2024年2月28日(水曜日) ／ 11:50 - 12:25

第12回「IEA Windセミナー」

Task44：ウイ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/


WIND FARM FLOW CONTROL
IEA Wind Task 44

うちだ　たかのり
内田 孝紀

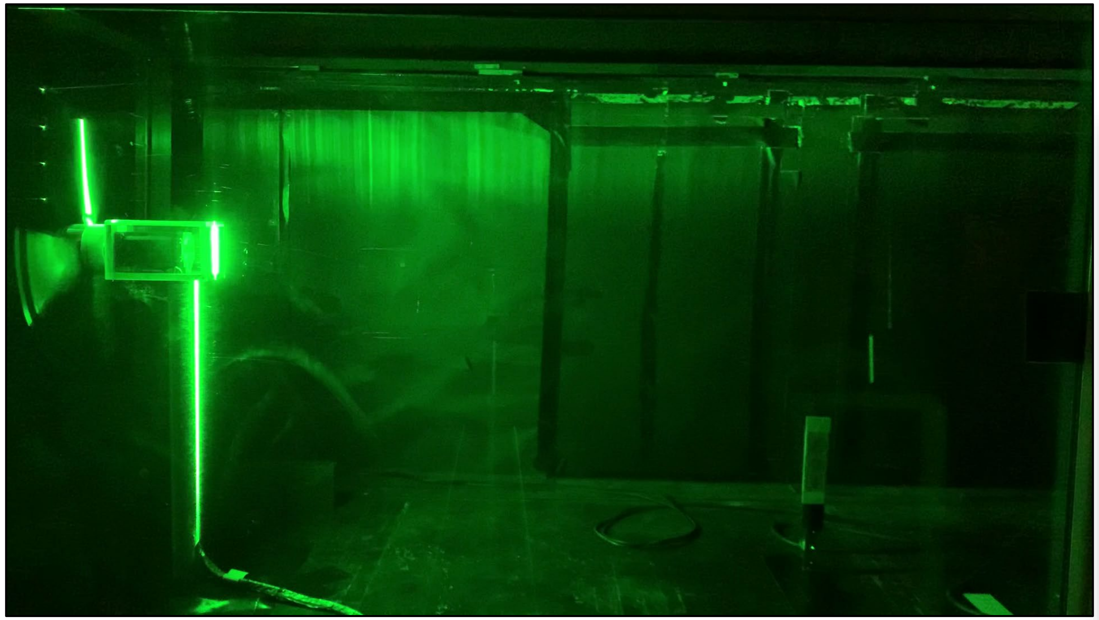
応用力学研究所/再生可能流体エネルギー研究センター/
洋上風力エネルギー高度利用分野/教 授

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

九州大学洋上風力研究教育センター
九州大学 KYUSHU UNIVERSITY
APPLIED MECHANICS

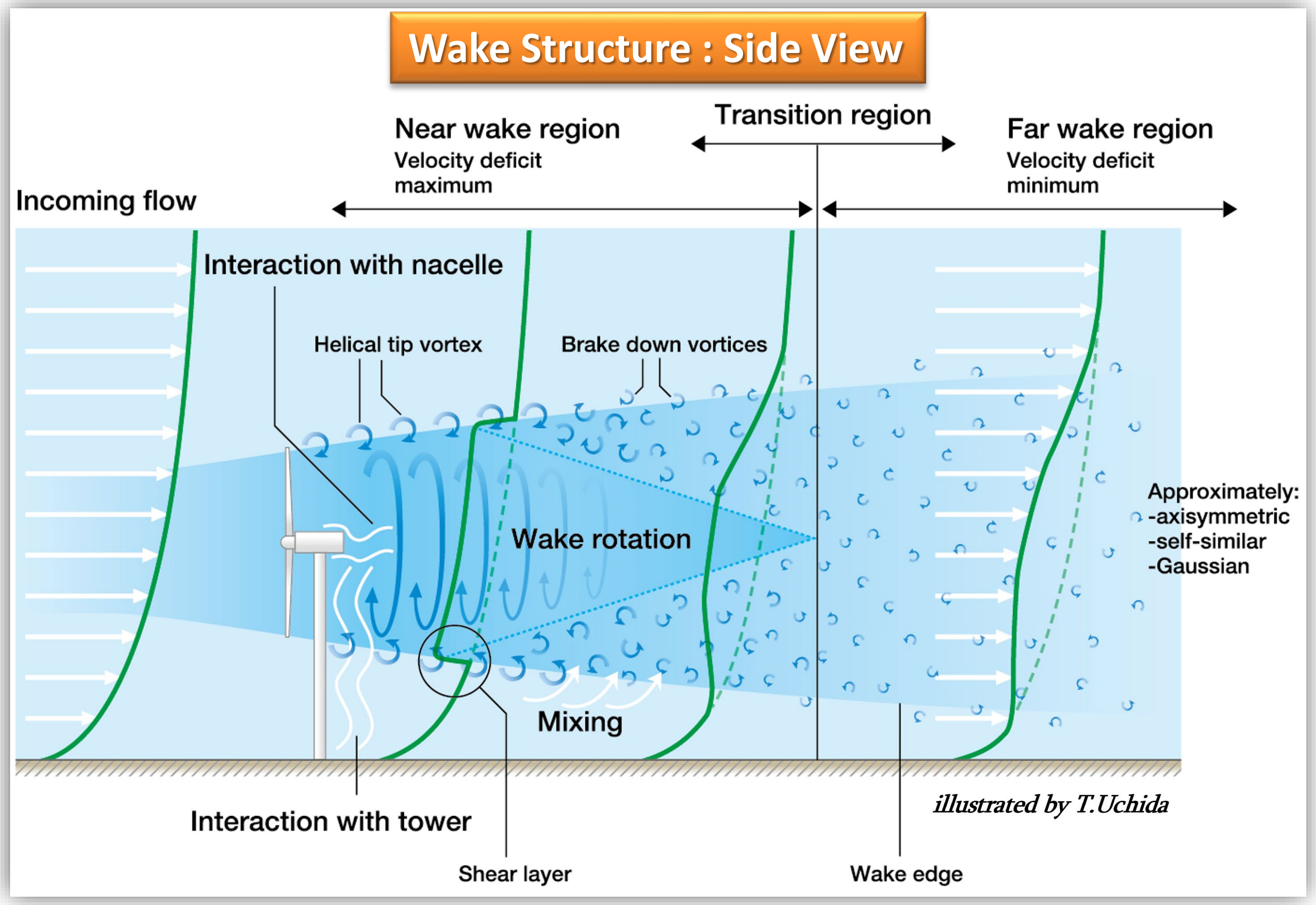
IEA Wind TCP Task44

WIND FARM FLOW CONTROL
IEA Wind Task 44



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 ?



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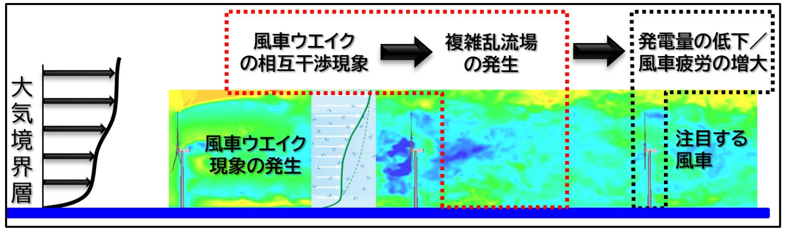
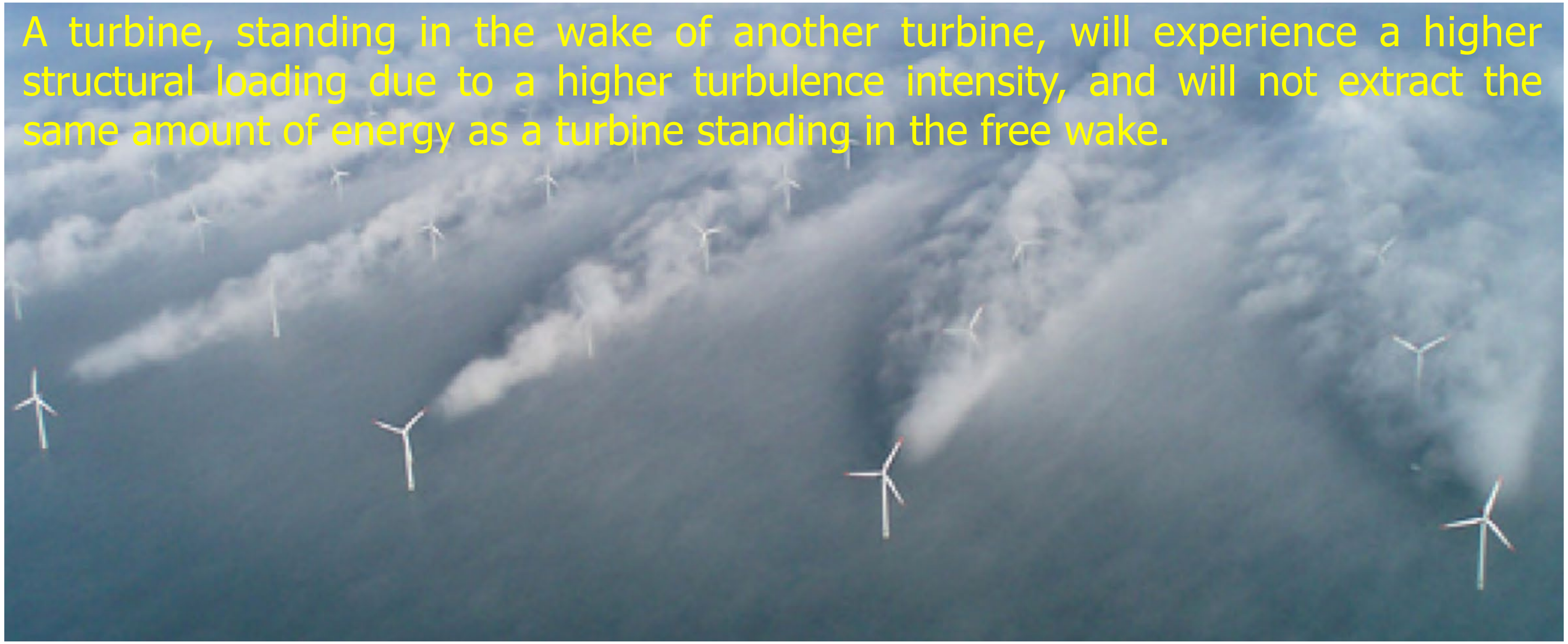
WIND FARM FLOW CONTROL
IEA Wind Task 44

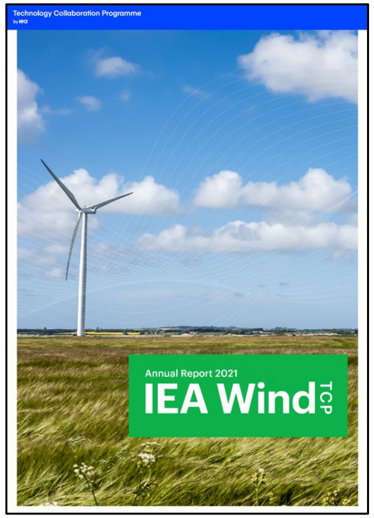




- Photograph taken by Christian Steinus in 2008, photo taken on the special atmospheric conditions.
- And what we nicely can see in this photograph is that there is interaction between turbines, so wake interaction.

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。



IEA Wind TCP Task44

WIND FARM FLOW CONTROL
IEA Wind Task 44

- 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

WIND FARM FLOW CONTROL
IEA Wind Task 44

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

- NREL NATIONAL RENEWABLE ENERGY LABORATORY — 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
- TU Delft WIND TU Delft Wind Energy Institute — デルフト工科大学(TUD) オランダ
- DTU — 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

WESC 2023
23 - 26 MAY | GLASGOW, UK

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.	

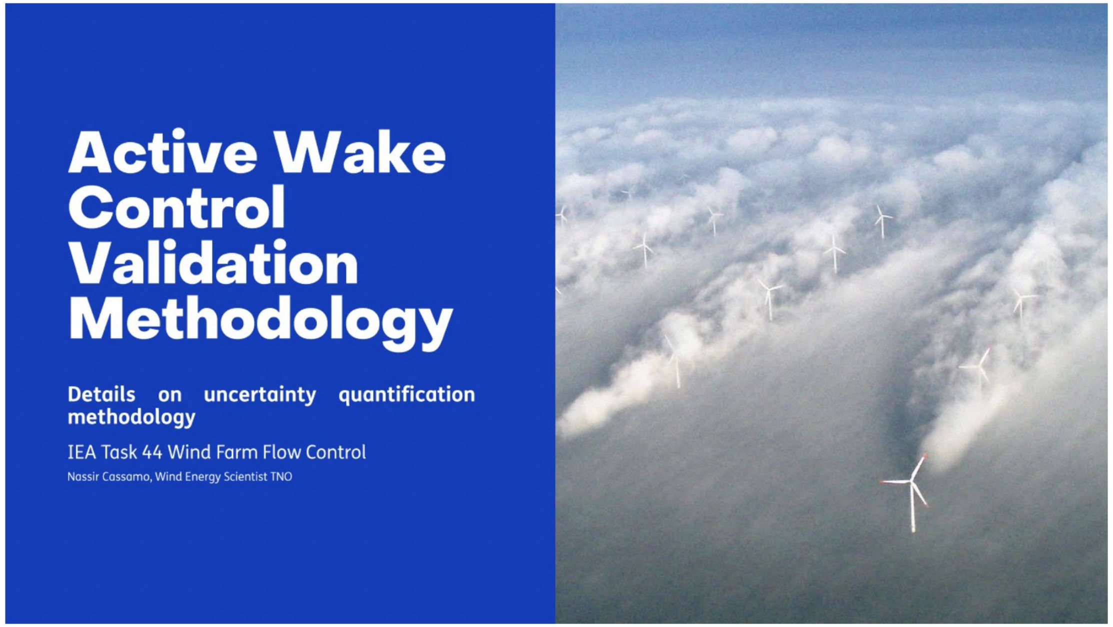
■議事項目

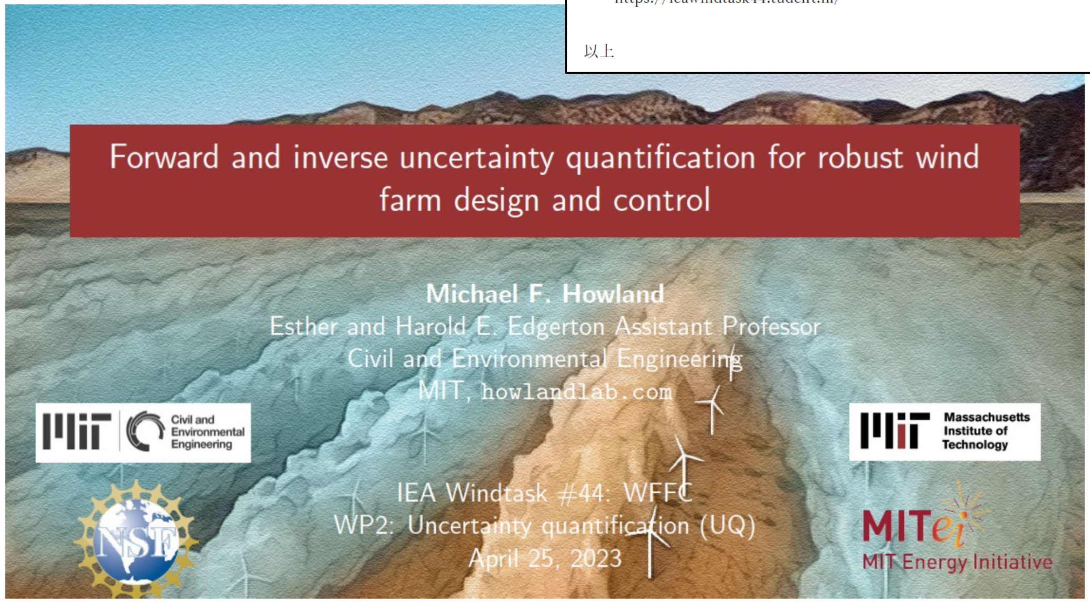
1. discussing and coordinating work on the paper “Review and best practices for wind farm control field validation.”

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



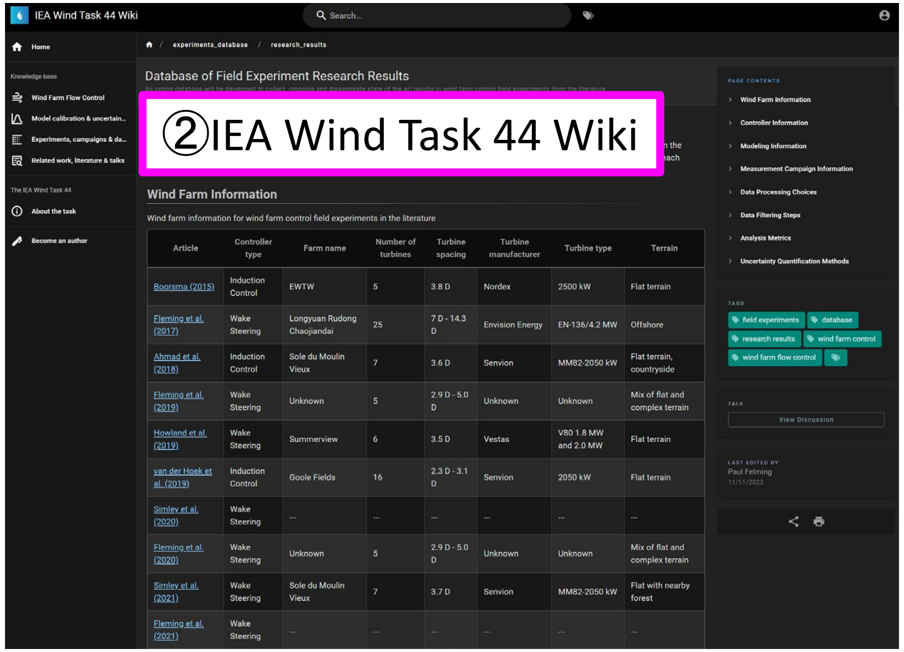


Monday, November 13, 2023 11:00 PM (JST)

IEA Task 44 General Meeting - Fall 2023

Paul Fleming, Task 44 Operating Agent
(paul.fleming@nrel.gov)

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



https://ieawindtask44.tudelft.nl/

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

NEXT GENERAL MEETING

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

UNIVERSITÀ DEGLI STUDI FIRENZE

DIEF DEPARTMENT OF INDUSTRIAL ENGINEERING

eawe european academy of wind energy

TORQUE 2024

Florence - Italy

May 29th - 31st, 2024

166	:	22	:	12	:	2
DAYS		HOURS		MINUTES		SECONDS

風車ウエイク研究会：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

<u>活動内容(2か月に1度をめどに開催)</u>：■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/

TUDelft

DATA DRIVEN CONTROL

Delft Center for Systems and Control

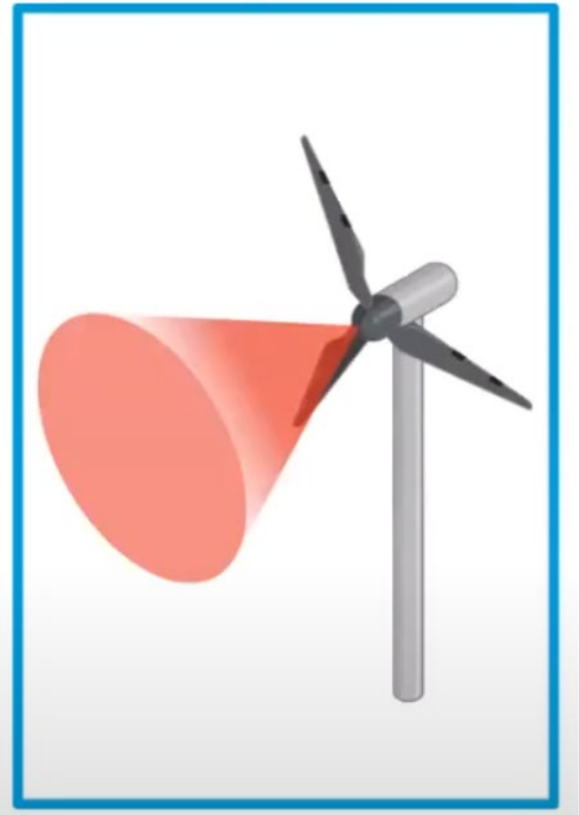
Wind farms that can reduce the effect of wakes

- 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/

TWIND aims to create a network of excellence that will dynamize a pool of specialized research professionals and trainers in the domain of offshore wind energy.

Lidar (sensors)



- Reconstruction wind field
- Prediction wind field
- Real-time optimization

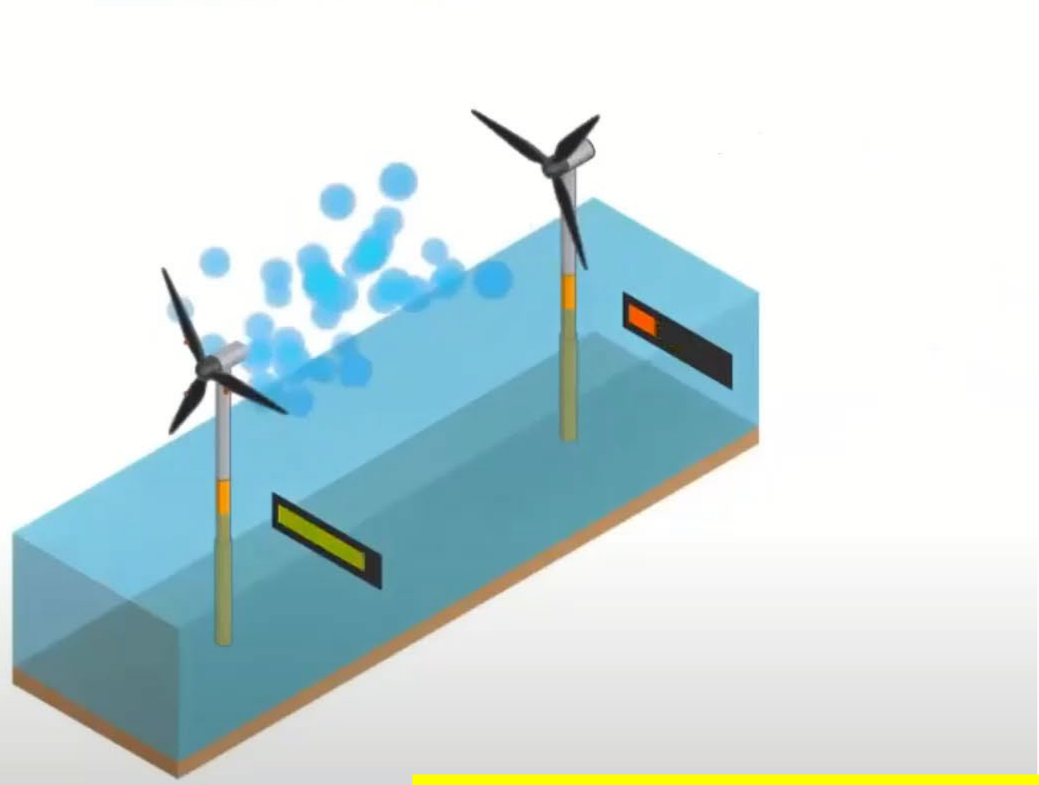
- In reality, we don't have access to the flow information. So the only thing that we have is measurements. So we only have measurements on a turbine level.

- 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



Quasi-steady flow control
Axial-induction-based control

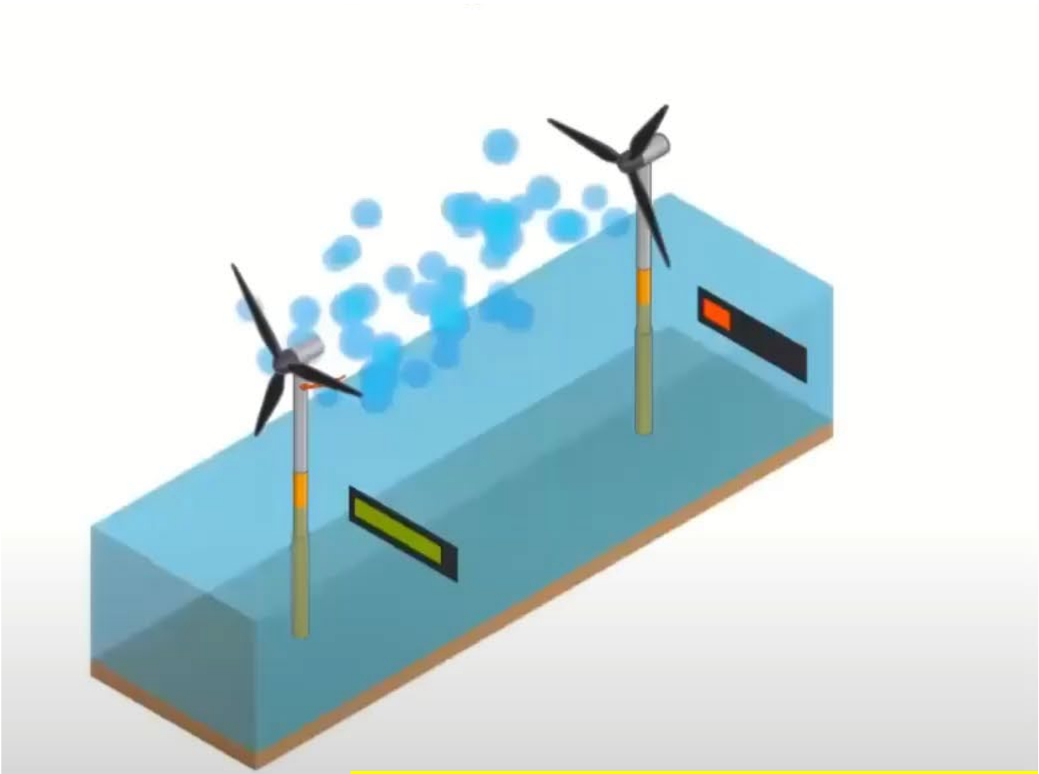
Static wake control concepts rely on affecting the wake through relatively slow changes of the control degrees of freedom of the turbine in a way that affect the time-averaged properties of the wake.

- 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

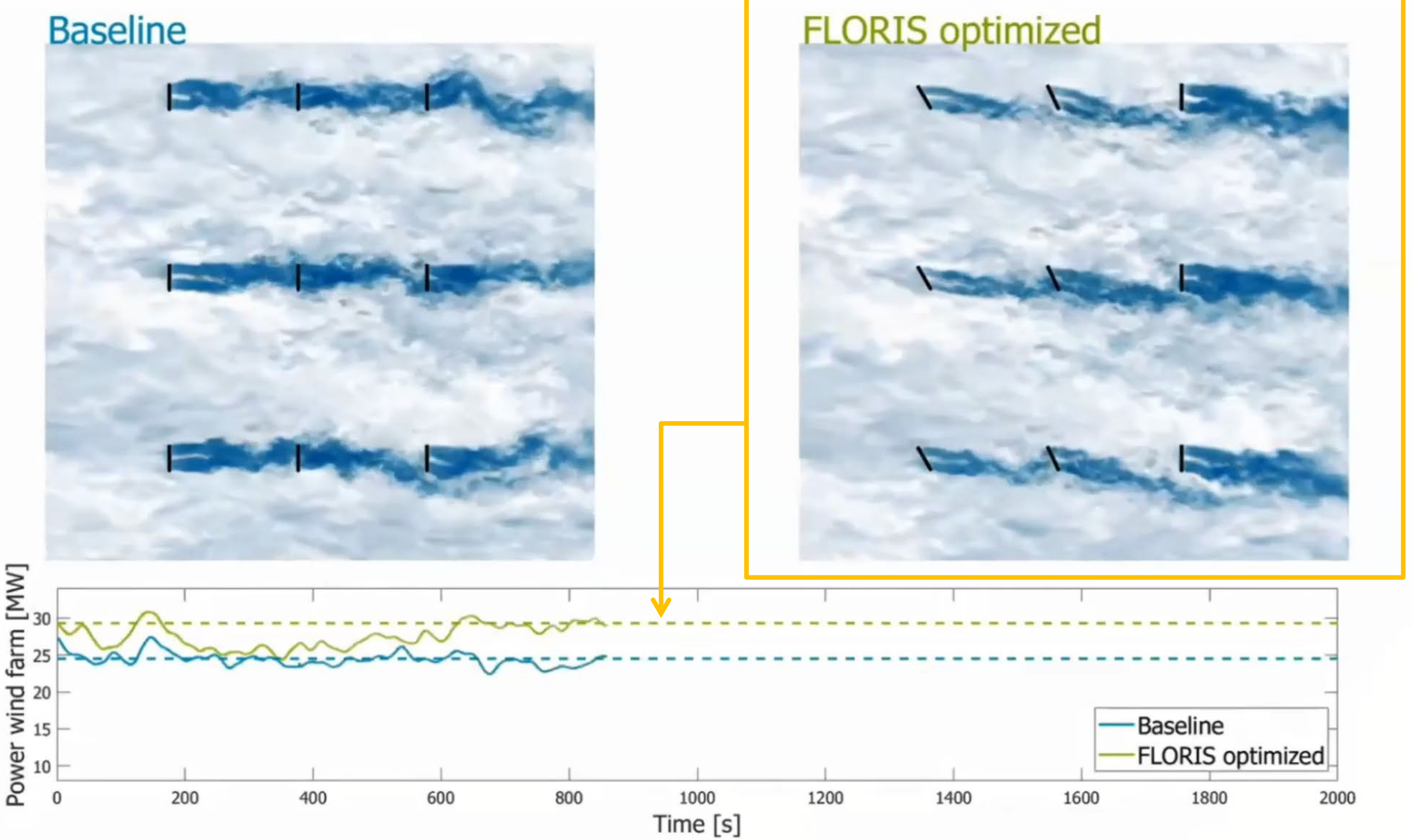
Static wake control concepts rely on affecting the wake through relatively slow changes of the control degrees of freedom of the turbine in a way that affect the time-averaged properties of the wake.

- 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.



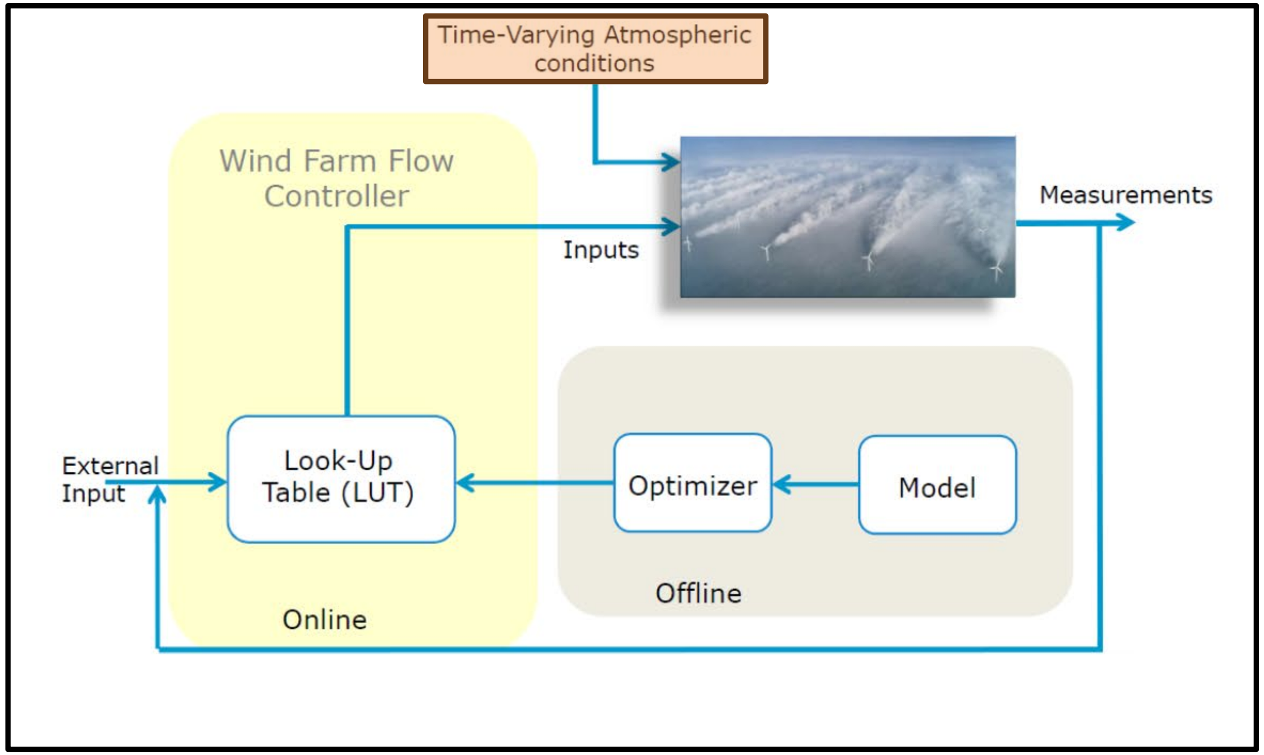
Quasi-steady flow control
Wake steering using yaw offsets

<u>Quasi-steady flow control</u>
Wake steering using yaw offsets

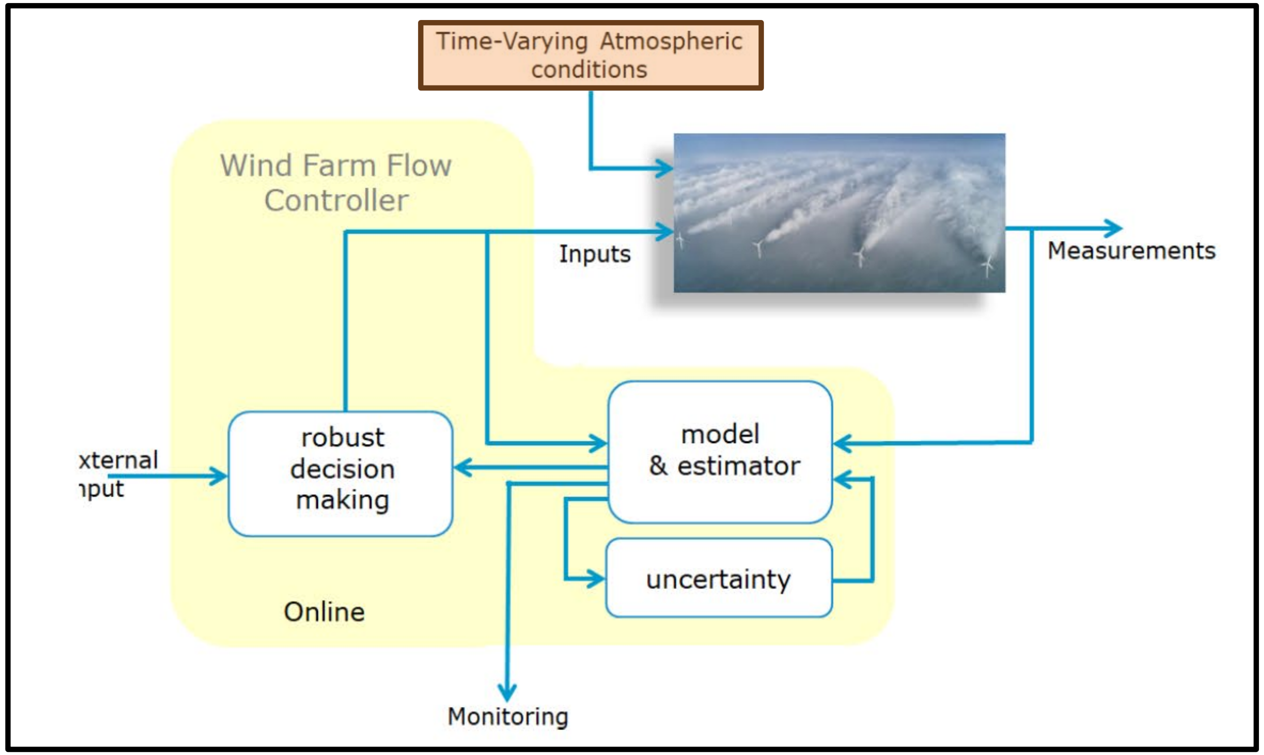


- At the left, we see the baseline. And at the right, we see the optimized setting.
- The optimized setting meaning that we had a first principles model, in this case the FLORIS.
- Then we optimized the optimal YAW settings. And what we nicely see is that we can do wake steering.
- Now in the graph, 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

补足

Open-loop diagram

指令だけをしてフィードバックを取らない制御

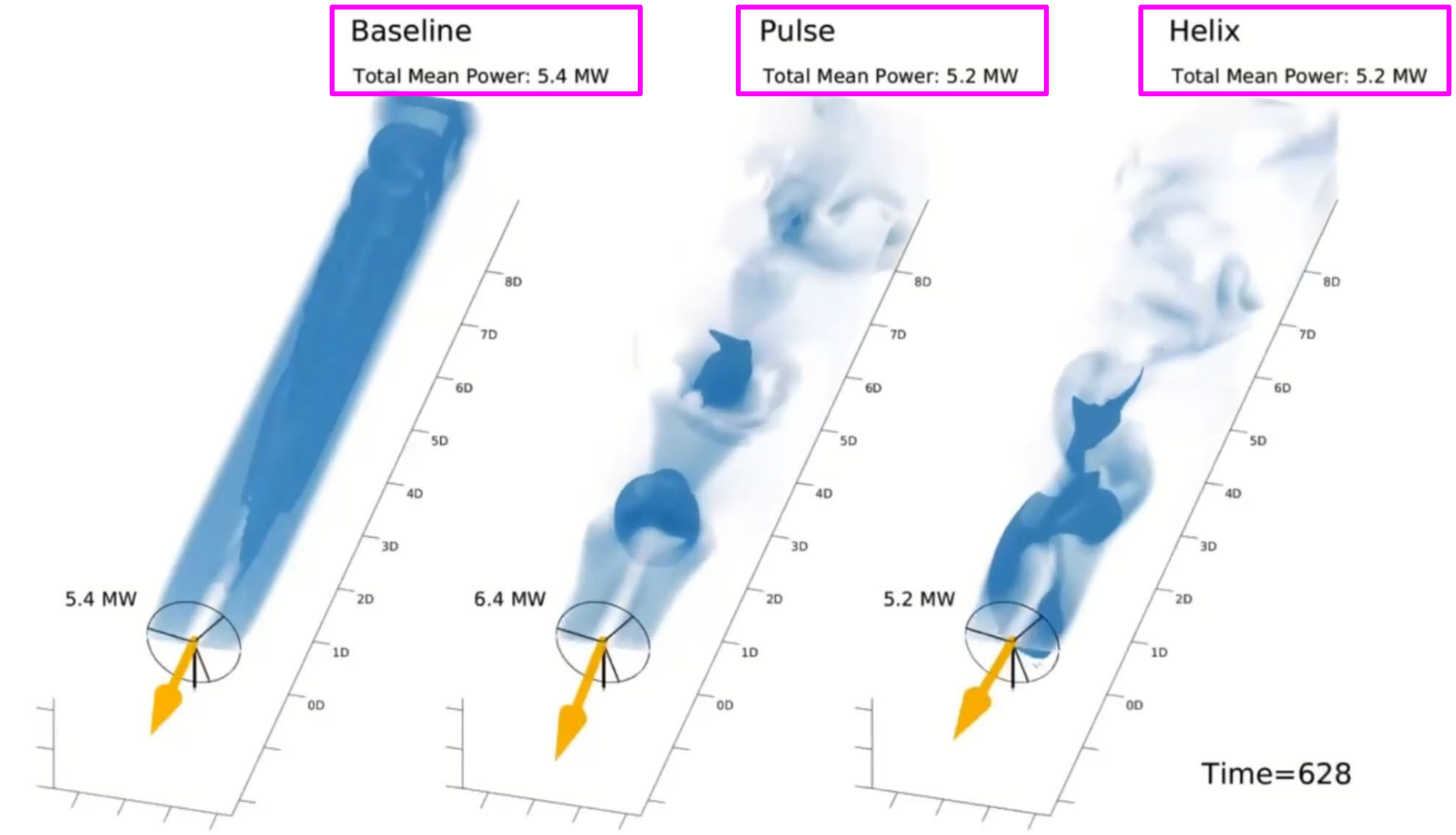
(例)シーケンス制御：あらかじめ定められた順序に従って制御の各段階を逐次進めていく制御」

Closed-loop diagram

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

https://www.altexcorp.co.jp/controlsystem/wocontrolsystem01-0-1-0

Wake-Mixing



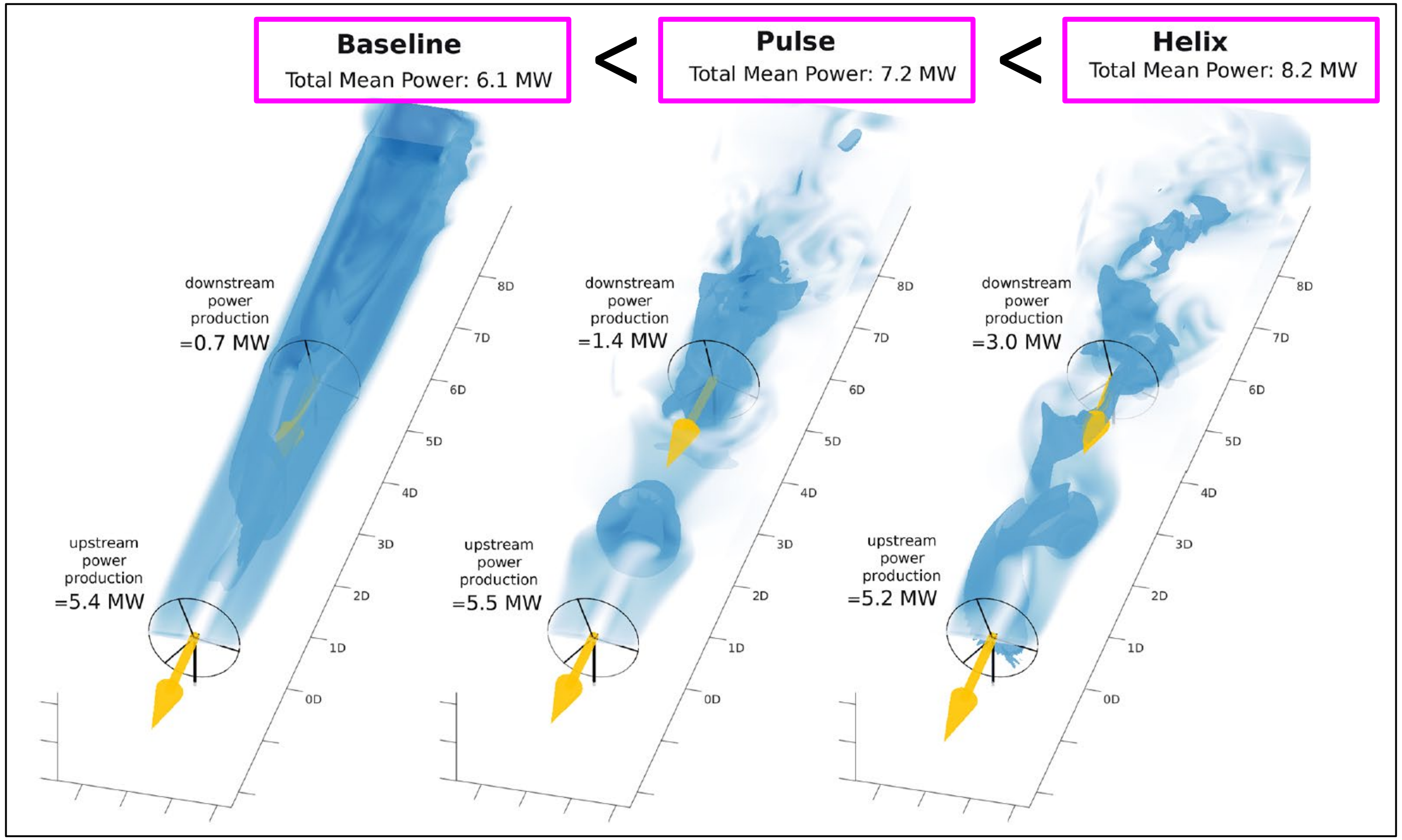
<u>Normal-operation wake</u> <u>(Periodic) dynamic induction control</u> <u>Helix approach</u>

- 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

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

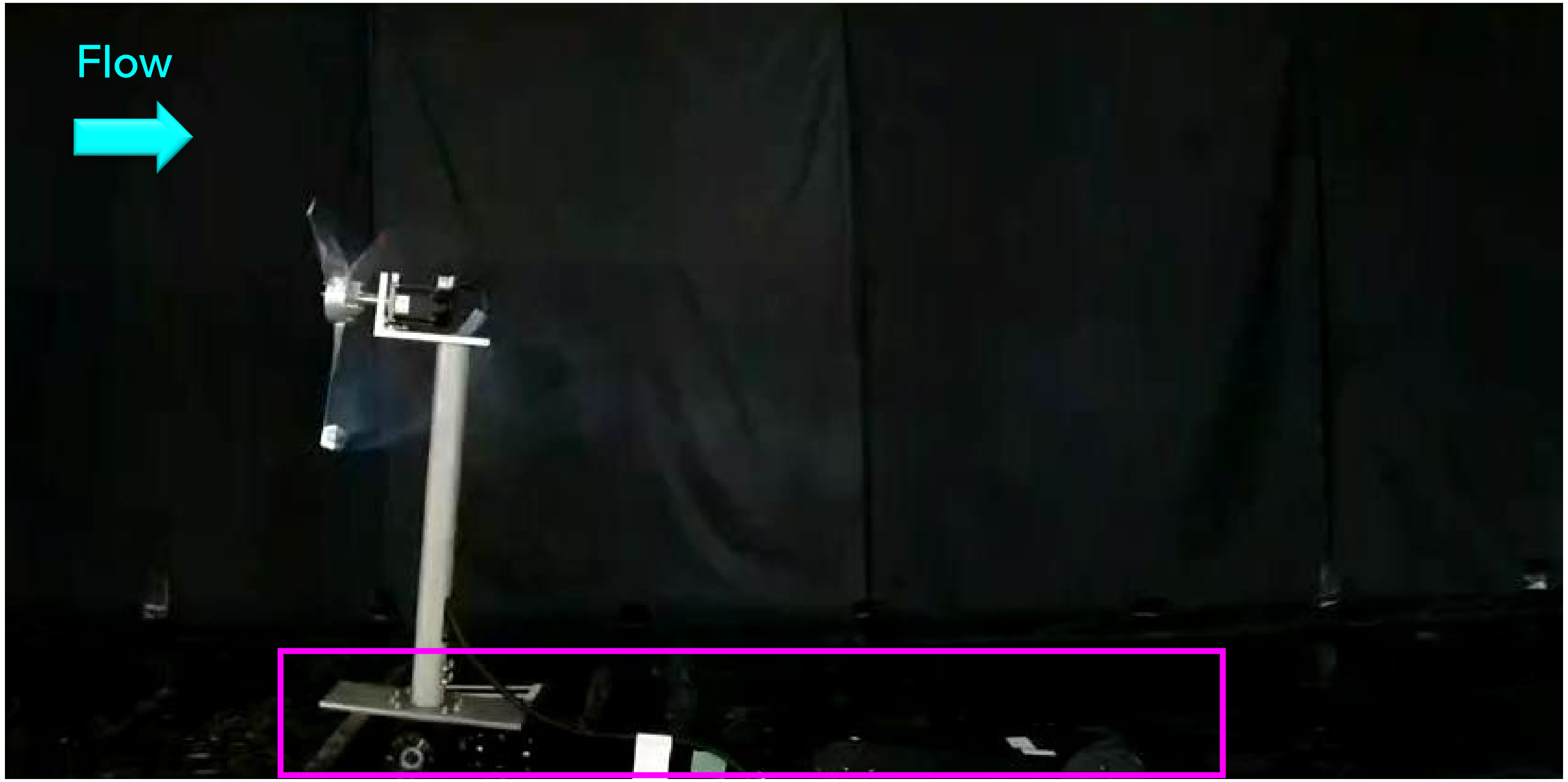
Wake-Mixing

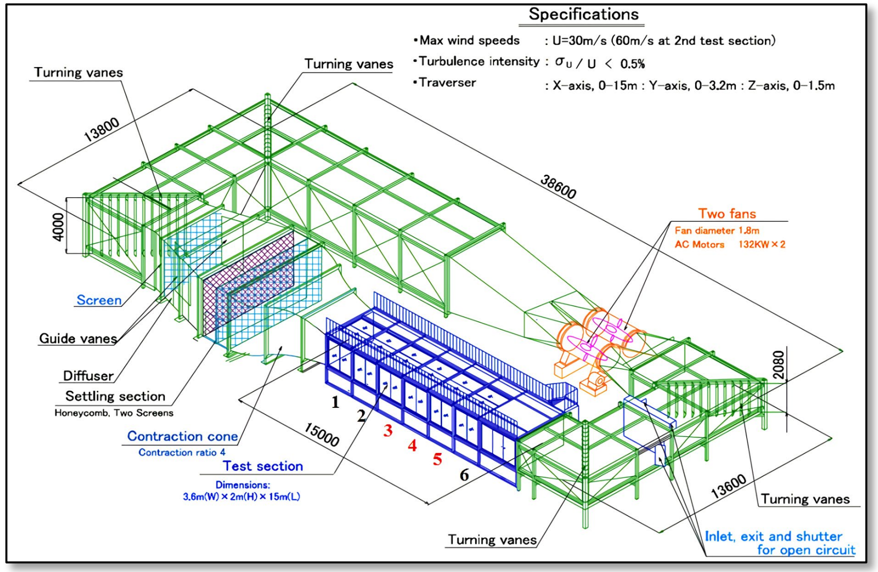


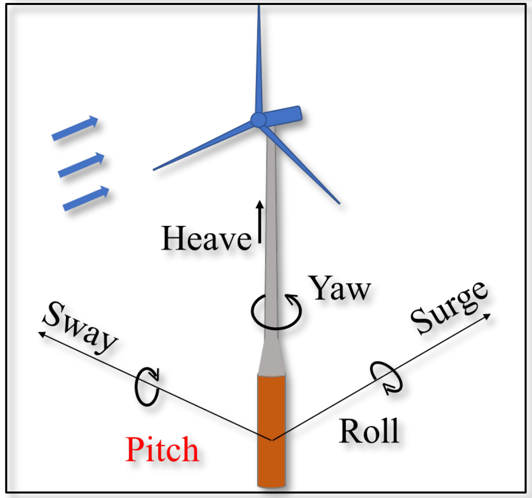
- However, then still you have to do all the safety checks and look at all the loads.
- So implementation wise, on paper it seems easy, but for industry it's quite a big step.

Wake-Mixing

九州大学･内田研究室での取組

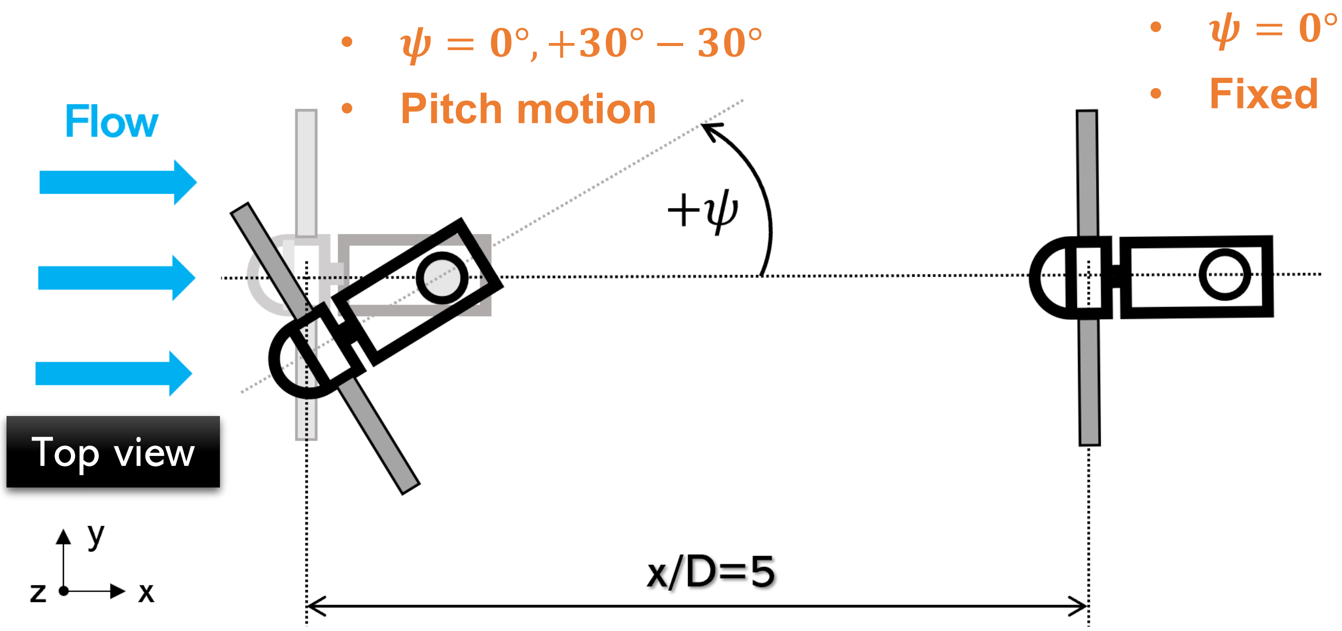




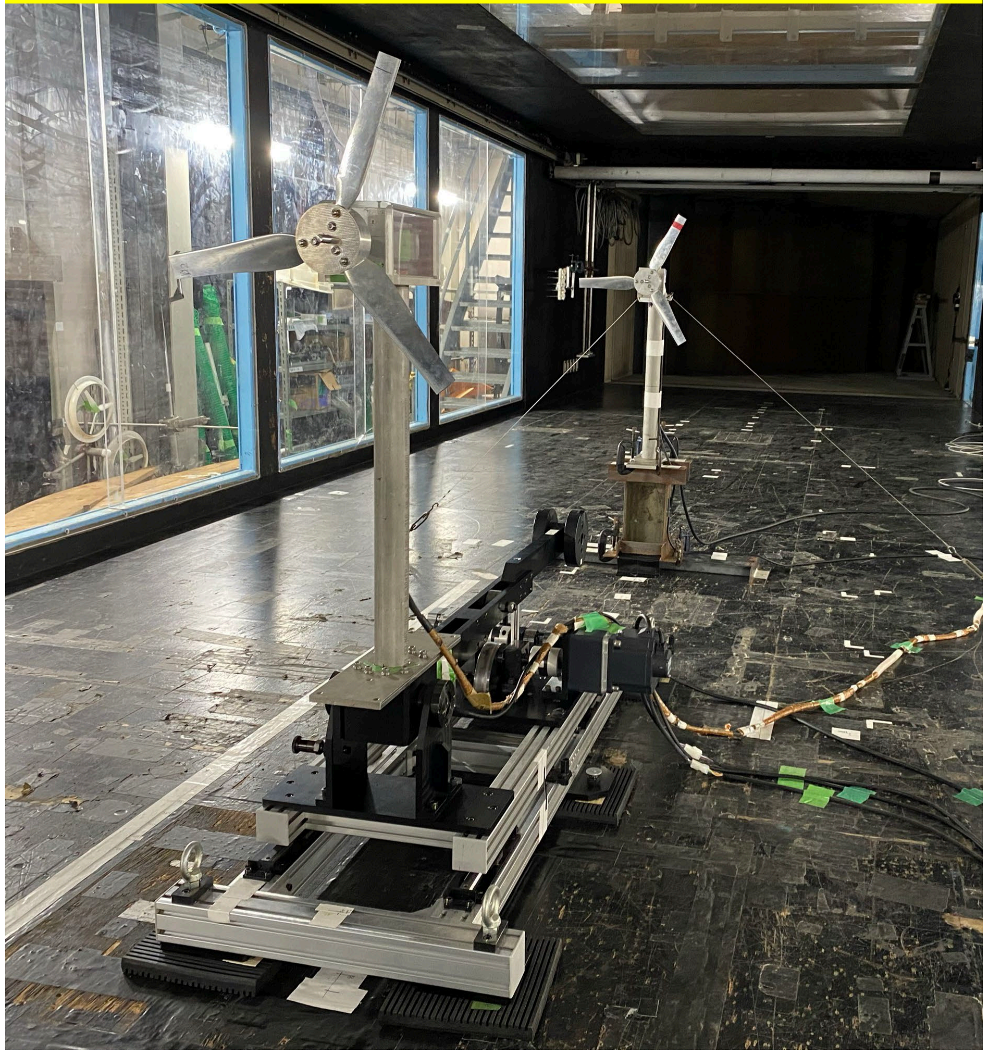


加振装置製作し、浮体の動揺（ピッチ運動）を再現

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

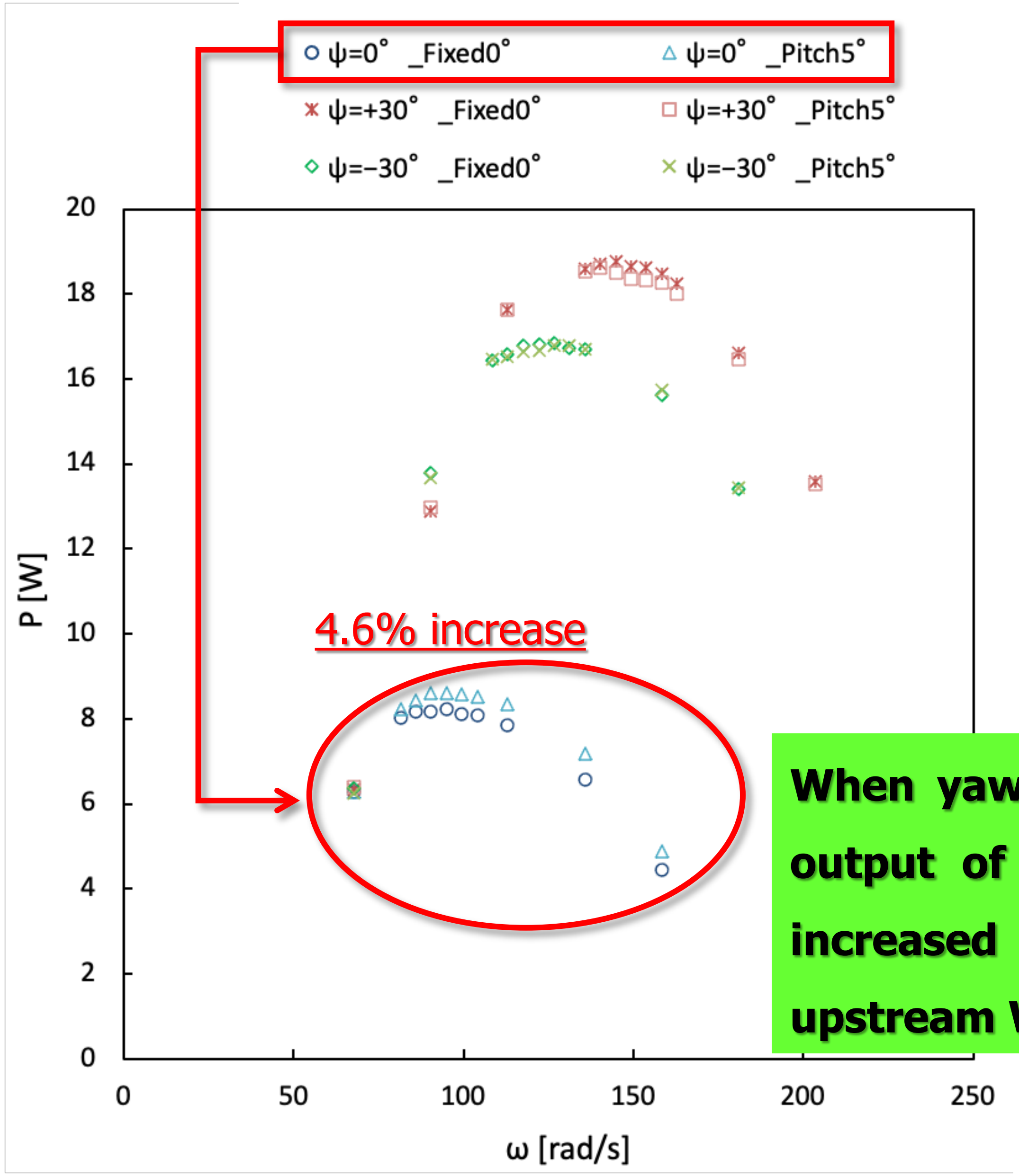


The power generation performance of the wind turbine was evaluated by varying the blade rotation speed.



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 output of downstream wind turbine



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

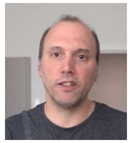
P [W]	:	Power
Tr [Nm]	:	Torque
ω [rad/s]	:	Angular velocity

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

参 考 文 献

2022年

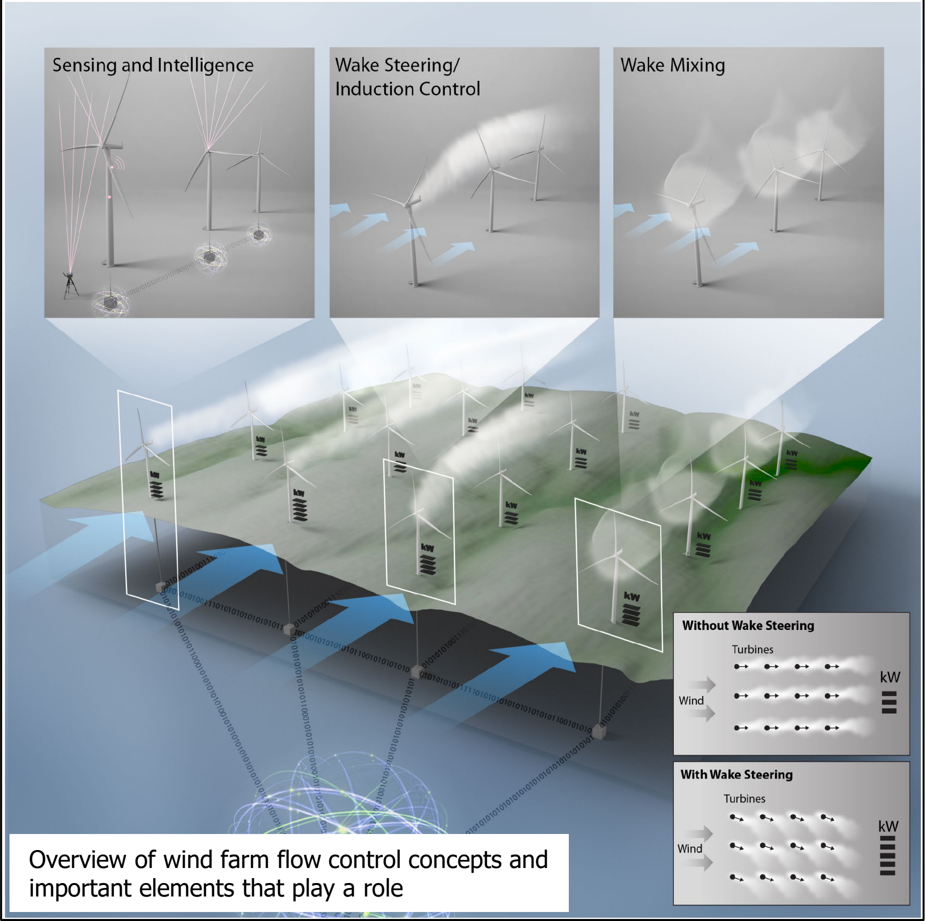
https://doi.org/10.5194/wes-2022-24
Preprint. Discussion started: 22 March 2022



eawe european academy of wind energy
Open Access
WIND ENERGY SCIENCE DISCUSSIONS

Wind farm flow control: prospects and challenges

Johan Meyers[1], Carlo Bottasso[2], Katherine Dykes[3], Paul Fleming[4], Pieter Gebraad[5], Gregor Giebel[3], Tuhfe Göçmen[3], and Jan-Willem van Wingerden[6]
[1]KU Leuven, Mechanical Engineering, Celestijnenlaan 300A, B3001 Leuven, Belgium
[2]Chair of Wind Energy, Technische Universität München, Boltzmannstr. 15, 85748 Garching b. München, Germany
[3]DTU Wind Energy, Frederiksborgvej 399, DK-4000 Roskilde
[4]National Renewable Energy Laboratory, Boulder, Colorado, US
[5]Siemens Gamesa Renewable Energy, Tonsbakken 16, 2740 Skovlunde, Denmark
[6]Delft University of Technology, Delft Center for Systems and Control, Mekelweg 2, 2628 CD Delft, The Netherlands



Overview of wind farm flow control concepts and important elements that play a role

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.

●
●
●
●

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