



Airborne Wind Energy

Introduction

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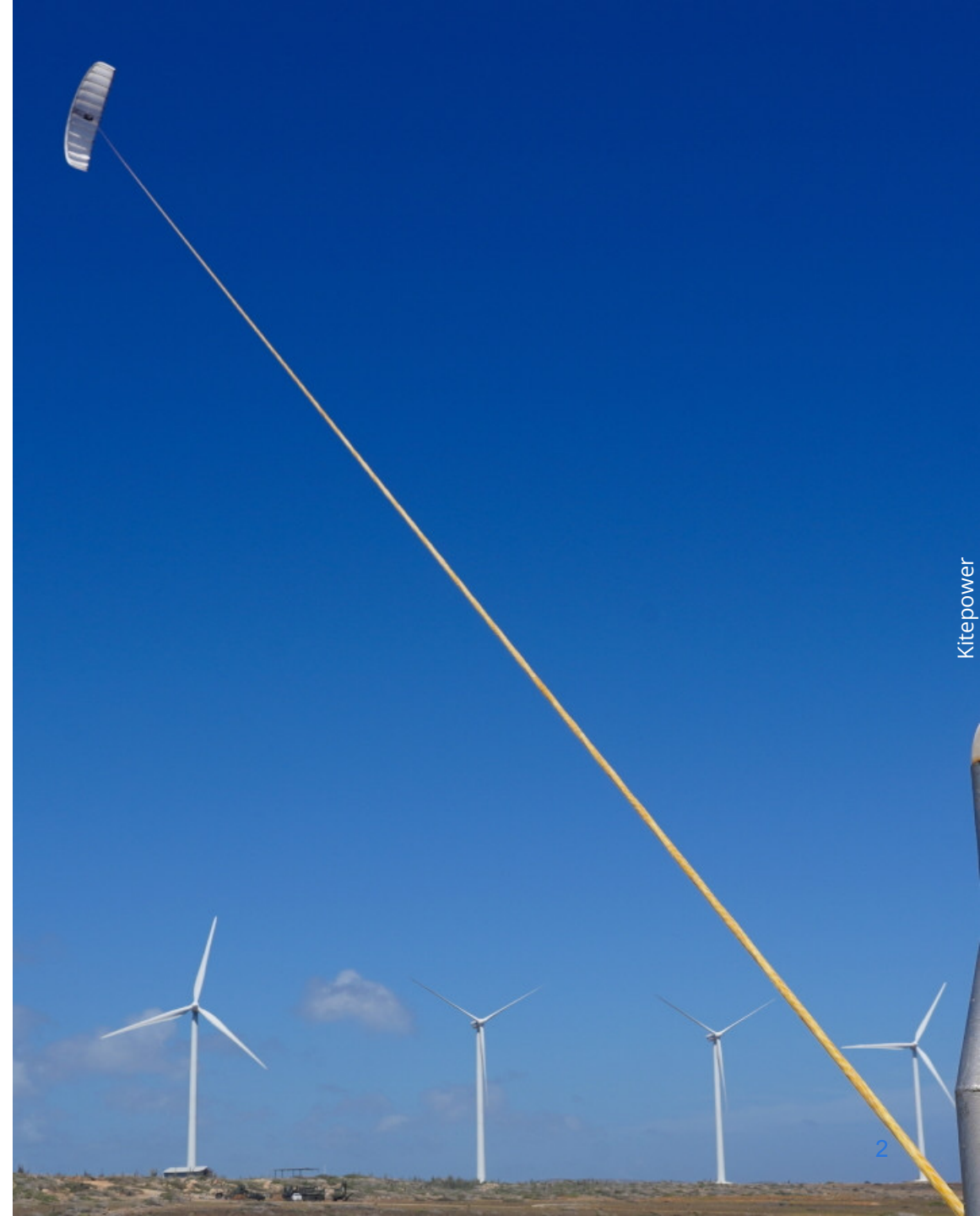
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Outlines

- Kite basics
- Ubiquitous use of kites
- Kite records
- Generating energy with kites
- Homework





Learning objectives

- Learn what **kites** are.
- Understand how kites can be used for **wind energy** harvesting.
- Understand the motivation behind **airborne wind energy**.
- Investigate what makes kites for airborne wind energy harvesting special?



Kite basics



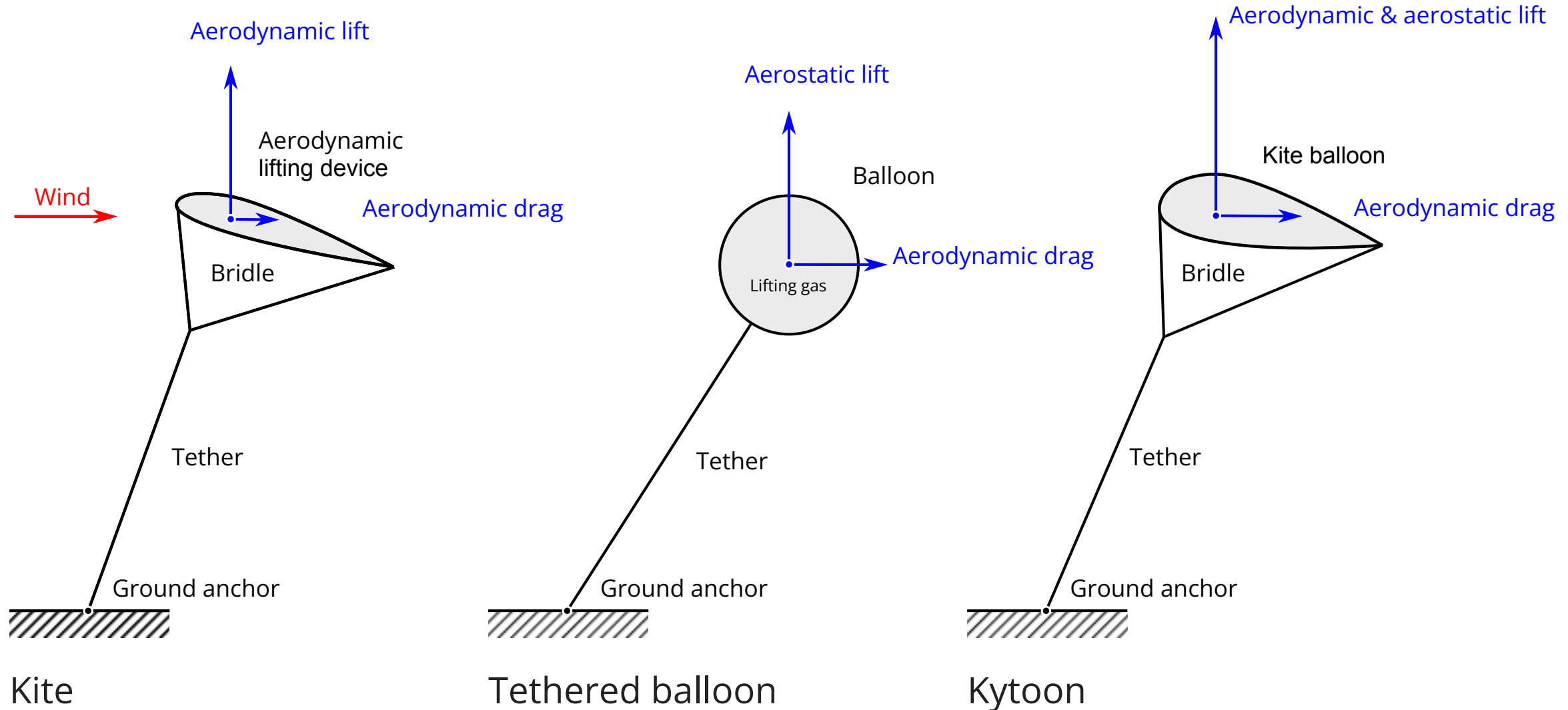


Definitions

- A **kite** is a tethered, heavier-than-air device with aerodynamic components that generate lift and drag forces from the relative flow.
- A **tethered balloon** is a lighter-than-air device not using aerodynamic lift, and not considered to be a kite.
- A **kytoon** or **kite balloon** is a tethered device using a mix of aerodynamic and aerostatic lift.



Definitions



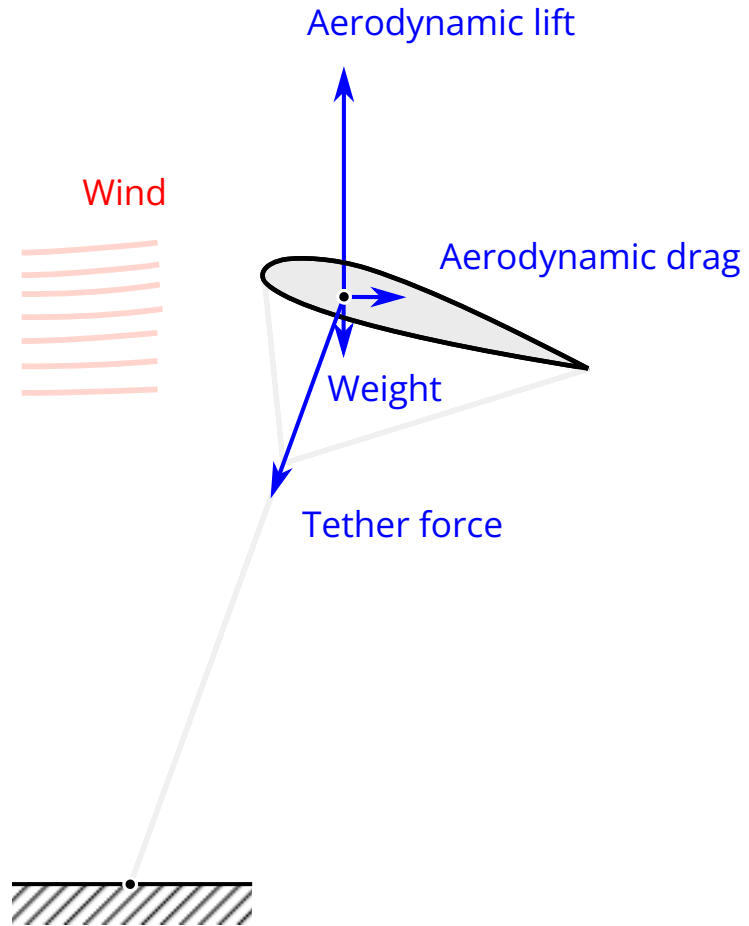


Why does a kite fly?

- A kite does not have a propulsion system, so, why does it actually fly?
- By anchoring the kite to the ground, the wind creates a relative flow.
- The relative flow around the lifting body generates the aerodynamic force components lift and drag.
- Compare this with an aircraft in leveled flight, where the lift component balances the weight force, and the drag component balances the propulsion system's thrust.
- For a static kite, the tether force balances the lift and weight forces in vertical direction and the drag force in horizontal direction.
- Compare this with a glider in steady descent, where the weight force alone balances the lift and drag components.



Why does a kite fly?

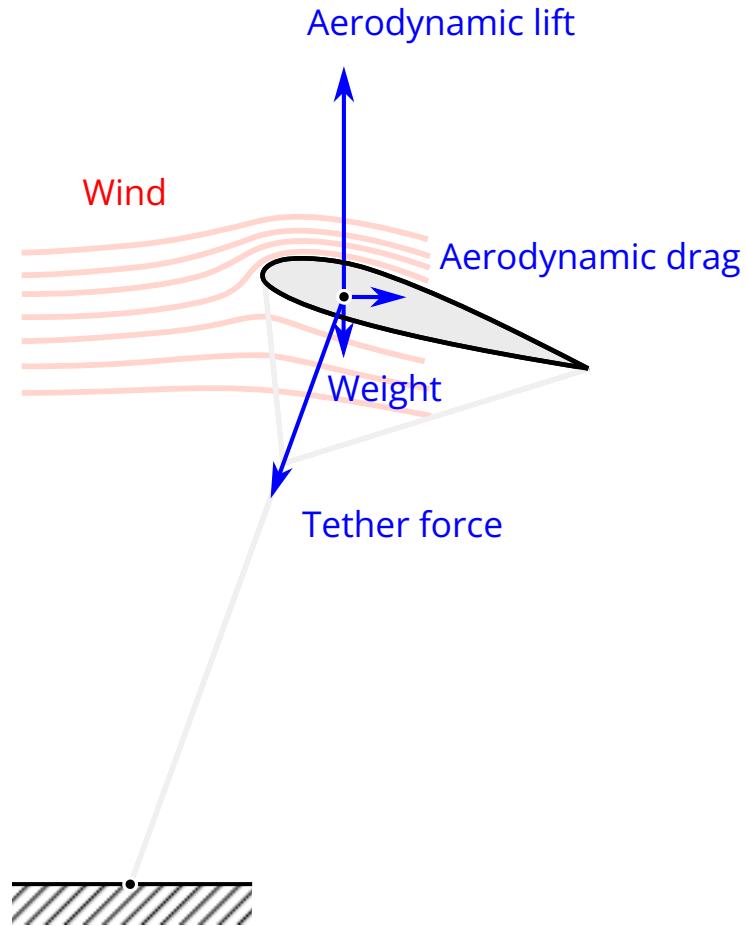


Static kite in wind field



Comparison with glider

Restart glide animation with **F5**



Static kite in wind field



Steady glider in still atmosphere



Difference between kite and aircraft

- A glider uses gravity to balance the aerodynamic forces.
- The gravitational force is a lot smaller than the tether force.
- A conventional aircraft requires a propulsion system to provide a thrust force.
- Kites do not employ a thrust force but fly due to the interaction of aerodynamic force and tether force.

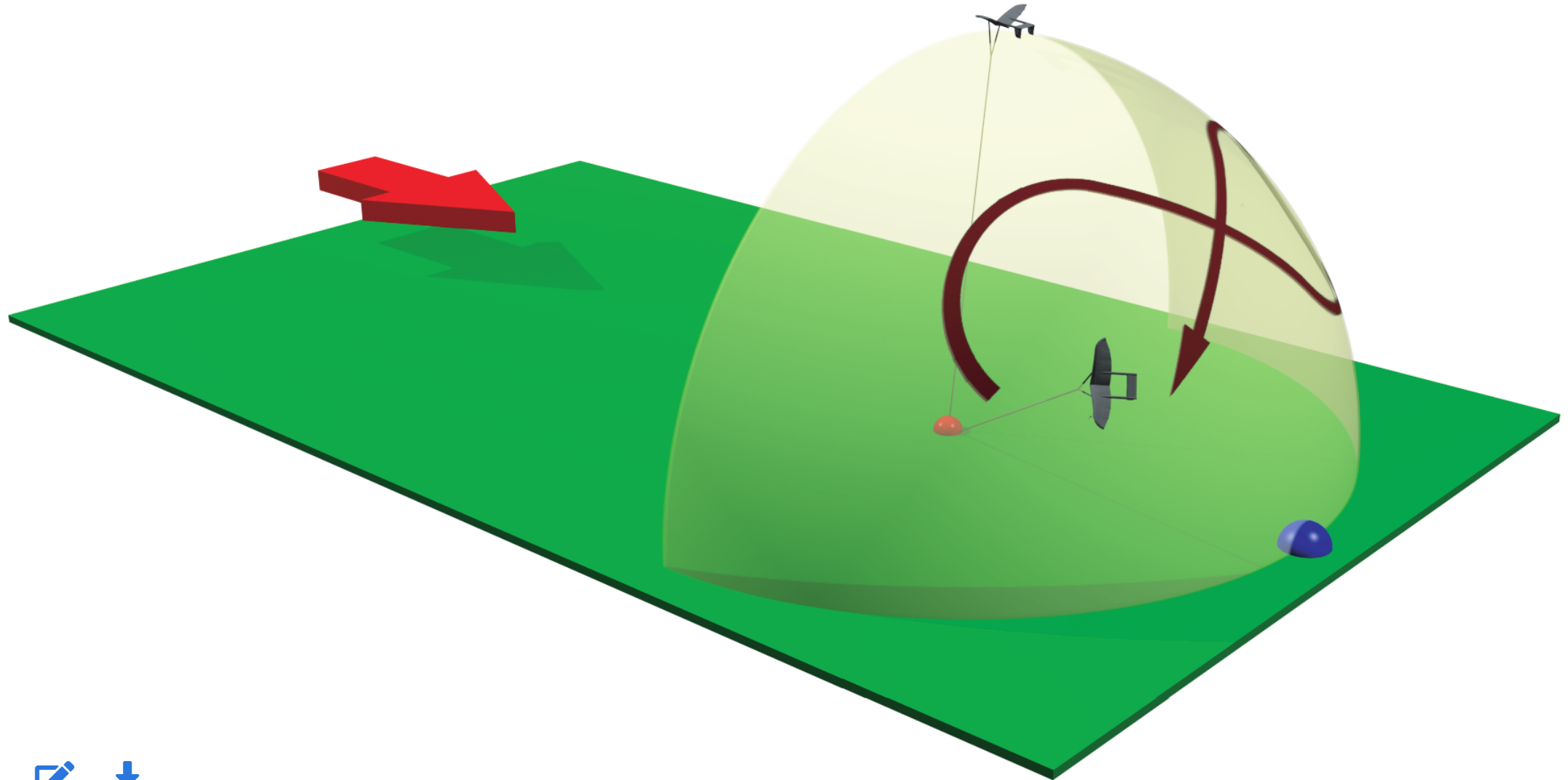


Kite flight modes

- Static flight
- Towing
- Reeling
- Crosswind flight



Crosswind flight





Static vs crosswind flight





Ubiquitous use of kites



Hobby & arts

2025 Mayo kite festival (Ireland)



Photo courtesy Kitepower



Sports (e.g. kitesurfing)





Kite records



Largest kite

"Flag of Kuwait" with 1019 m²





Highest kite

Altitude world record with a train of kites (1919)

**At Aeronautical Observatory Lindenberg (1914-1931)
with tethered ascends achieved heights in m**

Year	with kites			with tethered balloons		
	Number	Max. height	Mean daily height	Number	Max. height	Mean daily height
1914	778	6200	3340	454	8000	3668
1915	701	5610	3517	439	5500	3089
1916	755	7500	3998	400	9200**	4332
1917	720	8240	4025	360	8500	4160
1918	703	7305	3661	312	3990	2869
1919	601	9750*	3811	182	5334	2484
1920	697	6700	3306	91	3950	2427
1921	711	5710	2968	30	2560	1867
1922	697	5860	2880	—	—	—
1923	630	4720	2560	55	4080	1677
1924	410	4660	2800	203	3260	2089
1925	456	4470	2488	166	4270	2462
1926	431	5403	2551	203	4788	2384
1927	461	4708	2535	222	4219	2182
1928	508	4260	2321	320	4070	2309
1929	703	5705	2308	220	4175	2567
1930	640	5865	2553	233	4421	2594
1931	609	5772	3030	142	4131	2385
1914–1931	11211			4023		

*) 1.8.1919 9750 m anomaly

*) 26.9.1916 9200 m!



Fastest kite



Photo: Guillaume Fischer

Speed sailing record SP80 of over 108 km/h





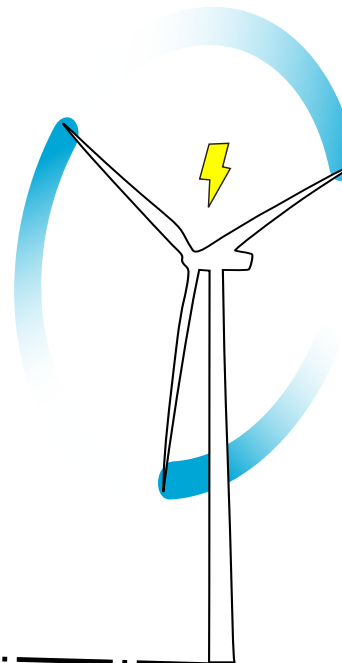
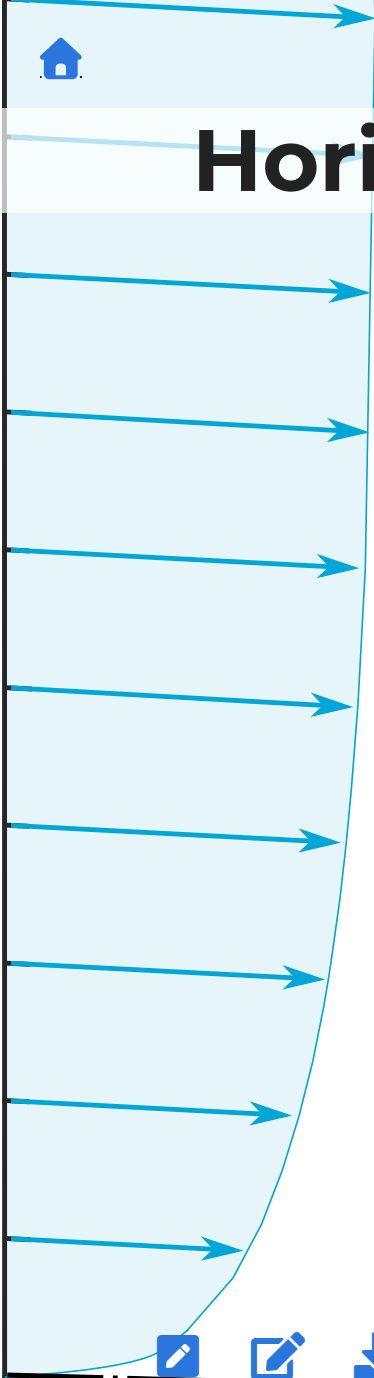
Generating energy with kites



Photo: Joep Breuer

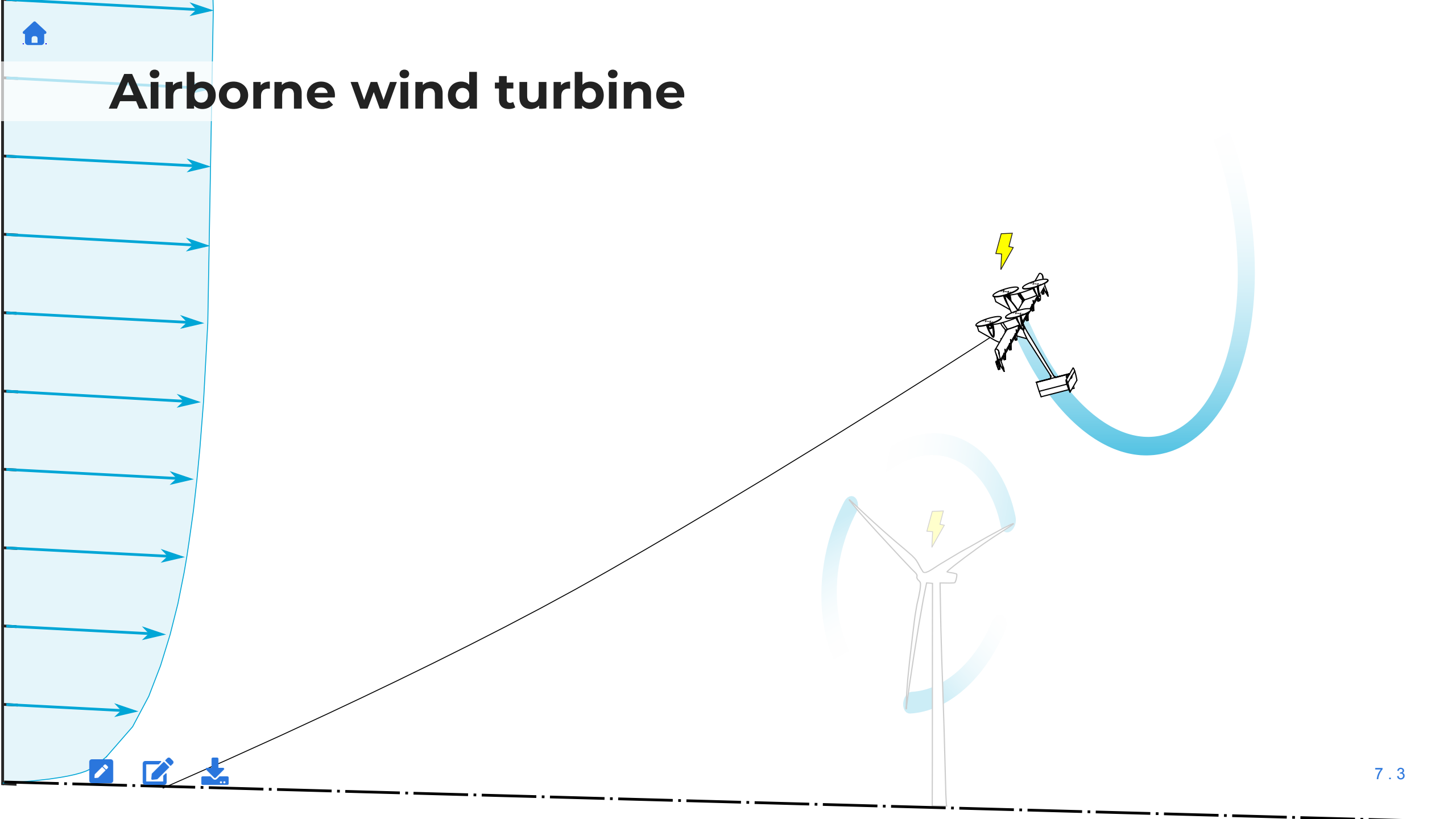


Horizontal-axis wind turbine



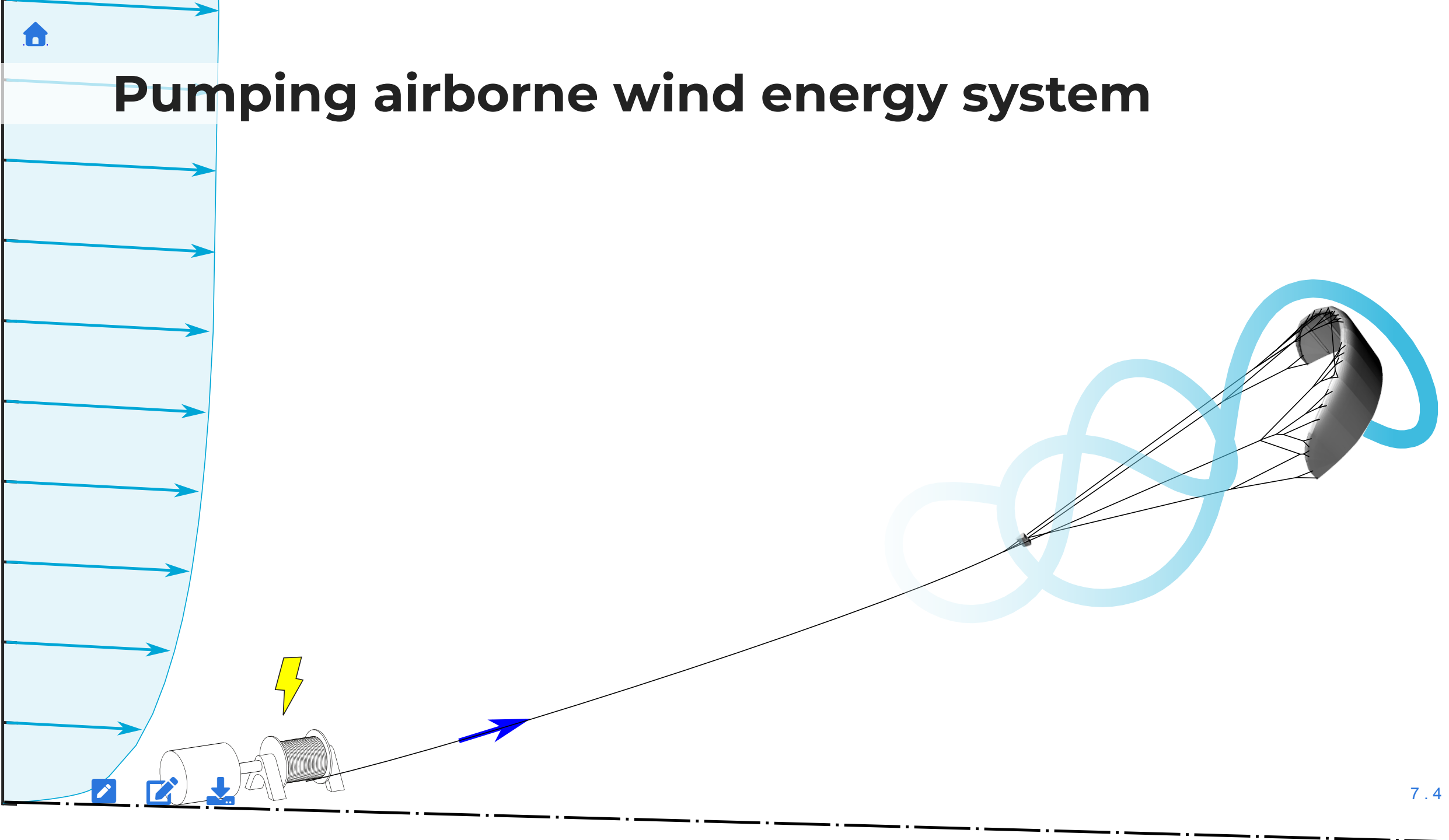


Airborne wind turbine



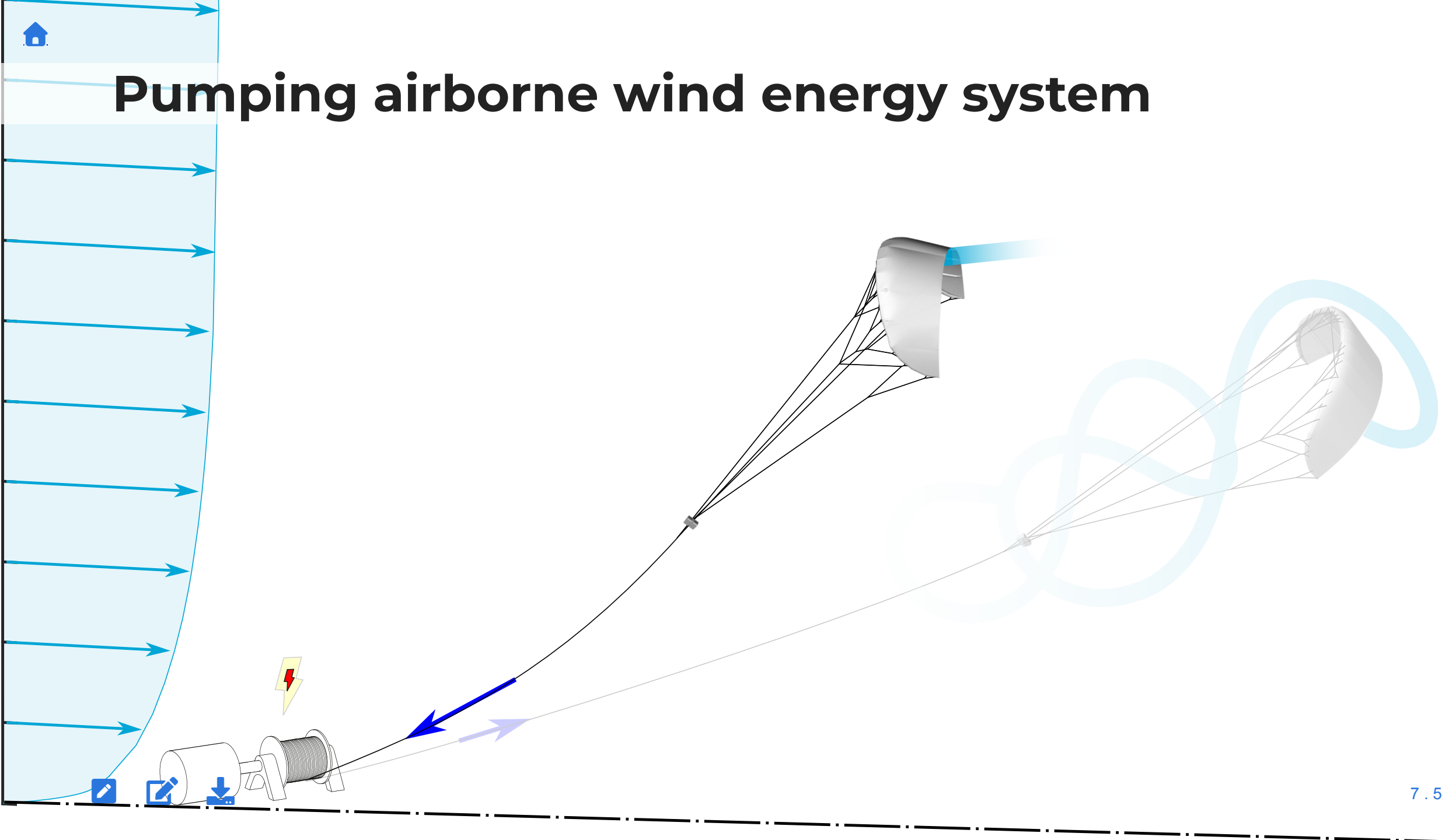


Pumping airborne wind energy system





Pumping airborne wind energy system





What is it?

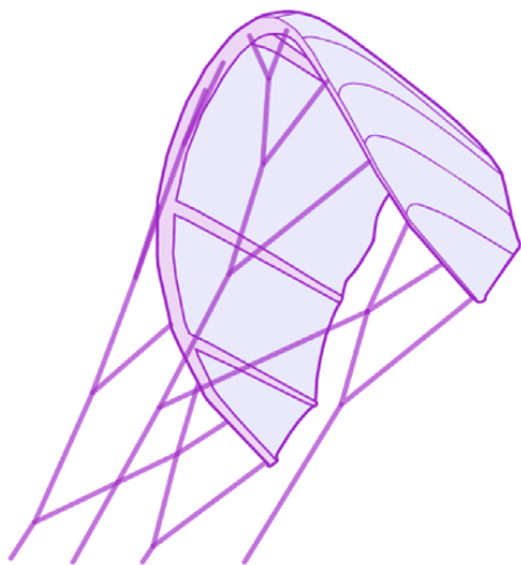
“ Airborne wind energy (AWE) is the conversion of wind energy into electricity using tethered flying devices. Some concepts combine onboard wind turbines with a conducting tether, while others convert the pulling power of the flying devices on the ground. Replacing the tower of conventional wind turbines 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. ”

awesco.eu/awe-explained/

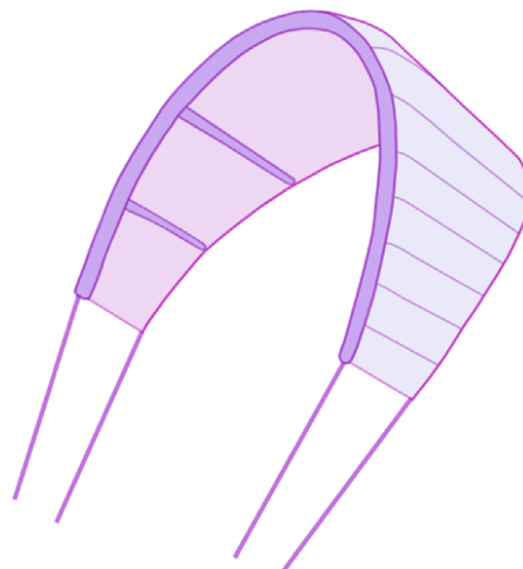


What are kites?

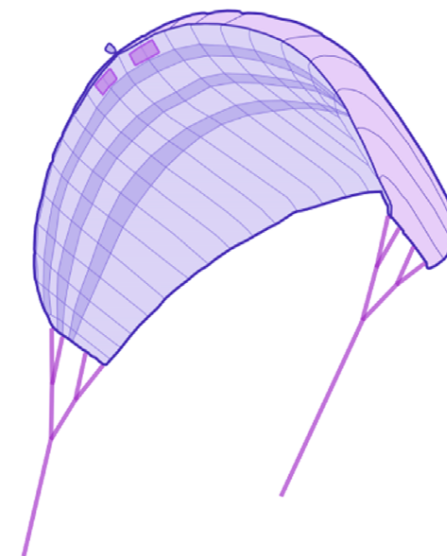
Cherubini et al. (2015)



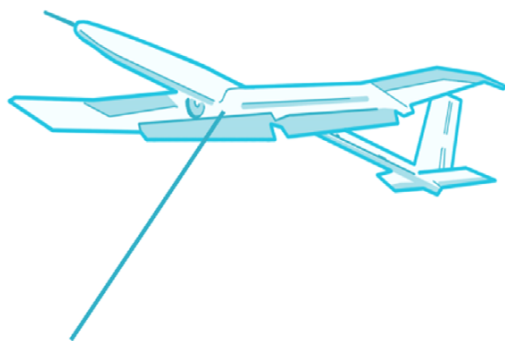
Bow kite
(Legaigoux 2005)



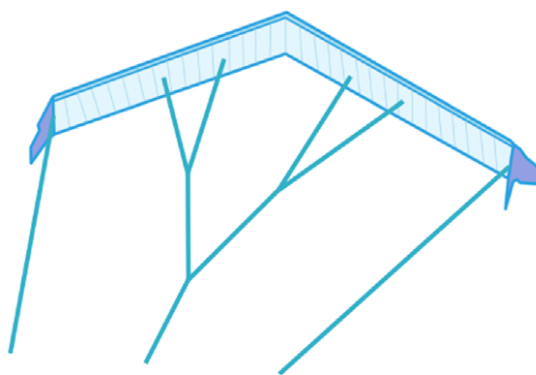
4-line C-kite
(Legaigoux 1999)



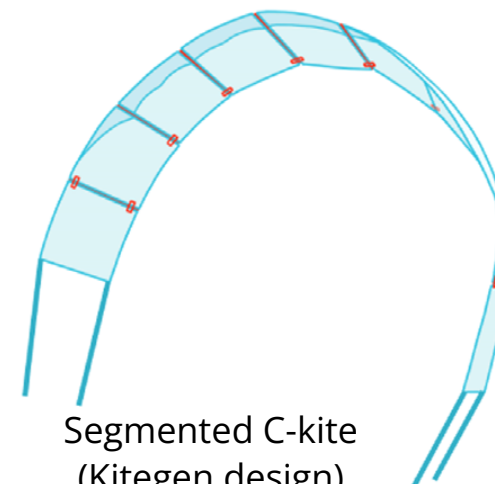
Foil kite
(Skysails design)



Tethered aircraft
(Ampyx design)



Swept fixed wing
(EnerKite design)



Segmented C-kite
(Kitegen design)



Kites for airborne wind energy

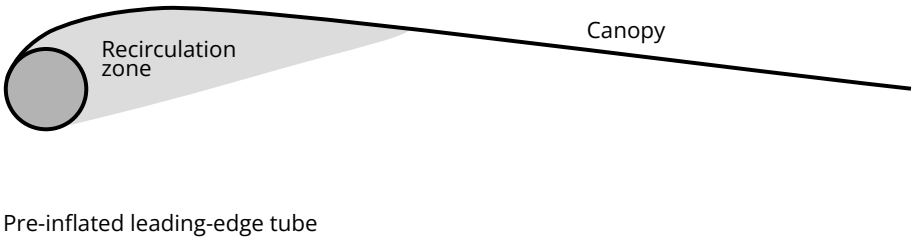


Photo: Helena Schmidt

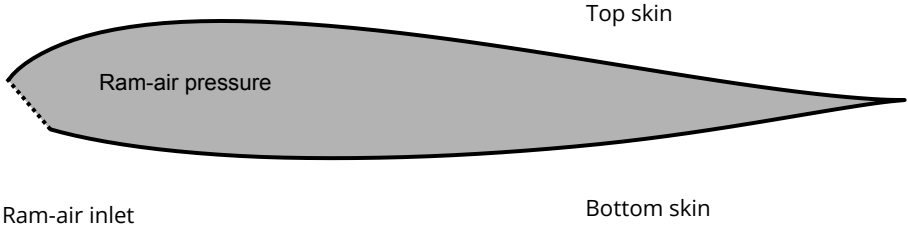


Kite aero-structural design

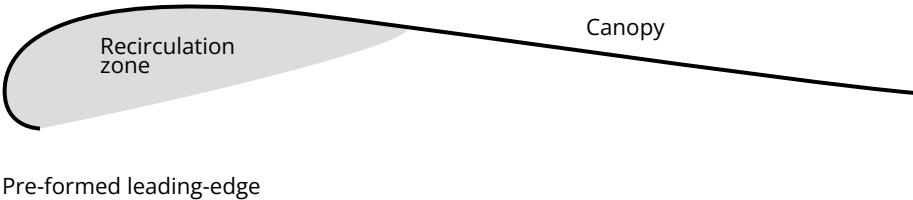
Leading-edge inflatable kite



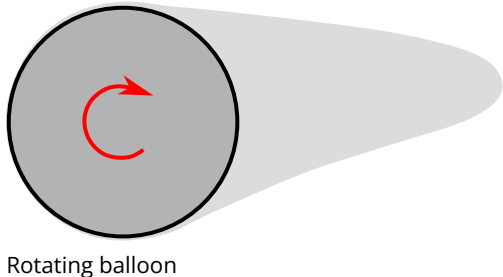
Ram air kite



Single skin kite



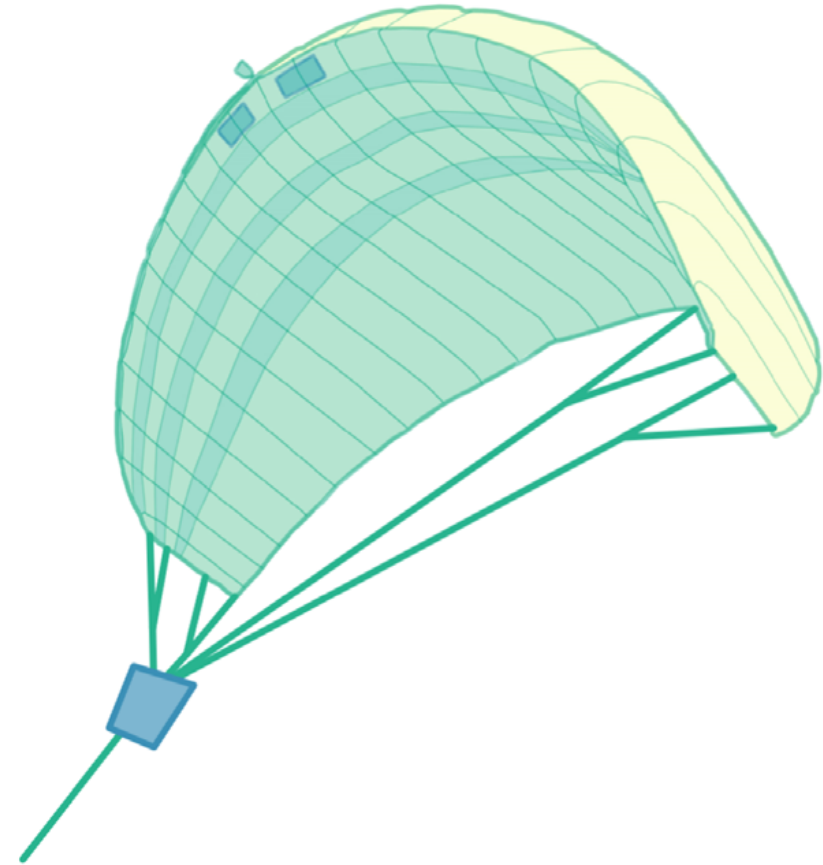
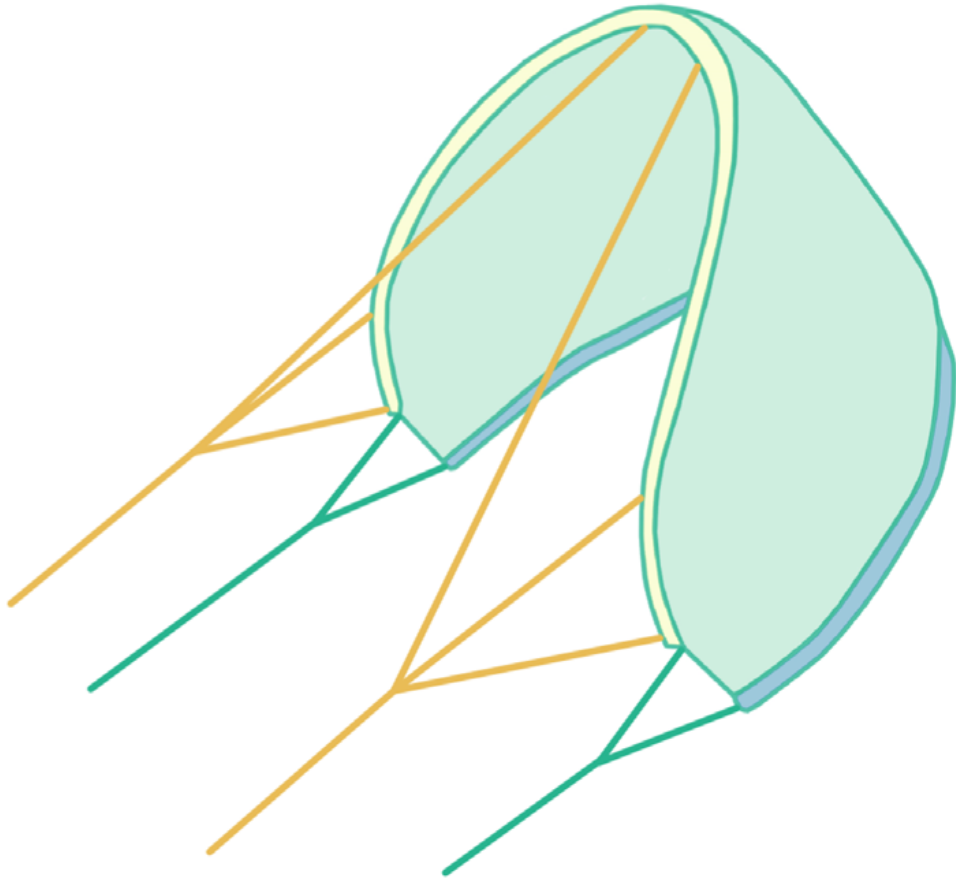
Rotating balloon kite





Kite control

Cherubini et al. (2015)



   Roll of wing and twist deformation
by actuated rear bridle lines

Roll of wing by tip bridle lines actuated
by a suspended control unit

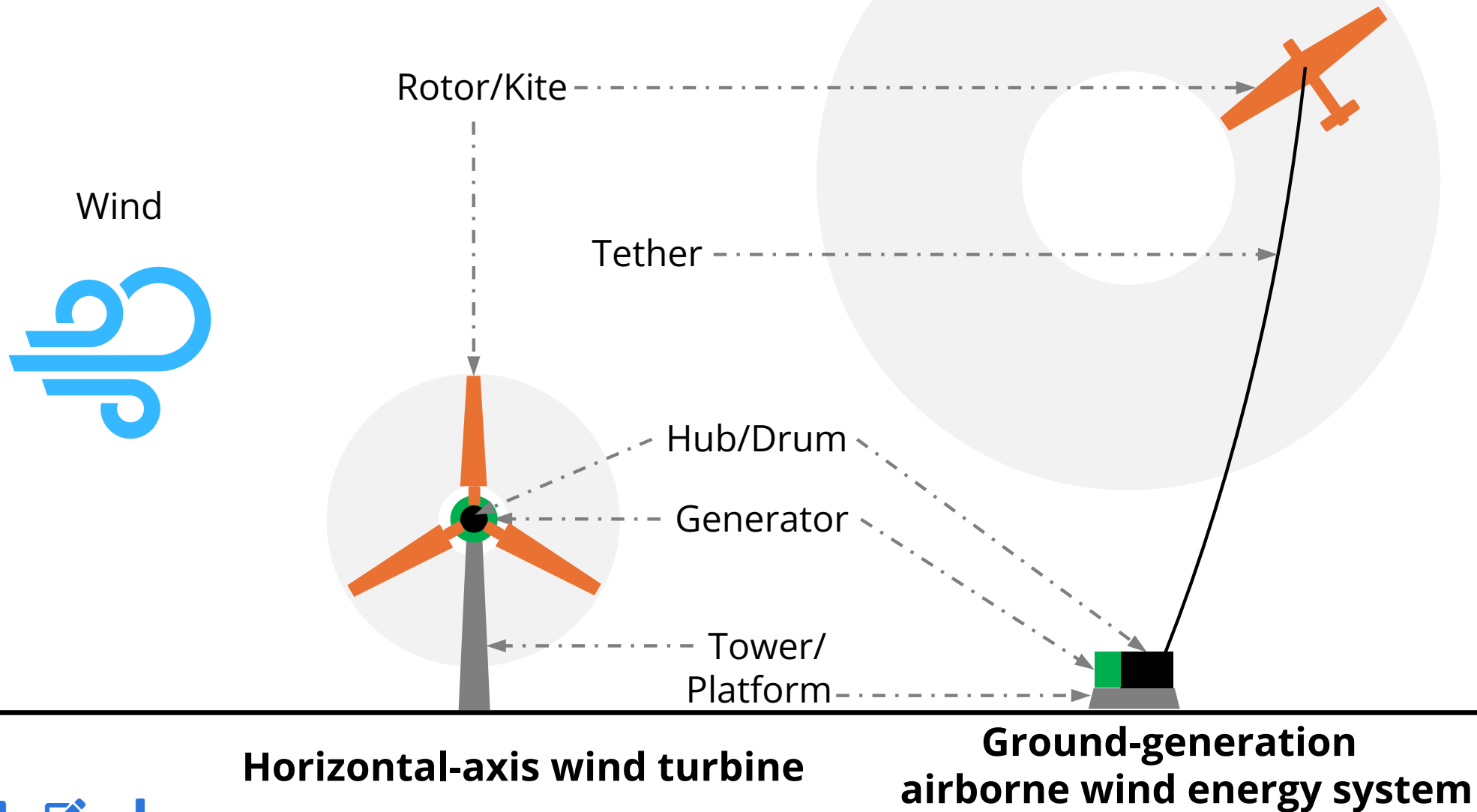


Terminology

- Airborne Wind Energy (AWE)
 - Airborne Wind Power
 - Kite Power
 - High Altitude Wind Energy (HAWE)
 - High Altitude Wind Power (HAWP)
-
- ▶ Often used interchangeably
 - ▶ Sometimes used to differentiate technologies.
 - ▶ Most common now is **Airborne Wind Energy (AWE)**



Analogies between HAWT and AWE system





Opportunities

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

Challenges

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



Homework

Read my 2019 essay [Airborne Wind Energy - An introduction to an emerging technology](#) and answer the following questions:

- What were the key concepts pursued commercially in 2019?
- What are the remaining key challenges for the commercial development of airborne wind energy?



References

Breukels, J.: An engineering methodology for kite design, <http://resolver.tudelft.nl/uuid:cdece38a-1f13-47cc-b277-ed64fdda7cdf>, (2011)

Cherubini, A., Papini, A., Vertechy, R., Fontana, M.: Airborne wind energy systems: A review of the technologies. Renewable and Sustainable Energy Reviews. 51, 1461–1476 (2015).
<https://doi.org/10.1016/j.rser.2015.07.053>



Questions?

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