Generating Wind Energy Using Kites

Wind Turbines and Earthquakes

Reducing Dynamic Loading of Towers

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Imagine a kite that looks like an aircraft and can be flown like one. An efficient, reliable and stable design. Such a kite is a portable pulling force in the air. With this force it is possible to do all kinds of exciting things such as pull ships and generate energy. At the Delft University of Technology, Faculty of Aerospace Engineering, kites are maturing from 'toys' to a serious force to be reckoned with.

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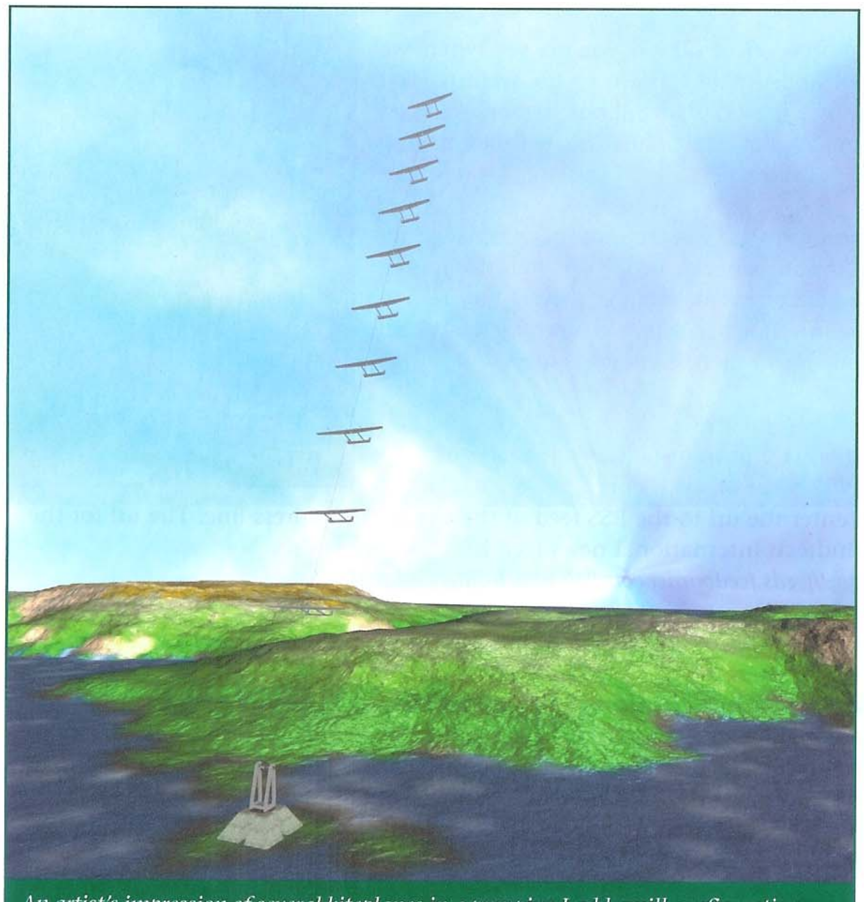
Generating Wind Energy Using Kites

Tethered Wing Design for the Laddermill Project

The energy within the wind that blows over our heads is tremendous. Current wind energy technology is a testament to the power the wind contains. However, until now only the wind close to the ground has been exploited. Here, the wind contains the least amount of energy because of its low velocity. At an altitude of 3 kilometres, the wind is much stronger and not affected by ground objects such as trees and buildings. Professor Ockels initiated research, which is currently being undertaken at the Faculty of Aerospace Engineering at the Delft University of Technology, to make use of these high-energy winds at high altitude.



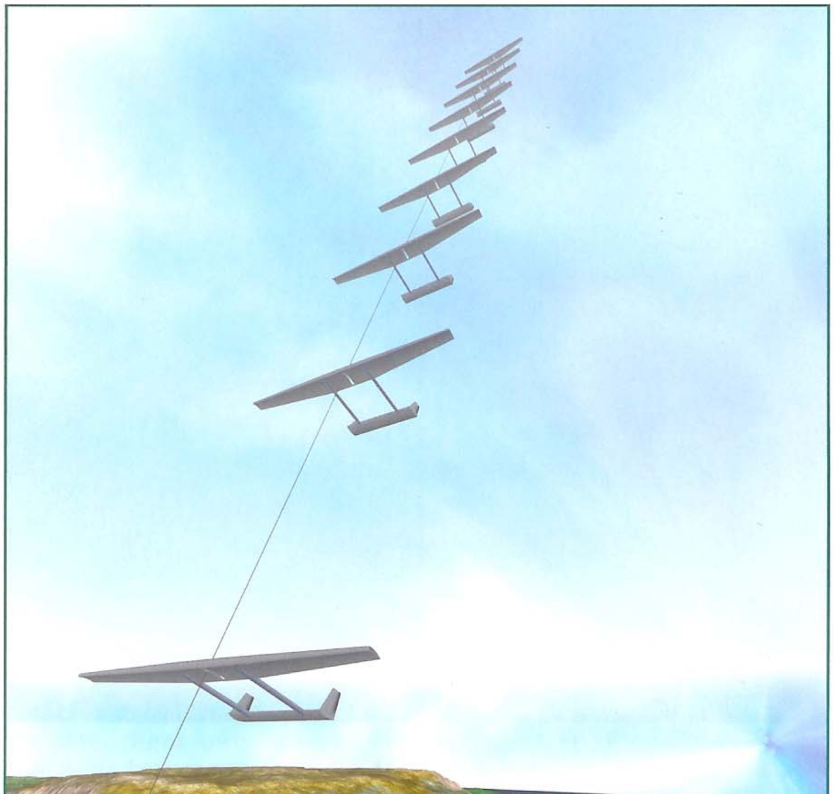
An artist's impression of several kiteplanes in a pumping Laddermill configuration

The technology being researched is called 'Laddermill' (patented). It uses large controllable kites to ascend and descend to generate energy. A series of kites is connected to a long tether. The other end of this tether is wound on a drum connected to a generator. While the kites ascend from, for example, 2 to 5 kilometres altitude, they are positioned such that they pull the tether off the drum, driving the generator and creating electrical energy. Once the kites reach their maximum altitude, they are positioned in such a way that they generate very little lift. The tether is retrieved by spinning the drum. Once the kites reach their low altitude level again, the process restarts. During ascent, kites can be steered in a figure of eight pattern to increase their velocity relative to the air and thereby increase the pulling force (crosswind power). During retrieval of the cable, some energy will be spent. The difference in the energy created in the upward motion and the energy spent during the downward motion is the amount of energy created during one stroke. In order to ensure a continuous generation of energy, several Laddermills can be linked and their strokes timed much like a piston engine.

Everyone who has ever flown a good and stable kite will know that a kite will ascend with relative ease. You have to be careful not to burn your hands on the outgoing kite line. However, retrieving the kite usually involves pulling it down with force. For an aeroplane, however, this is completely the opposite. An aeroplane needs large engines to climb to a certain altitude, but it can glide down under idle power. The kites to be used for the Laddermill combine these properties into a single craft, a craft that can fly up like a kite, and glide down like an aeroplane. That is why we call these kinds of kites kiteplanes.

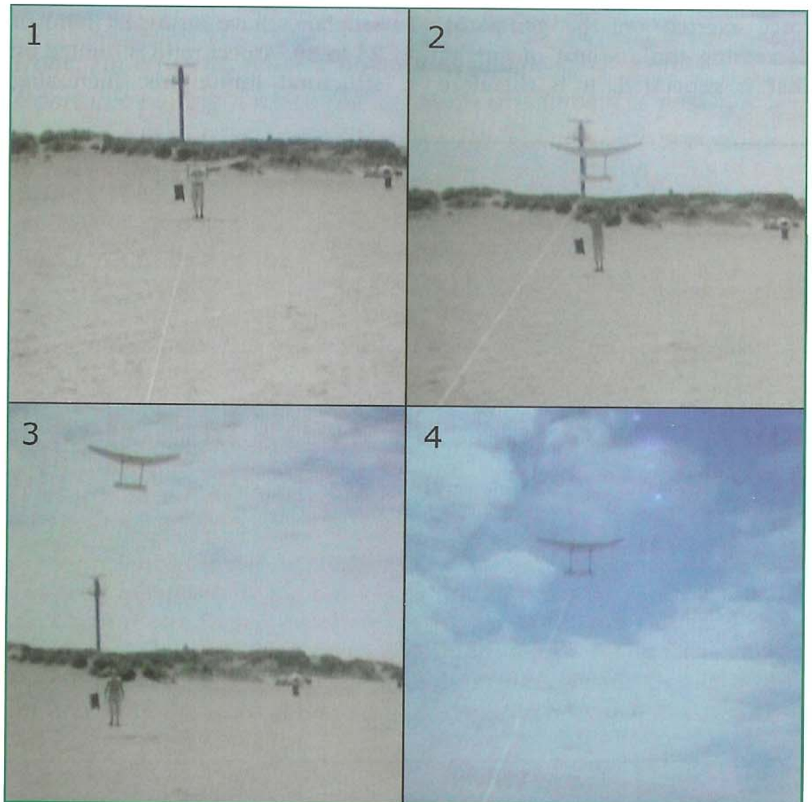
In order for a kiteplane to be able to fly like a kite, it needs to have sufficient lift at low airspeed. Since the kiteplane stands still with respect to the ground, the airspeed is equal to the wind velocity. And even though wind speeds can be impressive at high altitude, they are still much lower than the minimum speed of most aircraft. It is therefore imperative that the kiteplane is constructed in the most efficient way to make it as light as possible.

It seems obvious that the more lift a kiteplane generates, the more power it will create through the generator. Having the kiteplane ascend faster will allow for faster spinning of the generator and more strokes per hour of the whole Laddermill system. But, together with lift, the kiteplane also creates drag. Drag will cause the kiteplane to fly further away from the attachment point on the ground. The path of the ascending kite projected on the Earth's surface is called its footprint. When the kite has a large amount of drag, this footprint will elongate. This will increase the amount of cable needed to reach from the generator to the kite. An increased amount of cable means a larger weight that has to be carried by the kiteplanes. This increased deadweight will have an impact on the pulling force exerted on the generator, decreasing the amount of energy that is generated. It is therefore important that the kiteplane has a large amount of lift at a low amount of drag. In the world of aerospace, this is called a high lift over drag, or L over D.


An artist's impression of several kiteplanes in a pumping Laddermill configuration (close-up)

A flying craft creates drag in several ways. Friction drag is the drag created by the air flowing over a surface. Parachute drag is the drag crated by pulling an object through the air, pushing the air out of the way. And, finally, induced drag is related to the lift a wing creates and the resulting amount of downwash. Wing shape is of great influence on the amount of induced drag. Long and slender wings have far less induced drag than short, stubby wings. The slenderness of a wing is called its aspect ratio and is calculated by dividing the square of the wingspan by the wing surface. Current top-end surfkites have an aspect ratio of 4 to 6. Modern sailplanes have an aspect ratio of 25 to 30. Aspect ratio is limited by structural limitations. Increasing slenderness of wings will enlarge the bending moment and will put increased stress on the materials. However, by attaching the main cable to the kite through several branched sub-cables (called bridle lines) along the wingspan, the bending movement in the wing can be significantly reduced.

In order to build a kiteplane that is sufficiently light, the construction principle of inflatables is used. An inflatable structure is a structure that consists of beams made of a foil material, creating an airtight bladder. By inflating its internal bladder, tension is created in the beam, much like in an ordinary inflatable raft. When a beam bends upward at one end while clamped at the other, it creates tension on the lower side of the beam and compression on the upper side of the beam. The light foil materials



The launch of the model kiteplane

used are very strong in tension, but buckle like paper under compression. By inflating the beam, a pre-tension is created in the foil. This pre-tension will counter the compression stress created by the external loads on the beam. This principle will make the inflatable beam a stiff, load-carrying member, with its stiffness directly related to the internal pressure. Since this stiff beam only consists of a light foil material and the internal compressed air, it is a very light structure, ideally suited for use as a load-carrying member of a kiteplane. The principle of inflatable structures is already used on a large number of surfkites and has proved to be reliable and robust.

The model kiteplane in flight

In order for a kiteplane to perform its role, it also needs to be stable. Flight dynamics and stability theory of aircraft are well developed. However, for kites such a mature theory does not exist. Since the kiteplane shows great similarities with the layout of a conventional aircraft, some of the theory is transferable. But the presence of a cable will introduce modes of motion that do not exist for free-flying aircraft. The mathematical equations behind the stability of a kite are far more complicated than those of a conventional aircraft because the cable has to be taken into account as well.

In designing a kiteplane, this is where a big challenge lies. As it turns out, the drag a kite generates is directly related to its stability. A large amount of drag will create a stable kite. That is why, as children, we were told to attach long tails to our kites in order to make them 'fly better'. What was really meant is: Increase the kite's drag and move the centre of effort aft to increase its stability. But, as stated earlier, high drag is not something we want for an energy-generating kiteplane. A high L over D requires a low drag design. At the Delft University of Technology, kiteplanes have been built and flown. It turns out that they tend to have two particular modes of instability. The first one is what's called an unstable 'Dutch roll' oscillation. This is a combination of yaw and roll motions, which can spin the craft out of control. But because the kiteplane is attached to the tether at several points on the kite using a system of bridle lines, the effects of the Dutch roll oscillation are almost unnoticeable. The second instability mode is called the 'inverse pendulum' motion. This is the tendency of the kite to fall to either the right or the left while it is flying. The only force on the kite which truly knows up from down is the weight force of the kiteplane. And, since the weight of the kiteplane is very small with respect to the amount of lift it creates, the correcting force introduced by the weight of the kiteplane is simply not sufficient to overcome the unstable motion.

A way to remedy this is to increase the weight of the kite. But this goes directly against the wish for a high L over D and a large amount of power-generating capability. So, in order to overcome this pendulum instability, the kiteplane has to be fitted with an active control system that will return the kite to its equilibrium. Therefore, the kite is fitted with a sensor, which can detect the position, velocity and acceleration of the kite in all six degrees of freedom. This data is

The author and the model kiteplane on the ground

fed into a small onboard computer. When the sensor detects a deviation from the equilibrium, the computer counters the deviation by operating a number of servos on the kite which, in turn, operate control surfaces to create a correcting aerodynamic force.

To date, flight tests have been performed on a scale model with a wingspan of 3 metres. Results of these tests were encouraging and a second, much larger kiteplane is now in the design phase. The scale model was made out of a light foam material and its controls consisted of radio-operated control surfaces. The new kiteplane will be a fully inflatable wing and be computer-controlled. Manual control is still possible through a wireless connection with a laptop and a joystick on the ground. The design looks promising and we hope to fly it for the first time somewhere in the first part of 2007.

Biography of the Author

Jeroen Breukels obtained his master's degree in Aerospace Engineering at the Delft University of Technology in 2003. After graduation, he worked on a joint project for the Delft University and the European Space Agency called 'KitEye' for nearly a year. Currently, he is doing his PhD research project into the flight mechanics and construction of kites and kiteplanes under supervision of Prof. Dr Wubbo J. Ockels.

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