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Airborne Wind Energy needs shapewave

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This white paper explains how shapewave technology can be instrumental for the AWE industry to realize system upscaling. By using faster wings, which are currently unobtainable, the yield can be significantly improved. Upping the operating speed with 42% already doubles the AWE system output. Other advantages include manufacturing scale, wing durability, design freedom and cost efficiency.

Soft-wing kites

The Airborne Wind Energy (AWE) industry is dominated by soft-wing systems. These flexible membrane AWE systems fit in one ocean container and consist of a generator connected by a tether to the energy-harvesting kite.

Three of the biggest players are quickly approaching commercial readiness: Kitepower B.V.[1] using a leading-edge inflatable (LEI) kite, Skysails-power[2] using a ram-air kite and KiteNRG [3] also using a ram-air kite. The differences become apparent when looking at a cross-sectional 2D view that shows the airfoil, see Fig. 1. The LEI kite pressurised its tubes prior to operation and therefore remains at a fixed pressure during operation. The ram-air kite requires airflow to develop the pressure difference that allows its membranes to balloon into its design shape. Because the incoming airflow will vary depending on the flight conditions, the internal pressure is not constant.

[1] Kitepower B.V. `https://thekitepower.com/`
[2] Skysails-power `https://skysails-power.com/`
[3] Kitenergy `https://kitenrg.com/technology/`

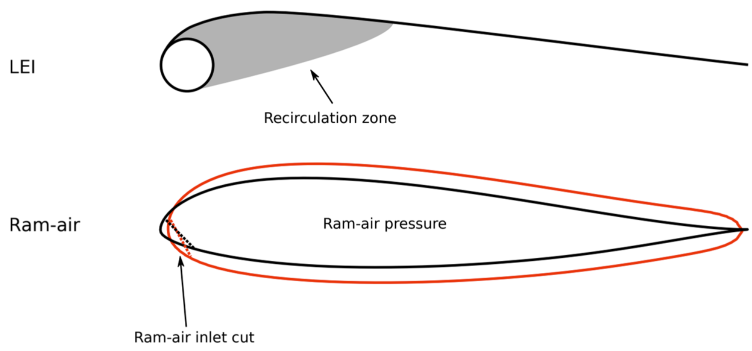

Figure 1: Illustration of a LEI and a ram-air kite, showing the different shapes and the recirculation zone present behind the leading-edge tube of the LEI kite, illustrations taken from [1].

Deformation

Both LEI and ram-air kites are originally designed for low-speed applications, e.g. kite-surfing, paragliding etc. At higher speeds, there are larger pressure differences which cause deformations. For the ram-air kite, the shape formed by ballooning is constrained by the web fabric that holds the top and bottom membrane together. When the web fabric is too weak to hold the pressure the shape deforms heavily, see Fig. 2. Because the web fabric has no contraction-resisting capabilities the ram-air collapses at high-pressure differences, thereby deforming significantly.

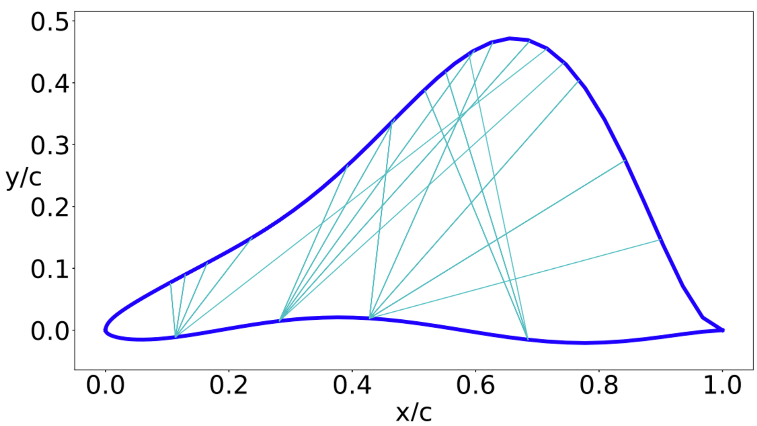

Figure 2: Illustration of a deformed ram-air kite section (airfoil), as a result of too high pressure and too weak webbing [2].

The internal pressure of the LEI kites is not reliant on the incoming airflow but has a material-determined limit. With increasing airflow speeds the pressure differences get higher than the internal pressure. This causes the tubes to collapse, leaving one with a deformed LEI kite shape. Another drawback of the LEI kite is that the designer is limited in how large the airfoil chamber, i.e. kite section thickness, can become. When the chamber is too large, the structural rigidity of the inflated tubular frame won't be able to maintain its shape hence limiting the design choices and thereby the performance.

Both LEI and ram-air kite deformations are problematic because it leads to a drastic decrease in the generated aerodynamic force, thereby decreasing energy production. Deformation will occur more frequently as the AWE systems are optimising for more incoming airflow, as this increases energy production. This currently limits the efficiency of the AWE system making that for higher energy production they have to build bigger kites. However, increasing the kite size comes with numerous problems, e.g. extra costs, difficult handling etc. Therefore, finding a way to increase the structural rigidity of the flexible AWE kites is considered key to enabling the technology to thrive.

Technology of shapewave

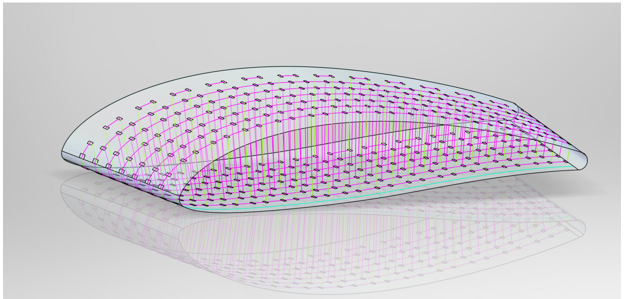

Figure 3: Isometric view of an inflatable shapewave airfoil.

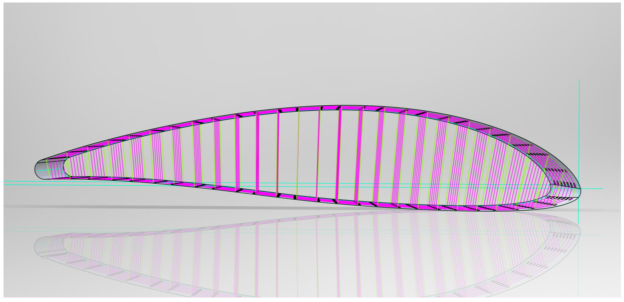

Figure 4: Side view of an inflatable shapewave airfoil.

The shapewave technology enables the AWE industry to quickly develop inexpensive inflatable structures of any shape and size that can withstand much higher pressures for the same or lower mass, see Fig. 4. For the flexible kites of the AWE this is the best solution as it simultaneously solves the deformation problems and higher speeds enable higher energy yield.

The generated aerodynamic force (F_{aero}) determines the energy output and scales with the velocity (V) squared, one needs to increase the velocity by 42%, see Eq. 1. Which with the increased structural rigidity enabled by shapewave is likely possible. Therefore, it is expected that doubling the energy output does not require one to double the size, but is possible with the same kite when using shapewave technology!

$$F_{aero} = 0.5\rho C_L S V^2 \tag{1}$$

Furthermore, as the shapewave technology enables any shape one can design airfoils with higher efficiency as the shape restrictions of the LEI and ram-air no longer fully apply, allowing the AWE industry to deploy vastly more efficient wing designs.

With shapewave one could use semi-automated manufacturing, leading to lower costs, better tolerances and easier production scaling. As the production process becomes more digitized and the manufacturing faster and more automated, one enters rapid prototyping enabling shorting lead times and thus accelerated design iterations. Without the reliance on manual labour, one is not economically driven to use low-wage manufacturing countries. This shortens lead times further, lowers costs, improves overall communication and most importantly reduces the environmental footprint.

Figure 5: A shapewave prototype built by inventor A.R. Enserink.

References

[1] M.A.M. Folkersma. "Aeroelasticity of Membrane Kites: Airborne Wind Energy Applications". In: Phd Thesis, Delft University of Technology, The Netherlands (2022). URL: https://doi.org/10.4233/uuid:eae39f5a-49bc-438b-948f-b6ab51208068.

[2] P. Folkersma. "An integrated aero-structural model for ram-air kite simulations: with application to airborne wind energy". In: Phd Thesis, Delft University of Technology, The Netherlands (2022). URL: https://doi.org/10.4233/uuid:16e90401-62fc-4bc3-bf04-7a8c7bb0e2ee.