Fusing Kite and Tether into one Unit

UMEÅ UNIVERSITY

Lars Bäckström[1] and Tom Guilloux[2]

[1]Department of Applied Physics and Electronics, Umeå University, Sweden
[2]ESTACA (Transport Engineering School), Laval, France

ESTACA ECOLE D'INGENIEURS

1. The Challenge

For airborne wind energy the Power Harvesting Factor ζ is of high interest:

$$\zeta = \frac{P}{\frac{\rho}{2} \cdot v_{wind}^3 \cdot A_{kite}} \leq \zeta_{max} = \frac{4 \cdot C_R^3}{27 \cdot C_D^2}$$

To maximize, low values of C_D is important. How to make it as low as possible?

Try to:

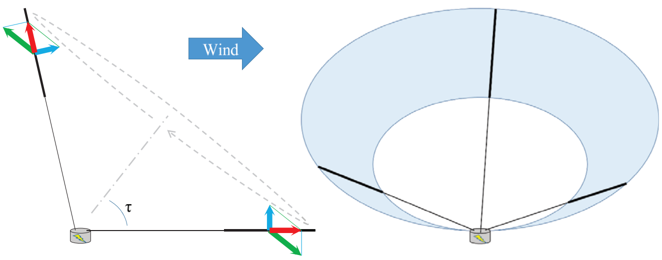
1) reduce tether drag losses
2) reduce tip losses
3) use good airfoil
4) reduce the use of elevators, tails etc!

2. Our Solution

Change the tether to an energy harvester by using an aerodynamic shape and let it fly in a conical path with its rotational axis pointing about 50° upwards in the direction of wind.

Lift forces are balanced by centrifugal forces with resulting forces in the direction of tethers. These forces are proportional to n^2 when C_L is compensated for upwind/downwind airspeed.

Below two tethers from side and three tethers in downwind direction, both with 40% airfoil.



3. Method

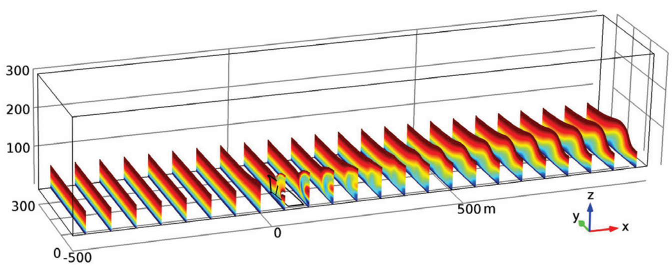
- In order for easy manufacture the chord is assumed to be independent of distance from generator. This gives the loading of the swept area proportional to distance from generator.
- Small scale flow simulations around the airfoil is simulated with Xfoil and Matlab. The developed airfoil produce pitching moments that stabilize the angle of attack when center of mass is placed near the leading edge. A so called plank glider profile.
- Control of lift force can be done by adjusting center of mass.
- Gravity and wake rotation is ignored.
- Big scale flow simulations around the turbine is simulated in COMSOL by approximating the swept area with a conical volume that produce the same forces on the wind field as the lift forces of the aerodynamically shaped tethers.

Due to symmetry half turbine is simulated. The selected data is:

- Wind speed: 6 m/s at 50 m height and roughness length 0.1 m (in x-direction)
- Centre of cone 10 m above ground
- Simulated wind field: y*z*x=300*300*1500 m (500 upwind, 1000 downwind)
- Cone angle τ: 38° to 56° in steps of 2°
- Peripheral pressure difference on swept area: 4, 8, 12, 16 and 20 Pa
- Percentage of tether width aerodynamic shape: 10% to 70% in steps of 10%
- Tether length: 80 m

All 11·5·7=385 combinations above are computed and extracted power from wind field and sideway losses are computed using volumetric integration.

Below computed wind field for (48°, 16 Pa, 50%). The swept area is the black cut cone with center at x, y, z = 0, 0, 10 m. Wind speed color coded and speeds over 6 m/s are transparent.

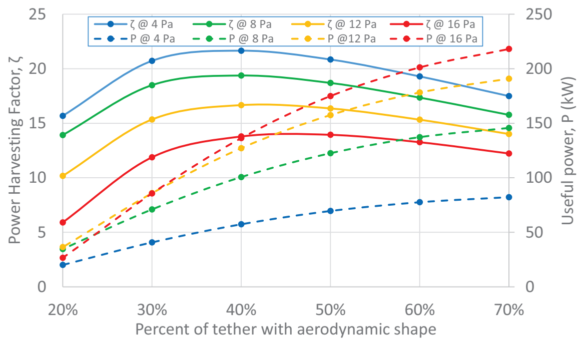


With tip speed ratio of λ=10, C_L=1, $C_{d,airfoil}$=0.011 and $C_{d,tether}$=1 needed airfoil area and various drag losses are computed for 1 to 4 tethers. Subtracting losses from extracted power gives useful power, P, and power harvesting factors, ζ.

4. Resulting Power Harvesting Factors

Very high Power Harvesting Factors of up to $\zeta = 22$ is achieved, which is about 4 times better than commercial wind turbines.

Below ζ as function of pressure and percentage is shown together with useful power. Each point at its best cone angle and three tethers.

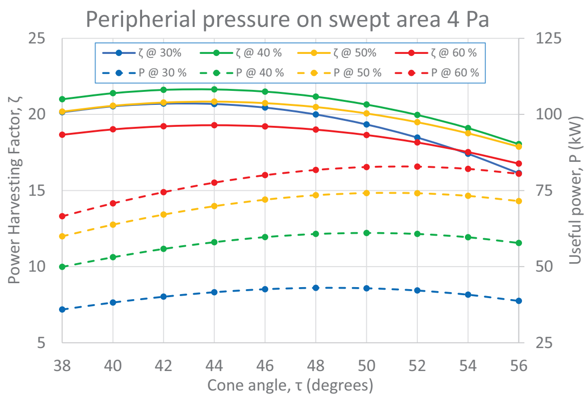


Of 1540 simulated cases the one with best ζ have a power balance as:

Extracted from wind field (P_X)	87 kW	
Sideway losses in wind field (P_{YZ})	2 kW	
Drag losses of airfoil (C_d=0.011)	16 kW	
Lift induced drag (tip losses)	4 kW	
Tether drag (6 mm)	7 kW	
Useful power, P	58 kW	2.8 kW/m^2
Power Harvesting Factor, ζ	**22**	
Equivalent C_D	**0.019**	

Best ζ is achieved with three flying tethers with 40% of length aerodynamically shaped (32 m) and the rest a 6 mm wire (48 m). Peripheral pressure on swept area 4 Pa needs a chord of 21 cm, aspect ratio 150 and a total aerodynamic area of 21 m^2.

In the figure below for the subset with peripheral pressure 4 Pa we find the best power harvesting factors at cone angles around 44° and the highest produced useful power around 50°.



5. Discussion

In these simulations a tip speed ratio of 10 is used. With the very low drag that is shown by this concept higher tip speed ratios give even better power harvestings factors. A drawback with higher tip speeds is increasing sound.

These simulations are done with a set of pressure values. To get a certain pressure the calculated chord depends on cone angle τ. This will favor low angles for power harvesting factors and high angles for useful power. If a set of chord values were used instead, the best cone angle is expected to be between the results of this study.

6. Conclusions

Promising concept with high Power Harvesting Factors and very low drag losses since:

1) Tether drag losses are reduced since fast moving part of tether is substituted by airfoil.
2) Tip losses are low due to extreme aspect ratios. $AR \geq 100$ ➔ $C_{Di} \leq 0.003$.
3) Airfoil with $C_d = 0.011$ is the dominant drag loss.
4) Using the developed airfoil elevators, tails etc. can be removed.

AIRBORNE WIND ENERGY CONFERENCE 2017