KU LEUVEN

AWESCO
Airborne Wind Energy
System Modelling, Control & Optimisation

Large Eddy Simulations of AWE Systems in the Atmospheric Boundary Layer

Thomas Haas, KU Leuven

1. Internal Research Review
AWESCO Kick-off Week
Feb. 29th – Mar. 4th, 2016
University of Freiburg

Content

- Introduction
- Motivation
- Research problem
- Research plan
- Actual research development
- Outlook

Content

Personal background

Personal Background 1

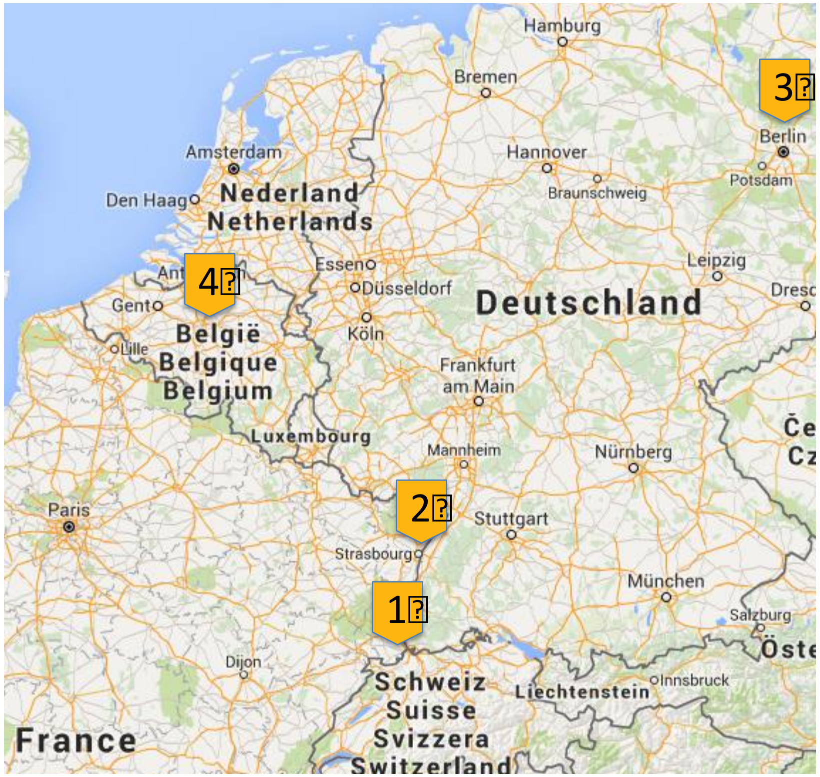
Born 14.10.1989 in France

B.Sc. Mechanical Engineering 2

- Uni. Strasbourg / FH Offenburg
- CFD study of mass flow meters

M.Sc. Engineering Sciences 3

- Technische Universität Berlin
- CFD study of impinging jets



➔**PhD and AWESCO fellow at KU Leuven** 4

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KU LEUVEN

Katholieke Universiteit Leuven

KU Leuven (founded 1425)

- Science, Engineering & Technology
- Biomedical Sciences
- Humanities and Social Sciences

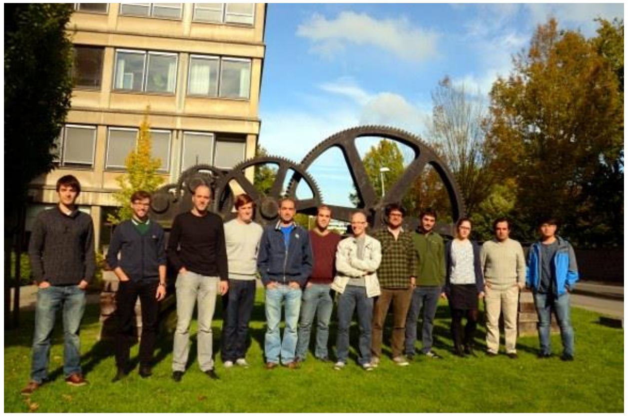
➔11.000 staff – 57.000 students

Turbulent Flow Simulation & Optimization

Prof. Dr. Johan Meyers

1 post doc – 9 PhD students

Research: Numerical methods / Wind energy



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A little thought experiment ...

Enerkite AWE system in operation [cleanthinking.de]

Project description and background

Virtual Wind Environment and Flight Simulator
for Airborne Wind Energy Systems (ESR6 – KUL)

Work package WP 1 - Modelling and Simulation

Main tasks

- → CFD simulation of AWE systems in the atmospheric bounday layer
- → Couple AWE controllers and test in simulation framework

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Content

Statement of research problem (ESR6 – KUL)

*Investigation of interaction between **atmospheric boundary layer** and **AWE systems** by means of **CFD simulations** and **optimal control** for **increased power extraction***

Keywords

- Physics of wind boundary layer
- Realistic model of AWE system
- Large Eddy Simulations
- Optimal flight trajectory

Research objective

Increase AWES's Power Extraction

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Atmospheric boundary layer simulation Advantages & challenges

Advantages

Cooperation with academic partners

→ Simulation of realistic wind conditions

→ Simulation of single AWES and farms

→ Numerical optimization methods

Challenges

Cooperation with industrial partners

→ Validation against experimental data

→ Resource intensive computations, i.e efficient computing (HPC)

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Research timeline & main objectives

AWESCO Year 1
- Implement AWE model & perform first computations

AWESCO Year 2
- Secondments at ALU-FR & TU Delft

AWESCO Year 3
- Numerical optimization (e.g. adjoint opt.) & additional secondment

KUL Year 4
- Research results dissemination & Thesis writing

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Planned secondments

1. **Secondment**

   Institution: ALU Freiburg

   Research: Optimal flight trajectory

   Duration: 3 Months – Summer/Fall 2016

2. **Secondment**

   Institution: Delft University of Technology

   Research: AWES modelling

   Duration: 3 Months – 2017

1. **Secondment**: e.g. model validation

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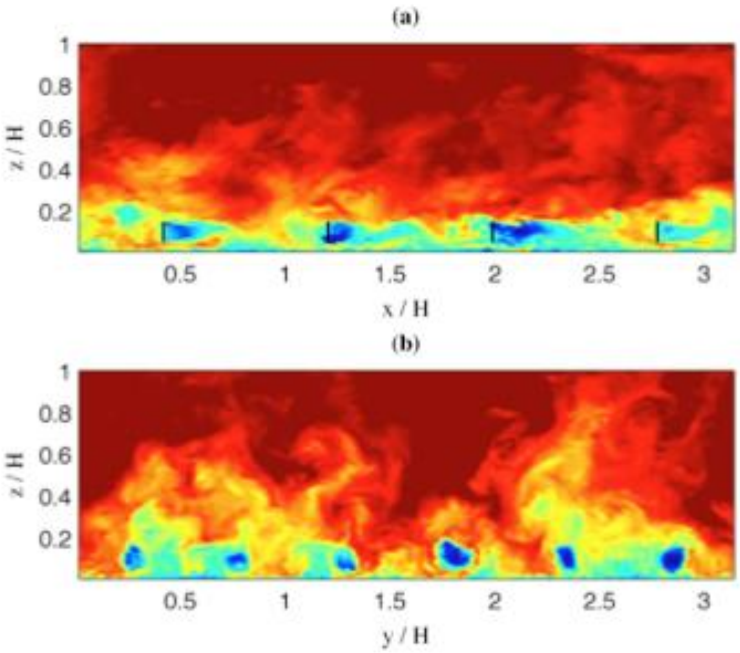
Simulation methodology

→ CFD simulation of AWE systems in the atmospheric boundary layer



Wind farm velocity fields [M.Calaf]

Computational Fluid Dynamics

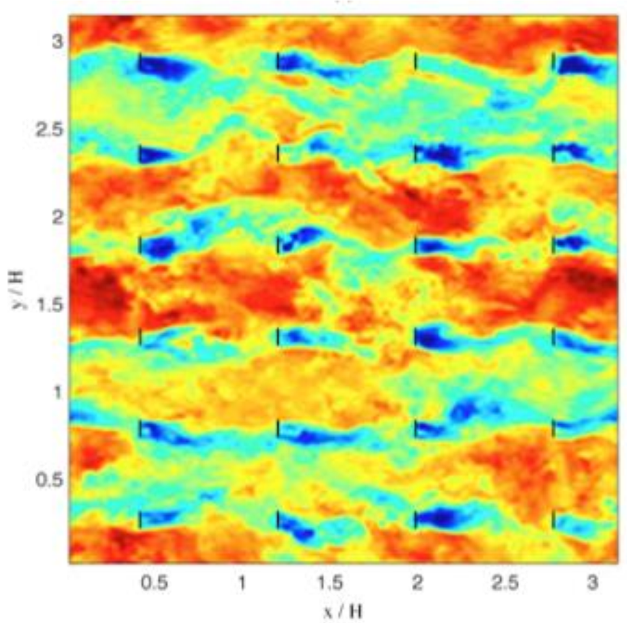
- Governing Navier-Stokes equations
- Spatial & temporal discretization
- Boundary & initial conditions
- High performance computing

Large Eddy Simulation (LES)

Large Eddy Simulation of turbulent (atmospheric) flow

➔Large scale flow phenomena are **resolved**

➔Small scale flow phenomena are **modelled**



Wind farm velocity fields [M.Calaf]

Domain size (km) & grid resolution

$$L_x \times L_y \times H = \pi \times \pi \times 1$$

$$N_x \times N_y \times N_z = 128^3$$

Single cell (m)

$$25 \times 25 \times 10$$

Cell Surface up to 600 m^2

Large Eddy Simulation (LES)

Large Eddy Simulation (LES) of turbulent (atmospheric) flow

→Large scale flow phenomena are **resolved**

→Small scale flow phenomena are **modelled**

Neutral flow equations *[M.Calaf et al.]* (continuity, momentum)

$$\partial_i \tilde{u}_i = 0,$$

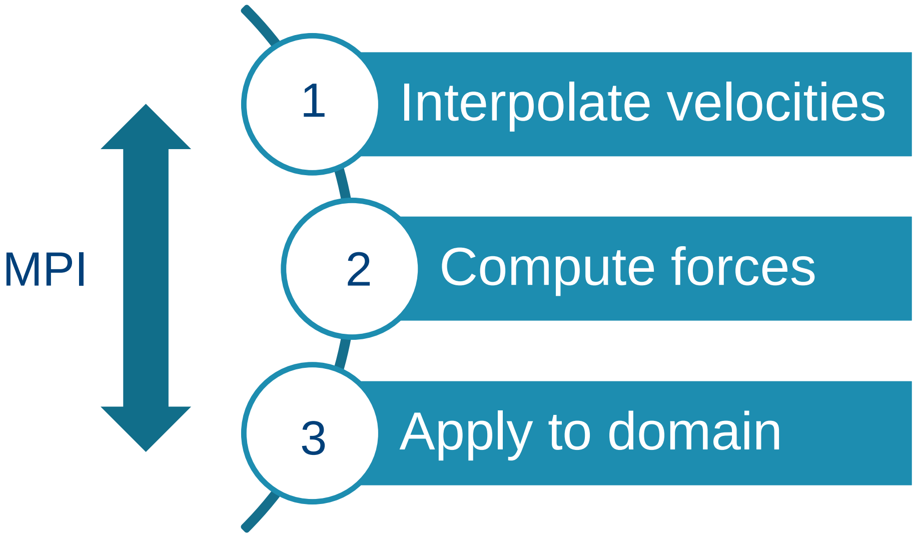
$$\partial_t \tilde{u}_i + \partial_j(\tilde{u}_i \tilde{u}_j) = -\partial_i \tilde{p}^* - \partial_j \tau_{ij} + f_i - \delta_{i1} \partial_1 p_\infty / \rho,$$

→Aerodynamic forces of kite and tether are added to the flow

Modelling aerodynamic forces

Aerodynamic forces of kite

- Lift force
- Drag force
- Weight



Further improvement

- Airfoil data
- Kite as multibody system
- Add tether forces

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Conclusion

Main tasks

- LES simulations of AWE systems in the atmospheric boundary layer
- Coupling CFD framework and controller to create test environment

Next steps

- Finish AWES model and perform first simulations

Cooperation

- Planned (ALU-FR/TUD) and additional secondments
- Ensure compatiblity between model and controllers
- Cooperation for model validation

Thank you

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