



**AWESCO**  
**Airborne Wind Energy**  
System Modelling, Control & Optimisation

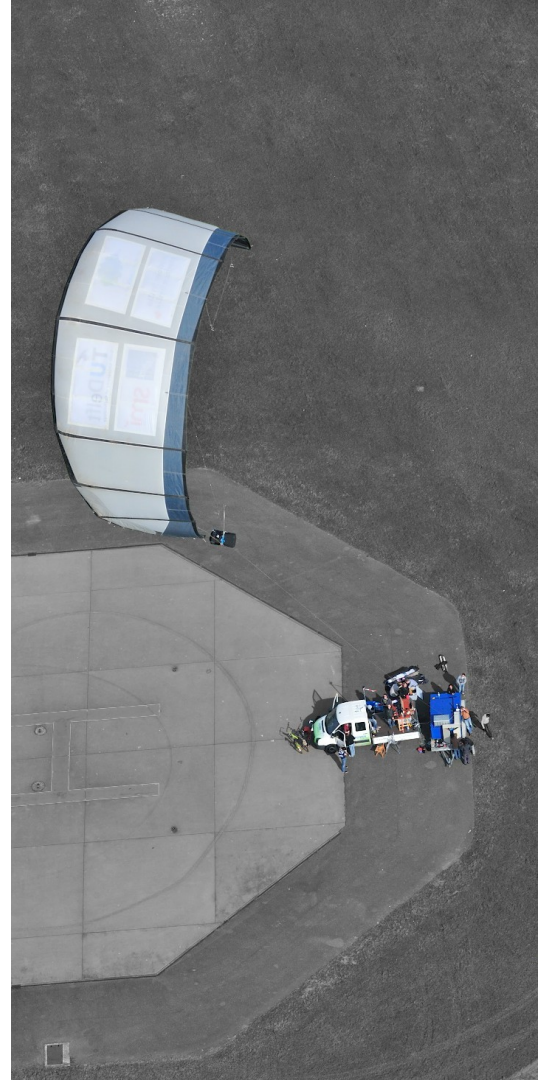
**Internal Research Review**

University of Freiburg  
2 February 2016



# Outline

- Societal context & mission statement
- Technology key features
- R&D activities until now
- AWESCO short sketch





# Societal Context

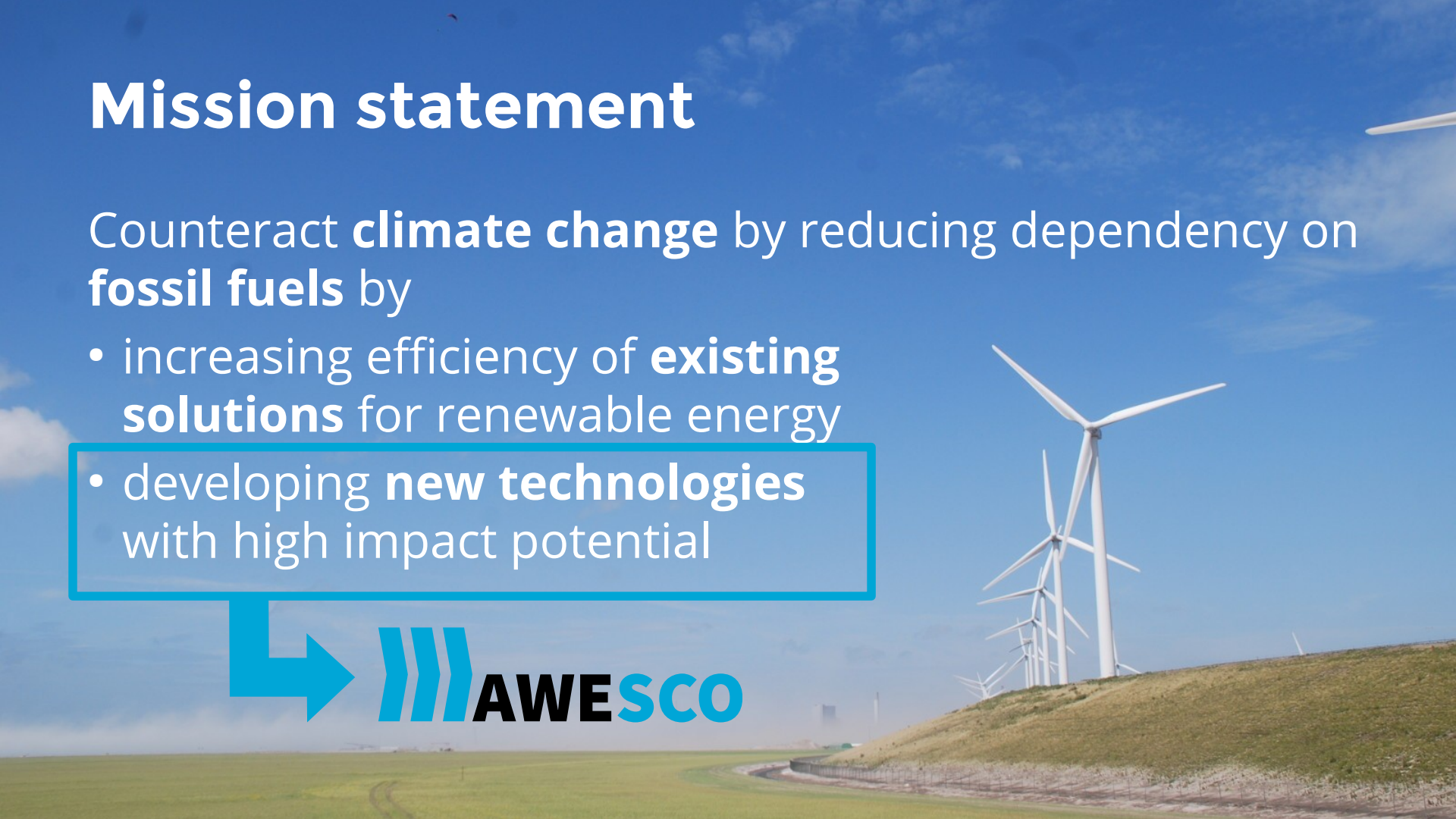
A wide-angle aerial photograph of Earth from space. The top of the image shows the curvature of the planet with a thin blue atmosphere. Below, a vast landscape is visible, featuring a large body of water in the center where a bright sunset or sunrise is occurring, casting a golden glow across the sky and reflecting on the water. The surrounding land is covered in dense green and brown vegetation, with some urban or developed areas visible. The overall scene is dramatic and emphasizes the global scale of the subject matter.

**No challenge poses a greater threat to future generations than climate change – Barack Obama**

# Mission statement

Counteract **climate change** by reducing dependency on **fossil fuels** by

- increasing efficiency of **existing solutions** for renewable energy
- developing **new technologies** with high impact potential





**Bill Gates**  
**(Financial Times, 25 June 2015)**

**High-Altitude Wind Energy**  
**Could be the “magic bullet”.**

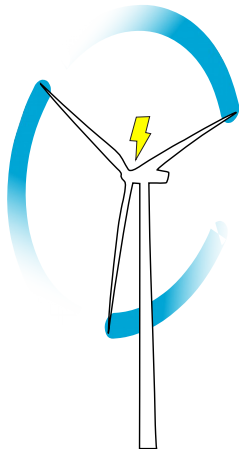




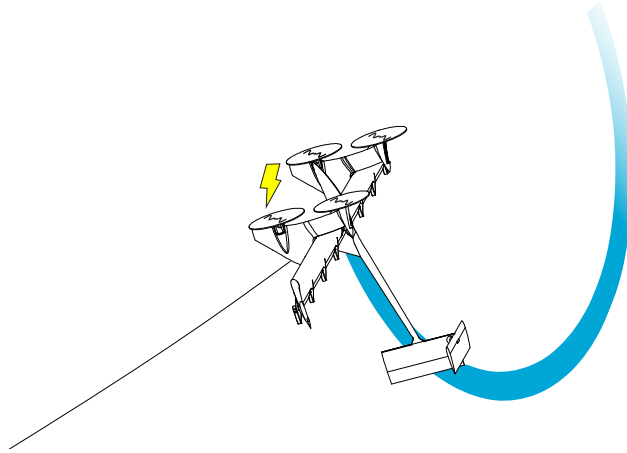
**Wubbo Ockels  
(1946 - 2014)**

**Dutch astronaut & pioneer  
of airborne wind energy**

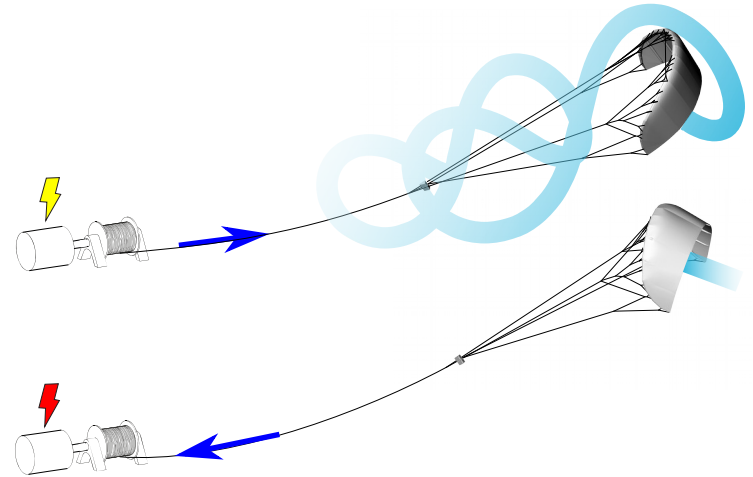
# Fundamental concepts



**Wind turbine**



**Airborne Wind Turbine**  
Makani Power / Google



**Pumping Kite Power System**  
Most others developers

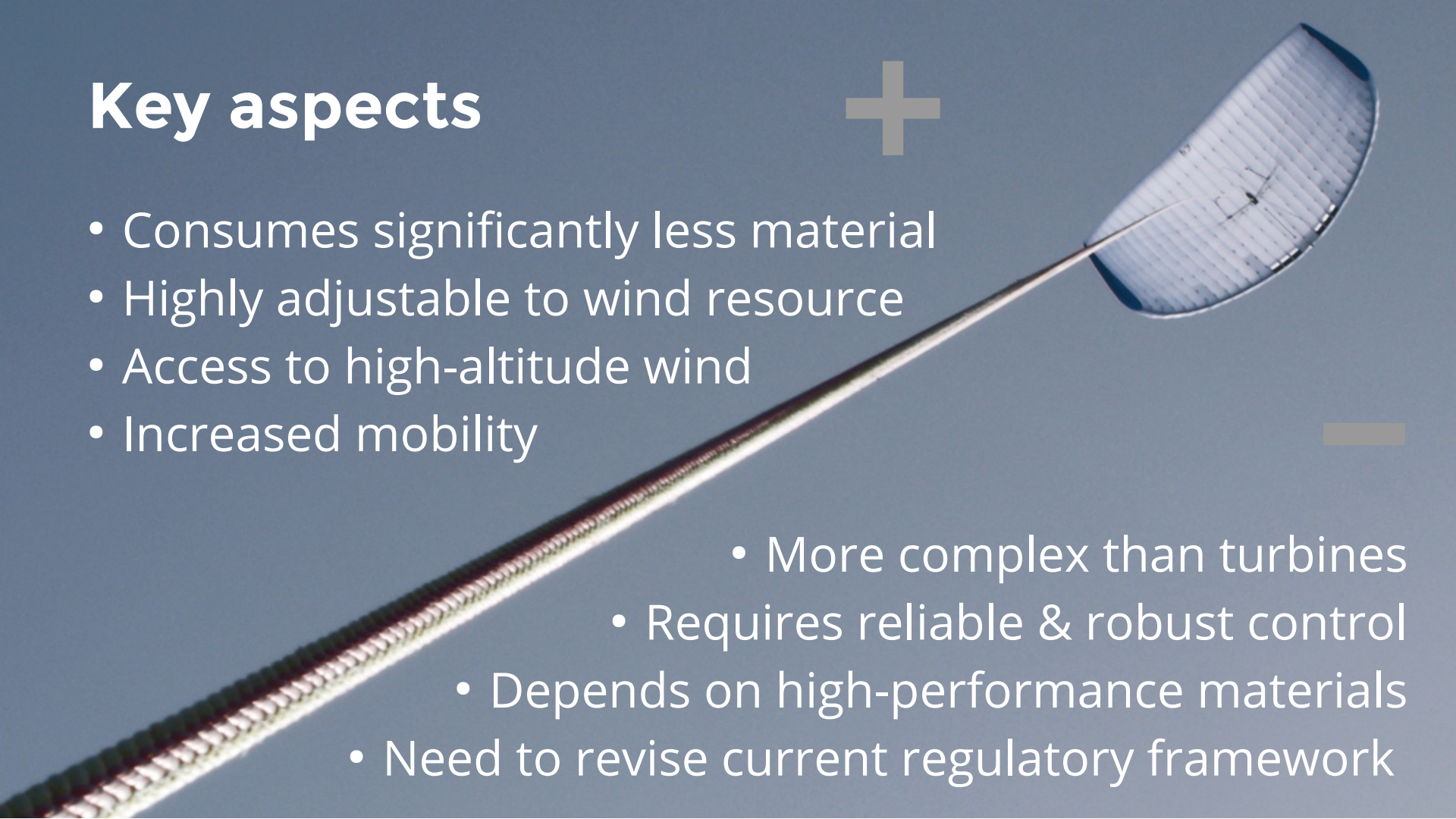


# Key aspects



- Consumes significantly less material
- Highly adjustable to wind resource
- Access to high-altitude wind
- Increased mobility

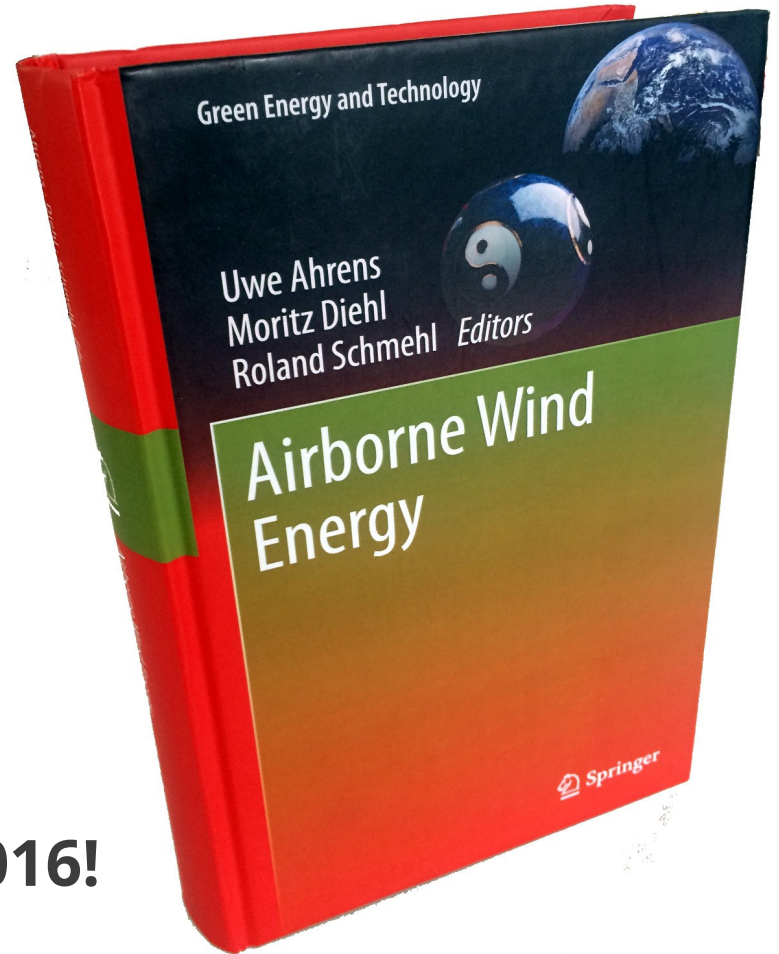
- More complex than turbines
- Requires reliable & robust control
- Depends on high-performance materials
- Need to revise current regulatory framework





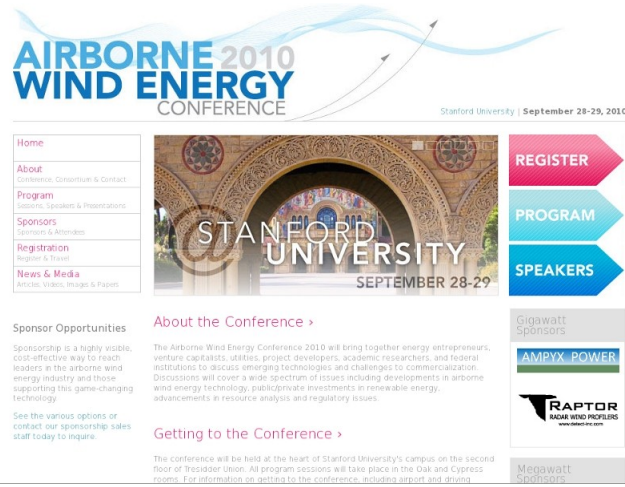
# AWE textbook 2013

- First textbook on AWE
  - Published 2013 with Springer
  - 35 peer-reviewed chapters
  - 611 pages
  - 45234 chapter downloads
- High-impact publication
- Second book in late **spring 2016!**



# Airborne Wind Energy Conferences

### Stanford (2010)



**AIRBORNE 2010 WIND ENERGY CONFERENCE**  
Stanford University | September 28-29, 2010

**Home**  
 About: Conference, Co-sponsors & Contact  
 Program: Facilities, Locations & Presentations  
 Sponsors: Sponsors & Attendees  
 Registration: Register & Travel  
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**About the Conference >**  
The Airborne Wind Energy Conference 2010 will bring together energy entrepreneurs, venture capitalists, utilities, project developers, academic researchers, and federal institutions to discuss emerging technologies and challenges to commercialization. Discussions will cover a wide spectrum of issues including developments in airborne wind energy technology, public/private investments in renewable energy, advancements in resource analysis and regulatory issues.

**Getting to the Conference >**  
The conference will be held at the heart of Stanford University's campus on the second floor of President Union. All program sessions will take place in the Oak and Cypress rooms. For information on getting to the conference, including airport and driving.

**Sponsor Opportunities**  
Sponsorship is a highly visible, cost-effective way to reach leaders in the airborne wind energy industry and those supporting this game-changing technology. See the various options or contact our sponsorship sales staff today to inquire.

### Leuven (2011)



### Berlin (2013)

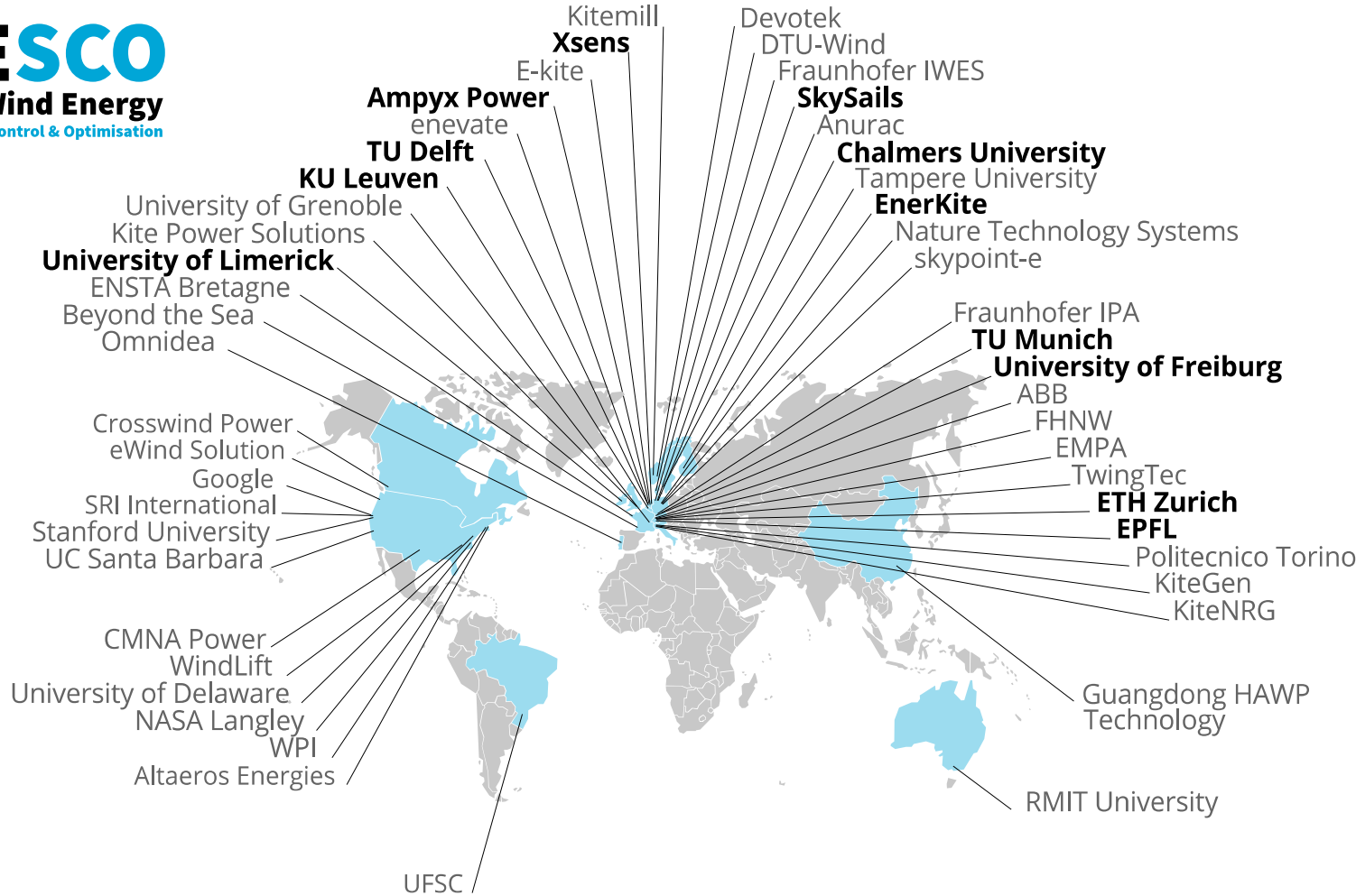




# AWEC 2015 in Delft

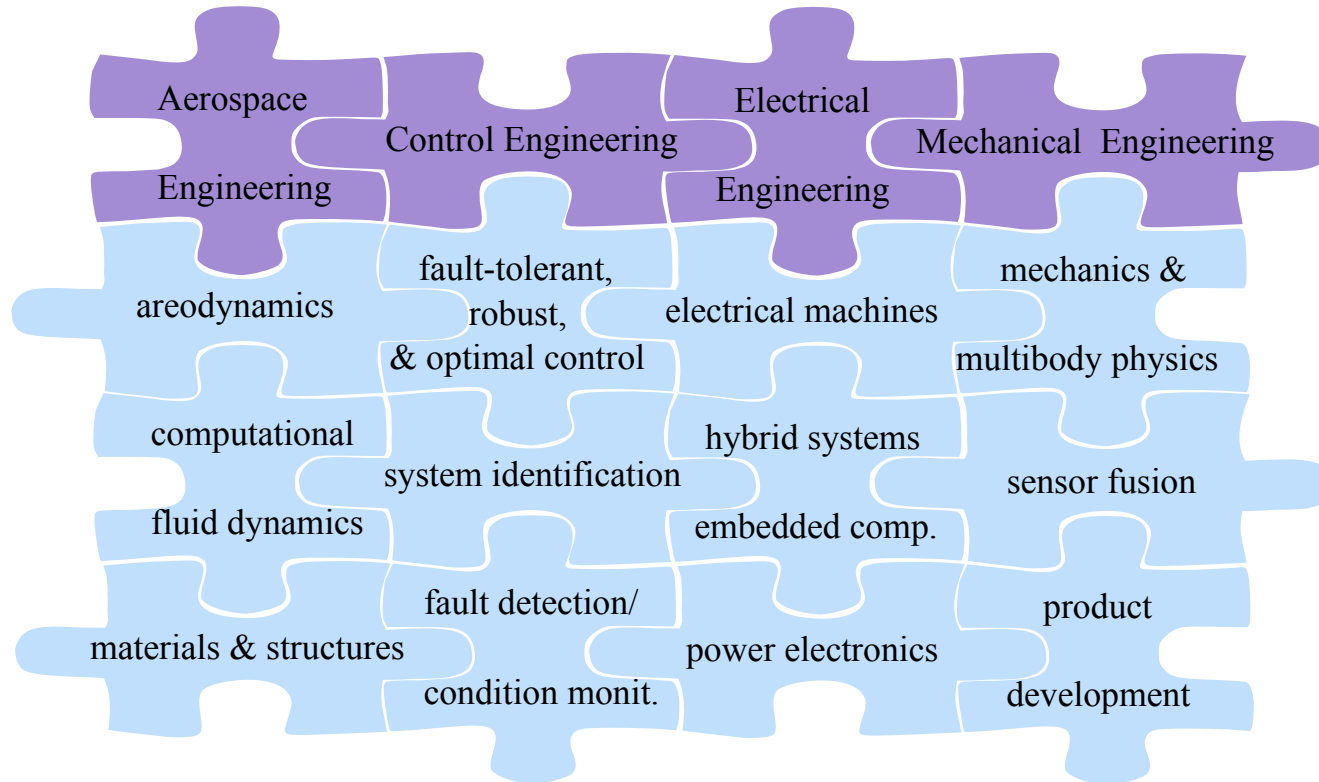








- Marie Skłodowska-Curie European Training Network
- 4 work packages focussing on scientific challenges:
  - **Modelling and Simulation** (WP lead: **TUD**)
  - **System Design and Optimisation** (WP lead: **ALU-FR**)
  - **Sensors and Estimation** (WP lead: **Xsens**)
  - **Control Systems** (WP lead: **TUM**)

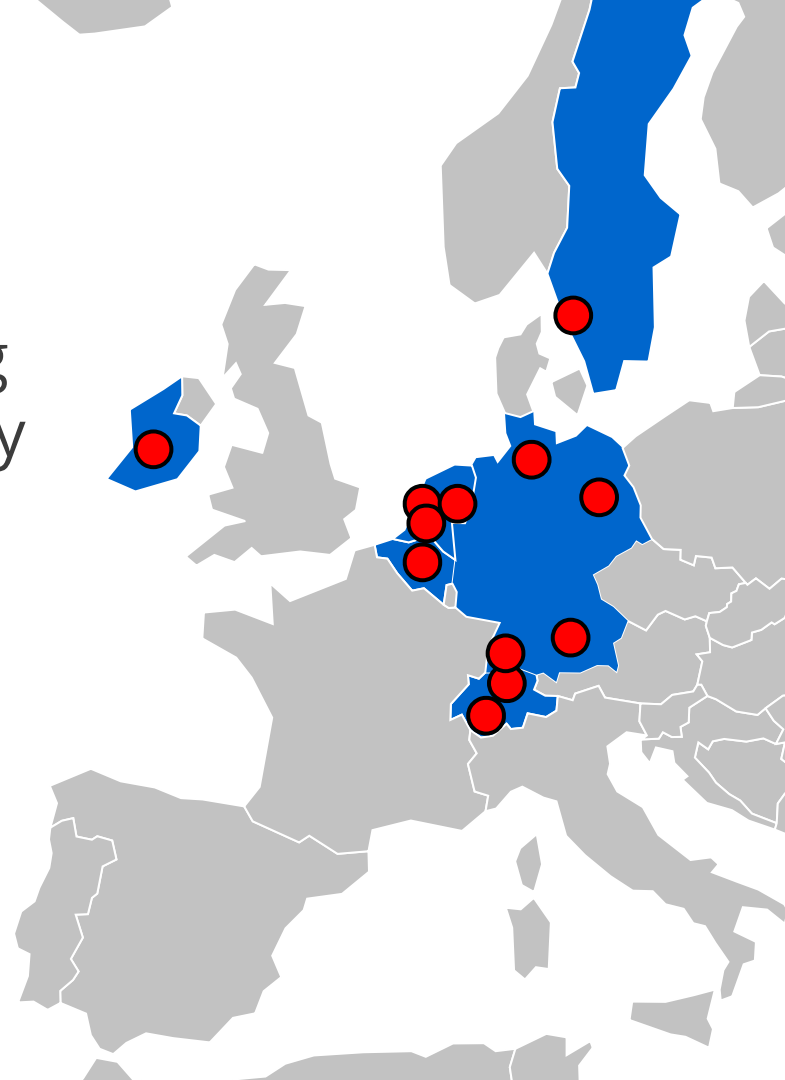




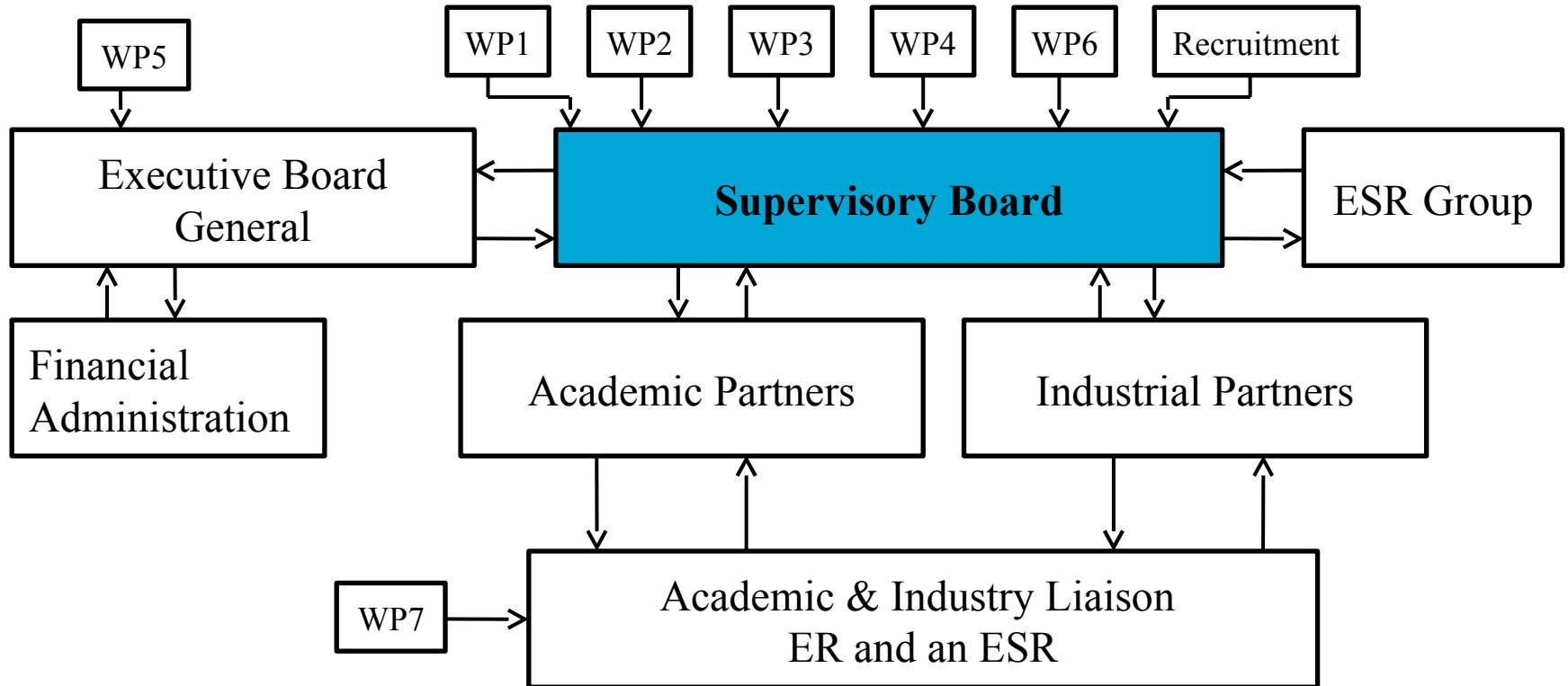


- **Not covered are**
    - Material research
    - Certification
    - Regulations
    - Environmental impact
- For other research project

- 14 PhD projects, all contributing to relevant questions of industry
- 10 EU-funded partners
- 2 CH-funded partners
- 3.4 M€ total budget



# Management Structure





# Associated Partners

- **Fraunhofer IWES** (Bremerhaven & Kassel)
- **Fraunhofer IPA** (Stuttgart)
- **Google / Makani Power** (Mountain View & Alameda)
- **Flysurfer** (Marquartstein)

# Conclusions



## FUTURE

Pumping Kite Power System

## PRESENT

Nuon & Eneco 1.5 MW Wind Turbines

## PAST

E.ON 550 MW Coal Power Plant



# AWESCO

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## Introduction Round







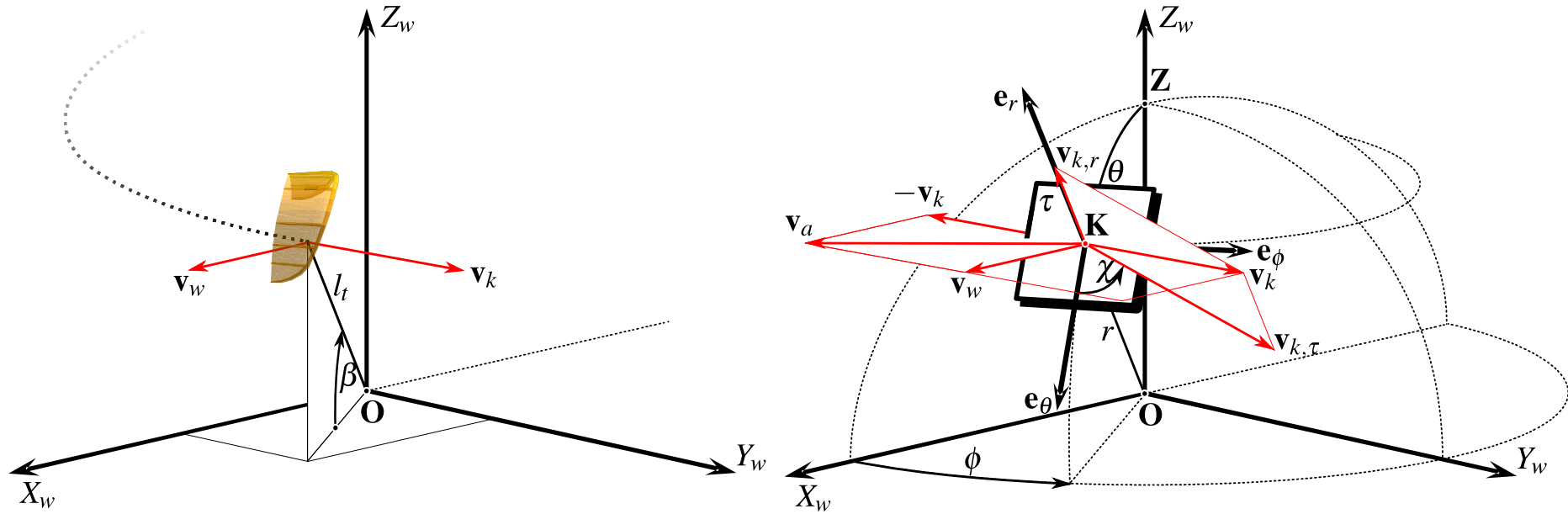
## **Modelling and Simulation**

Work Package 1



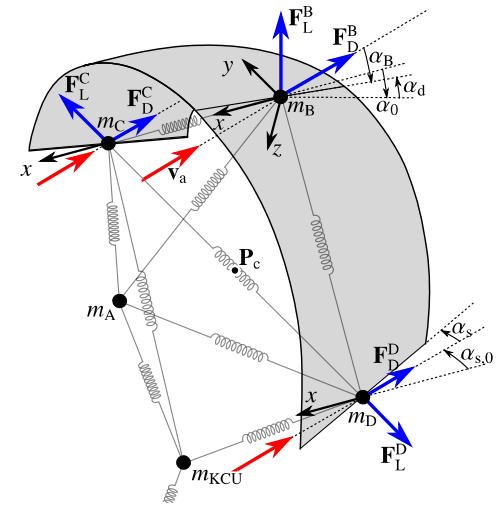
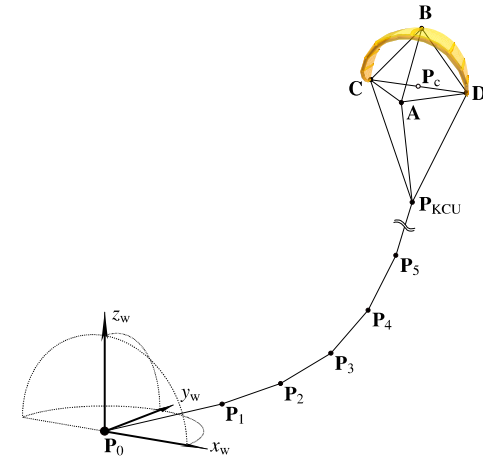


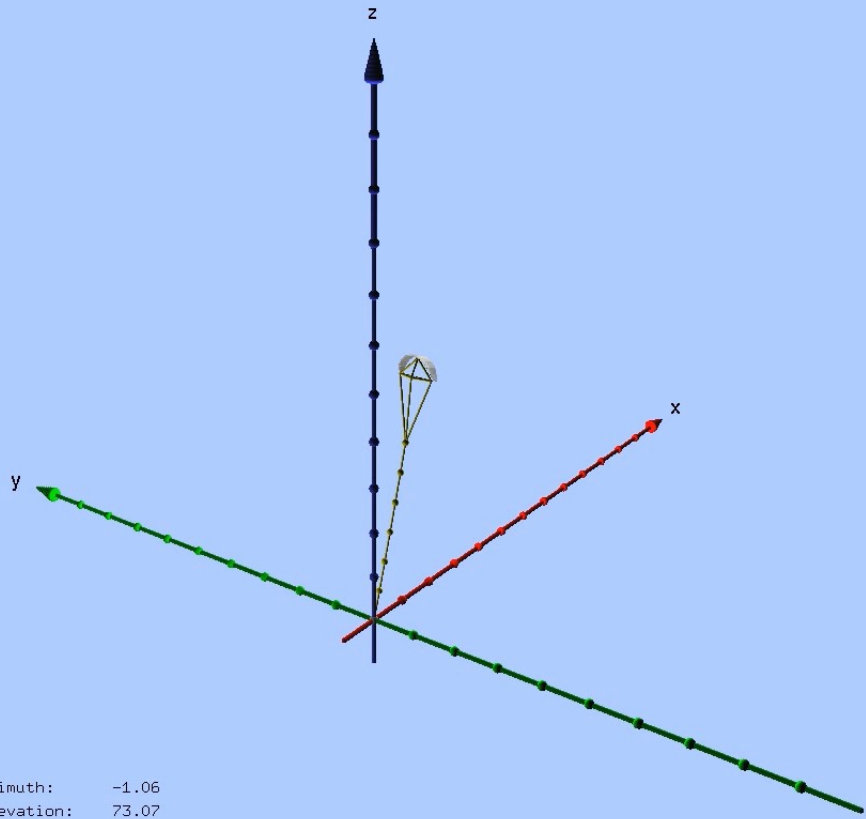
# Quasi-steady system model



# Dynamic system model

- Dynamic forces on system components
- Tether sag (gravity & aerodynamic drag)
- Coarse aero load distribution on wing
- Flight & winch controllers





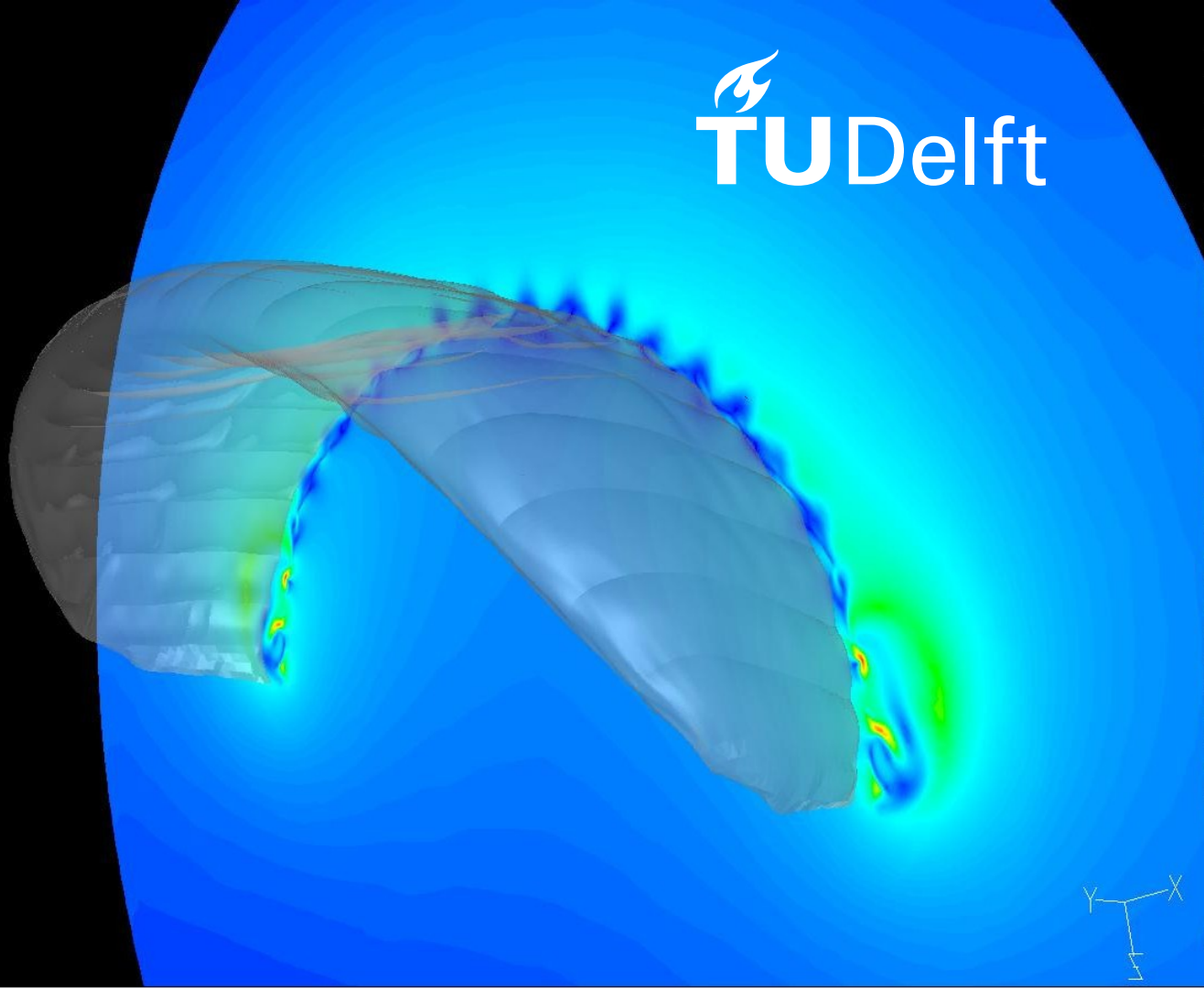
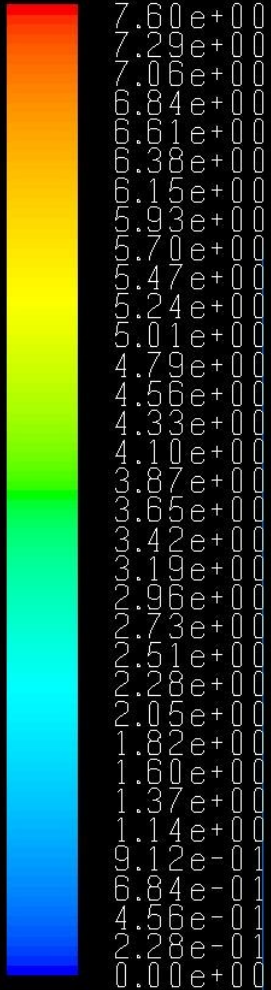
azimuth: -1.06  
elevation: 73.07  
v\_reel\_out: 0.03  
l\_tether : 150.67  
force [N] : 1439.55



# Dynamic modelling challenges

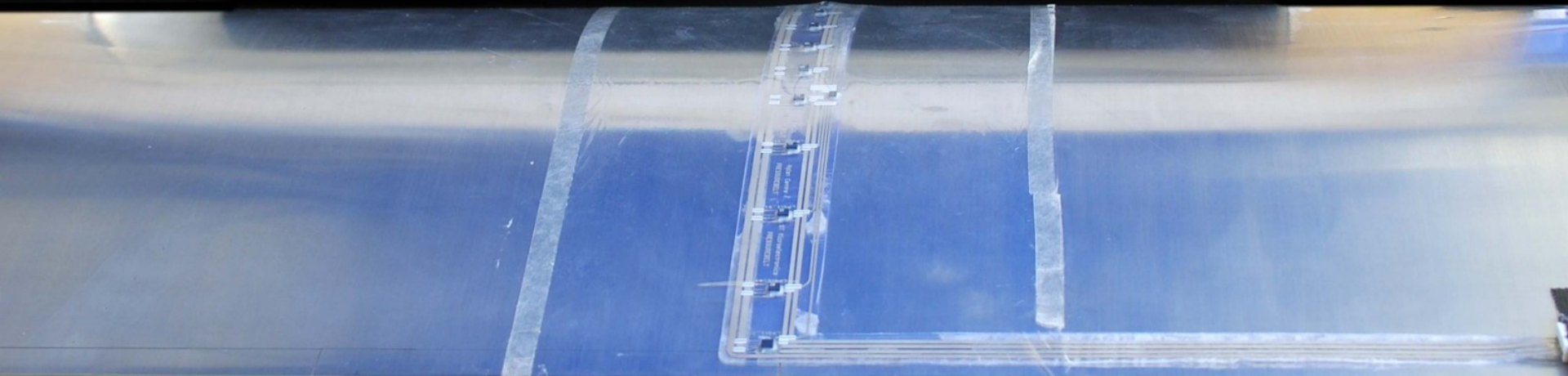






# Insitu Measurements

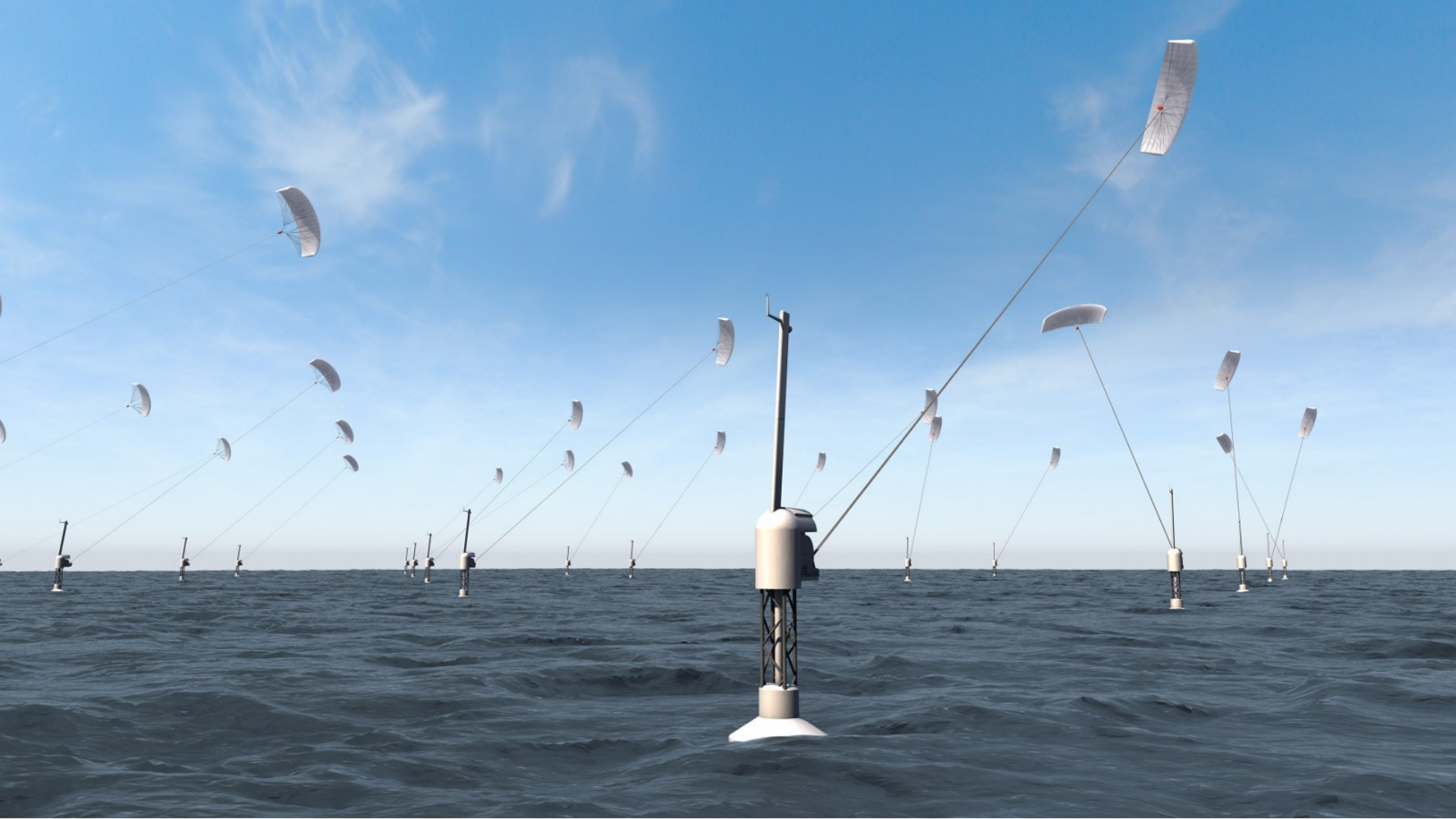
Flexible strip for measuring aerodynamic load distribution during flight operation



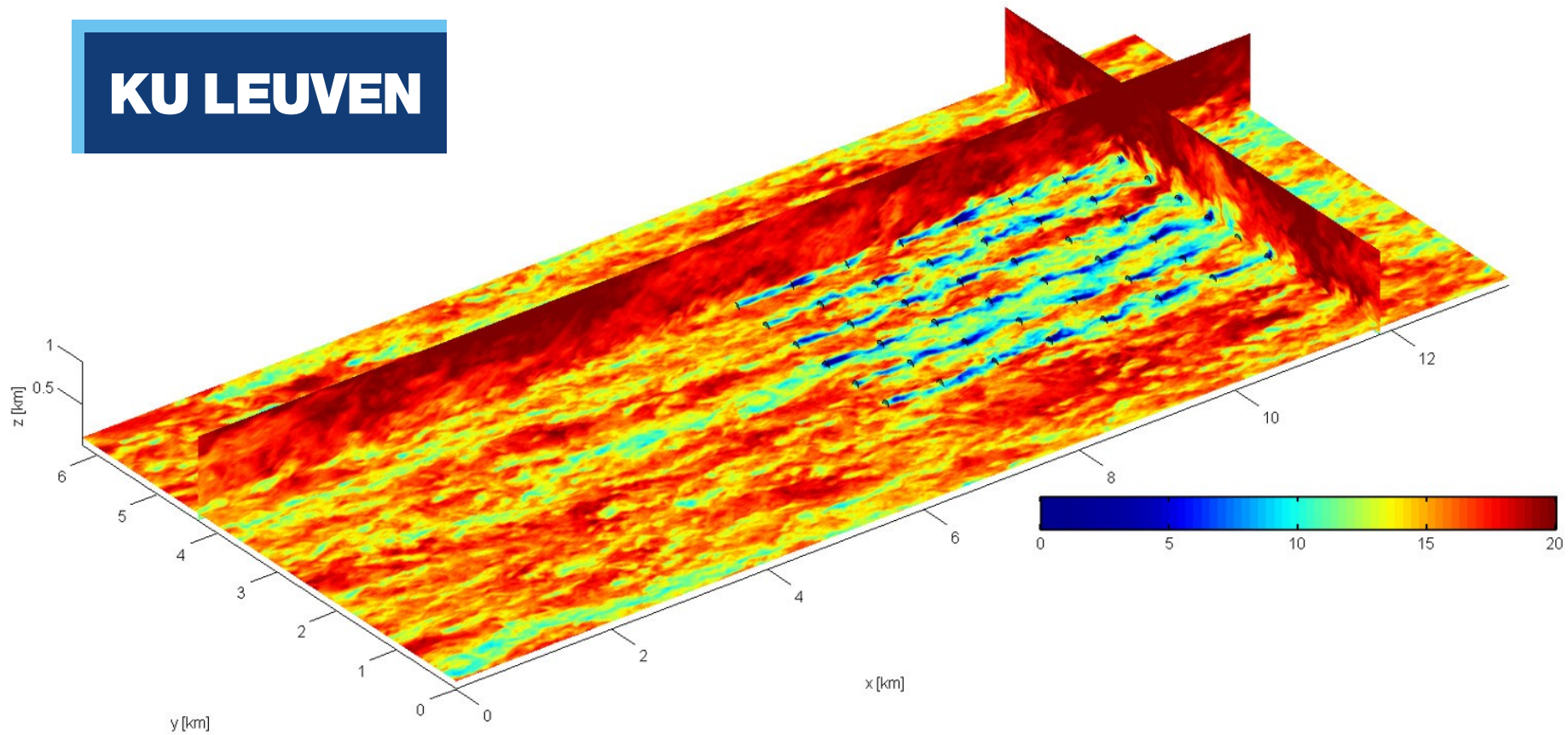


**SkySails**





**KU LEUVEN**



# Conclusions

- Modelling and simulation is indispensable for efficient development of large-scale AWE systems
- Additional DoFs and complexity of operation represents extra challenges for physical model development
- Modelling and simulation approaches need to be tailored to application case and problem to be solved!