Wind Tunnel Study of a "Floating" Wind Turbine's Wake in an Atmospheric Boundary Layer with Imposed Characteristic Surge Motion

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The Floateole Project

Figure: FLOATGEN, the prototype floating offshore wind turbine, used as a reference in this project. Source: https://sem-rev.ec-nantes.fr/medias/photo/sem-rev-bj-132-bd_1539862739781-jpg?ID_FICHE=196422 Accessed: 2020-09-21

- Duration of the project: 2017-2021
- Funding: Pays de la Loire, Centrale Nantes
- PhD thesis partly funded by ADEME
- Work includes wind tunnel experiments (PhD) and field measurements (LIDAR, Post-Doc)
- Comparison of measurements, when both data sets are available
- Industrial partners: D-ICE Engineering, IDEOL

Main Questions

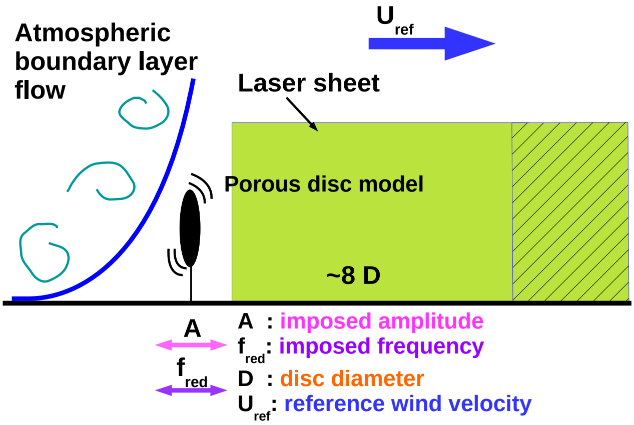
- **How does imposed surge motion affect the wake?**

→ **How is the spatial evolution of the wake affected?**

→ **Are physical processes modified by imposing surge motion?**

Boundary Layer & Scaling

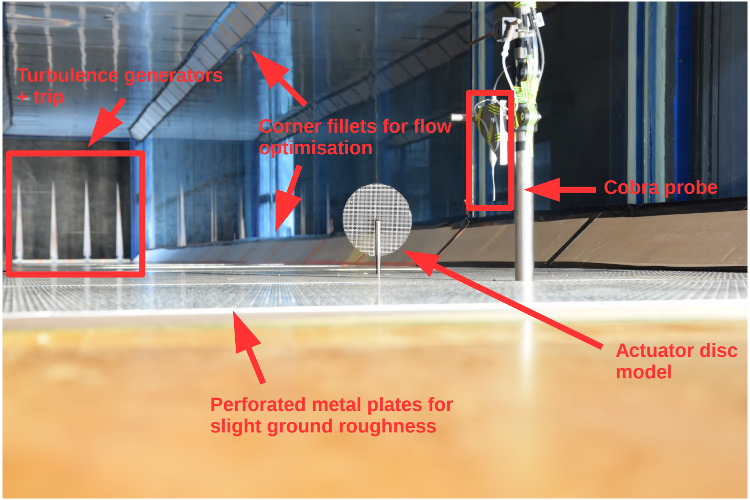
Experimental Set-up



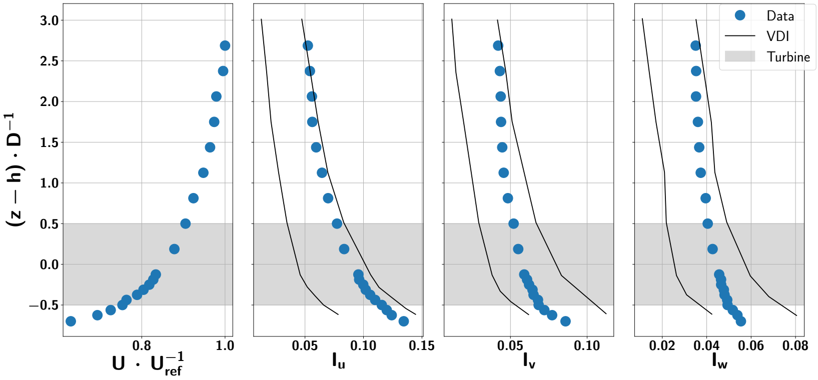
- Geometric scaling: 1 : 500
- Velocity scaling: 1 : 2.5
- Frequency scaling: 200
- Characteristic A: $A = 0.125\,D$ or 10 m full-scale
- Characteristic f_{red}: $f_{red} = 0.1$ or 0.01 Hz full-scale

$\rightarrow$ **Motion derived from numerical simulation**

Experimental Set-up



Modelled Boundary Layer



- Profiles indicate that the flow is representative of a maritime boundary layer according to VDI (2000).

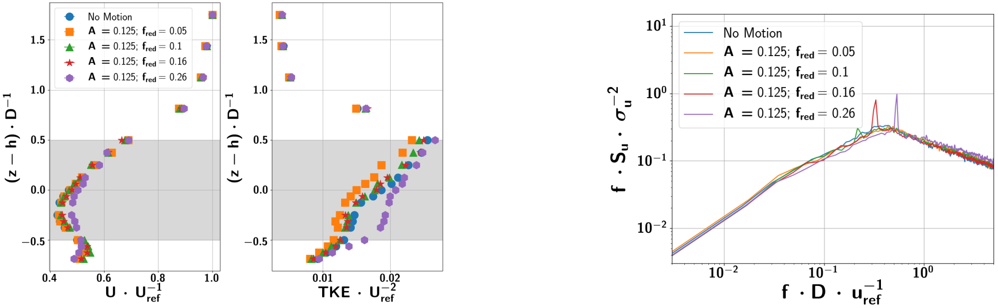
Modelled Boundary Layer

Table: Adaptation from VDI Guideline 3783. z_0 is the roughness length, α the exponent coefficient and L_u^x the integral length scale. Added values for the modelled boundary layer.

Roughness class	Target values	**Modelled**
Type of terrain	ice, snow, water surface	**water surface**
z_0 $[m]$	10^{-5} to 5×10^{-3}	**5.5×10^{-6}**
α	0.08 to 0.12	**0.11**
L_u^x $[m]$	200 to 250	**200**

- **Profiles and values show: flow is representative of a maritime boundary layer** ✓
- **Spectra also correspond to atmospheric boundary layer reference data** ✓

Previous work

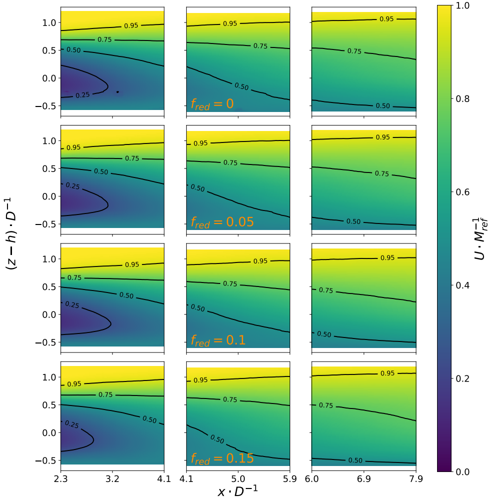


$$f_{red} = \frac{f \cdot D}{U_{ref}}$$

- Modifications of *U* and *TKE* in the wake through imposed motion
- Peaks in spectrum at imposed motion frequencies
- Figures from Schliffke et al. (2020)

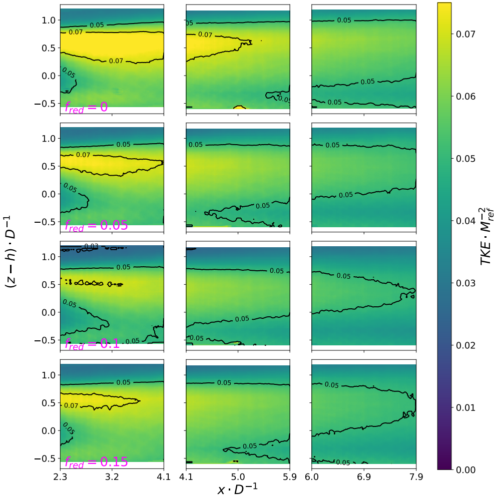
PIV Measurements

PIV - Velocity



- From top to bottom: $f_{red} = 0$, $f_{red} = 0.05$, $f_{red} = 0.1$, $f_{red} = 0.15$
- From left to right: distance from model from 2.3 D to 7.9 D
- Motion below $f_{red} <= 0.1$ has little effect on the mean flow
- $f_{red} = 0.15$ leads to of faster recovery of the mean flow

PIV - TKE



- From top to bottom: $f_{red} = 0$, $f_{red} = 0.05$, $f_{red} = 0.1$, $f_{red} = 0.15$
- From left to right: distance from model from 2.3 D to 7.9 D
- Motion reduces *TKE*, but not systematically

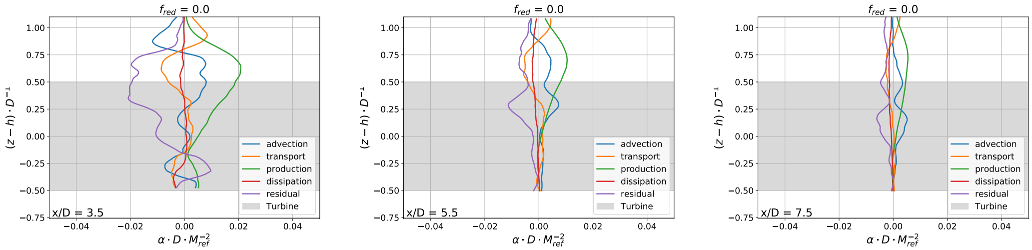
PIV - TKE budget - Introduction

0 = - Advection - Production - Transport
- Pressure Transport - Viscous Transport
- Dissipation

- Method following approach described in Blackman et al. (2017)
- **Advection**: ✓
- **Production**: ✓
- **Transport**: ✓
- **Pressure transport**: ✓
- **Viscous transport**: ✗
- **Dissipation**: ✓ (using LE-PIV method proposed by Sheng et al. (2000))
- Reminder:

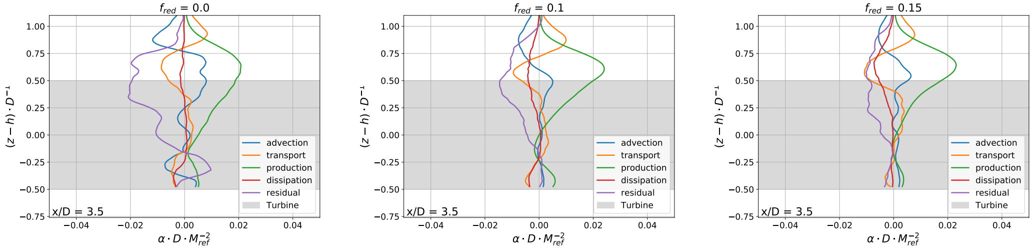
$$TKE = 0.5 \cdot \left(\sigma_u^2 + \sigma_v^2 + \sigma_w^2\right)$$

PIV - TKE budget - Fixed Turbine



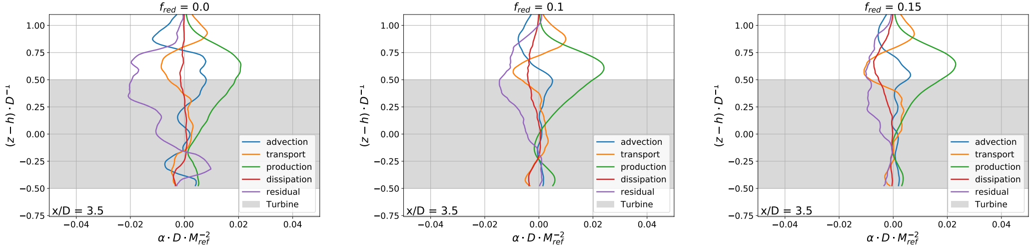
- Production and advection are strongest gain of *TKE* around top tip
- Turbulent transport is a sink below 0.75 and then a gain, decreasing magnitude downstream
- Dissipation plays an increasingly important role with increasing distance
- Pressure transport/residual largest sink
- $x/D > 3.5$: all terms behave similarly $\rightarrow$ not shown in the following

PIV - TKE budget - Advection



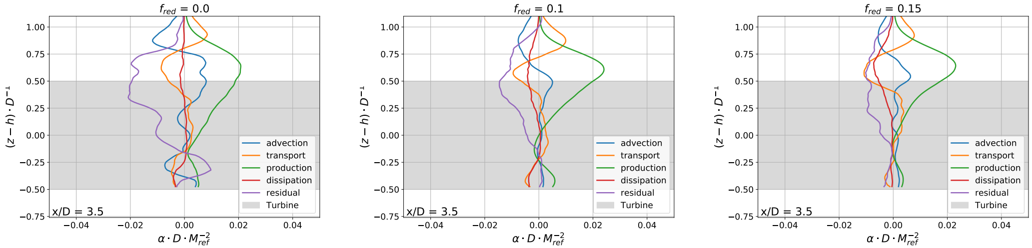
- Motion reduces amplitude of *TKE* advection

PIV - TKE budget - Transport



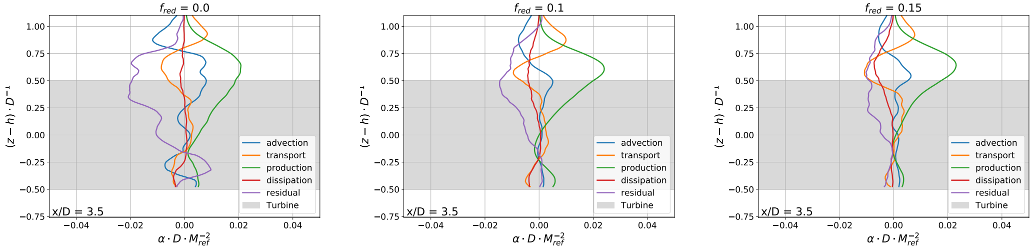
- Motion reduces amplitude of *TKE* advection
- Imposed surge motion has little effect on transport

PIV - TKE budget - Production



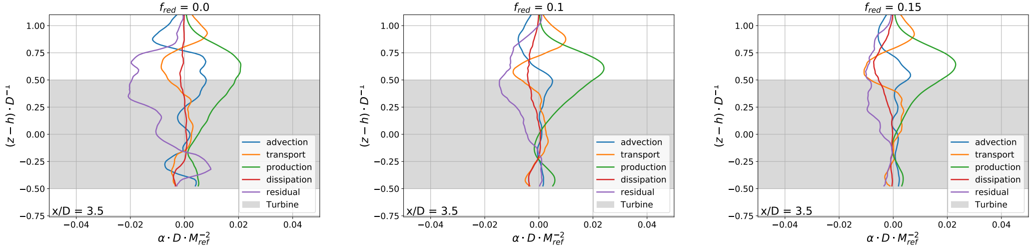
- Motion reduces amplitude of *TKE* advection
- Imposed surge motion has little effect on transport
- Imposed surge motion increases production above top tip

PIV - TKE budget - Dissipation



- Motion reduces amplitude of *TKE* advection
- Imposed surge motion has little effect on transport
- Imposed surge motion increases production above top tip
- Imposed surge motion increases dissipation systematically

PIV - TKE budget - Residual



- Motion reduces amplitude of *TKE* advection
- Imposed surge motion has little effect on transport
- Imposed surge motion increases production above top tip
- Imposed surge motion increases dissipation systematically above top tip
- Residual/pressure transport decreases with motion

Conclusions

Conclusions

→ How is the spatial evolution of the wake affected?

- **Velocity:** $f_{red} <= 0.1$: little effect on the mean flow; $f_{red} = 0.15$: perceived faster recovery
- **TKE:** *TKE* reduced overall
- → **First analysis seems to confirm observations in Schliffke et al. (2020)**

→ Are physical processes modified by imposing surge motion?

- Dissipation and production of *TKE* are increased with motion at $x/D = 3.5$
- The residual *TKE* budget equation is reduced with motion at $x/D = 3.5$
- → **Increased dissipation could explain the observed reduction in *TKE* with higher f_{red}, as the motion introduces higher frequencies into the wake that may expedite the transport of energy down the energy cascade. How does increased production fit in here?**

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References

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