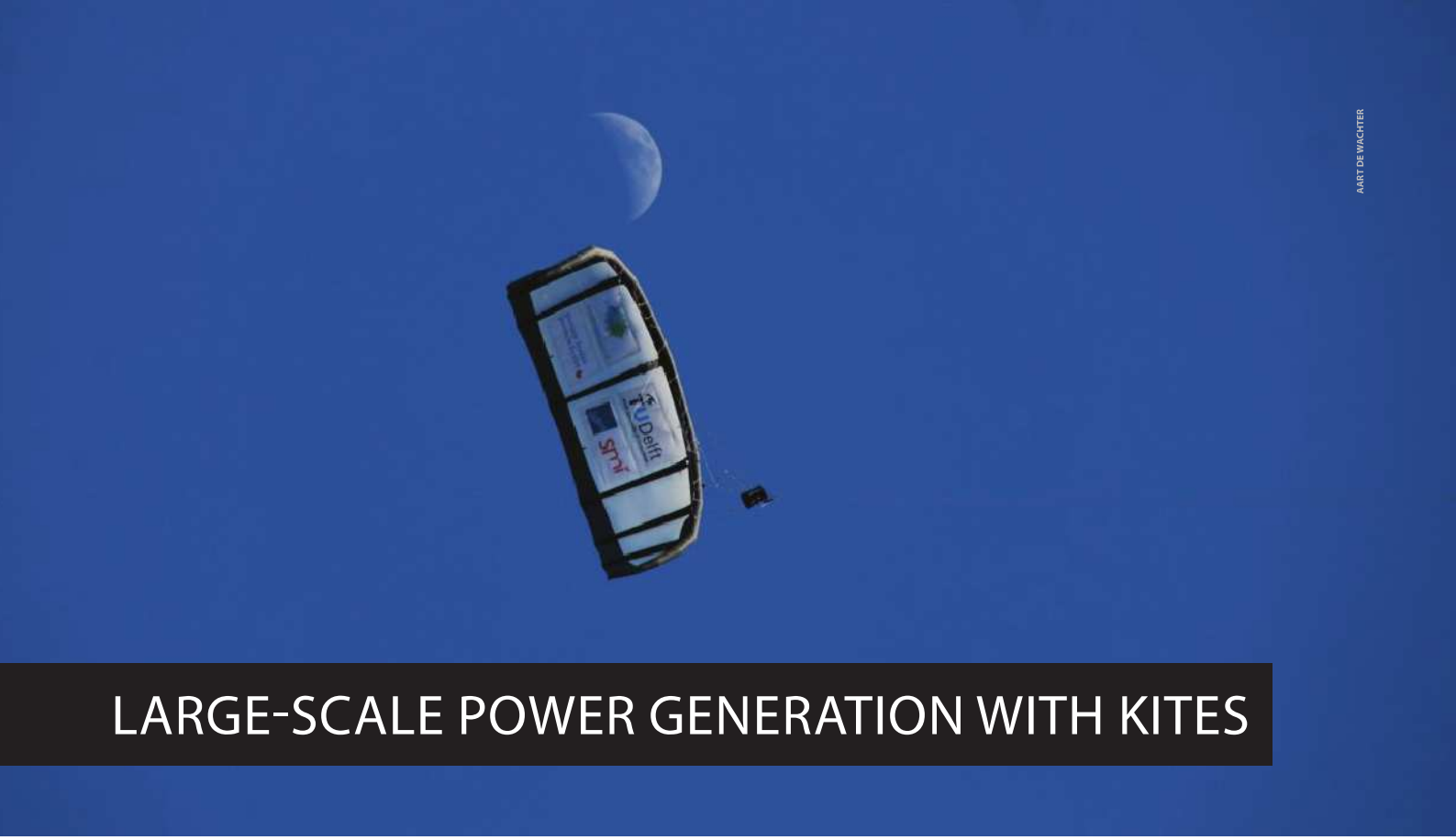

AART DE WACHTER

LARGE-SCALE POWER GENERATION WITH KITES

Wind at higher altitude is a major source of renewable energy. However, this potential is far beyond reach for conventional wind energy systems using rigid tower structures. One of the possible solutions to capture high altitude wind energy is the use of kite power systems, such as the one developed by the research group of Delft University of Technology. The innovative development is reviving a comprehensive scientific and engineering heritage.

TEXT **Roland Schmehl, Associate Professor, Delft University of Technology**

GOLDEN AGE OF THE KITE

With a history dating back several thousands of years, kites are reported to be the earliest man-made flying objects. First appearing in Asian and later also in Polynesian cultures, they have been used for military purposes, as religious symbols, for entertainment and for many other practical applications. An example that is still in use is the technique of using kites for fishing. Before the invention of engine-propelled flight at the beginning of the 20th century, there were basically two aircraft types capable of lifting significant payload high up into the air: balloons, employing the principle of aerostatic lift, and kites, employing the principle of aerodynamic lift. Yet, for many purposes kites were the superior technology. For example, they could be operated at wind conditions in which tethered balloons were unusable and, employing the kinetic energy of wind to generate lift, they were generally less expensive. As a result, kite applications flourished in particular in the period between 1860 and 1910, which is often denoted as the "Golden age of kites". In the beginning of the 20th century, many meteorological stations in Europe and the US employed kite trains. These consisted of several kites arranged along the tether to perform daily ascends up to several kilometers altitude. The highest recorded kite ascent to date is a heritage of these times: in 1919, a train of eight kites reached an altitude of 9740m at the meteorological observatory of Lindenberg (see Figure 1). In 1901, inventor Guglielmo Marconi used a kite-supported antenna for his first transatlantic wireless transmission and in 1906, photographer and aviation designer George Lawrence used a camera suspended from a train of kites for aerial documentation of devastated San Francisco after the great earthquake.

DECLINE OF KITE APPLICATIONS

But also the development of engine-powered aircraft benefited largely from available kite technology. To investigate the use of wing warping for flight control, Orville and Wilbur Wright suspended glider prototypes of their airplane on tethers and flight-tested them as kites. However, the ensuing success of the airplane marked also a beginning decline in kite applications and, except for some military applications in the two world wars, it would take until the end of the century before the kite would resurface in larger numbers as a water sport device. But already before the advent of kite surfing in the late 1990s, during the 1970s energy crisis, Miles Loyd, an engineer of Lawrence Livermore National Laboratory, proposed to use tethered aircraft for large-scale wind energy conversion. In his visionary paper "Crosswind Kite Power" from 1980, he estimates an average power output of 6.7MW from a tethered aircraft of 576m^2 wing surface area in a wind of 10m/s. He further outlines the two different concepts: electricity generation on board of the aircraft by means of propeller turbines or using the traction power of the aircraft to drive a generator on the ground. It took another twenty years, until an emerging interest in renewable energies and major advances in control and simulation triggered a growing interest in kites.

RENEWED INTEREST IN KITES

At Delft University of Technology, Wubbo Ockels proposed the Laddermill concept to access the kinetic energy of high altitude wind. In his patent application from 1998 he outlined a cable loop running

Figure 1. Box kite above the winch house of the meteorological observatory Lindenberg (1930)

Figure 2. 25 m² tube kite flying cross wind observed from the ground station

through a pulley at the ground station several kilometers into the sky with kites attached to the cable at equidistant intervals. In 2001, German company SkySails began developing a kite traction system for large container vessels. Commercially released in 2007, the system using a 160 m^2 ram-air kite has been fitted to several ships by now, achieving up to 35% fuel savings. Between 2006 and 2008, Californian startup company Makani received $15 million from Google.org to develop high altitude wind power conversion technology. Securing an additional $3 million ARPA-E grant from the US Department of Energy, the company has won the Popular Mechanic's 2011 Breakthrough Innovator Award in the Energy Category for their tethered rigid wing system with onboard propeller turbines, currently at a 20kW prototype stage. But these are just some activity highlights and in fact, more than forty different teams are currently involved in Airborne Wind Energy projects. Accordingly, the Airborne Wind Energy Conference 2011 which was held at the University of Leuven saw more than 120 participants from around the world.

DELFT KITE POWER SYSTEM

Development of the current kite power technology started at Delft University of Technology in 2005 when Ockels established a dedicated research group. The system is based on a single inflatable membrane wing which is tethered to a cable drum / generator module on the ground. The system is operated in pumping cycles with periodically alternating reel-out and reel-in phases. To maximize the energy generated during the reel-out phases, the wing is flying figure-of-eight or circle maneuvers perpendicular to the wind (see Figure 2). This crosswind technique increases the relative wind velocity at the kite and by that also the aerodynamic forces. During the reel-in phases, the cable drum/generator module is operated as motor winch, pulling the kite back towards the ground station. To reduce the traction force, the angle of attack of the wing is decreased by rotating it into the relative wind. By "flagging" the wing, the reel-in phases require only a small fraction of the energy generated during the reel-out phases. Steering and de-powering is both done by a Kite Control Unit, which is a small, remote-controlled cable robot suspended below the kite (see title image). To balance the electrical energy over the alternating phases of the cycles the ground station incorporates a battery module.

MONTHLY SYSTEM TESTS

Equipped with a 25m^2 kite and a 20kW generator, the third and latest technology demonstrator is tested on a monthly basis since January 2010. By now, more than 160 pumping cycles have been recorded and analyzed in detail. At the present test site, the former naval airbase of Valkenburg, the maximum altitude is limited to 300m. As a result of systematic optimization on component- and system-level, affecting the kite and bridle system design, the responsiveness of the ground station winch and the flight trajectory, the currently achieved traction power average is 6.5kW, and the goal is to further increase this value to 10kW. In December 2011, the technology demonstrator was successfully performing automated pumping cycles, with the autopilot software alternating between a figure-of-eight flight trajectory controller for the reel-out phases and symmetry plane stabilization during the reel-in phases.

RESEARCH AND EDUCATION

The project is co-financed with €136,000 by the Dutch province of Friesland and with €1 million by the Rotterdam Climate Initiative (RCI). For June 2012 it is planned to demonstrate the automatic operation of the kite power system as part of a public presentation. The multidisciplinary character of the technology (aerodynamics, structures, materials, flight dynamics and control, modeling and simulation, wireless communication, etcetera), the corresponding scientific and engineering challenges and the availability of a relatively inexpensive airborne research and development test bed makes the project particularly suitable for educational purposes. By now, many research activities have been performed by students, on the one hand from Delft University of Technology or other Dutch institutions, but also many from various places in the world. The statistics show that students from countries where innovation and renewable energies are top priorities (e.g. Germany) seem to be particularly motivated to engage in the subject. The interest is also reflected by the continuously increasing number of students enrolling in the master-level courses "Kite Power & Propulsion" (AE4T40) and "Wind Power" (AE4W20), both part of the curriculum of the Faculty of Aerospace Engineering of Delft University of Technology, and both addressing the theoretical background and working principles of Airborne Wind Energy conversion concepts.

It is the mission of the research group to revive the scientific and engineering heritage of the "Golden age of kites", advance it by combination with latest high-tech, to develop innovative solutions for the energy problem.

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Contact: r.schmehl@tudelft.nl