

第12回「IEA Windセミナー」

Task44: ウィンドファームの流れ場制御

■Operating Agents

Paul Fleming (NREL), Jan-Willem van Wingerden (TU Delft)

■Web Page

<https://iea-wind.org/task44/>



うちだ たかのり

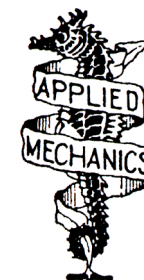
内田 孝紀

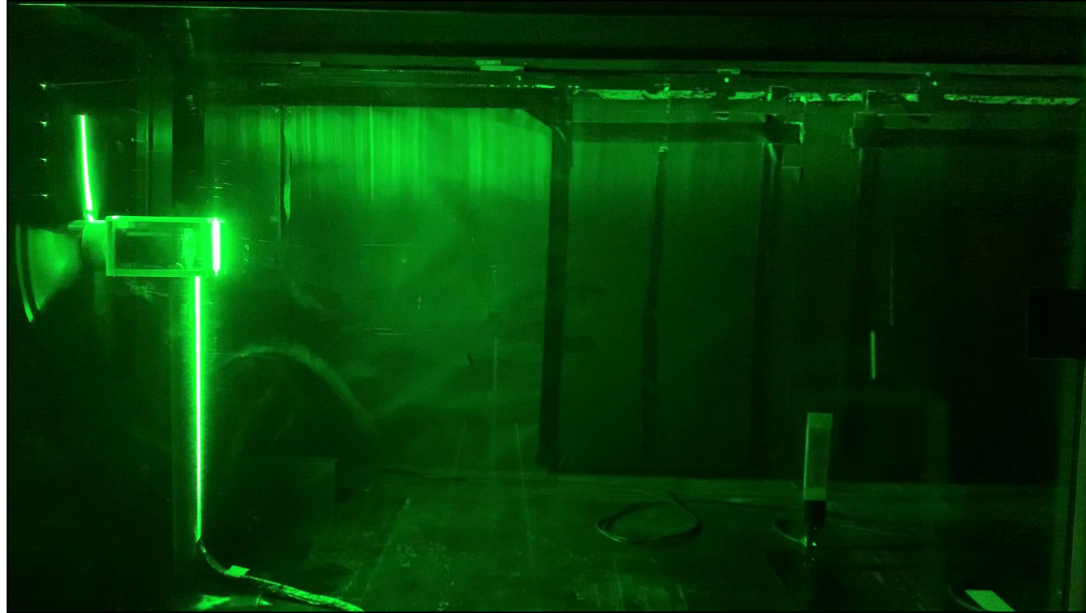
応用力学研究所/再生可能流体エネルギー研究センター/
洋上風力エネルギー高度利用分野/教授

兼務：洋上風力研究教育センター/
マルチスケール洋上風況研究部門/部門長



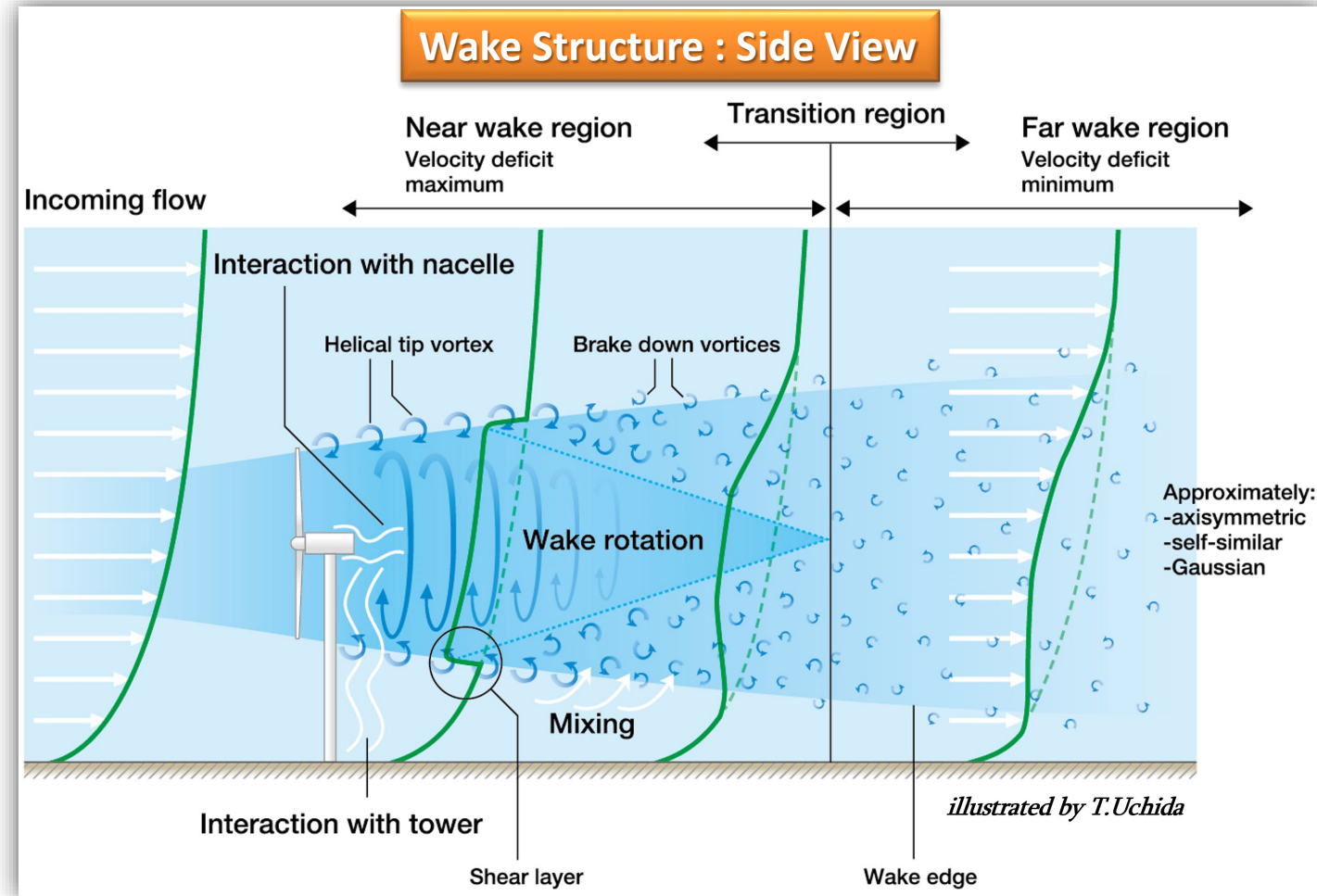
九州大学
KYUSHU UNIVERSITY

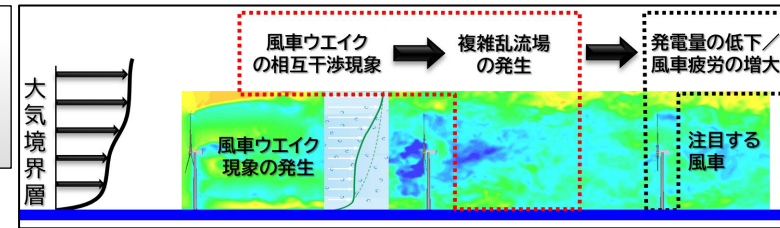




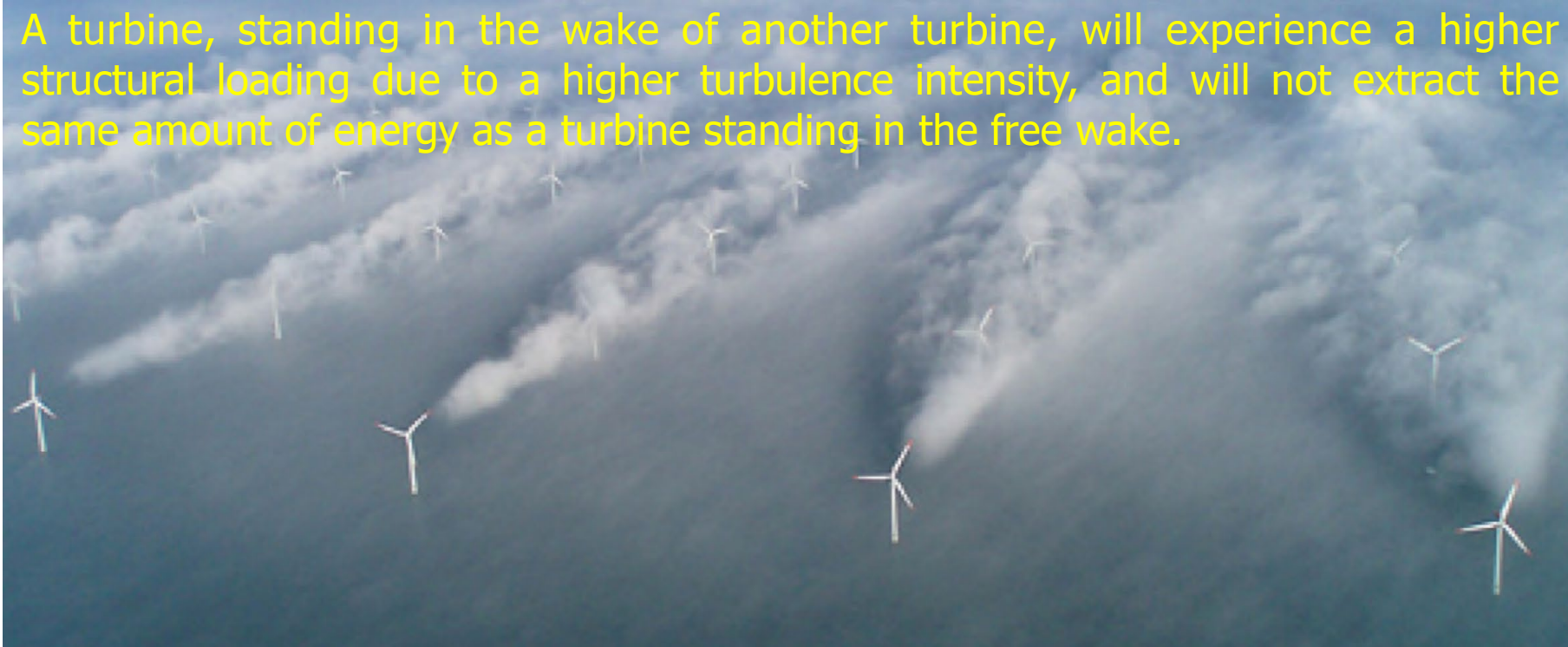
九州大学応用力学研究所
温度成層風洞にて撮影
2020年11月12日

What is the wind turbine wake phenomenon ?





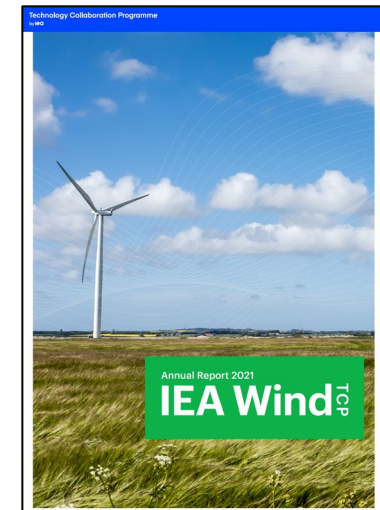
A turbine, standing in the wake of another turbine, will experience a higher structural loading due to a higher turbulence intensity, and will not extract the same amount of energy as a turbine standing in the free wake.



- Photograph taken by Christian Steinus in 2008, photo taken on the special atmospheric conditions.
- And what we nicely can see in this photograph is that there is interaction between turbines, so wake interaction.

Wind farm control is an active and growing field of research in which the control actions of individual turbines in a wind power plant are coordinated to minimise wake interactions.

ウィンドファーム制御は、風力発電所内の個々の風車の制御動作を調整して、風車ウエイクの相互作用を最小限に抑える、活発で成長している研究分野である。



- 国際エネルギー機関(IEA)は, 風力技術協力プログラム(略称:IEA Wind TCP)を主催している.
- IEA Wind国内委員会(締約機関:NEDO)からの推薦・審議を経て, IEA Windの国際共同研究活動(Task 44)に参画している(2021年12月15日~).

Task 44 (Wind Farm Flow Control) のスコープ

- 風力発電所の制御分野における**国際共同研究**
- 風力発電所の制御アルゴリズムと性能向上への貢献が焦点

(研究の目的)

- ✓ 風力発電量の増産による電力システムや電力市場における風力発電の価値の最大化
- ✓ 風車のウェイク荷重の低減による、風力発電コストの低減化
- ✓ 風力発電所の制御モデルのベンチマークとベストプラクティスの開発、ベストプラクティス・データ交換の促進

IEA Wind TCP Task44



主な参加機関

洋上風力研究に関する海外トップ大学/研究所が参画



国立再生可能エネルギー研究所(NREL)
アメリカ



CENER | NATIONAL RENEWABLE
ENERGY CENTRE

国立再生可能エネルギーセンター(CENER)
スペイン



デルフト工科大学(TUD)
オランダ



デンマーク工科大学
デンマーク

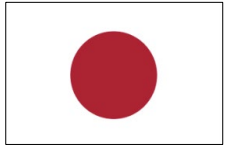
参加国

米国, オランダ, 英国, フィンランド, アイルランド,
デンマーク, スペイン, ドイツ, ノルウェー, 日本



日本の体制

- 九州大学/内田 孝紀 (代表者)
- ジャパン・リニューアブル・エナジー, 4名
- 東芝エネルギーシステムズ, 3名
- 日立造船, 4名
- 東京ガス, 2名



2.4a Mini Symposia: Wind Farm Flow
Control research organized by IEA Wind
Task 44
WHEN 8:30am - 10:15am
TRACK Room 04 - Conference Room 2 (Level 3)



Task44 ワークパッケージ(WP)

Work Package 1

Track the evolving state of the art in wind farm control through collection of research results and expert elicitations

Develop set of recommendations and best practices

研究成果の収集

Work Package 2

Characterize and quantify sources of uncertainties

Develop methods for estimating AEP/loads with overall uncertainty

Develop set of recommendations and best practices



Work Package 3

Characterize the building blocks which define wind farm control

Build an overview of available options, specifications and assess TRL of each

Give a full landscape of the solution space

技術・アルゴリズムの開発

Work Package 4

Collaborate and coordinate with other IEA Tasks and other wind farm control R&D activities

Based on tasks 1-3 and external projects, identify research gaps

Develop research roadmap

他のプロジェクトとの連携

メインにWP2へ参加

Uncertainty Quantification / 不確実性の定量化

WP2 活動状況

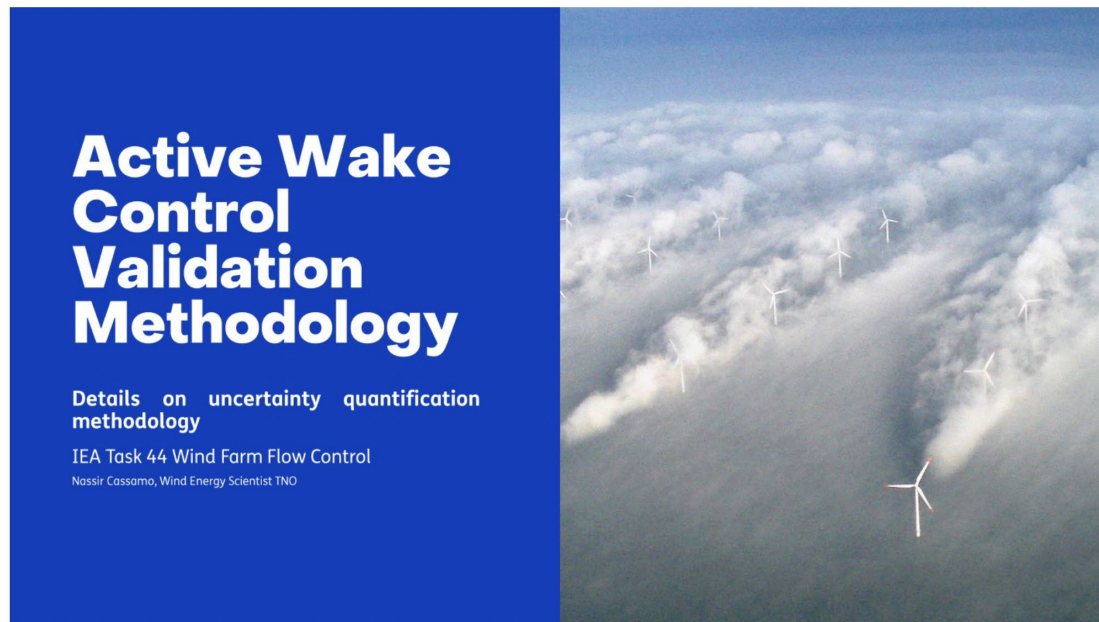
- Monthly meetings
- “Review and Best Practices” papers

Review and best practices for wind farm control field validation

- Presenting at a monthly meeting!

MTG_20220523
 MTG_20220531
 MTG_20220615
 MTG_20221208
 MTG_20230201
 MTG_20230301
 MTG_20230425
 MTG_20230627
 MTG_20230725
 MTG_20230926
 MTG_20231024
 MTG_20231113_GeneralMTG
 MTG_20231129

IEA Task44 WP2 Monthly Meeting 議事録	
2023/7/25	
プロジェクト	IEA Task44
開催日時	2023 年 7 月 25 日 (火) 23 : 00-24 : 00
場所	Microsoft Teams
出席者 (順不同/敬称略)	東京ガス 東芝 ESS 村上 深谷
議題	1. discussing and coordinating work on the paper "Review and best practices for wind farm control field validation." 2.
■議事項目	
1. discussing and coordinating work on the paper "Review and best practices for wind farm control field validation."	
発表者: Eric Simley@NREL	
➢ Task44 メンバーで執筆中の論文の構成や、各章の担当者などに関する議論。	
➢ 論文の構成は以下:	
タイトル: Review and Bast Practice for Wind Farm Flow Control Filed Assessment	
1 章: Introduction	
2 章: Overview of Field Validation Method for Wind Energy Application	
3 章: Review of Wind Farm Control Field Validation Experiment	
4 章: Recommendation for Filed Validation of Wind Farm Flow Control	
5 章: Demonstration of Filed Validation for Example Wind Plants	
6 章: Conclusion	
➢ IEA Wind Task 44 Wiki のリンクが以下に変更	
https://ieawindtask44.tudelft.nl/	
以上	



IEA Wind Task 44 Talks ①

@ieawindtask44talks21 · チャンネル登録者数 161人 · 13本の動画

このチャンネルの詳細 >

登録済み

ホーム 動画 コミュニティ

新しい順 人気の動画 古い順

Reinforcement Learning: offline

Try mix of random actions and actions from policy. π_t Update policy to increase reward / decrease cost. Slow offline training

Christiane Adcock - Differentiable Predictive Control for Dynamic Wake Steering

149 回視聴 • 1 年前

H_∞ CONTROL

Why?

- Robustness
- WFO to address coupling
- Higher order models
- Direct shaping of frequency response for specific transfer functions

Aoife Henry - A Robust Auto-Tuning Procedure for Wind Turbine Individual Pitc...

176 回視聴 • 1 年前

Results

Stowman & Mørch, 2. Fluid Mech 2021

Johan Meyers - Towards LES-based optimal control of wind farms

273 回視聴 • 1 年前

Wake Mixing Dynamics: Applied to a FWT

First method in OpenFOAM

- STOCHASTIC turbine on Triple Span¹ platform.
- Wake Phase and Wake over range of floater locations
- $W = \frac{1}{2} \rho A V_{tip}^2 = 0.0001 \dots 0.00012 \text{ W}$
- Define frequency response functions from tasks with input to steady state models

Daniel van den Berg - How dancing floating wind turbines can alleviate turbine wake...

310 回視聴 • 1 年前

Wind Model

WECC

Adam Stock - StrathFarm: A Demonstration of the University of Strathclyde Wind Farm...

148 回視聴 • 1 年前

Data Filtering

Eric Simley - Results from a Wake Steering Experiment at a Commercial Wind Plant

168 回視聴 • 1 年前

Inverse UQ, correction parameter identification

Robert Braunbehrens - Wind farm as a sensor: Improving FLORIS predictions with...

176 回視聴 • 1 年前

New optimization algorithms

Christopher Bay - FLORIS v3.0: Speed-ups and the new Cumulative-Curl model

414 回視聴 • 1 年前

WSE-TSR tracking control

Sebastiaan Mulders - The limitations of state-of-the-art torque control strategies fo...

197 回視聴 • 1 年前

Wake steering LES numerical experiments

Michael Howland - Wind farm wake steering control under transient atmospheric...

741 回視聴 • 1 年前

Simulation Case: REIQs from virtual sensors

Adrien Guilloire - The development of load surrogates models for wind farm control...

295 回視聴 • 1 年前

ROSCO - A Standard Workflow

Nikhar Abbas - ROSCO: A reference controller for fixed and floating wind...

956 回視聴 • 1 年前

Comparison

Marcus Becker - FLORIDyn: Development of a fast-running dynamic wind farm model fo...

446 回視聴 • 1 年前

IEA Wind Task 44 Wiki

Database of Field Experiment Research Results

② IEA Wind Task 44 Wiki

Wind Farm Information

Wind farm information for wind farm control field experiments in the literature

Article	Controller type	Farm name	Number of turbines	Turbine spacing	Turbine manufacturer	Turbine type	Terrain
Boorasma (2015)	Induction Control	EWTW	5	3.8 D	Nordex	2500 kW	Flat terrain
Fleming et al. (2017)	Wake Steering	Longyan Rudong Chaojindai	25	7 D - 14.3 D	Envision Energy	EN-136/4.2 MW	Offshore
Ahmed et al. (2019)	Induction Control	Sole du Moulin Vieux	7	3.6 D	Servion	MM82-2050 kW	Flat terrain, countryside
Fleming et al. (2019)	Wake Steering	Unknown	5	2.9 D - 5.0 D	Unknown	Unknown	Mix of flat and complex terrain
Howland et al. (2019)	Wake Steering	Summerview	6	3.5 D	Vestas	V80 1.8 MW and 2.0 MW	Flat terrain
van der Hoek et al. (2019)	Induction Control	Goole Fields	16	2.3 D - 3.1 D	Servion	2050 kW	Flat terrain
Simley et al. (2020)	Wake Steering	...	...	...	...	...	...
Fleming et al. (2020)	Wake Steering	Unknown	5	2.9 D - 5.0 D	Unknown	Unknown	Mix of flat and complex terrain
Simley et al. (2021)	Wake Steering	Sole du Moulin Vieux	7	3.7 D	Servion	MM82 2050 kW	Flat with nearby forest
Fleming et al. (2021)	Wake Steering	...	...	...	...	...	...

<https://ieawindtask44.tudelft.nl/>

③ LinkedIn

IEA Wind Task 44 - Wind Farm Flow Control

Coordinating international research in the fields of wind farm flow control.

リサーチサービス · 104人のフォロワー · 51~200人の従業員

フォロー中 ウェブサイトにアクセス

ホーム 概要 投稿 求人 従業員

今後のイベント

水 (2024年5月29日) 4:00
Task 44 General Meeting

参加者3人

<https://www.linkedin.com/company/iea-wind-task-44-wind-farm-flow-control/>

<https://www.youtube.com/@ieawindtask44talks21>

NEXT GENERAL MEETING

Planning to meet Tuesday, May 28th before the start of Torque



UNIVERSITÀ
DEGLI STUDI
FIRENZE

DIEF
DEPARTMENT
OF INDUSTRIAL
ENGINEERING



 **TORQUE 2024**

Florence - Italy

May 29th - 31st, 2024

166	:	22	:	12	:	2
DAYS		HOURS		MINUTES		SECONDS

風車ウェイク研究会：2021.4～2023.3



IEA Wind TCP Task44 との連携

ウィンドファームの流れ場制御研究会：2023.4～2025.3

活動内容(2か月に1度をめどに開催)：■海外の動向調査 ■国内の情報共有 / 情報発信

研究会名称	ウィンドファームの流れ場制御研究会	
研究の目的, 期待される成果	IEA task 44 のウィンドファームの流れ場制御(Flow Farm Control)では、風力発電所の制御アルゴリズムと性能向上への貢献を目的とし、風車ウェイクステアリング手法等が議論されている。日本からも内田が代表者となり、数名の委員登録の下、task 44 に参加している。今後、国内の洋上風力発電分野においても task 44 で議論されている研究開発が重要になってくる。そのため、本研究では IEA task 44 の国内チームと連携を図りつつ、最新の風車ウェイク研究について調査を行う。また同時に国内の風車ウェイク研究についても情報交換を行う。	
体制		
主査/副主査	会員氏名	所属
主査	内田孝紀	九州大学応用力学研究所
副主査	鈴木章弘／谷垣洋一郎	(株) 風力エネルギー研究所
年月	内容	費目・予算
2023 年 3 月	メンバー公募	
2023 年 4 月	研究会発足	
2025 年 3 月	学会誌特集号投稿	

海外の最新動向

Wednesday July 7th 2021

Smart wind farms

Jan-Willem van Wingerden

※Task44のOperating Agent



TWIND, Delft, The Netherlands

Full professor TU Delft, DCSC,
Data Driven Control, Wind Turbine
and Wind Farm Control

(Lab HP) <https://www.janwillemvanwingerden.nl/>



Delft Center for
Systems and Control

Wind farms that can reduce the effect of wakes



- The main objective is to get more energy out of the wind farm, but also taking into account that we don't want to increase the loading too much on the individual turbines.
- We typically build a first principles model. But the first principle model doesn't capture all the dynamics of a real wind farm or a real wind turbine.
- So what we believe is that we always have to augment our model with measurements. And again, we use here the data driven control approach.

Quote source: TWIND Summer School - Session_Morning_07_07

More info: <https://twindproject.eu/>

Lidar (sensors)



Reconstruction wind field



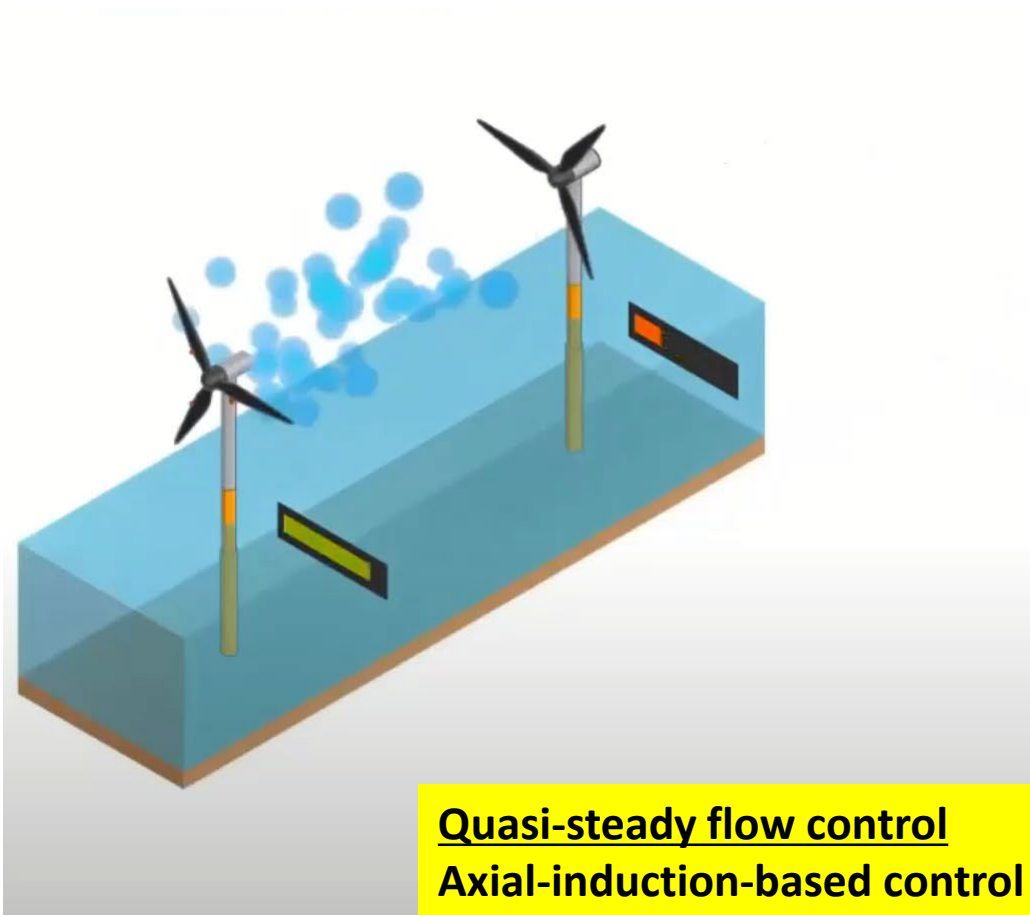
Prediction wind field



Real-time optimization

- In reality, we don't have access to the flow information. So the only thing that we have is measurements. So we only have measurements on a turbine level.
- So what we have to do if we want to do wind farm control and maybe this repositioning (floating). And we have to reconstruct the wind field.
- Then if we have the wind field we have to predict what's going on.
- And then we have to optimize. And then we can do a repositioning (floating). But we can also use already existing control technology on a turbine to maximize the energy capture and or to reduce the structural loading in the wind.

Control Technologies



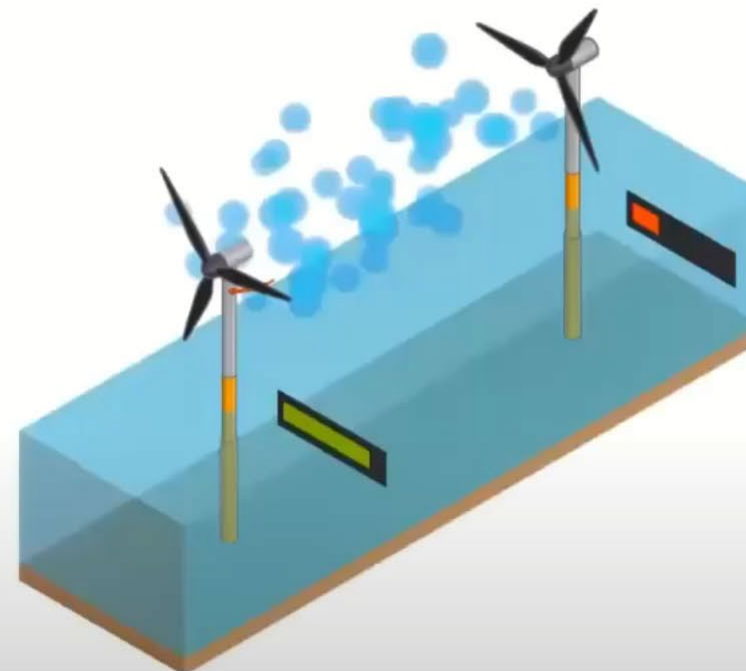
Static wake control concepts rely on affecting the wake through relatively slow changes of the control degrees of freedom of the turbine in a way that affect the time-averaged properties of the wake.

- Induction control (誘導制御) is basically derating (負荷低減).
- If we derate the first turbine, then it will let energy go. And then we hope that the energy that we let go will be picked up by the turbines in the wake.
- We hope that the sum of the energies will be bigger than the greedy approach.
- Now recent results basically show that actual induction control doesn't work. So the energy that we let go is not picked up by all the other turbines.
- High-fidelity wind tunnel and field tests have shown that the benefits of induction control are very limited.

Control Technologies

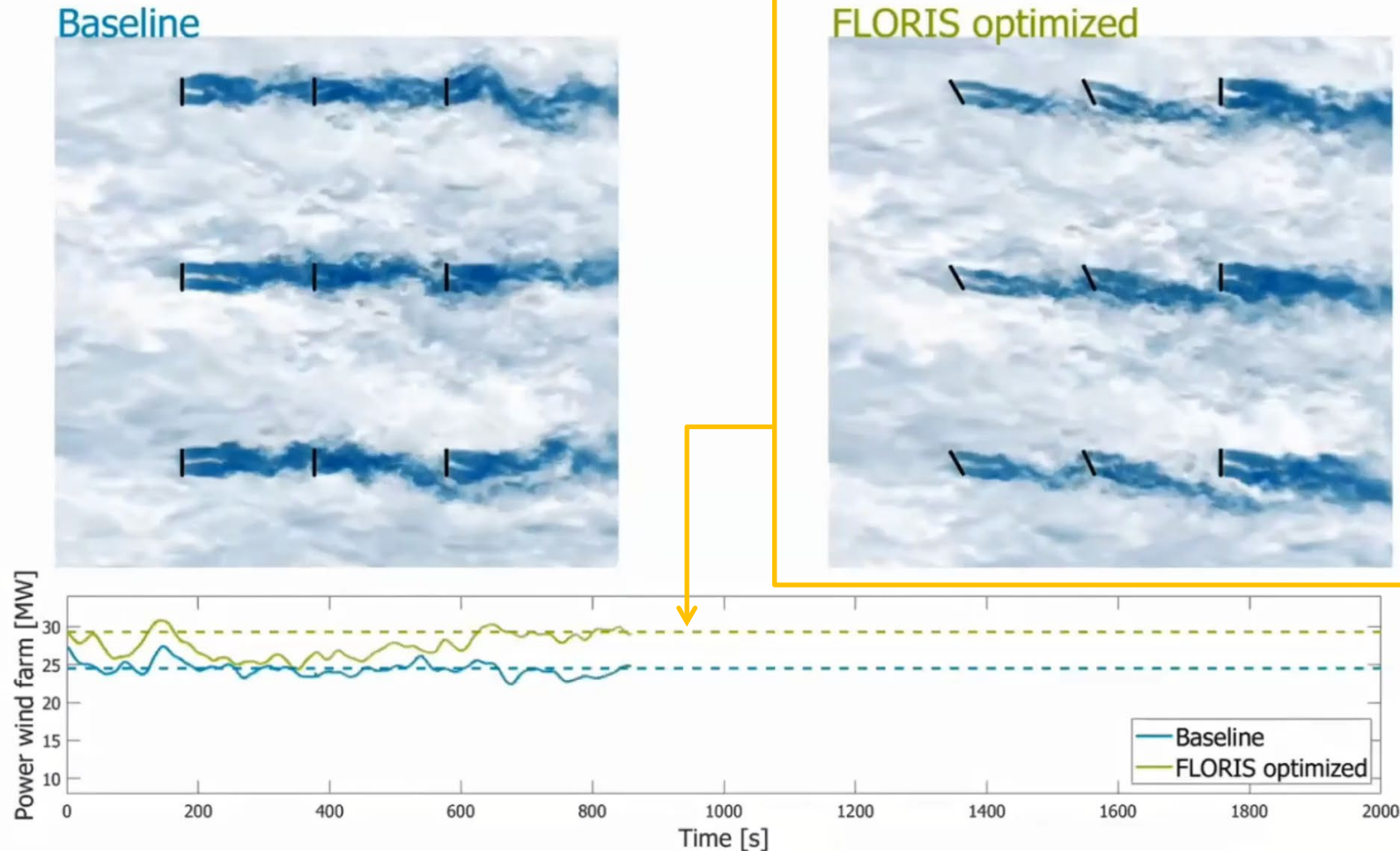
- On the other side, there is another existing control technology which is called wake steering.
- We misalign the first turbine with the main wind direction.
- If we misalign the turbine, we can redirect the wake. So what we try to do is that the wake doesn't hit the turbines downstream.
- This technology seems to have a lot of potential in wind tunnel experiments, high fidelity simulations, and field experiments.

Static wake control concepts rely on affecting the wake through relatively slow changes of the control degrees of freedom of the turbine in a way that affect the time-averaged properties of the wake.



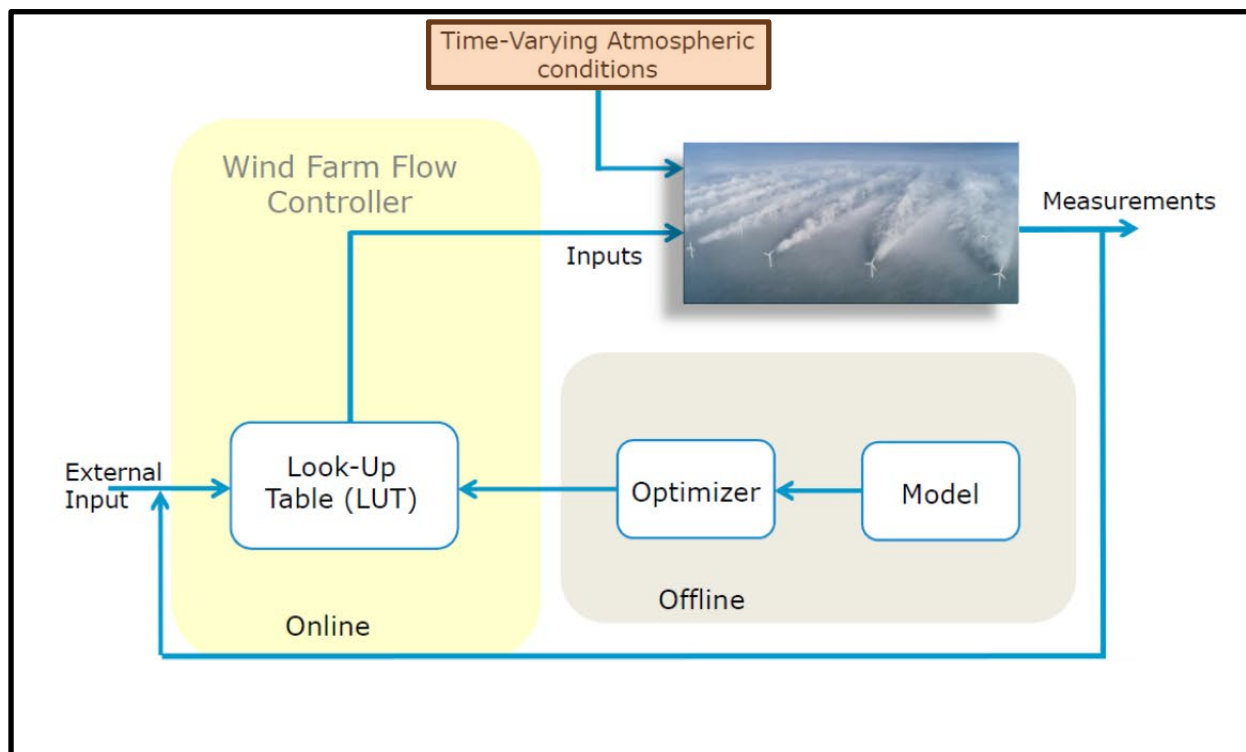
Quasi-steady flow control
Wake steering using yaw offsets

Quasi-steady flow control Wake steering using yaw offsets

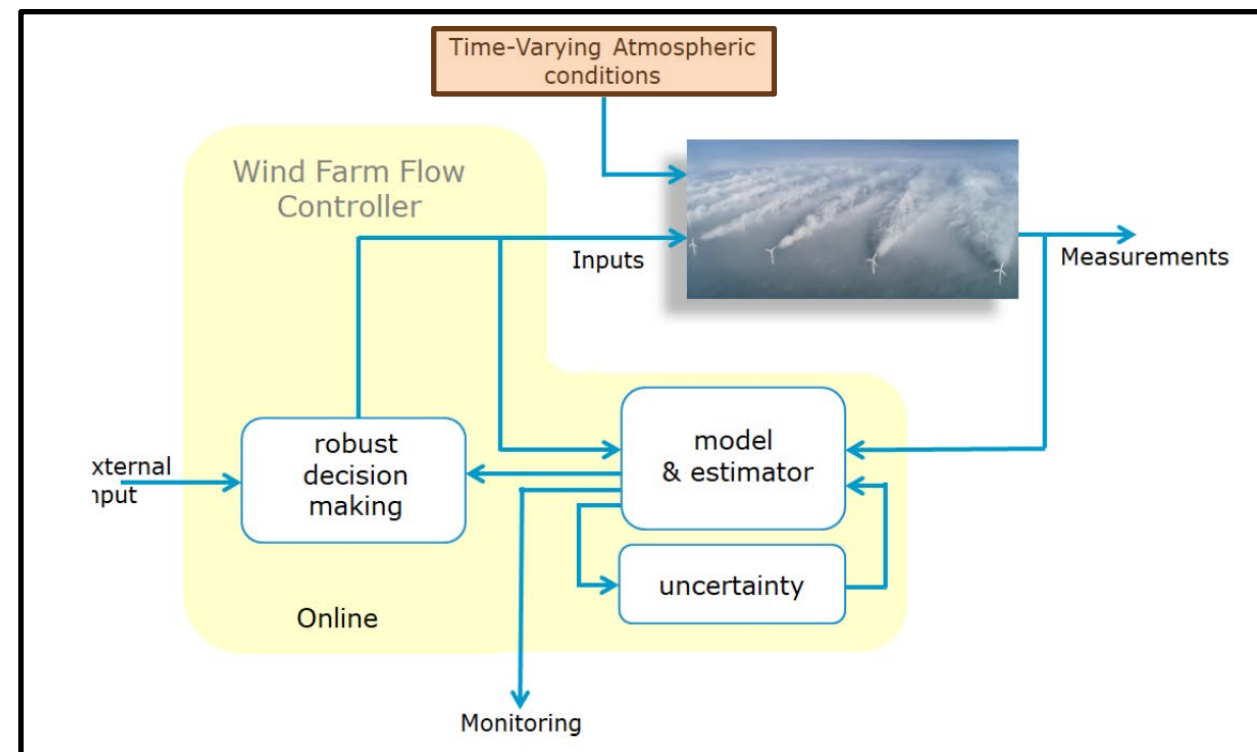


- At the left, we see the baseline. And at the right, we see the optimized setting.
- The optimized setting meaning that we had a first principles model, in this case the FLORIS.
- Then we optimized the optimal YAW settings. And what we nicely see is that we can do wake steering.
- Now in the graph, we can also see the potential and the amount of energy that we can now extract out of a wind farm (Of course, this is a high fidelity simulation).
- The wind conditions are more or less steady. It's the same inflow direction and also the turbulence intensity is more or less the same.
- So we believe that also if we really want to apply wake steering in a wind farm, we also have to make it more robust with respect to time varying conditions.

Open-loop wind farm control scheme

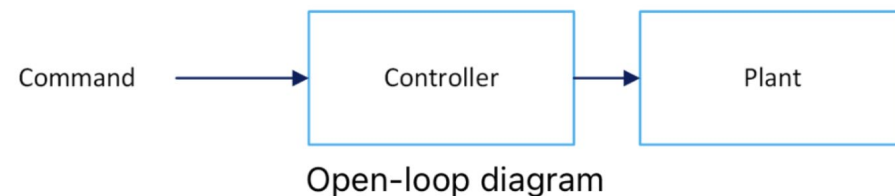


Closed-loop wind farm control scheme



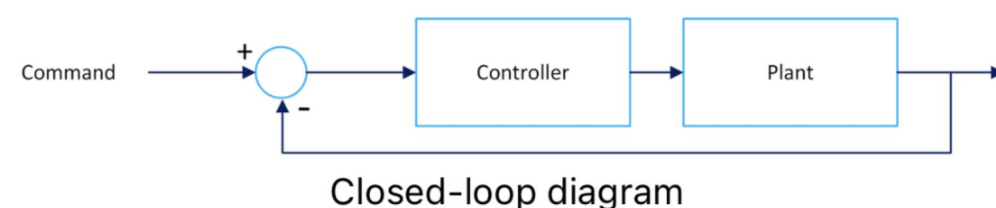
Key words : data driven approach,
MPC (モデル予測制御) principle

補足



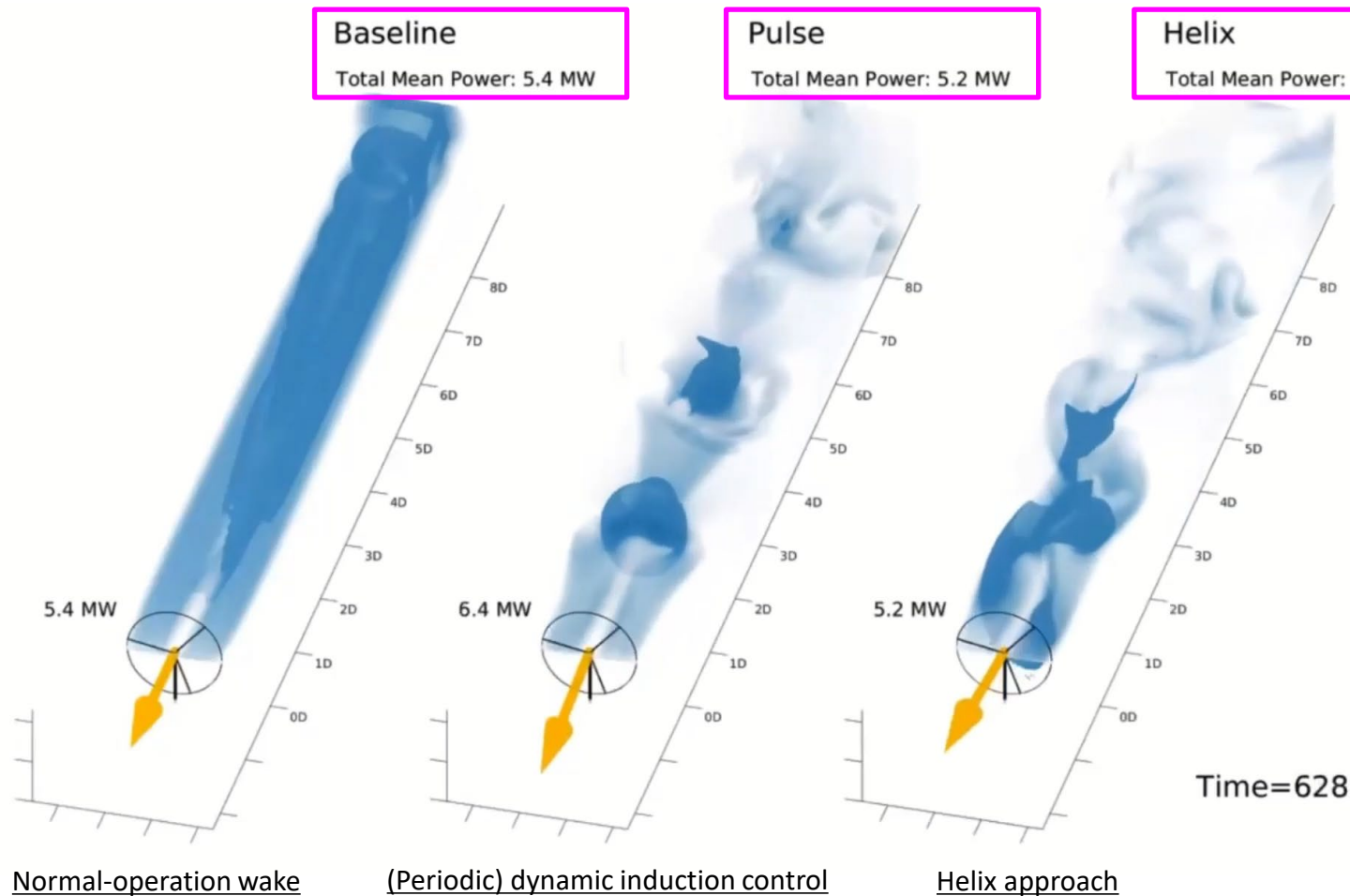
指令だけをしてフィードバックを取らない制御

(例)シーケンス制御：あらかじめ定められた順序に従って制御の各段階を逐次進めていく制御」



プラントの出力値(測定値)を出力し、それをフィードバックさせ、入力値と出力値を常に比較して両者を一致させるように全体の操作量を調整する制御

Wake-Mixing

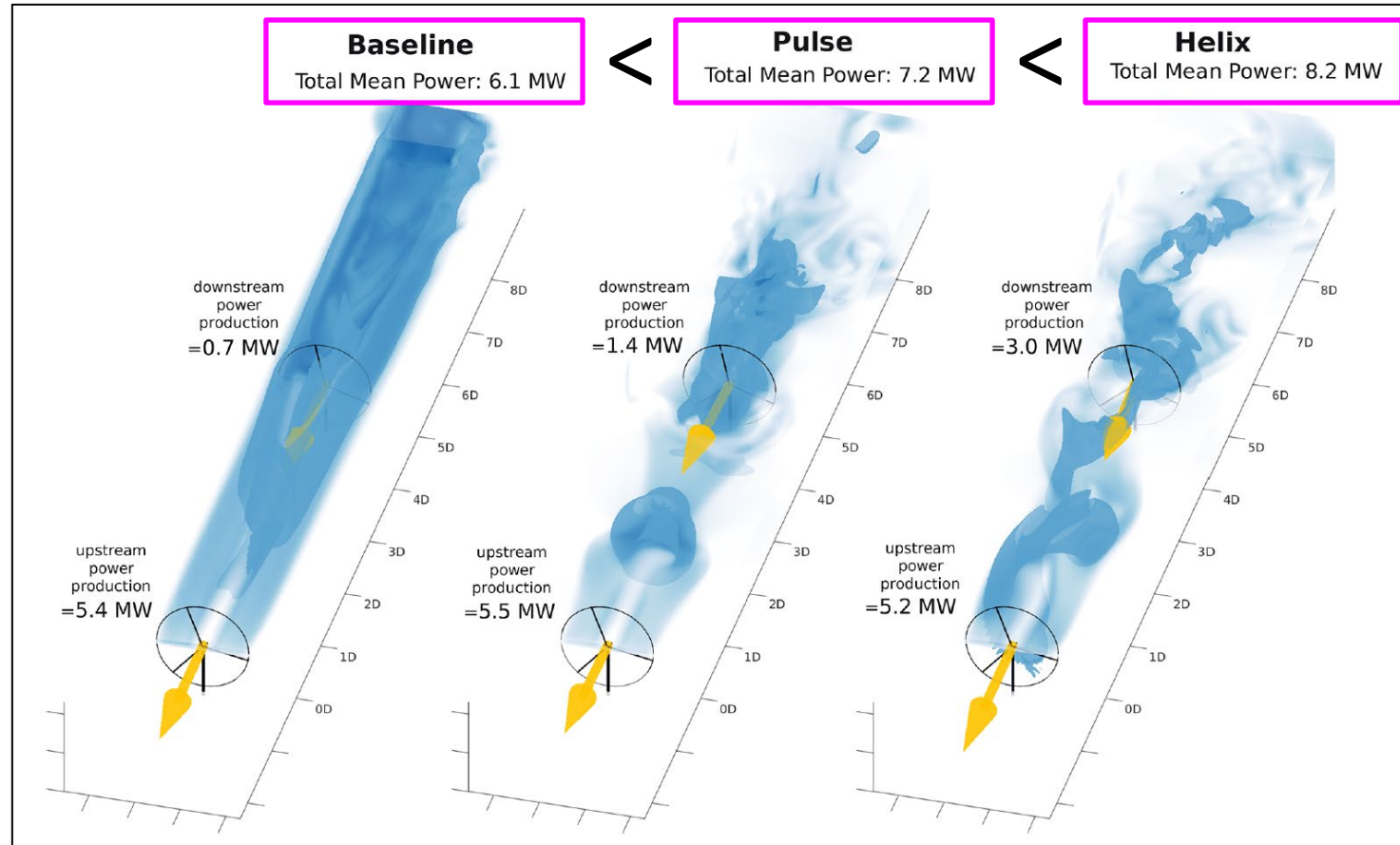


- Here, we focus on the challenges related to triggering and interacting dynamically with wakes and turbulence as a means to control wind farm flow and to speed up wake breakup or to increase mixing and entrainment into the wakes.
- Recently, some first studies suggest that this effect may be leveraged to significantly increase the energy extraction of wind farms.

Illustration from an LES study (SOWFA), 10MW Wind Turbine

Dark blue shading corresponds to an isosurface of the velocity;
light blue shading in the horizontal plane corresponds to velocity magnitude.

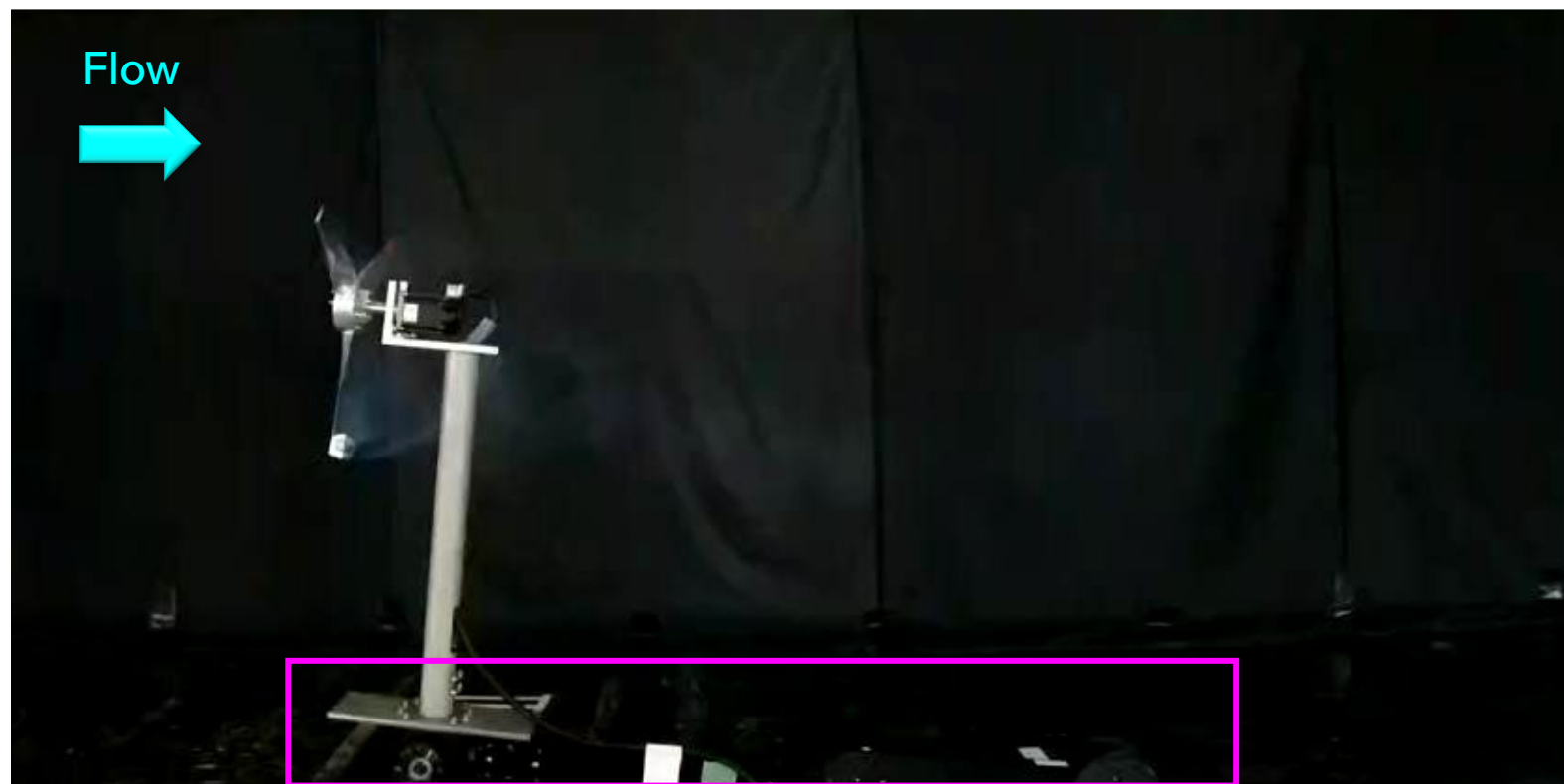
Wake-Mixing



- However, then still you have to do all the safety checks and look at all the loads.
- So implementation wise, on paper it seems easy, but for industry it's quite a big step.

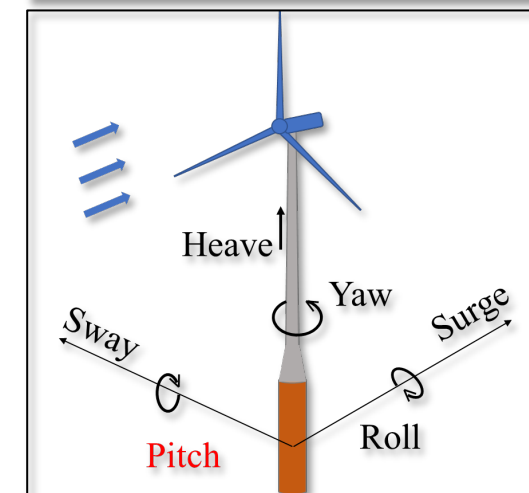
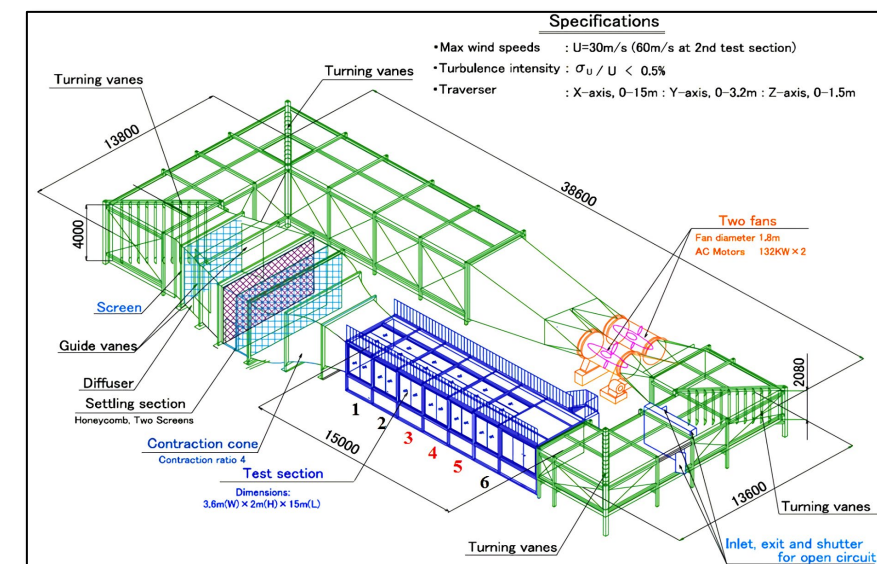
Wake-Mixing

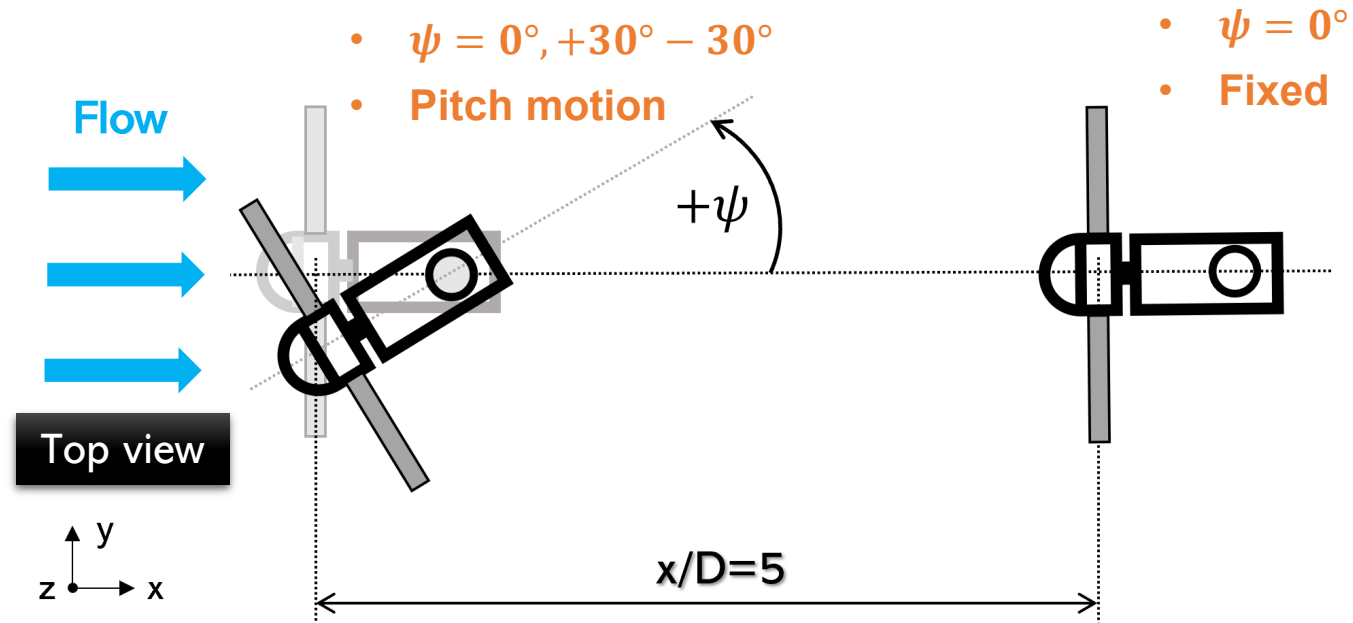
九州大学・内田研究室での取組



加振装置製作し、浮体の動揺(ピッチ運動)を再現

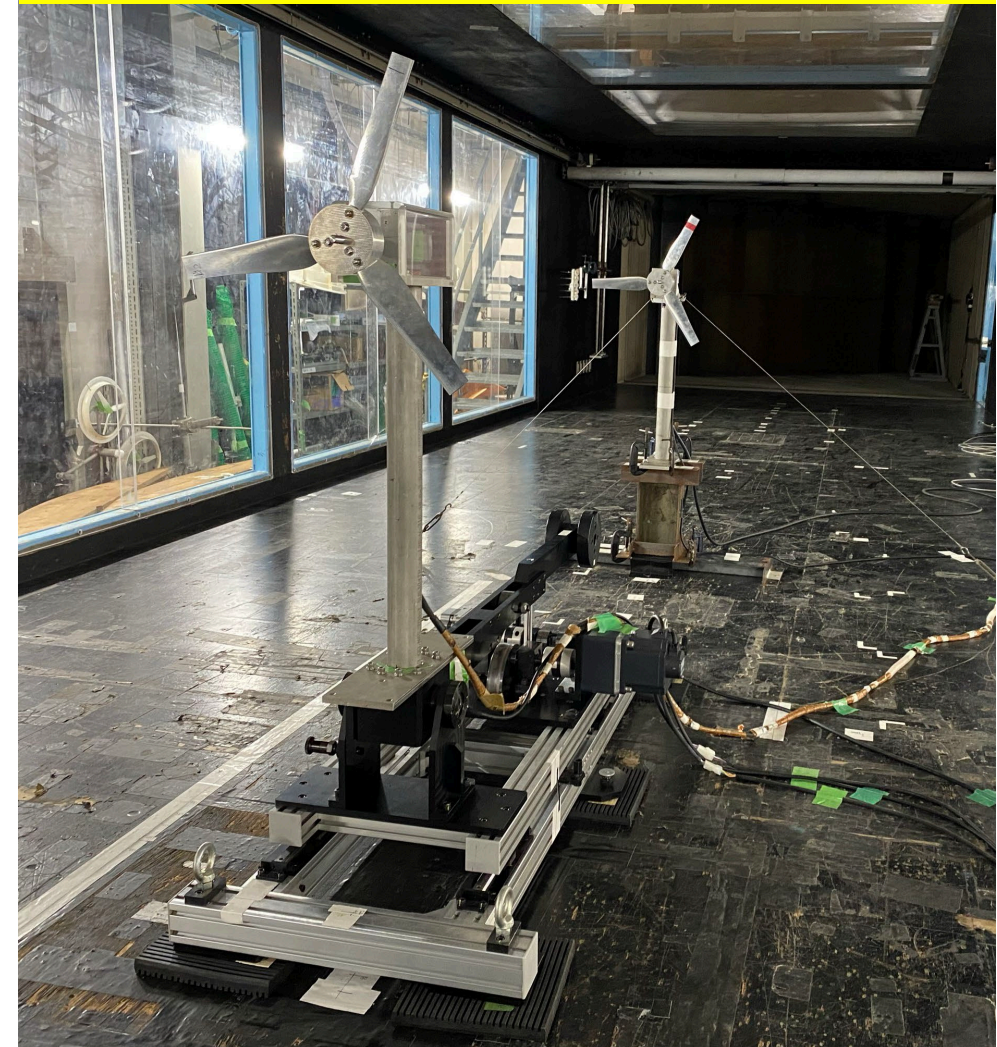
- Pitch motion amplitude: ± 5 [deg]
- Pitch motion period: 0.8 [s]

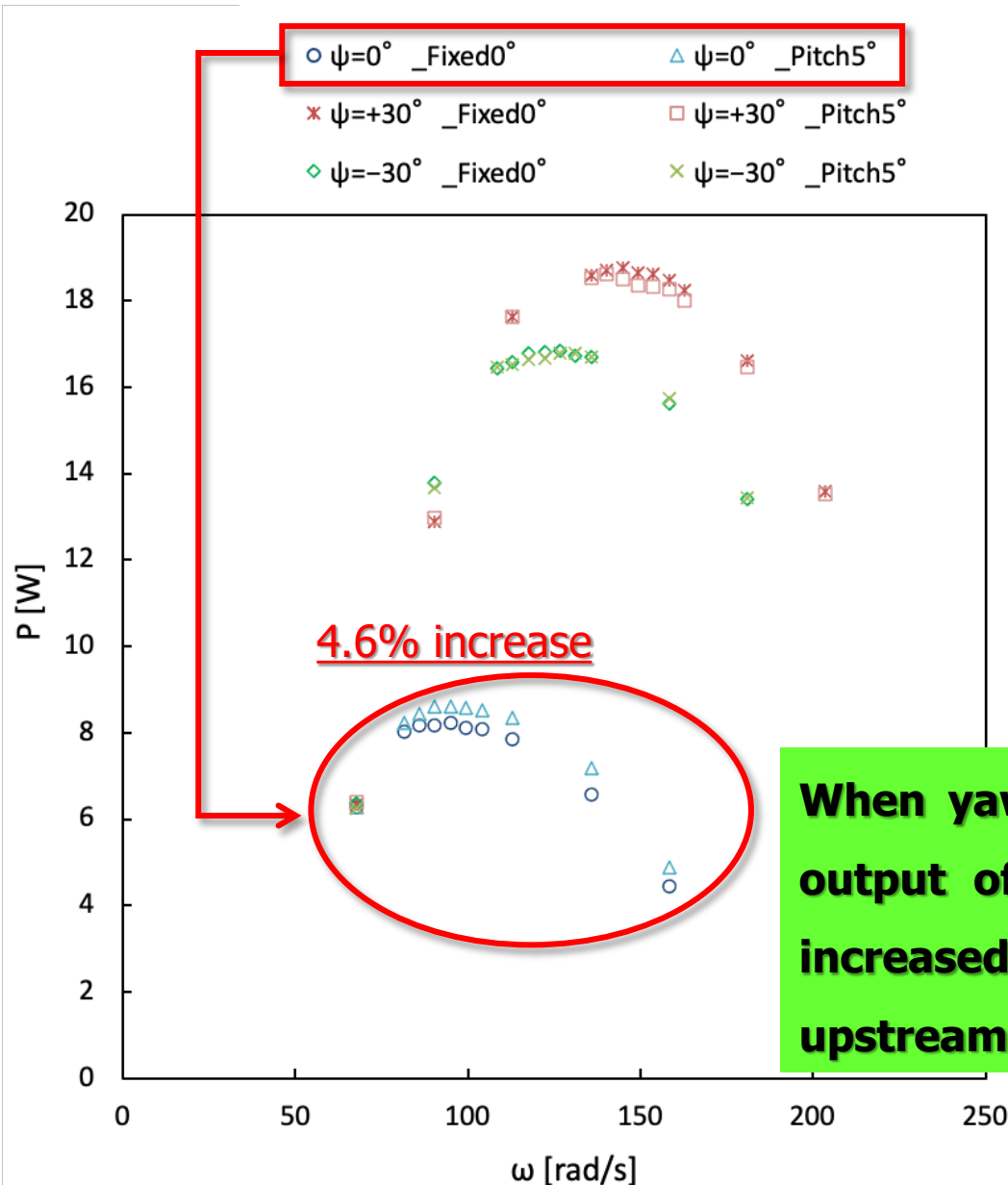




Parameter	Value
Inflow wind speed [m/s]	10
Rotor diameter [m]	0.442
Tip speed ratio of the upstream wind turbine [-]	3.6
Rotor speed of the upstream wind turbine [rpm]	1556
Sampling frequency [Hz]	1000
Sampling time [s]	60
Pitch motion amplitude [deg]	± 5
Pitch motion period [s]	0.8

The power generation performance of the wind turbine was evaluated by varying the blade rotation speed.





- The power generation performance of the wind turbine was evaluated by varying the blade rotation speed.
- Torque was measured and power output was computed.

P [W] : Power
 Tr [Nm] : Torque
 ω [rad/s] : Angular velocity

When yaw angle is 0° , the power output of the downstream WT is increased by pitch motion of the upstream WT.

2022年

<https://doi.org/10.5194/wes-2022-24>
Preprint. Discussion started: 22 March 2022
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Wind farm flow control: prospects and challenges

Johan Meyers¹, Carlo Bottasso², Katherine Dykes³, Paul Fleming⁴, Pieter Gebrad⁵, Gregor Giebel³, Tuhe Göçmen³, and Jan-Willem van Wingerden⁶

¹KU Leuven, Mechanical Engineering, Celestijnenlaan 300A, B3001 Leuven, Belgium

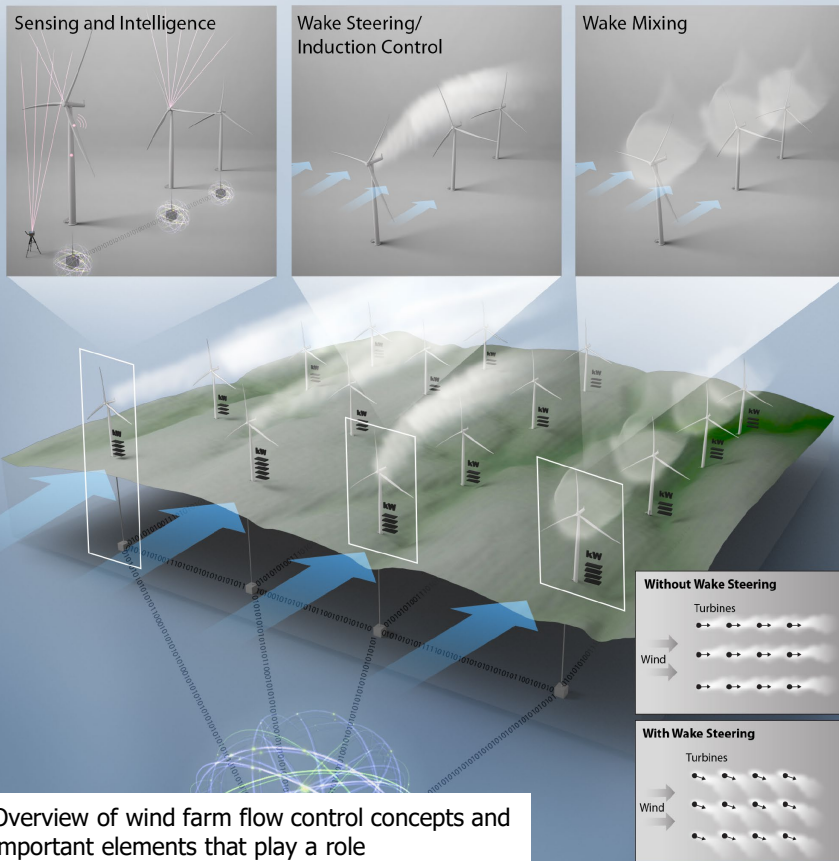
²Chair of Wind Energy, Technische Universität München, Boltzmannstr. 15, 85748 Garching b. München, Germany

³DTU Wind Energy, Frederiksborgvej 399, DK-4000 Roskilde

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Wind farm control has been a topic of research for more than two decades. It has been identified as a core component of grand challenges in wind energy science to support accelerated wind energy deployment and transition to a clean and sustainable energy system for the 21st century.

風力エネルギー科学における壮大な課題の中核要素として特定されている。

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In summary, the field of wind farm flow control is an active area of research and innovation, with many interesting multidisciplinary challenges(※), and exciting prospects for the increase of the total value of wind energy for society.

※学際的な課題

1 Introduction

- 1.1 Main control objectives studied to date
- 1.2 Control approaches
- 1.3 Outline

2 Wind farm flow control physics: turbulence, wakes and the atmospheric boundary layer

- 2.1 Quasi-steady flow effects
 - 2.1.1 Axial-induction-based control
 - 2.1.2 Wake steering using yaw offsets

2.2 Wake dynamics and turbulence

- 2.2.1 Wake dynamics
- 2.2.2 Boundary-layer turbulence

2.3 Mesoscale effects, blockage and wind farm wakes

3 Control algorithms

- 3.1 Current practice — Open-loop control
- 3.2 The closed-loop paradigm
- 3.3 Synergies with artificial intelligence and other digitalization concepts
- 3.4 Controllability, observability, and sensors

4 Validation and industrial implementation

- 4.1 Proof-of-concept studies in high-fidelity simulation tools
- 4.2 Validation in wind tunnel experiments
- 4.3 Validation via field tests
- 4.4 Industrial implementation

5 Integrated design and systems perspective

- 5.1 Progress in wind farm design optimization research
- 5.2 Wind farm control co-design (CCD)
 - 5.2.1 Wind farm CCD for AEP and LCoE objectives
 - 5.2.2 Wind farm CCD for profitability objectives
 - 5.2.3 Wind farm CCD for non-economic objectives

6 Conclusions