Grid Integration of Airborne Wind Energy

AWESCO Kick-off meeting

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Chalmers University of Technology, Gothenburg, Sweden

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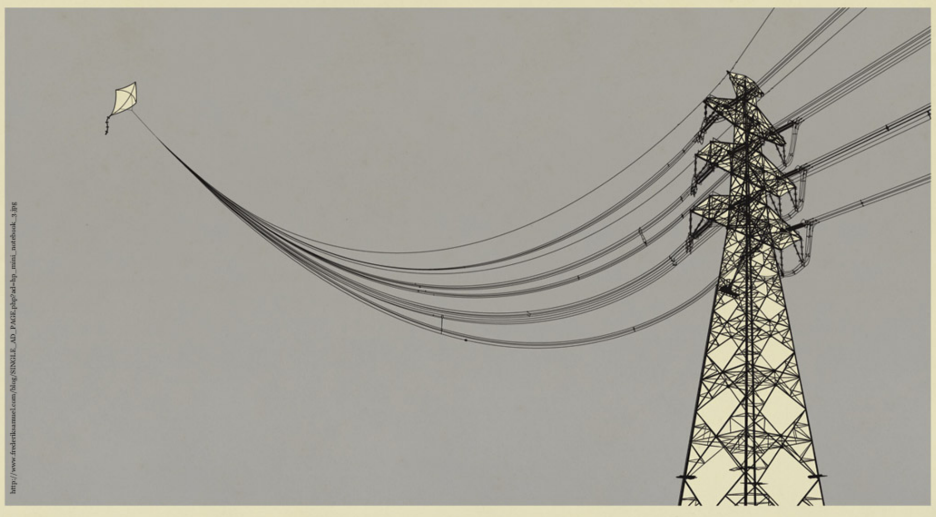
About me

Background:	Wind Power Systems, Aalborg University
Research Topic:	Optimization of the Electro-Mechanical & Grid Interactions for AWE systems
Location:	University of Chalmers, Göteborg, Sweden
Supervisor:	Sébastien Gros

Outline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Grid Integration issues of Wind Power Systems

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- Active power control (Storage?)
- Modulation of active and reactive power
- Limitation on harmonics
- ...

Grid codes ?

All power generators have to comply with certain requirements to ensure grid safety

This problems probably also appear for AWES.
But in which extend? What are the differences? And how can we deal with that?

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Project keypoints

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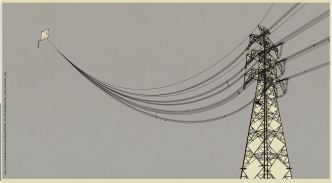

1. Study/Optimize the power output of an AWE farm
2. Generator & power electronic constraints (Electro-Mechanical Interactions)
3. Interaction between a strong/weak power grid and an AWE farm? (Grid Interactions)

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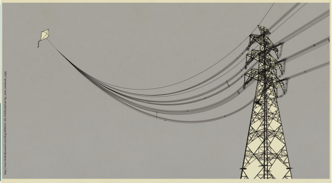

1. Study/Optimize the power output of an AWE farm
2. Generator & power electronic constraints (Electro-Mechanical Interactions)
3. Interaction between a strong/weak power grid and an AWE farm? (Grid Interactions)
4. How to implement grid-code compliance in practice?

Project plan

First Year

Model of large scale electro-mechanical power systems and their interaction with the power grid.
Study control and optimization theory.

Second Year

4 month secondment in Freiburg: Numerical and large scale optimization.
Solutions for AWE systems with grid interactions.

Third Year

Methods applications to a test scenario defined by Skysails.
2 month secondment at Skysails.

Outline

1. Background & Motivation
2. Project Description and Project Plan
3. Results

Development of a kite model (Python/Casadi)

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S. Gros, M. Zanon and M. Diehl, "A relaxation strategy for the optimization of Airborne Wind Energy systems,"

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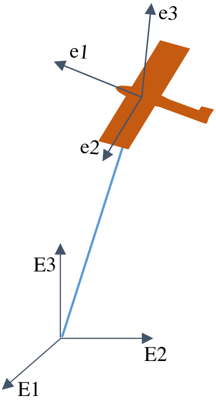

... flying a circular trajectory

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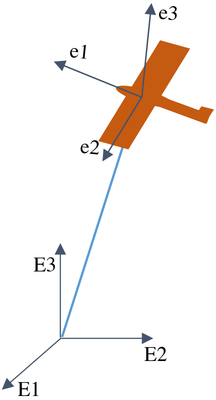

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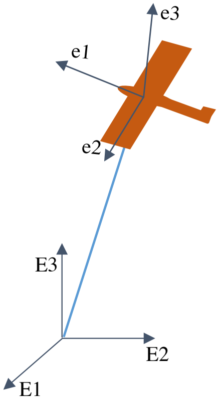
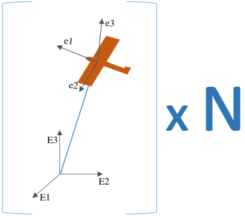


Goal

1. Optimize power output
2. Scale up system to AWE farm



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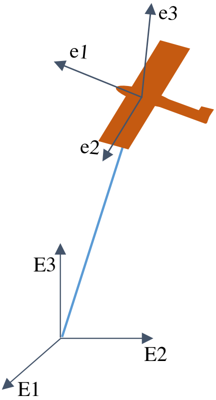

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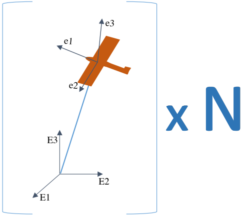


So, how is this optimization problem implemented?

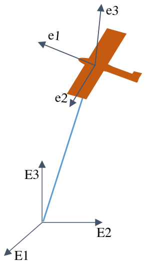
Modelling of an AWE system for optimization

Dynamics:

$$\begin{bmatrix} m\cdot \mathrm{I} & \mathbf{p} \\ \mathbf{p}^\top & 0 \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{p}} \\ z \end{bmatrix} = \begin{bmatrix} \mathbf{F}_\mathrm{g} \\ -\dot{\mathbf{p}}^\top \dot{\mathbf{p}} - L\ddot{L} - \dot{L}^2 \end{bmatrix}$$

$$\dot{R} = R\omega_\times$$

$$J\dot{\omega} = \mathbf{T} - \omega \times J\omega$$



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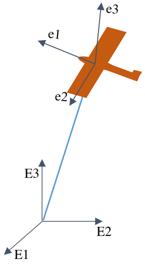

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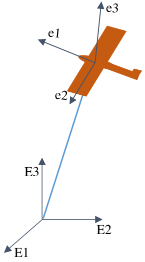

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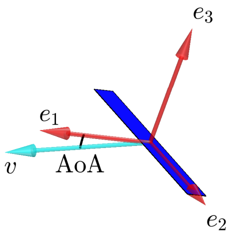

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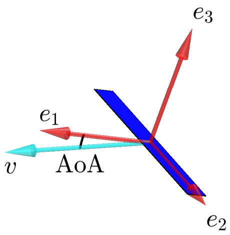

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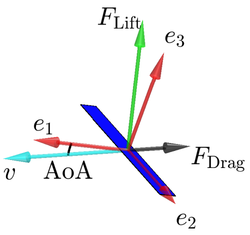

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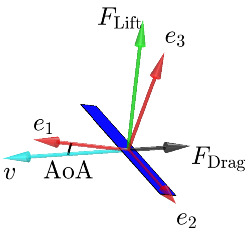

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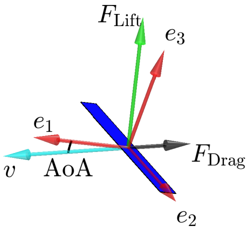

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- Power in drag-mode: $P = F_\mathrm{Power} \mathbf{e}_1^\top \dot{\mathbf{p}}$

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Power optimization problem

$$
\begin{aligned}
\max_{\mathbf{x}, z, R, \mathbf{u}, t_\pi} \quad & \frac{1}{t_\pi} \int_0^{t_\pi} P(\mathbf{x}, z, \mathbf{u})\, dt & & \textit{Cost Function} \\
\text{s.t.} \quad & \mathbf{F}(\dot{\mathbf{x}}, \mathbf{x}, R, z, \mathbf{u}, \mathbf{w}) = 0 & & \textit{Dynamics} \\
& \boldsymbol{\pi} = 0, \quad \mathbf{c} = 0 & & \textit{Periodic \& tether constraints} \\
& \mathbf{h}(\mathbf{x}, z, \mathbf{u}, \mathbf{w}) \leq 0 & & \textit{Path constraints}
\end{aligned}
$$

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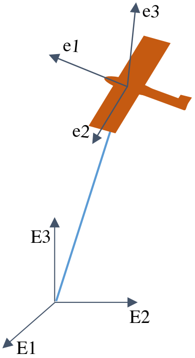
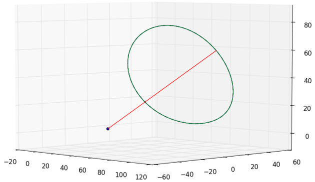


Differential states: $\mathbf{x} = \{\mathbf{p}, \dot{\mathbf{p}}, \omega\}, R, E$
Algebraic state: $z \in \mathbb{R}$
Inputs: $\mathbf{u}$ for control surfaces

Things to be careful about..

- Good initial guess needed



Things to be careful about..

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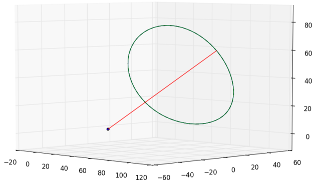
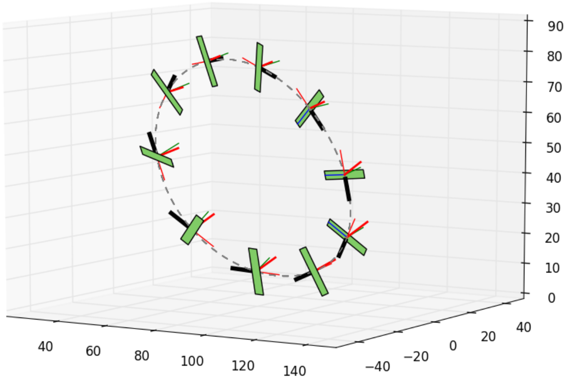
- Aerodynamic forces and moments create nonlinear feedback loops $T_A(x, R, w, u)$ and $F_A(x, R, w, u)$

  Use of **homotopy** , i.e. switch from artificial forces to the 'real' physical model



Visualize Results

Just a beginning...



Optimal trajectory for one cycle when optimizing for maximum power output

Outlook

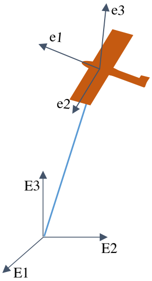
What's next?

- Add wind shear
- Power optimization for pumping mode
- Introduce cable drag
- Scale up to AWE farm

Wrap up

What has been done so far:

- Studies on Optimization & Optimal Control
- First steps in development of an AWE model with the aim of optimizing power output



Future Research

- Include electrical drive constraints
- Study harmonics in power output