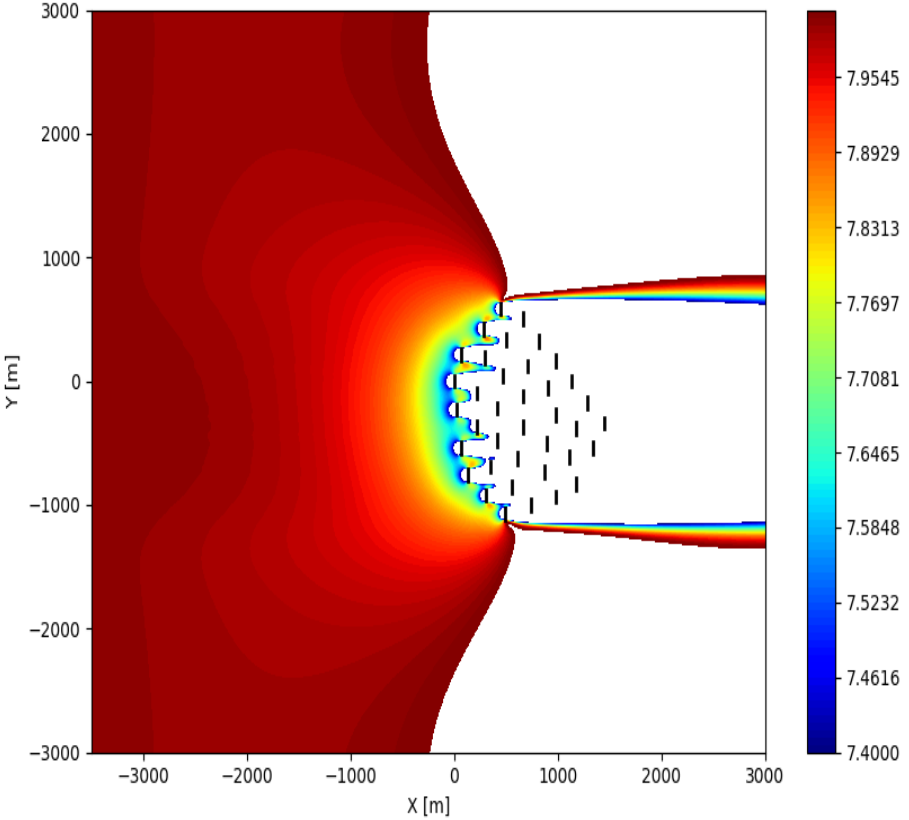
Only the first row



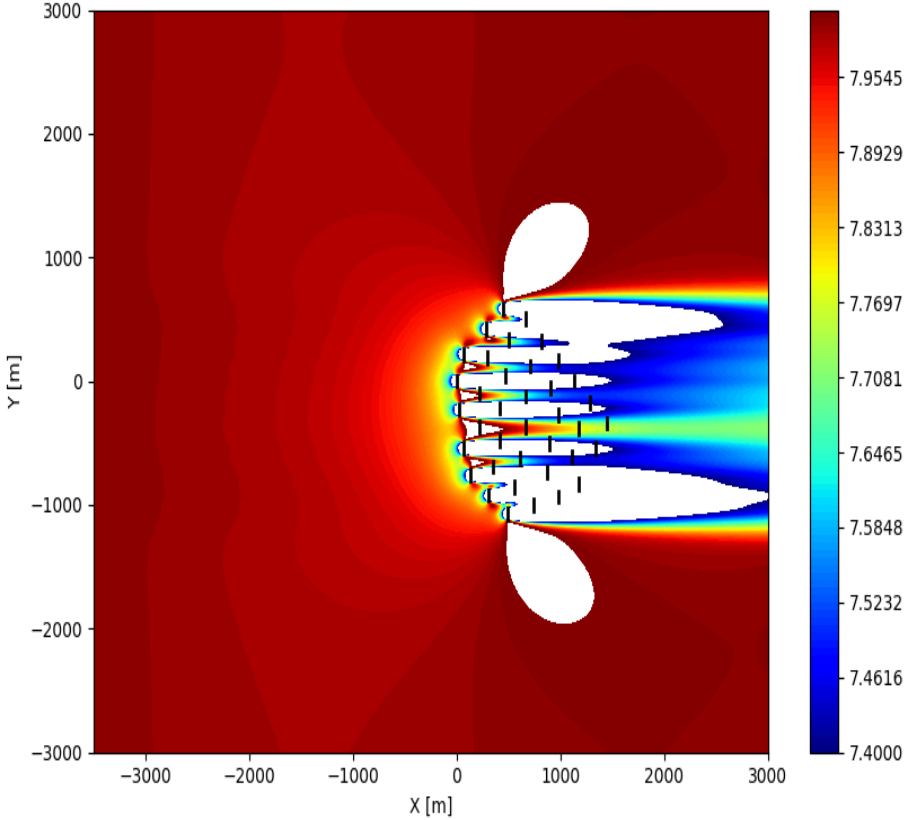
Arbitrary near circular layout (2.3 MW, D=93m)

Hub height velocity (zoom)

All turbines



Only the first row



Conclusions

- Blockage effects occur offshore and onshore
- The magnitude of the blockage depends on the thrust forces on the flow imposed by the turbines
- Higher turbulence and corresponding lower wake losses implies also higher relative blockage !
- Blockage effects has to be accounted for, even onshore !
- The tool ORFEUS can be used to quantify these effects for any wind farm conditions !

Thanks for listening !