Airborne Wind Energy (AWE) Systems – An Introduction and Overview

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Introduction

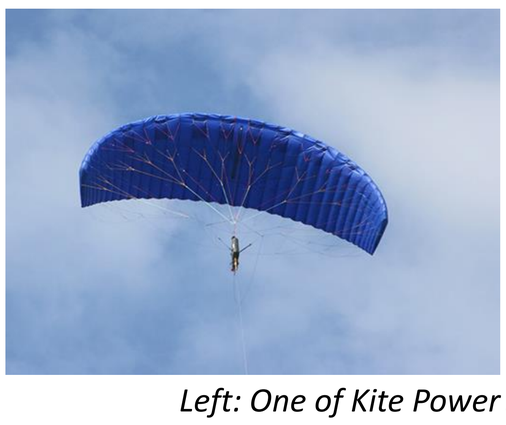
- Airborne wind energy (AWE) is the term used to describe an energy system that uses a wing or kite anchored to the Earth's surface via tensioned tethers. It is envisaged that AWE's will reduce the cost of wind energy.
- The table shown below gives the global average wind speeds and available power for different heights above the Earth's surface.
- In general the further from the Earth's surface the stronger and more consistent the wind becomes. This leads to more power being available for any energy extraction device.
- Due to the need for large towers, and their associated cost, the current design of horizontal axis wind turbines (HAWTs) will always be limited to lower altitudes.
- AWE systems use airborne devices that support their own weight through their aerodynamic properties. Therefore large towers are not required making it feasible to reach higher altitudes.
- By using lightweight materials in tension rather than heavy materials in compression, costs can be dramatically reduced.
- By accessing higher altitudes it is envisaged that AWE systems will achieve lower costs compared to current HAWTs of comparable power rating.

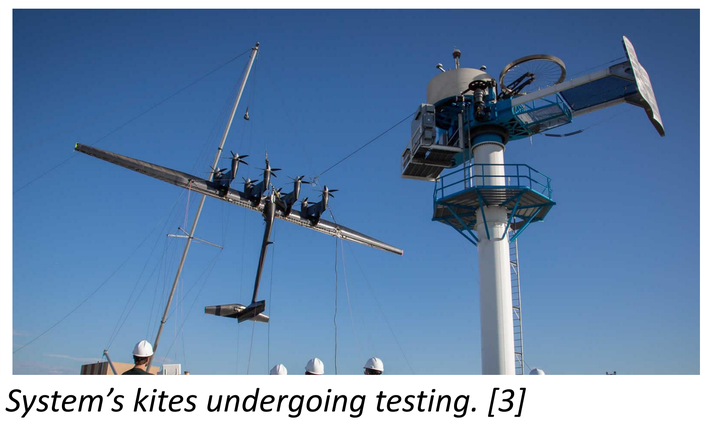
Altitude (*m*)	Global Average Wind Speed (*m/s*)	Average Wind Power (W/m^2)
10	3.3	22
80	4.6	58
800	7.2	205

Global average wind speeds and available wind power at different heights above Earth's surface. [1]

AWE Industry

- Unpowered airborne devices have been around for centuries. They have been used to see approaching enemy forces and as a mode of transport.
- The first literature looking at utilising them for electricity generation was in 1980 by Miles L. Loyd [2].
- Although established 40 years ago it has only really been in the last 10 years that AWE systems have started to see more accelerated growth. We are now beginning to see prototypes rated to 100's of kW.
- With over 50+ individual research groups globally, there is a wide range of different designs, which can make comparing them difficult.
- All AWE systems can be broken down into three main areas.
    1) Energy extraction – how the energy is extracted from the wind
    2) Energy transfer – how the energy is transferred to the ground
    3) Energy conversion – how and where the energy is converted into electricity
- One major difference between AWE systems is where the electricity is generated. This can be on the airborne wing/kite or on the ground, referred to as on-board or ground based generation.
- AWE designs can also be categorised according to the materials used for the airborne components. These are either flexible like traditional kites or more rigid like aeroplane wings.
- The two images below show two different AWE designs that are introduced next.





Left: One of Kite Power System's kites undergoing testing. [3]
Right: Makani's 600kW system undergoing tests. [4]

Kite Power Systems – 500 kW Prototype

- Kite Power Systems (KPS) are soon to start testing their 500 kW prototype just South of Glasgow. Their design uses flexible kites in a pumping cycle and operates at heights of up to 450 meters.
- The kite flies in figures of eight downwind. As this happens the kite pulls a tether out from a drum on the ground which turns a generator.
- Once the end of the tether is reached the kite is controlled to minimise the tether force. Some of the energy created is then used to wind the tether back in. The process is then repeated and is referred to as a pumping cycle.
- The KPS design uses two kites out of phase with each other to provide more consistent overall power generation.

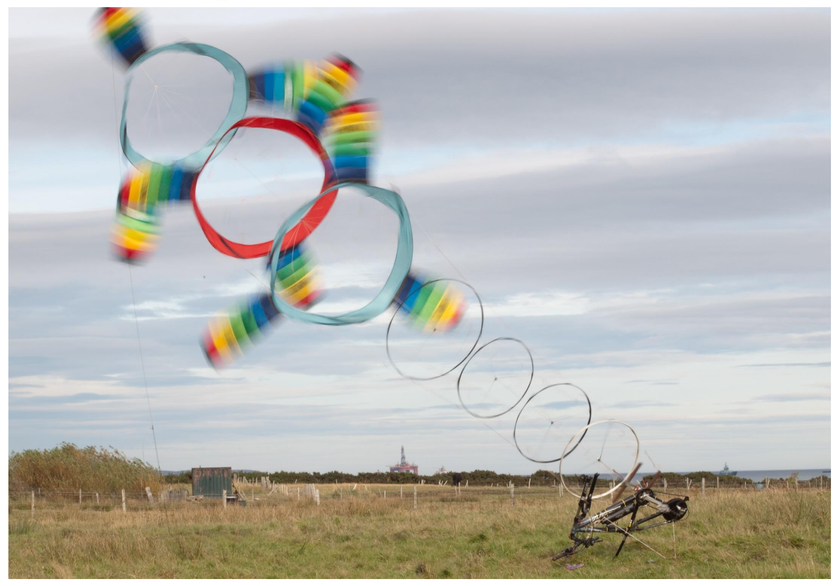
Makani – 600 kW Prototype

- Makani have developed a 600 kW prototype. Their design uses a rigid wing with on-board turbines to generate the electricity and operates at heights of up to 300 meters.
- The wing flies in circles to increase the relative wind speed that the on-board turbines see. The electricity is transmitted to the ground via the tether.
- The on-board turbines can also be driven and used to launch and land the device.

- The AWE industry is just beginning to see much larger prototypes emerge. It is unclear as to which design will dominate and become the most successful.
- With more concepts and designs appearing all the time it is important to investigate each one. This is to asses the potential and establish the limitations of the different designs.

Daisy Kite Development

- This PhD is to investigate a novel rotary kite airborne wind system.
- Over several years Windswept and Interesting Ltd have developed the Daisy kite shown in the image below.
- The Daisy kite has been developed through multiple prototypes and a series of practical tests on each iteration of the design.



Daisy kite prototype undergoing testing on the Isle of Lewis. Photo taken by Rod Read, founder of Windswept and Interesting Ltd [5].

- The Daisy kite design uses the effect of autorotation to create lift and usable shaft power.
- A lifter kite is used to pull the system into the air, where the driver kites cause the entire system to rotate.
- The device uses a cylinder of tensioned tethers held apart by several rigid rings to transmit the rotational motion down to the ground station.
- The current prototype has produced a maximum output of 450W.
- By producing mathematical models of the device and developing control systems, this PhD aims to investigate and progress the Daisy Kite design.

References

[1] – M. Ippolito. Kitegen research. [Online]. Available: http://www.kitegen.com/en/technology/wind-data
[2] - Loyd, M.L., 1980. Crosswind kite power (for large-scale wind power production). Journal of energy, 4(3), pp.106-111.
[3] – Kite Power Systems. [Online]. Available: http://www.kitepowersystems.com/
[4] – Makani. [Online]. Available: https://x.company/makani/
[5] – R. Read. Windswept and Interesting Ltd. [Online]. Available: http://windswept-and-interesting.co.uk

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