

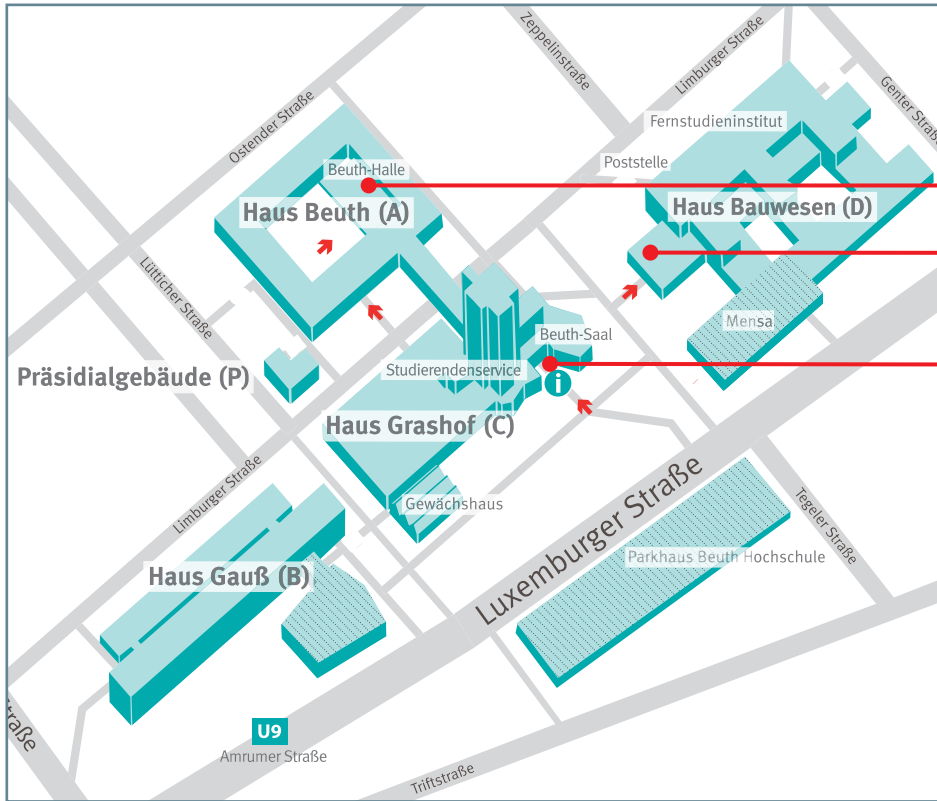
SEPTEMBER 10-11  
BEUTH UNIVERSITY  
BERLIN · GERMANY  
[www.awec2013.de](http://www.awec2013.de)

# AIRBORNE 2013 WIND ENERGY CONFERENCE

## BOOK OF ABSTRACTS



**BHWe**



BEUTH HOCHSCHULE  
FÜR TECHNIK  
BERLIN

University of Applied Sciences

**Beuth-Hall = (Old Machine Hall)  
Dinner**

**Auditorium H2, First Floor**

**Auditorium Beuth  
Registration  
Coffee and Lunch Buffet**

# **AIRBORNE 2013** **WIND ENERGY** CONFERENCE

SEPTEMBER 10-11  
BEUTH UNIVERSITY  
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### **The German Airborne Wind Energy Association**

#### **(BHWE Bundesverband Höhenwindenergie e.V.)**

This year's AWEK is organized by the BHWE, which undertakes the task of making the public aware of the benefits and potential of AWE. The association supports studies and research projects to develop and promote this future-oriented branch of industry in a constructive and targeted manner.

It is committed to the general dissemination of knowledge about the significance of high-altitude wind energy for global climate protection as well as for the comprehensive and sustainable promotion of the deployment of high-altitude wind energy from a political, technological, social and economic perspective. The association is a non-profit organization.

[www.bhwe.org](http://www.bhwe.org)

# AIRBORNE 2013 WIND ENERGY CONFERENCE

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# Welcome to the Airborne Wind Energy Conference 2013

Guido Lütsch

President of the German Airborne Wind Energy Association  
Bundesverband Höhenwindenergie e.V. (BHWE)



**Guido Lütsch**

President of the  
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**BHWE**

Dear AWE-friends and AWEC 2013-participants,

The German Airborne Wind Energy Association is delighted to welcome you to AWEC 2013.

Renewable energy in general is currently the subject of crucial debate. Accused for being insufficiently predictable and available, solar and wind energy are blamed as one of the major causes of rising energy prices.

At the same time we are facing a worldwide increasing demand for energy which is mainly being met through the building of new fossil fuel power plants. Fossil fuels are a "cornerstone" of our current prosperity, but fossil fuels are limited. I do not wish to discuss whether they will last 70, 100 or 120 years, but in terms of decades and centuries the era of fossil fuels is almost over. It is therefore necessary to protect fossil fuels and to consume them only in a sustainable way. It is high time to find alternatives which are economically and socially viable throughout the world.

Wind-generated energy is considered to have the greatest potential within "renewable energies" for substituting fossil fuels. The success formula for the future lies in the considerable improvement of the efficiency and availability

of wind power plants. To achieve this they need to be able to harness stronger and above all more consistent winds. These conditions can be found nearly everywhere at higher altitudes and call for Airborne Wind Energy (AWE) technologies that access winds at heights of 300 to 500 meters.

AWEC 2013 will provide you with an exclusive overview of the various trends in AWE activities worldwide. The AWE companies will provide information on the current development status and their next steps into serial production. Universities, colleges and research institutes will present the results and findings of their studies.

I hope that through the combined efforts of the program and organizing committees, we succeed in putting together all the ingredients that are necessary for an exciting, interesting and inspiring conference and that you will enjoy AWEC 2013.

Have an AWESome time and welcome to AWEC 2013.

All the best  
Guido



**Prof. Dr. Sebastian von Klinski**

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BEUTH HOCHSCHULE  
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University of Applied Sciences

## Welcome to the Beuth University of Applied Sciences Berlin

Prof. Dr. Sebastian von Klinski

Vice-President of Research, Beuth University of Applied Sciences

The Beuth University of Applied Sciences Berlin is very happy to welcome you to the Airborne Wind Energy Conference 2013 on our main campus here in the capital of Germany.

Besides the technological challenges our society faces during its ongoing transition from fossil fuel consumption to harnessing renewable energies, projects in this field of research will increasingly require interdisciplinary approaches. Almost any challenge concerning the implementation of new technological approaches will require the experience of increasingly specialized engineers for distinctively different scientific domains, thereby adding a new dimension of complexity to research projects.

It is not sufficient anymore merely to have an electrical engineer, a mechanical engineer or an IT specialist on board to achieve expedient innovations. Rather, highly educated experts from distinct fields of research are required to work in unison; they need to collaborate in a manner that achieves synergy and they must also be supported by good project management. Many technologically sophisticated projects fail to reach their technological aims or to produce outcomes leading to financial success due to lack of synergetic cooperation between project participants from diverse fields of expertise. Off-shore wind parks present a good example of an ongoing research endeavor that has encountered a great diversity of unexpected setbacks. The Beuth University of Applied Sciences Berlin not only provides the most comprehensive range of degree programs in

engineering disciplines in Germany, it very actively participates in numerous applied-science research projects. Among others, several professors of the Beuth University are participating in various Airborne Wind Energy projects. Not only from such projects our university experiences this increasing demand for a greater focus on interdisciplinary education as well as on the application of diverse disciplines of science. Thus, the Beuth University has started to develop degree programs and project initiatives that span several study and research disciplines. While it is a strategic advantage for the Beuth University covering most areas of engineering competence at one institution of higher education, it still remains a challenge to bridge the differences in approach and know-how between the various disciplines. Nevertheless, our ongoing initiatives demonstrate that specifically such interdisciplinary cooperation spawns very exciting and rewarding projects.

The Airborne Wind Energy represents an impressive example of such a field of research that is venturing into uncharted territories. Consequently, the Beuth University of Applied Sciences Berlin is much honored indeed to host this inspiring conference of the German Airborne Wind Energy Association. We wish you stimulating interdisciplinary exchanges that hopefully result in momentous insights through your utilization of synergy.

Best regards,  
Sebastian von Klinski







### **AWEC 2013 is dedicated to Corwin Hardham**

We honor Corwin Hardham, one of the pioneers of Airborne Wind Energy who died unexpectedly but peacefully while working at his desk on October 23rd 2012 at the age of 38.

Trained as a mechanical engineer and modern and ballet dancer, Corwin held a BS from the University of Washington and a PhD from Stanford University.

In 2006, Corwin co-founded Makani Power, a clean energy company focused on harnessing the untapped resource of high-altitude wind. During the six years that Corwin was a cofounder in the company, and for his last several years its Chief Executive Officer, the Makani Airborne Wind Turbine evolved from a soft textile kite powering a generator on the ground to a rigid, high performance wing with

onboard generation. His love for the wind and the elements informed every aspect of his professional life, from his innovations in sporting equipment to his enduring commitment to alternative energy.

His clear vision and deep commitment to transformative innovation in clean energy inspired us all. He was generous in sharing his understanding and know-how about Airborne Wind Energy with the whole AWE-community. As Chairman of the Board of the Airborne Wind Energy Consortium in 2012, his contributions in building an international AWE nonprofit organization continue to be sincerely appreciated.

AWEC 2013 Organization Committee





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## Automated Landing and Take-off System for Rigid Wing AWES

Tommi Berg, Ilpo Suominen, Juha Pulkkila

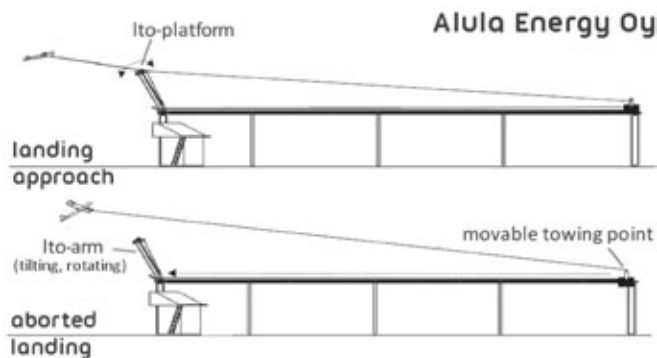
Alula Energy oy

Alula Energy is a startup company developing landing and take-off (LTO) technology for airborne wind energy. Our goal is to make airborne wind energy commercially available for international markets by making the rigid wing AWES fully automated and easy to use and maintain.

We have analyzed the obstacles to the economic viability of AWES and as a result the automatic landing and take-off clearly stand out in a single sector needing the most input. Our proprietary fully automated landing and take-off technology is very well suited for land based operations in for example farmlands or deserted areas.

Alula Energy has developed and tested prototypes in a laboratory and an outdoor environment. Our company has strong engineering and R&D background. We are also doing co-operation with other companies in developing our system. In AWEC, we are interested in presenting our technology for possible co-operating partner companies and investors.

*Our LTO-system in landing mode (upper image) and showing also interrupted landing/take-off functionality.*



## EnerKite. Portrait of the Company.

Alexander Bormann

Enerkite

This presentation portrays the company EnerKite which set out in 2010 to build an mobile AWEC prototype using a three-line actuated system, the EK30. The history of the company until now, will be outlined as well the company goals and the design decisions that led to the construction of the current prototype. The results of the first year of operation in three countries and at 5 different sites within Europe will be presented, including progress in controller development as well as flight data plots of trajectories and power quantities. Finally an overview about the recent activities and cooperations and the planned product line and applications are given.

Alexander Bormann

Has become an aircraft mechanic in 1987 and studied aeronautical and wind engineering in Kiev (Ukraine) and Berlin (Germany) respectively. He degreed with its PhD in the field of structural mechanics from TU Berlin in 2004. Involvement

in wind engineering thru the working group of Prof. Robert Gasch were he has become a research assistant since 1993. His first international publication was about innovative tower concepts of megawatt wind turbines in 1995 together with Andreas Reuter (today Fraunhofer IWES). Since that time he was investigating ways to solve the transport and erecting issues of wind turbines and engaged in the development of innovative concepts for lighter than air transport. His first company aeroix became known for revolutionary buoyancy concepts, innovative technical textiles and the development of the first autonomous kite system CyberKite - in cooperation with Festo. After the successful roboted flights from early 2008 on the focus shifted towards energy generation. As a cofounder and CEO of EnerKite since 2010 he shapes his vision for resource efficient and cost effective wind energy generation.



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# EnerKite



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## Engineering Guidelines for Airborne Wind Energy Tethers with HMPE Fibers<sup>(1)</sup>

Rigo Bosman

DSM Dyneema

Airborne Wind Energy tethers are a critical component in many AWE systems. The challenge in designing an AWE tether is finding the optimal balance between system performance and lifetime of the tether. Both aspects are crucial in determining the economic feasibility (generated energy price) of the whole system. The presentation will elaborate on the different parameters responsible for the performance and for the service life of the HMPE tether.

There are many diverse systems that are currently under development, this presentation focusses on tethers for the so called pumping yo-yo system. In these systems, the tether is the critical component for transfer of the kinetic energy from kite to ground station. Given the desired hardware (sheaves and winches) and performance expectations (over one year continuous use) this presentation will give insights on a first estimation of the tether design and dimensions.

As a starting point an overview will be given on fibers available to system developers in the industry, but soon it will be concluded that for this application the base material of

choice is HMPE fibers. The presentation will explain some of the fundamentals of different HMPE materials involved and elaborate on possible failure mechanisms that may occur in the pumping yo-yo system. Especially creep lifetime and bending fatigue insights are described for long term lifetime performance checks. Other conditions like sand ingress, system fleet angles, that may influence the longevity of the tether are briefly mentioned, but since firm testing data is lacking, it is recommended to perform these checks on case by case basis.

An engineering method will be proposed to come to a first design of the tether. As an illustration a real life example pumping yo-yo tether (Kite Power) will be worked out. For static use of the tether (no bending fatigue) only the creep lifetime consideration can be taken into account.

*(1) The presentation is based on the chapter that has been submitted for publication in the accompanying Airborne Wind Energy book to be presented at the AWEC2013 in Berlin.*

## Enterprises and Prototypes

Stephan Brabeck  
SkySails

Airborne Wind Energy is one of the last unexplored natural energy resources besides conventional wind turbines and solar energy. The first AWE technology visions drawn in last century resulted in several developments by teams all over the world. From the initial research teams small enterprises were founded in the last two decades.

Stephan Brabeck describes the learnings of a small enterprise starting with big visions on its way to becoming an economically independent company. As an example, the history of SkySails will be investigated and the different steps of the companies' development with the individual technical and commercial challenges will be explained.

A short overview about the different AWE technologies will be given in advance of the session.

### About Stephan Brabeck:

Stephan Brabeck, as technical director (CTO) of SkySails GmbH, has leadership oversight of research and development, manufacturing and service. He was born in Cologne in 1962 and earned an engineering degree (Dipl.-Ing.) from RWTH Aachen University where he majored in aerospace engineering. Stephan Brabeck is an internationally renowned expert for ship propulsion. Before joining SkySails' executive board in 2005, he was employed by Schottel, a manufacturer of ship propulsion systems for 14 years as development engineer,

director of R&D and acting managing director. An avid sailor, he contributes in-depth expertise, years of management experience and exceptional market knowledge to the company.

### About SkySails:

SkySails is a green shipping pioneer and the first mover in the development of products that increase energy efficiency in the shipping industry. Since its founding in Hamburg in 2001, SkySails GmbH has been the market and technology leader in the field of automated towing-kite systems and the proud manufacturer of SkySails wind propulsion for ships.

As such, SkySails has acquired years of experience and expertise in the collection, measurement, analysis, and transmission of fuel-consumption, propulsion and weather data on seagoing vessels.

This formed the basis for developing the SkySails Performance Monitor for shipping that was introduced commercially in late 2011 and starting the development of an airborne wind power generation system in 2012.

SkySails employs 50 people from a broad range of disciplines and specialties, including sailors, shipbuilders, naval architects, software developers and management professions, all of whom support our customers in making fleet operations more profitable, while simultaneously reducing harmful emissions.



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## **Airborne Wind Energy: An Approach to Broaden the Horizon of Conventional Wind Energy**

Adrian Gambier<sup>1</sup>, Michael Strobel<sup>2</sup>

<sup>1</sup>Fraunhofer Institute of Wind Energy and Energy System Technology, <sup>2</sup>ENERCON GmbH

In the last years, it becomes clearly apparent that the life on Earth will require more energy. On the other hand, this demand will destroy the planet if it is not possible to introduce renewable energies. One of them is the wind energy. However, wind energy systems are slowly reaching several limitations and therefore, some research groups started studies around ten years ago about obtaining energy from wind by using kites.

As practically all new technological developments, it is necessary to have not only courage but also monetary resources and, at the end, the courage for supporting with funds the efforts. However, this support should be undertaken on the basis of a solid scientific analysis of plausibility and practicability, so that enthusiasts can convince the skeptics.

The present work has the main objective of reviewing the new technology of power generation based on kite systems, estimating the real potential of the systems, revising the current state of development and trying to establish a real comparison framework between competing approaches as well as between new systems with conventional wind energy plants.

In a first stage, an extensive literature review was carried out. Different algorithms were implemented in a simulation environment in order to obtain results for steady-state as well as dynamic behavior. In particular, three concepts were studied: the kite pumping system (jo-jo-concept), the carousel concept and the on-board concept (Makani concept). Moreover, studies about the economical potentiality of such plants including an estimation of costs,

about high wind properties and place availability in Germany for the establishment of wind parks based in the new technology were also performed.

First results show that wind availability and wind properties between 300 and 800 meters satisfy in Germany the requirements of kite systems and that it is possible to obtain a power production, at least, equivalent to conventional wind energy systems. Thus, kite systems are able to produce electrical energy in a stable and dependable way. Moreover, existing approaches in Germany are actually not competing between them because they are oriented to different objectives (on-shore, off-shore, small, middle and large power plants). Finally, kite systems should not be seen as competing with but as complementing to conventional wind energy systems because they are working at completely different altitudes and moreover, investing costs are similar.

However, it is very important to remark that the developments are now at the beginning. The performed studies are theoretic supported by simulation results. There is no prototype at present that includes a ground station with automatic take-off and landing. No prototype has been tested in continuous operation. These aspects will be the next steps in the development. Thus, huge efforts have to be done before reliable kite systems may be connected to the power grid.

The next stage of the current work is to carry out in cooperation with several German companies a series of measurements on the existing prototypes in order to validate the simulation results.

# Commercial Scale Design of the Sky WindPower Flying Electric Generator

Daniel Gelbaum (Speaker Garrett Smith)  
Sky WindPower

Since Sky WindPower demonstrated power generation from a Flying Electric Generator in December, 2011, we have been working to design a larger scale machine, one that could produce power on a scale useful for commercial electric power generation. We have used the data gathered in our testing to refine our analyses, which have helped us scale up our designs from our test prototype to a commercial scale generator that will operate well above the boundary layer at altitudes beyond 2000m. Our concept has been reviewed by a large Aerospace Engineering company in an independent, self-funded study which verified the technical feasibility of our design, including scaling up to at least 250kW per Flying Electric Generator (FEG). This study made use of Sky WindPower test data and the findings of a paper presented at a 2012 AIAA exposition entitled "Optimum Pitch Settings and RPM

for Tethered, Yawed Wind Turbines," a paper that makes an in-depth study of the Flying Electric Generator.

Sky WindPower has made advances in tether technology and direct-drive, high voltage motors, and continues to add to its intellectual property portfolio. These innovations will be discussed as they relate to our commercial scale FEG design.

This presentation will explain our FEG concepts and give a brief history of our development and testing of the Flying Electric Generator to date, plus describe the key features of a commercial scale FEG design and show feasibility of the design.

Sky WindPower plans to make this presentation in about 15 minutes with an additional 5 minutes for questions, time allowing. The level of detail can be adjusted to the time allotted.



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## **Altaeros Energies**

### **Development Process for Buoyant Airborne Wind Turbines**

Ben Glass (Speaker Chris Vermillion)

Altaeros Energies

Altaeros Energies is developing a buoyant airborne wind turbine for remote power applications. The Altaeros 30, currently under development, will deploy within remote communities and industrial sites that currently rely on diesel for most of their power needs. By deploying from two standard shipping containers and operating up to 2000ft above ground, the Altaeros 30 simplifies the logistics and installation costs of traditional renewables in remote locations, while delivering more net energy, ultimately reducing diesel consumption by up to 60% in a wind-diesel hybrid configuration.

Altaeros' buoyant shell is designed to incorporate sufficient lifting gas volume to stay aloft in light winds while providing aerodynamic lift and passively stable flight characteristics in strong winds. This represents an aerodynamic design problem that is not only challenging but also expensive to confirm through relatively large flight prototypes with sufficient buoyant lift. To address the challenges and expense of building small-scale lighter-than-air test vehicles, Altaeros has developed a design process utilizing a number of numerical

and empirical tools to thoroughly evaluate the performance of candidate designs before building flight prototypes. The Altaeros team has developed a 6 degree-of-freedom dynamic model that has been used to evaluate flight characteristics under a range of wind inputs and identify desirable aerodynamic parameters, which represent a design target for the aerodynamicist. Aerodynamic parameters of candidate designs are evaluated using Reynolds-averaged Navier-Stokes (RANS), and CFD calculations and fed back into the dynamic model to verify flight characteristics. A full CFD sweep of angle-of-attack and side-slip angle is performed on promising designs and the resulting aerodynamic force and moment curves are verified or modified based on wind tunnel measurements. Finally, dynamic characteristics are empirically evaluated using very small scale, buoyant tethered models in a 2ft x 2ft water channel. This unique water channel test environment enables inexpensive validation of new designs in a dynamically-scaled environment, while also providing a tool for validating and refining the 6-dof dynamic model.



## SwissKitePower - A Collaborative R&D Project

Corey Houle, Jannis Heilmann, Dominik Sommer, Heinz Burtscher  
Fachhochschule Nordwestschweiz

The SwissKitePower project started with the goal of developing a vision of what a kite power plant would look like. Over the past three years re-searchers from FHNW, Empa, ETH-Zurich and Alstom Switzerland AG have worked together to achieve this goal. A working groundstation has been constructed at FHNW, which has been used as a test platform for the development of a novel kite concept Empa and

flight control algorithms from ETH. Under the guidance of Alstom, an economic analysis of kite power has been conducted which highlights the long term potential of the technology. Going forwards, researchers from FHNW and ETH have teamed up with EPFL-Lausanne to conduct a nationally funded project on the topic of Autonomous Airborne Wind Energy.



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## **Towerless Radio Station with Airborne Wind Energy Technology**

**Bernd Lau**

[www.airborne-wind-turbine.com](http://www.airborne-wind-turbine.com)

This project started 2009 with the first ideas of the airborne wind energy technology. The team built a lot of investigations and calculation to this point. In 2010 they made their first demonstrator, a construction of helium filled donuts. In Leuven, AWEC 2011, they presented their knowledge of this case.

To the AWEC 2013 they will present the development status of the actual project. That is a towerless radio station with the airborne wind energy technology as an island solution for low populated areas or disasters. They use a tethered airplane system with their self-made energy solution and a fully automatic start and landing system.

## Moderator Topic Enterprise

**Guido Lütsch**

President of the German Airborne Wind Energy Association (BHWE)

Born 1965, married, 2 children With a master degree as business administrator of the international renowned University of St. Gallen/Switzerland Guido started his business career at Kraft Foods. As Brand Manager he developed new coffees and introduced them in various European countries. He was a founding member of the Environmental Task Force and signed responsible for various sustainable projects at Kraft Foods. 1996 Guido founded an international marketing agency and led famous campaigns for global players such as Volkswagen, Schering AG, Veuve Clicquot etc.

Since 2006 Guido is working in the field of Airborne Wind Energy. From 2007 - 2013 he was assigned as General Manager of Berlin based NTS GmbH. He is the Executive Director of the international Airborne Wind Energy Consortium and since January 2013 President of the German Airborne Wind Energy Association (BHWE Bundesverband Höhenwindenergie e.V.).



**Guido Lütsch**

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## Design and Testing of the KE60 Yoyo AWE Generator

Mario Milanese, Franco Taddei, Stefano Milanese

Kitenergy srl

The advances are presented in the design and testing of a 60 kW yoyo AWE generator, developed by Kitenergy, a start-up founded in 2010 with the aim of leading to industrialization a yoyo (or pumping) AWE technology developed since 2005 by the Complex Systems Modeling & Control Group of Politecnico di Torino, headed by the first author, in collaboration with some small high-tech companies of the Torino/Milano area. A quite complete report of the activities performed up to 2010 can be found in papers [1,2], including mathematical modeling of the KE-yoyo generator, control design, numerical simulations, evaluation of the Capacity Factor (CF), design of KE-yoyo farms, comparisons of simulation and experimental results obtained from a first 20 kW prototype. Based on these activities, the preindustrial KE60 yoyo generator has been designed, constructed and extensively tested.

In the presentation, the main components of the KE60 generator (electro-mechanical structure, sensors and data communication, energy management system, hardware and software for real-time control) will be described. Results will be

reported from some of performed tests and the experimental energy and power values are compared with the theoretical optimal value based on the simplified analysis in Loyd's seminal paper [3], as well with computer simulations based on the model and control strategy developed by Kitenergy research group. In particular the results of recent tests are presented, where a custom made 25 m<sup>2</sup> kite has been used, designed in order to optimize the features required for energy generation, such as aerodynamic efficiency, steerability, wing loading. Movies of some of the tests will be also presented.

[1] L. Fagiano, M. Milanese, and D. Piga, "High-altitude wind power generation", *IEEE Transactions on Energy Conversion*, 25, 2010.

[2] L. Fagiano, M. Milanese and D. Piga, "Optimization of airborne wind energy generators", *Int. J. Robust. Nonlinear Control*, 22, 2012.

[3] M. L. Loyd, "Crosswind kite power", *Journal of Energy*, 1980, vol. 4, no. 3: 106–111.

# Modeling and Testing of a Kite-Powered Water Pump

David J. Olinger<sup>1</sup>, Alireza Mahdavi Nejad<sup>1</sup>, Jitendra S Goela<sup>2</sup>, Gretar Tryggvason<sup>3</sup>

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This presentation summarizes recent work at Worcester Polytechnic Institute (WPI) to model, design, fabricate, and test a low-cost kite-powered water pump. The system is designed to be used in developing nations to alleviate water shortages. It uses a kite and tether that transmits the generated aerodynamic forces to a rocking arm, and through a mechanical linkage to a displacement (or lift) pump on the ground. Dynamic equations were developed for the kite, a flexible tether with applied lift, drag, and weight forces, the rocking arm, mechanical linkage and pump.

A steady-state analysis of the kite aerodynamics was incorporated into the dynamic equations of the kite-powered system. The governing equations were solved numerically to assess how performance parameters of the system such as water pumping rate, tether profile and tension, and kite motion varied with tether length and diameter and wind speed. The results showed that for a kite

area of 8 square meters and wind speeds of 6 meters per second, the operation of a kite powered water pump is feasible with a maximum water pumping rate of 8000 liters/day. This pumping rate would provide water for about 400 people in a developing nation. Design limits, above which system pumping rates were negatively affected, on tether length and diameter were determined from the water pump simulations to be about 500-m and 3-mm, respectively. Ongoing efforts to build and test a working kite-powered water pump at WPI will be presented.

We will report on recent successful field tests of the system in spring and summer 2013. We will also summarize other work on airborne wind energy at WPI including early efforts to develop a Navier-Stokes based simulation of the power and retraction phases of a pumping cycle kite power system. In these simulations wind flow over a two-dimensional flexible kite is modeled, and kite motion is predicted.



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## Ampyx Power: Preparing for Commercialization

Dr. Richard Ruiterkamp

Ampyx Power

Ampyx Power is one of the leading Airborne Wind Energy companies. Richard will expand on the developments of Ampyx Power since last year's AWEC conference in Hampton, VA. Obviously, technology development and achieved performance and milestones will feature in his presentation, as well as the further technology development path preparing for market introduction of PowerPlanes. In addition, Richard will elaborate on the non-technical

aspects required for market introduction. Starting in 2012, Ampyx Power has been preparing for commercialization of its PowerPlane technology, which includes dealings with a variety of stakeholders. In addition, Ampyx' financing needs increased significantly, and Richard will give insight in some of the crucial choices Ampyx made in its financing strategy, with particular focus on Ampyx' successful informal investment campaign.

# Design of a Power Plant based on the X-Wind Technology

Clemens Töpfer  
NTS

In Friedland in Mecklenburg-Vorpommern, the suitability of the X-wind technology to generate electrical energy has been demonstrated in numerous tests.

Based on the measurement results, the basic parameters of a large plant are object to be determined.

Dimensioning is given for the main components of distance,

generator and kite control to fit a power plant in multi-megawatt range.

The dependencies of wind conditions, altitude and operating mode are presented.

Potentials to improve the overall performance are derived and discussed.



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# What are the Success Factors for Profiting from Innovation in the Emerging Airborne Wind Energy Industry?

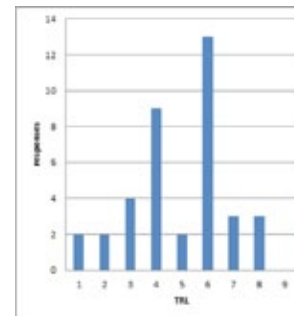
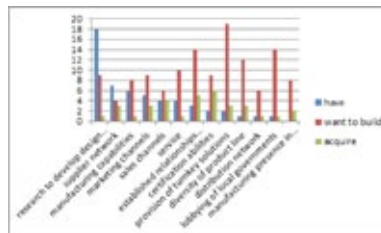
## A Competition Analysis in the Face of Innovation

Simon Bolten

Technische Universität München, Fakultät für Wirtschaftswissenschaften

In the emerging airborne wind energy (AWE) industry most research is focusing on engineering problems and evaluating different design concepts. Little attention has been focused on technology and innovation management questions such as ‘Who will be most likely to profit from AWE innovation?’ This thesis aims to address this gap of knowledge, and to analyze the competitive environment of airborne wind energy systems (AWES) using David J. Teece’s (1986) theory on ‘profiting from innovation’. The industry

specific variables: appropriability regime, industry life cycle phase and complementary assets will be examined. To allow for this analysis, data will be collected through a survey with 81 AWE stakeholders. The findings help to determine a company’s competitive position and help companies in appropriating rents from their innovation. Furthermore, the findings allow for solving a ‘management puzzle’ resulting from the need to decide when to build or contract different complementary assets.



# Financial Support by KfW: Optimize your Opportunities!

**Jürgen Daamen**

Authorized Representative in Marketing of KfW Banking Group

KfW is one of the world's leading promotional banks. With its decades of experience KfW's mission is to improve the economic, social and ecological living conditions all over the world on behalf of the German federal government and the federal states. In 2012 alone, KfW provided promotional funds totalling Euro 73.4 billion for this purpose. 40 per cent of these funds were committed for investments in climate and environmental protection.

KfW finances and supports business start-ups, small and medium-sized enterprises (SME) as well as investments in economic growth and employment projects in Germany. KfW offers a variety of different promotional products. The most relevant products for innovative SME's are

- **ERP Start-up Loan – StartGeld:**  
For start-ups and young enterprises up to three years, maximum loan of Euro 100.000, KfW bears 80% of the credit risk
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For established enterprises with at least three years experience, maximum loan of Euro 25 m, KfW can bear 50% of the credit risk on request
- **ERP-Innovationprogramme:**  
For established innovative enterprises with at least two years experience, maximum of Euro 2,5 m or 5 m, subordinated loan for research and development or introduction of new products in the market

These are promotional loans which can be applied for long term investments as well as working capital. All promotional loans are provided by commercial, cooperative or savings banks. Those banks conclude the loan contract with the entrepreneur or the SME. Despite the option of risk sharing between KfW and the bank, the entrepreneur always bears the complete risk for the loan.

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## Moderator Topic Financing

Alois Flatz  
Zouk Capital

Alois Flatz joined Zouk in 2006 and is a Partner. With 18 years' experience in private equity, investment management and sustainability, Alois brings significant cleantech experience and global networks to Zouk. Alois sits on the boards of portfolio companies Triton Water, FFK, va-Q-tec and The Mobility House.

Before joining Zouk, Alois was a Partner and Head of Research at Sustainable Asset Management in Zurich, where he co-founded the Dow Jones Sustainability Index. Alois

was also Managing Partner of BTS Investment Advisors, a private equity advisor in India with over \$3 billion AUM, and an advisor to the Austrian Ministry of the Environment. A published author on sustainable investment, Alois has a PhD in Business Administration from the University of St. Gallen, an MBA from Vienna University of Economics and studied International Management at HEC Paris.

## 5 Years financing Airborne Wind Energy Projects

Carlo Perassi  
WOW SpA

Abstract for the Airborne Wind Energy Conference AWEC 2013 in Berlin Wind Operations Worldwide S.p.A. - WOW SpA, see <http://wow.pe/> - is a financial holding, founded in Leghorn, as WOW Srl, on 23rd May 2008 and turned into WOW SpA on 31st October 2009.

It was the first worldwide and it is still one of the few financial holdings founded to support the airborne wind energy industry.

This short presentation is going to describe the projects it is funding, focusing on what emerged during the last two

years, since the last time an AWEC Conference took place in Europe (Leuven, 2011).

The central part of the talk regards our current activities: in Calabria, with a project merging AWE and agriculture; in Tuscany, where a second project involves AWE and sailing; in the USA, describing the results of our partnerships with American AWE companies.

The closing part of the talk describes what the "Italian AWE test field" would be, ending with a few predictions, saving a few minutes for questions and answers.



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## **AWE Financing Strategies Obstacles - Strategies - Outlook**

Udo Zillmann

Daidalos Capital

### **Obstacles**

Providing sufficient funding for costly technology developments of start-up companies has often proved difficult. In the field of AWE many companies have experienced funding constraints, many potential founders failed to even start their project due to lack of financing. The presentation will show the results of interviews on the financing situation that were conducted at the beginning of 2013 in the AWE community amongst start-ups and financing parties.

These results will be compared with the financing difficulties that are experienced by start-ups in general and more specifically in the field of renewable energy. It will be shown whether and to which extent the financing constraints are AWE specific.

Also, the biggest (perceived) obstacles for securing sufficient financing for this industry will be identified.

### **Strategies**

The talk will depict the financing strategies AWE companies used so far and are planning to use in the near future. It will be analyzed which general rules can be derived from these strategies and which lessons other AWE start-ups can learn from these strategies regarding suitable financing sources and the prerequisites to successfully tap them.

### **Outlook**

It is clear that the financing needs of AWE companies will further increase as prototypes and technology demonstrators grow in size and sophistication. Once final market products have to be developed, tested, certified, built, and deployed in wind parks, the financing requirements will reach new dimensions. The presentation will discuss whether and how sufficient (and new?) financing sources can be found to meet these needs or if AWE companies will have to perish in the "Valley of Death". Special emphasis will be put on the role of Venture Capital investments in AWE companies, together with reasons for their low involvement in the past and whether this will likely change in the future.

### **Presenter**

Udo Zillmann has been an active investor in various AWE start-ups for the last years. Through his investment vehicle Daidalos Capital he is advising other investors on investments in AWE companies. For a publication in the upcoming AWE book he has conducted a series of interviews amongst AWE companies and financing parties regarding the status quo and future of AWE financing and has compared this with the situation in other technology fields. He was a speaker in AWEC2011 and presented AWE at the European Wind Energy Association yearly conference 2012

# Innovative Approaches for Certification, Permission and Safety(Functions) of ABWE

Christoph Haucke<sup>1</sup>, Alexander Bormann<sup>1</sup>, Christiane Schmidt<sup>2</sup>

<sup>1</sup>EnerKite, <sup>2</sup>Reiner Lemoin Institut

To make the licensing procedure easier as well as increase safety standards it is necessary to find a standard in Certification for small-windturbines. The guideline 61400 includes all relevant details for this development proposal. This paper shows how these guidelines can be used for airborne wind turbines. Thereby we can observe the applicability of ISO 61400 regarding the set definitions (airborne wind turbine = small wind turbines, rotor surface = kite surface), the transferability of components of small wind turbines to airborne wind turbines (see graphic) as well as the safety standards. By accomplishing a certification we achieve better approval by authorities and make the licensing procedure easier.

Since only a few components of a airborne wind turbine and a classic windturbine are identical, there is a large need for clarification, how the effect (load) and safety requirements for components such as the rotor can be transferred to a airborne wind turbine. The claimed static test for rotor blades from the ISO 61400- 23 can't be used for the Kite. Here we need new innovative thoughts regarding an adaption of the components and we have to consider the fact, that some of the airborne wind turbines are mobile systems.

Adopting the ISO 61400 for airbornewindturbines: In which extent is it possible to make use of existing guidelines for

airbornewindturbines? Is there a way to interpret claimed conditions new/differently?

With regard to innovative approaches, the absence of a rigid support structure causes not only safety and reliability issues, it also allows to define the wind energy converter in an entirely new way. Therefore the authors will present pending procedures for the operation which will be more in detail explained in the paper and when by then the IP issues are clarified.

Up to now, there are lack of experience on the part of the approval-related institutions due to the innovative technology of high altitude wind turbines. Right here must be valued and to develop a method to simplify and speed up the approval process. To develop and implement this process there could be obtained a research partner, which already has experience in the field of certification and approval of advanced technologies. The strategy is the practical testing by building representative test sites, which will give characteristic reveals of environmental compatibility, acceptance, and which provides potential risks. First steps towards acceptance and sensitization are done by having a long-term authorization for the flight test operation in the Berlin- Brandenburg region.



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## Experimental Investigation and Modeling of Noise of Airborne Wind Energy Converters

David Janke

Beuth Hochschule für Technik Berlin / University of applied sciences

As a next generation of Wind Turbines, Airborne Wind Energy Converters (AWECS) use flying devices to harvest the wind in high altitudes. A Kite, flying fast in crosswind direction, reels out a tether which is connected to a generator winch on a ground station. By reeling out, the winch is turned and produces electrical energy. Similar to conventional wind turbines, AWECS have to deal with environmental regulations in terms of noise emission,

which could become a limiting factor concerning flight operation and kite design.

This paper describes the development of a modeling tool for aerodynamically induced noise with further investigation of the noise emitted by the tethers. Free field test measurements were performed to validate the model. The results for a 30kW Kite-Tether System are presented.



BEUTH HOCHSCHULE  
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University of Applied Sciences

# Kite-based Wind System Grid Integration and Stand-alone Operation

Mariam S. Ahmed\*, Ahmad Hably\*\*, Seddik Bacha\*

\* G2ELAB, \*\* GIPSA-lab

Using tethered-aerofoils or kites to exploit high altitude wind energy (HAWE) is now undergoing a lot of research [1], including modelling, control, and power extraction techniques. Meanwhile, power transformation for grid integration and stand-alone operation in micro-grids did not yet receive as much attention.

The HAWE system is a relaxation-cycle system that periodically generates and consumes power, which adds new challenges compared to other renewable energy sources (RES) when connected to the grid.

## KITE-BASED SYSTEM GRID CONNECTION

Simply stated, the energy generation concept of a kite-based wind system is to mechanically drive a ground-based electric machine using one or several tethered kites. The kite, however, cannot pull continuously because the tether length and the kite power region are limited, so it should be periodically redrawn to its initial position, consuming energy as doing so. As a result, a generation and a consumption phase are distinguished, and a control strategy must minimize the consumption and maximize the average generated power. Accordingly, the system is classified as a relaxation-cycle system. In order to be invested as a renewable energy resource, the kite-based system needs to have a high performance, that is the ratio between the average power and the maximum power:

The kite-based system harnessed mechanical power is converted into electrical that is later injected in the grid by means of a power transformation system. The proposed structure of this system [2] consists of a permanent magnet synchronous machine (PMSM) functioning as a generator or a motor depending on the kite-based system phase. The machine is driven by a three-phase transistor-based AC/DC converter, connected to the grid/load via an AC/DC converter. A DC/DC converter

connected on the DC-bus level is implemented to provide an interface with a storage unit. In the case of an infinite grid, the goal is to generate the maximum possible power and inject it in the grid, whereas the grid provides the necessary power during the system's consumption phase. While, in the case of a load connection, the system is controlled to produce the load's required power, and the storage unit should provide the consumption phase power. The control scheme adopted for the power transformation interface is divided into three levels, the low and intermediate levels control directly the electrical variables of the electric chain, while the upper level generates the reference signals for previous control levels using for example an MPPT algorithm, and supervises and determines the power flow in the system by controlling all its switches.

In order to insure that the control strategy is effective, a simulation on Matlab/Simulink is followed by a semi-soft-semihard simulation: a hardware-in-the-loop (HIL) simulation. The HIL simulator allows replication of the dynamic behaviour of the real system with the possibility of controlling the working conditions in the laboratory [3]. In the simulator the tethered kite behaviour is emulated by a direct current machine (DCM), while the rest of the system is physically fully presented. In addition to considering the issue of kite-based systems grid integration, our research is currently  $\eta = P_{av}/P_{max}$  virtual constraints-based control of the kite for orbit tracking and stabilization.

**REFERENCES** [1] M. Ahmed, A. Hably, and S. Bacha, "High altitude wind power systems: A survey on flexible power kites," in *Electrical Machines (ICEM), 2012 XXth International Conference on. IEEE, 2012*, pp. 2085–2091. [2] —, "Kite generator system: Modeling and grid integration," accepted for *IEEE Transactions on Sustainable Energy*, 2013. [3] I. Munteanu, A. Bratcu, S. Bacha, D. Roze, and J. Guiraud, "Hardware-in-the-loop-based simulator for a class of variable-speed wind energy conversion systems: Design and performance assessment," *Energy Conversion, IEEE Transactions on*, vol. 25, no. 2, pp. 564–576, 2010



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## Moderator Topic Storage

Werner Diwald

Enertrag AG

Over the past 13 years, Mr. Diwald was the person mainly responsible for the business fields of Project Development and Political Affairs within the group of companies of ENERTRAG Aktiengesellschaft. Since October 2008 he has been a member of the Management Board of ENERTRAG Aktiengesellschaft and responsible for the entire field of the international development of wind farm projects, technology development and plant engineering and construction in the field of hydrogen (electrolysis, hybrid power plant), as well as the aviation obstruction lighting for wind turbines.

After the successful completion of training as a certified technician and the subsequent study to Diplom-Kaufmann (German degree in business administration, equivalent to MBA) in 1995, Mr. Diwald has been active in the renewable energy sector. He thus has 18 years of professional experience in the field of the development of system components for wind turbines, the design of service concepts for construction and maintenance of wind turbines, as well as the development of wind farm projects in different companies.

Based on his activities, ENERTRAG was able in 2011 to successfully put into operation the first hybrid power plant. In 2011, he built up the ENERTRAG HyTec GmbH, which develops and manufactures electrolyzers.

In addition, Mr. Diwald is a board member of GENI e.V. (Association for Grid Integration), board member of Akademischer Bildungsverein e.V. (Academic Education Association), member of the Board of Trustees of the Brandenburg University of Technology, spokesman of the "Performing Energy" Initiative, member of the Federal Expert Committee on Climate, Environment and Energy Policy of the CDU, and member of the Federal Expert Commission on Energy Policy of the Economic Council Germany.

In 2008, he was appointed as an expert of the Federal Environment Committee for the consultation on the update of the Renewable Energy Act.

# Discussion on Electrochemical Energy Storage Devices to cope with the Alternating Energy Flow in YoYo-AWEC Fed Off-grid Systems

Nicolas Lewkowicz

Beuth Hochschule für Technik Berlin / University of applied sciences

Power delivery of AWECs using a YoYo operational procedure is pulsed and needs to be buffered by energy storage systems with high power ratings and high cycling capabilities.

Analyzing the exact power requirements in off-grid systems using an enerkite as single power supply in three different consumer configurations, leads to battery specifications, that regular battery systems do not comply with. Searching for a cost efficient battery design, existing electrochemical systems will be discussed for energy efficiency, cost efficiency and cyclability. Alternative cell and assembly designs will be presented focusing on a bipolar electrode application.

While lead-acid batteries are still widely used for cost reasons, lithium-ion based batteries do reach higher energy efficiency requiring more invest. Batteries consist of electrochemical cells, that need to be mechanically and

electronically integrated into energy storage systems. System cost and performance is not only driven by the i.e. cost intensive lithium based materials, but as well by the component and production cost setting up the storage system. Cost reduction potentials can be addressed on the system layout according to the specific needs, the selected material and the production process.

The addressed evaluations are part of a project called ECEWIN (ElectroChemical Energy storage for Wind energy fed Isolated Networks). In this project requirement analysis is carried out by the HTW Berlin, University of Applied Sciences, based on test data by enerkite. In the batteries lab of Beuth Hochschule, University of Applied Sciences, batteries are set up on a laboratory prototype scale in order to validate battery performance and cost estimation. The project is funded through the IFAF-Institute by beBerlin.



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## Economy of Hydrogen Production by Parafoil-Pulled Ships

J. C. Kim<sup>1</sup>, C. Park<sup>2</sup>

<sup>1</sup>Korea Aerospace Research Institute, <sup>2</sup>Korea Advanced Institute of Science and Technology

Economy of the method of producing hydrogen proposed earlier by the present authors, in which liquefied hydrogen is to be produced on board a ship pulled by parafoils, is examined. Performance calculation is made for two representative such ships, a one-thousand tonner made using currently available components and the other a ten-thousand tonner using upgraded components, while constraining the ship's speeds to be those of existing similar ships. Price of liquefied hydrogen so produced is estimated using the parameters extrapolated from the data for existing liquefied natural gas tankers. Results show that the price of hydrogen produced by the one-thousand tonner would be 3.1 US dollar per gasoline gallon equivalent, which is nearly the same as that by the wind turbine-electrolysis method. The price of hydrogen produced by the ten-thousand tonner would be about 1.2 dollar per gasoline gallon equivalent, which is the same as that by the nuclear-thermochemical method.

Prof. Chul Park is a graduate of Imperial College London, 1964, worked in NASA for 37 years and in Tohoku University

for 3 years before joining Korea Advanced Institute of Science and Technology in 2003. He participated in the making of the Apollo vehicle, was recognized as one of the one-hundred people that made the Space Shuttle vehicle, and was a major contributor to the Project Galileo in which a spacecraft was sent to the planet Jupiter. He is a Fellow of American Institute of Aeronautics and Astronautics, a recipient of two medals from the U.S. government and two highest honors from American Institute of Aeronautics and Astronautics, the author of the graduate textbook titled Nonequilibrium Hypersonic Aerothermodynamics used widely, and is one of the most quoted authors in the world.

Korea Advanced Institute of Science and Technology is South Korea's premier Engineering University modeled after Massachusetts Institute of Technology. Prof. Park teaches aerothermodynamics and hypersonic vehicle design in the Department of Aerospace Engineering. He conducts research on many topics of high speed flight and green energy technology.

# Sail Energy: Generating Renewable Fuels by Wind-driven Energy Ships and Power-to-gas

Prof. Dr.-Ing. Michael Sterner

Forschungsstelle Energienetze und Energiespeicher (FENES), Fakultät für Elektro- und Informationstechnik  
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We have developed a new storage and fuel generation concept: sail energy. The sail energy concept uses offshore wind and marine currents to generate renewable fuels like hydrogen and methane. This process is combining mechanical, electrical and chemical conversion steps, like shown in the following figures:

First, offshore wind power is converted by various sailing technologies (conventional, kites or Flettner rotors) on a ship into mechanical translation power. This force is converted into mechanical torque by using a marine turbo machine fixed at the vessel, that extracts energy from the ship's propulsion. The turbo machine includes an electrical generator for power generation.

The generated electricity is used to split water into oxygen and hydrogen onboard in an electrolysis unit. Optionally,

the so produced hydrogen can be converted into methane, which is fully compatible with today's natural gas infrastructure with all its multiple applications for heating systems, gas power plants and especially gas cars. Other possible fuels are methanol or other hydrocarbons.

By following the wind, the energy in the wind can be harvested constantly and thus very high full load hours of the energy ship and the conversion technology onboard achieved.

The paper describes the concept and its individual components. It shows general proportions and component dependencies based upon exemplary ship and process calculations. Additionally included is an analysis of the technical potential, proving that sail energy could cover the global energy demand. It will be among the first time, the concept is presented at a conference.



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## Performance Characterisation of Airborne Wind Rotor

Kazuo Arakawa

Research Institute for Applied Mechanics, Kyushu University

To harvest wind energy at high altitude, we constructed an airborne wind rotor using a rocket shape balloon. As a transport method of wind energy from high altitude to the ground, we employed the elastic deformation of tether rope made of polymeric fibers. Different from traditional wind turbines that convert wind energy into electric power using a generator located near a turbine and send electric current to a ground by metal wires, the present method can permit a large weight saving of the wind rotor. This study examined the air stability of the wind rotor and measured the torque and tension of the tether rope induced as a function of time. Analytical model was also used to examine the performance of the constructed wind rotor.

We constructed an airborne wind rotor as follows: A rocket shape balloon was fabricated using vinylchloride of thickness 0.13 mm. The balloon size was 1.3 m in diameter, 8.2 m in length, and 18 m<sup>3</sup> in gas capacity, and the mass was about 8 kg. Three blades made of corrugated plastic plates were attached to the rear part of the balloon. The blade size was about 0.65 x 0.8 m and the blade angle was 14 deg along the circumference of the balloon. Tether rope was connected

through support lines hooked to the nose-section of the balloon to avoid stress concentration.

The elastic deformation of a tether rope is an important parameter to investigate energy transportation from the wind rotor to the ground. A torque and tension measuring device was then constructed to evaluate the elastic deformation. This device is consisted of a torque and tension gauge connected linearly to determine two forces simultaneously. We used a torque gauge, a tension gauge, and a data logger to record two forces. Two nylon ropes with 30 m in length and 6 mm in diameter were used as the tether ropes.

We measured the torque and tension of the tether ropes at the ground as a function of time. An analytical model was introduced to determine force and torque of an airborne wind rotor and to compare with tension and torque of the tether ropes. Although data fluctuation existed, the experimental results positively suggest that the constructed wind rotor has a promising structure for harvesting wind energy at high altitude. We are now measuring electric power due to the torque of tether ropes at the ground using an electric generator.

# Aerodynamic Performance Prediction of a Tetrahedral Kite

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In collaboration with Argentinian artist Tomas Saraceno an airborne platform is developed that is held in the air by wind energy, essentially being a large kite. A prototype is planned to fly in August 2013 on the Maasvlakte 2 in Rotterdam, The Netherlands. In contrast to conventional applications, wind energy is not used to generate electricity but to elevate a platform from the ground. The artist intends to have people aboard of the platform, resembling a flying park. However, the current prototype design is an artwork to show the artists idea and to express his vision, not to actually lift heavy loads with it.

A tetrahedral kite type, an idea founded by Alexander Graham Bell in 1903, is chosen as the base concept. This kite is build up of tetrahedral cells with two sides closed by a canopy which function as a lifting surface. The individual tetrahedral cells are used in a modular fashion increasing the lifting surface and improving the stability. The tetrahedral concept is chosen as, due to the presence of a rigid structure, it mitigates the launch and inflating problem that soft kites encounter.

In the presentation a method is shown that, based on the geometry of the tetrahedral kite, can predict the aerodynamic performance and provide the structural engineer with an aerodynamic force distribution per tetrahedral cell in a multi-celled Bell kite. This knowledge enables an accurate prediction of the load in the structure which in turn allows for a weight-optimised design for different multi-celled configurations.

The method is developed by taking a close look at the

aerodynamic characteristics of a single tetrahedral cell through small scale in-house wind tunnel experiments, inviscid CFD simulations and by using flat plate approximations of the canopy. The lifting surfaces of the tetrahedron will operate at high angles of attack, hence nonlinear aerodynamic models are employed for the calculation of the flat plate approximation.

Dimensional analysis is used to determine the general relationship between the geometry and aerodynamic performance indicators as lift and drag. This data combined yields an aerodynamic performance prediction model for a single tetrahedral cell.

Additionally the flow stability is investigated. The frequency and size of the vortices shed by a tetrahedral cell have a large impact on the flight stability of the whole platform. A large number of small tetrahedral cells that shed small vortices have less impact on the flight stability than big tetrahedral cells.

The single cell model is augmented with wake models based on existing sail and flat plate wake literature. It is found that solar panel arrays resemble the 2D flow situation in a tetrahedral kite, hence wake studies concerning these arrays are also incorporated in the method development.

With the collected knowledge different stagger configurations are modelled and verified through wind tunnel tests. This ultimately resulted in a general method that can predict the aerodynamic forces in each tetrahedral cell of a multi-celled Bell kite.

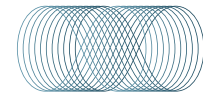


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## High Altitude Wind Turbines using a Hybrid System of Bernoulli and Buoyant Lift

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This paper examines the technology and economics of the dual lift high altitude wind turbine (HAWT) design by LTA Windpower.

In the technology domain, this hybrid approach aims to lower technology risk by harnessing proven subsystems, albeit in a novel way. It aims to mitigate the risks unpredictable wind conditions present for active kites dependent on automated flight control systems, while avoiding the high cost of helium based buoyant lift. A conscious effort is made to minimize ground crew requirements and avoid the need for a winch. The result is a neutrally buoyant design.

The design begins with a conventional blimp, that is, a non-rigid airship. Instead of a gondola, the blimp has airplane-like wings. There are two generator nacelles with downwind propellers (one on the trailing edge of each wing). The combination might be compared to an airplane with a wide-bodied inflatable fuselage, stubby wings and oversized push propellers. The distinguishing feature in an operational sense is the combined use of both buoyant and Bernoulli lift. The buoyant lift allows gently managed takeoffs and landings under all

conditions even in the absence of wind and with no ground crew, while the Bernoulli lift is used to reduce the downwind lean of the lifting body as winds increase. The design allows for the use of hydrogen as a lifting gas in view of the high cost and poor supply of helium. Steps to mitigate the risks of working with H<sub>2</sub> are considered.

In the economic domain, compared to terrestrial wind HAWTs' prospects in general are difficult to quantify because of the complete lack of commercial operating experience with HAWTs. HAWTs in general will probably not be scalable to the same sizes as terrestrial wind turbines, nor will they be competitive in locations with strong steady surface winds and low construction costs. HAWT is shown to have advantages when these conditions are not met.

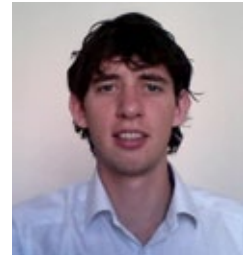
The dual-lift HAWT technology here proposed has higher build costs per unit output than active kites, but is believed to offset this with lower risk of catastrophic failure and greater scalability. It should be highly competitive with other techniques using buoyant lift. Meaningful quantitative comparisons to answer these unknowns are not yet possible

# Experimental Developments of a Pumping Mode Kite Power Demonstrator with Non-reversing Generator.

Joseph Coleman, Hammad Ahmad, Daniel Toal  
University of Limerick

This presentation outlines the recent developments of the University of Limerick airborne wind energy project using soft kites. The results of experimental tests from an 8kW pumping mode AWE system are presented. The system ground station utilises a non-reversing generator, with dedicated recovery motor. The tasks of power generation (reel-out phase) and tether recovery (reel – in phase) are electrically and mechanically separated through an arrangement of clutches. The system hardware is briefly discussed and an analysis of computational timing budgets for the

implementation of advanced control strategies (LQR, MPC and control allocation) on a real time operating system is presented. Simulation work of a novel AWE farm electrical power take off design approach is presented. Through the use of directly interconnected, non-reversing synchronous generators a continuous power supply can be achieved from several pumping mode generators. This arrangement in has been simulated in a small AWE wind farm arrangement. Encouraging results of these simulations are presented.



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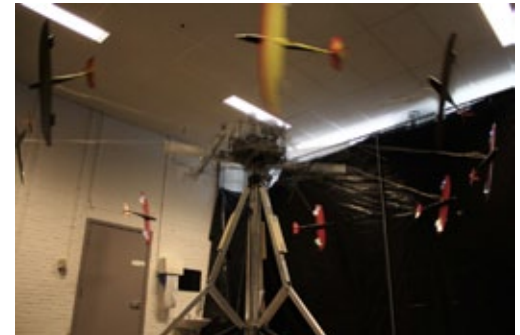
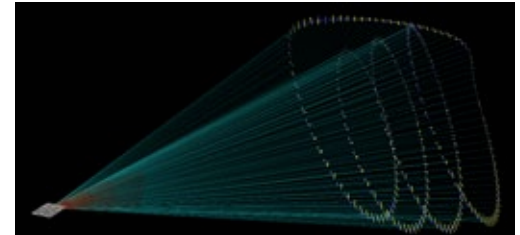
## Automatic Control and Rotation Start of a Rigid-Wing AWE System in Pumping Mode

Moritz Diehl\*

KU Leuven

This talk presents the airborne wind energy (AWE) research at the University of Leuven that focuses on the automatic control and start-up of tethered rigid wing systems. Airborne wind energy systems with rigid wings promise high power output per wing area, good durability, reliable controllability in all weather conditions, and the possibility to build on existing aircraft technology. However, automatically starting and landing them is a nontrivial task due to the fact that they typically need relative airspeeds higher than the wind speed to overcome gravity. In case of on-board turbines that can be operated in propeller mode, vertical take-off and landing (VTOL) is a possibility, but for a pumping AWE system without on-board turbines/propellers, the only possibility is to bring the airplane to sufficiently high speeds. Fortunately, this can be achieved by a rotation setup (see the left figure for the current setup at KU Leuven) that consists of a small rotating arm – a carousel - from which the main tether extends to the airplane. Rotating the carousel will allow one to bring the airplane to sufficient speed in a small volume, and the tether length can then slowly be increased until transition into power generating orbits is possible (see the right figure for an optimized power orbit in simulation). In addition, a carousel setup is ideally suited to do indoors and outdoors testing of advanced control systems without the need to have large testing sites. The talk describes the experimental setup and the control technology developed within the ERC Project HIGHWIND at the KU Leuven. In particular, we describe how nonlinear simulation models can be used not only for system and trajectory optimization, but also for on-line state and parameter estimation and for feedback control,

using the concepts of moving horizon estimation (MHE) and nonlinear model predictive control (NMPC). We show experimental flight results using MHE and NMPC and compare the flown trajectories with simulations.



*\*Joint work with Jan Swevers, Sebastien Gros, Andrew Wagner, Kurt Geebelen, Milan Vukov, Mario Zanon, Greg Horn, Joris Gillis*

# Design Challenges Towards Automated Flight Control for Tethered Kites

Michael Erhard  
SkySails GmbH

In order to operate power plants exploiting high altitude wind energy economically, a fully automated and reliable flight control of the airborne system is an indispensable prerequisite and key to success. The highly dynamic operation modes as well as notable perturbations coming along with the natural resource of wind pose extraordinary engineering challenges in setting up the data acquisition and control designs for tethered kites. The first part of the talk summarizes a simple model used for control design and demonstrates its practical and robust applicability by presenting system identification data. Subsequently a brief overview of the controller design and controller performance is given. The second part aims at presenting the sensor data acquisition and navigation algorithm challenges to be tackled in order to achieve a robust automated operation.

After an introduction of the sensor system, the focus is put on the discussion of exceptional conditions and solution approaches developed during several years of flight experience. In summary, a grasp of the state-of-the art flight control as well as of major challenges to be tackled in the near future shall be given.

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# Automatic Crosswind Flight of Tethered Wings: 2-step and Direct Approaches

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Joint work with A. Zraggen and M. Morari (Automatic Control Laboratory, ETH Zurich, Switzerland) and  
C. Novara (Politecnico di Torino, Italy)

Recent research activities in the field of control of tethered wings for airborne wind energy are presented. A flexible wing moving in a wind flow and linked to the ground by three lines is considered. The wing's motion can be influenced by means of a steering deviation, obtained by actuating a difference of length of the so-called steering lines. The considered problem is the design of a feedback control law able to achieve "figure-eight" flying patterns in crosswind condition, i.e. roughly perpendicular to the wind. This problem involves nonlinear, time-varying, uncertain dynamics subject to constraints.

Two approaches able to tackle this problem are presented. The first one is a classical 2-step approach consisting of 1) model derivation and 2) control design based on the derived model. For this approach, the derivation of a parametric model suitable for control design is presented, bridging the gap existing in the literature, between the experimental evidence of turning behavior of the wing and the available mathematical models.

The second approach is a technique to compute a feedback controller directly from measured data, avoiding the need for a model of the system, by learning the behavior of a human operator.

In addition to the control approaches, the design of sensor fusion algorithms to estimate the required feedback variables is also presented.

All of the presented design approaches are supported by experimental results of extensive tests carried out with the automatic

control system running on a small-scale prototype. An example of the obtained experimental results is shown in Fig. 1. A movie of the experimental tests is available online [1]. The presentation is based on recent publications [2]-[4]

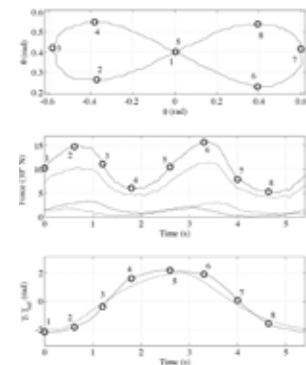


Fig. 1. Experimental results. Single figure-eight path obtained during automatic test flights with about 2.9 m/s wind speed at ground level. From top to bottom: flying path in spherical coordinates, course of the total force acting on the lines (solid line) and of the forces acting on the left (dotted), right (dash-dot) and center (dashed) lines, course of the wing's heading angle and reference heading (dashed).

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# Dynamic Kite-Power System Modelling

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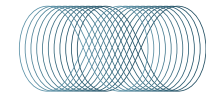
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Kite-power systems are a promising approach to reach high capacity factors even with small to medium on shore wind energy systems. They need an accurate control system for the trajectory of the kite. For the development, optimization and comparison of these control systems a fast system model is needed, that is sufficiently accurate to cover the main dynamic behaviour of all system components: The kite, the tether and the ground-station. To the best knowledge of the authors, no system model was published until now that covers the dynamics of all three system components. In the past in most cases a straight tether was assumed. The straight line assumption does not provide enough accuracy for high-performance controller design, especially for the reel-in phase. Additionally, previous models were not sufficient to develop controllers for automated launch and landing. We implemented a system model as implicit problem in Python, using different DAE solvers from the Assimulo suite. The basic model structure is a particle simulation build of point-masses and spring-damper elements. To achieve realtime performance

we used the LLVM (low level virtual machine) based Numba just-in-time compiler [1]. We verified the model in two ways: First manually by connecting two joysticks as input (for the kite and the reel-out speed of the ground-station), and additionally by connecting the same automatic control system that we already used in field tests. We compared the results to the measurement data. The simulation matched the measurements well. The new modelling approach enables the development of improved, optimized control systems. Realistic software-in-the-loop testing of kite-power system controllers becomes possible. Compared to previous approaches it is easy to change model components like the ground-station or the kite.

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**KitePower**  
LADDERMILL

# Development of the Kite Control Chassis

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Finding solutions to organizational and technological challenges, particularly within the production environment of industrial enterprises. That, in a nutshell, is the key focus of the research and development work carried out at the Fraunhofer Institute for Manufacturing Engineering and Automation IPA.

Together with our partner NTS GmbH, Fraunhofer IPA had developed a control chassis to steer the kites. The motion of the flying kite is used to pull the control chassis along a track. A generator then transforms the kinetic energy into electricity. The kites are tethered to control chassis by ropes of about 700 m in length. The rope handling system and the rope measuring unit, as well as the communication and control technology, are positioned on the chassis.

The development of this control chassis is represented. Select growth points are explained.

For example in case of this concept an essential growth was the scalability of the mechanical design for Kites to approx. 300 sqm.

The experiences from use of the control chassis are a further main emphasis of the lecture unite.

From the collected experiences potential development fields are introduced in future.

E.g. this could be:

- Low wear rope drive technology
- Miniaturization of the onboard control and drive technology
- Ground based kite positioning

# Lei Kites Research at ENSTA Bretagne - Application to Vessels Auxiliary Propulsion by Lift-To-Drag Ratio Estimation and Velocity Prediction Program

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The Leading Edge Inflatable kites research is one of the activities of the Naval and Offshore Structures research department of the ENSTA Bretagne graduate and post graduate school of engineering located in Brest Brittany. This college of engineering is one of the technical universities of the French ministry of defense. The team is formed of four associate professors, one Ph.D. student, two master students (naval hydrodynamics). The team was launched in 2011 to work closely with the French sailor Yves Parlier on his "Beyond the Sea" project, a nature sensitive innovative approach for sea-users developing traction by 100% natural energy. Indeed, the request in reducing the CO2 emissions and the increasing oil prices affect all transportation industries and especially the maritime industry.

In this context, taking advantage of wind energy by using kites as auxiliary propulsion device is considered as a promising solution. The complexity to numerically simulate the flight of a kite requires the development of computationally efficient models, such as those based on the lifting line theory to evaluate the aerodynamic characteristics of the kite. This presentation highlights a 3D lifting line model approach,

which takes into account the three-dimensional shape of the kite and the viscous drag [1, 2]. The methodology exposed was applied to a F-one Revolt LEI kite to predict its lift-to-drag ratio. Results appear to be in very good agreement with RANSE simulations in the case of a paragliding wing, but need much less computational effort. Consequently, the modeling approach was successfully integrated into a velocity prediction program loop to assess kite auxiliary propulsion efficiency for merchant vessels. Effects on propulsion energy benefits are presented and discussed according to true wind angle. These results are expected to be extended to the flying shape identification for future structural analysis required by the design of huge kites.

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## From Surf-kites and Sailplanes to Twings

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The kite is arguably the most critical piece of hardware of a kite power system. Its performance dictates the efficiency and the capacity factor of the system and thus to a large extent the levelized costs of energy (LCOE), the ultimate benchmark for airborne wind energy. The emergence of powerful surf-kites from the sports industry in the last decade has fueled the development of kite power. No surprise that most of the kitepower groups start out with surf-kites, either from the shelf or slightly modified. Surf-kites are easy to get, relatively cheap, rather simple to control and to a large extent crash resistant. On the other hand a few groups are pursuing concepts with a rigid wing. These plane-like configurations are “borrowed” from the aviation industry and are in most respects very different from surf-kites. So what is really crucial for the kite? For a pumping cycle kitepower system, the four most important wing properties with respect to the efficiency of the system are the lift to drag ratio, the wing loading,

the mass per wing area and the ability to fly depowered during the retraction phase. While the outstanding feature of the surf-kite is its very low weight, it fails short with respect to the three other criteria. On the other hand, a rigid, sailplane like structure can have a high lift to drag ratio, good depower and high wing loading. However, the structural weight is a major challenge.

We at the Center for Synergetic Structures have put our focus on the development of the wing for pumping cycle kitepower. In the framework of the SwissKitePower R&D project we have performed theoretical studies, numerical simulations and numerous field tests. Based on these results we have developed the twing (tethered wing), which can be seen as a synergetic combination of the sailplane and the surf-kite. The presentation will describe our quest for the optimal wing for kitepower and give insights into our twings.



Materials Science & Technology

# Harnessing High Altitude Wind Energy employing a Hybrid Lighter-than-air Platform with Aerodynamic Lift from the Magnus Effect

R.J.M. Penedo, T.C.D. Pardal, P.M.M.S. Silva, N.M. Fernandes and T.R.C. Fernandes.

Omnidea

The last decade has seen an increasing number of initiatives to harness energy from the greater power density present in high altitude winds. The different concepts can be classified into three broad groups: static approaches which hover in the air; crosswind approaches and vertical approaches where the motion of the device is perpendicular to the ground.

Omnidea is developing a system in the third category based on a pumping cycle of a hybrid lighter-than-air platform that benefits from buoyancy and aerodynamic lift from the Magnus effect of a rotating cylinder. The system being developed under the HAWE project, comprised of an airborne module (ABM) tethered to a winch at a ground station via a multi-functional cable is described, in which the motor acts both as a winch and a generator. Rotation of the ABM by small on-board electrical motors causes movement of the surrounding air producing a vortex around the ABM which results in aerodynamic lift due to the Magnus principle, and together with the buoyancy of the lighter-than-air construction, gives rise to an upwards force that is used to generate electrical power.

The power-generating sequence of a pumping cycle consisting of four phases operating essentially in a two-dimensional vertical plane is described.

A simplified model, assuming certain conditions, is developed to assess the maximum theoretical performance that can be achieved by the system. A more realistic model is elaborated taking into account parameters such as wind speed varying with altitude, the energy spent in the rotation of the ABM and transition phases from the production phase to the recovery phase. The two dimensional model derived is used to analyse loads and power produced and to investigate the effects of different control strategies related to issues such as load limitation and power optimization amongst others.

Typical operating characteristics are described. The results of a demonstrator 16 metres in length and 2.5 m in diameter are provided as a proof-of-concept and current tests using a larger scaled-up version of 25 metres are discussed as a basis of a system that will deliver power in the megawatt range and be capable of operation at altitudes of about five km.



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## Flight Dynamic Modelling of Inflatable Membrane Kites including Aeroelasticity Effects

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The flexibility of kites and tethers is a challenge for modeling and simulation of many Airborne Wind Energy Systems. This holds particularly for the lightweight membrane structure of an inflatable kite under aerodynamic loading. The structural dynamics and exterior aerodynamics are strongly coupled and dominate the flight dynamic characteristics, the steering and de-powering of the wing. The presentation describes a numerical modeling approach for the flight dynamics of a tethered inflatable wing as a central component of a kite power system. The deformation of the wing is described within a geometrically nonlinear Finite Element framework to cover large displacements that occur due to changing bridle line geometry and varying aerodynamic loading. The effect of the external flow is described in terms of discrete pressure distributions for the different wing sections. The empirical model

takes into account the shape parameters chord length, camber and thickness per section and is derived by fitting pre-computed data from Computational Fluid Dynamic analysis. To reduce computation times, local dynamic deformation phenomena are neglected. Each integration time step, the steady aerodynamic loading is determined first and subsequently used to update the static equilibrium shape of the wing. This static aeroelastic model is embedded in a dynamic system model which includes all remaining airborne components tether, bridle lines and Kite Control Unit. The iterative approach can accurately describe bending and torsion of the wing, which contribute to the aerodynamic steering moments. The presented approach is used to simulate figure-eight flight maneuvers which are typical for Airborne Wind Energy systems.

# Validation of a Quasi Steady Kite Power System Model

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The traction force of a kite can be used to drive a cyclic motion that extracts energy from the atmosphere. This pumping kite concept provides a simple yet effective solution for wind energy conversion at a potentially low cost. A quasi steady modelling framework is proposed for estimation of the power extracted from the atmosphere over a full pumping cycle. A trade off is made between modelling accuracy and computation speed such that it is specifically useful for the purpose of optimisation and scaling in economical feasibility studies.

Different modelling methodologies for the estimation of power extracted over a full cycle have been proposed. Yet only few of these methods have been compared to experimental results. Modelling results are compared to experimental data obtained with the TU Delft kite power demonstrator. It is shown that the theoretical framework corresponds well with the experimental results.

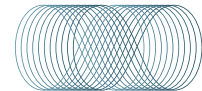


**Rolf van der Vlugt**

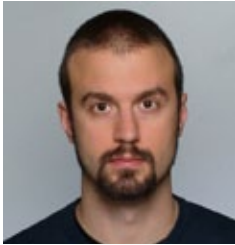
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## Fast Solvers for Nonlinear Optimal Control and Estimation with Applications to Tethered Kites

Milan Vukov, Rien Quirynen, Moritz Diehl  
KU Leuven

Tethered flight can be characterized as a strongly nonlinear and unstable process. Those facts motivate usage of control and estimation techniques based on nonlinear optimization. Moreover, the process dynamics requires fast sampling times, thus algorithms which can be executed in millisecond range.

Fast nonlinear model predictive control (NMPC) and moving horizon estimators (MHE) solvers are developed for mechatronic and aerospace applications. Here we present an automatic C-code generation strategy for real-time NMPC and MHE. The automatic code generation is realized as the ACADO Code Generation tool within the software package for dynamic optimization ACADO Toolkit.

The tool enables one to export highly customized solvers for NMPC and MHE which allow for very advanced control strategies including nonlinear measurement functions as well as the formulation of general nonlinear constraints along the process trajectory. In the context of estimation, the tool provides an elegant procedure for multi-rate sensor fusion. This procedure for sensor fusion removes the need for intermediate steps, e.g. averaging high frequency measurements before feeding them to the estimator.

Simulation results provide insight into some benchmarks, showing very promising performance and execution times. Furthermore, we present real flight experimental results performed on the kite carousel at KU Leuven, Belgium.

# On Real-Time Optimization and Adaptation of Airborne Wind Energy Generators

A. Zraggen (joint work with L. Fagiano and M. Morari)

Automatic Control Laboratory, Swiss Federal Institute of Technology, Switzerland

Airborne wind energy generators aim to generate renewable energy by means of the aerodynamic lift produced by a wing tethered to the ground and controlled to fly crosswind paths. The automatic control of the tethered wings plays a major role for the efficiency and thus also economics of such energy generators. The goal is to control the wing in order to fly a crosswind path under constraints such as actuator or wing position limitations, while maximizing the generated power. At constant tether speed operation, the power is related to the traction force generated by the wing. Thus, in order to maximize the power output, the wing should fly on a path that yields the highest traction force for the given wind condition. This problem has been studied by several research groups. Most of these approaches employ an optimal path, computed off-line for specific wind conditions based on a nonlinear point-mass model. An automatic controller is then designed to follow this optimal reference trajectory. Yet, the offline generated optimal trajectories are subject to modelplant mismatch, hence they may be sub-optimal or even infeasible in practice. Moreover, the mentioned approaches assume that the wind speed and direction at the wing's location are known in order to employ the computed optimal path. However, the wind field changes over distance and time and it is difficult to estimate with only a few measurement points, like those available with ground anemometers.

The problem of optimizing the operation during the traction phase of an airborne wind energy generator is considered. The aim is to maximize the average power developed by the generator, in presence of limited information on wind speed and direction. In order to tackle this problem, we propose a

model-free optimization approach, based on realtime adaptation of the flown paths, with no exact knowledge of the wind conditions. First, a study of the traction force is presented for a general path parametrization. In particular, the sensitivity of the traction force on the parameters, defining the crosswind path, is analyzed in order to assess the most important aspects of the flown trajectory for the sake of power generation. Then, the results of this analysis are exploited to design an algorithm to maximize the force, hence the power, in real-time. The algorithm uses only the measured traction force on the tether, and it is able to adapt the system's operation to maximize the average force with uncertain and time-varying wind, i.e. no knowledge of the wind direction or profile. The presented algorithm is not dependent on a specific hardware setup and can act as an extension of existing control structures. Both numerical simulations and real-world experimental results are presented to highlight the effectiveness of the approach.

A short movie of a test with the adaptive algorithm is available online [1]. The presentation is based on recently submitted publications [2], [3].

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## Moderator Topic Wind

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Besides other publications related to Airborne Wind she published in 2009 together with Ken Caldeira the "Global Assessment of High-Altitude Wind Power": The available wind power resource worldwide at altitudes between 500 and 12,000 m above ground is assessed for the first time. Twenty-eight years of wind data from the reanalyses by the National Centers for Environmental Prediction and the Department of Energy are analyzed and interpolated to study geographical distributions and persistency of winds at all altitudes. Furthermore, intermittency issues and global climate effects of large-scale extraction of energy from high-altitude winds are investigated.

# Optimal Altitude Estimation for Power Generating Kites in an Uncertain Wind-Field

Ioannis Lympereopoulos and Colin Jones

Automatic Control Laboratory, EPFL

Building on previous knowledge for the correlation structure of wind forecast uncertainties in spacetime and using measurements both from the ground and onboard the flying kite, we are able to provide filtering estimates for the wind speed. We filter for the full span of altitudes of interest, with varying confidence, depending on the availability of measurements at each height. We proceed to calculate the potential power that can be extracted at different altitudes and force the kite to gradually move towards the region with the maximum available power. During this process, the incoming measurements are continuously employed to improve on the previous filtering estimates and a new optimal altitude may arise. Simulation results show that even using such a simple method, power extracted could improve with a factor of more than 20% in the case of fixed tether length and considerably more in the case of variable length.

The flying kite is experiencing a wind-field that varies in space and time. We assume that the wind is comprised of two components, the forecast (nominal part) and the forecast error (stochastic part). The nominal part is available to the operator while the stochastic part is modelled as a random field, with a zero mean multivariate Gaussian distribution [2]. For the length and time spans considered here (few km, 100s of seconds), both horizontal and time correlations are very strong, while correlation with altitude fades quickly. Simple kinematic equations are used to simulate the trajectory of the kite since we are mostly interested in finding the optimal flying altitude rather than estimating the actual optimal orbit. We assume that power ( $P$ ) is proportional to the cube of the wind speed ( $v_w$ ) but is also strongly affected by the inclination ( $\theta$ ) of the cable to the horizontal level (a trade-off to cross-wind conditions), and

slightly affected by the decrease of air-density ( $\rho$ ) with altitude ( $h$ ), as in [1], namely

$$P(h) \propto \rho(h) \cos^3(\theta(h)) v_w^3(h)$$

Our system is comprised of two wind speed sensors, one positioned 10 m above the ground and another mounted to the kite (the kite is not allowed to operate below a certain height). We assume drag mode operation, therefore fixed line-length. Each time a new set of measurements arrives, we appropriately condition the multivariate distribution to incorporate them into the correlation structure of the wind forecast error. This provides an update to the forecast error mean and covariance of the wind speed across all altitudes. We use the mean to calculate the optimal altitude at each time step and force the mean flying altitude of the kite towards this direction with a vertical speed  $v_h$ . If a new optimum is found while transversing the wind-field the kite will be again directed towards it.

Simulations of the described setup exhibit encouraging results. The method is able to improve performance by more than 20% on a scenario to scenario basis for a fixed tether length. If we vary the tether length two-fold (in order to be able to exploit higher altitudes, without being significantly penalised for deviation from cross-wind conditions) this performance increases considerably. Finally, it is worth noting that the margin from the case where the real wind optimal altitude is available is considerably small.

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## 20 Years of Wind Measurements in Germany Results and Future Developments

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Wind loading is a relevant issue in the design of high and slender steel structures. Due to this fact since 1989, the Institute of Steel Structures at Braunschweig University has been operating a data acquisition system on a 344 m high guyed mast called Gartow II, which is owned by Deutsche Telekom AG. The guyed mast is located in the north of Germany at  $53^{\circ}03'55''\text{N}$ ,  $11^{\circ}26'33''\text{E}$  and was formerly used as a directional radio antenna for broadcasting phone calls to West Berlin. This measuring system is one of the best equipped worldwide and provides the possibility to get an inside view of the wind's structure.

With the installed equipment it is possible to measure wind velocities and directions from a height of 30 m above the ground, with a vertical distance of 18 m up to a height of 341 m. For measuring meteorological data, 14 cup anemometers, four propeller anemometers, four ultrasonic anemometers, seven wind vanes, and four PT-100 temperature sensors are installed. The wind sensors are located on the western side of the mast shaft and are mounted on 7.5 m long stayed cantilevers. In addition the mast's response is measured with 17 strain gauges, five accelerometers and 32 force sensors.

In this paper the equipment for the measuring of wind flow is presented and an overview of the measured data and their analysis from the past two decades is presented. The measured data is compared with theoretical and empirical models

for the height dependent wind speed and turbulence intensity profiles. In addition measured time series of wind speed are analysed with respect to their statistical characteristics using correlation- and coherence functions.

Using Hellmann's power law for the description of the mean wind speed profile, the profile exponent shows a large scatter and is dependent from absolute wind velocity. Scatter reduces for higher wind velocities, the profile exponent fits to the on-site topography. Compared to the log-law profile the Hellmann's law is adequate for heights up to 350 m. For low wind velocities, the wind speed profile can differ significantly from the power law profile. Thus wind speed profile shapes have been identified and sorted to six classes using a neural network.

It can be shown that the distribution of the turbulent energy can be described well using the von Kármán-spectra for the longitudinal and for the lateral velocity component respectively. Coherence functions are very much dependent on the numerical evaluation process.

At the moment, the mast is being equipped with 48 additional Ultrasonic-Anemometers, fixed on the guy-cables. This upgrading of the measuring equipment will allow for 3D measurement and analysis of the wind flow. The measuring concept and technical details will be presented in the paper.

# Future Prospects of Airborne Wind Energy (AWE)

Uwe Ahrens

NTS

The paper shall give a summary of the necessity of alliances in the industry of AWE

A short historical overview using examples of previous developments of basic technology inventions and its impact to the future will underline it.

Particularly with regard to the power market the paper shall illuminate future options and/or reactions to respect or realize. From author's point of view, not only the different AWE concepts are important for a success story, because:

- The most AWE concepts promise energy competitive to fossil fuels.
- The most AWE concepts promise less use of resources compared to existing renewable systems.
- The most AWE concepts promise capacity factors up to 2-3 times of conventional wind turbines.

Important will be other factors like:

- The success will be more dependent of the ability to cooperate
- The acceptance will be more dependent of the public opinion
- The acceptance will be more dependent of the political decisions influenced by public opinion,
- The regulations
- The dependency on subsidies of either public or private investments.

If the factors of success of our AWE technology are used appropriate this will have a tremendous influence of the future development of the global economy.

The paper will show the do's and don'ts by lessons from former basic technology inventions.



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## The Big AWE Picture

Christof Beaupoil

AWE is easy - All that is needed for an Airborne Wind Energy Converter are four functional components: The components

<b>LIFT</b> ...to stay airborne	<b>ENERGY TRANSFER</b> ...to bring the energy to the ground
<b>BLADE</b> ...as the wind to mechanical energy converter	<b>GENERATOR</b> ...for the mechanical to electrical energy conversion

can be varied in order (GENERATOR before or after the ENERGY TRANSFER) and combined (e.g. a BLADE that produces lift and mechanical energy). For each of the functional components there are many proven solutions available:

So why do we – after generations of bright people have in-

<b>LIFT</b> Aerodynamic lift, buoyancy,...	<b>ENERGY TRANSFER</b> Drag/traction, electric current,...
<b>BLADE</b> Rotor, Wing,...	<b>GENERATOR</b> Rotary generator, linear generator,...

vested time and money – still not see a competitive solution to tower based wind energy that leverages the stronger, more consistent wind in higher altitudes? It took 3000 years for today's predominant three bladed horizontal axis tower based

wind turbines to evolve from the first wind energy converters in Persia. On the way hundreds of designs have been tested - thousands have been proposed. We should shorten the process for AWE.

The first part of the proposed talk aims to presents a complete overview of all theoretically possible ways to do AWE – Based on an analysis of airborne wind energy patents and publications and a clustering of the included four functional components.

The second part focuses on proposing selection criteria aimed to filter out the most promising approaches that can be expected to be technically and economically feasible. These criteria include:

- Weight efficiency
- Energy efficiency
- Airspace efficiency
- Cost efficiency
- Inherent stability/reliability/safety
- Maximum expected operational height
- Output variability
- Availability of base technology

This might lead to the identification of designs that are currently not tested in the scientific and industrial community.

# Sustainable Design and Innovation in Clean Tech

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CAD as CAD can



“Autodesk” and “Mensch und Maschine” are companies which have the vision to help people to imagine, design and create a better world by developing and using clean technologies.

But what is the concrete meaning of “clean technology”? If you ask Wikipedia, you will get the following answer:

“Clean technology includes recycling, renewable energy (wind power, solar power, biomass, hydropower, bio-fuels), information technology, green transportation, electric motors, green chemistry, lighting, Greywater, and many other appliances that are now more energy efficient. It is a means to create electricity and fuels, with a smaller environmental footprint and minimize pollution.” ([https://en.wikipedia.org/wiki/Clean\\_technology](https://en.wikipedia.org/wiki/Clean_technology))

The Clean Tech Partner Program of Autodesk and Mensch und Maschine represents the part of information technology in the definition of Wikipedia. The Program supports customers who are engaged in clean technologies by providing software, training and support. In this way they are able to design, visualize, and simulate their ideas. Clean tech companies which are interested in benefiting from computer aided design solutions are invited to apply to the Clean Tech Partner Program. Under certain conditions customers get up to 120000€ worth of software for only 50€.

The customers of Autodesk and Mensch und Maschine are architects, designers and engineers who are creating

everything built, designed and manufactured. There are many industries that are complying with the conditions of the Clean Tech Partner Program.

The software which supports customers in developing clean technology solutions consists of several CAD software tools:

- Autodesk Product Design Suite Ultimate: a software solution suite which enable 2D and 3D mechanical design as well as electrical design, simulation and visualization.
- Autodesk Building Design Suite Ultimate: Software Products which are supporting the Autodesk Building Information Modeling (BIM) that supports the customers to integrate analysis, simulation and visualization for a better realizing of green architecture, engineering and construction.
- Autodesk Vault: a product data management tool which manages data of engineering and documentation processes.
- Autodesk Vault might be completed which special tools from Mensch und Maschine (e.g. “pinpoint”) to a very powerful and configurable Data Management tool.

In this lecture a historical overview of clean tech design for the harnessing of wind energy is given. Additional there will be mentioned the possibilities of Autodesk Clean Tech Software and some examples for using these products by well-known customers.



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## Cooperative Kite Networks: Scaling Open Source Hardware

Roderick Read

Windswept and Interesting Limited

I propose an engaging open discussion on the following;  
Open source hardware motivation, ethos, reasoning, design and lessons.

An open source hardware AWE engineering team has formed. Team administration is coordinated online mostly over open channels. Kitepowercoop.org is developing a hub for AWE services working within cooperative frameworks.

Open data is a key motivation to membership. Robust solutions, open market structure and accountability benefit the business. The speed of discourse, project prestige and breadth of field help to keep the open market sociable and fun.

Contracted payments and project achievements have exceeded member expectations. The cooperative provides licensing and offers symbiotic guidance on development. Whole community benefits come from a simple democratic ethical code.

Many of the coop's physical AWES reflect the team's organisational structure. Designing with simple codes; structural networks have evolved which transmit addressed energy transactions between symbiotic components. Guidance of each module is actuated by neighbouring structures and programmed tension differentials. Whole network responses focus energy to a common output.

Cooperative evaluation and peer review allowed testing of unlikely, exotic and even seemingly nonsensical ideas. This huge shared learning resource, lead to a strong pool of co-operatively licensed IP. Initial coop AWES releases will be small scale devices. As stronger performance data emerges the coop is confident of AWES license releases over increasing scales.



# Airborne Wind Energy in Teacher Education

Ariadne Schefold<sup>1</sup>, Prof. Dr. Franz Stuber<sup>2</sup>

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In teacher education, Airborne Wind Energy technologies begin to become an inspiring part of the curriculum.

Within this framework, our educational project kite & tech is embedded. The project kite & tech focusses on the kite as guiding theme with its manifold applications in sports and outdoor education as well as in technology and media.

For concept and results see our wiki on:

<http://www.ibl.fh-muenster.de/en.kitewiki/>

Currently, the discussion and work process in our project concerning AWE revolves around the following issues:

- Introducing AWE as clean energy: see the main category „Industrial applications“ in the wiki ([http://www.ibl.fh-muenster.de/en.kitewiki/index.php?title=Category:industrial\\_applications](http://www.ibl.fh-muenster.de/en.kitewiki/index.php?title=Category:industrial_applications)) (Sachanalyse)
- Identifying core skills for the prospective operation and service of AWE technologies: work and qualification analysis exemplarily for the Kitepower/ TU Delft and NTS approaches are currently in process (Zielgruppenanalyse)

- Developing learning tasks that integrate AWE in teacher education and vocational training curricula: see the AWE learning project for non-academic mechanical and electrical engineering professions ([http://www.ibl.fh-muenster.de/kitewiki/index.php?title=Kategorie:Lernaufgaben#Lernprojekt\\_22\\_Airborne\\_Wind\\_Energy.22](http://www.ibl.fh-muenster.de/kitewiki/index.php?title=Kategorie:Lernaufgaben#Lernprojekt_22_Airborne_Wind_Energy.22)) (didaktisches Design)

All these issues depend on exchange of knowledge and ideas with various protagonists of AWE. Coming into discussion with the conference participants we hope to find strategic partners who are interested in new integrative R&D projects as well as in sponsoring the kite & tech activities to foster our aims.

We'd like to give a short oral presentation on our project as well as present a project poster and flyers.



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## Land and Space used

Pierre Benhaïem

To estimate the return of investment (ROI) of an Airborne Wind Energy System (AWES), an analysis of its land and space used regarding produced energy must be realized.

### Land used

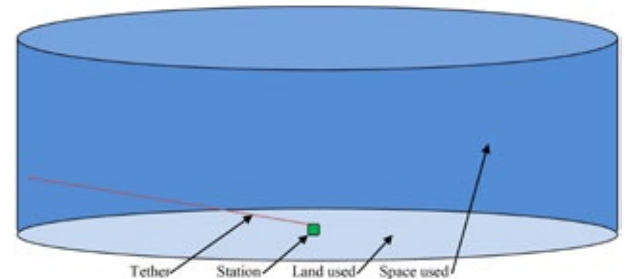
In both conventional and airborne wind energy land used can be divided into the whole area usually determining power (in MW)/land (in km<sup>2</sup>) ratio for a farm of machines, and the area occupied by stations where AWE takes an advantage. But concerning the whole area of land and due to safety requirements, a zone empty of inhabitants is necessary. With cross-wind AWES, this zone is for each unity a disk where the radius is at least the length of tether, that due to all possible changes in wind directions.

### Space used

An important third dimension is added, preventing any air traffic in the worked space.

### Conclusion

Both land and space used are huge, so an implementation off-shore or in deserts is required, so AWES should be studied for a complete maximization of swept area into the space used. So some ratios can be implemented: swept area/whole land used, swept area/land used by stations, swept area/space used, that for each unity, but above all for a complete farm of unities or a complex system.



*Note: The correct shape should be a dome, but the simpler, cylindrical shape, is better locatable by the users in the aviation.*

# Fluid-Structure-Interaction in Kite Design

Merlin Bungart  
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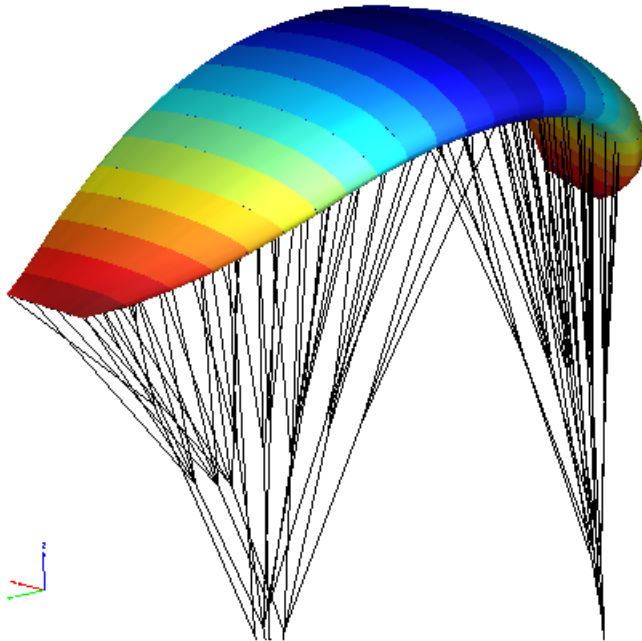
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The presented poster will contain information about academic kite development.

Mainly numerical methods, like CFD (Computational Fluid Dynamics), FSI (Fluid Structure Interaction) or real-time kite behaviour simulations will be covered.

For a deeper insight into real kite constructions for high performance applications (like HAWK), some information about the way how to use simulation data for a reliable kite design will be given.

Figure 1: Example Kite Model 20sqm





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## The Unrealised Potential of a Kite

J. Conradi, B. Akkermann, F. Sievers

Kippenberg-Gymnasium Bremen, Q1e Lk Mathematik, Projekt P5

### Background:

In recent years a lot of research has been conducted on the conversion of the traction power of kites into electricity. Kites can be flown with different manoeuvres, the most common being the lying eight. This paper analyses which manoeuvres produce the most traction power and therefore, the most electric energy.

### Methods:

In order to determine the most efficient method of traction power generation a 6 m<sup>2</sup> surf kite was flown at wind speeds averaging 19 knots. The steering of the kite was proceeded by a conventional bar with four lines. A force sensor was attached to the "chicken loop" during the loop and lying eight manoeuvres. Measurements were taken every 0.4 sec. for each manoeuvre. The average of 6 runs for each manoeuvre was calculated and compared. The recorded data was analysed using Microsoft Excel for Mac 2011.

### Results:

The measurements show that more power was exerted by a loop manoeuvre in comparison to a lying eight manoeuvre.

The average power for the loop was 1193 Newton and for the lying eight 1012 Newton. This translates into an increase of 17.83%.

### Conclusions:

It can be concluded that the use of loops in producing electric energy is more efficient than the lying eight. The difference between these two manoeuvres can be explained by the fact that during a loop the kite has a constant directional change and during a lying eight the directional change alters always. For that reason the kite could gain more speed, which is related to the power. Another explanation for the different values could be seen that flying circles keeps the wing more centred at the maximum power point (zero azimuth angle). A lying figure of eight is wider and the wing spends comparatively more time at positions towards the sides of the wind window (i.e. at larger azimuth angles). The instantaneous traction power decreases towards the sides of the wind window and so does the average.

Further research is needed to develop kites and equipment, which can provide this manoeuvre. Due to the limits of this study further research is required to gain more data.

# Un-tethered Autonomous Flying Wind Power Plant

Dr. Gábor Dobos

Chemotronik R&D Ltd., Hungary

IP rights.

Hungarian patent. Registration number 227 468

PCT International Application No: PCT/2010/000028,  
published under WO 2010/106382 A3.

Because of financial reasons the invention became a public property.

The reasons for seeking a new solution

Conventional wind power plants (WPP) have their limits due to the low energy density and fluctuations of surface winds, as well as their low efficiency. The idea of harnessing high-altitude winds seems to be promising. Tethered flying energy harvesting devices have been known for a long time, but they also have their drawbacks, probably as a result of the tether itself and the related complications.

The solution

An untethered autonomous flying energy-harvesting unit (an airplane, glider or the like) as well as a receiver ground-station are integral parts of the complete system. These two physically detached parts constitute a logistic unit, and their collaboration according to a fixed timetable ensures the realization of the invention. A ground-station could support several flying units.

Temporary energy storage on the plane is the most critical problem of the idea. The invention itself grants a great degree of freedom to the user in choosing the method of energy storage. Practically any kind of physical, chemical, electrical or other solution may be used as an energy storage medium, among them liquid air or batteries too. The latter two are the preferred competing methods. Both are subjects of ongoing

research projects all over the world. It doesn't matter to us which development wins in the end (or even if a third possibility proves the best). Any of them can be applied by the IFO. The system is utilizing well known technical solutions, but the result of their synthesis and unique application has yielded new routes and so far unutilized possibilities in wind energy production. The invention is feasible but the details need significant further R&D, as well as investment.

Benefits

- Powerful high altitude winds and especially the much larger airspeed of a DS-ing glider than the speed of the prevailing wind allow for smaller and lighter devices.
- Our flying energy harvesting glider is capable of following the advantageous winds. There is no other WPP capable of doing so.
- It does not need large areas to function like conventional WPP-s do. It needs only a small airport, or rather, a short grassy runway.
- Generates no infrasound and does not disturb birds.
- Dispatchability.
- The system is able to function as a peak load power plant.
- "Onboard" superconductive technology
- Short payback time, excellent profitability even without any government subsidy.

Upon preliminary calculations, this project needs about a 4-6 year R&D period and 60MUSD funding for R&D and the implementation of a Pilot Plant of 20 MW rated power. The pay off time is about 4-5 years. This 60MUSD is not more than the cost of a conventional WPP of the same power today.



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## The New Highwind Carousel for Outdoor Rotational Start Experiments

Kurt Geebelen

(Joint work with Andrew Wagner, Mathias Clinckemaillie, Jeroen Stuys,  
Wouter Vandermeulen, Dirk Vandepitte, Jan Swevers, Moritz Diehl)

KU Leuven

This poster presents an improved version of an experimental test setup developed within the ERC Highwind project at the University of Leuven. The setup will be used for airborne wind energy (AWE) research that focuses on the automatic control and start-up of tethered rigid wing systems. Automatic starting and landing of rigid wing systems that lack on-board propellers can be done using a rotation start. In the rotation start, an arm rotates around a central axis and brings the airplane up to speed. Once the airplane has achieved sufficient speed, the tether can be extended, allowing the airplane to gain altitude. A transition to crosswind flight is performed when the achieved speed and altitude is high enough.

In contrast to the previous experimental setup, the new carousel will rotate a 2 m radius arm 4m above the ground. This carousel has a nominal rotational velocity of 60 rpm at which it can deliver a maximum towing power of 4 kW. Mounted at the heart of the carousel is a winch that rotates with the arm. This winch is driven by a 10 kW motor/generator with a maximum reel in/out velocity of 10 m/s. Furthermore, the carousel is weatherproof and is mounted on a trailer for easy transportation to outdoor flying sites. The airplane that will be used for initial testing on this setup has a wingspan of 3 meters and a surface area of 1 square meter.

*The figure to the right shows the new Highwind carousel, which is currently under construction. By the time of the AWE conference, the winch, arm, and plane will have been completed and installed, and the first round of flight experiments will have been performed.*



*The poster will describe the design of the experimental setup, as well as share some of the first experimental results achieved in outdoors testing with this setup.*

# Simulation Based Design of Kite Power Systems

Flavio Gohl, Rolf H. Luchsinger  
Empa – Center for Synergetic Structures

A versatile simulation tool for kitepower systems is presented. The core of the simulator is a detailed aerodynamic model of the kite based on the Vortex Lattice Method (VLM). The kite is assumed to be a rigid body while the tether is modeled as a flexible cable. In a multiline configuration the kite is steered by tether actuation from the ground taking e.g. the effects of the line sagging on the controllability of the kite into account. The full simulation step runs in real-time. This could only be achieved by developing all the software components in-house in C++. The real-time simulation allows the user to fly the kite with a joystick, a feature we found crucial for analyzing and optimizing different wing designs with respect to their dynamic behavior.

In a second step, the simulation tool was extended to fly

complete pumping cycles with automatic control. Next to the simulation of the traction phase and the retraction phase, the transition between the two phases is of great interest. Especially for the retraction phase and transition phases the detailed physical model of the presented simulator is of utmost importance. Various wing configurations, flight patterns and control strategies were studied with respect to their influence on the power output of the pumping cycle kite power system. Different scenarios such as high and low wind were also considered, where the flight strategy might be adapted. Finally, the flexibility of the simulator allows the modeling of other AWE concepts such as the flying generator or the carousel, too. In this presentation, the potential and limitation of this simulation framework are discussed.



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## Beyond Electricity Generation: AWECS for Energy Storage and Industrial Processes

Leo Goldstein  
Airborne Wind Energy Labs

It is already known (e.g., <http://dx.doi.org/10.1016/j.energy.2013.03.087>) that airborne wind energy conversion systems can be 10x cheaper than conventional wind turbines for the same electrical power output while being more dependable in the same time.

This presentation proposes airborne conversion of wind energy into energy forms, suitable for storage or for use in industrial processes. The central idea is an AWECS, directly converting wind energy into internal energy of gas. The output is hot compressed gas (such as air or steam), which can be further used for energy storage or in industrial processes, currently using fossil fuels as the energy source.

One proposed device is shown in the figure below. It employs multiple pressure cylinders, driven by a belt, attached to the airborne wing's tether. The wing flies cross wind, as in most modern AWECS. Moderately compressed gas (such as air, water steam, argon etc.) is injected into the cylinder in the beginning of the stroke; the piston, engaged by the belt, compresses the gas further; hot compressed gas exits through a valve as the output from this process.

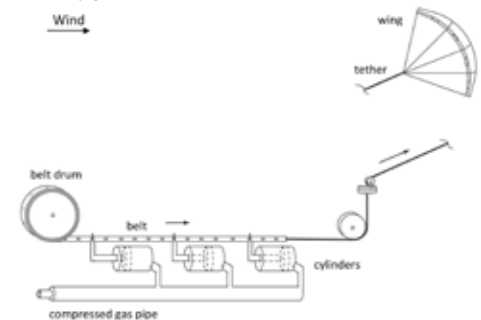
Hot compressed gas can be further used to charge an energy storage device of thermal type (e.g. one using molten salt or hot and cold storages.)

The stored energy can be recovered and converted into electricity in the times, when the wind is absent. Thus an AWECS

farm, combining “conventional” airborne wind-to-electricity systems with energy storage and recovery systems like the one proposed, can ensure a firm capacity and eliminate intermittence – the inherent disadvantage of the wind energy systems.

Hot air or steam produced as described above can be also used as the energy source in manufacturing fertilizers or production of liquid fuels, e.g. synthetic fuel from natural gas.

Thus the airborne wind energy can become a significant factor in reducing consumption of fossil fuels besides electricity generation.



*AWECS converting wind energy into internal energy*

# Kite Power for Developing Countries

Christoph Grete

Delft University of Technology

Delft University of Technology is developing a wind energy system which uses the traction power of a tethered flexible wing. The 20 kW technology demonstrator reached the key milestone of automatic operation in spring 2012, making it suitable for commercial development. In the past year the feasibility of technology implementation in less developed countries, especially in rural areas, has been assessed. Preliminary research with the focus of identifying the optimal location and business model suggested developing countries as the ideal starting point for several reasons. The Airborne Wind Energy system KitePower overcomes many of the main barriers and challenges that are persistent in rural areas. This was confirmed during a visit to the countries Senegal, Tanzania in Kenya. Within seven weeks, various important stakeholders such as relevant ministries, NGOs and companies working in the field of renewable energy have been met.

First of all, the majority of the people do not have reliable access to affordable electricity if at all a connection to the national grid exists. Secondly, the proximity to the equator results in darkness in the early evening, making solar-only solutions expensive due to the required costly energy storage. Depending on the region, wind speeds at ground level can be rather low; often throughout the entire year. This makes AWE systems more applicable than conventional wind turbines. Another advantage of KitePower is the low amount of material and the high mobility of the system which allows for deployment in remote areas with poor infrastructure.

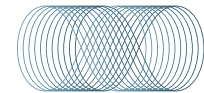
After the first phase of this explorative mission, the focus lays on the planning and realization of a pilot project in one of the countries. Reaching this mid-term goal will yield many opportunities to attract investors for commercialization attempts in the future.



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## Reverse Pumping: Theory and Experimental Validation on a Multi-kites System

R. Lozano Jr, M. Alamir, A. Hably, J. Dumon

Gipsa-lab/CNRS, University of Grenoble

Classic kite wind power systems have a great drawback that wind turbines do not have: they cannot stay in the air if there is no sufficient wind. Most of the kite systems need to land when there is no wind, and to take-off once there is enough wind. As these maneuvers happen close to the ground, where the wind is most turbulent, there is a great probability of crashing the kite. Also, "classic" landings and takeoffs need a landing zone, ground handling or infrastructures such as pylons, thus reduce the advantages of kite systems. A first solution to overcome these drawbacks is to use helium balloons to make kites fly in still air, but balloons have leaks and need refilling solutions. Another solution is to add engines to our kites so that we transform them into vertical takeoff and landing tethered airplanes. There are two ways of supplying energy to the engines, the first is to use electric cables that transmit energy to the kite, and the other solution is to use an embedded battery. For the first solution, the electric cable is heavier than the classic cable and limits the maximum reachable altitude, therefore limiting the maximum harvested energy. The problem of the battery solution is that the vertical flight duration depends on the mass of the battery. In order to minimize the number of landings and takeoffs, we need to have enough energy to remain in flight during the period where there is no sufficient air, or to have enough energy to reach altitudes where the wind can lift the system's weight. Reverse pumping brings a partial solution to these problems.

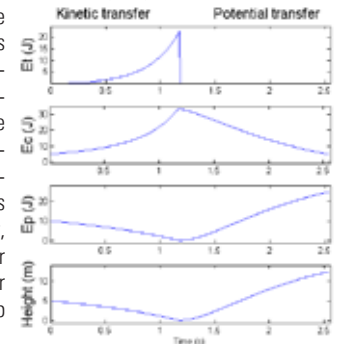
The proposed reverse pumping method can be decomposed in two phases, the kinetic charge and the potential transfer phases (Fig 2). During the kinetic charge phase, the amount of energy  $\Delta E_k$  will be consumed on the ground by pulling the kite with

the rope. As a consequence, the kite will increase its kinetic energy by  $\Delta E_k$ . The gained energy will be transformed into potential energy  $\Delta E_p$  by taking height during the potential transfer phase. At the end of the cycle, the total energy of the kite should remain greater than or equal to its initial value, even in the presence of energy losses  $\Delta E_{lost}$ . The kite's energy variations obey the following equation,  $\Delta E_t = \Delta E_k + \Delta E_p + \Delta E_{lost}$



Fig.1. The twin kite system used for the reverse pumping experiment.

Fig.2. Energy variations during the kinetic charge phase and the potential transfer phase. Note that the final height is greater than its initial value.



Using this method, the kite can stay in flight even in the absence of wind. The reported study is composed of a theoretical investigation of the reverse pumping, the numerical simulations applied to a twin kites system and finally, the validation of our simulations on our experimental setup (Fig 1).

# Traction Power Generation with Tethered Wings

Michael Noom, Roland Schmehl, Rolf van der Vlugt  
Delft University of Technology, Faculty of Aerospace Engineering

A tethered wing can be used in two different ways, to lift payload or to provide traction power. The latter is the basis of several innovative technical applications, such as kite-assisted ship propulsion and pumping-kite wind energy conversion. We present a theoretical analysis of traction power generation by a tethered wing. The objective is to establish the fundamental relationships between system and operational parameters on the one hand, and the achievable mechanical power output on the other hand. It is assumed that the instantaneous flight state of the wing can be approximated by the steady equilibrium of aerodynamic and tether forces.

The analysis covers the general case of controlled flight along an arbitrary, predefined trajectory with varying tether length. The analysis is compared with several special cases that are available in literature. In a second step, the effect of weight and centrifugal acceleration of the wing is included in the analysis, as well as the effect of weight and aerodynamic drag of the tether. To estimate the potential traction power generation the analysis is applied to the specific trajectory of a pumping cycle, which is characterized by a traction phase, in which the kite performs figureeight maneuvers, a retraction phase and a transition phase.

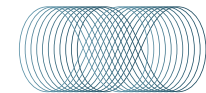


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## **SkySails Towing Kites for Ship Propulsion and Power Generation Design and Operation of Industrial Scale Kites**

Xaver Paulig and Bernd Specht

SkySails GmbH

For the economic operation of AWE based power plants, durable and high performance kites of industrial scale are indispensable. In this contribution we report on design considerations and operational experience of towing kites developed for sea-going vessels. Challenges arise due to high system loads up to 320kN at kite sizes of 320m<sup>2</sup> in combination with

flight stability and operational constraints such as machine assisted handling in off-shore conditions for the purpose of reefing, stowing and maintenance. Detailed illustrations will cover kite steering concepts, steering stability, material selection, durability tests, aerodynamic design considerations as well as experimental data.



# Rotokite: A different Approach for the Exploitation of the High-altitude Wind

Giovanni Vergnano  
Sequoia IT S.r.l.

The use of piloted kites to capture upper-level wind energy is object of many research and project. This Rotokite project is extremely innovative even if compared to new technologies in the field of kites , as it uses a new form of aerodynamic profile which rotates around its own axis.

The principle of rotation simplifies and optimizes in a significant way the use of light profiles for the exploitation of high-altitude winds. It eliminates the difficult problem of in-flight control of kites thanks to its stable aerodynamic shape. Also, it eliminates the problem related to the aerodynamic resistance to the translation of long control cables which fasten drive the traditional kites. The interconnection cable placed between the rotor and the generation system placed on the ground is meant to mechanically transmit the generated energy.

There are no constraints in exploiting the wind even at high altitudes, because the interconnection cable is subjected only to length variations.

During the traction phase, the profiles rotate and automatically modify their own aerodynamic balance according to the angular position.

This enables to create both the traction force on the cable connected to the generator, and it also brings a lift component which maintains the system at high altitude. For all other functions, this system operates in the same way as the single kites: once the pre-established altitude is reached, the traction phase stops and a quick recovery phase starts, up to the height of the beginning of the cycle, with low energy consumption thanks to the profile modification.

It is currently underway a study for the realization of a prototype, in collaboration with Enerkite Company, thanks to funding and grants of Italian government.

In the following months, the Rotokite project will be separated from Sequoia IT and it will become the core business of a new company, which will have to find financial and technical collaborations for its development.



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## Airborne Wind Energy Based on Dual Airfoils

M. Zanon, S. Gros, G. Horn, M. Diehl  
OPTEC, KU Leuven

The Airborne Wind Energy paradigm proposes to generate energy by flying a tethered airfoil across the wind flow at a high velocity. While Airborne Wind Energy enables flight in higher-altitude, stronger wind layers, the extra drag generated by the tether motion imposes a significant limit to the overall system efficiency. To address this issue, two airfoils with a shared tether can reduce overall system drag. While this technique may improve the efficiency of AWE systems,

such improvement can only be achieved through properly balancing the system trajectories and parameters. That problem can be tackled using optimal control. A generic procedure for modeling multiple-airfoil systems with equations of minimal complexity is proposed. A parametric study shows that at small and medium scales, dual-airfoil systems are significantly more efficient than single airfoil systems, but they are less advantageous at very large scales.



## AWE. The Documentary

Chase Honaker

The AWE documentary chronicles the developers and innovators of Airborne Wind Energy against the backdrop of wind energy politics and the challenges faced by tapping this vast and powerful resource. We are balancing technical & educational elements alongside the human story.

We are compelled to tell the story of Airborne Wind Energy and how it can impact energy production on the planet. We want to get the word out, generate interest, and inspire innovators to tackle the technical and political challenges of Airborne Wind Energy. Out of all the energy sources, airborne wind lends itself best to film since the energy generation is both visible and visually stunning.

Themes we will explore include the politics of big energy, the

financial hurdles associated with implementing a new technology, the diversity of utility-scale and rural applications, transparency, intellectual property and open source, and social opposition to new technology. Most importantly, is this technology a viable alternative energy source for the world to embrace?

The majority of the documentary principal production will be filmed in Europe around AWEC 2013. We are screening a short preview of the documentary showcasing our ideas for the feature length film. We are actively seeking input from people inside the industry. If you would like to be a part of the film, please come find me during the conference or email me.



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Guido Lütsch