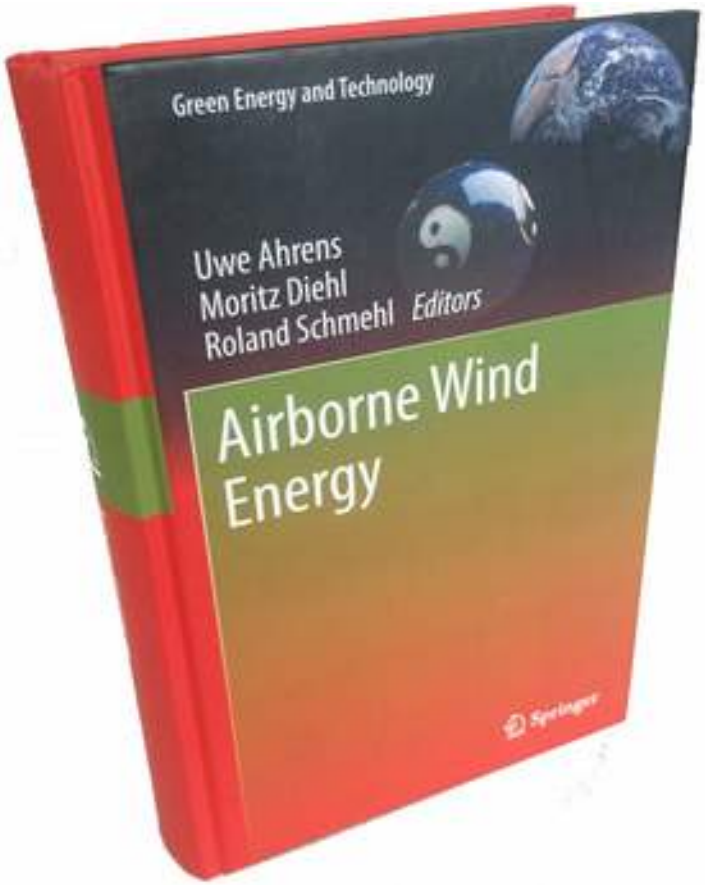
Airborne Wind Energy

An innovative renewable energy technology

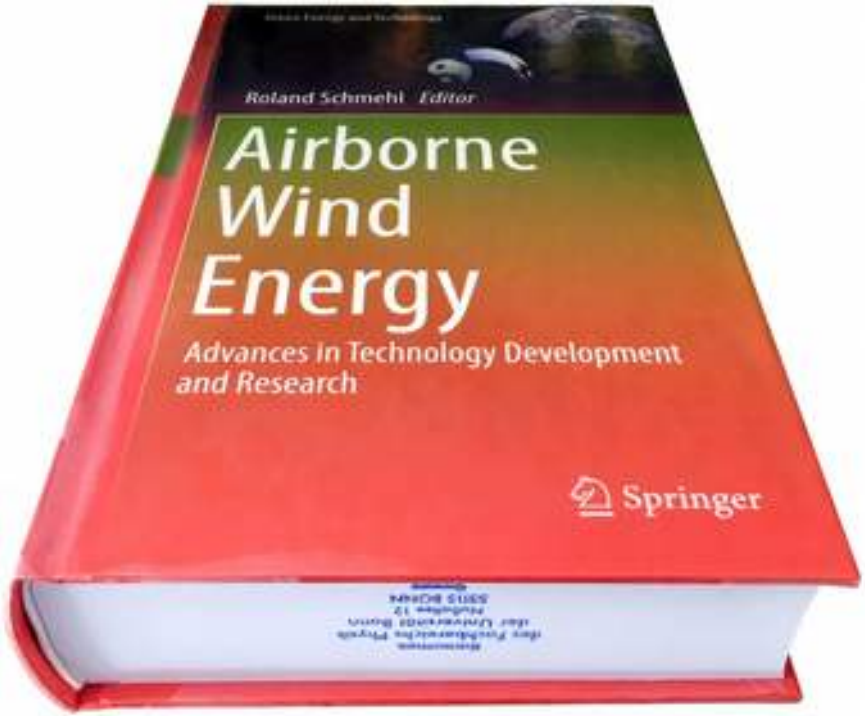
Roland Schmehl, TU Delft

Presenter

- Associate Professor at Delft University of Technology
- Co-founder of Kitepower BV
- Coordinator of 2 H2020 projects (AWESCO & REACH)
- 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


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

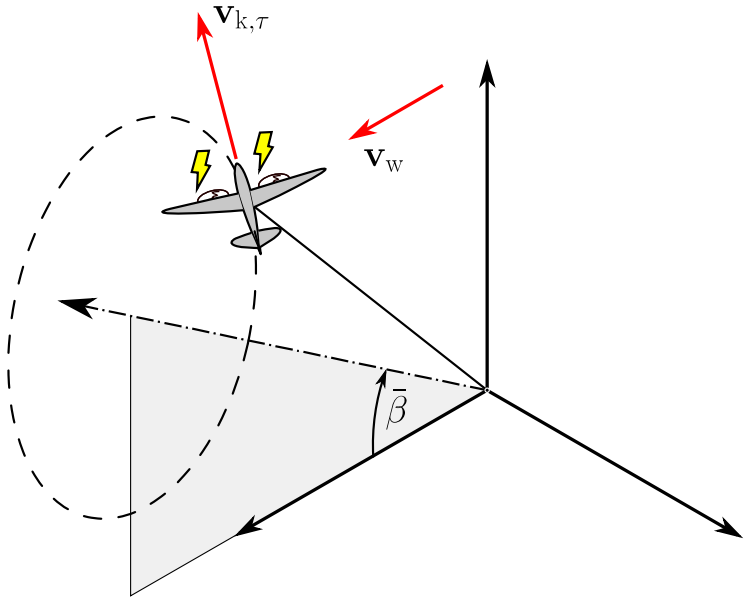
2018

Outline

- Fundamental working principles
- Theoretical framework
- Technology demonstrators
- Development of the sector
- Performance of pumping AWE systems
- Current challenges for R&D

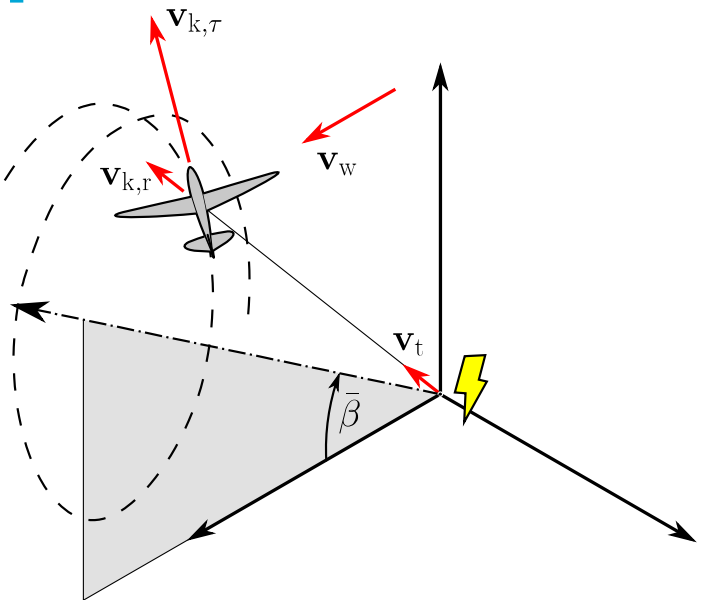
Fundamental concepts

Miles L. Loyd (1980)



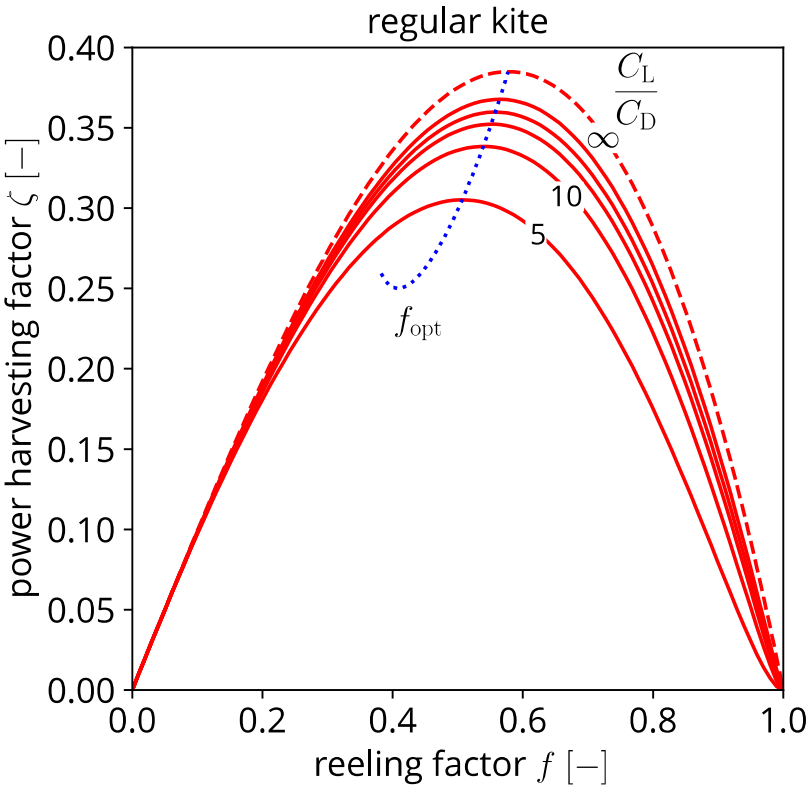
Drag power:

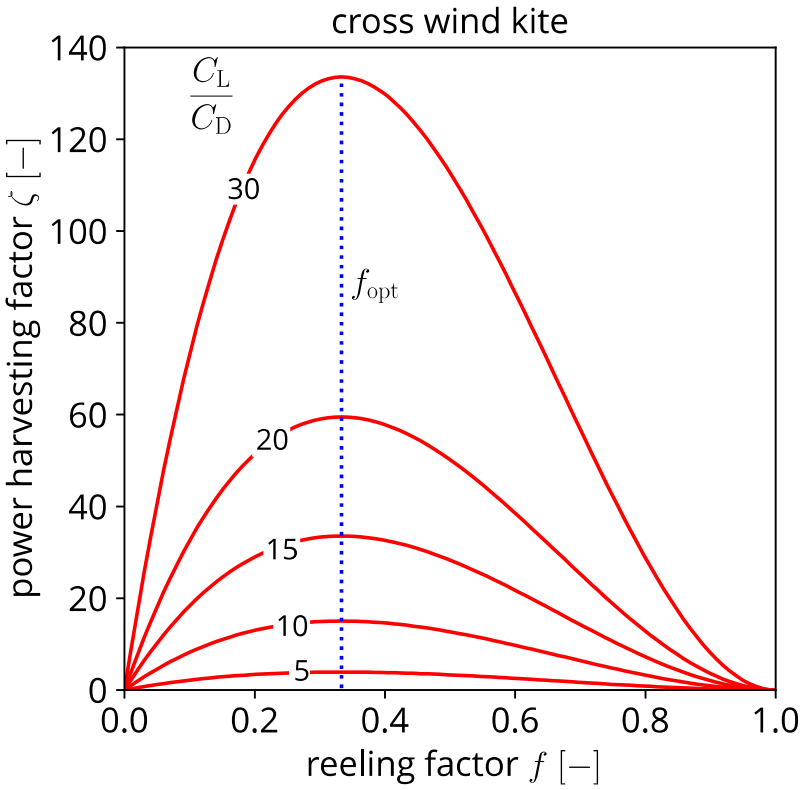
- Flying wing ⇝ shaft power
- Shaft power ⇝ electricity (ω ↑)
- Electricity ⇝ conductive tether



Lift power:

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





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

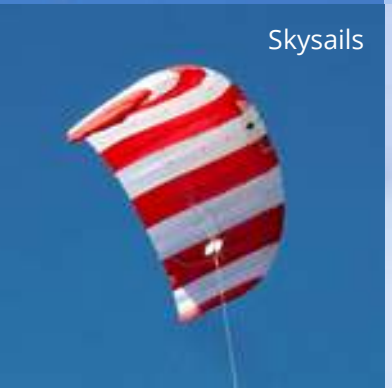
mechanical power P, wing surface area S

Key aspects

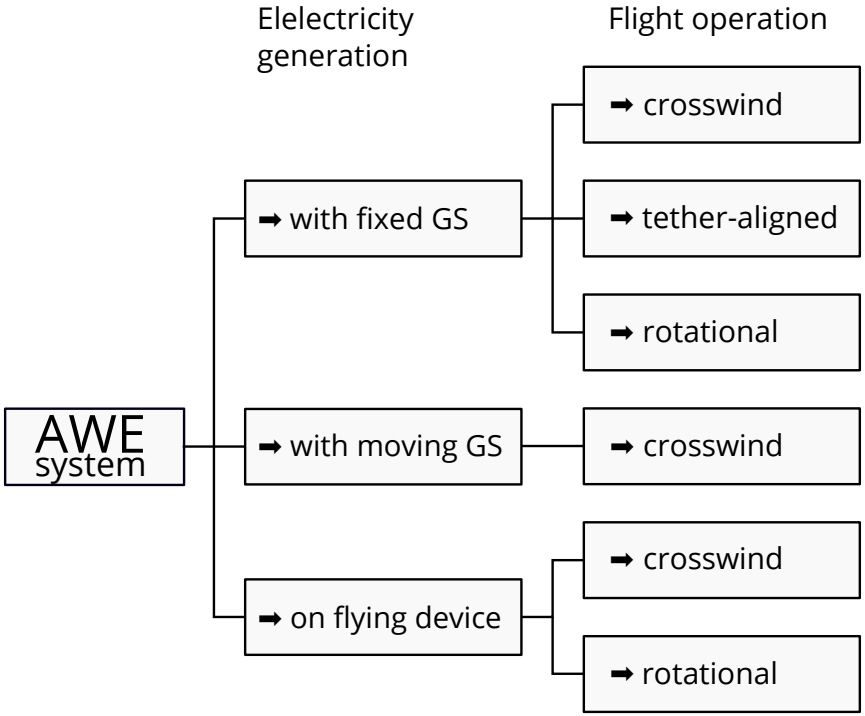
- Consumes significantly less material
- Highly adjustable to wind resource
- Access to high altitude wind
- Increased mobility

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

Technology demonstrators



AWES classification

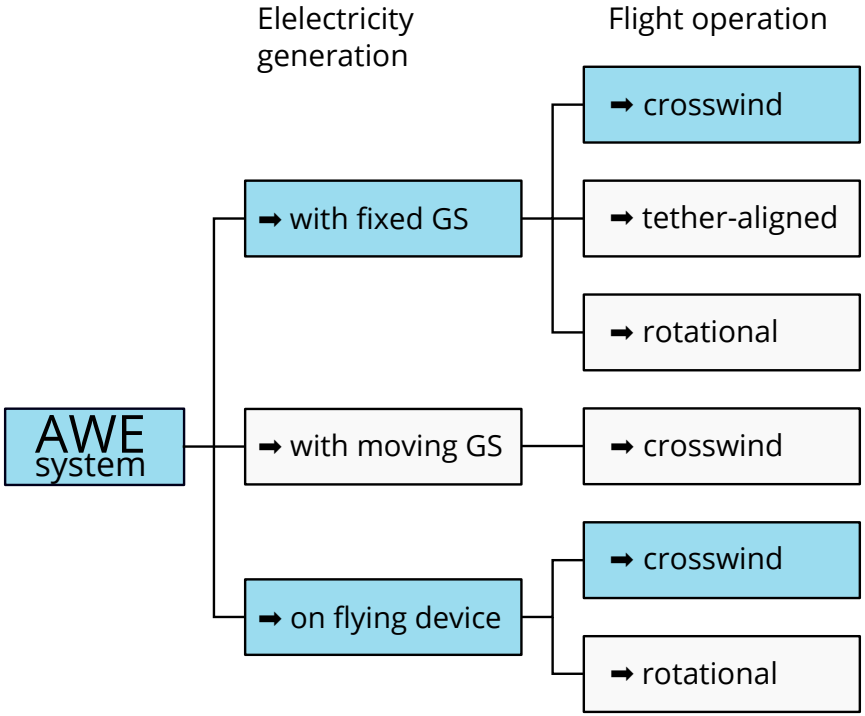


- Kitemill
- Skypull
- TwingTec
- E-Kite
- EnerKíte
- Ampyx
- KPS
- Kiteswarms
- Kitepower
- Kitenergy
- eWind Solutions
- KiteGen stem
- SkySails Power
- Omnidea
- Laddermill
- Guangdong HAWP
- Windswept
- someAWE
- X-Wind loop track
- KiteGen carousel
- Kitewinder
- Makani
- KiteKraft
- Windlift
- 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
- Skypull
- TwingTec
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- Kiteswarms
- Kitepower
- Kitenergy
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Adapted from: Watson et al. “Future emerging technologies in the wind power sector: a European perspective”, Renewable and Sustainable Energy Reviews, 2019.

Wing7 (30 kW)

MAKANI

California 2013

M600 (600 kW)

MAKANI

California 2017


MAKANI
Hawaii 2018


MAKANI
Norway 2019

AP-2 (50 kW)

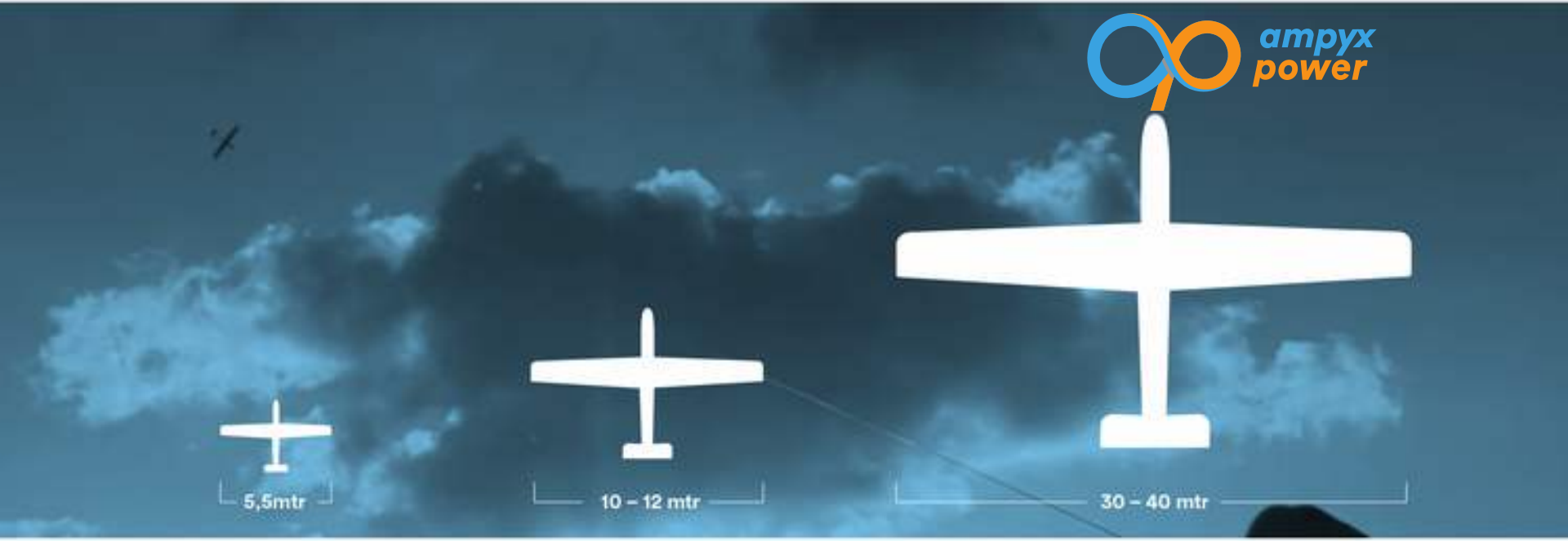
Noordoostpolder 2013

AP-2 (250 kW)

Marin 2018


SCHELLING

= ±250 households*



50kW

Prototype AP2
30 households

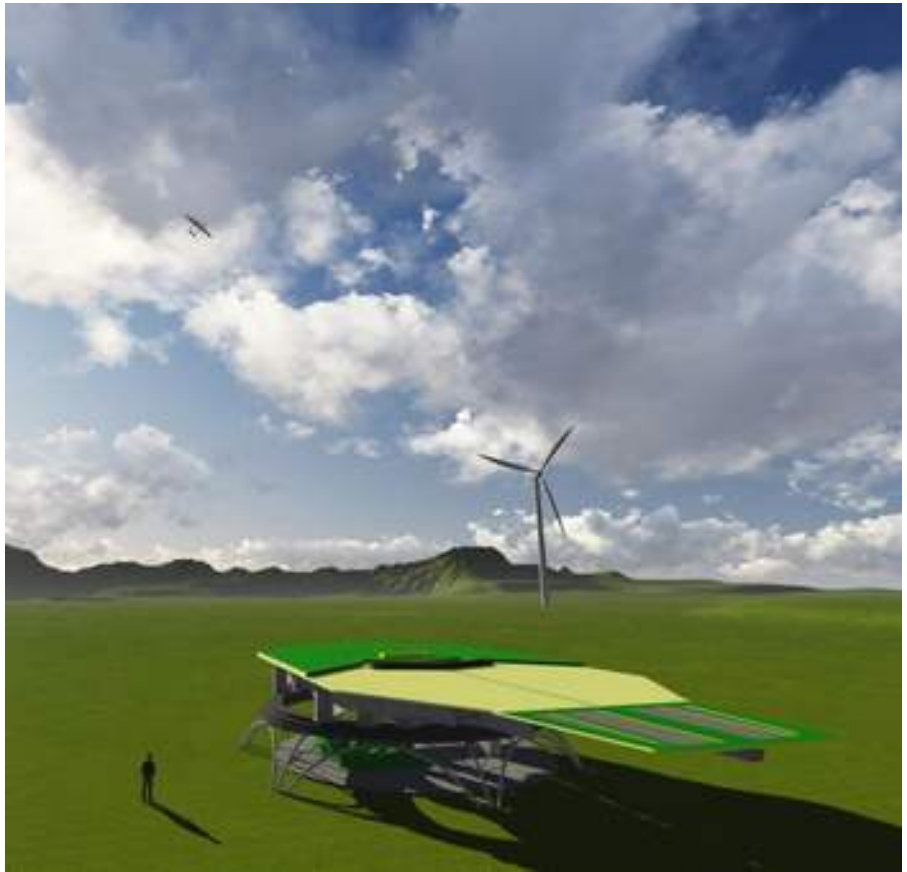
250 kW

Demo AP3 full functionality, certifiable,
restricted type certification 150 households

2 MW

Commercial product AP4 certified,
minimal cost of energy 1000 households

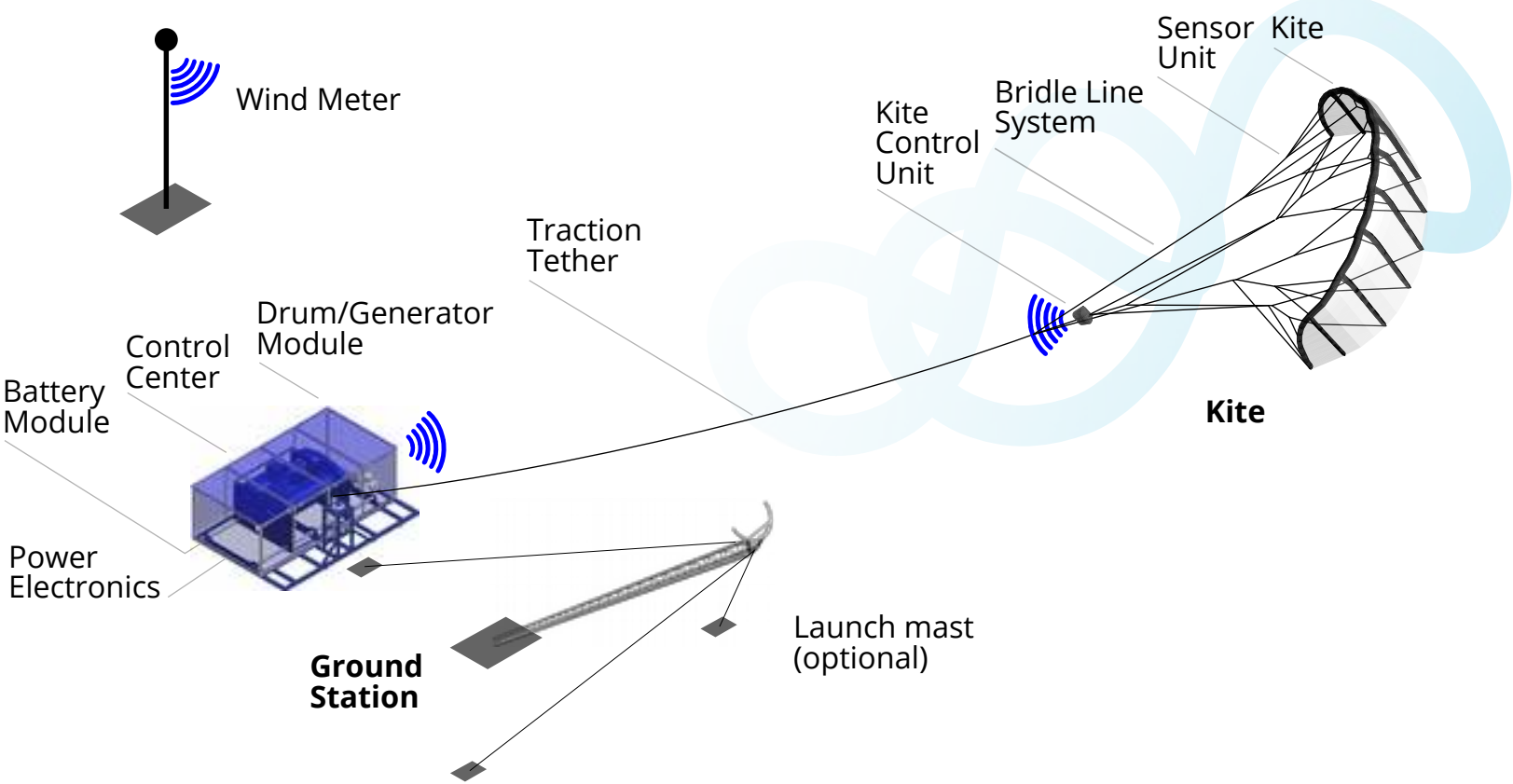
Ampyx Power AP4: 2 MW

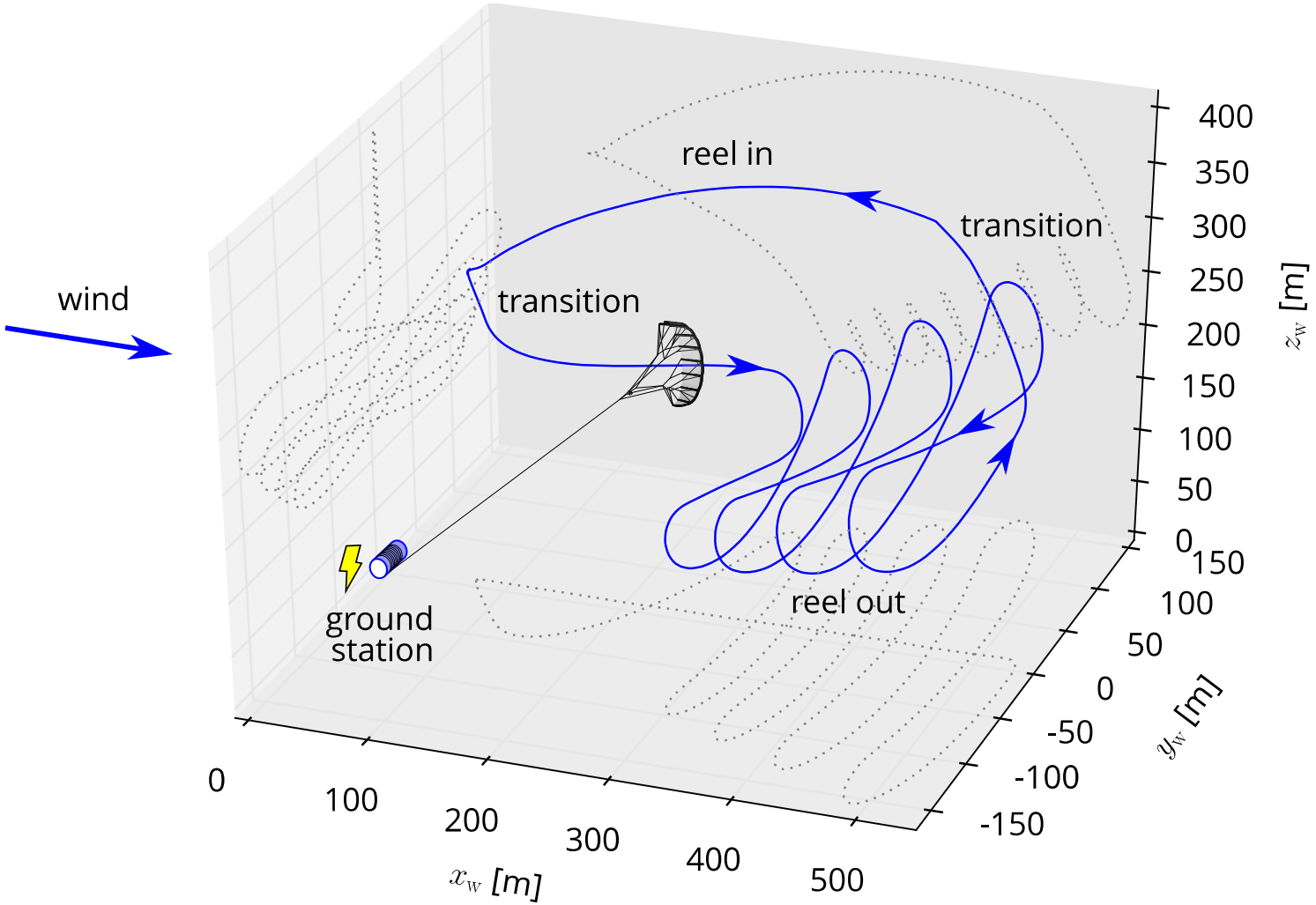


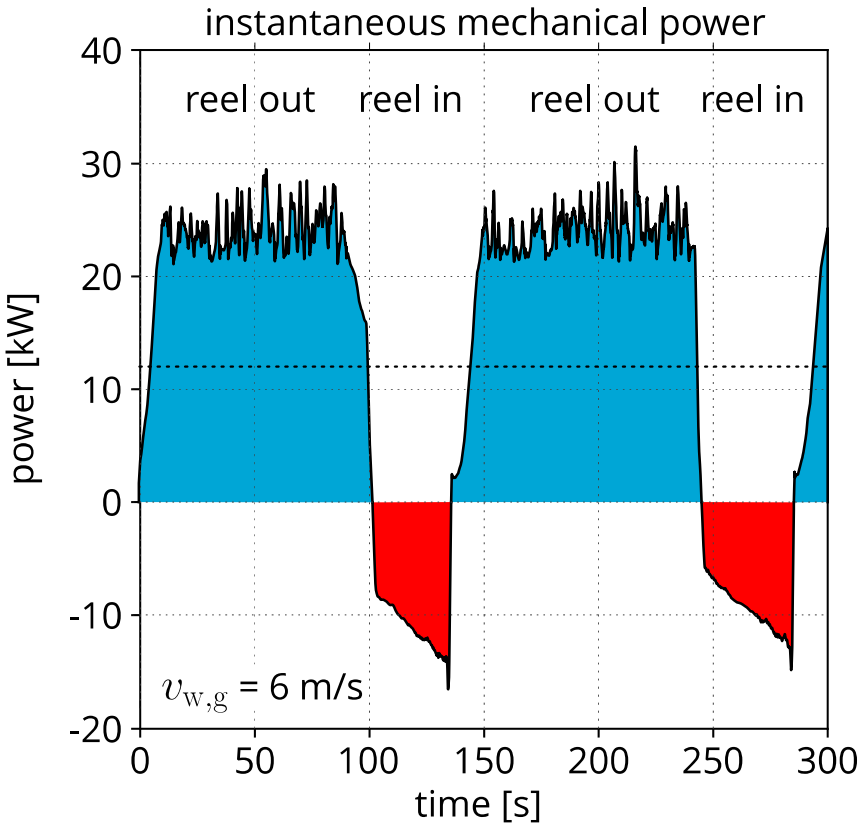
25 kW kite power system

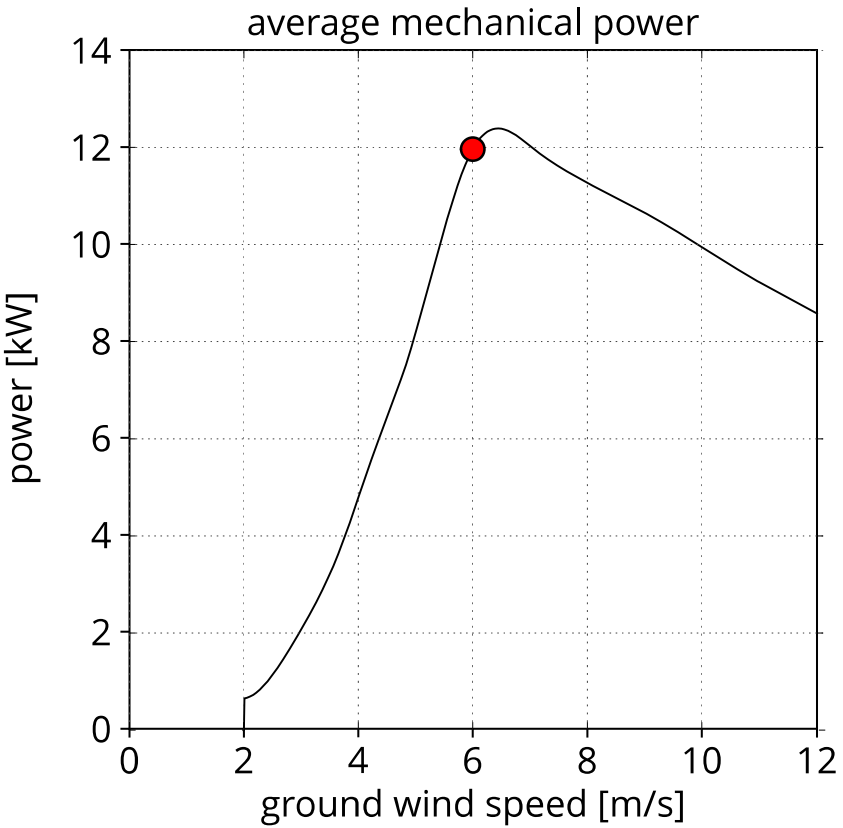
TU Delft

2012


Wind Meter
Sensor Unit
Kite
Bridle Line System
Kite Control Unit
Traction Tether
Drum/Generator Module
Control Center
Battery Module
Power Electronics
Kite
Ground Station
Launch mast (optional)


wind
reel in
transition
transition
reel out
ground
station
0
100
200
300
400
500
x_W [m]
-150
-100
-50
0
50
100
150
y_W [m]
0
50
100
150
200
250
300
350
400
z_W [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

40 m² kite

airborne wind energy
KITEPOWER
2017

100 kW ground station


airborne wind energy
KITEPOWER


airborne wind energy
KITEPOWER


KITEPOWER ™

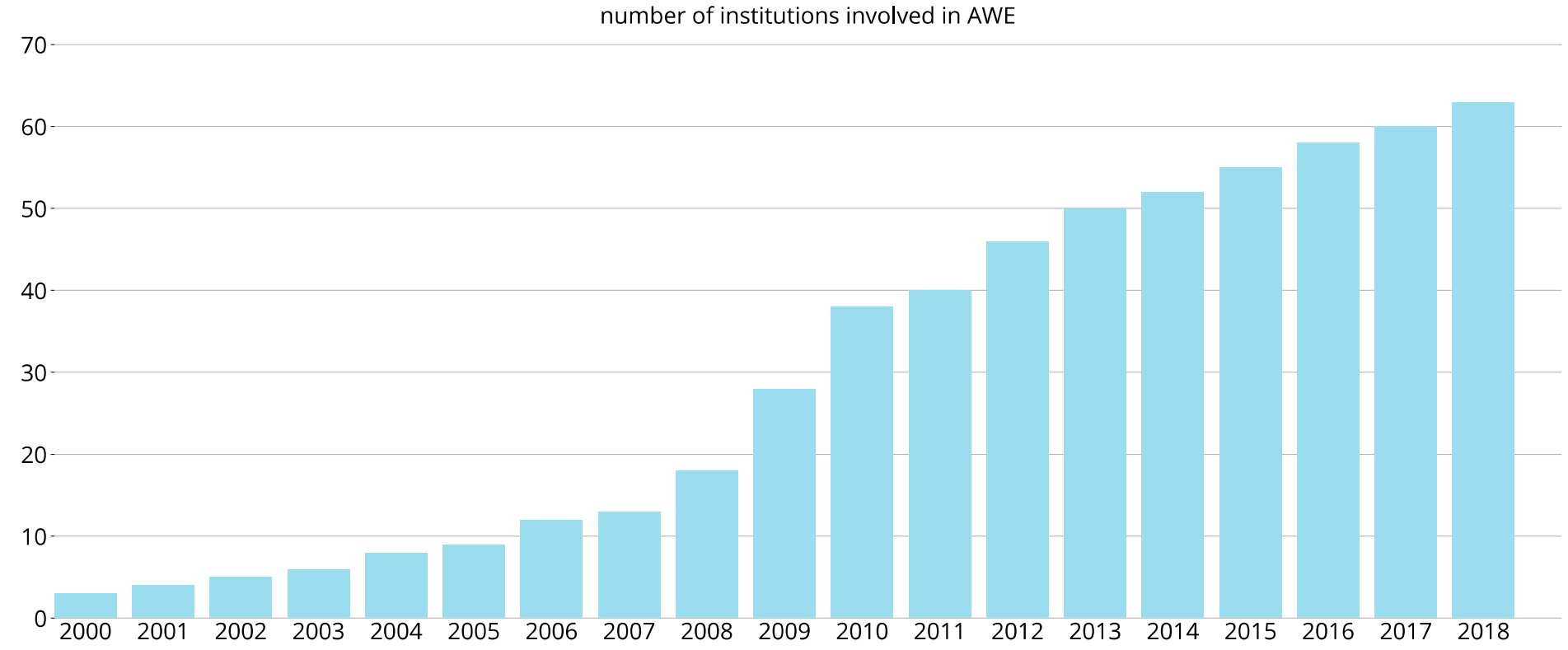

KITEPOWER™

Kite development: 25 – 40 – 60 m²

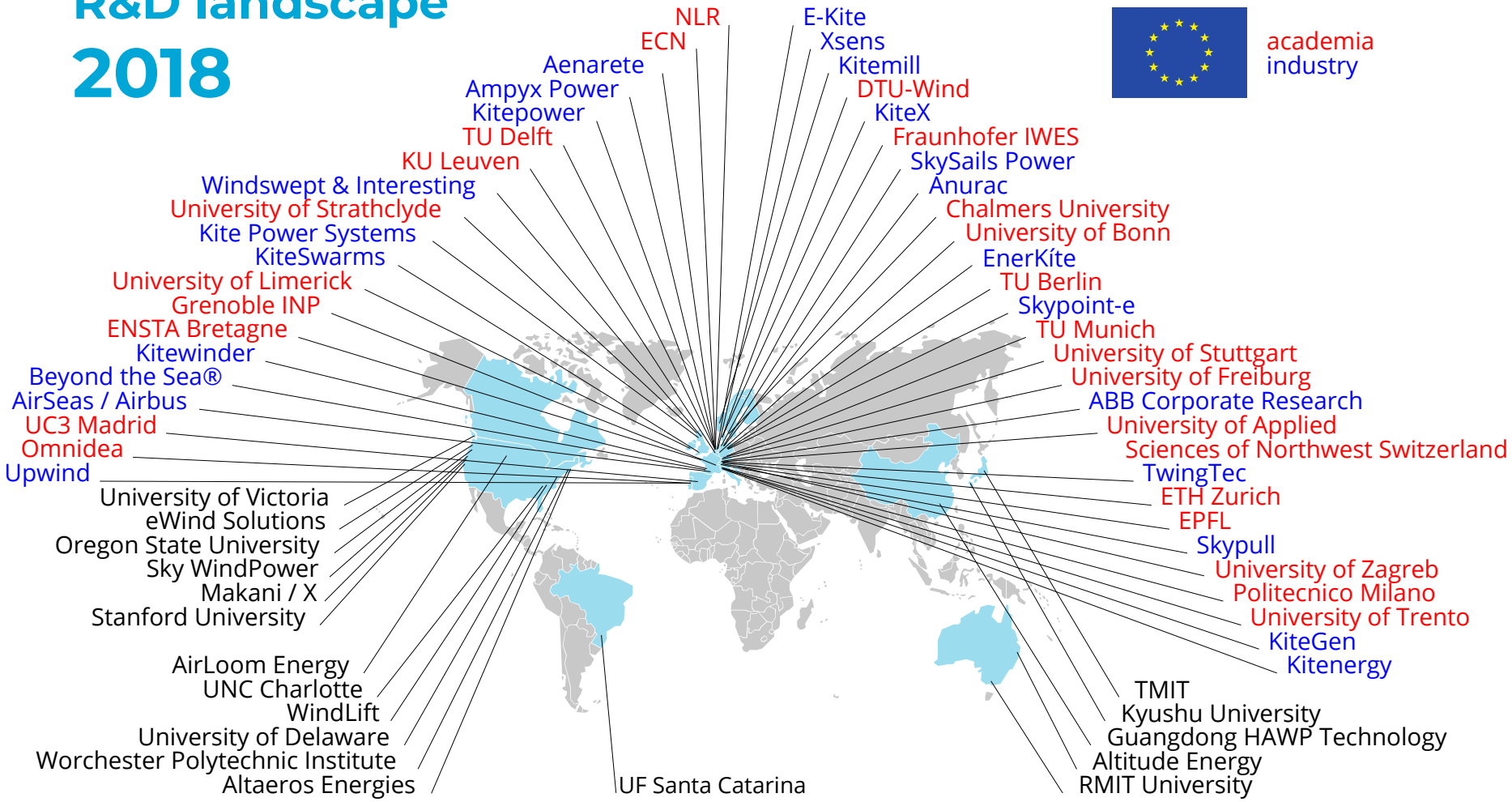
Kite development: 100 m²


airborne wind energy
KITEPOWER

Development as an industry



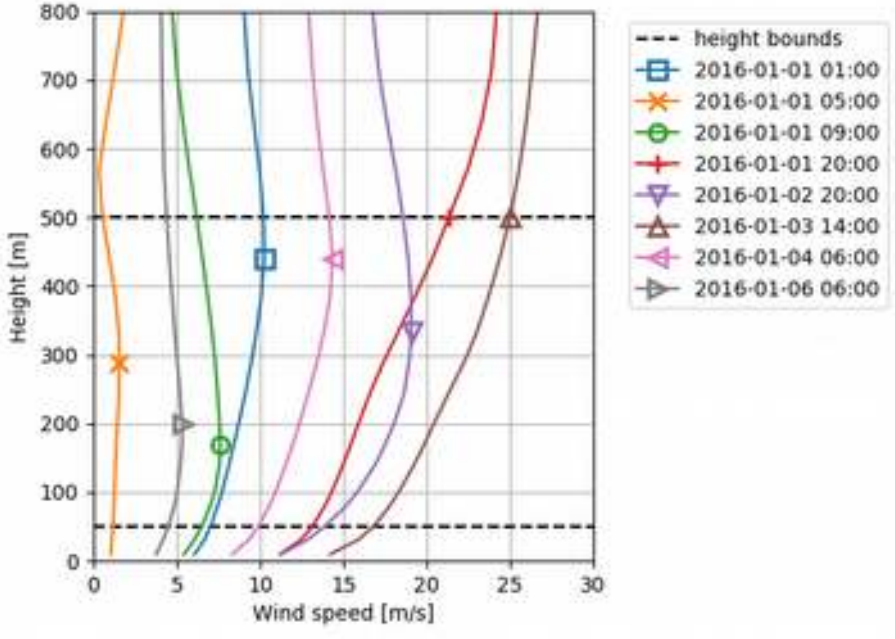
R&D landscape 2018

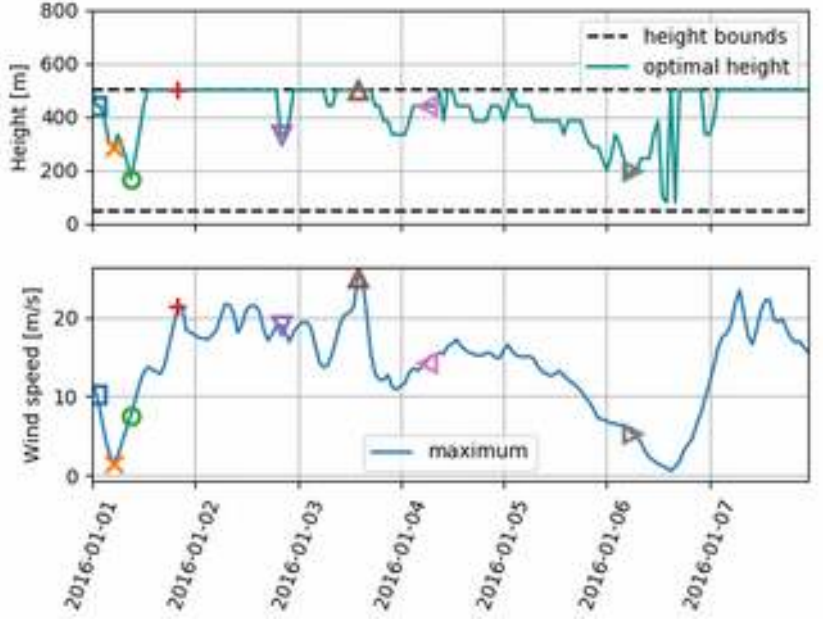


Challenges

- 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

AWE resource assessment



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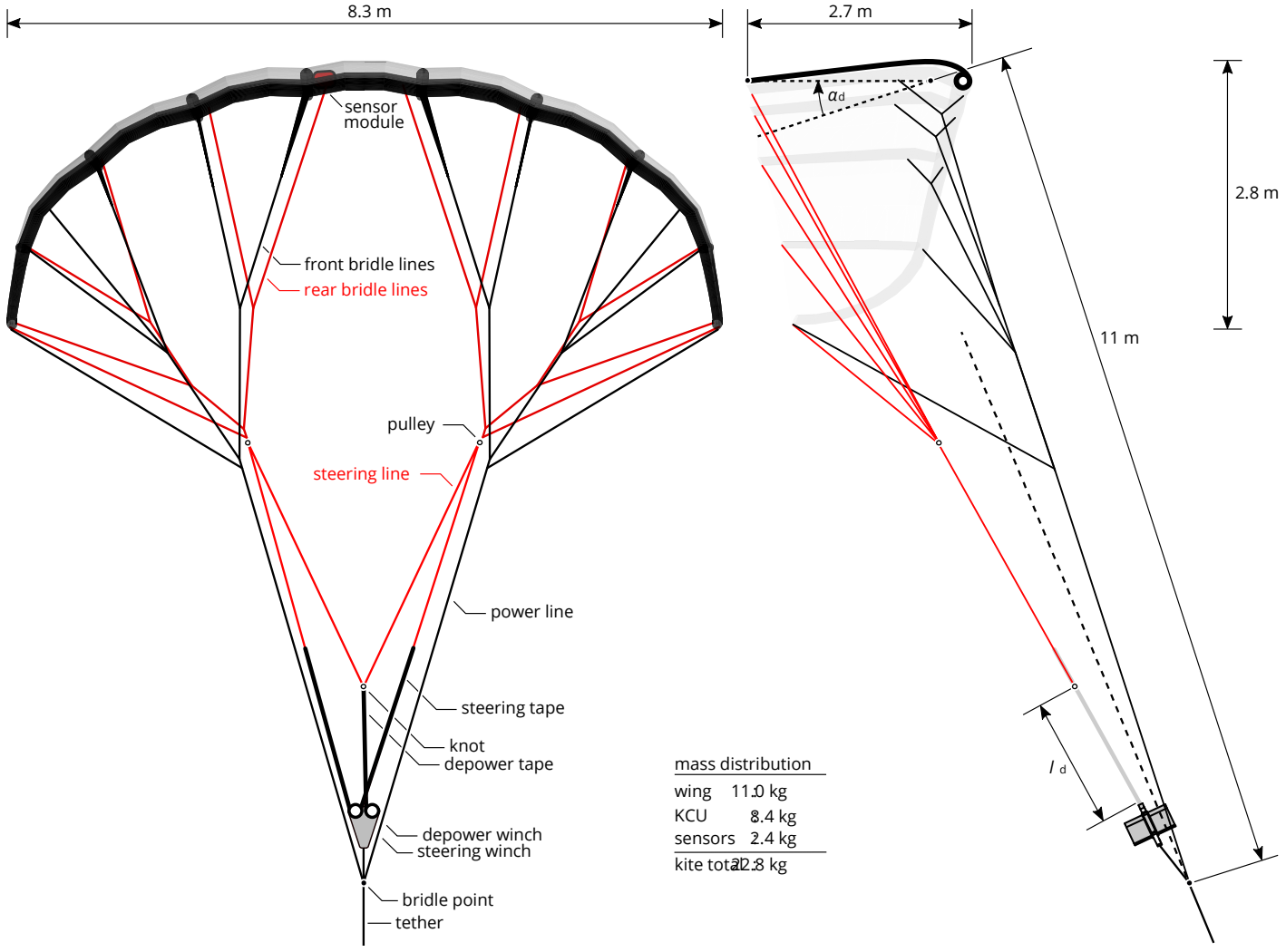
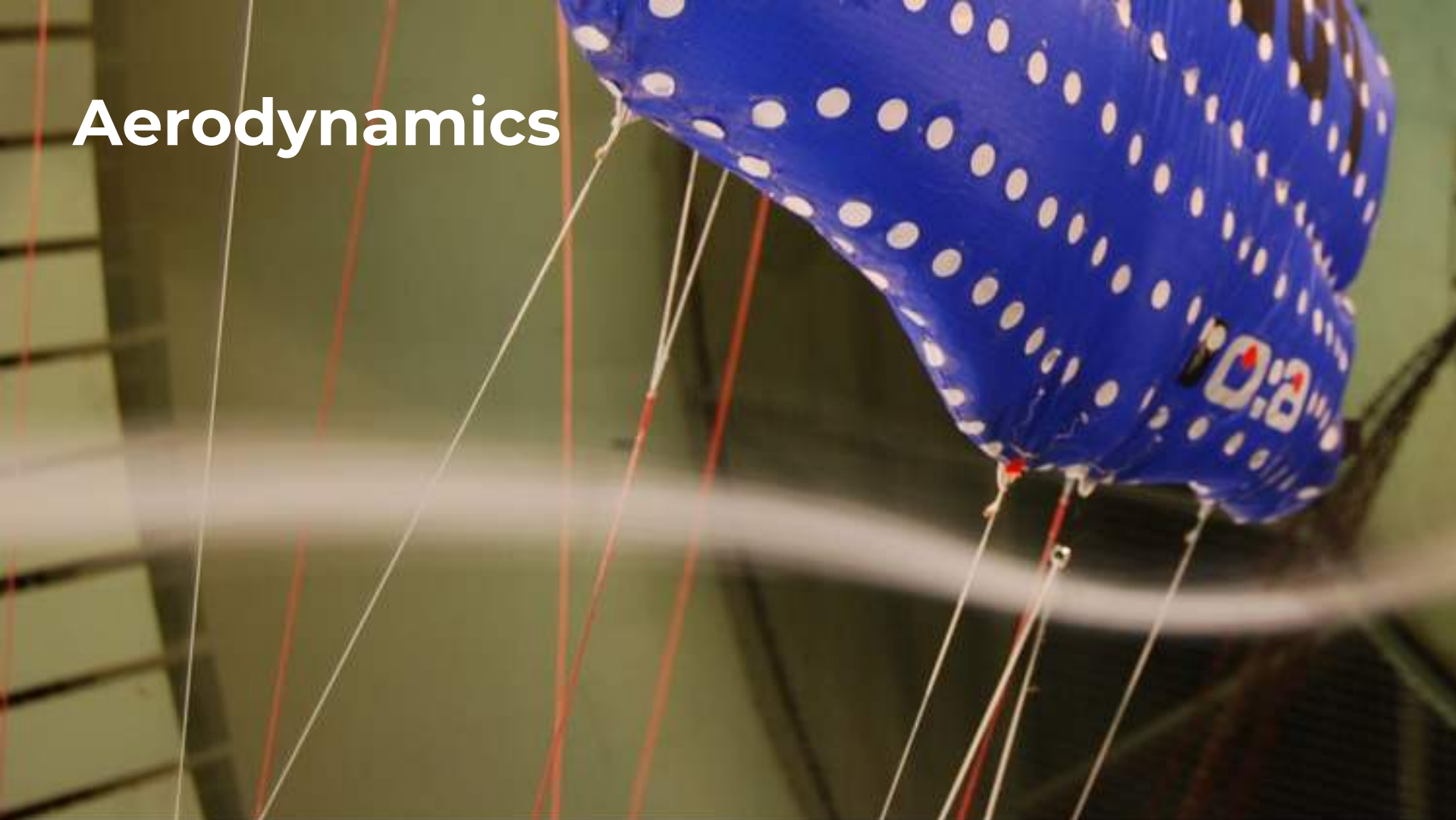
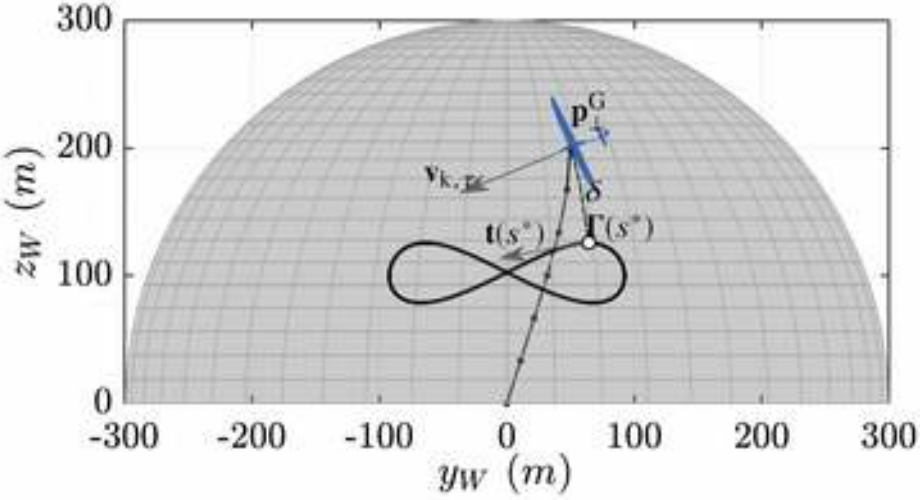
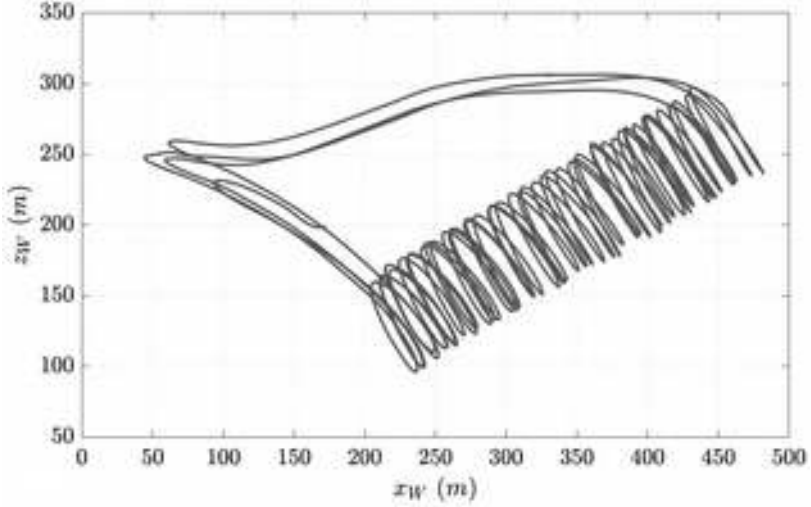


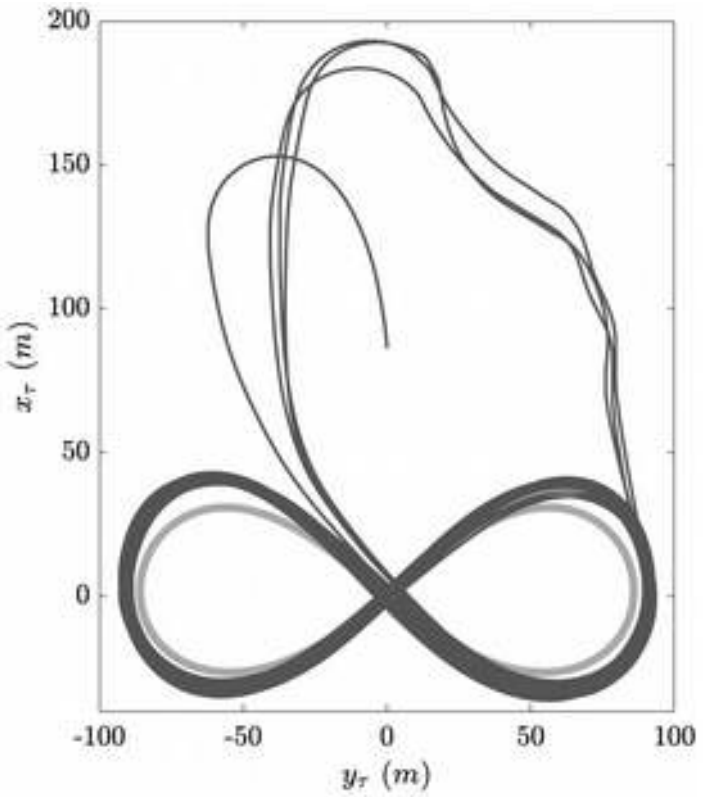
mass distribution	
wing	11.0 kg
KCU	8.4 kg
sensors	2.4 kg
kite total	22.8 kg

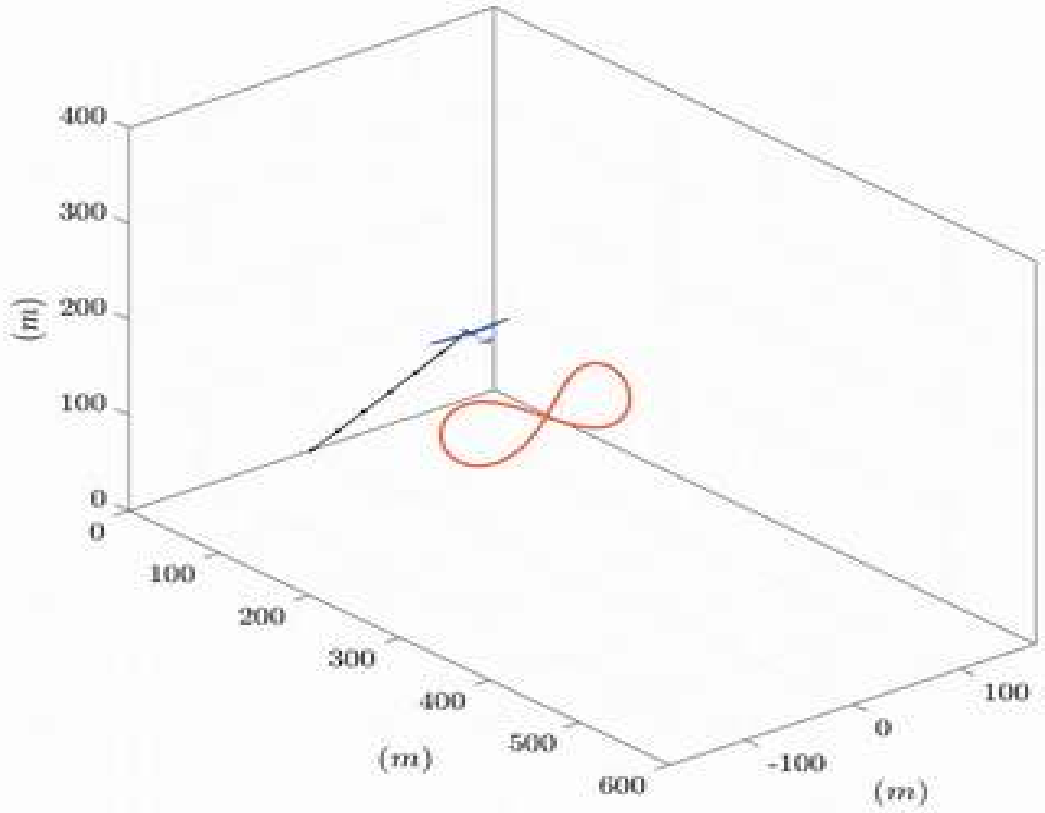
Aerodynamics



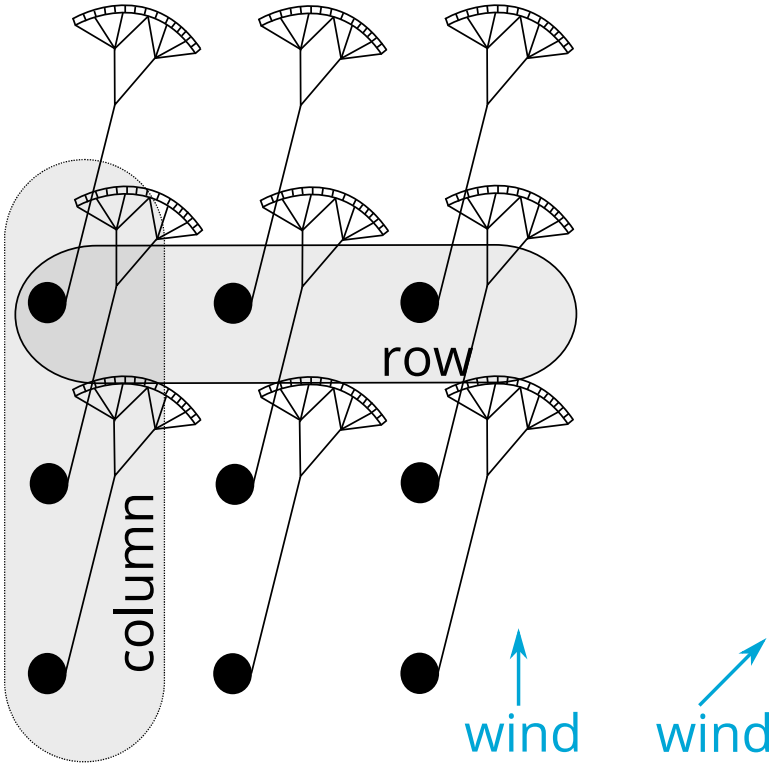

300
200
100
0
z_W (m)
-300
-200
-100
0
100
200
300
y_W (m)
$\mathbf{p}_i^G$
$\mathbf{v}_{k,T}$
δ
$\mathbf{t}(s^*)$
$\Gamma(s^*)$

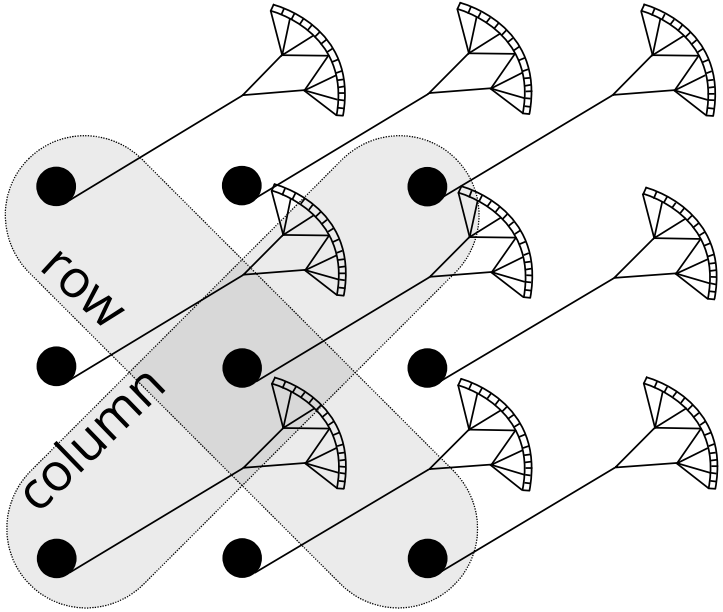

350
300
250
200
150
100
50
z_W (m)
0
50
100
150
200
250
300
350
400
450
500
x_W (m)


200
150
100
50
0
x_T (m)
-100
-50
0
50
100
y_T (m)

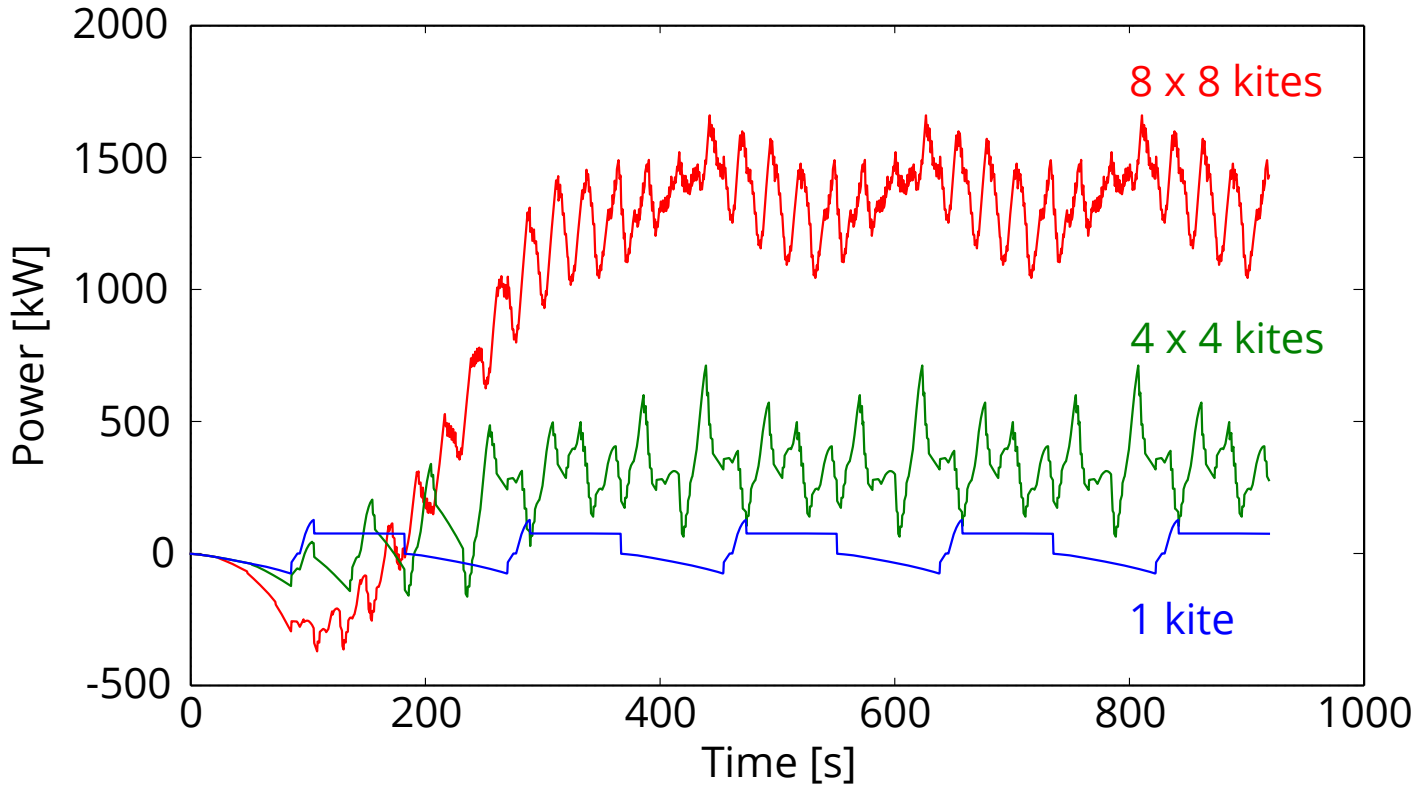

400
300
200
100
0
(m)
0
100
200
300
400
500
600
(m)
100
0
-100
(m)

Kite park layout





Kite park power output




ETH zürich
DTU
TU Delft

Development as an industry

- Many bottom-up initiatives, e.g. by students and PhD researchers, only later picked up by academic staff
- Initially driven by research on control & optimization
- Full automation, reliability and materials are critical technical challenges
- Developed in parallel to conventional wind energy
- Since a few years also the wind energy community shows interest

Infrastructure

- EU-H2020 doctoral school AWESCO (2015-2018)
- Industry association “Airborne Wind Europe”
- EAWE Technical Committee “Airborne Wind Energy”

Impact of EU funding

FP7

- **HAWE** - FP7-ENERGY
- **Highwind** - ERC

Horizon 2020

- **AWESCO** - European Training Network
- **AMPYXAP3** - SME Instrument Phase I & II
- **REACH** - Fast Track to Innovation Pilot

AWESCO
Airborne Wind Energy
System Modelling, Control & Optimisation

Impact of EU funding

Horizon 2020

- **NEXTWIND** - SME Instrument Phase I & II
- **AWESOME** - SME Instrument Phase I & II
- **SKYPULL** - SME Instrument Phase I
- **TWINGTEC** - SME Instrument Phase I
- **TWINGPOWER** - Eurostars

Delft

AWEC 2019, 15-16 October, Glasgow, United Kingdom
Book of Abstracts, edited by Roland Schmehl, Oliver Tulloch, 164 pages.
ISBN 978-94-6366-213-0
doi:10.4233/uuid:57fd203c-e069-11e9-9fcb-441ea15f7c9c
shortdoi:10/dcjm

AWEC 2017, 5-6 October, Freiburg, Germany
Book of Abstracts, edited by Moritz Diehl, Rachel Leuthold, Roland Schmehl, 188 pages.
ISBN 978-94-6186-846-6
doi:10.4233/uuid:4c361ef1-d2d2-4d14-9868-16541f60edc7
shortdoi:10/cd54

AWEC 2015, 15-16 June, Delft, The Netherlands
Book of Abstracts, edited by Roland Schmehl, 123 pages.
ISBN 978-94-6186-486-4
doi:10.4233/uuid:6e92b8d7-9e88-4143-a281-08f94770c59f
shortdoi:10/bjhs

AWEC 2013, 10-11 September, Berlin, Germany
Book of Abstracts, edited by Guido Lütsch, Christian Hiemenz, Roald Koch, 77 pages.
ISBN 978-94-6186-848-0
doi:10.4233/uuid:f91af52c-4e76-4cf5-917a-129455b3fca9
shortdoi:10/c5j3

AWEC 2011, 24-25 May, Leuven, Belgium
Book of Abstracts, edited by Jacqueline De Bruyn, Moritz Diehl, Reinhart Paelinck, Richard Ruiterkamp, 73 pages.
ISBN 978-94-6018-370-6
doi:10.4233/uuid:54a23dff-74f9-4007-b1d6-e92e0c458491
shortdoi:10/czgh

AIRBORNE WIND ENERGY CONFERENCE 2019

University of Strathclyde
Glasgow·UK·15-16 October

http://awec2019.com

Questions?

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https://twitter.com/kite_power

http://awesco.eu/

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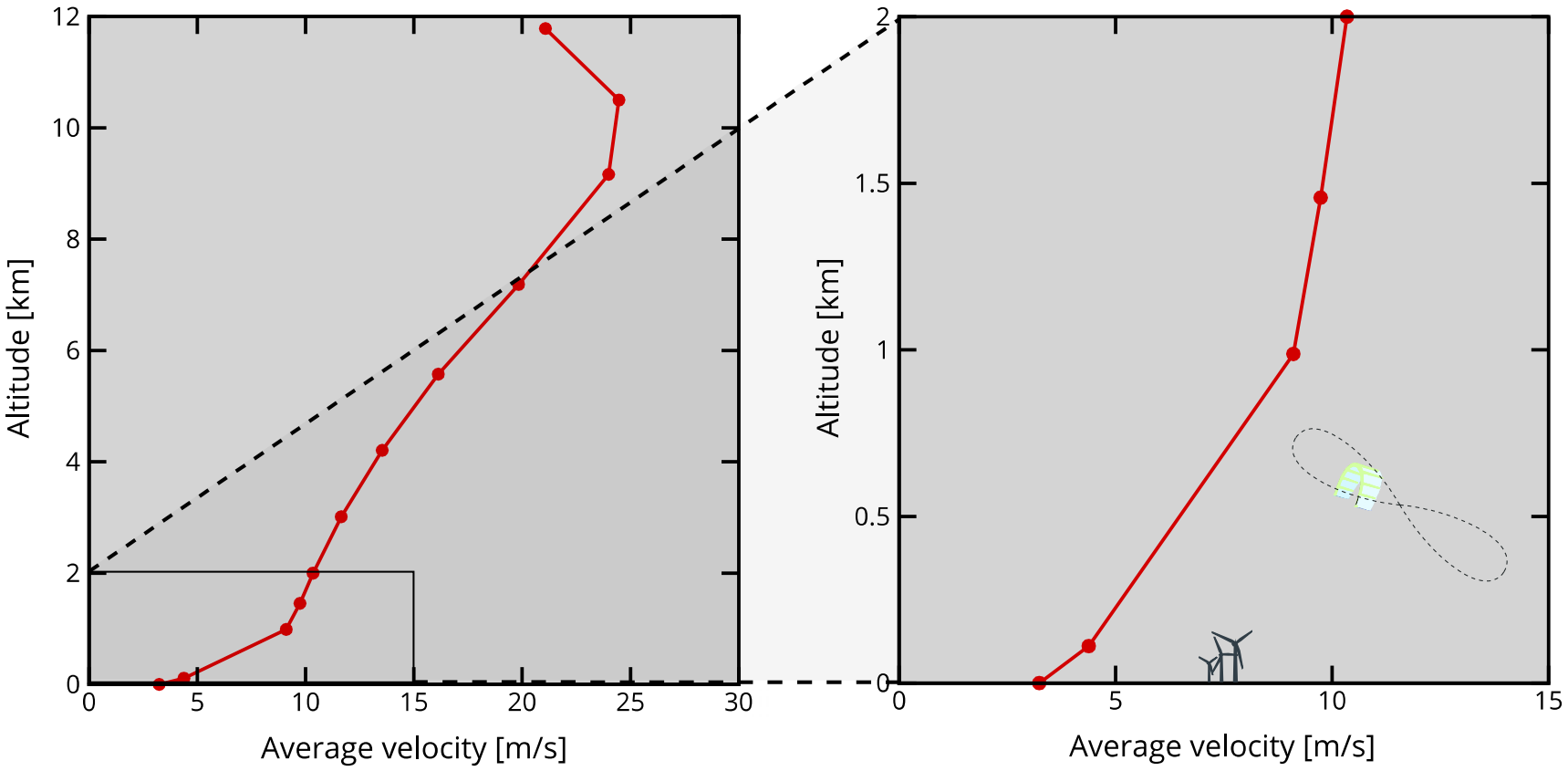

KNMI 20 year average wind data for De Bilt, the Netherlands.