Airborne Wind Energy

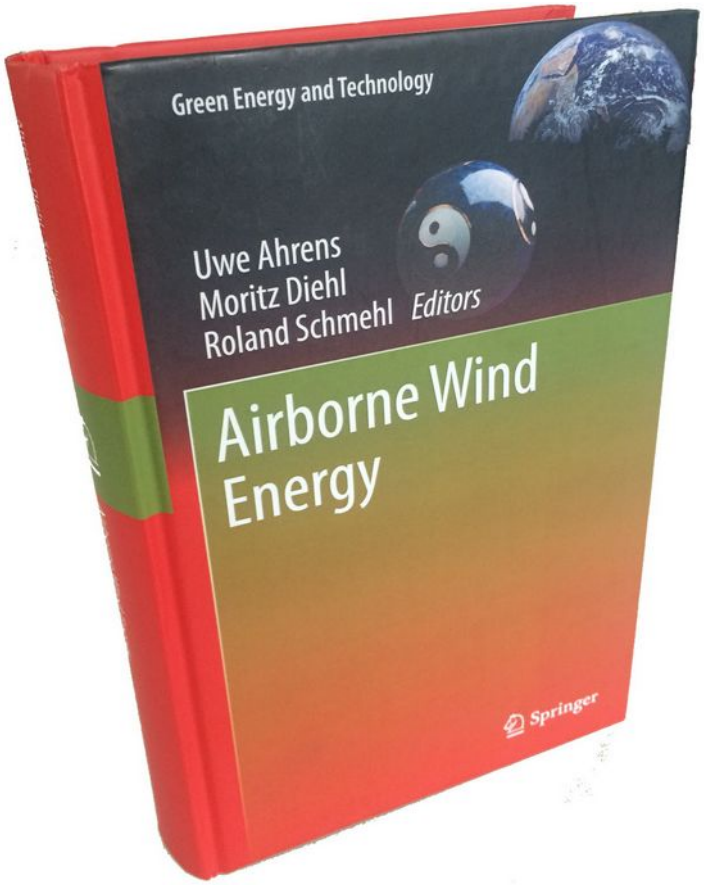
PowerWeb webinar lecture

Roland Schmehl

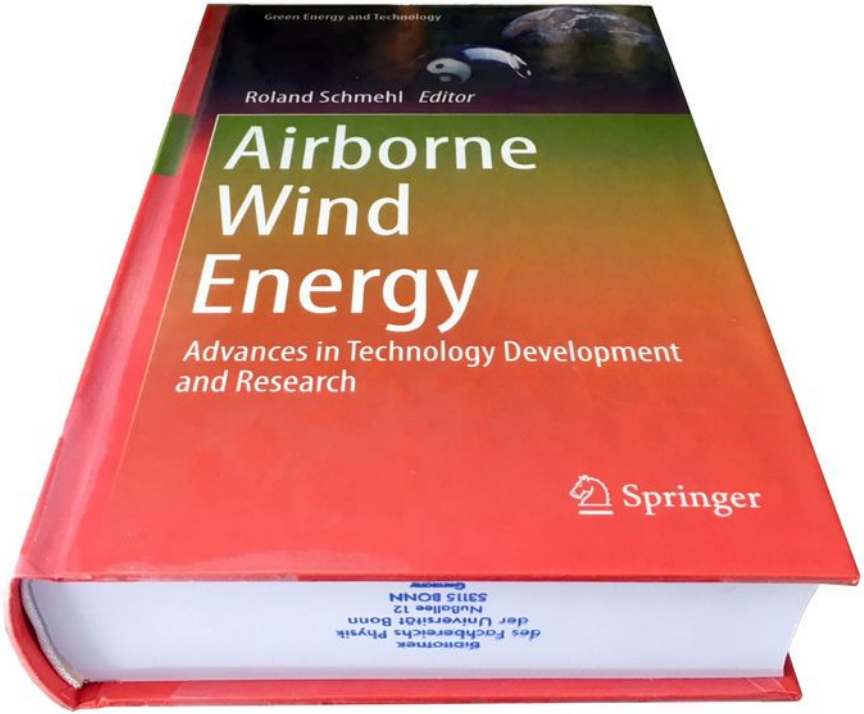
TU Delft

Presenter

- Associate Professor at Delft University of Technology
- Co-founder of Kitepower BV
- Coordinator of 2 H2020 projects (AWESCO & REACH)
- AWE-responsible PI in Dutch NWO project NEON
- Co-organizer of AWEC 2015, 2017 and 2019
- Co-editor and editor of 2 Springer textbooks on AWE


Green Energy and Technology
Uwe Ahrens
Moritz Diehl
Roland Schmehl Editors
Airborne Wind Energy
Springer

2013


Green Energy and Technology
Roland Schmehl Editor
Airborne Wind Energy
Advances in Technology Development and Research
Springer

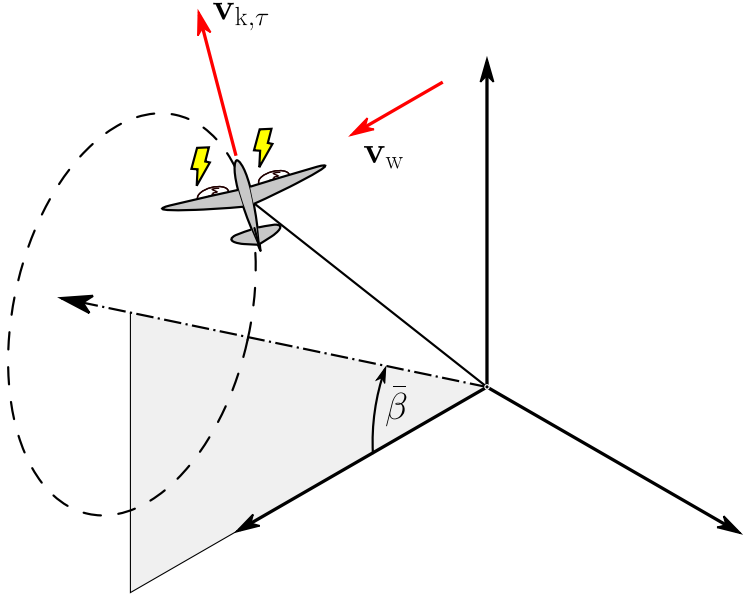
2018

Outline

- Fundamental working principles
- Classification of concepts
- Implemented technology demonstrators
- Development challenges
- Research challenges
- Development of the sector

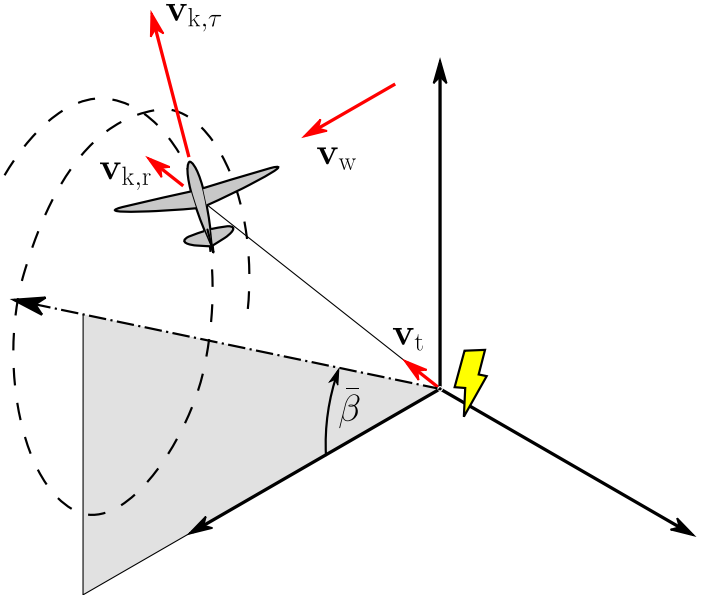
Fundamental concepts

Miles L. Loyd (1980)



Drag power:

- Flying wing ⇝ shaft power
- Shaft power ⇝ electricity (ω ↑)
- Electricity ⇝ conductive tether



Lift power:

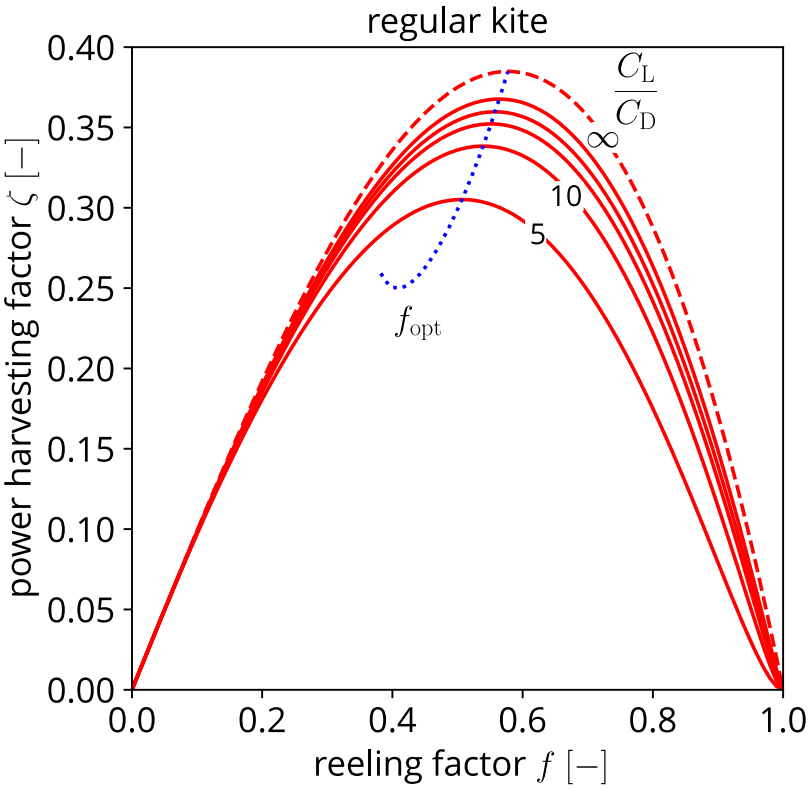
- Flying wing ⇝ traction force
- Traction force ⇝ shaft power (ω ↓)
- Shaft power ⇝ electricity

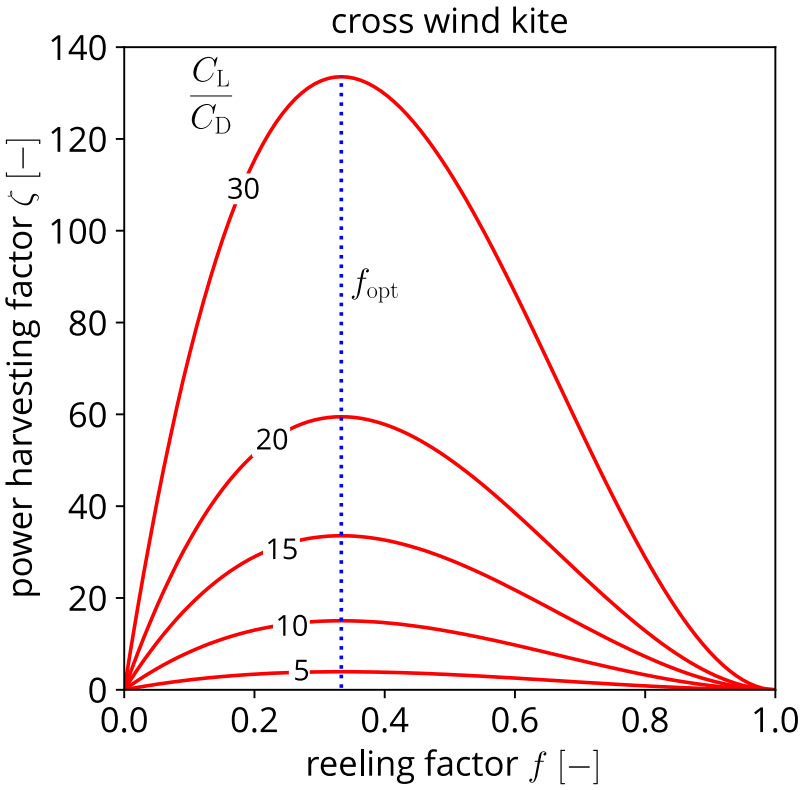
Key aspects

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

Image source: Skysails

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

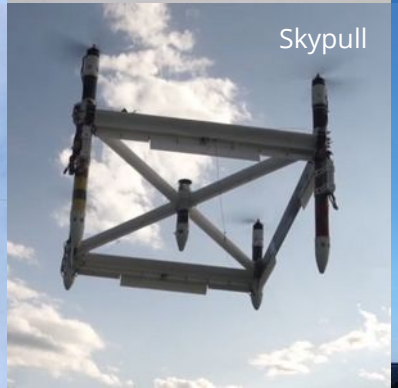




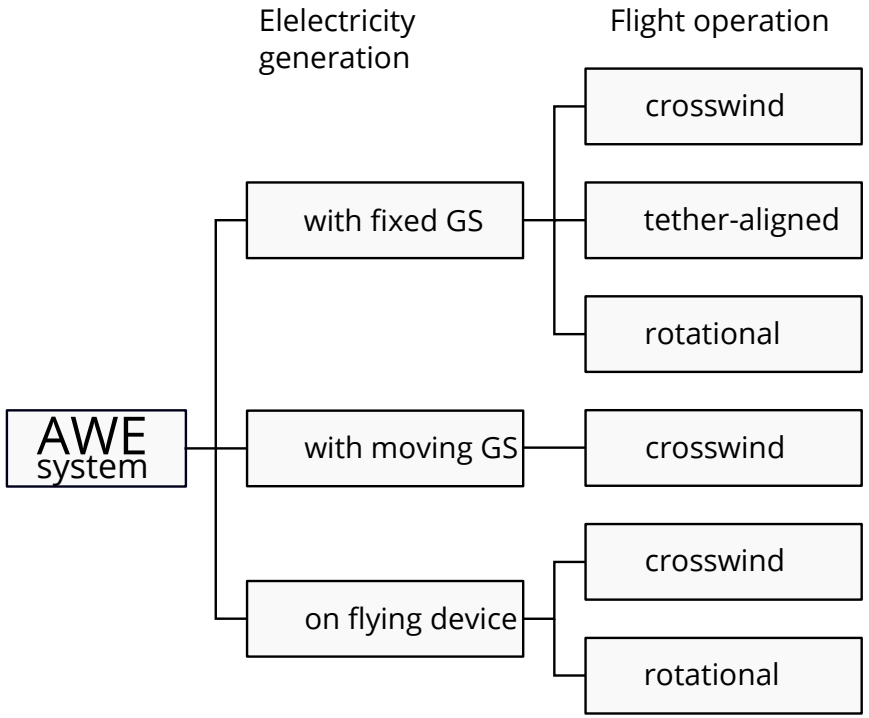
power harvesting factor $\zeta = \frac{P}{P_w S}$, wind power density $P_w = \frac{1}{2}\rho v_w^2$, reeling factor $f = \frac{v_t}{v_w}$,

mechanical power P, wing surface area S

Technology demonstrators



AWES classification

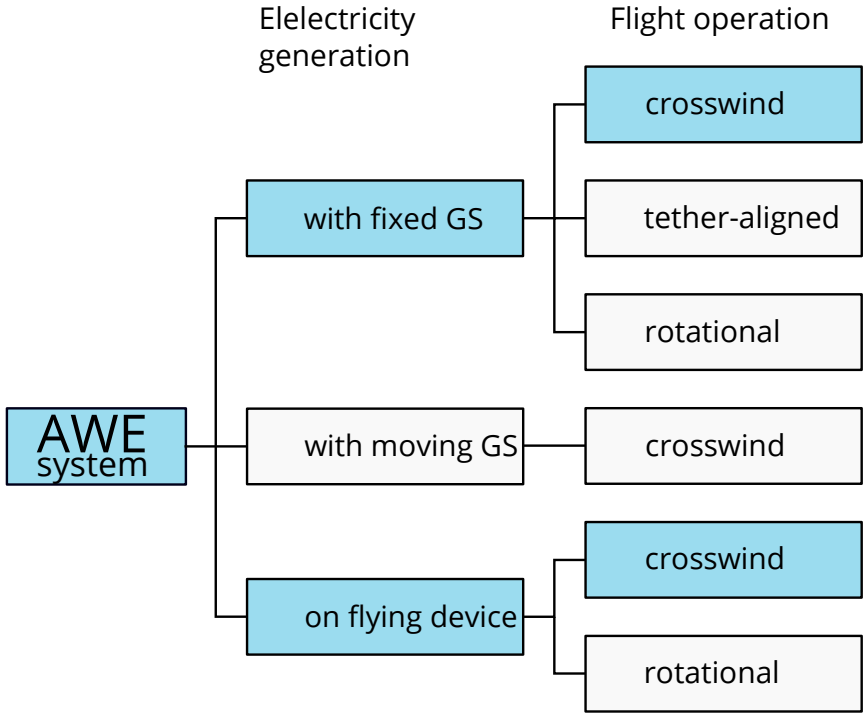


- Kitemill
- Skypull
- TwingTec
- E-Kite
- EnerKíte
- Ampyx
- KPS
- Kiteswarms
- Kitepower
- Kitenergy
- eWind Solutions
- KiteGen stem
- SkySails Power
- Omnidea
- Laddermill
- Guangdong HAWP
- Windswept
- someAWE
- Kitewinder
- X-Wind loop track
- KiteGen carousel
- Makani
- KiteKraft
- Windlift
- KiteX
- Altaeros
- Magenn
- Bladetips
- Brainwhere
- Sky WindPower

- Vertical take-off and landing (VTOL)
- Horizontal take-off and landing (HTOL)
- Multi-drone concepts
- Ligther-than-air concepts
- Flexible wing concepts

Adapted from: Watson et al. “Future emerging technologies in the wind power sector: a European perspective”, Renewable and Sustainable Energy Reviews, 2019.

AWES classification



- Kitemill
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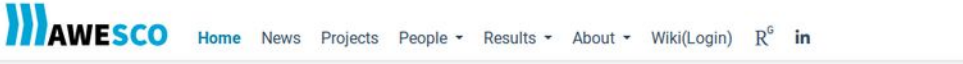
Further reading: awesco.eu/awe-explained



Airborne Wind Energy

An introduction to an emerging technology.

Roland Schmehl

20 Jun 2019

Airborne wind energy (AWE) is the conversion of wind energy into electricity using tethered flying devices. Some concepts combine onboard wind turbines with a conducting tether, while others convert the pulling power of the flying devices on the ground. Replacing the tower of conventional wind turbines by a lightweight tether substantially reduces the material consumption and allows for continuous adjustment of the harvesting altitude to the available wind resource. The decrease in installation cost and increase in capacity factor can potentially lead to a substantial reduction of the cost of wind energy. Wind at higher altitudes is also considered to be an energy resource that has not been exploited so far.

Table of Contents

Technology demonstrators

- Makani
- Ampyx
- Twingtec
- Kitepower

Wing7 (30 kW)

MAKANI

California 2013

M600 (600 kW)

MAKANI

California 2017


MAKANI
Norway 2019

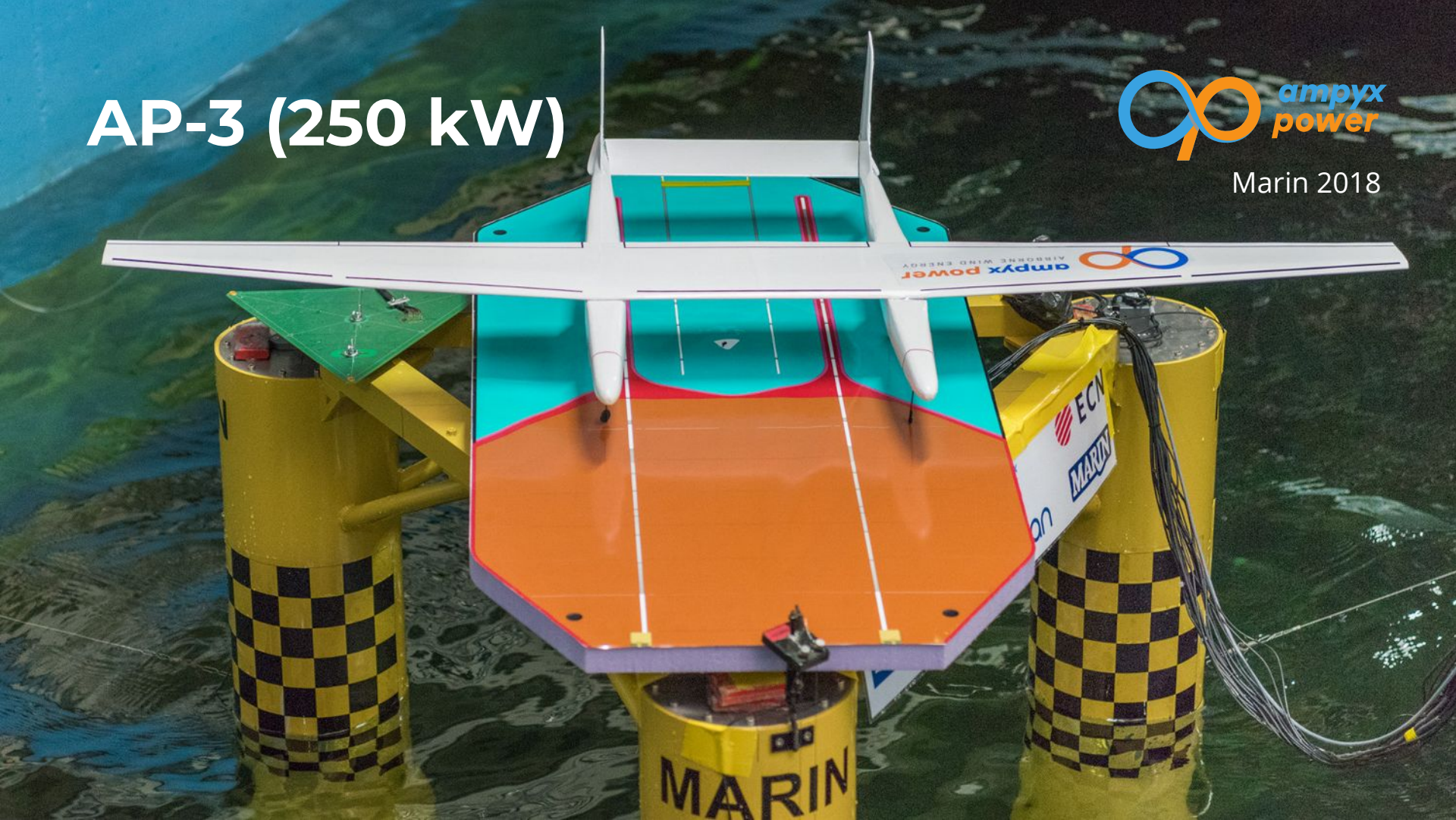
AP-2 (50 kW)

Noordoostpolder 2013

AP-3 (250 kW)

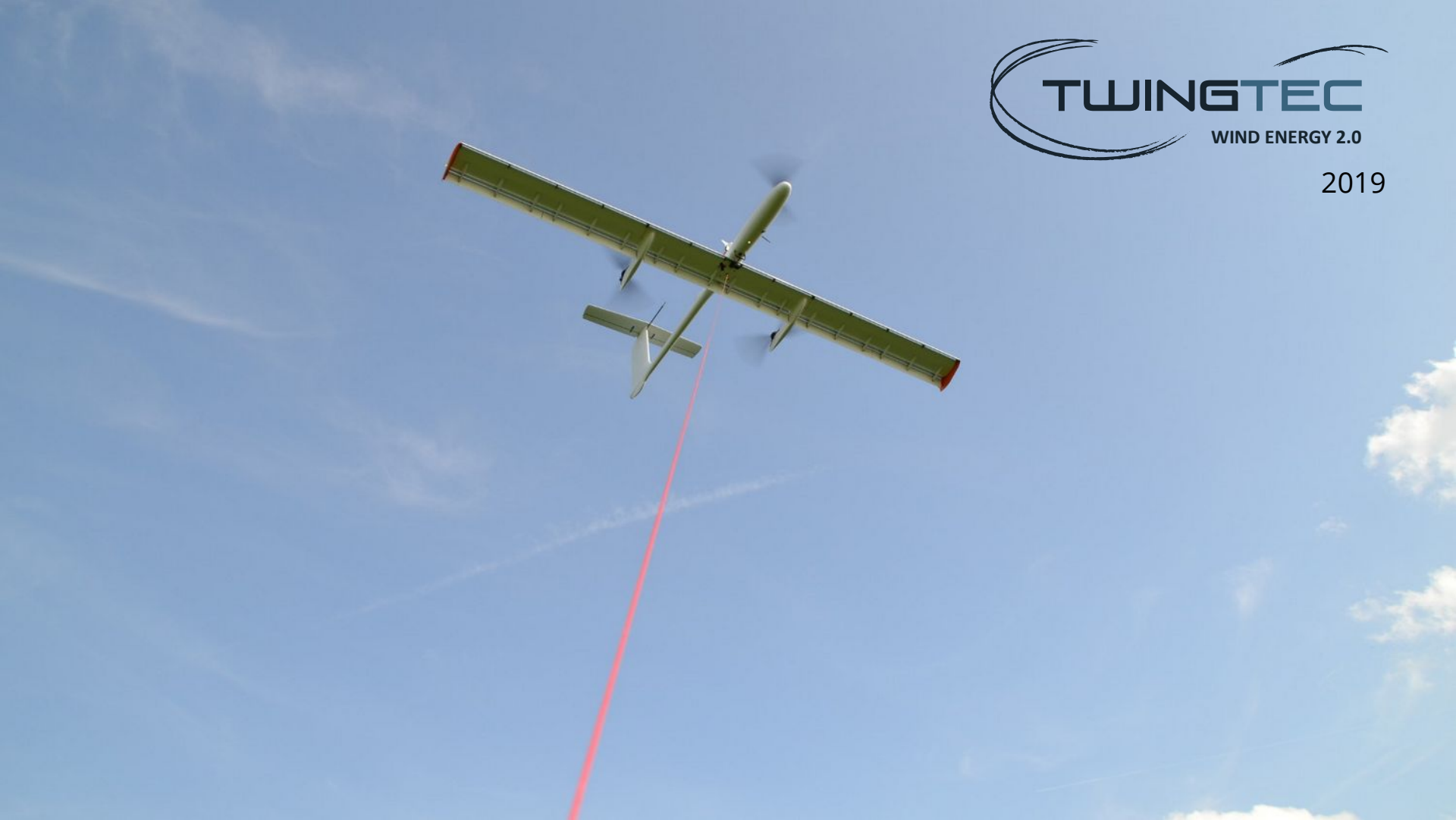
ampyx power

Marin 2018




Ampyx Power


SCHILLING


TWINGTEC
WIND ENERGY 2.0
2019

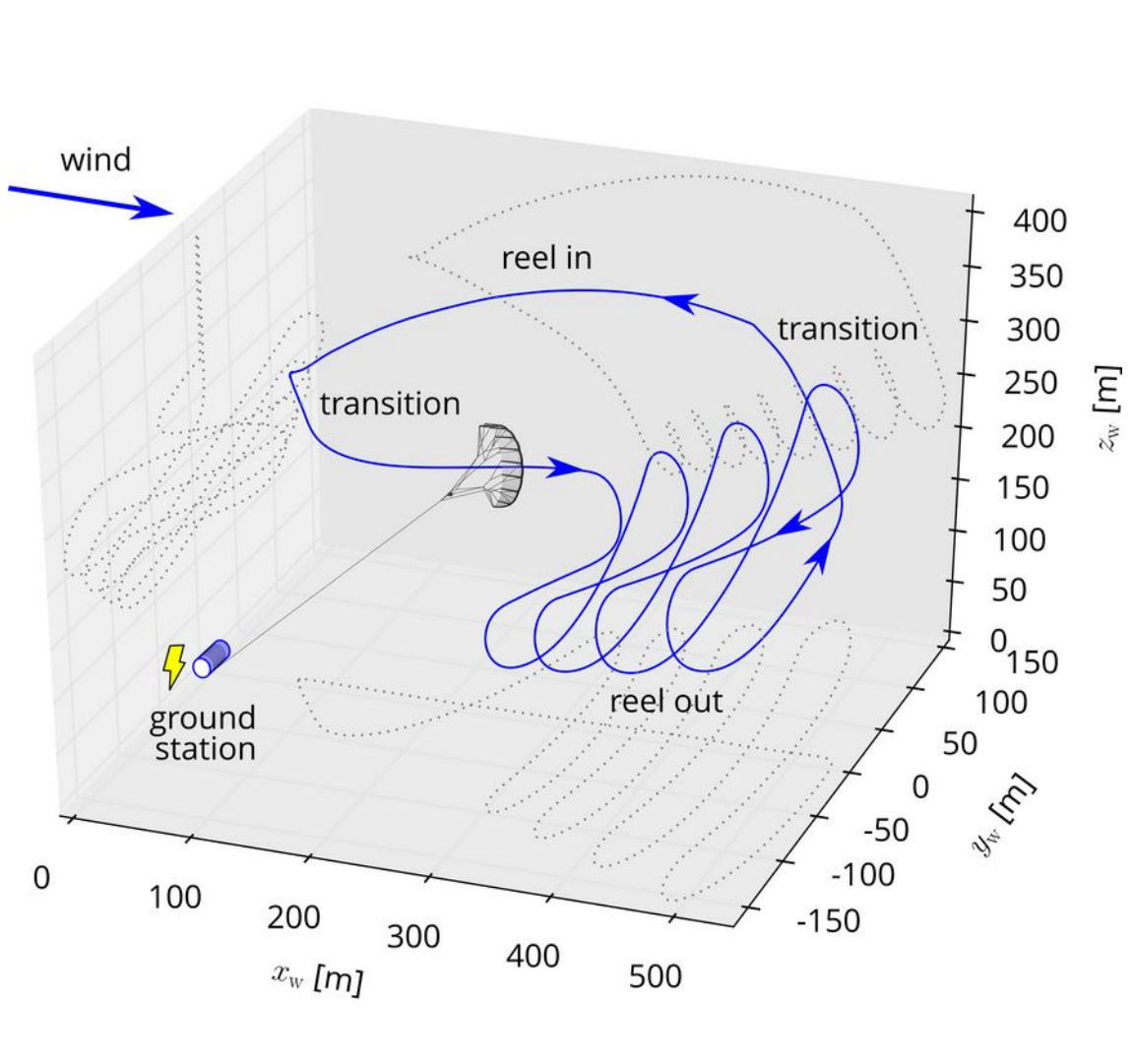

TWINGTEC

TwingTec pilot next to turbine with same power

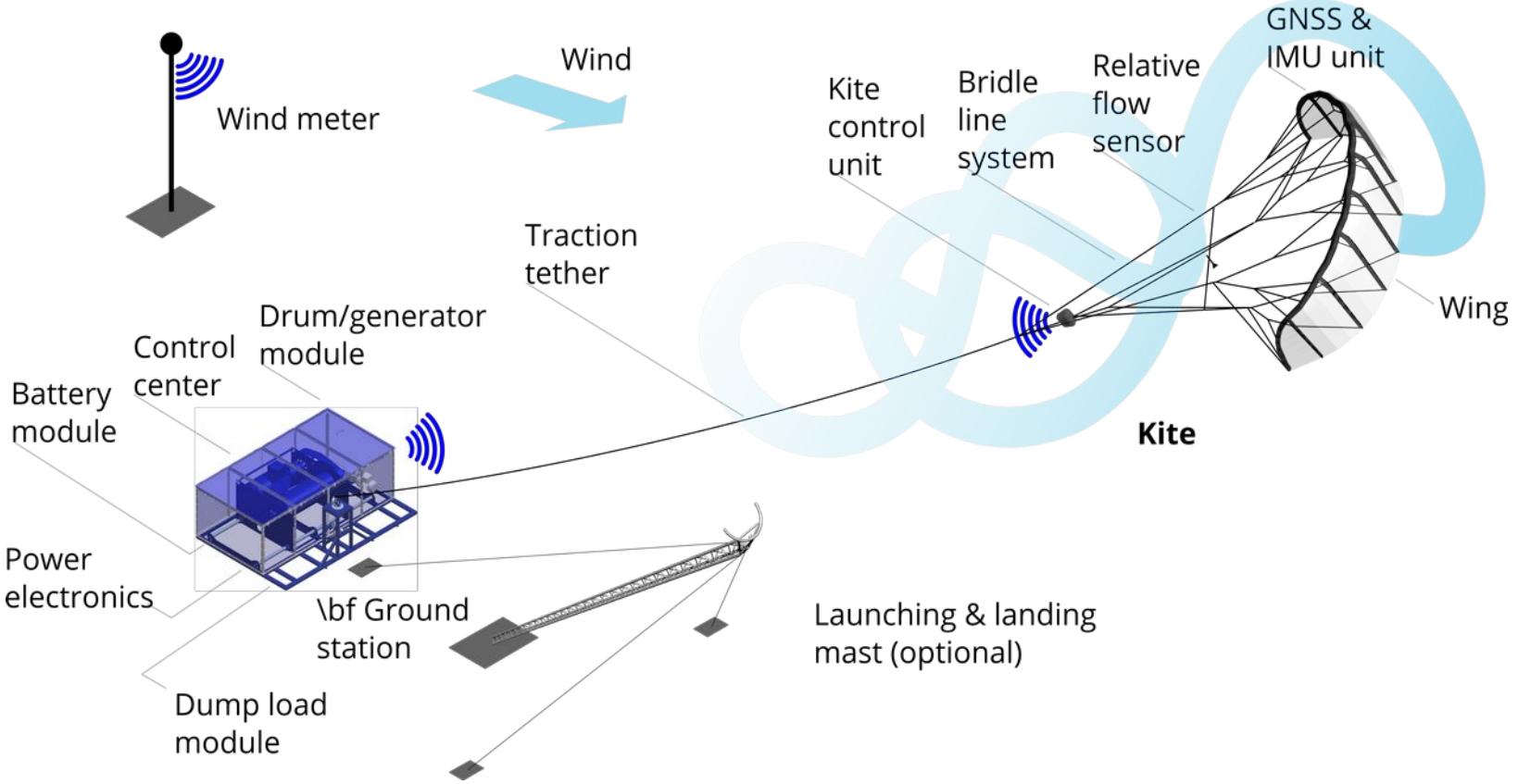
25 kW kite power system

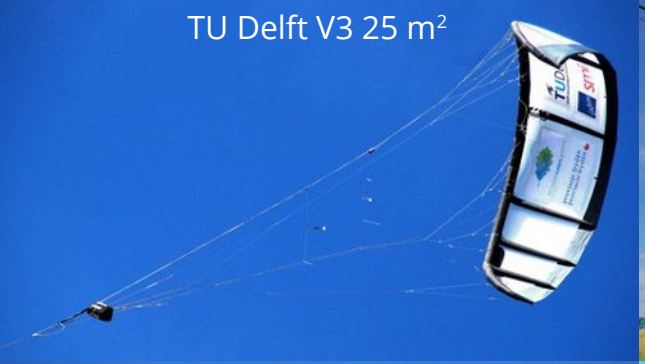
TU Delft

2012


wind
reel in
transition
transition
reel out
ground
station
0
100
200
300
400
500
x_w [m]
400
350
300
250
200
150
100
50
0
z_w [m]
150
100
50
0
-50
-100
-150
y_w [m]

System components

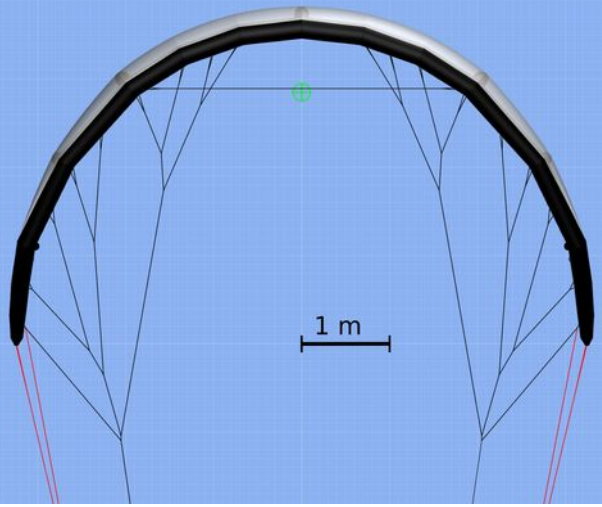


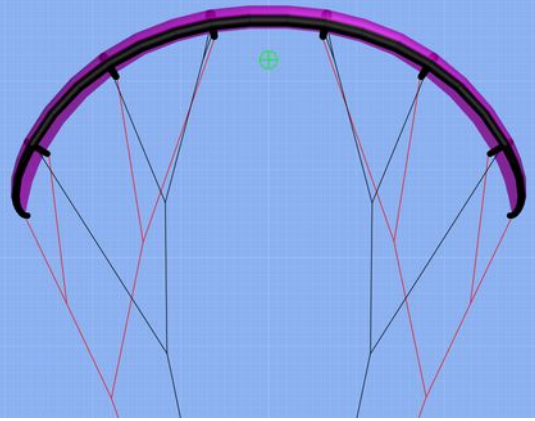

TU Delft V3 25 m²

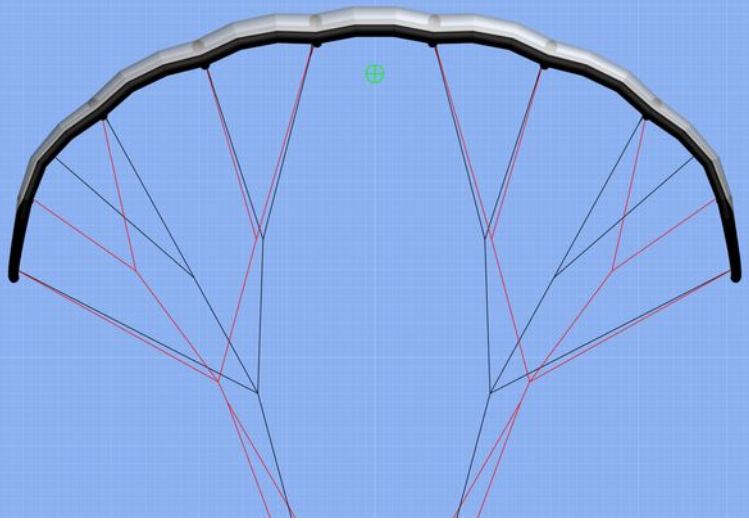

Genetrix Hydra 14 m²


TU Delft V3 25 m²

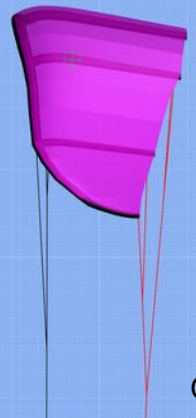

TUDelft
provincie fryslân



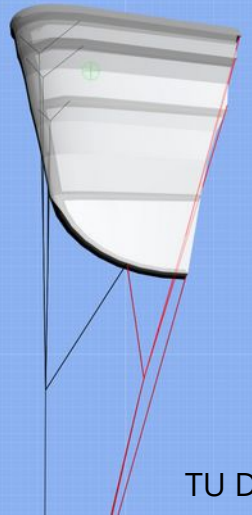




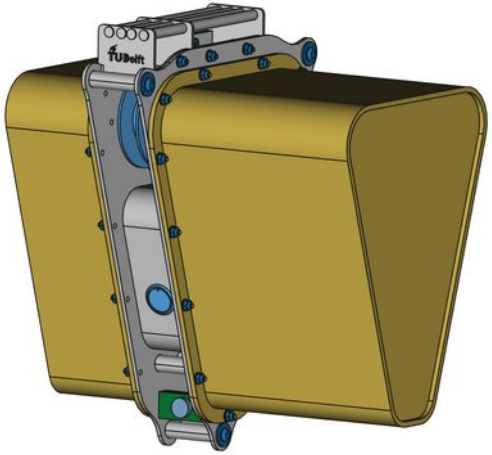
TU Delft V3 25 m²

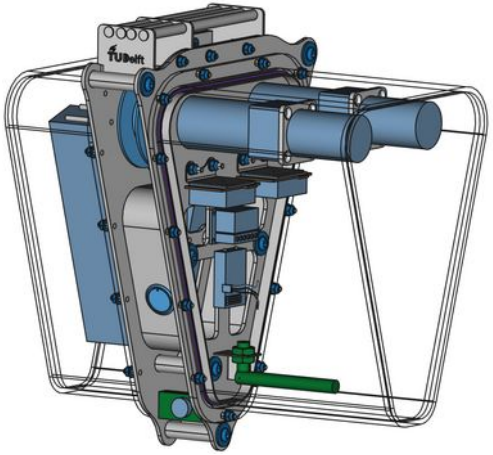


Genetrix Hydra 14 m²



TU Delft V3 25 m²


TUDelft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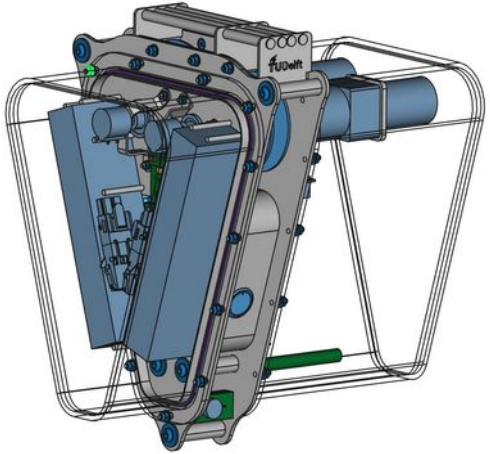
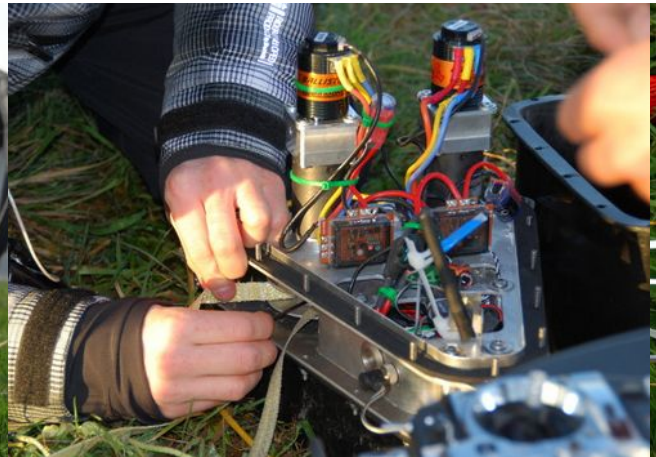
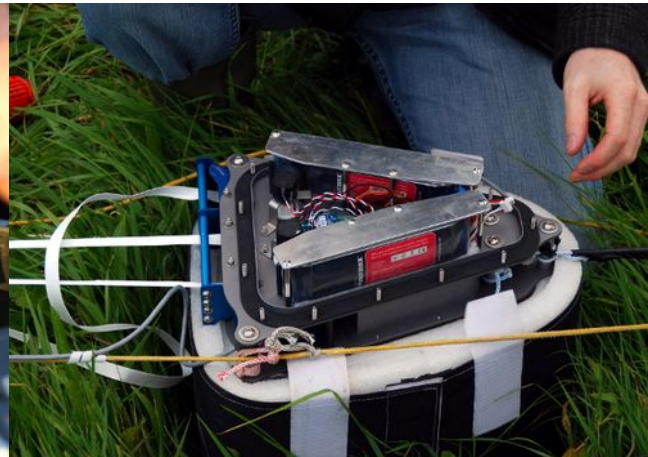
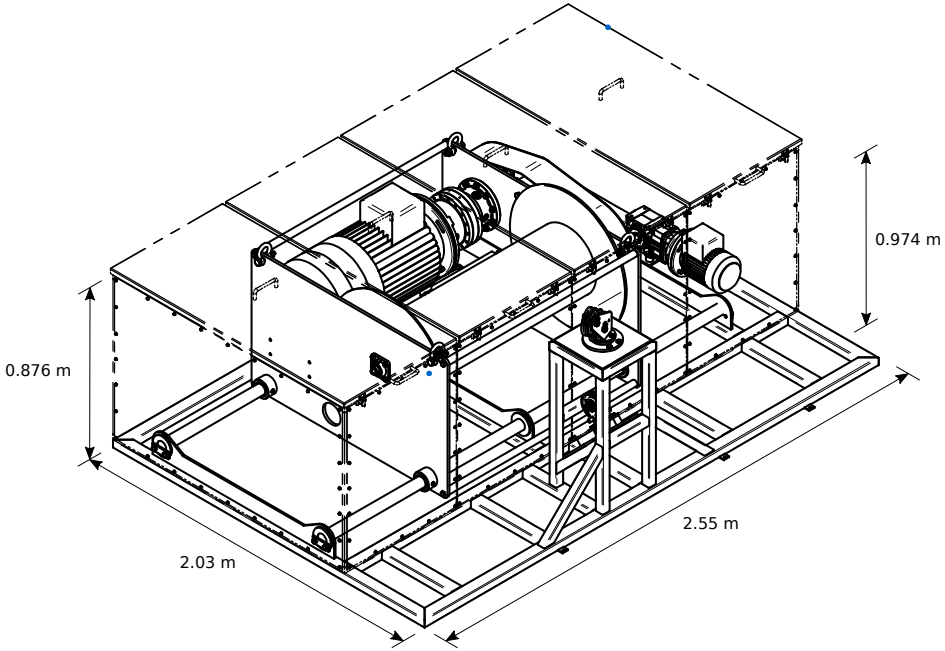
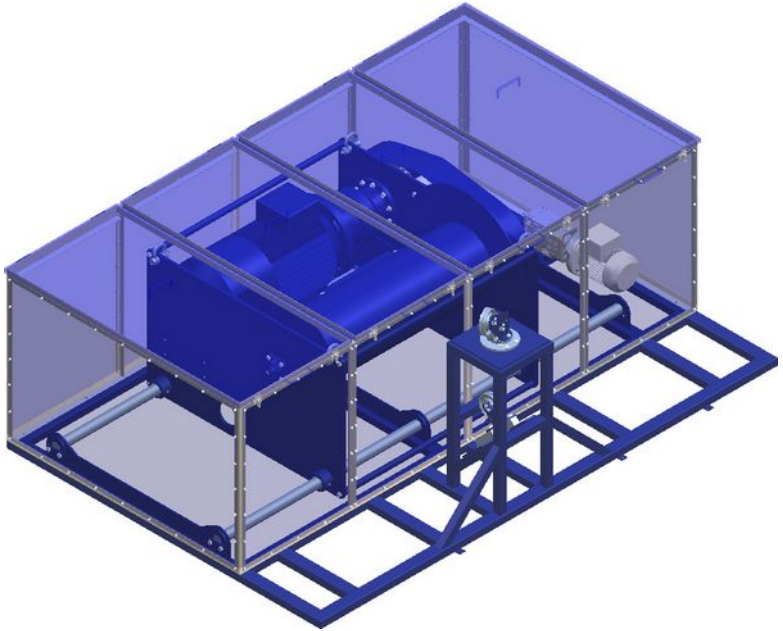

TUDelft

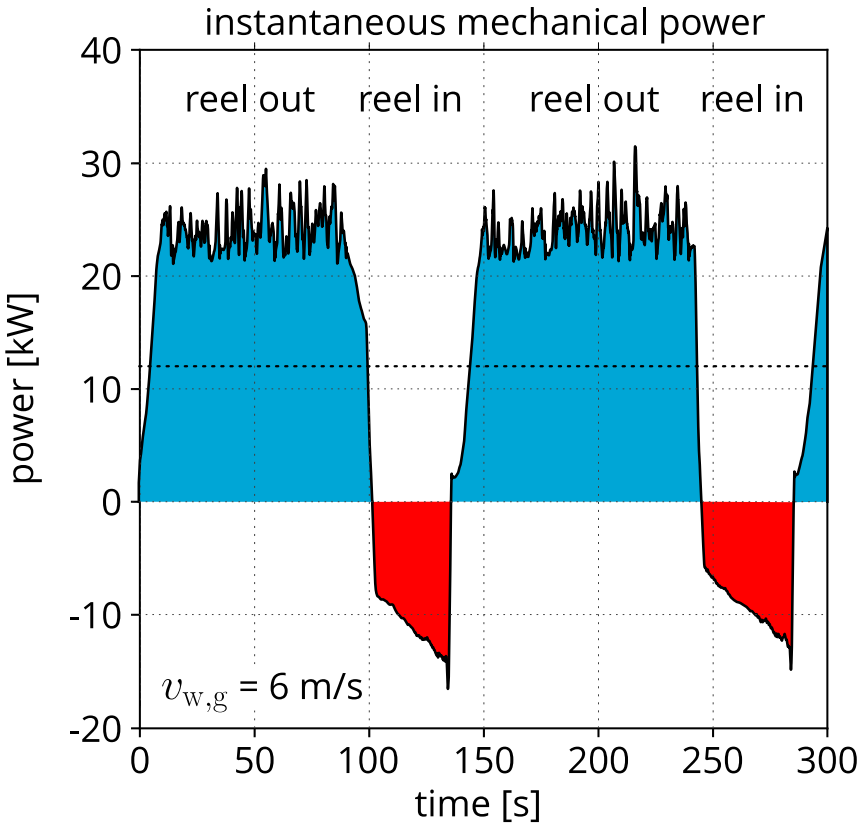

TUDelft

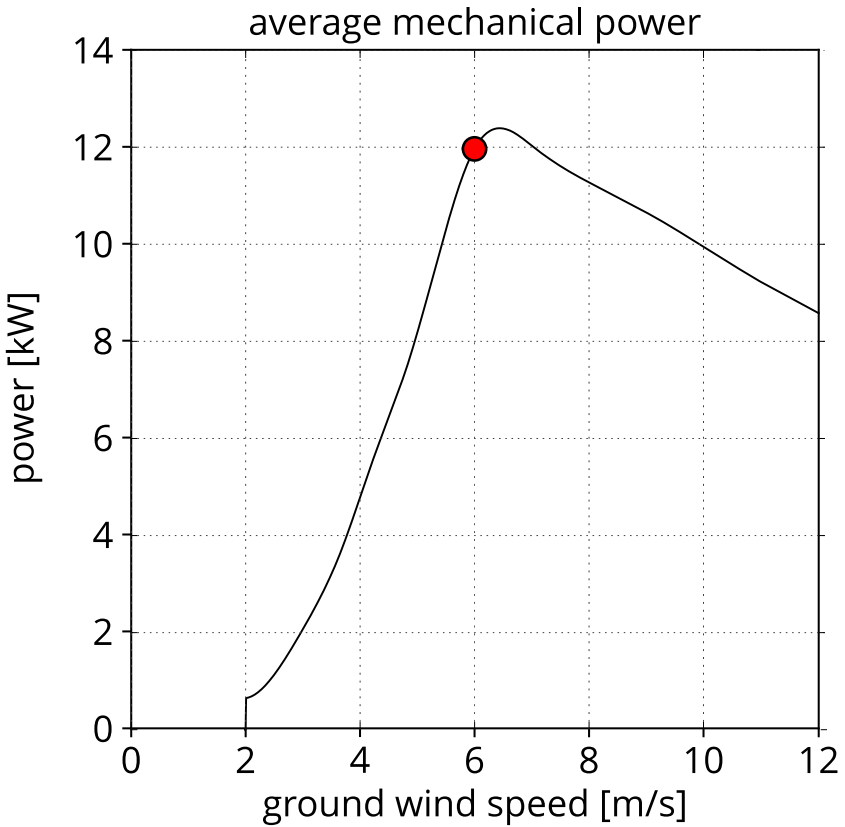





0.974 m
0.876 m
2.03 m
2.55 m




instantaneous mechanical power
reel out
reel in
reel out
reel in
power [kW]
time [s]
$v_{W,g}$ = 6 m/s
40
30
20
10
0
-10
-20
0
50
100
150
200
250
300


average mechanical power
power [kW]
ground wind speed [m/s]
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12

TU Delft

2012

Automatic pumping cycles at Maasvlakte II of Rotterdam Harbor

Launch from upside-down position

- The following three videos show the same launch attempt on 2 August 2012
- The videos are taken from three different positions
  - GoPro video camera on the ground next to mast
  - GoPro video camera taped to the leading edge
  - Photo camera on the ground
- Weak link ruptures as result of sudden tether disengagement from mast head

40 m² kite

airborne wind energy
KITEPOWER
2017

100 kW ground station


airborne wind energy
KITEPOWER


airborne wind energy
KITEPOWER

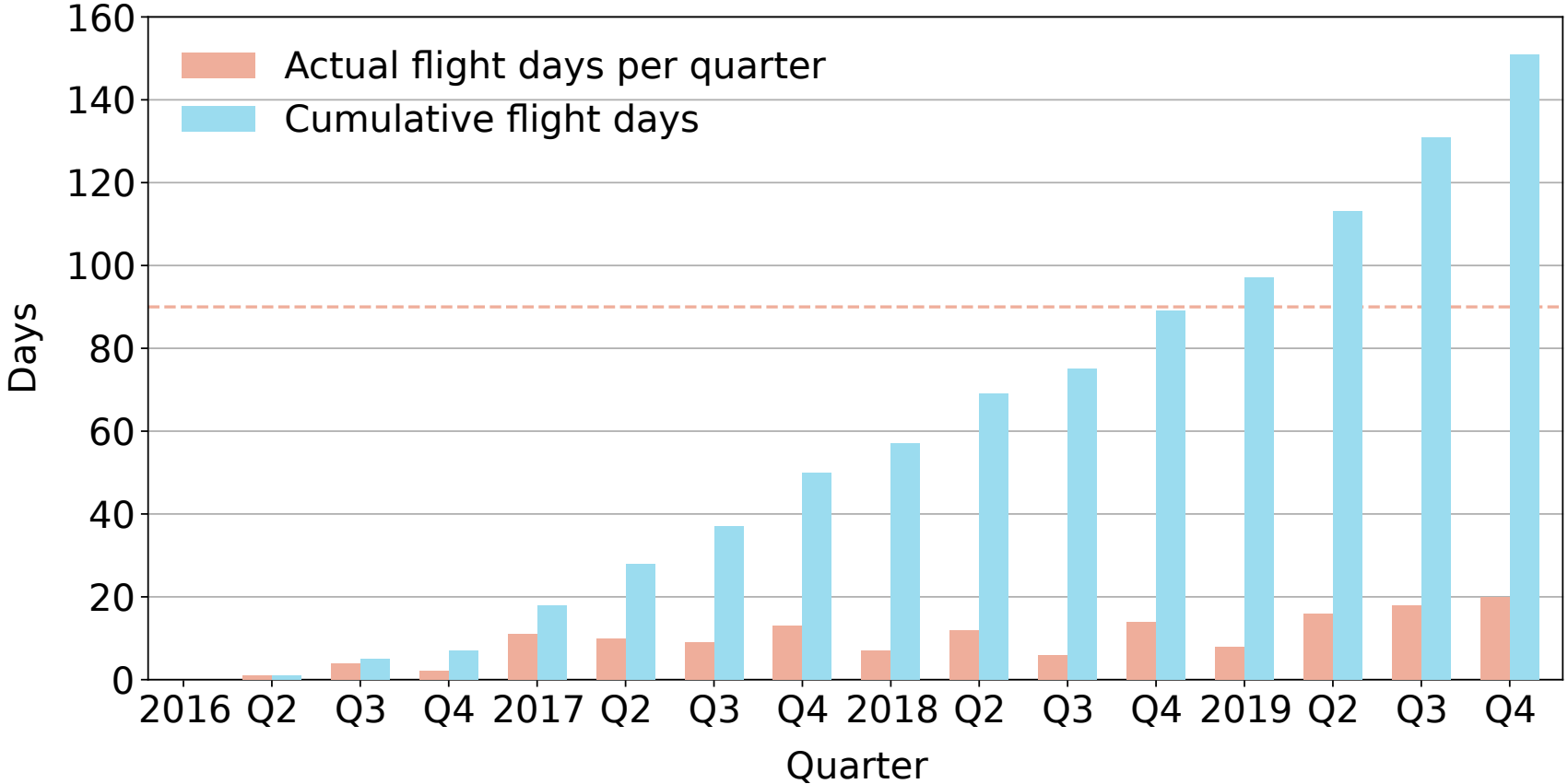

KITEPOWER
TM


KITEPOWER™

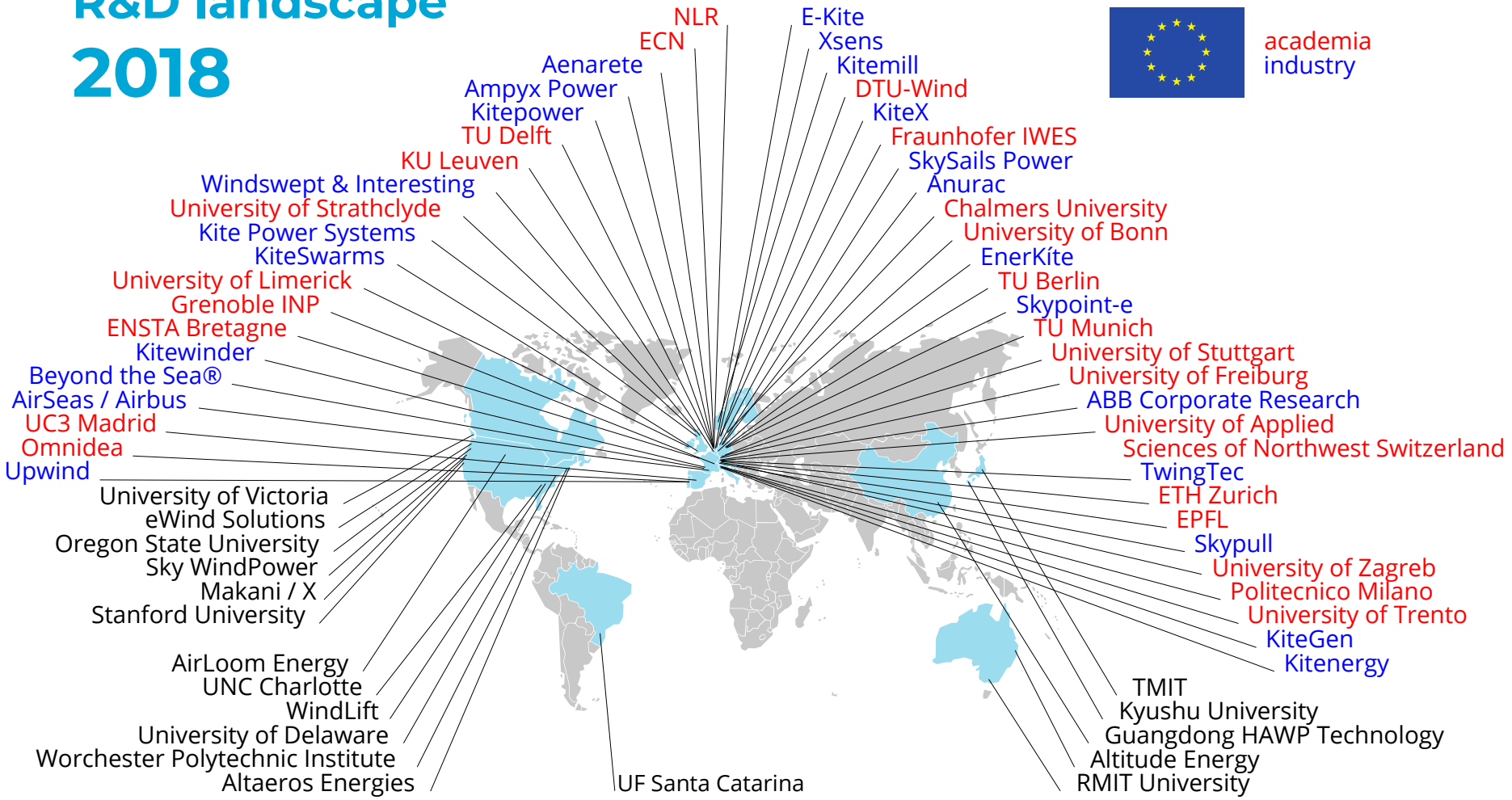
Kite development: 25 – 40 – 60 m²

Kite development: 100 m²

Flight days


Actual flight days per quarter
Cumulative flight days
Days
Quarter
0
20
40
60
80
100
120
140
160
2016 Q2
Q3
Q4
2017 Q2
Q3
Q4
2018 Q2
Q3
Q4
2019 Q2
Q3
Q4

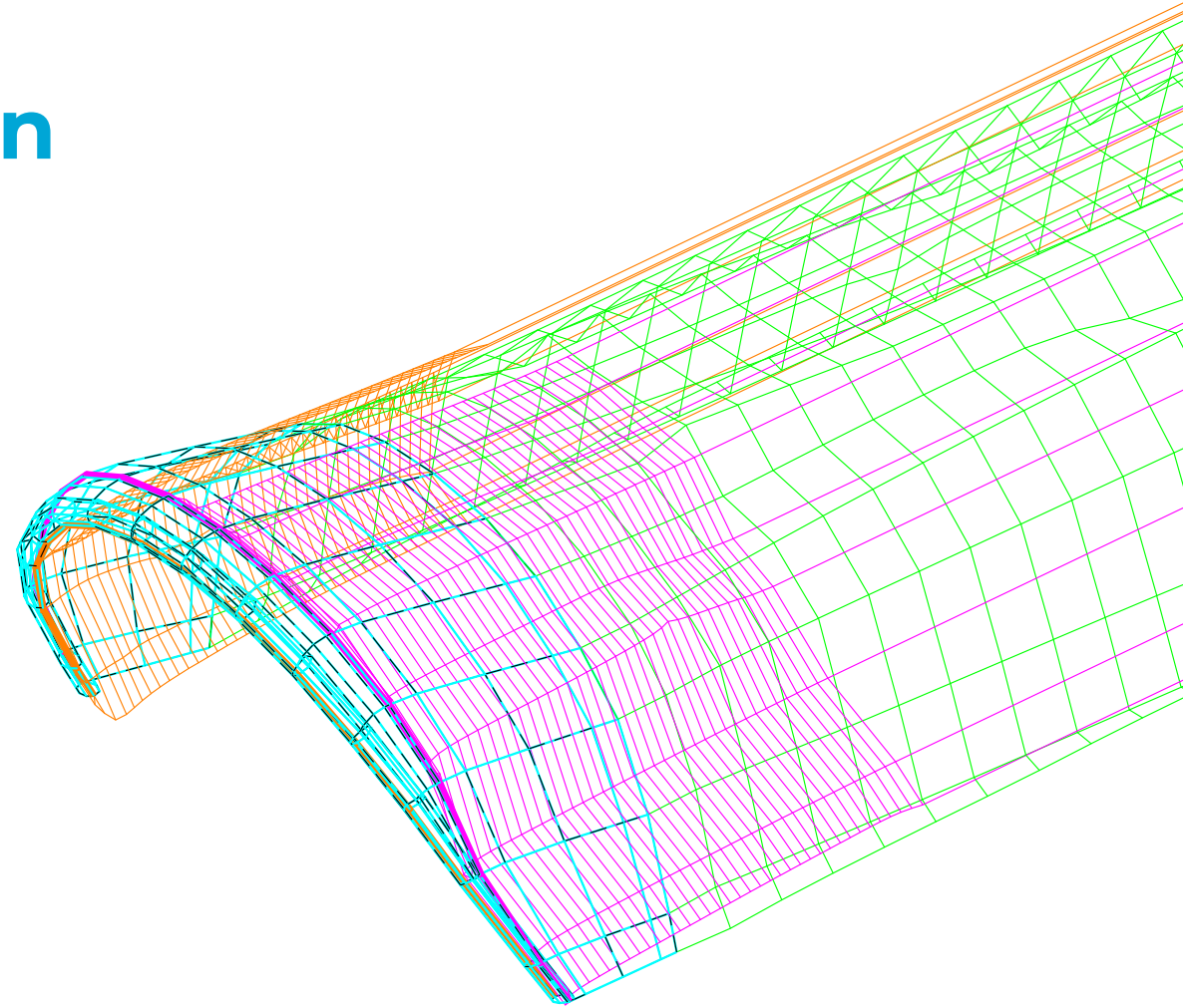
R&D landscape 2018



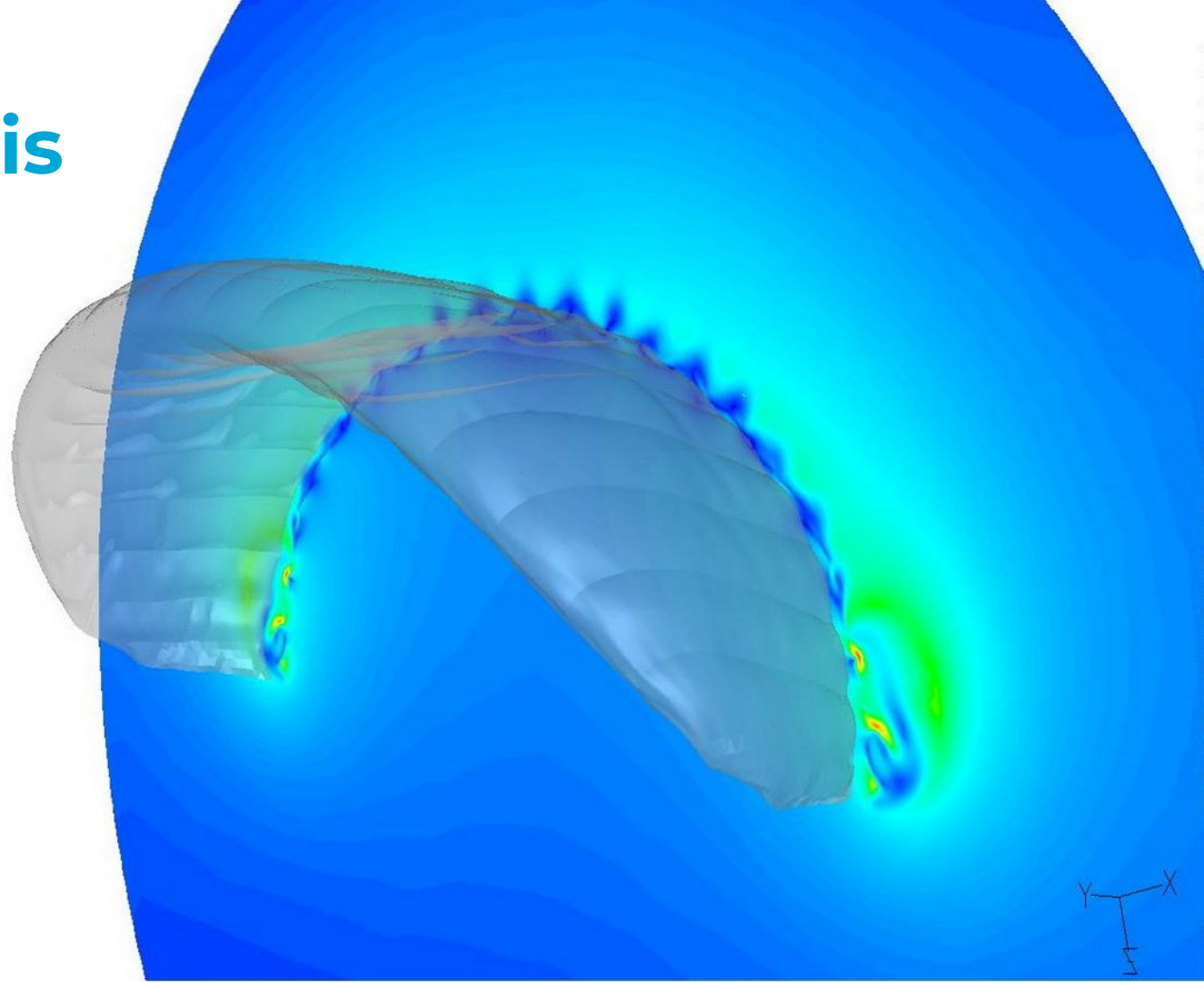
Challenges

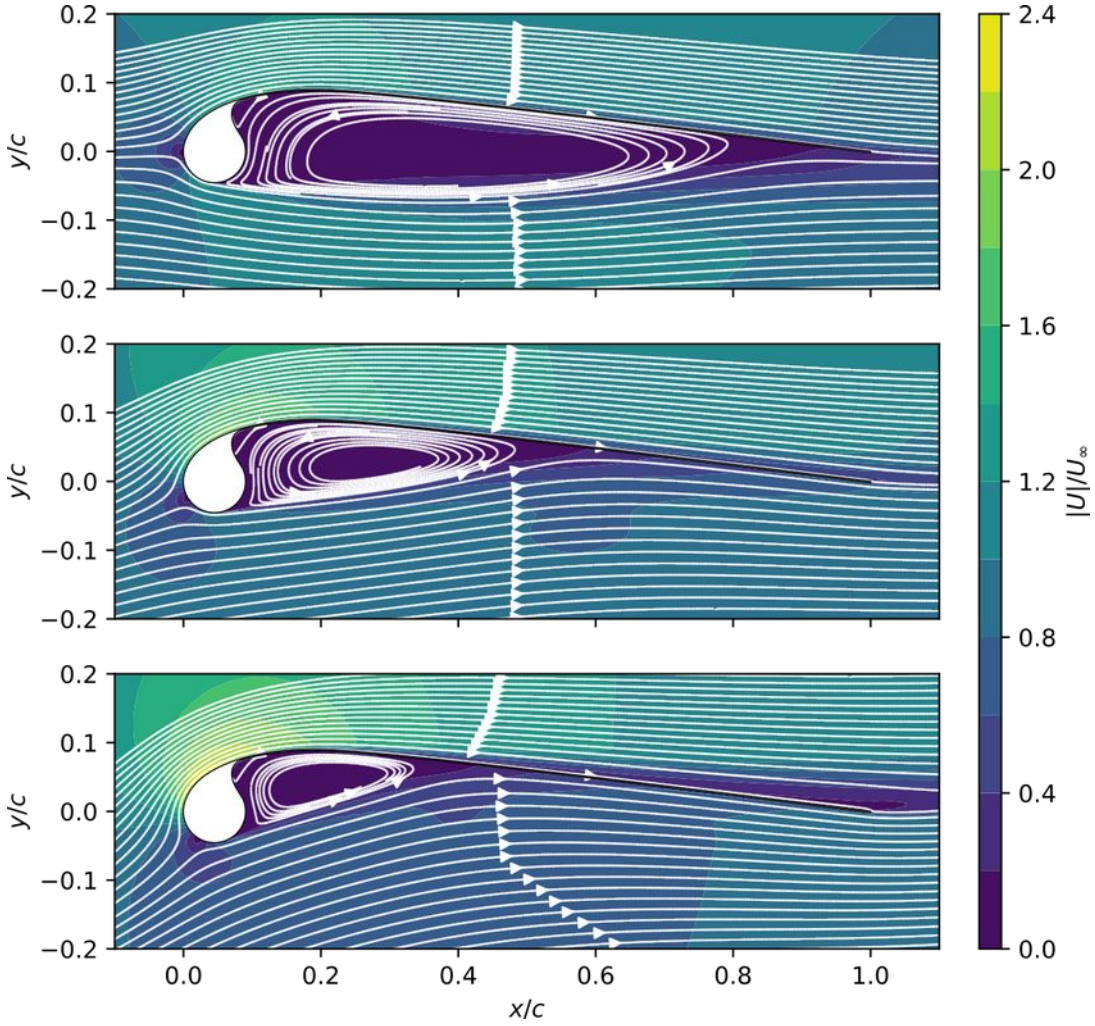
- Reliability & Safety
  - None of the projects has proven more than a few days of operation
  - Operation in kite parks
- Durability of materials
  - Tether and kite are critical components
- Regulations
  - Interference with air traffic and ground use

VLM simulation

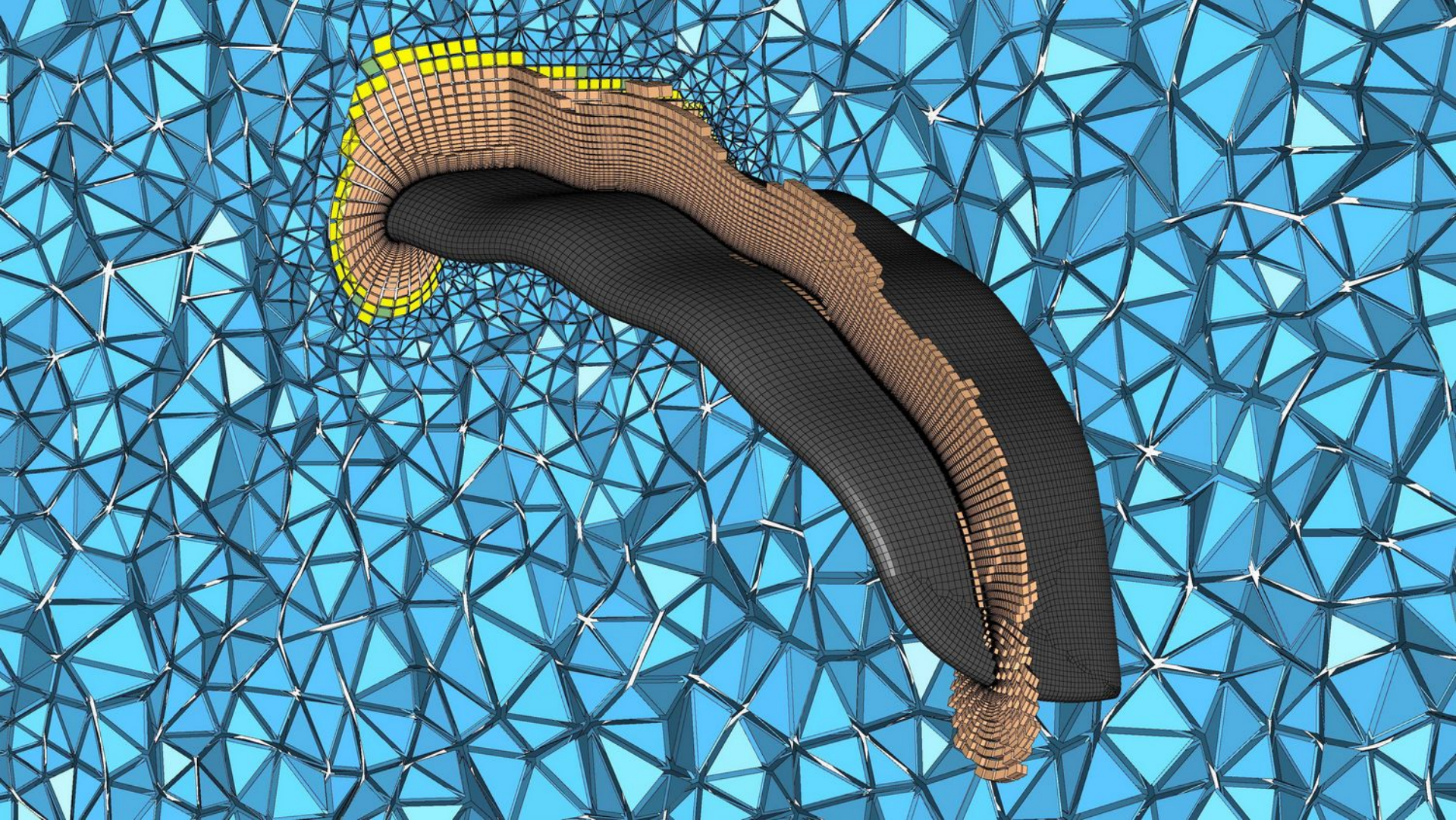


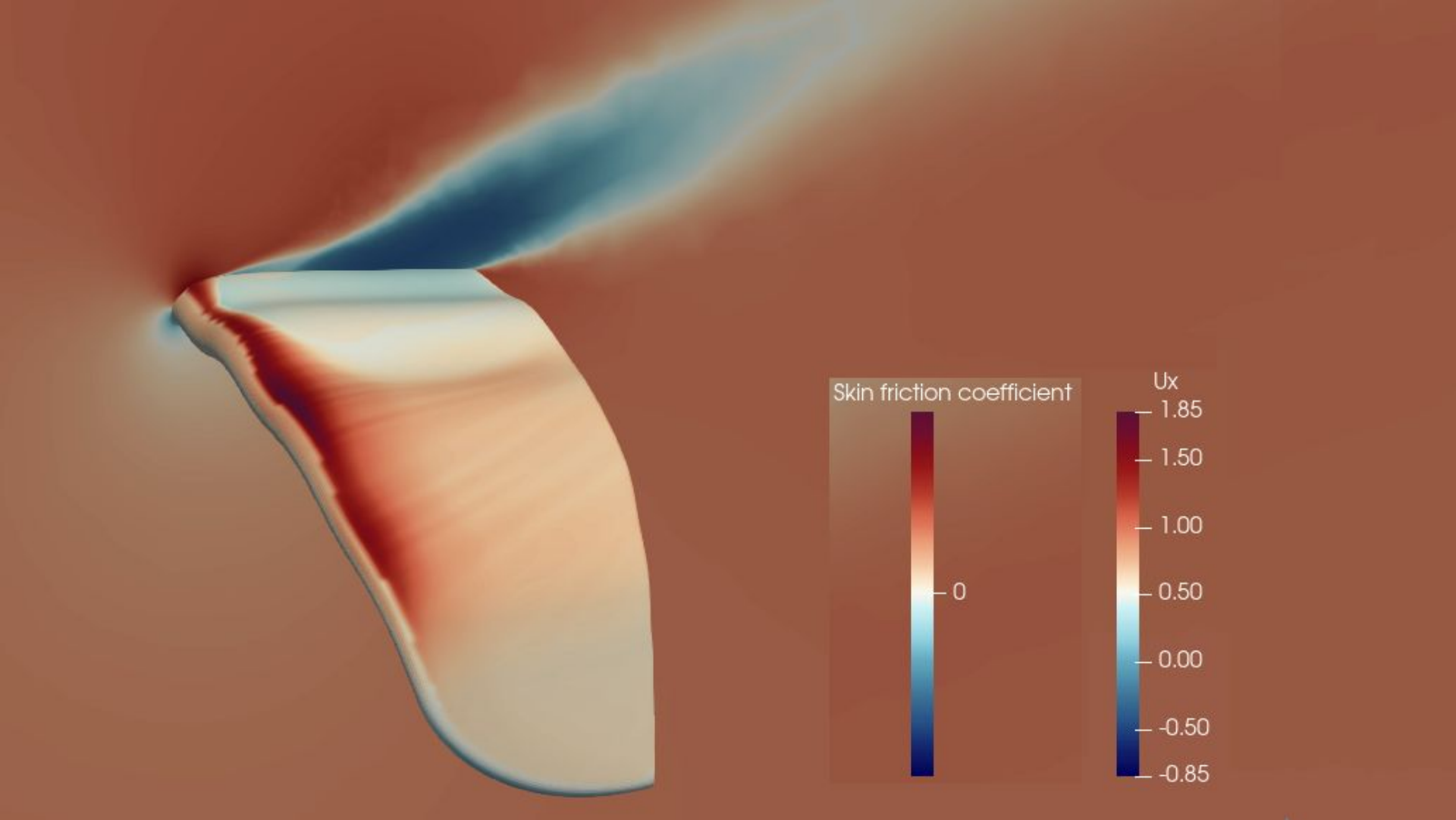
CFD analysis

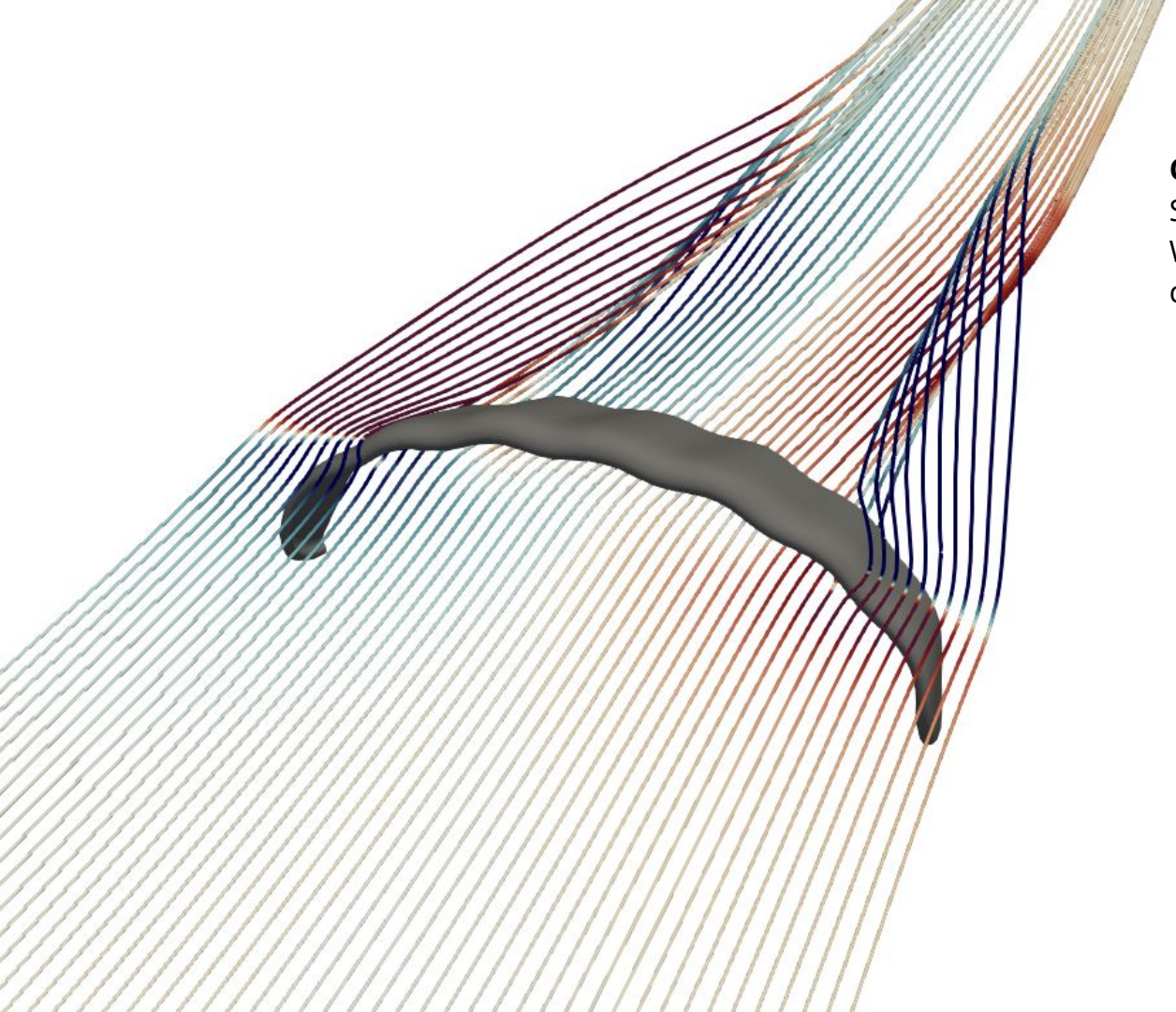




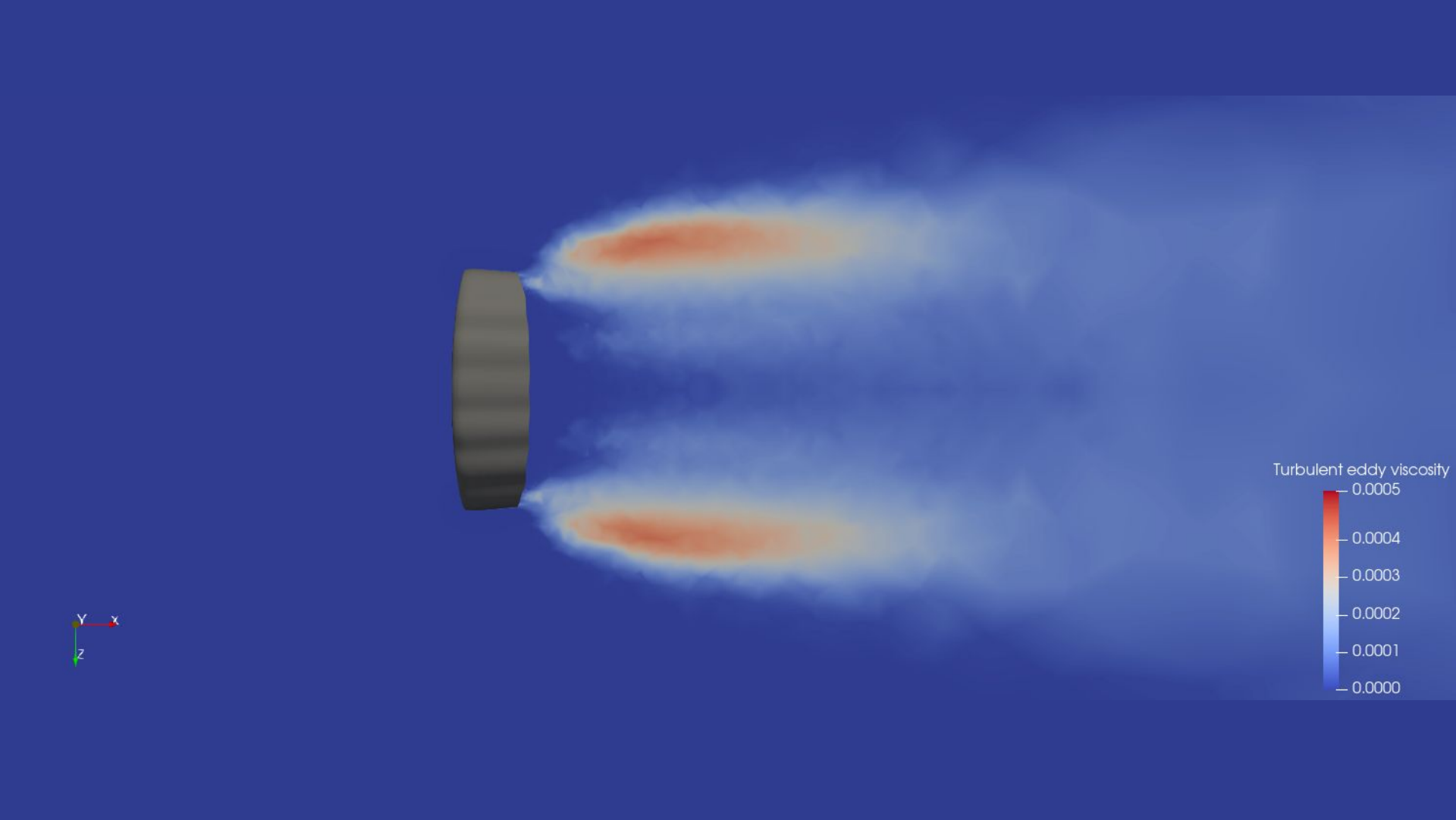
Oehler & Schmehl. "Aerodynamic characterization of a soft kite by in situ flow measurement". Wind Energy Science, 2019

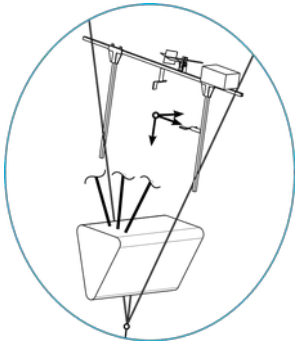



Skin friction coefficient
0
Ux
1.85
1.50
1.00
0.50
0.00
-0.50
-0.85

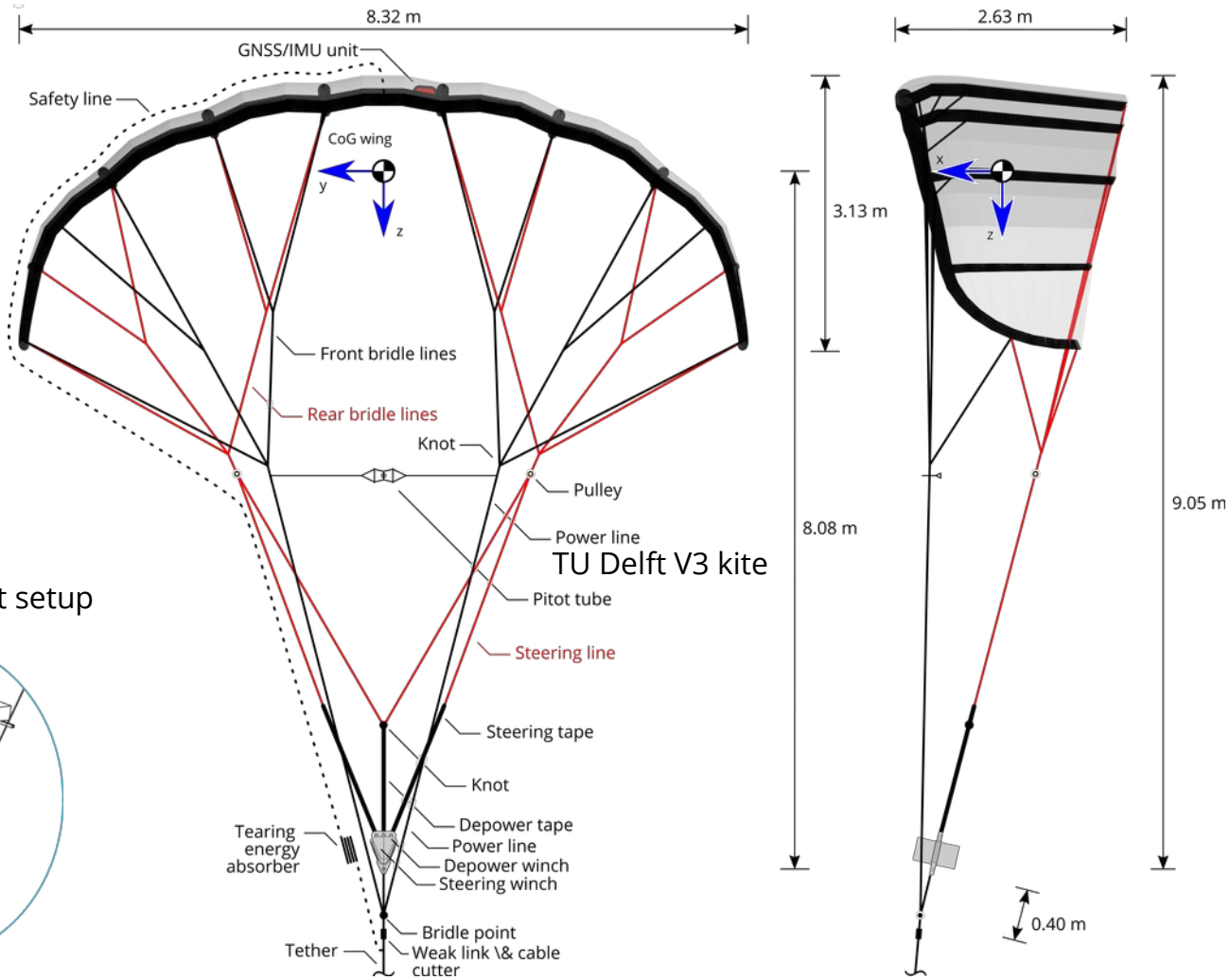


CFD simulation with OpenFOAM
Streamlines around the kite colored
With the spanwise velocity component,
computed for Re=3x10^6 and 12° AoA


Turbulent eddy viscosity
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
Y
X
Z



Relative flow measurement setup



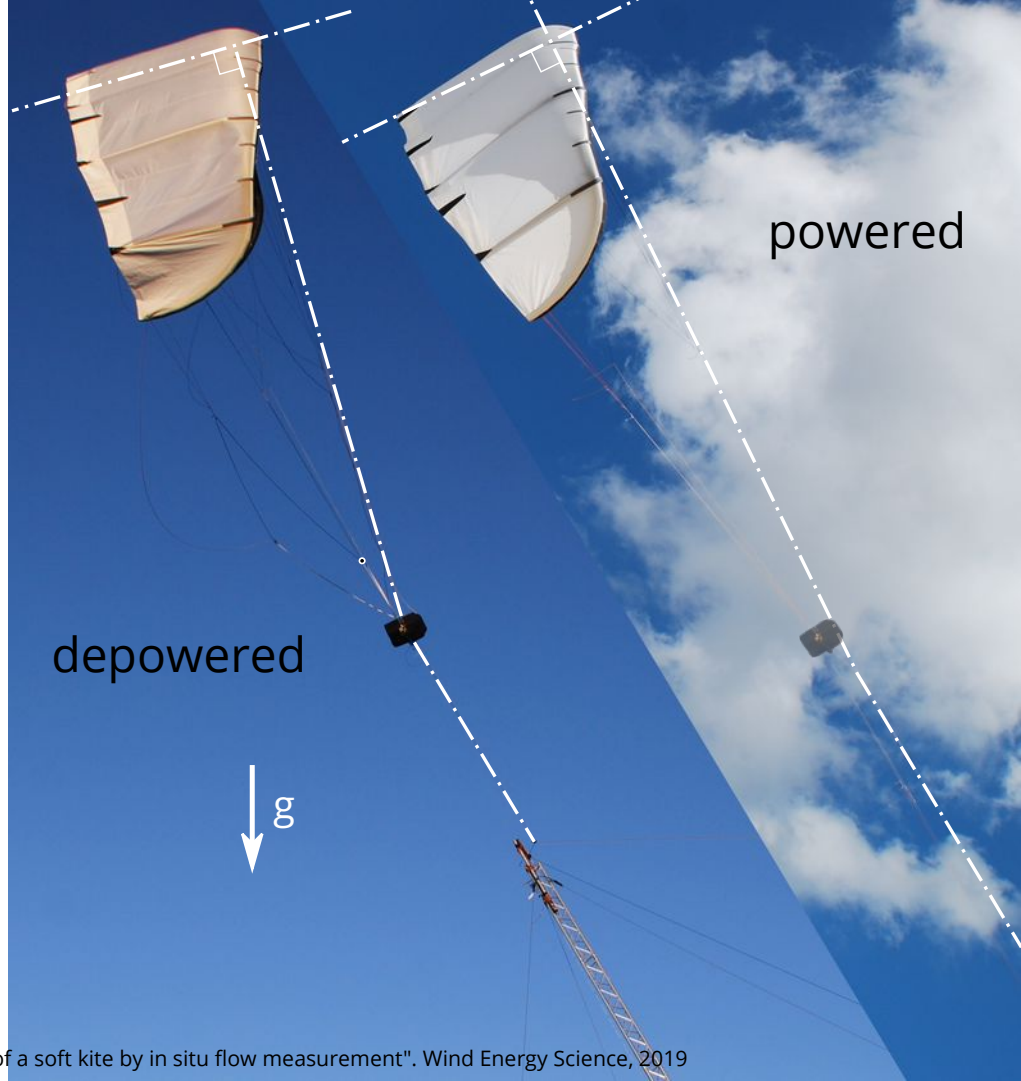
TU Delft V3 kite

Oehler & Schmehl. "Aerodynamic characterization of a soft kite by in situ flow measurement". Wind Energy Science, 2019


MAKANI
Norway 2019

Effect of power

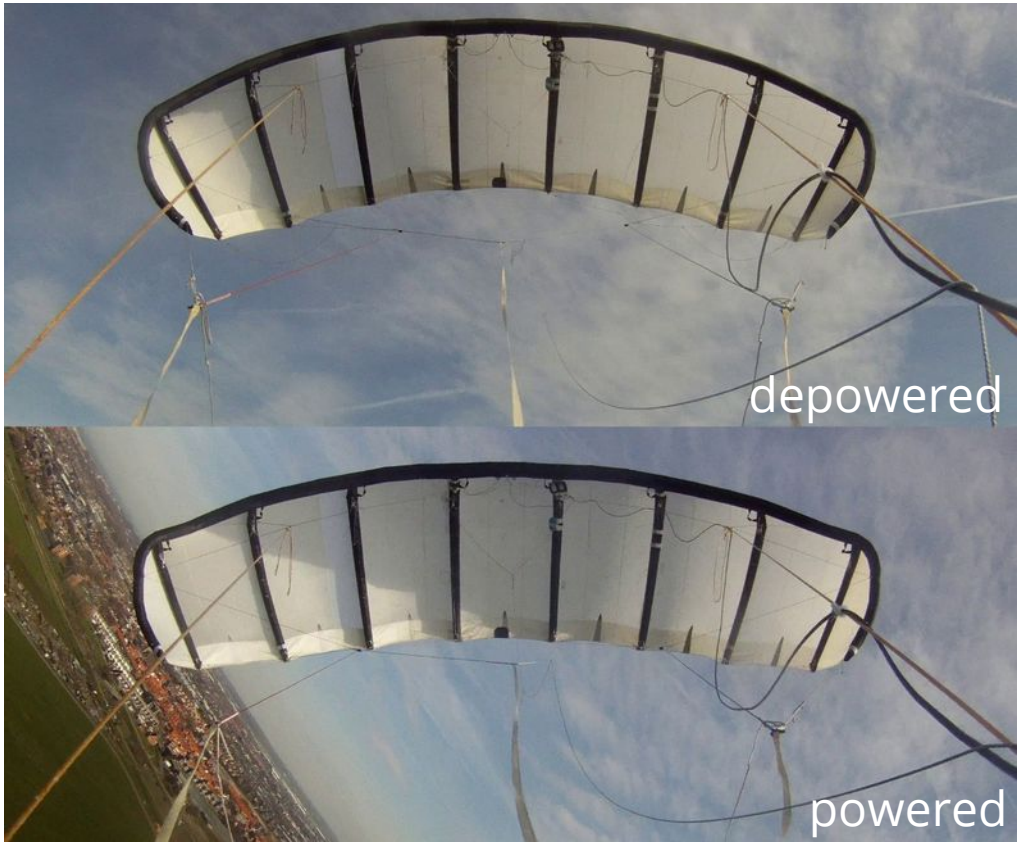
- Changes chordwise force distribution
- Powering up the wing makes wing pitch backwards



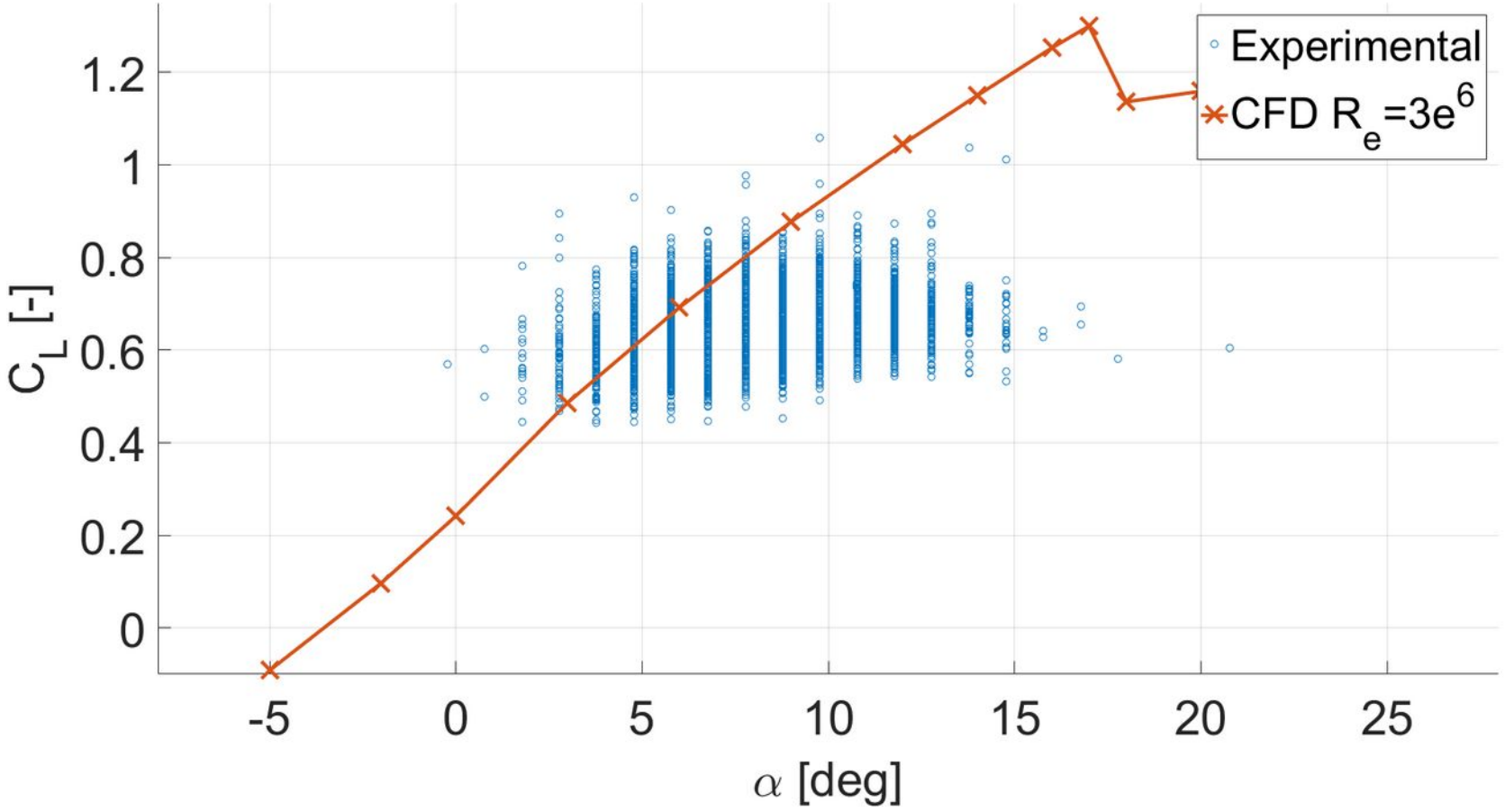
Oehler & Schmehl. "Aerodynamic characterization of a soft kite by in situ flow measurement". Wind Energy Science, 2019

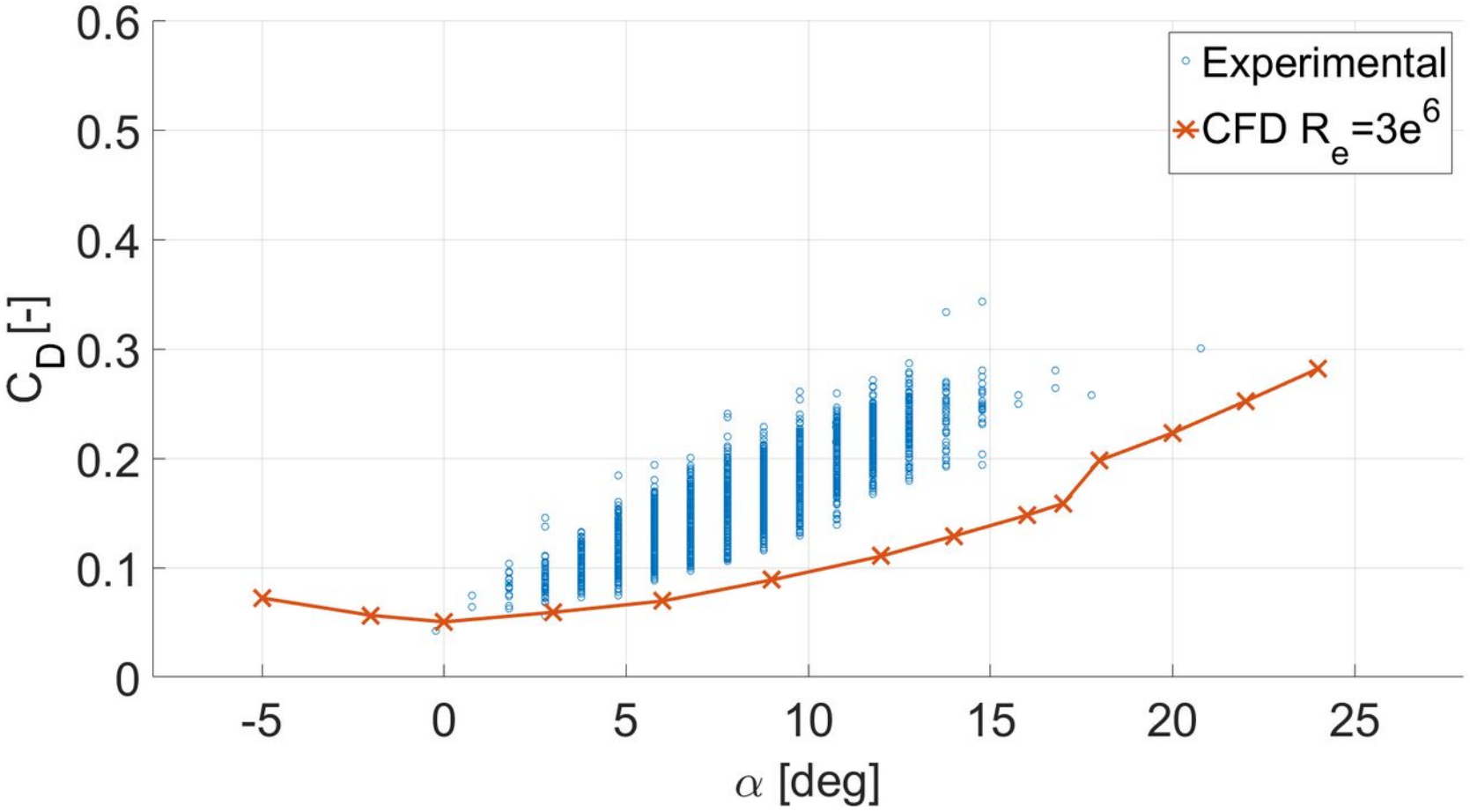
Effect of power

- Wing flattens
- Force increase also by area increase

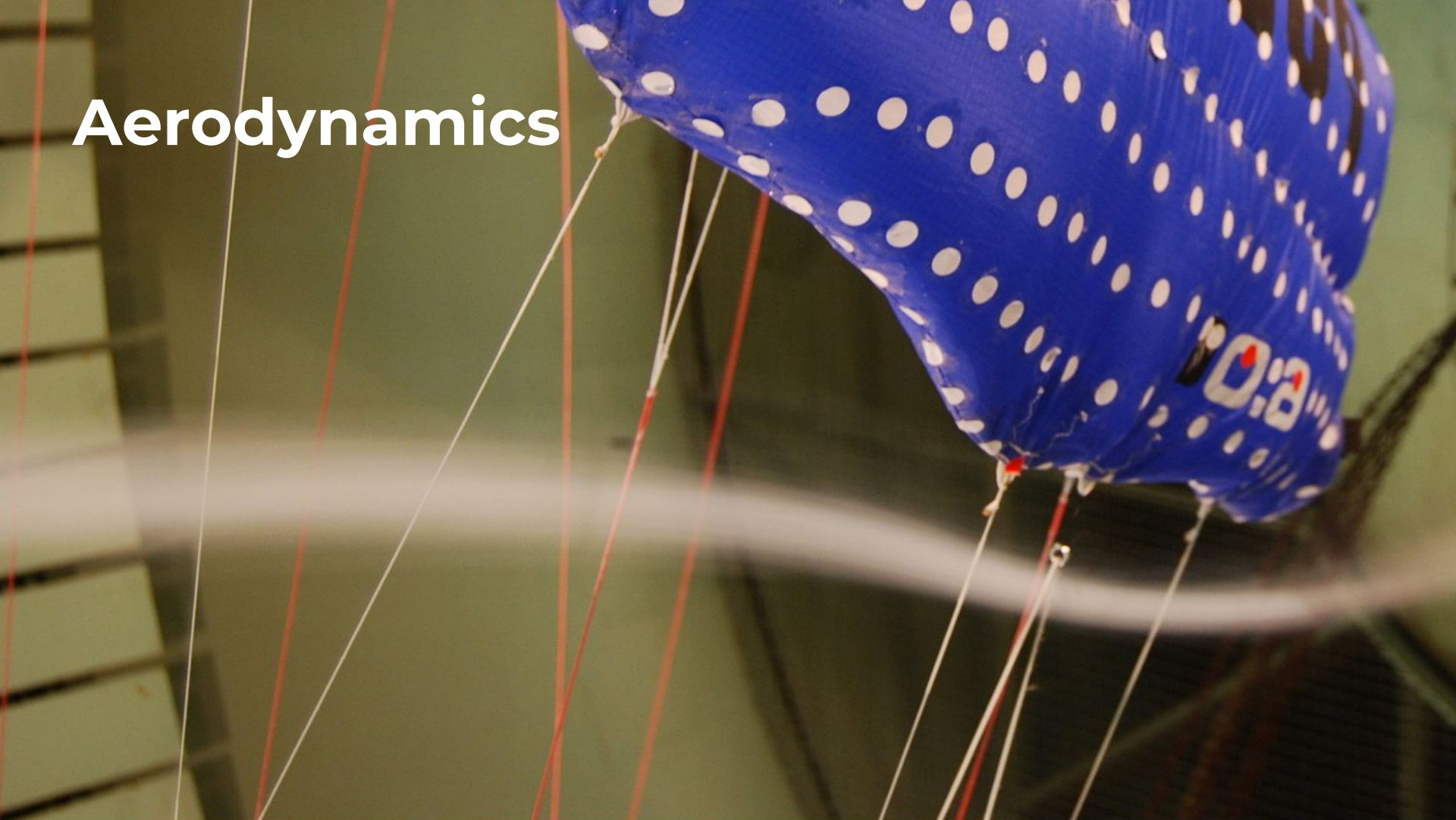


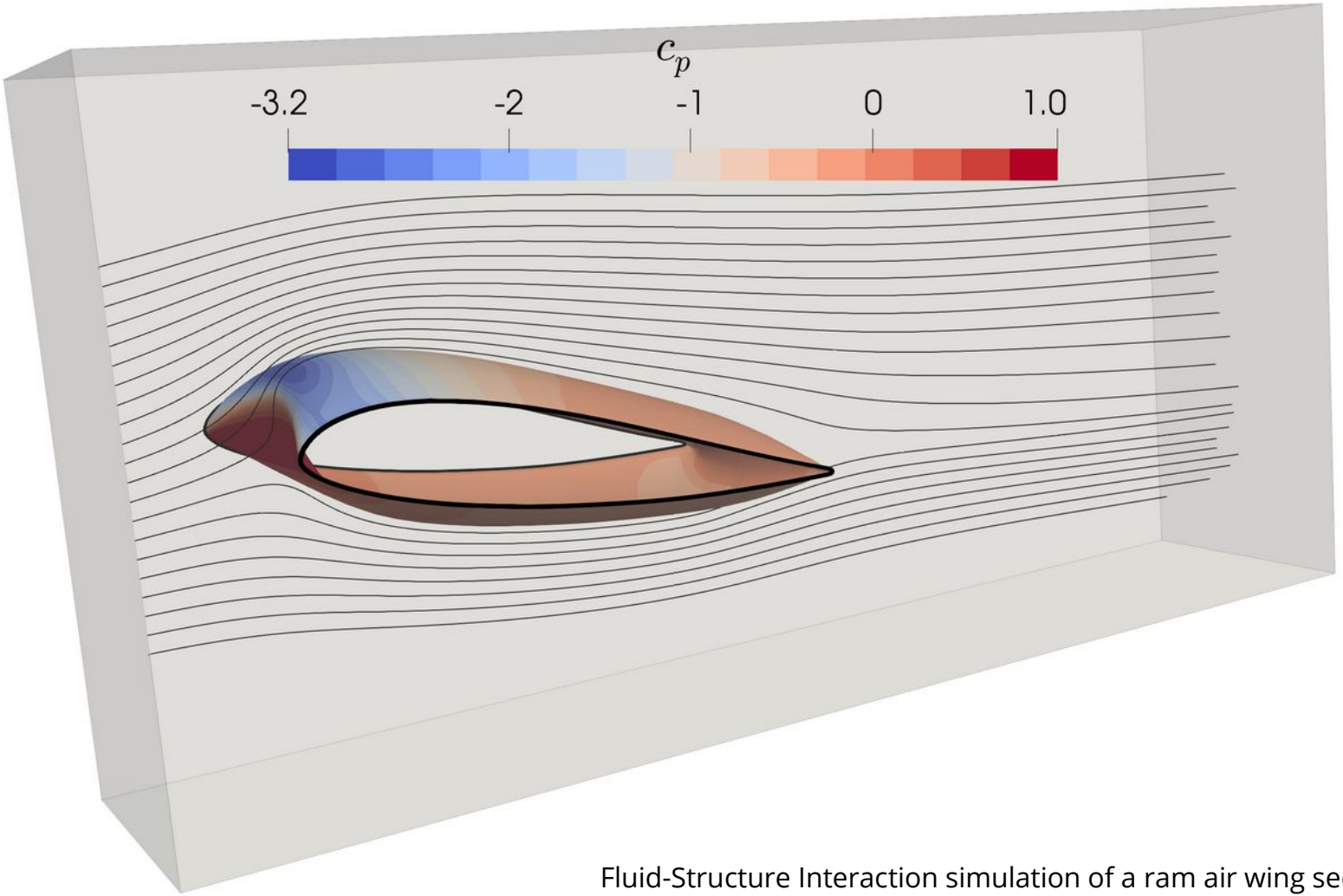
Oehler & Schmehl. "Aerodynamic characterization of a soft kite by in situ flow measurement". Wind Energy Science, 2019


Experimental
CFD R_e=3e^6
C_L [-]
1.2
1
0.8
0.6
0.4
0.2
0
-5
0
5
10
15
20
25
α [deg]


0.6
0.5
0.4
0.3
0.2
0.1
0
C_D [-]
-5
0
5
10
15
20
25
α [deg]
Experimental
CFD R_e=3e^6

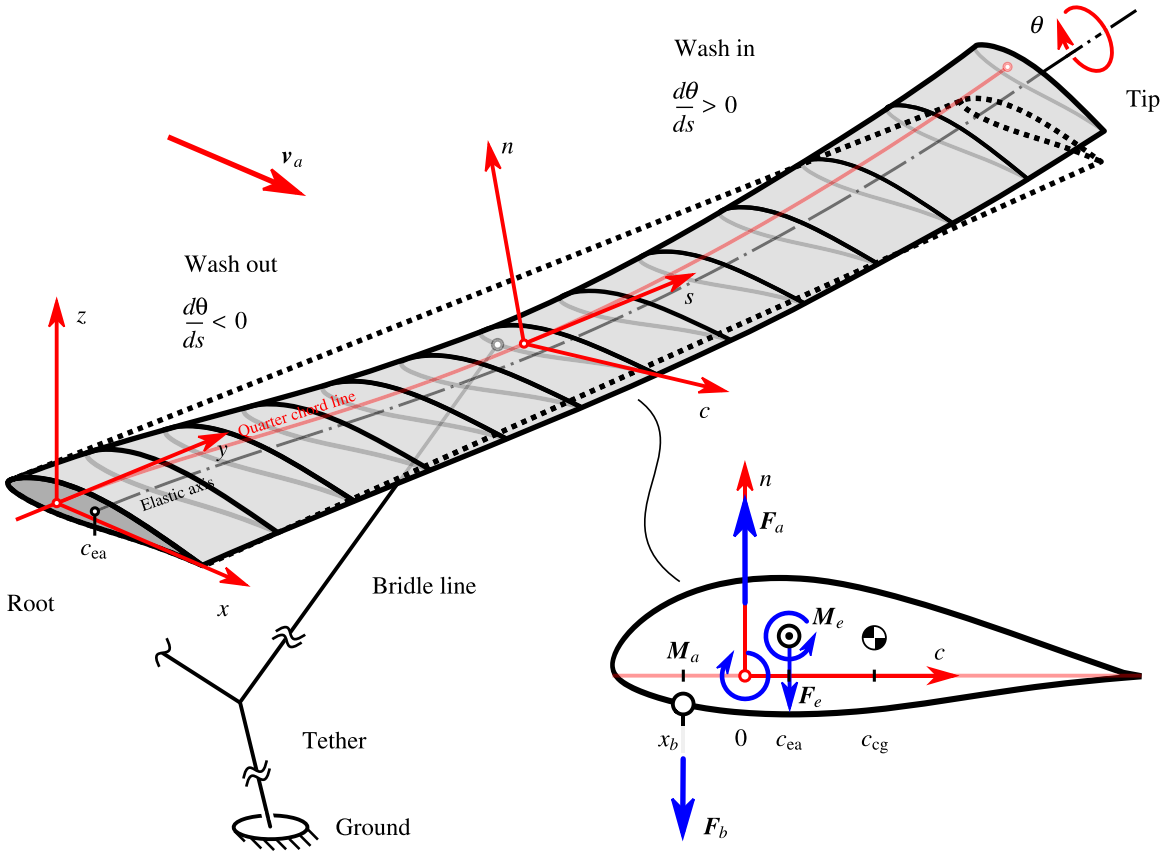
Aerodynamics





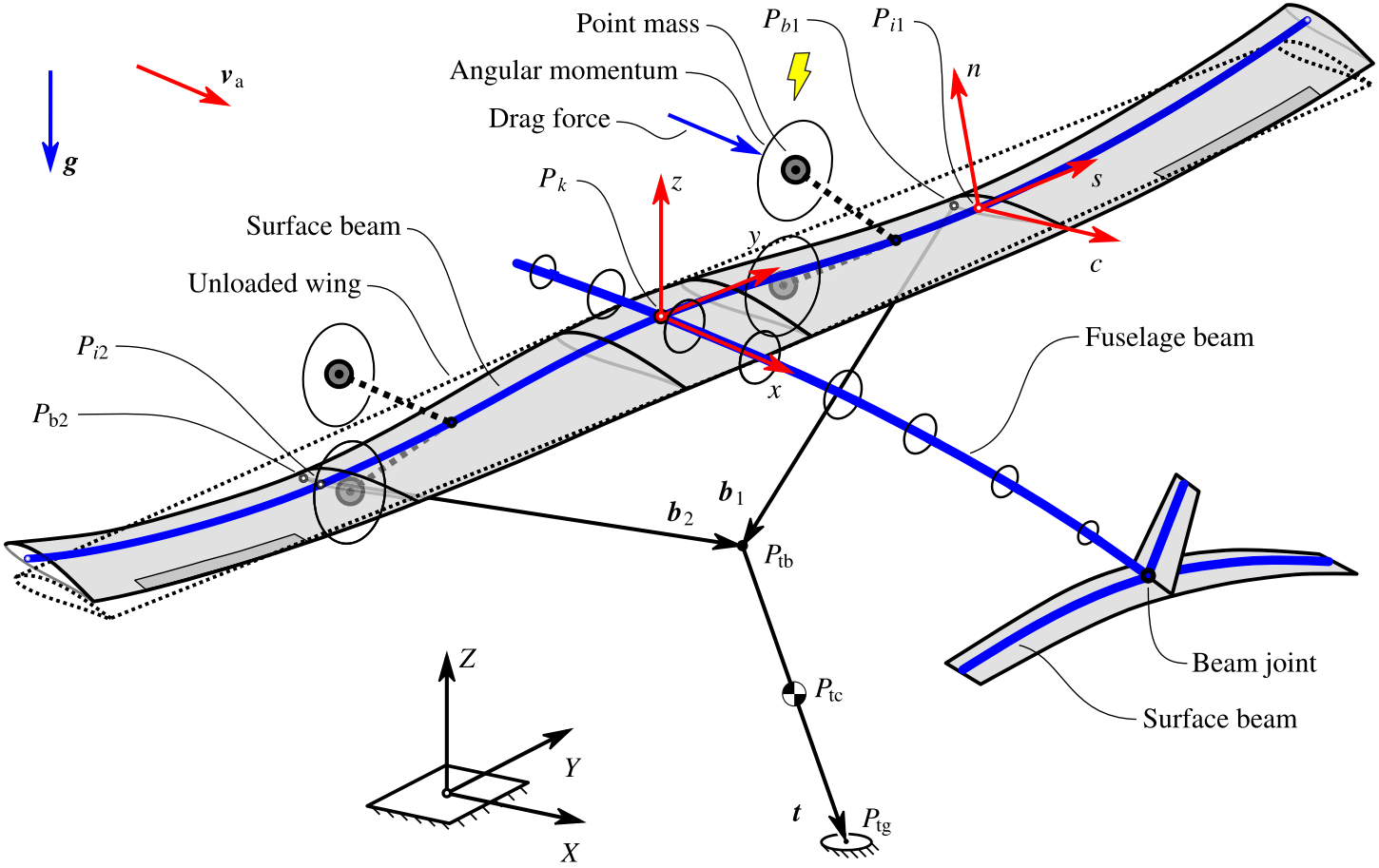
Fluid-Structure Interaction simulation of a ram air wing section

Aeroelastic bending and torsion of a half wing supported by a bridle line



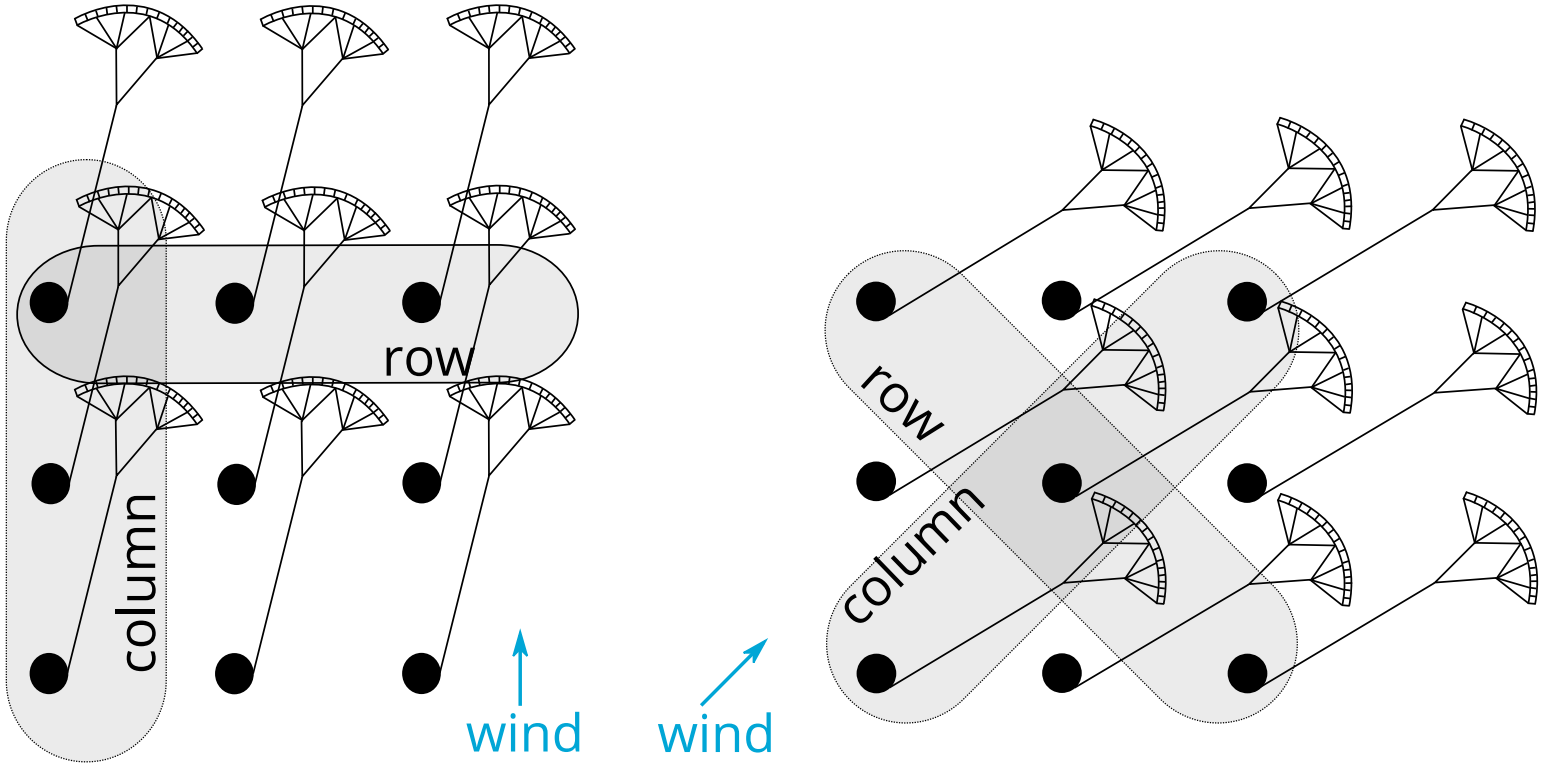
Wijnja, Schmehl, De Breuker, Jensen and Vander Lind: "Aeroelastic Analysis of a Large Airborne Wind Turbine". Journal of Guidance, Control and Dynamics, 2018

Aeroelastic model of an AWT and the tensile support system connecting it to the ground



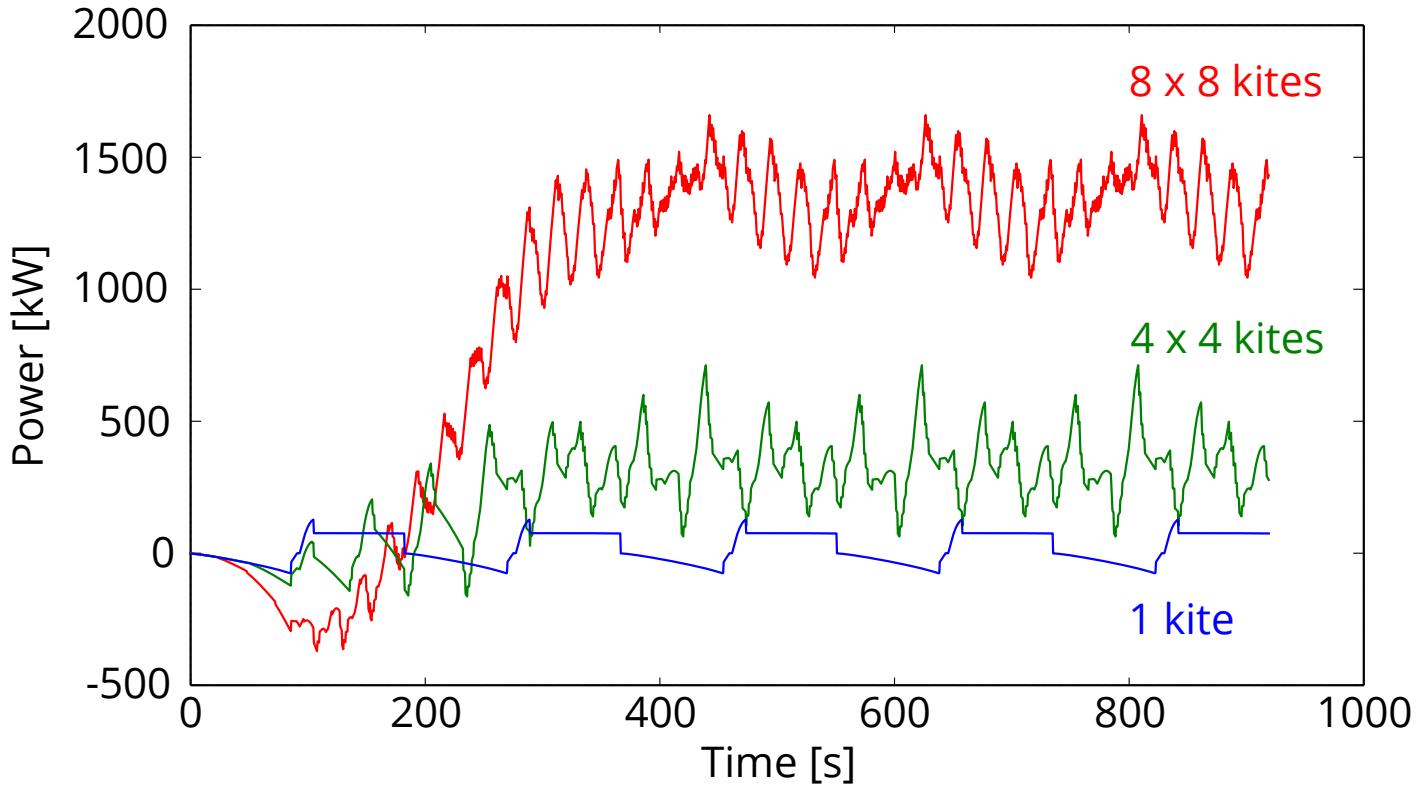
Wijnja, Schmehl, De Breuker, Jensen and Vander Lind: "Aeroelastic Analysis of a Large Airborne Wind Turbine". Journal of Guidance, Control and Dynamics, 2018

Kite park layout



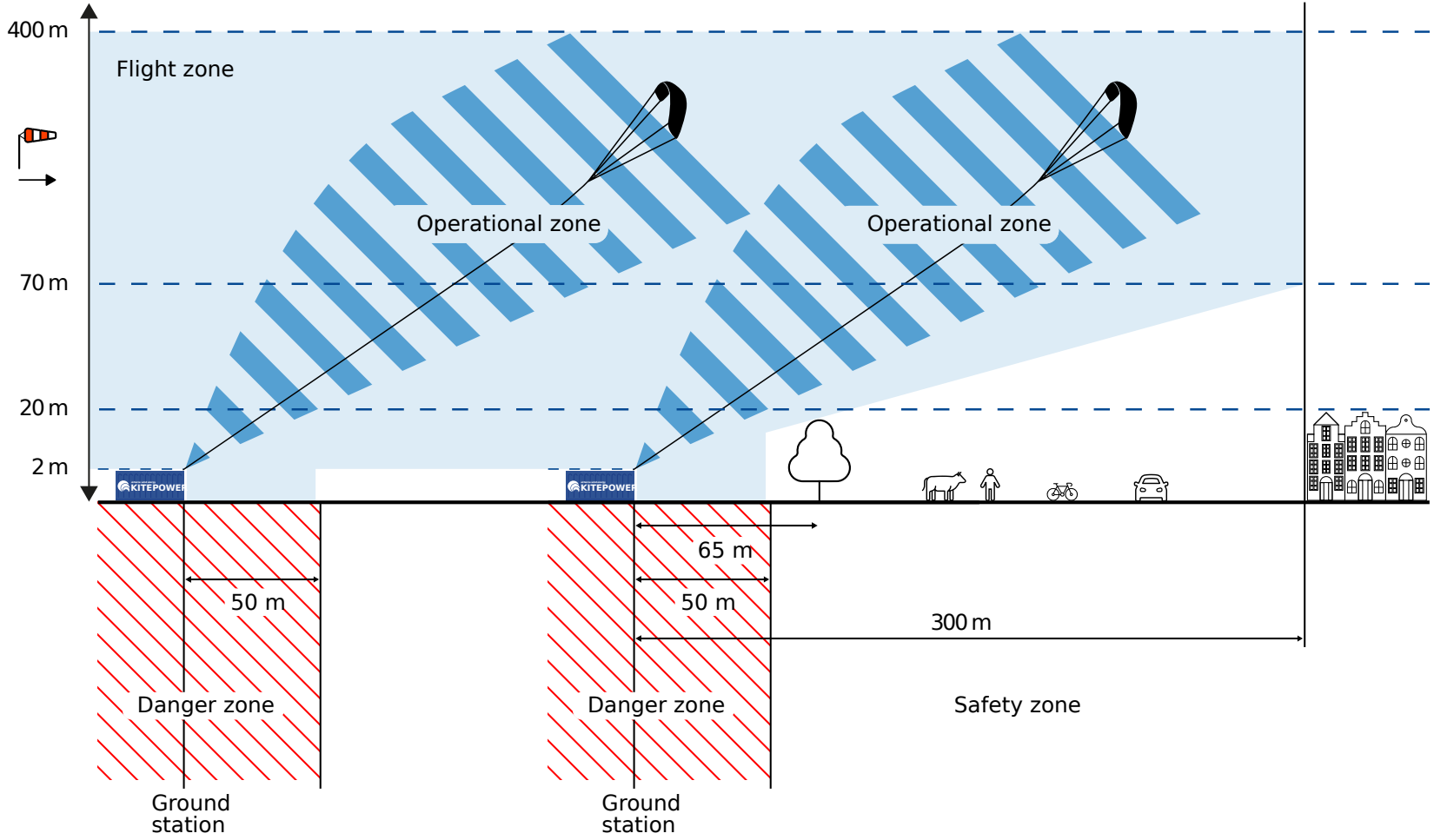
Faggiani & Schmehl. “Design and Economics of a Pumping Kite Wind Park". In: Schmehl (ed.) "Airborne Wind Energy - Advances in Technology Development and Research", Springer, 2018

Kite park power output

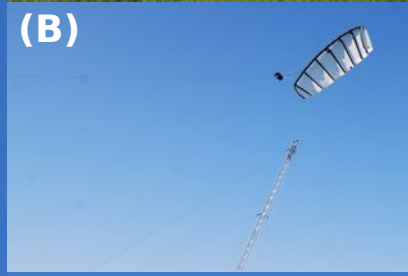


Faggiani & Schmehl. “Design and Economics of a Pumping Kite Wind Park". In: Schmehl (ed.) "Airborne Wind Energy - Advances in Technology Development and Research", Springer, 2018

Safety & reliability



Salma, Friedl & Schmehl: "Improving Reliability and Safety of Airborne Wind Energy Systems", Wind Energy, 2019



2012/08/02

Salma, Friedl & Schmehl: "Improving Reliability and Safety of Airborne Wind Energy Systems", Wind Energy, 2019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AWE Lab
Airborne Wind Energy
Reference System by DyNAT
DTU
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Questions?

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