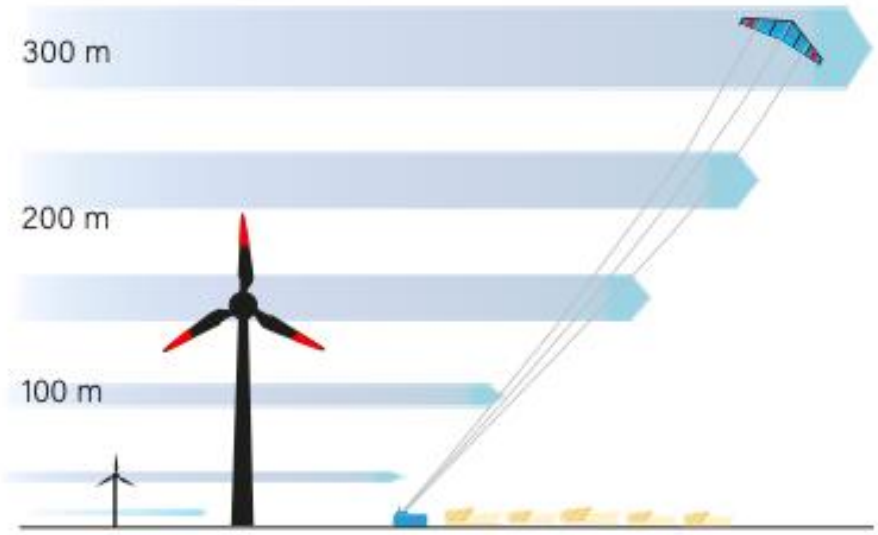
EnerWing_xM
Development of a Scalable MW-Class Airborne Wind Energy System

Denes Fischer, Benjamin Church, C.N. Nayeri, C.O. Paschereit

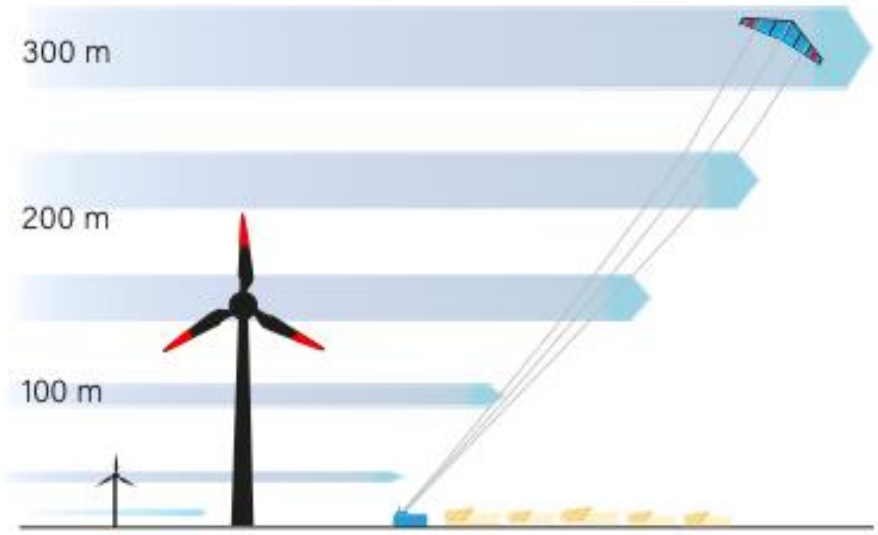
Chair of Fluid Dynamics
– Hermann-Föttinger-Institut –
Technische Universität Berlin

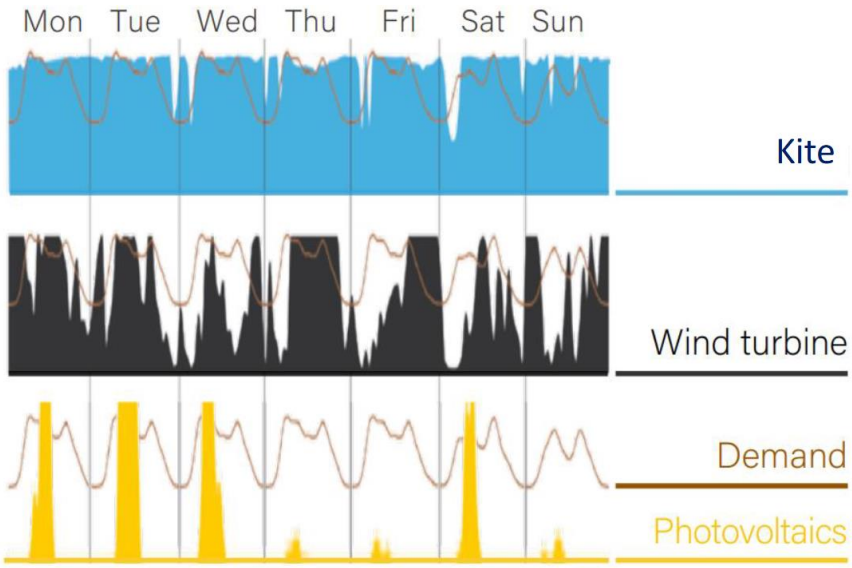
Airborne Wind Energy

- What & why?



- What & why?





EnerKite

Airborne Wind Energy

- How?

Airborne Wind Energy

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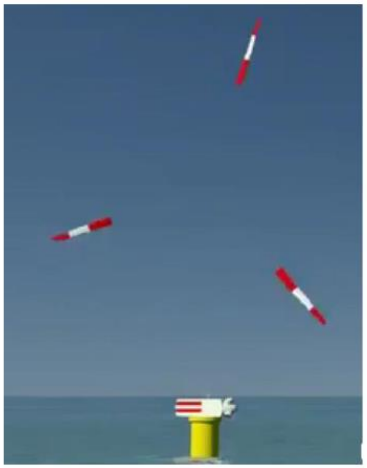
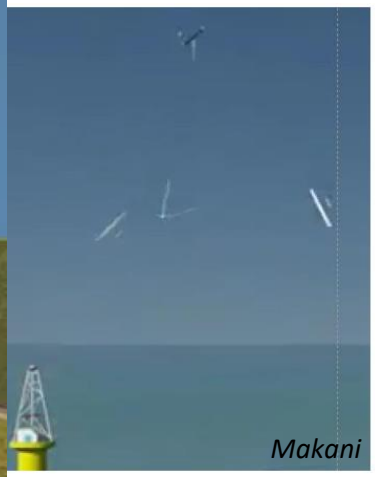


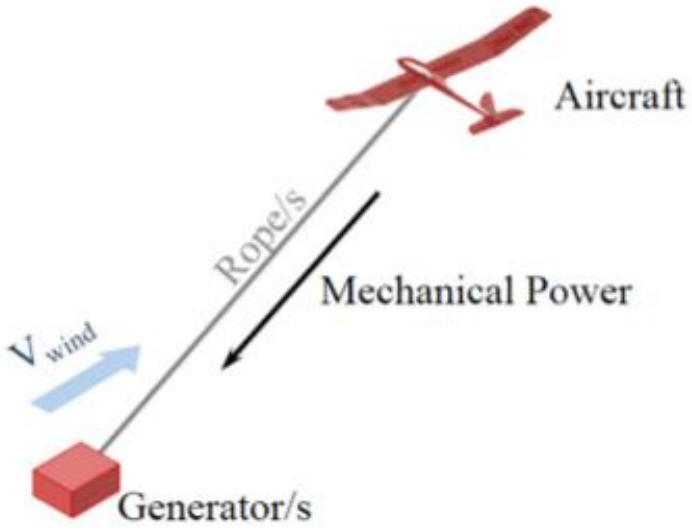
Airborne Wind Energy

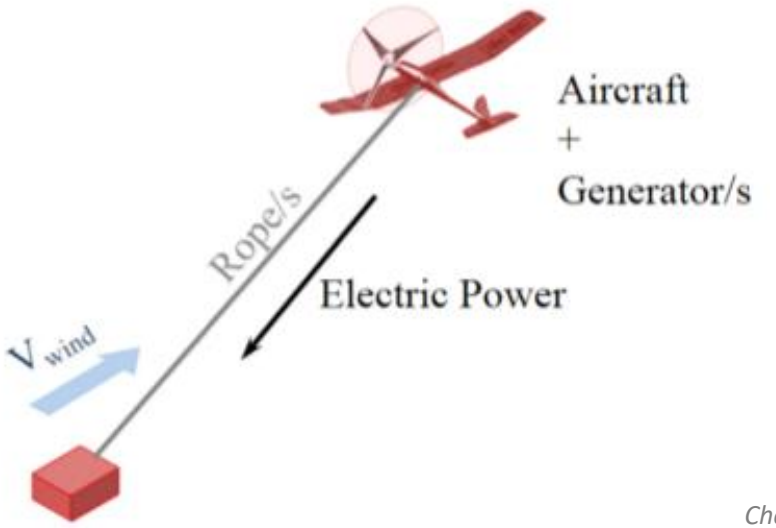
- How?



Airborne Wind Energy

Ground-Gen vs. Fly-Gen

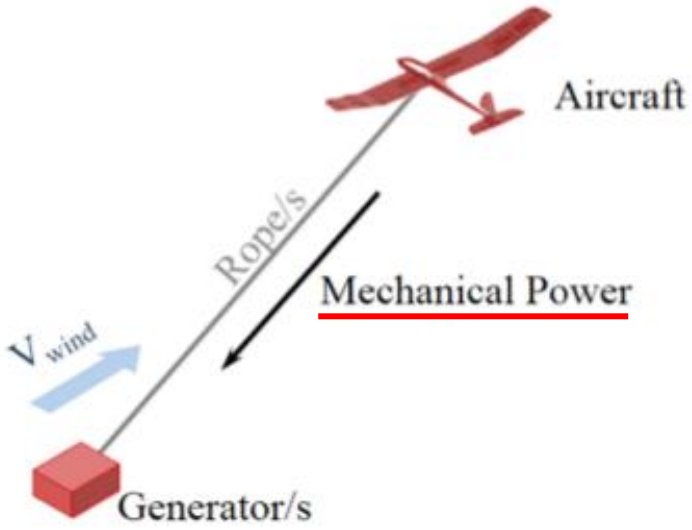


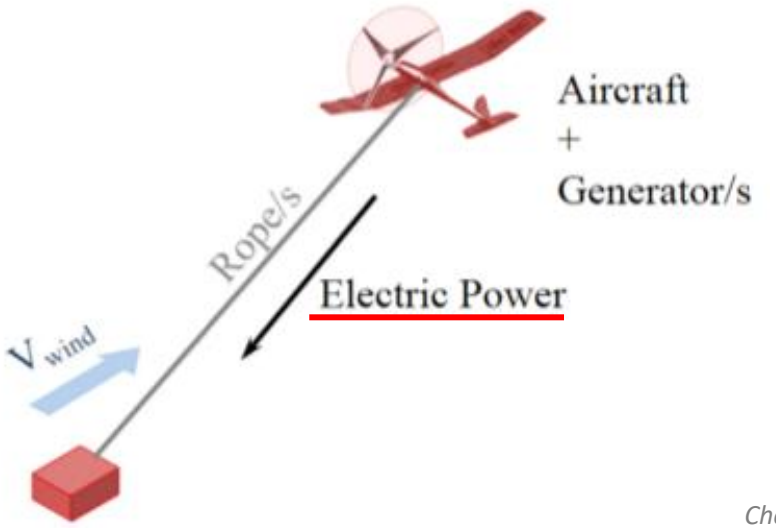


Cherubini et al.

Airborne Wind Energy

Ground-Gen vs. Fly-Gen





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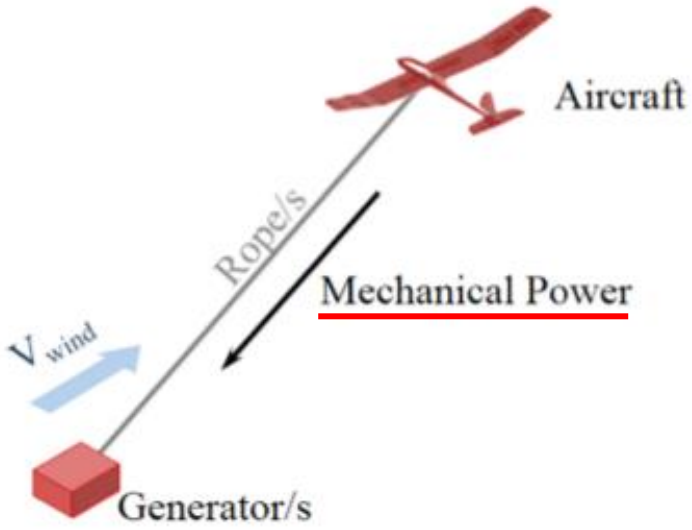

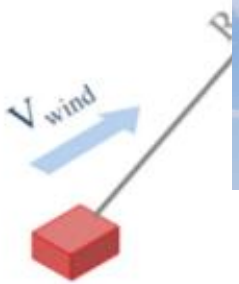

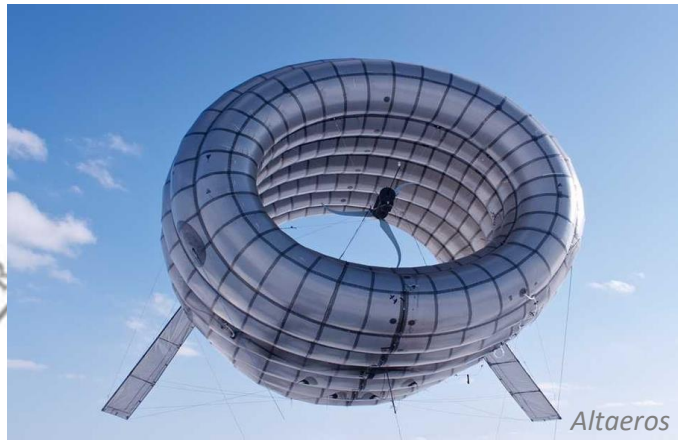

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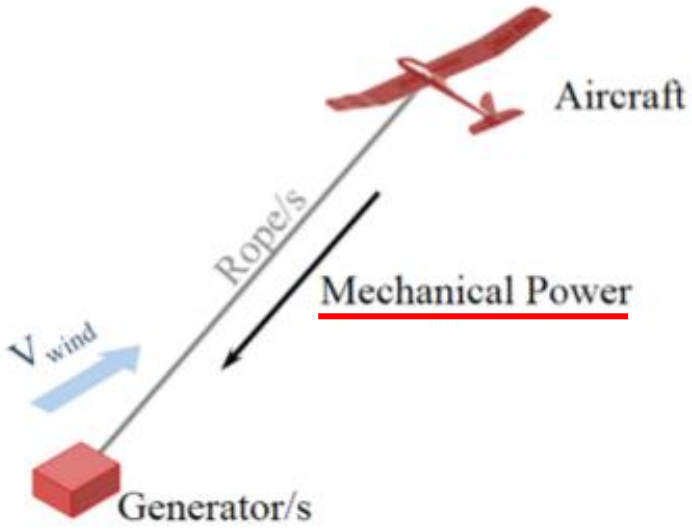
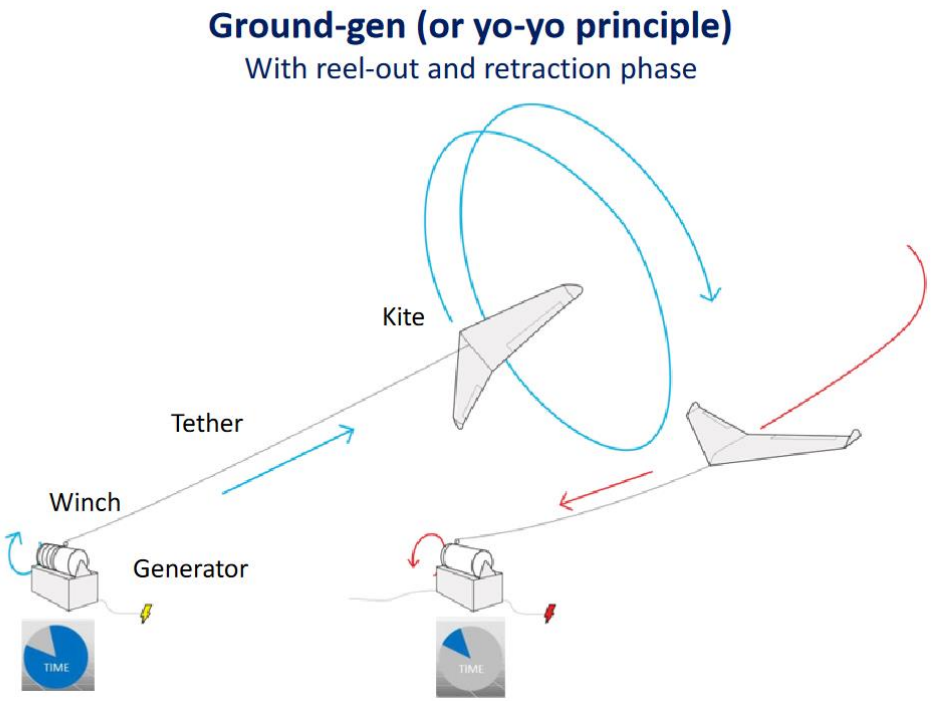
Airborne Wind Energy

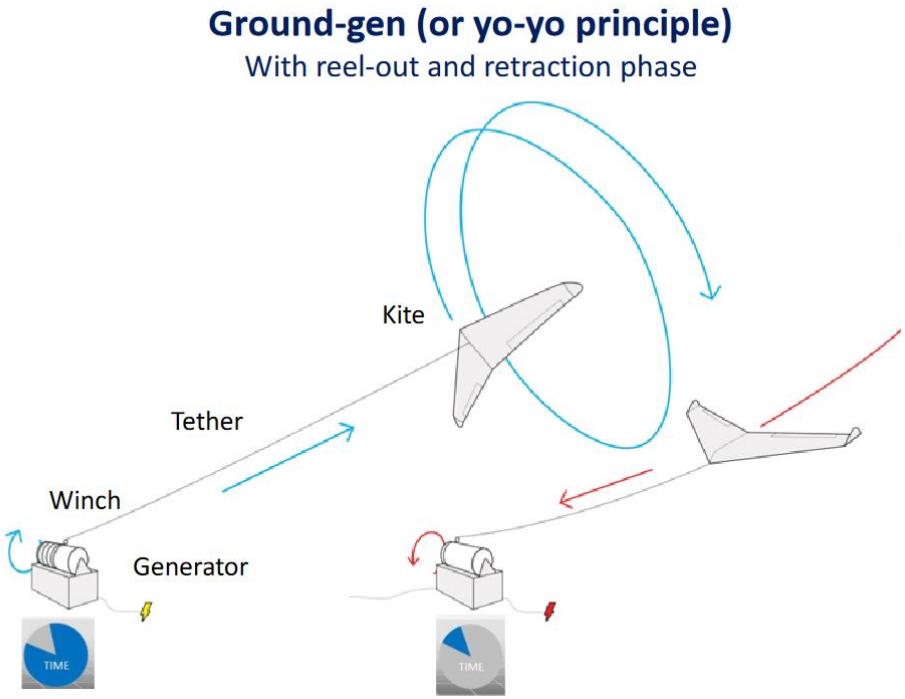
Ground-Gen vs. Fly-Gen



- Ground-Gen


Ground-gen (or yo-yo principle)
With reel-out and retraction phase
Kite
Tether
Winch
Generator
TIME
TIME

- Ground-Gen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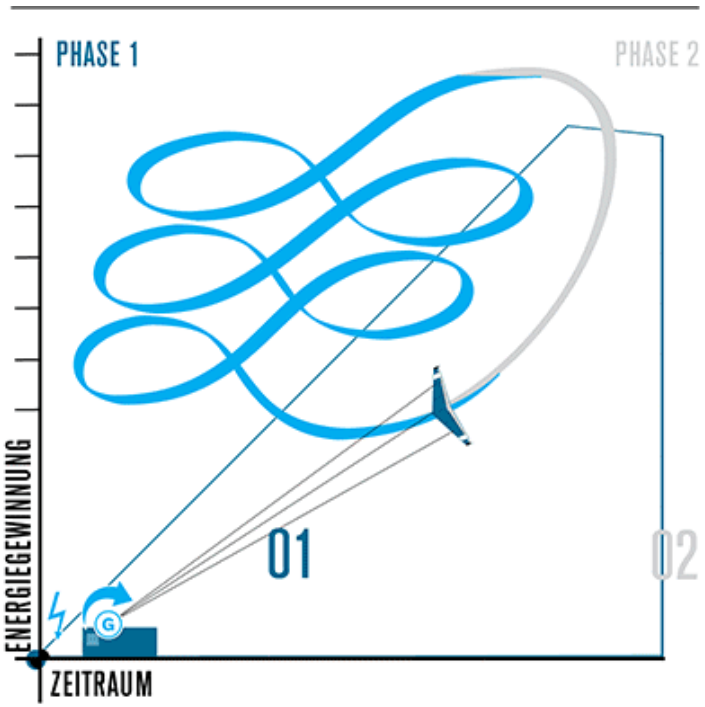
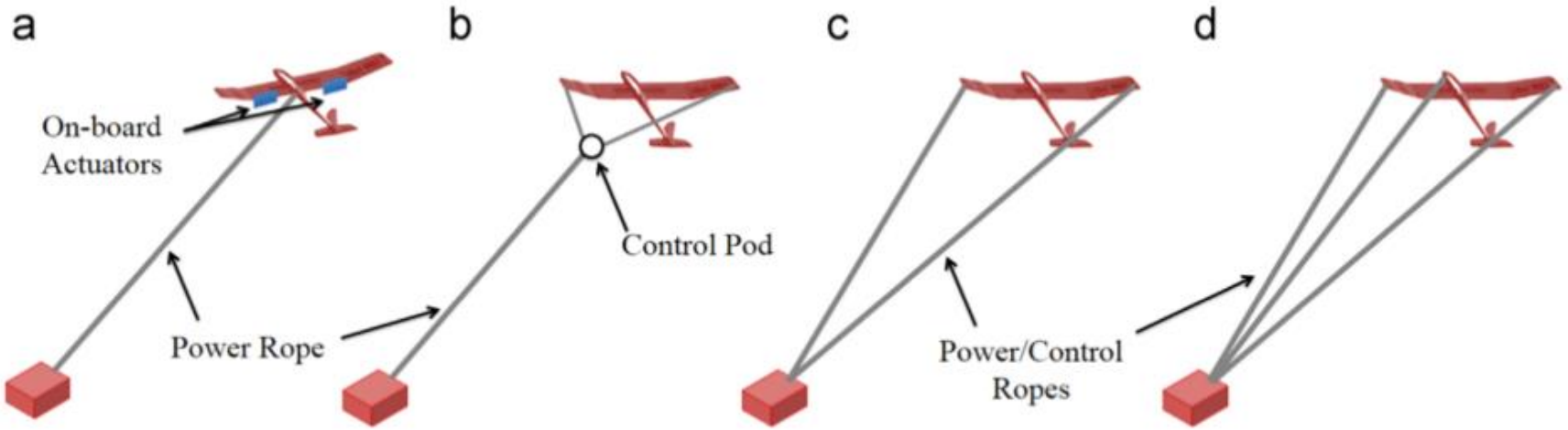

PHASE 1
PHASE 2
01
02
ENERGIEGEWINNUNG
ZEITRAUM

Airborne Wind Energy

- Kite control



a	b	c	d
Ampyx Power	Skysails	Kitegen Stem	Windlift
KU Leuven	Kitepower	Kitenergy	Enerkite
Kitemill	SwissKitePower	SwissKitePower	SwissKitePower
		Kitegen Carousel	
		NTS Energie	
		e-Kite	

Cherubini et al.

Airborne Wind Energy

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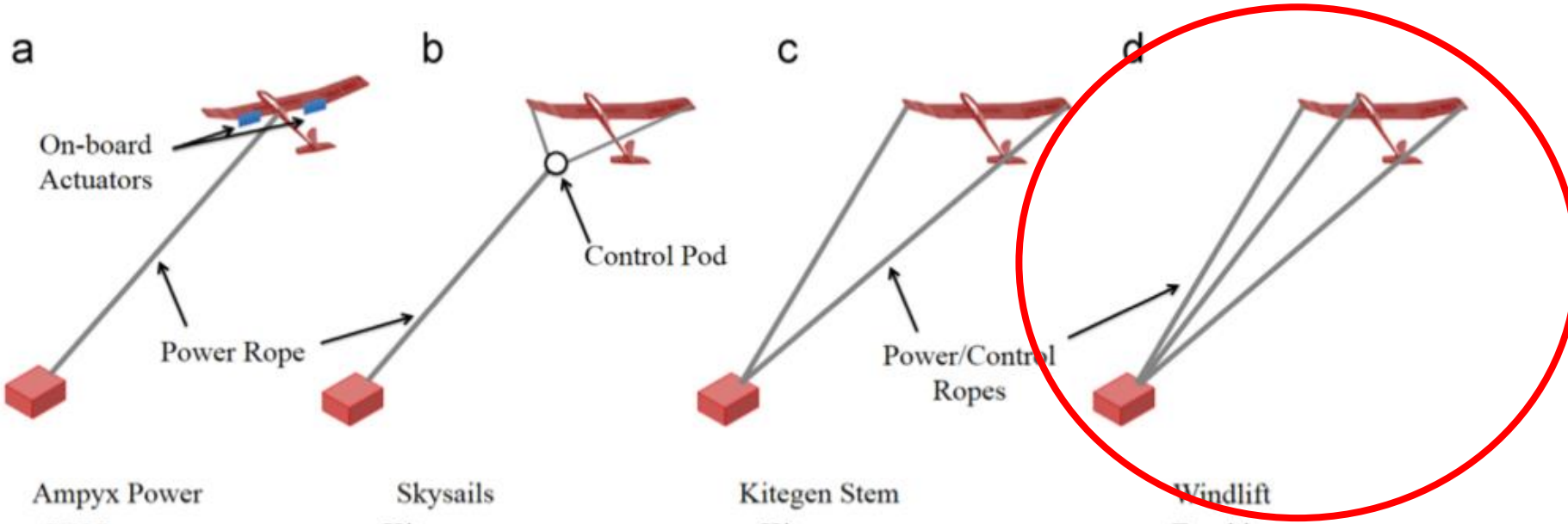

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Airborne Wind Energy

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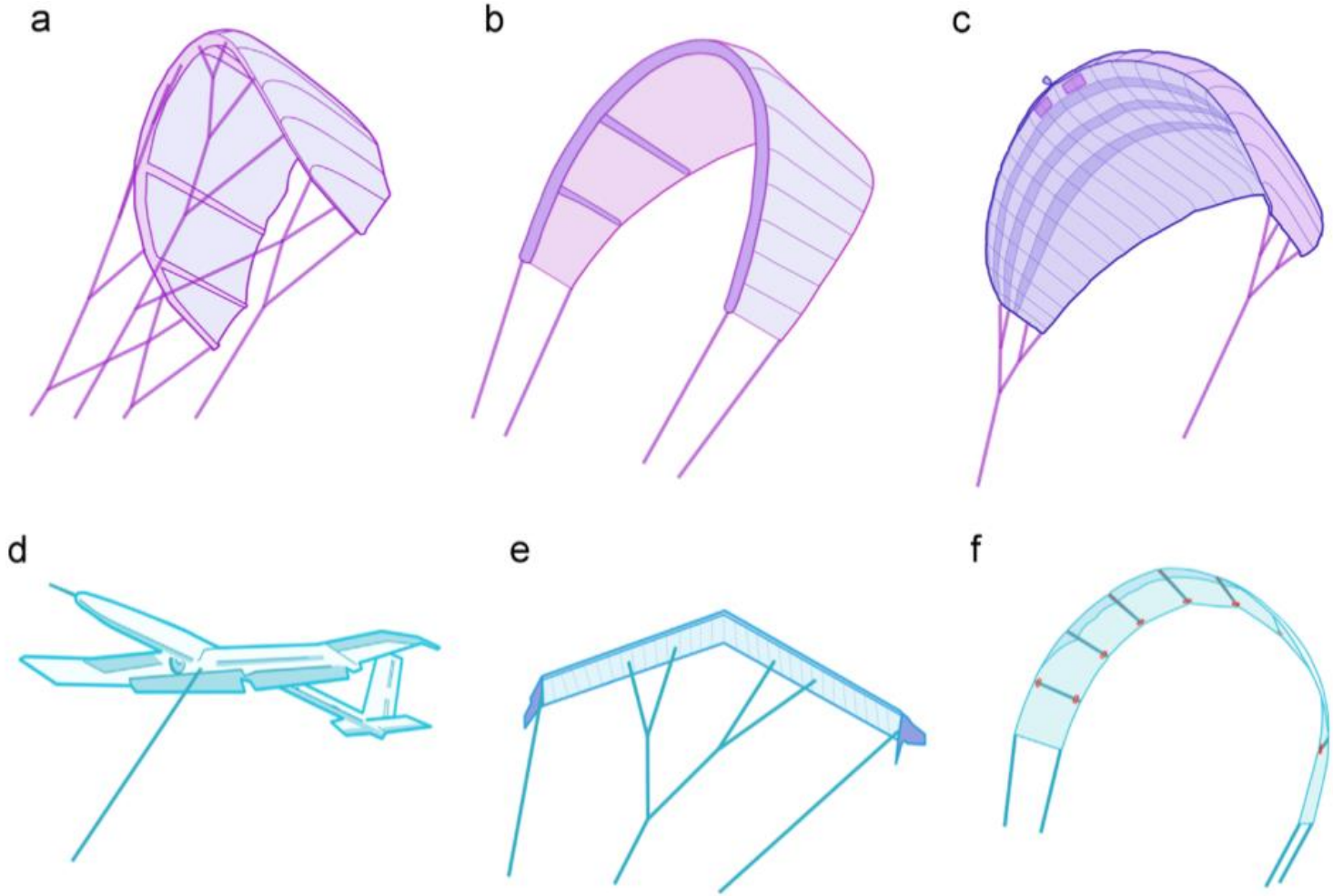

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Airborne Wind Energy

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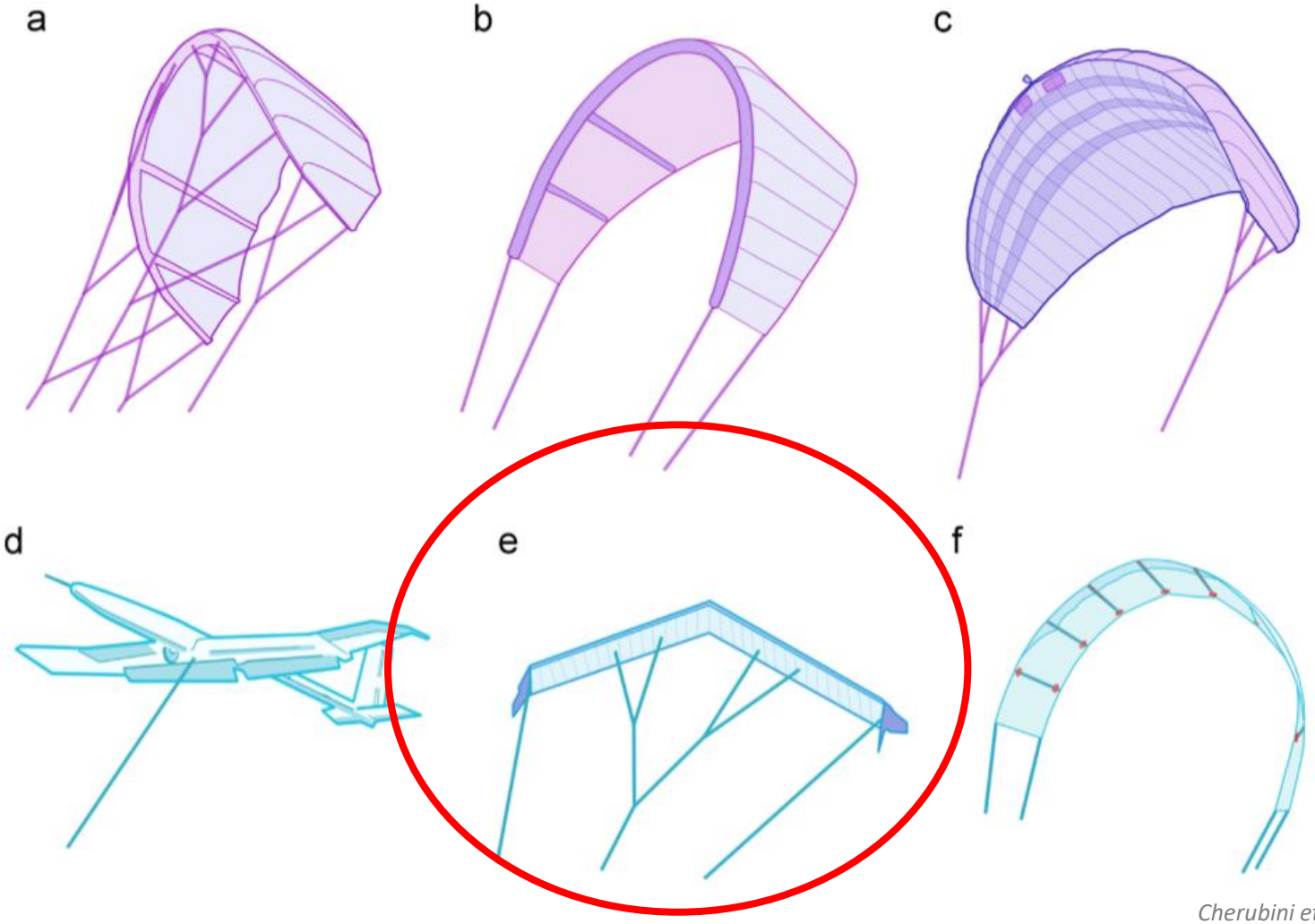

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AWE sales-pitch

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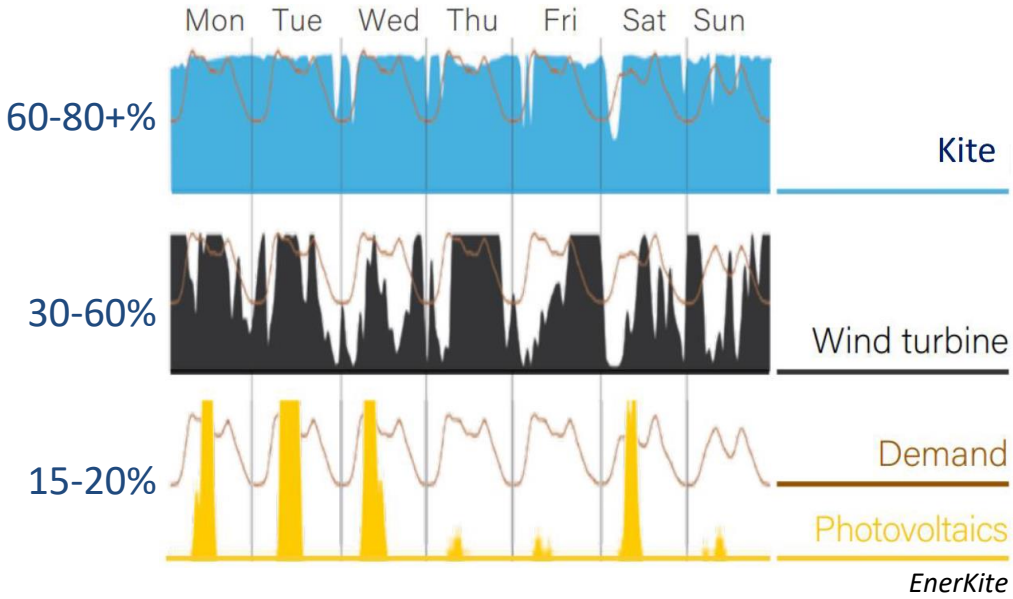
- high capacity factor



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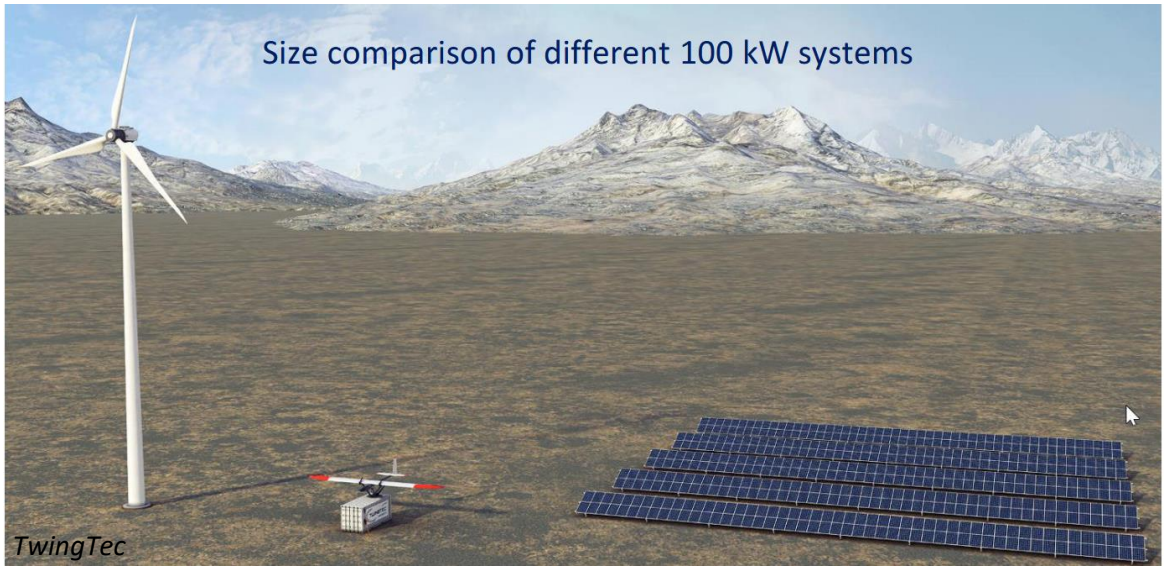
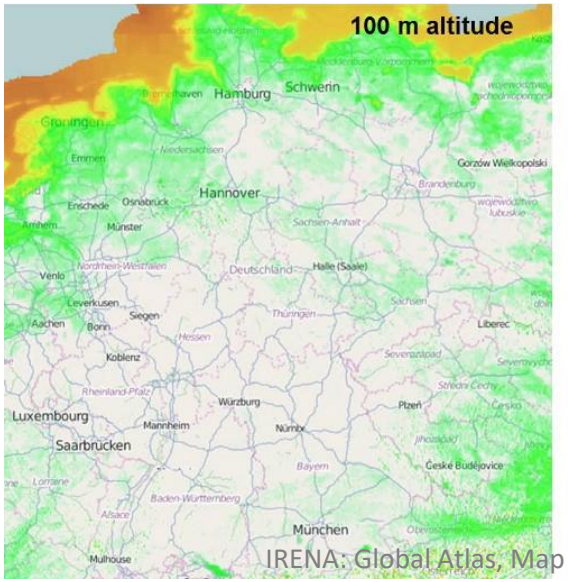
AWE sales-pitch

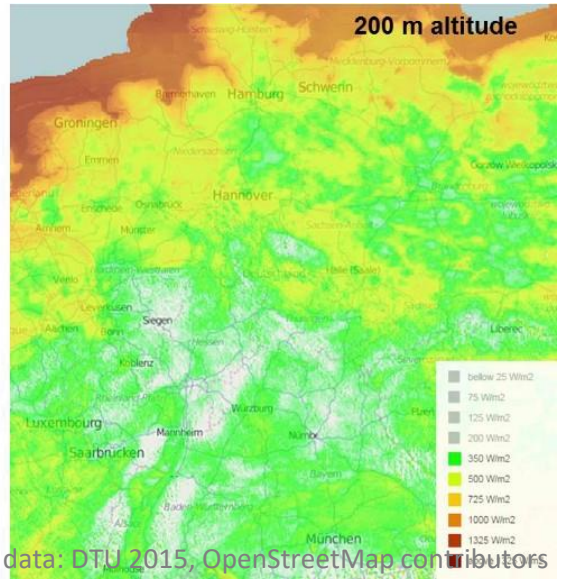
- high capacity factor
- less material



AWE sales-pitch

- high capacity factor
- less material
- more available resources

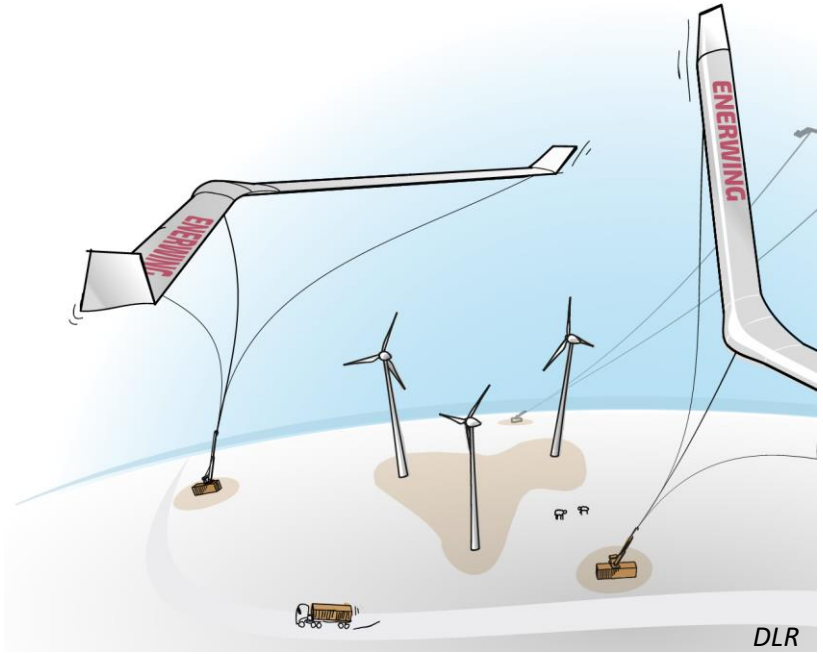




IRENA: Global Atlas, Map data: DTU 2015, OpenStreetMap contributors

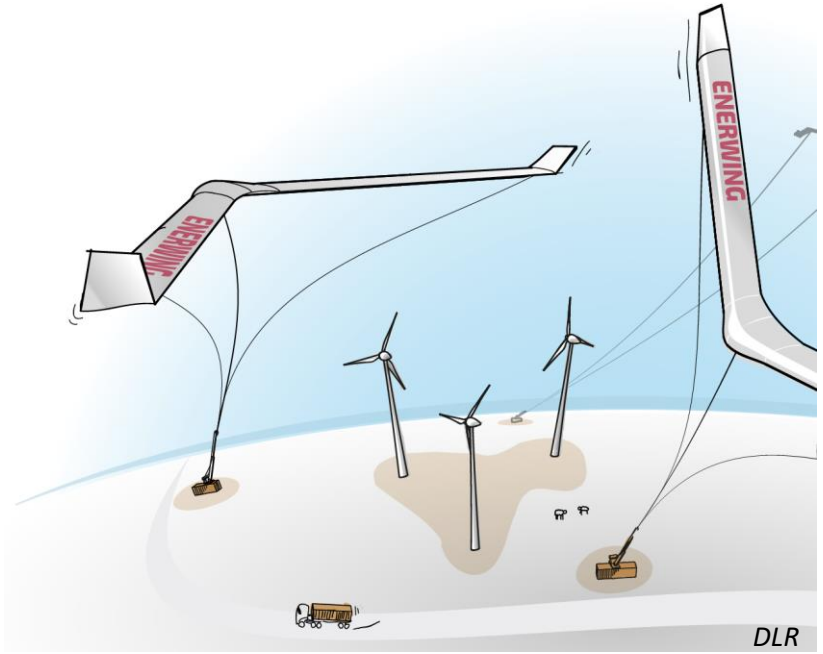
AWE sales-pitch

- high capacity factor
- less material
- more available resources
- flexibility



AWE sales-pitch

- high capacity factor
- less material
- more available resources
- flexibility
- scalable (few kW – several MW)
- low cost of energy produced
- …



EnerWing

Development & construction of a scalable MW-class AWE-system

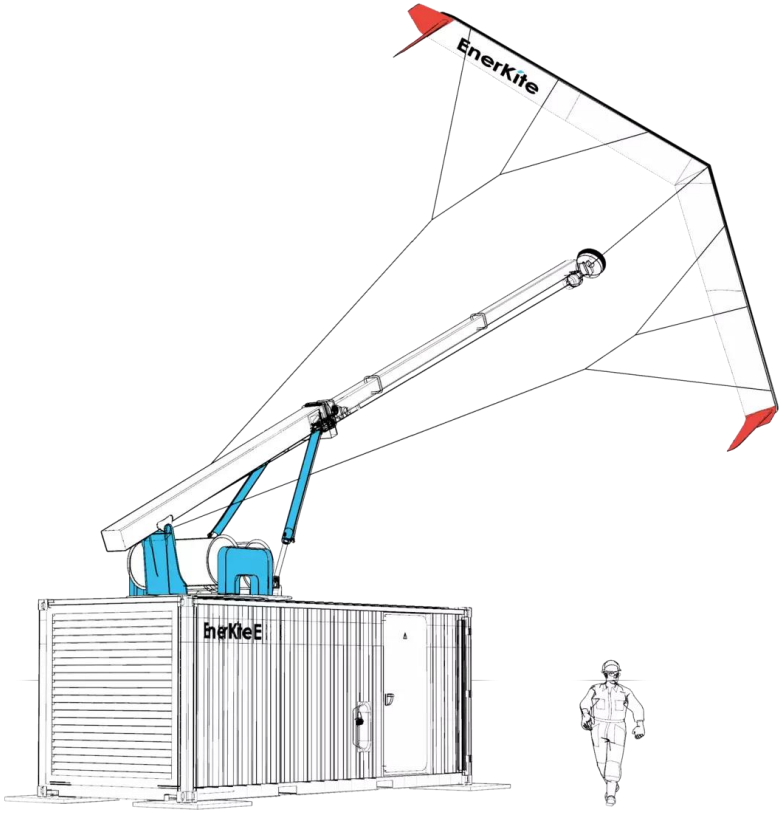
EnerKite DLR berlin INVENT Teut Windprojekte GmbH

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

EnerWing

- Development & construction of a scalable MW-class AWE-system (wing, ropes, start & landing, electronics, …)

ENERWING



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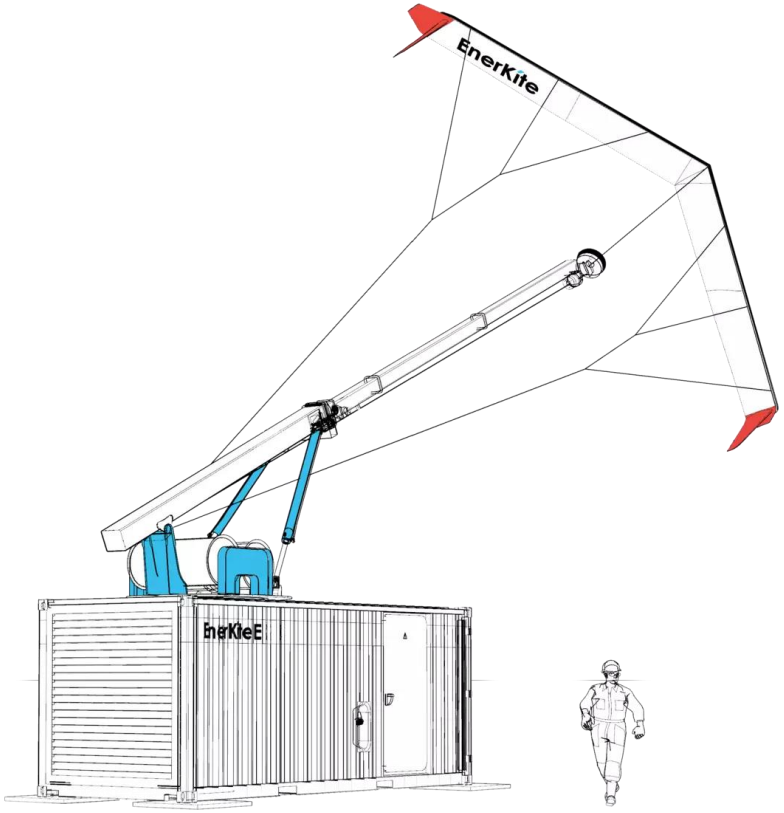

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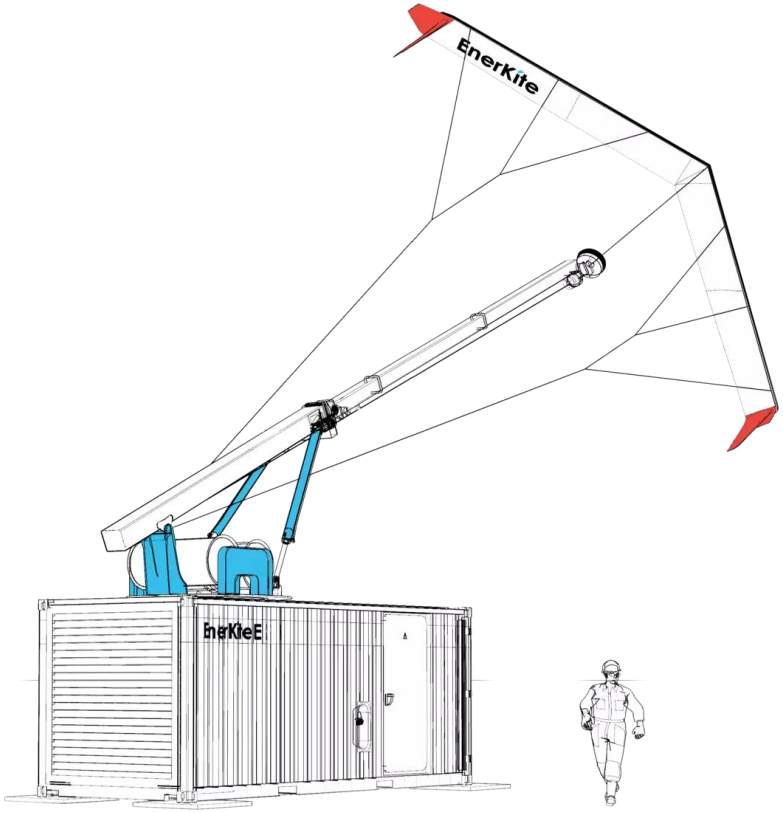

Tethered MW-wing:

- high aerodynamic performance
  - generation
  - retraction
  - start & landing
- light & stiff
- transportable in ISO-Containers
- scalable manufacturing process

  (10m – up to 50m)

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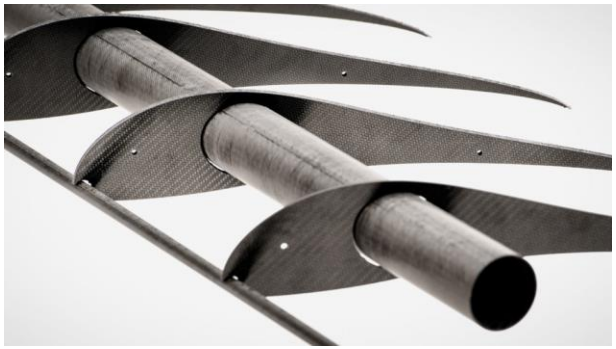

EnerWing

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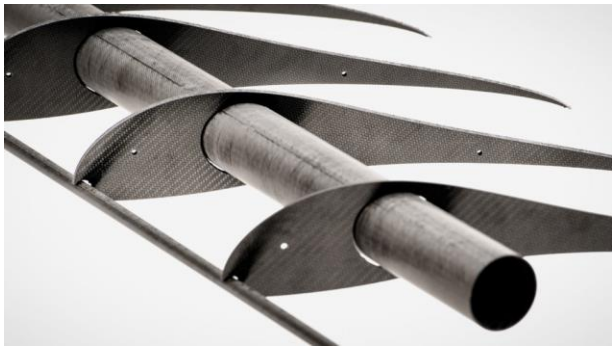

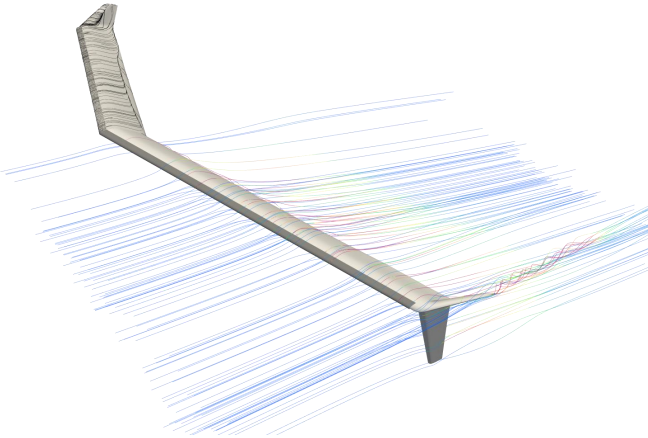

EnerWing @ TU Berlin

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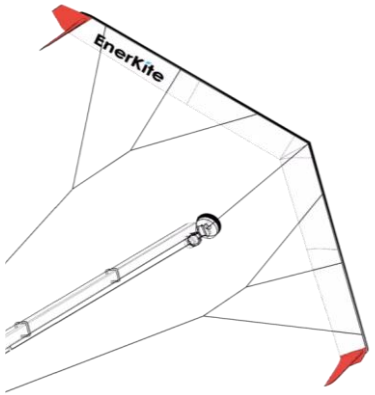
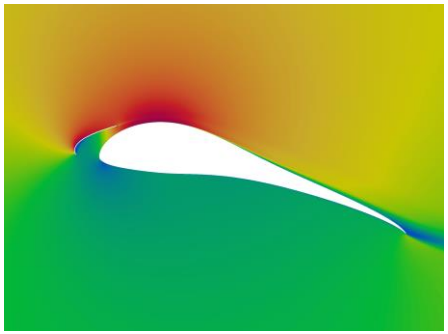
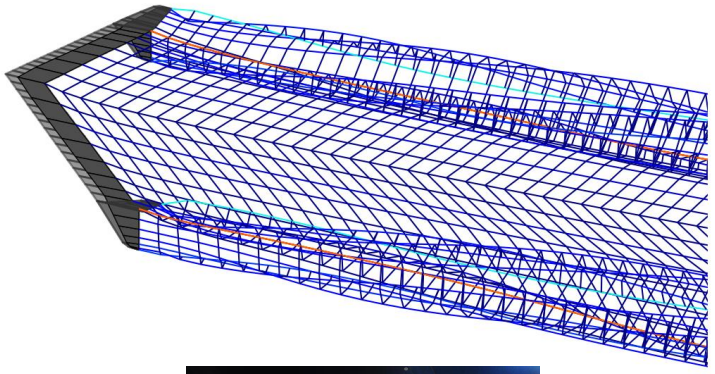
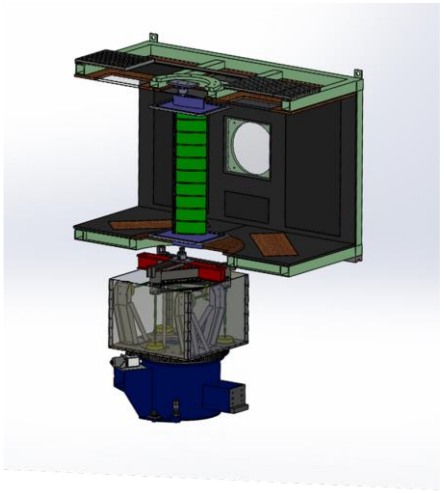
ENERWING

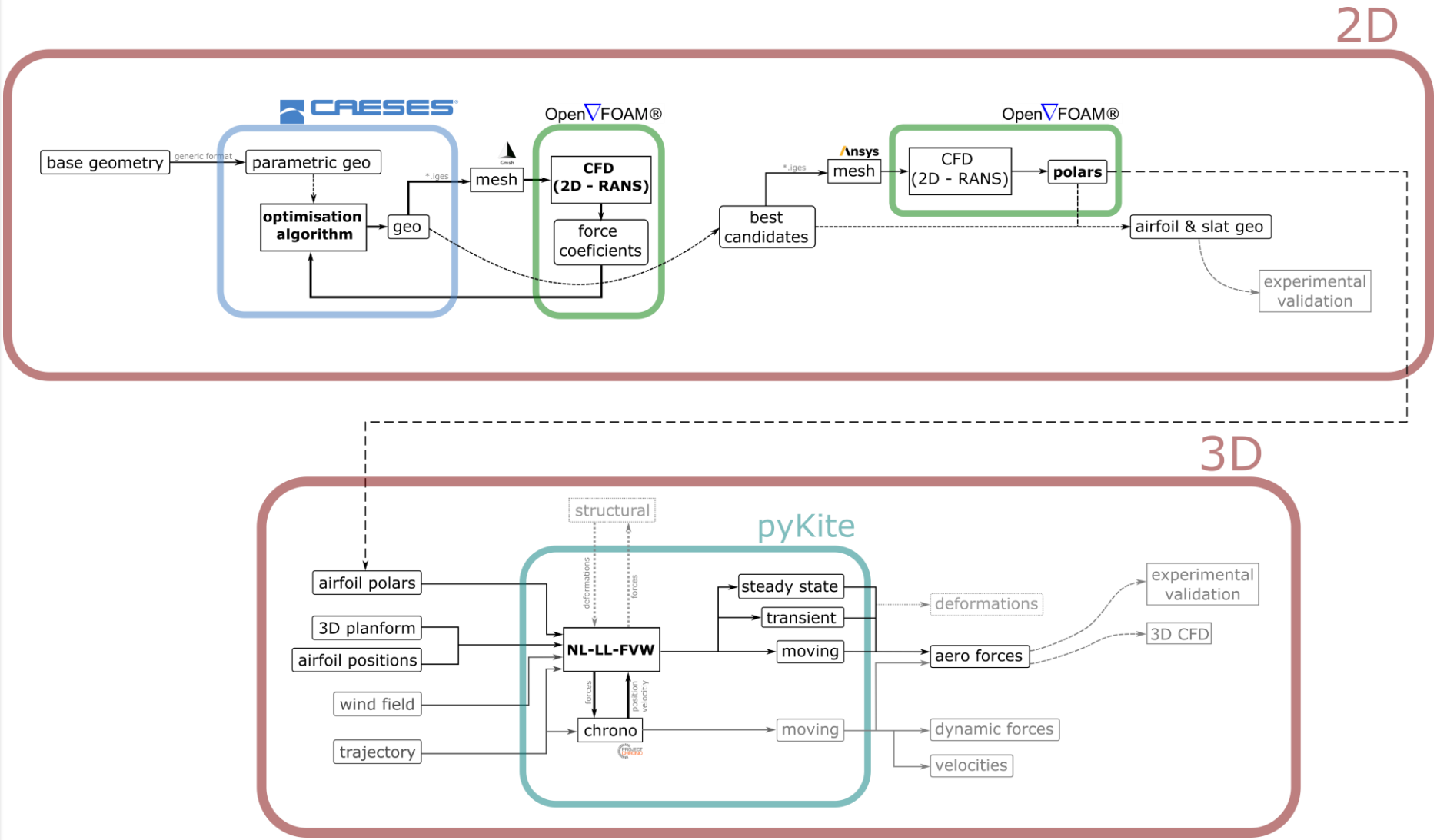


- Scope:
  - high-performance passive rigid-wing
- Aims:
  - reliable prediction of aerodynamic properties in an early design stage
  - validated tools & process

EnerWing @ TU Berlin

	2D	3D
numerical		
experimental		

Numerical workflow



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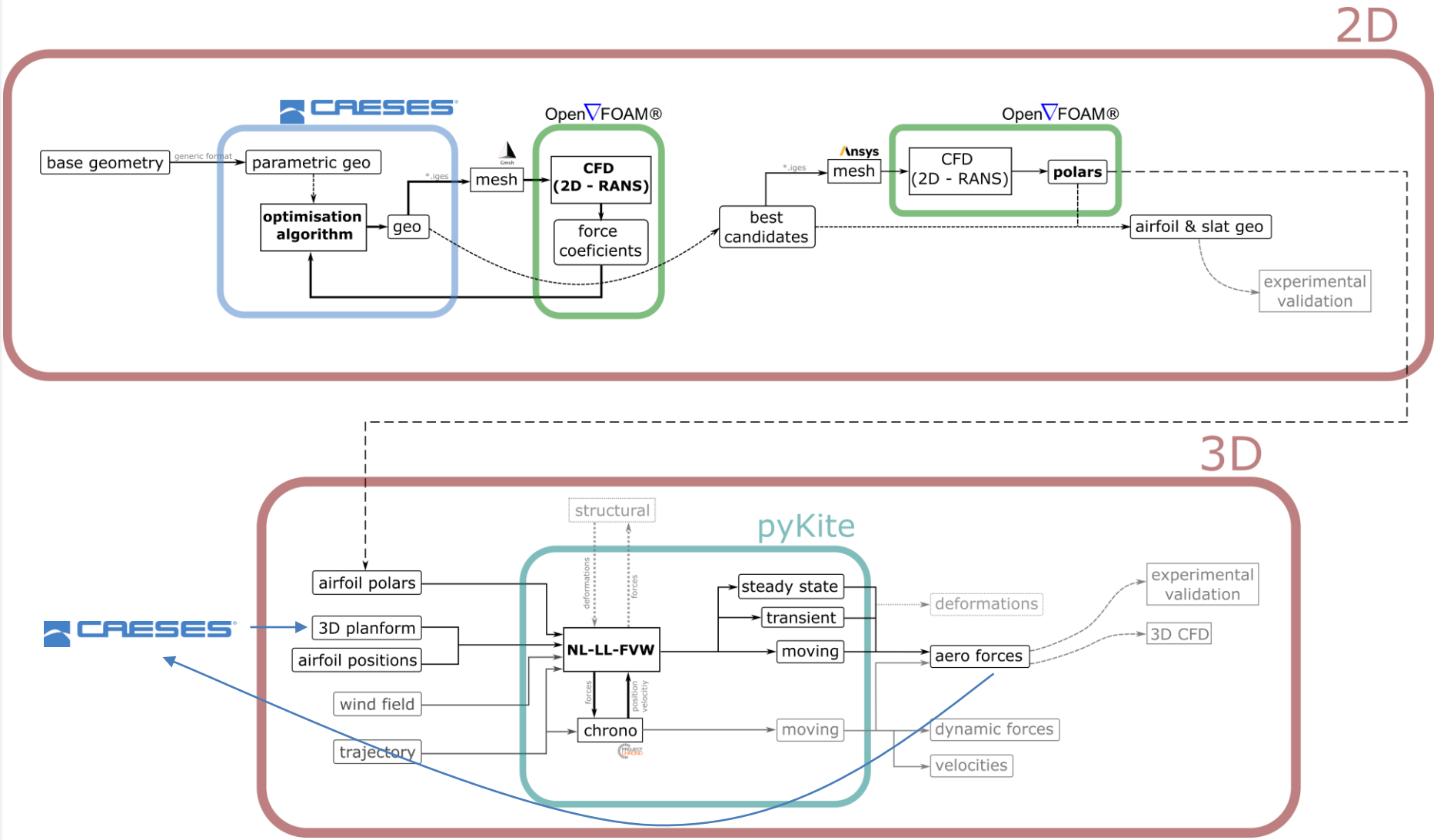
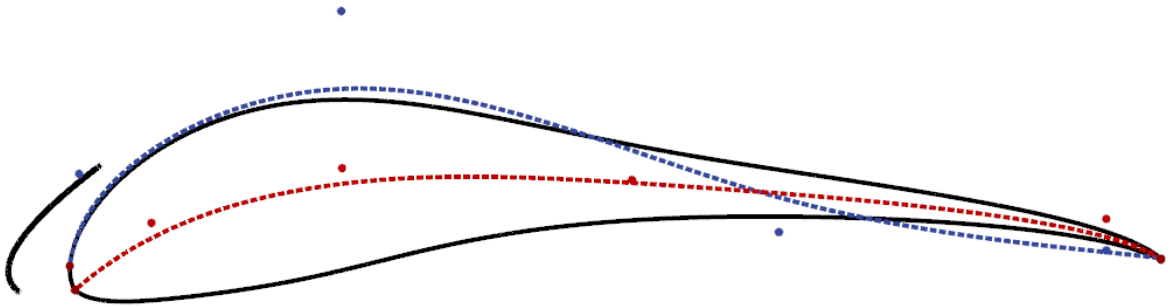


2D - Optimisation

- Constraints:
  - fixed slat
  - thin slat
  - high Reynolds-number (1.5e6)
- Optimisation:
  - Start: S1223
  - max. $\frac{C_l^3}{C_d^2}$, max. C_l



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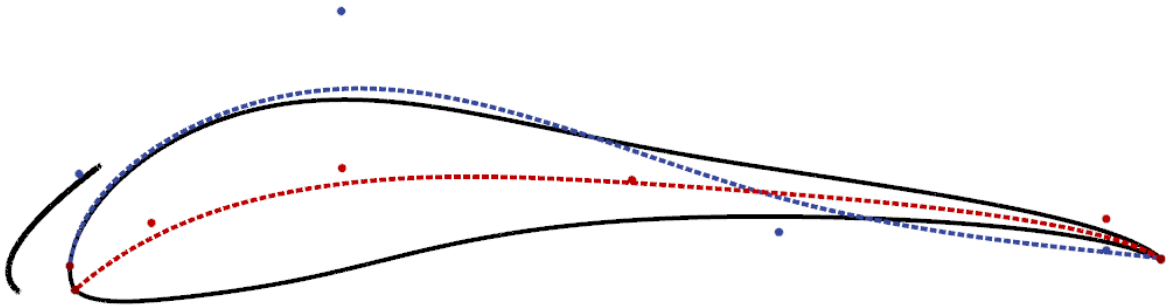
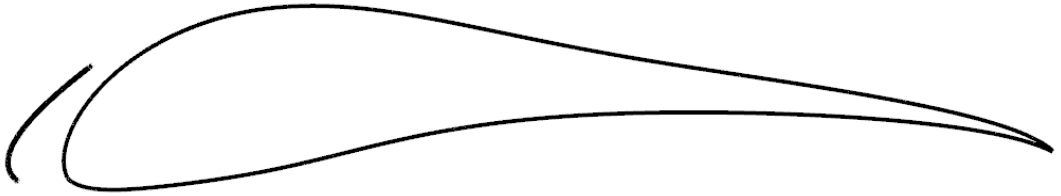


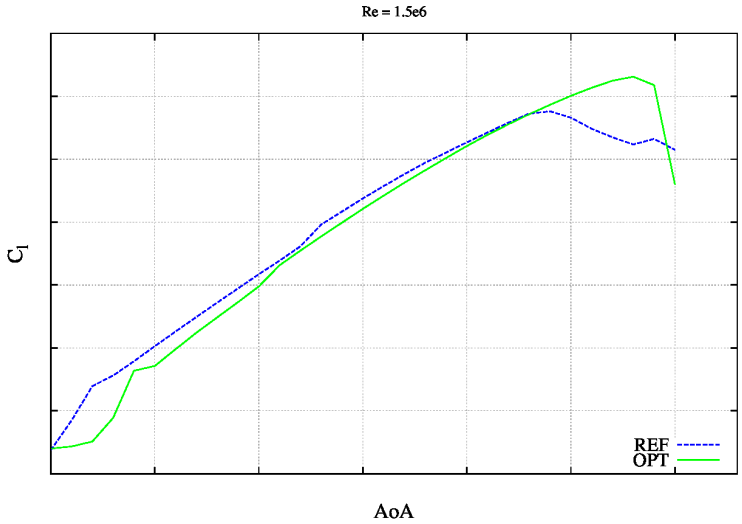
CAESES ⟷ OpenFOAM®

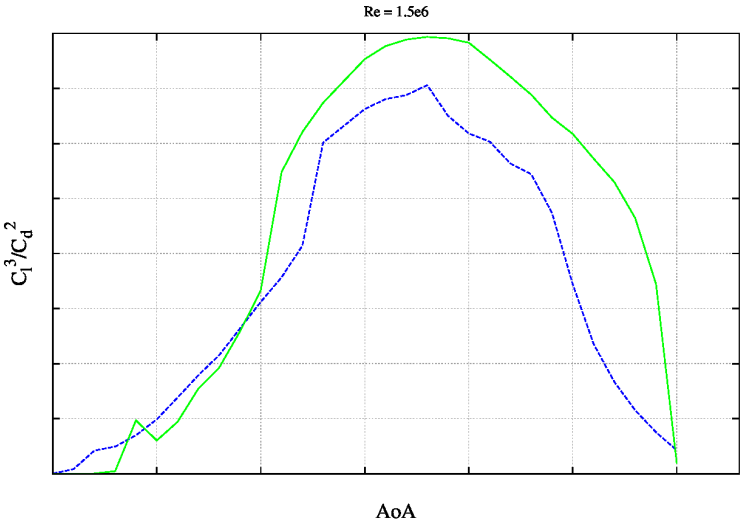
- B-splines
- NSGA-II & Tangent-Search
- 2D-RANS
- k-ω-SST-LM

2D - CFD

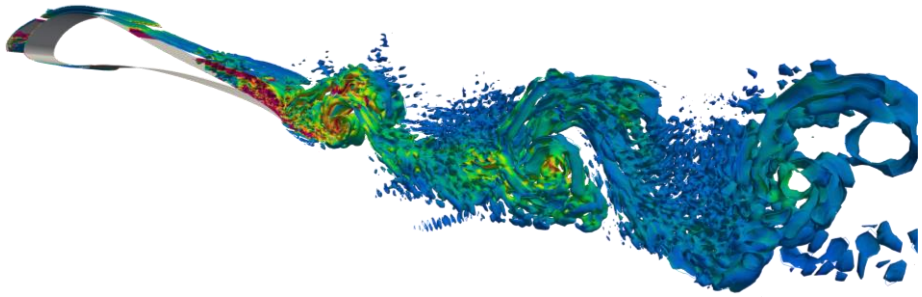
- 2D k-ω-SST-LM-RANS
- Re = 1,500,000







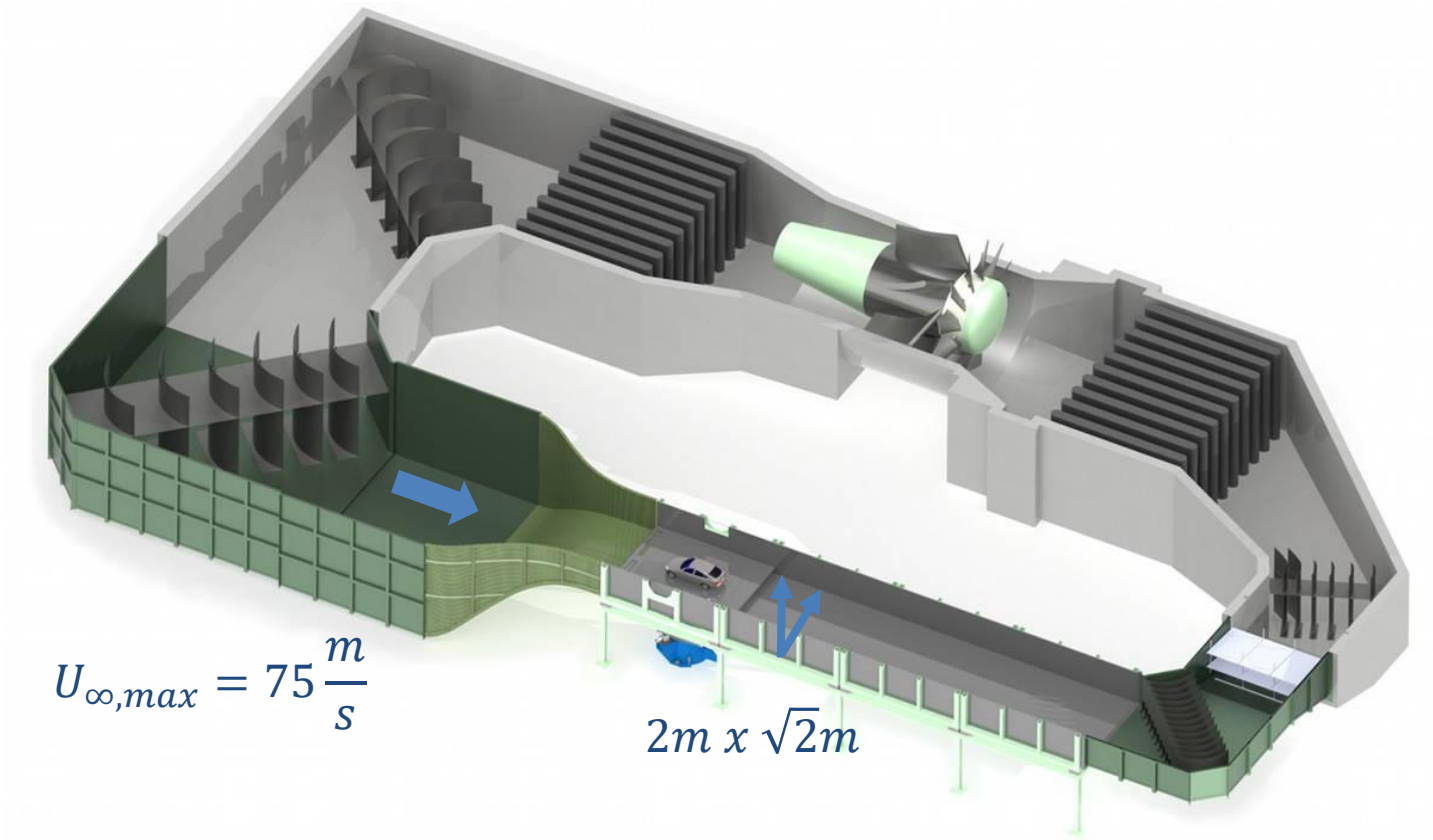
- DDES:



OpenFOAM®

2D - Experiments

- Wind-Tunnel (GroWiKa @ TU Berlin)



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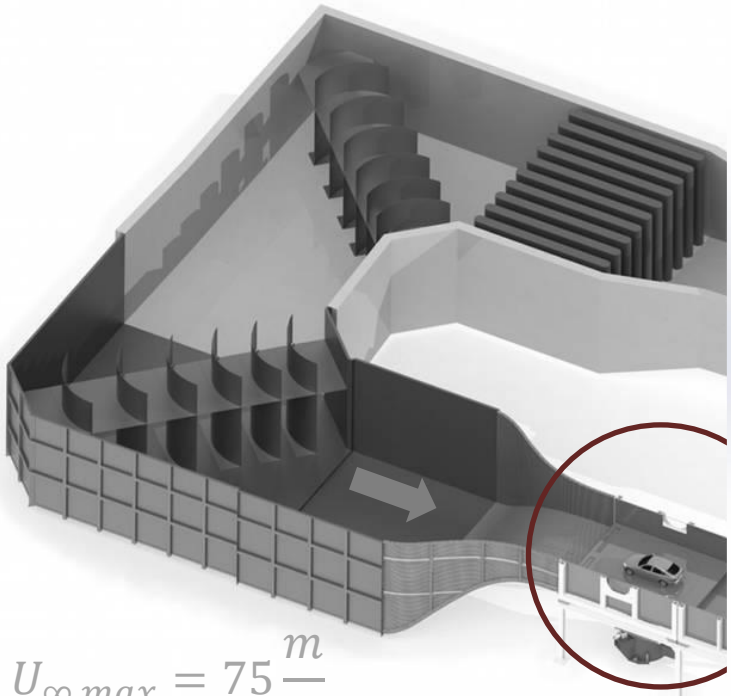
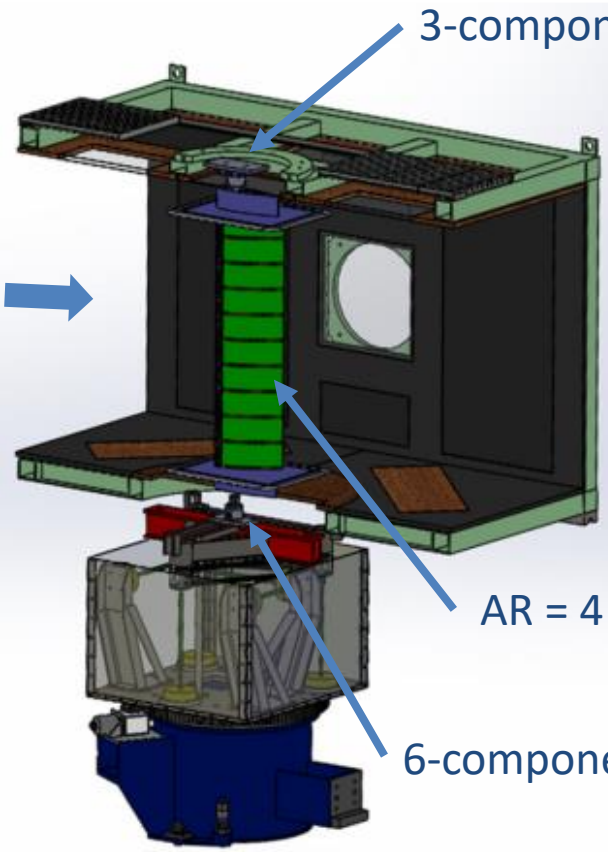


$U_{\infty,max} = 75 \frac{m}{s}$

$2m\ x$



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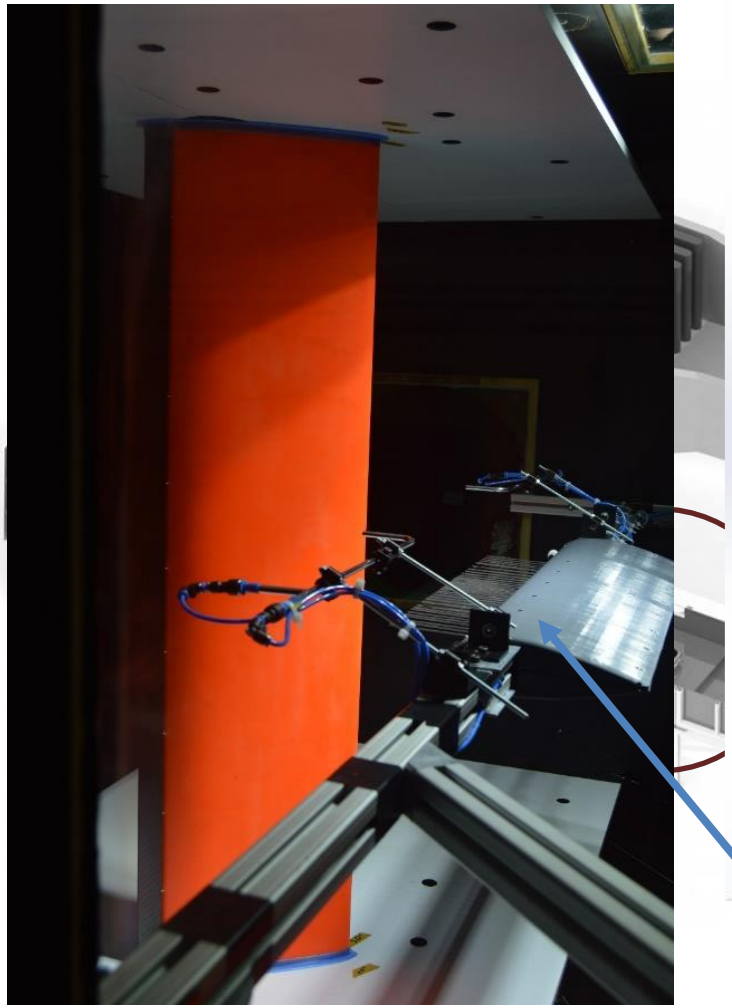
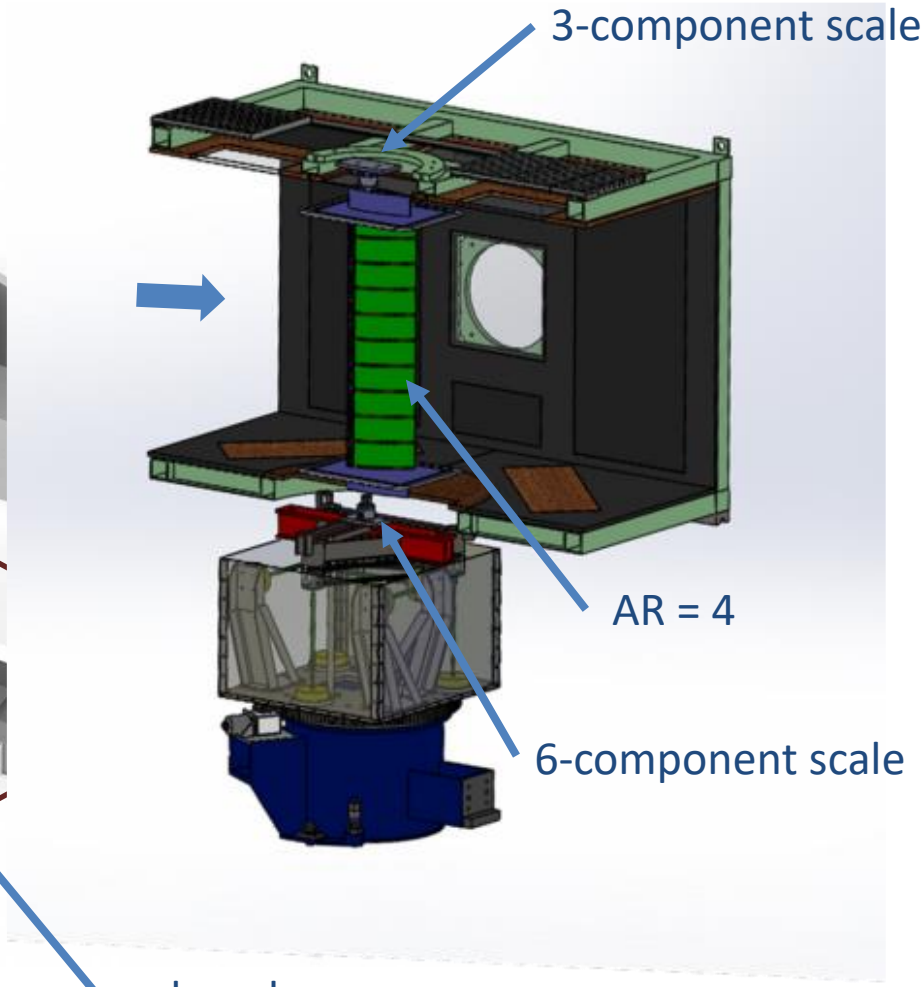
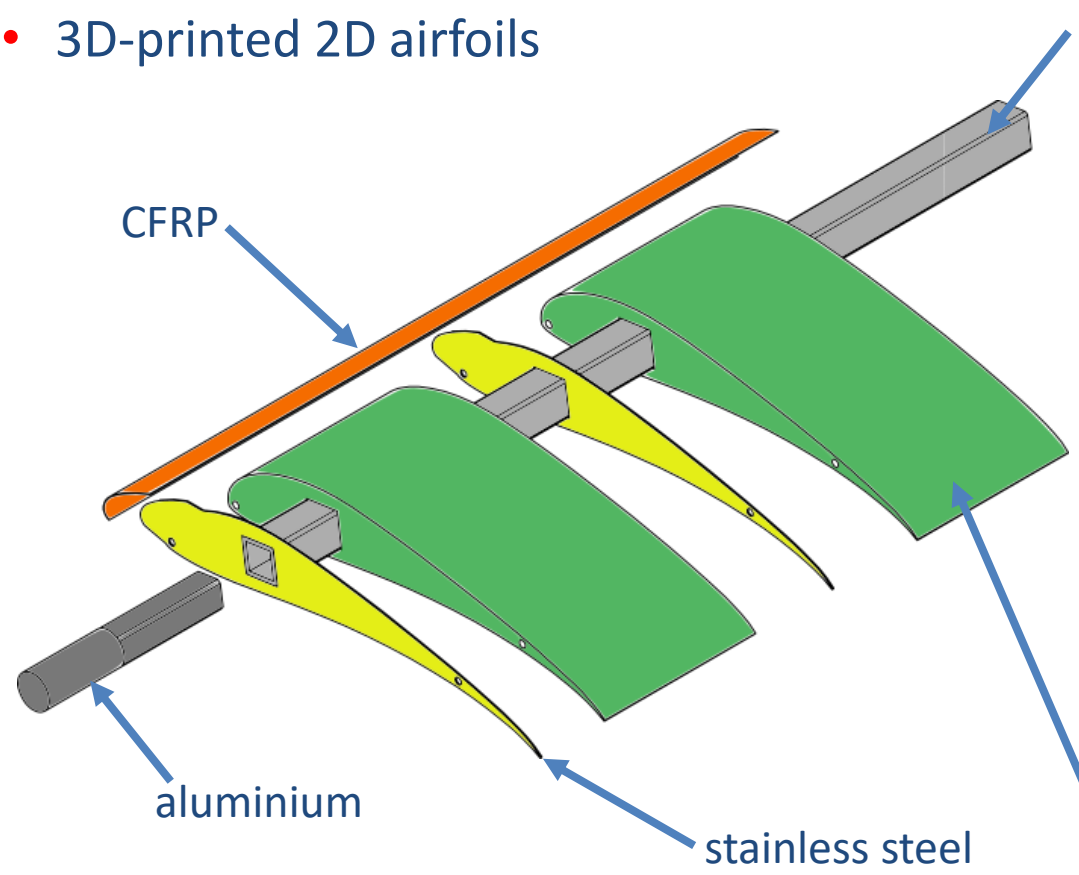
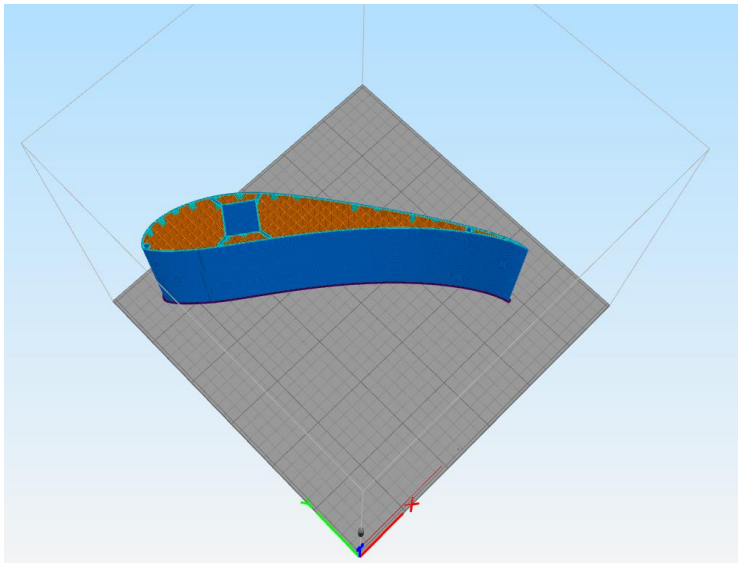




2D - Experiments

- 3D-printed 2D airfoils

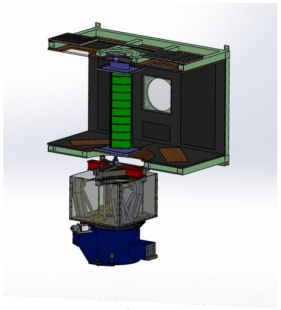




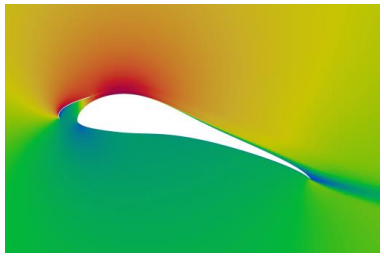
- c = 300mm
- AR = 4 (10 segments)
- $Re_{max} \sim 7\ 10^5\ -\ 1\ 10^6$

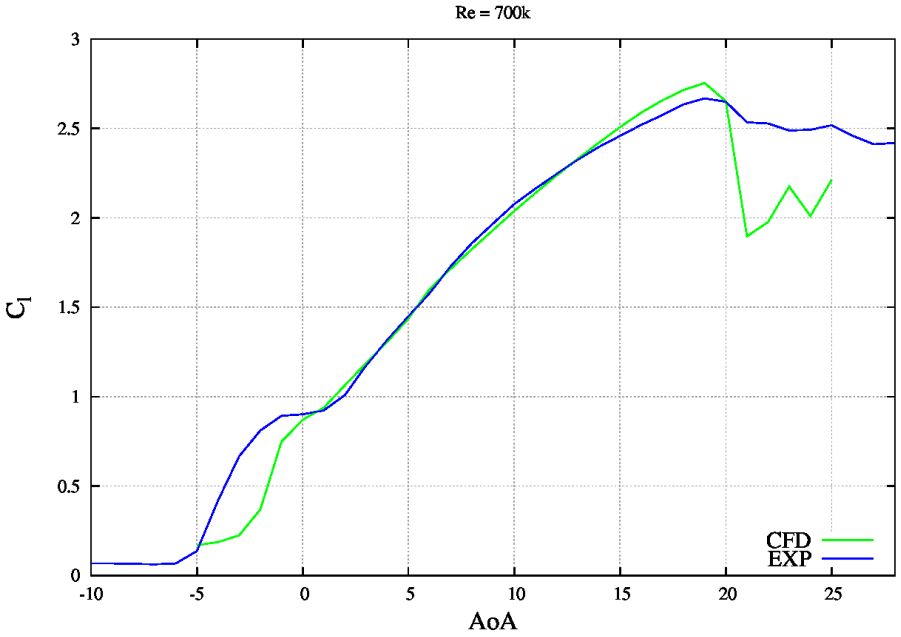
2D - Experiments

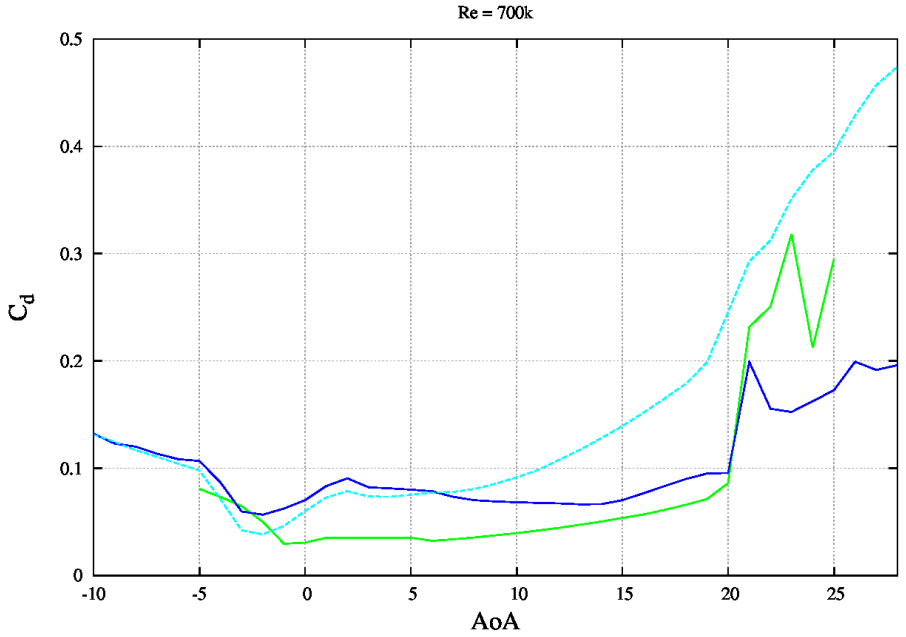
- Re = 700,000



vs.

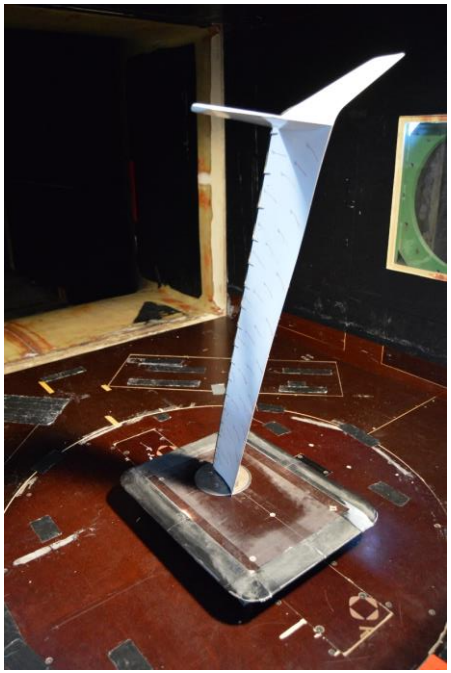


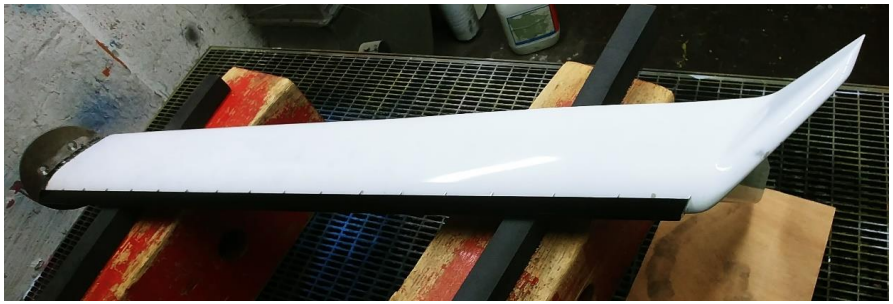




3D - Experiments

- Re = 300,000
- c = 133mm , span/2 = 800mm





3D - CFD

- Re = 300,000
- k-ω-SST – RANS
- polyhedral surface mesh with hexahedral core
- $y^+ < 1$
- 60M cells

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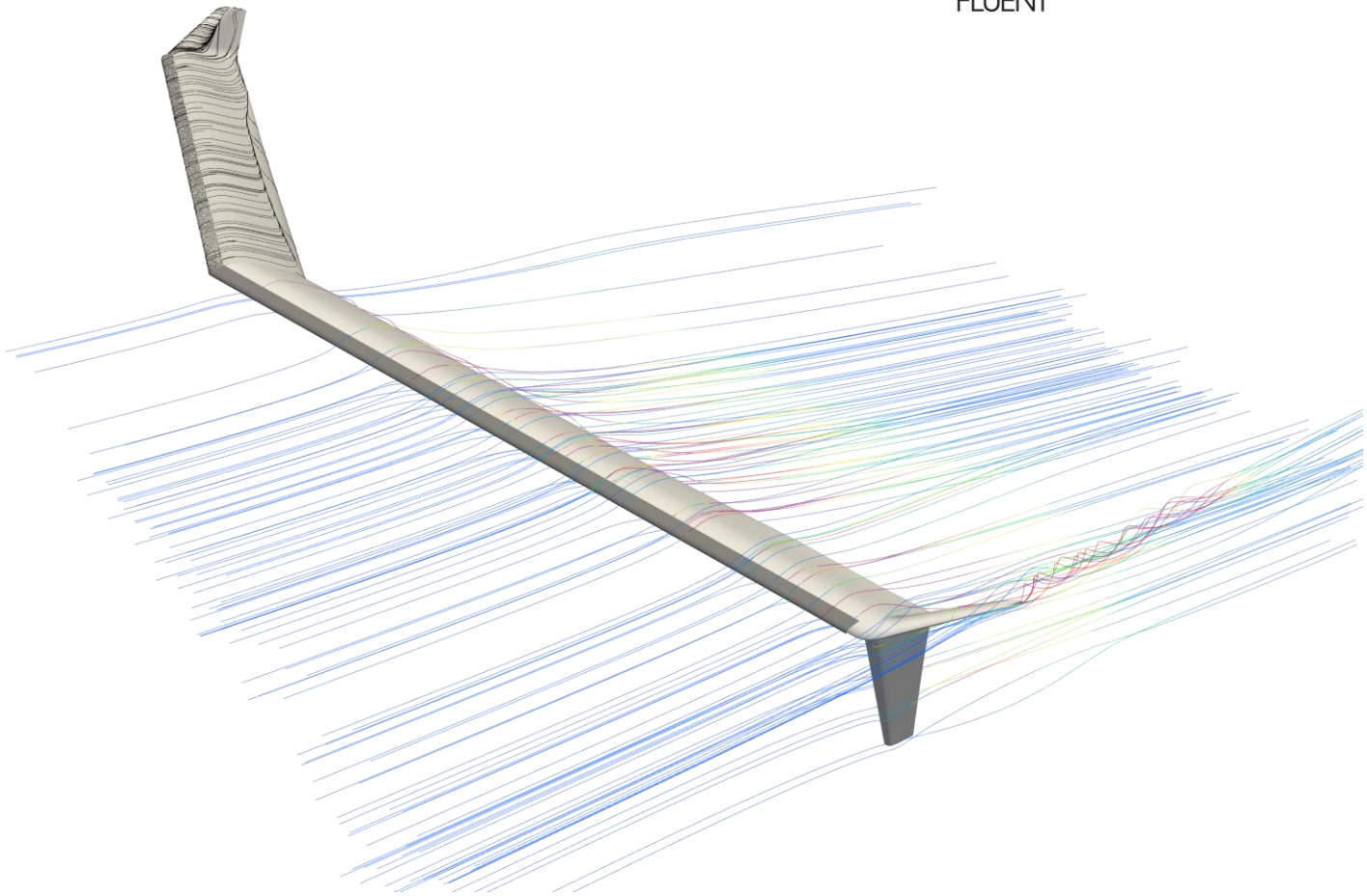

3D - CFD

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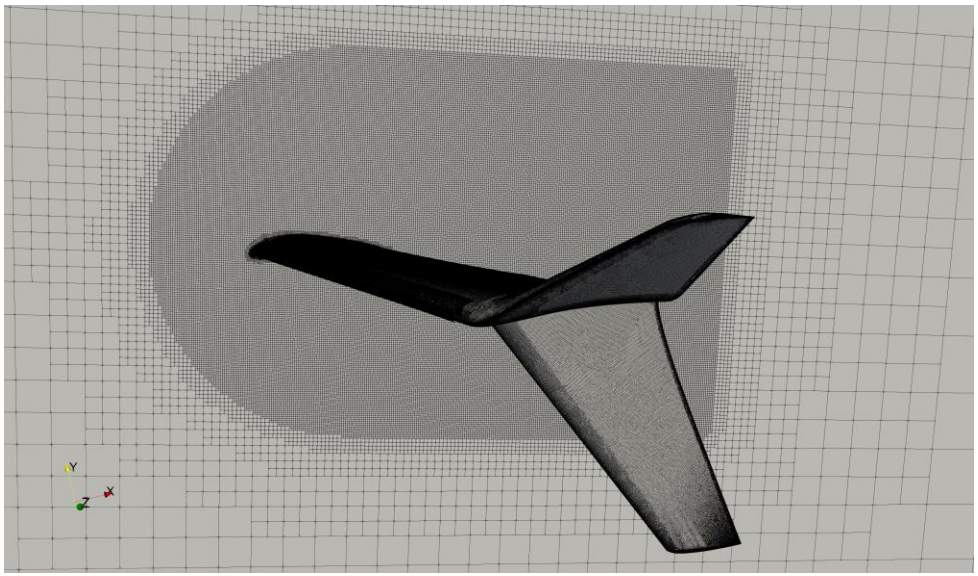
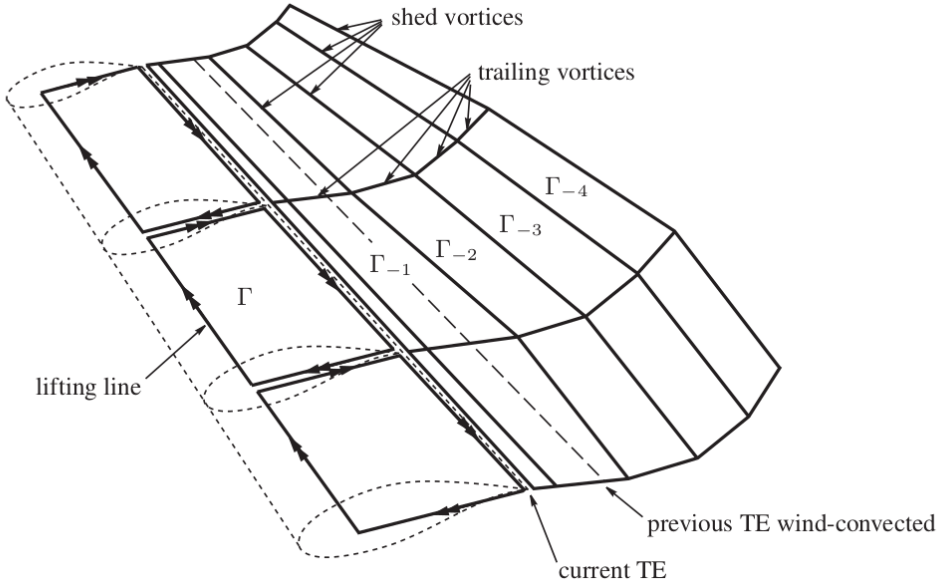
OpenFOAM®

ANSYS FLUENT



3D - medium order

- pyKite
  - focus on fast & reliable prediction of aerodynamic performance
  - method: Non-linear lifting-line free vortex wake (NLLFVW)



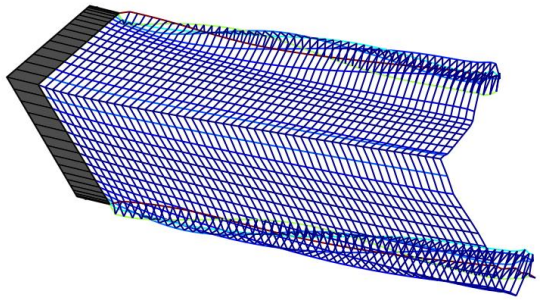
Van Garrel, 'Development of a Wind Turbine Aerodynamics Simulation Module'. ECN, 2003.

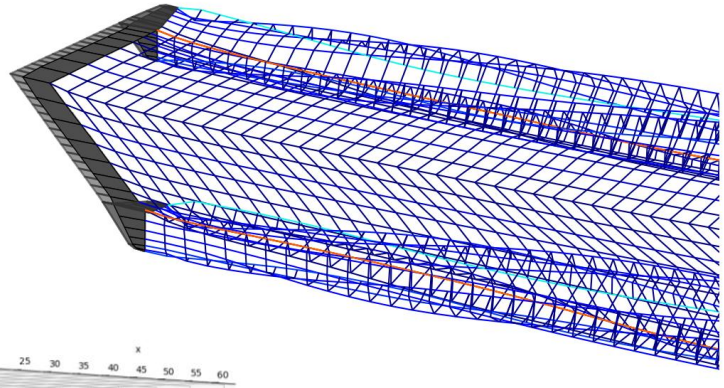
python™

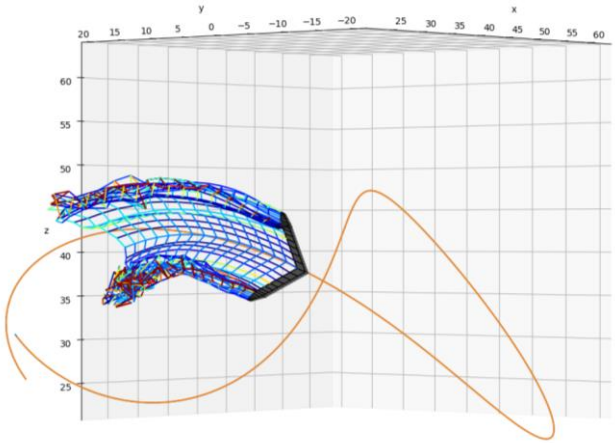
PROJECT CHRONO

3D - medium order

- pyKite - key features
  - inexpensive prediction of aerodynamic properties
  - transient aerodynamic effects
  - simulation of all flight phases
  - extendible to include aeroelasticity







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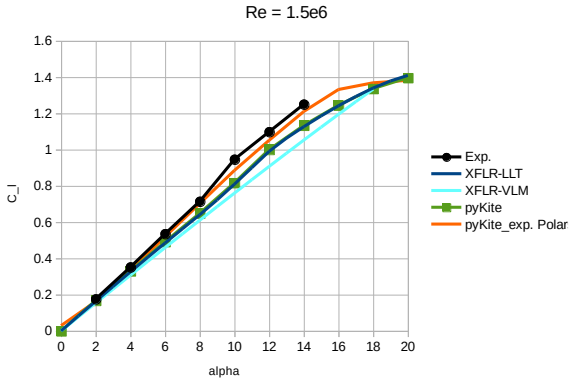
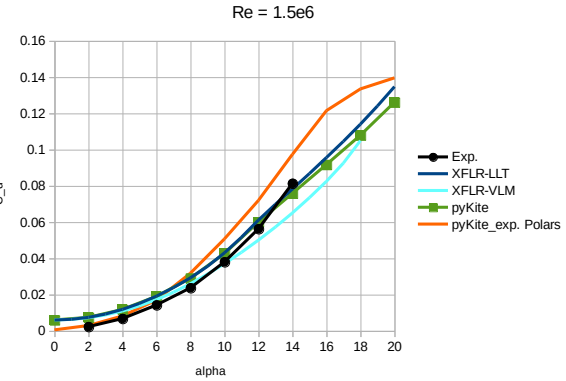
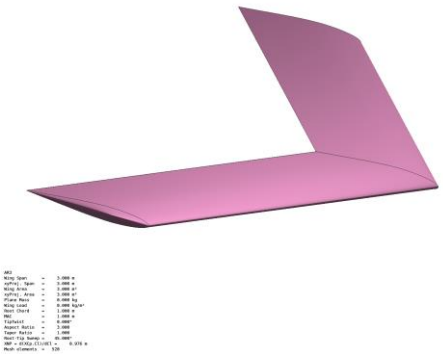
PROJECT CHRONO

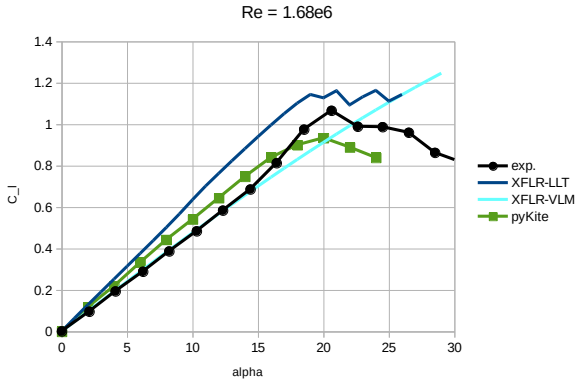
3D - medium order

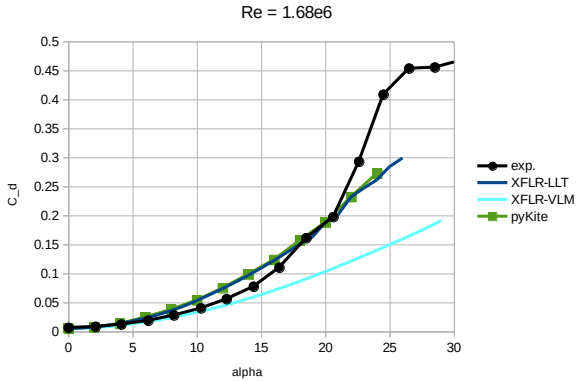
- validation





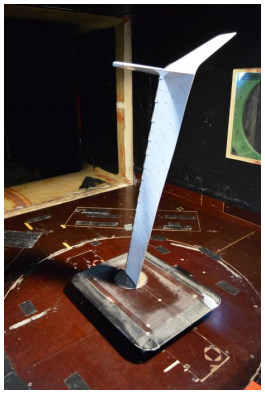




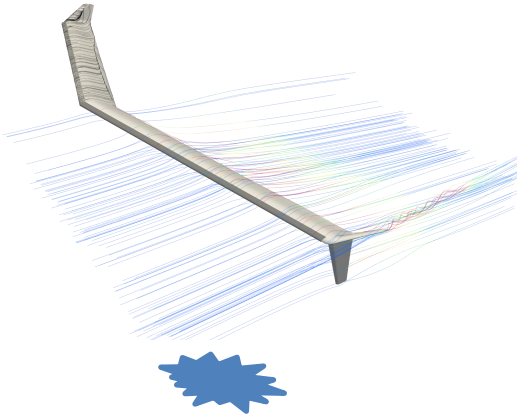


Experimental Data: McAllister, K.W., and Takahashi, R.K. 'NACA 0015 Wing Pressure and Trailing Vortex Measurements'. NASA, 1991
Weber,J., and Brebner, G.G. 'Low-Speed Tests on 45-Deg Swept-Back Wings'. Reports and Memoranda. HMSO, 1951.

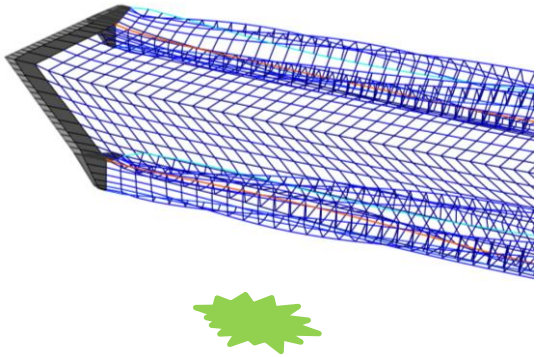
3D - medium order

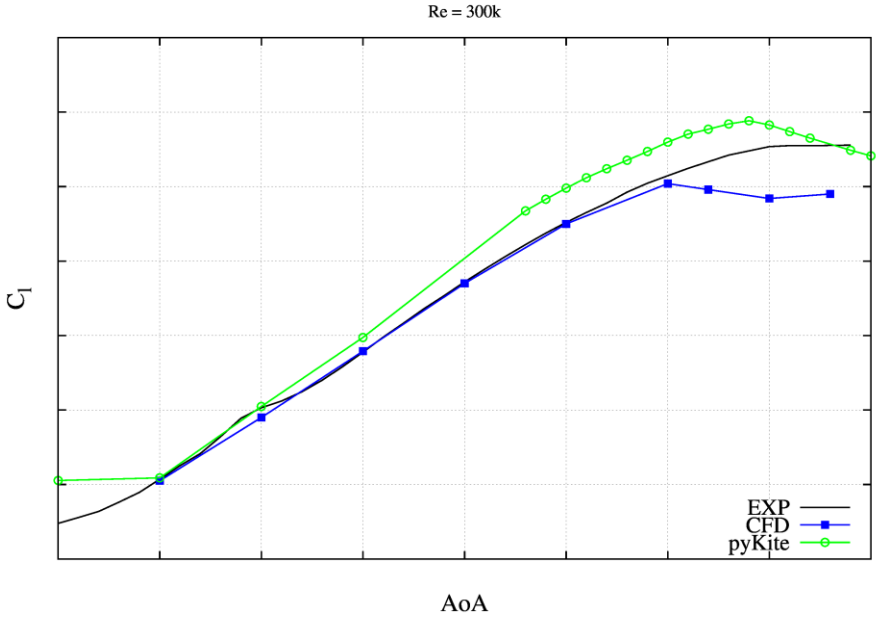


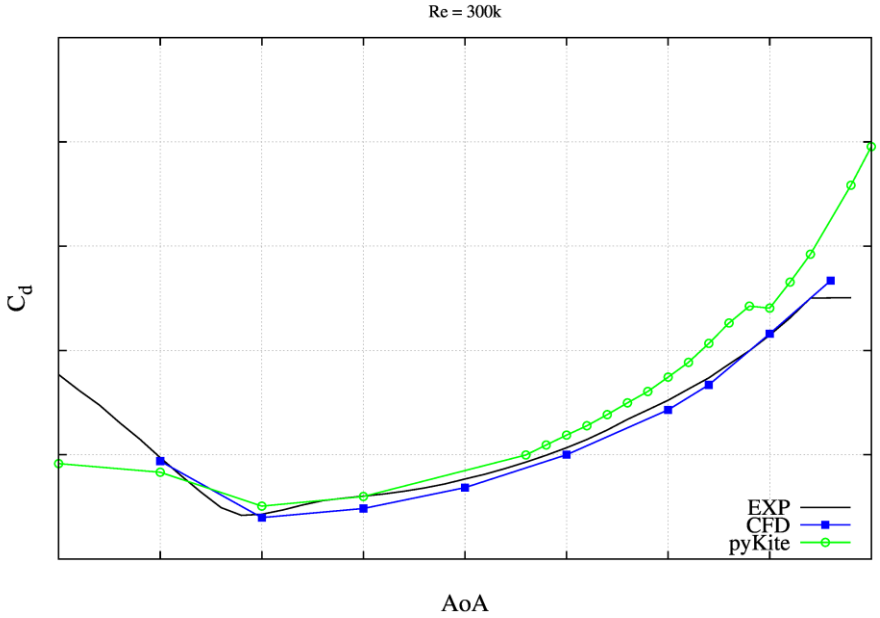
vs.



vs.

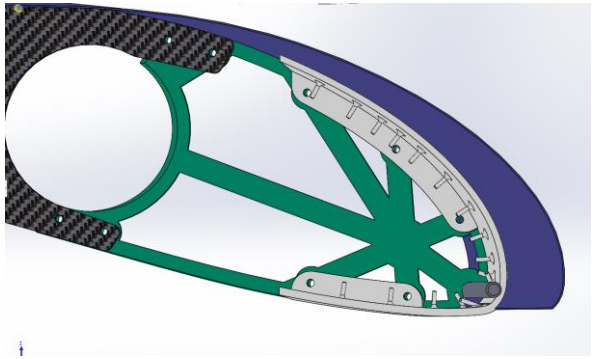






up next

- surface-pressure measurements for full-scale wing (incl. slat)
- optimised airfoil & slat
- 3D-optimisation
- modular AWE research wing



Thank you!

Denes Fischer
d.fischer@tu-berlin.de

Benjamin Church
b.church@tu-berlin.de

FRIENDSHIP SYSTEMS

CAESES

HLRN
NORDDEUTSCHER VERBUND FÜR HOCH- UND HÖCHSTLEISTUNGSRECHNEN

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
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