Design and testing of a remotely controlled surfkite for the Laddermill

Bas Lansdorp, M.Sc.
Delft University of Technology
bas.lansdorp@lr.tudelft.nl

B. Remes
Delft University of Technology

Prof. dr. W.J. Ockels
Delft University of Technology

Abstract

This paper presents the design and testing of a remotely controlled surfkite for the Laddermill. The Laddermill is a novel concept to generate electricity from high altitude winds. It generates electricity by pulling a rope from a generator, with lift generated by kites. Part of the rope that is connected to the kites is wound around the generator. The kites pull the rope from the generator, thus driving it. Subsequently the kites fly down in a configuration that generates significantly less lift than during the ascent. This way the tether is retrieved and the process is repeated. The Laddermill concept allows very large single unit powers.
For an early demonstration of the Laddermill principle, a commercially availably Peter Lynn surfkite is used. This surfkite is radio controlled, by means of drag creating actuators on the wing tips. This paper presents the actuator design and results of testing of the surfkite. Preliminary results of generation of Laddermill energy are also presented.

1. Introduction

While the wind energy content of the atmosphere increases significantly with increasing altitude, no electrical power is currently generated from high altitude winds. Figure 1 shows the average wind over 20 years in the Netherlands versus the altitude. This paper presents the design of a novel concept that enables wind energy generation from high altitude winds; the Laddermill [1].
In the year 2000, 1.2% of the Dutch electricity consumed, came from renewable sources [2]. In 2000, the Dutch government has set targets in order to comply with the Kyoto protocol, to reduce the Dutch CO_2 emissions. The targets are to generate 5% of the electricity consumption from renewable sources by 2010 and 10% by 2020 [2].
The wind at higher altitudes is more constant. Recent simulations show the Laddermill can have a capacity factor of about 65% [4,5], while the installed power of a single unit may be up to 100 MW [5]. This will enable generating substantial percentages of a country's electricity requirements from wind. It will take only about 20 such 100 MW Laddermills to generate 10% of the Dutch electricity demand.

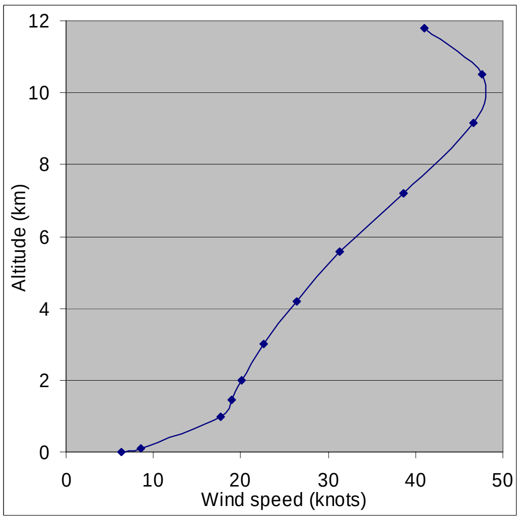

Figure 1: Average wind over the Netherlands versus the altitude [1,3]

2. The Laddermill concept

The Laddermill concept makes use of lifting bodies, called kites or wings, connected to a tether that stretches into the higher regions of the atmosphere. The tether of the kite is wound around a drum. The tension that the kite creates in the tether pulls the rope off the drum, thus powering a generator.

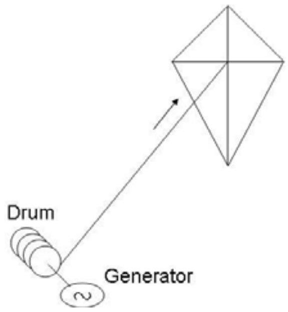

Figure 2: Simple illustration of the Laddermill principle

When the kite is moving up the angle of attack is high to generate high lift and a large tension in the cable, shown in Figure 3.

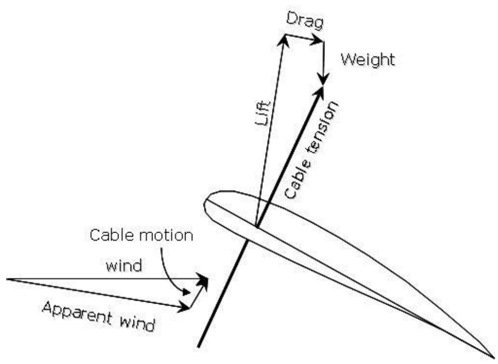

Figure 3: Kite ascending

When the entire tether has been pulled of the generator, the tether must be retrieved. In order to do this efficiently, i.e. without sacrificing substantial amounts energy to pull the cable back in, the lift of the kite is reduced by lowering the angle of attack, shown in Figure 4.

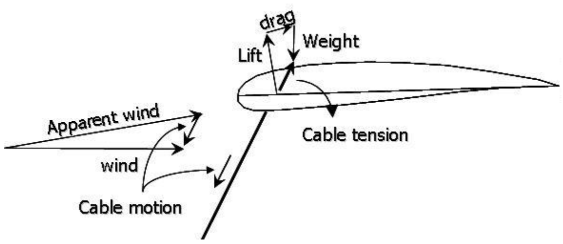

Figure 4: Kite descending

A high ratio between the cable tension when ascending and the cable tension when descending will increase the efficiency of the Laddermill.
The actual Laddermill will have several wings connected in the upper section of the tether.
The installed power of a Laddermill can be higher than that of conventional windmills. Since the wings are high up in the air, their size is not limited like the blades of a conventional windmill. Higher installed power will lead to a larger tether diameter and a larger, ground-based, generator. Larger single-unit outputs are expected to decrease the cost per kWh.

3. Radio Controlled surfkite

The surfkite used for the tests is a commercially available Peter Lynn Bomba surfkite [6], a moderately stable kite with a total area of 8.5 m^2. In normal use, surfkites are controlled by a steering rod, as presented in Figure 5.

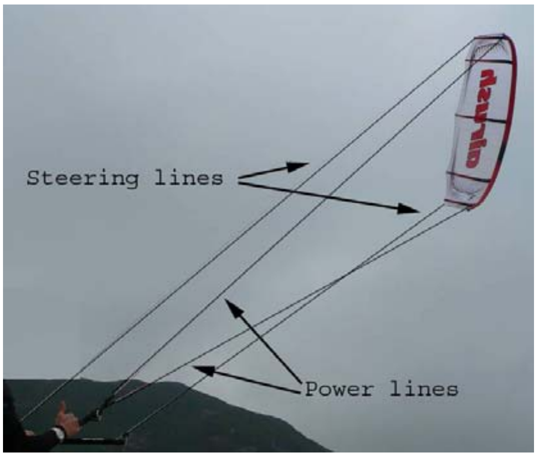

Figure 5: Kitesurfer operating his kite

The remotely controlled surfkite presented in this paper is controlled by means of drag flaps on the wing tips. One of the drag flaps is presented in

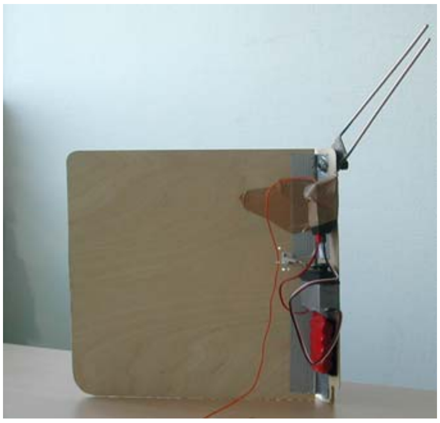

Figure 6: Drag flap actuator

For the tests, only the power lines are attached to the kite. The steering lines are replaced by the drag flaps. This is shown in Figure 8. The power lines are connected 25 m below the surfkite, continuing to the ground as a single line. This is illustrated in Figure 7.
While removing the steering lines makes the kite easier to control, it also reduces the power generated by the kite, because the steering lines increase the angle of attack of the kite. A radiocontrolled kite with passive steering lines is still under investigation.

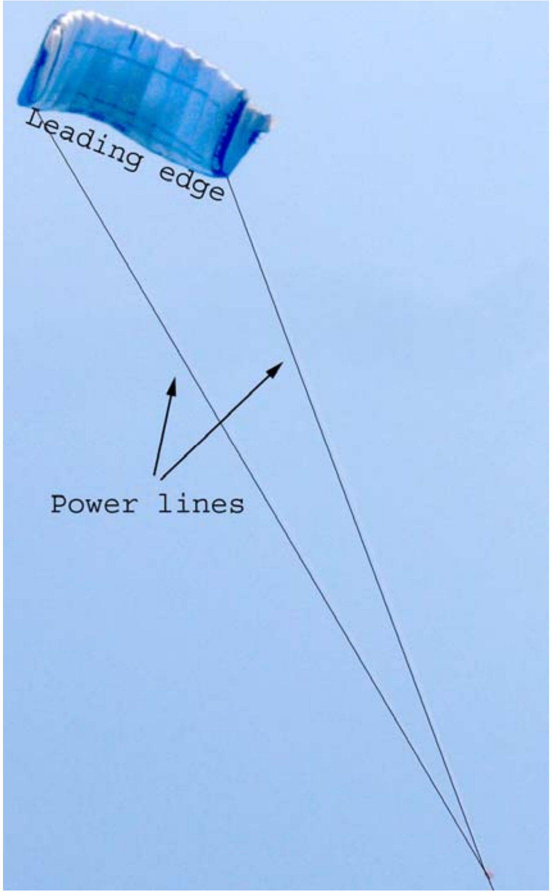

Figure 7: New cable configuration

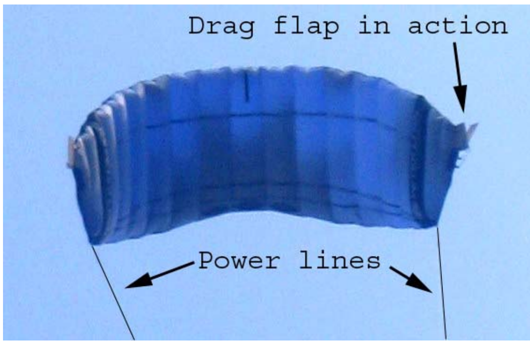

Figure 8: Location of the drag flaps

The drag flap surface that is required to control the surfkite can be determined. The desired angular acceleration is estimated from manual handling; 0.25 rad/s^2.

Wing mass + air mass (m)	~4	kg
Inertia (I)	~5.33	Kg m^2
Projected wing span (2r)	~4	m
Wind speed (v_w)	20	m/s

The value to be determined is the angular acceleration α of the kite caused by opening a single drag flap. The required torque can be determined as:

$$T = I \cdot \alpha$$

$$T = F_d \cdot r$$

$$F_d = c_d \frac{1}{2} \rho v^2 S$$

The drag coefficient c_d was estimated to be the average of an infinite wedge (c_d = 1.55) and a cone (c_d = 0.5), so c_d = 1 [7].
Now the required surface can be determined as

$$S = \frac{2I\alpha}{c_d \rho v^2 \cdot r} = 0.034 \text{ m}^2$$

This is achieved by a drag flap height of 0.25 m and an effective opening of about 0.12 m, as illustrated in Figure 9.

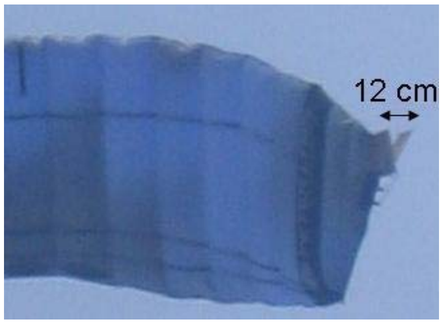

Figure 9: Opening of the drag flap

While an opening of 12 cm was measured on the ground, it appears that the force of the wind decreases the opening. Stronger servo motors will be installed on new versions of the drag flap.

4. Test results of the kite

The surfkite was tested several times in a large number of different wind speeds.

4.1. Stability

In general it can be concluded that the kite is controllable by remote control in winds above 3-4 Beaufort. The higher the windspeed, the more stable the observed behaviour of the kite. The kite has not been tested in windspeeds above 6 Beaufort, but is expected to operate in windspeeds up to 9 Beaufort. It can also be concluded that a longer cable contributes to the ease of manoeuvring the kite in low wind speeds.
The stability of the kite is quite high: even without remote control the kite will stay mostly in the vertical position. Larger oscillations may occur, especially at wind speed below ~22 km/h. The reason of these oscillations is not understood yet.

4.2. Controllability

When the kite was tested in a windspeed of 20 km/h, it was determined from video recordings that the time needed to steer the kite 45 degrees is about 3 seconds. The angular acceleration of the kite was therefore:

$$\theta = \frac{1}{2} \alpha t^2$$

$$\alpha \approx 0.17 \text{ rad/s}^2$$

Which is quite close to the expected angular acceleration of 0.25 rad/s^2. The reason that the realised acceleration is lower could be that the drag flap is closed somewhat by the windforce.
When using the control flaps, the kite can be held stable without any difficulty. Even when very large oscillations are induced, the kite is easily returned to the 'equilibrium' position.

4.3. Suitability for the Laddermill

In principle, the Peter Lynn Bomba kite is suitable for the Laddermill. The tension in the cable can be increased by flying figure eights, and decreased by not moving the kite around. This should enable a tension ratio in the cable of about 10:1; the tension in the cable is high when the kites are powering the generator, and low when the generator retrieves the cable. The kite is more or less stable which improves safety: if the steering mechanism fails, nothing bad will happen.
On the other hand, the kite is so stable because it has a rather low lift over drag (L/D). Kites with a higher L/D will be able to generate higher tension ratios, resulting in higher efficiency of the Laddermill. Tests with radio controlled kites that have higher L/D have up till now been unsuccessful, but are subject of further research.

5. Future test plans

A number of tests are planned to find out what is the best suitable surfkite for a Laddermill

5.1. Controlling the kite liftforce

It is clear that the best way to controlling the liftforce of a kite is by changing the apparent wind. The apparent wind can be increased by means of cross wind power [8]. This can be done by circling, figure eighting or other profiles, thus increasing the lift force. When the kite is not using cross wind power, the lift will be much lower.
Other strategies could be reducing the effective surface of the kite, changing the wing profile of the kite and reducing the angle of attack. At this moment, especially the first strategy, reducing the wing size, is under investigation. Changing the wing profile is an advanced option that is subject to further research. Changing the angle of attack has been attempted, but unsuccessfully up till now.
More than one principle can be used for the same Laddermill.

5.2. High L/D kites

High L/D kites, as mentioned before, are a straightforward approach to increase the power of a Laddermill, and to improve the tension ratio in the cable. The higher L/D has a negative effect on the stability, which makes such kites harder to control.

5.3. Multiple kites

For the Laddermill, it is planned to have many kites attached to the cable. Therefore, it is planned to test multiple surfkites on a single line in the near future. The dynamics of a cable with two or more kites is more challenging than that of a single kite. It will need to be investigated if the system is stable, and if steering does not result in oscillations. Also, it is useful to know if every kite on the cable should have its own actuator system or if only the top kite, or several of the top kites, need control capability.

6. Preliminary Laddermill test results

Up to now, several successful tests were performed with a surf kite laddermill that have resulted in power generation with the Laddermill. While the power generation was low (~200 W), the principle has been demonstrated. Up to now, no tests were performed in high wind speeds of 5 Bft and higher, limiting the power that can be generated with an 8.5 m^2 surfkite.

7. Acknowledgements

This work is part of the Laddermill project sponsored by: Shell research, Fugro, Gasunie, University of Groningen, Delft University of Technology, the province of Groningen, the county of Groningen and the county of Delft.

8. References

[1] Ockels, W.J., 2001, "Laddermill, a novel concept to exploit the energy in the airspace", *Aircraft design 4* (2001), pp 81-97.
[2] Dutch Ministry of economic affairs, 2001, "Bestuursovereenkomst Landelijke Ontwikkeling Windenergie (Blow)", accesseble at http://appz.ez.nl/publicaties/pdfs/BLOW-BW1.pdf accessed 27-06-2005.
[3] Royal Netherlands Meteorological Institute.
[4] Lansdorp, B., Ockels, W.J., 2005, Comparison of concepts for high-altitude wind energy generation with ground based generator, NRE 2005 conference proceedings pp. 409-417, Beijing, China.
[5] Lansdorp, B., Ockels, W.J., 2005, Design of a 100 MW laddermill, 7th World Congress on Recovery, Recycling and Re-integration, R'05 conference proceedings, Beijing, China.
[6] Peter Lynn Kites webpage, www.peterlynnkites.com, accessed 23-06-2005.
[7] S.F. Hoerner, 1965, Fluid Dynamic Drag.
[8] Loyd, M.L., 1980, "Crosswind Kite Power", *Journal of Energy*, vol. 4, No. 3, pp 106-11.