BOOK OF ABSTRACTS

AIRBORNE WIND ENERGY 2011 CONFERENCE

LEUVEN, BELGIUM
MAY 24-25, 2011

Book of Abstracts of Airborne Wind Energy Conference 2011

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AIRBORNE WIND ENERGY CONFERENCE 2011

BOOK OF ABSTRACTS

WELCOME !

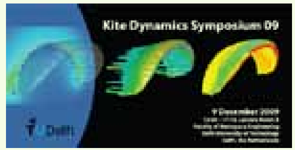
Welcome to Leuven, welcome to the Airborne Wind Energy Conference 2011 !

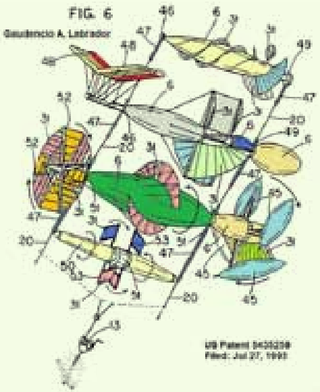
We are delighted and honoured to welcome you to the Airborne Wind Energy Conference 2011, in the historic city centre of Leuven. The AWEC 2011 is the 2nd in a series of annual conferences organized by the Airborne Wind Energy Consortium, after its start in 2010 in Stanford, California. This is the first time that the AWEC takes place in Europe. The conference is a joint effort of the company Ampyx Power, the Airborne Wind Energy Consortium and the Katholieke Universiteit Leuven (K.U. Leuven), and it is hosted in the Irish College in Leuven.

The Airborne Wind Energy (AWE) community is still young, but even before the 2010 Stanford conference had some history of international workshops. In recent years, for example, the *"International Workshop on Modelling and Optimization of Power Generating Kites 2007"* in Leuven, the *"High altitude wind power conference 2009"* in Chico or the *"Kite Dynamics Symposium 2009"* in Delft brought together increasing numbers of researchers. At all these and other meetings, many contacts, ideas and informal bonds emerged so that we can nowadays start to speak of a true research community on airborne wind energy.

The AWE industry is in a crucial year: after Fukushima, the world is more intensively than ever looking for alternatives to both fossil fuels and nuclear power, to avoid the different problems associated with them, and finally, solar and wind power are widely recognized as realistic alternatives. The fore-seeable boom in conventional wind power, which in contrast to airborne wind energy is a tested technology with well-known investment risks, will create a novel environment for AWE developers. On the one hand, economies of scale will make the competition with conventional wind power installations tougher and tougher every month; on the other hand, a growing overall market for wind power will also lead to more investment in research and development of niche products.

First International Workshop on
Modelling and Optimization of Power Generating Kites
(KITE-OPT 07)





AWE products might grow in one of these niches, with the potential to significantly extend the economical scope of wind power in particular off-shore and in remote locations. It is a good time to bring together at AWEC 2011, close the European capital, a critical mass of scientists, entrepreneurs, investors, and political actors, that are interested in shaping the future of airborne wind energy.

We hope that, in a joint effort of the program and organizing committees, we succeeded to put together all ingredients that are necessary for an exciting, interesting and inspiring conference.

The local organization would not have been possible without the support of our sponsors and supporting institutions. In particular, we acknowledge financial support by the European Research Council (ERC) via the project HIGHWIND, and by the Research Council of K.U. Leuven via its Optimization in Engineering Center OPTEC. We also thank our industrial sponsors DSM, EnerKite and EMCE. Thanks go to Autodesk & Ecogood for offsetting all emissions caused by this conference.

Many thanks go to a lot of members of K.U. Leuven's Optimization in Engineering Center (OPTEC) and of the Electrical and Mechanical Engineering Departments of K.U. Leuven for their tireless efforts, in particular to Quoc Tran Dinh (presentation hardware), Attila Kozma (preparations), Kurt Geebelen (city tour), Mario Zanon (photography). Special thanks go to the conference secretary, Jacqueline De bruyn, as well as the financial administrators, Elsy Vermoesen and John Vos, not least for the numerous hours they spent with answering many people's requests and special wishes, for handling the hotel reservations and for organizing the social events.

Finally, we would like to thank the keynote speakers for having accepted our invitations as well as the accepted talk and poster presenters for having made possible to compose a very promising high quality program, as we believe. Enjoy the conference and your time in Leuven and its surroundings!

On behalf of the organizing and program committees,

Moritz Diehl, Reinhart Paelinck and Richard Ruiterkamp

Ladies and Gentlemen,

On 28 September 2010, the German government adopted the Energy Concept for an environmentally sound, reliable and affordable energy supply. This is the first time that a long-term, cross-sectoral Energy Concept has been agreed on. With this Concept we have drawn up an overarching strategy which maps out Germany's path to the age of renewable energies. We want to cover our energy supply mainly with renewable energies, and we want to use energy as efficiently as possible. The Energy Concept also helps us to pursue our goal of significantly reducing greenhouse gas emissions in order to reach our climate protection targets and mitigate climate change.

By 2020, the share of renewables in final energy consumption is to reach 18 percent, and then gradually increase to 60 percent by 2050. A 35 percent renewables' share in electricity generation is planned by 2020, an 80 percent share in 2050.

Technical and technological progress is essential for the future. We want Germany to reinforce its lead in the competition to develop innovative concepts for renewable energies and energy efficiency.

Wind power is already contributing considerably to electricity generation in Germany. By the end of 2010, a total of 21,585 wind turbines with an installed capacity of 27,204 MW had been connected to the grid. Wind power accounts for the largest share of all renewable energies in the electricity sector. It covers around 6 percent of total electricity consumption and statistically provided electricity to more than 10 million average households. Apart from small niches, the three-blade wind turbine is the most commonly used design today.

KATHERINA REICHE
Parliamentary State Secretary
at the German Federal
Ministry for the Environment,
Nature Conservation
and Nuclear Safety

http://www.katherina-reiche.de

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

Wind power will continue contributing a major share to electricity supply in future as well. For this reason, the Federal Environment Ministry supports the expansion of offshore energy generation and the setting up of high-capacity onshore wind farms. Over the past years other approaches have also been developed.

Here, power generation using airborne systems such as kites seems interesting and promising. Studies from other countries have shown that this technology holds interesting potential. I therefore expressly welcome that experts have come together here in Leuven to study the possibilities of this technology.

So far, kite technology has mainly been researched outside Germany. In future, these systems will be tested in Germany as well.

I am looking forward to hearing about the results, also with a view to international comparison. I wish this conference every success and an active exchange of ideas and experience.

Ihre

Katherina Reiche

ORGANIZING COMMITTEE

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***Irish College Garden**, Photo Credits: Yonatan Vaizman*

AIRBORNE WIND ENERGY CONFERENCE 2011

PRESENTATIONS

The conference program consists of various presentation types, all of them plenary. This enables the participants to enjoy the work of all presenters. The nature of the reviewed abstracts allowed us to make a distinction between so called “project”- and “technical“ presentations, as well as poster sessions for the really technical topics.

During the two days you will be able to attend:

- 5 keynotes of 40 minutes duration,
- 9 technical presentations of 20 minutes,
- 14 project presentations of 10 minutes,
- 2 poster sessions with 14 contributions.

POSTERS

All posters will undergo a close examination by the “best poster”-award jury, so the hard work of students/designers will not be unnoticed! The jury consists of Alexander Bormann, Corwin Hardham, Mario Milanese, and David North.
The poster sessions do not only provide a communication platform to the poster presenters, but also create a moment of extensive networking.

NETWORKING

Other possibilities for exchanging ideas with fellow conference attendees include taking part in the city tour and welcome reception in Leuven’s town hall on the evening before the conference, the conference dinner in the 14th century buildings of K.U. Leuven’s Faculty Club on May 24, and the coffee and lunch breaks.
For your convenience we have published a list of participants at the end of this book of abstracts, together with the contact info for each person.

AIRBORNE WIND ENERGY CONFERENCE 2011

MAY 24

09:00	**REGISTRATION** + Welcome Coffee		
09:50	Welcome Words		
10:00	KEYNOTE **Wubbo Ockels**	**High Altitude Wind Power, from the Early Days until Today**	**p. 13**
10:50	Mario Milanese	Kitenergy Technology for Offshore Wind Plants	p. 15
11:15	Coffee		
11:35	Corey Houle	SwissKitePower - Novel Wind Energy Extraction Technology	p. 16
11:50	Rolf Luchsinger	Towards the Design of Twings	p. 17
12:05	Tiago Pardal	Omnidea's System for HAWE	p. 18
12:20	Alain Goubau	LTA Wind Turbines in Military Markets	p. 19
12:35	Sandwich Lunch		
13:30	KEYNOTE **Stephan Brabeck**	**SkySails – Ship Propulsion by Automated Towing Kites**	**p. 21**
14:20	Simon Bolten	Windward Energy at TU Munich *(copresenters: Patrick J. Lauffs, Michael Schölkopf)*	p. 22
14:45	Aart De Wachter	Current Development Status of the Laddermill Kite Power System	p. 23
15:00	Poster Introductions		
15:20	Poster Session **1**	(+ Coffee)	p. 11
16:00	KEYNOTE **Christian Egenhofer**	**EU Innovation Policy**	**p. 33**
16:50	Moritz Diehl	HighWind : Simulation, Optimization and Control	p. 34
17:05	Damien Reardon	Potential for Airborne Wind Power in Australia - Baseload ?	p. 35
17:20	Guido Lütsch	How HAWP will Participate at the Markets for Emission Reduction	p. 36
17:35	Carlo Perassi	Three Years of Wind Operations Worldwide Financing	p. 37
17:50	Hans Gründel	Assystem Airborne Wind Turbine	p. 38
18:05	Dave Santos	Toward Gigawatt-scale Kite Energy	p. 39
18:25	Closing Remarks of the Day		
19:00	**Gala Dinner at Faculty Club**		

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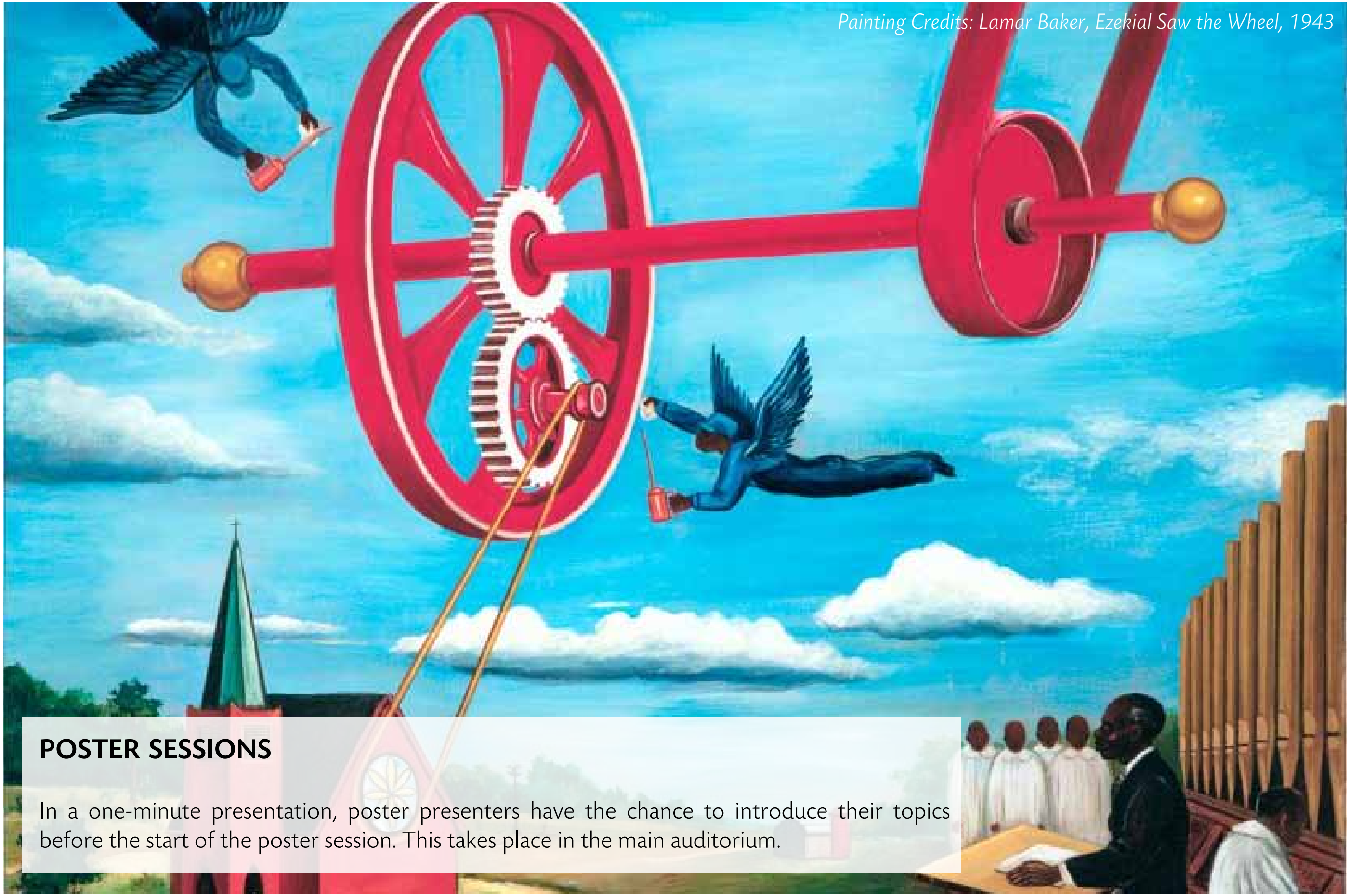
MAY 25

08:50	**Welcome Words, day 2**		
09:00	KEYNOTE **Corwin Hardham**	**Advances in Crosswind Power Generation**	**p. 41**
09:50	Alexander Bormann	Enerkite – Wind Energy Redefined	p. 42
10:15	Sören Sieberling	Rotating Platform for Takeoff and Landing of a Tethered Aircraft	p. 43
10:40	Coffee		
11:05	David Olinger	Airborne Wind Energy Research at Worcester Polytechnic Institute	p. 44
11:30	Pauli Rautakorpi	Stable Lying-Eight Orbits for Kites	p. 45
11:45	Roland Schmehl	Modeling and Simulation of Kite Power Systems	p. 46
12:00	Uwe Fechner	Performance Factors of HAWP in Pumping Operation	p. 47
12:25	Henry Hallam	Challenges in GPS Receiver Design for Airborne Wind Turbine Guidance	p. 48
12:40	Lunch Buffet		
13:30	KEYNOTE **David North**	**Airborne Wind Energy Technology and Regulatory Gaps: a NASA Perspective**	**p. 51**
14:20	Joseph Coleman	Dynamic Analysis, Simulation and Design of Winch for AWE	p. 52
14:45	Bruce Weddendorf	Development of the Sky Windpower Flying Electric Generator	p. 53
15:10	Poster Introductions		
15:25	Poster Session **2**	(+ Coffee)	p. 11
16:15	Udo Zillmann	Do You Want to Invest in Flying Windmills? Challenges and Perspectives	p. 61
16:40	**Panel Discussion**	What are the Next Milestones for Airborne Wind Energy?	
17:30	**Closing Remarks + Poster Award Ceremony**		
17:45	**Goodbye Coffee**	**(+ Sandwiches for the Hungry Travellers)**	



Painting Credits: Lamar Baker, Ezekial Saw the Wheel, 1943

POSTER SESSIONS

In a one-minute presentation, poster presenters have the chance to introduce their topics before the start of the poster session. This takes place in the main auditorium.

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POSTER SESSION 1

MAY 24

POSTER SESSION 2

MAY 25

WUBBO OCKELS

Prof. Dr. Wubbo Johannes Ockels is a Dutch physicist and a former ESA astronaut. In 1985 he participated in a flight on a space shuttle, making him the first Dutch citizen in space. He currently is a professor at the Institute for Applied Sustainable Science, Engineering and Technology at the faculty for Aerospace Engineering, Delft University of Technology and the driving force behind the "Laddermill", among a variety of other projects.

Wubbo Ockels was born March 28, 1946, and obtained his MSc degree in 1973 and subsequently a PhD degree in physics and mathematics in 1978 from the University of Groningen. His thesis was based on experimental work at the Nuclear-physics Accelerator Institute (KVI) in Groningen.

Photo Credits: T.U.Delft Kitepower

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Delft University of Technology

HIGH ALTITUDE WIND POWER, FROM THE EARLY DAYS UNTIL TODAY

W. Ockels, *ASSET Institute, TU Delft*

The TU Delft Institute for Applied Sustainable Science, Engineering and Technology, ASSET, has started in 2004 various developments in the field of kite power, focusing on the so-called "laddermill". In this concept, a ground-based electric generator is driven by kites that are attached to a vertical cable loop. The kites pull with a strong force while rolling outbound (ascending) and a low force while coming back (descending). The institute has developed a firm position in the global R&D landscape consisting of some 40 research and development groups.
The use of kites for electrical power production has been receiving a growing attention because of the urgent need to reduce CO2 emissions and because of the abundant wind energy available at higher altitudes. Its potential is significant, as well as in cost (lower than coal plants) and flexibility (developing countries). The wind availability at altitude was studied based on 20 years measurements. Higher altitudes (above 500m) are favourable for power, frequency and stability (laminar flow).
Several methods are studied nowadays to exploit the high altitude wind. A fundamental difference is the location of the generator, namely on ground or airborne. Advantages and disadvantages are discussed. The effect of a kite can be drastically improved through crosswind. The motion perpendicular to the wind increases the power which can be described as a virtual increase of surface. The drawback is a lower effective lift over drag, thus resulting in a lower elevation.
Fundamental questions arise related to the advantages of high altitude versus crosswind and other drawbacks of larger systems. The "spider" system is discussed, a combination of the laddermill and a two kites system. Of particular interest is insight in cost of kite surface versus maximum and cumulative load. Certainly, a large diversity of kite systems is required in this phase of pioneering. The application for propelling a ship is also considered, including upwind sailing. In this case, the ground station is not stationary, but its motion results in a higher apparent wind speed for the kite, while the horizontal component of the kite adds to the ships drag.


Photo Credits: Christian Steiness

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KITENERGY TECHNOLOGY FOR OFFSHORE WIND PLANTS

M. Milanese, *Kitenergy srl*
L. Fagiano, *Politecnico di Torino/UC Santa Barbara*
I. Gerlero, *Modelway srl*

The talk presents an investigation of the offshore application of the AWE technology under developement by Kitenergy, which exploits the automatic flight of tethered airfoils (e.g. power kites) to extract energy from wind flows blowing between 200 and 800 meters above the sea.

The key points of such a technology are described and the related operational parameters are optimized in order to maximize the generated power while satisfying constraints on the maximal loads exerted on the offshore support structure. The obtained results indicate that Kitenergy technology could bring forth significant advantages with respect to the actual wind turbine technology. In particular, the structural loads exerted on the offshore platform is 4-5 times less than that of a wind turbine of the same rated power and the capacity factor is 2 times higher. Thus, for a given cost of the support structure (fixed foundation, floating platform,..), Kitenergy technology can give 8-10 higher energy production with respect to wind turbines, reducing significantly the present offshore wind energy production costs.

SwissKitePower – novel wind energy extraction technology

C. Houle, *Fachhochschule Nordwestschweiz FHNW*

SwissKitePower is a collaborative research and development project being conducted by three Swiss technical institutes and Alstom Switzerland AG. With a recently awarded federal grant from the Competency Center for Energy and Mobility, the project aims to develop a vision of what a kite power plant will look like, how it will function and what markets it will serve. The long term goal of the project is to set the stage for the installation of a pilot plant within Switzerland which will demonstrate the functionality and long term reliability of the technology.

The roles of the project partners will be briefly presented, but the talk will focus on the kite test bench which is currently under development at FHNW. This system has been designed and constructed through a series of student projects over the past two years. Apart from serving as a useful tool for airborne wind energy research, its didactic value has also been noteworthy. An overview of the system as well as preliminary test and simulation results will be presented.

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EMPA
Materials Science & Technology

TOWARDS THE DESIGN OF TWINGS

R.H. Luchsinger, *EMPA*

The Center for Synergetic Structures at Empa focuses on the development of twings (tethered wings) dedicated to airborne wing energy applications. We are convinced that the ideal airfoil for this application is a synergetic combination of the surf kite and the sailplane. Key features are a reasonable aerodynamic efficiency and minimal weight, while resilience under crash is a major asset at least in the development phase.

Our approach is to use Tensairity for the load bearing structure of the twing. Combining an inflated structure with cables and struts, Tensairity integrates the materials of the flexible and rigid wing on the structural level. Our first prototypes with up to 8m span demonstrate the potential of Tensairity in kite design.

Currently, the aerodynamic efficiency of various wing shapes is studied by means of vortex lattice method simulations. Furthermore, a set up for instrumented towing tests is developed and the production process is investigated. Once airborne, our twings will produce electrical power within the SwissKitePower collaboration. The presentation will give an overview of our work in progress.

OMNIDEA'S SYSTEM FOR AIRBORNE WIND ENERGY

T. Pardal, R. Fernandes, P. Silva
Omnidea

Omnidea has been engaged in R&D to harness clean and renewable energy from high altitude wind and has already been granted patents in this field. This proprietary technology under investigation consists of a lift generating airborne module that is anchored to a ground station by a tether cable, operating in a two phase cycle. During the power production phase the airborne module generates lift, pulling up on the tether cable which, at the ground station, drives for instance a flywheel connected between a winch and an alternator to produce electricity. When the tether cable is unwound, the recovery phase starts and the cable is reeled back to its initial position decoupled from the flywheel, completing a cycle.

The paper describes the airborne group and the reeler as well as the process of tensioning and unwinding the cable. The R&D covers a multitude of technological fields such as materials, aerodynamics and control required for the development of a wind power system capable of harnessing the energy potential of high altitude wind without the need for heavy towers or expensive elevated nacelles. A significant advantage is that the proposed system can easily be deployed offshore in either shallow or deep water.

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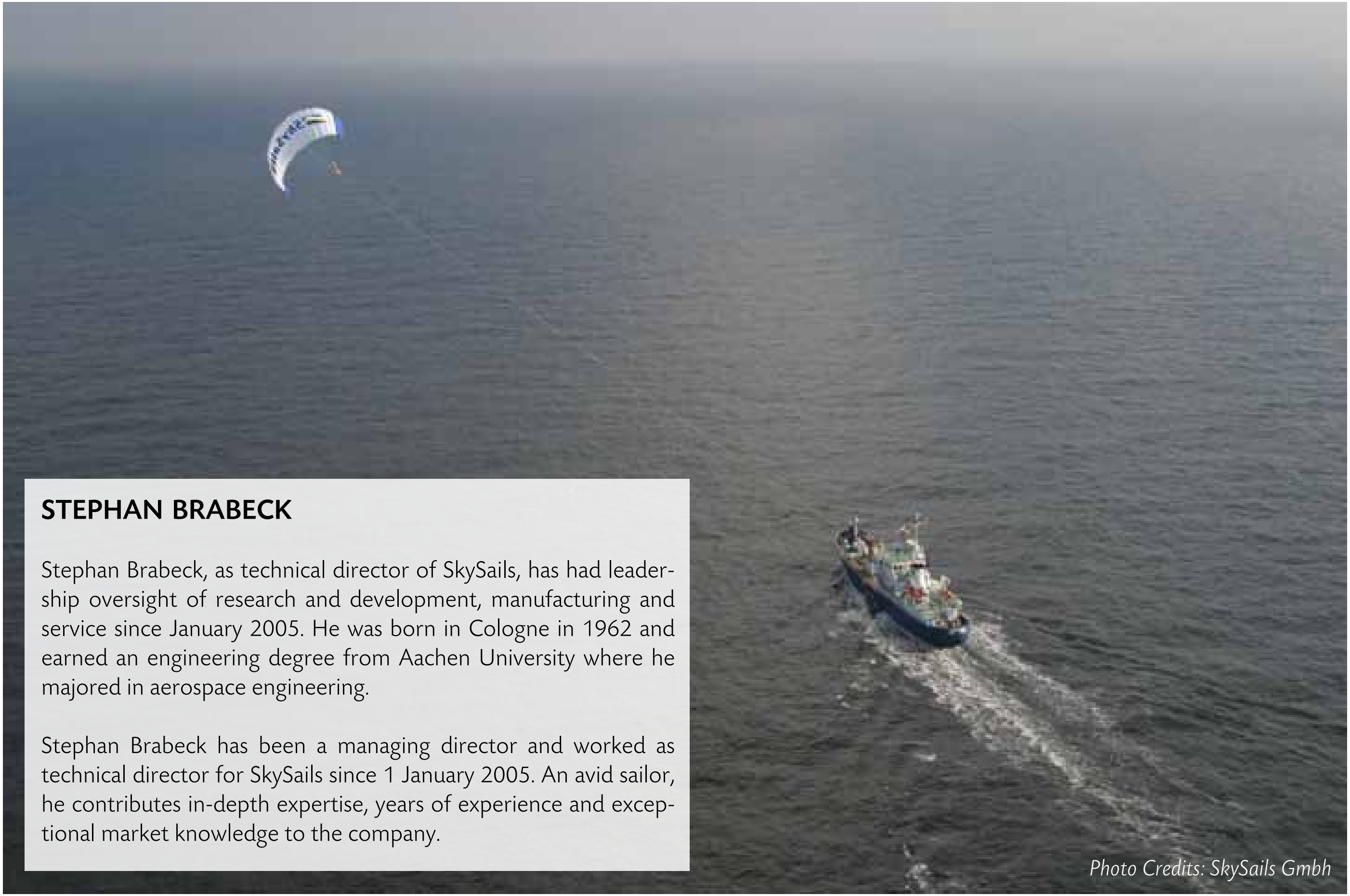
LIGHTER-THAN-AIR AIRBORNE WIND TURBINES IN THE MILITARY MARKET

Ben Glass, Adam Rein, Alain Goubau
Altaeros Energies

Altaeros Energies is developing an airborne wind turbine based on lighter-than-air technology. The Altaeros 100 kW turbine is targeted at displacing diesel consumption on remote sites – namely isolated communities, island nations, mining and logging sites, and military bases. Any military solution must be mobile, durable, autonomous, and have no impact on the mission at hand.

The Altaeros turbine is designed to meet these requirements. In order to provide lift, the system uses a buoyant shroud initially deflated for transport. Components such as nacelle and blades are integrated into the shroud after its initial inflation. The base station winches and tethers are also constructed to be portable. This solution allows remote sites to relatively quickly take advantage of high altitude wind resources and avoids the complicated logistics and installation requirements of other ground-based renewable energy technologies.

The solution also leverages existing helium distribution networks and operational know-how inherent to the military as it operates and services the aerostats already deployed in combat zones for surveillance and communication applications.



STEPHAN BRABECK

Stephan Brabeck, as technical director of SkySails, has had leadership oversight of research and development, manufacturing and service since January 2005. He was born in Cologne in 1962 and earned an engineering degree from Aachen University where he majored in aerospace engineering.

Stephan Brabeck has been a managing director and worked as technical director for SkySails since 1 January 2005. An avid sailor, he contributes in-depth expertise, years of experience and exceptional market knowledge to the company.

Photo Credits: SkySails Gmbh

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SkySails - Ship Propulsion by Automated Towing Kites

S. Brabeck, *SkySails GmbH & Co. KG*

SkySails is developing, producing and selling an internationally patented wind propulsion system for cargo ships based on large, automated towing kites. The latest SkySails product generation with a kite area of approximately 320m² has a maximal propulsion power of more than 2 MW. The system can be installed as auxiliary wind propulsion on a major part of the existing ships as well as on newbuildings.

The SkySails system consists of three main components: A towing kite with rope (flying system), a launch and recovery system, and a control system for automatic operation.

The SkySails wind propulsion system has been long-term tested on board cargo ships during regular shipping operations for the past three years. All insights, operational experiences and results gained throughout this long-term testing phase were fed simultaneously into the SkySails product development effort, thus continuously enhancing the technology.

Stephan Brabeck *(Technical Director SkySails GmbH & Co. KG)* will present the SkySails towing kite technology and speak in depth about the operational experiences on board of cargo ships.

AIRBORNE WIND ENERGY AT THE TECHNICAL UNIVERSITY MUNICH

Michael Schölkopf, Simon Bolten, Patrick J. Lauffs
T.U.Munich, Windward Energy

The team of Windward Energy, located at TU Munich, is working on high altitude wind energy since 2009. It has developed and tested small-scale prototypes of kite steering units, as well as a ground station for kite-pumping.
The team consists of two engineering students (Aerospace & Product Development) and one student of economics (Technology and Management oriented). All three are graduates from the scholarship 'Manage&More' from the Center for Innovation and Business Creation at TU Munich.

The thesis of Michael Schölkopf, that will be presented, deals with the conception of a ground station for a 1 MW Kite wind power plant. A comparison of possible mechanical components, like generators, energy storage and gearing, for fulfilling the needed functions are in the focus. Furthermore an estimation is given about development, investment and operation costs to derive the total costs for electricity and make a prediction about the cost-effectiveness of such a system.

The steering unit that will be presented by Patrick J. Lauffs offers the ability to control the steering lines, as well as to change the angle of attack. It is designed to be manually controlled from the ground station, but also offers the possibility to run closed loop control algorithms based on the states of flight. The current development focuses on optimizing weight and maneuverability in addition to the implementation of automatic control.

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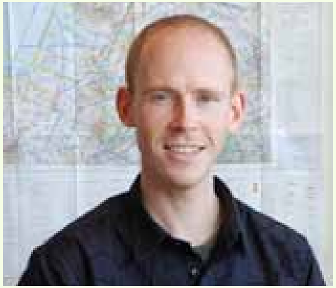

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CURRENT DEVELOPMENT STATUS OF THE LADDERMILL KITE POWER SYSTEM

A. de Wachter, *Delft University of Technology*

Since AWEC 2010 the laddermill kite power system of TU Delft received some major improvements and changes. This presentation aims to show what has improved and how this affected the performance of the system.

The ground station has gone through extensive testing to determine the losses of both mechanical and electrical components. This has resulted in the replacement of certain components.
The kite control units have been replaced with more reliable and advanced units. The hardware and software architecture makes the implementation of autopilot control possible. Different autopilot systems are currently under development.
In September 2010 the second generation purpose developed kite for the Laddermill was delivered. Special attention in this model was paid to reinforcement of critical areas. Further development of the bridle lines of this kite was done by TU Delft researchers. This lead to a significant increase of the load bearing capability and depower capability of the kite.
These performance improving changes resulted in a big performance improvement of the Laddermill system between September 2010 and May 2011.

UNMANNED POWER AIRSHIP FOR AIRBORNE WIND ENERGY GENERATION AND GROUND DISTRIBUTION

Ndilokelwa F. Luis[1], Alexandra A. Gomes[1], Paulo A. Cardoso[2],
[1]Instituto Superior Tecnico, Portugal, [2]Alva Alta, Lda., Portugal

In this work we present the first results for the preliminary design of an unmanned power airship (UPA) to carry out a given mission of airborne wind energy generation and ground distribution. The proposed approach pursues the maximization of the cost effectiveness of the mission with design variables involving structures, aerodynamics and trajectory.

We consider an untethered airship basically consisting of two vertical-axis wind turbines, disposed between two torus shaped envelopes enclosing a lighter than air fluid. The energy generated while airborne is distributed to a respective energy conversion system installed at at least one stationary location within a given region, and a remanding amount is used to fly the airship.
The first results point to the viability of the proposed concept.

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KATHOLIEKE UNIVERSITEIT LEUVEN

REVERSED PUMPING FOR TETHERED AIRPLANES IN NO-WIND CONDITIONS

Joris Gillis, Jan Goos

K.U. Leuven

The main advantage of kite-based wind-technology is that they can reach higher altitudes, where the wind is stronger, and more consistent. Obviously, the kite has to go through the lower atmosphere to get there, and it may be possible that there is little or no wind in this region. Reversed pumping makes it possible to inject the kite into a power harvesting orbit without any on-board propulsion. Also, even if there is not enough wind to produce power, it can be more interesting to keep the kite flying than to land it en re-deploy it later.

The Leuven Kite Power tethered airplane was therefore outfitted with a winch system. Power can be added by varying the cable length at key moments. This leads to a two-phased cycle: the tether is lengthened when the cable tension is low, and pulled in whenever the cable tension is high. The winch acts as a motor here. In effect, we use the pumping scheme from lift-mode kite systems, but applied in reverse mode.

We show optimal control calculations for periodic orbits that use reversed pumping to stay in the air during no-wind conditions and simultaneoulsy minimize energy losses.

INVESTIGATION OF VARIOUS TURBULENCE MODELS ACCURACY IN CFD SIMULATION OF VERTICAL AXIS WIND TURBINES

P. Fard, M. Layeghi, A. Foruzandeh, A. Borujerdi,
Energy Department, Materials and Energy Research Center, Karaj, Tehran

Computational Fluid Dynamics can be defined as the analysis of systems involving fluid flow, heat transfer and associated phenomena such as chemical reactions by computer based simulation. Using this technique became popular since the 1980's in the wind turbine industry to save a significant amount of time and money which was required for wind tunnel test. In practice, the assumptions made regarding the modeling of the turbulent component of engineering flows have proved to be a major source of error in wind engineering simulations. These fundamental errors are one of the main reasons why computational fluid dynamics techniques have not yet been fully accepted by the wind engineering community.

In this research, the authors have detailed and tested some of the most widespread techniques and compared their accuracy and shortcomings in computational wind engineering. In this respect standard, RNG and realizable k-model, k-, Spalart-Allmaras and Reynolds stress model have been taken into account for simulation of a vertical axis wind turbine performance.

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POSSIBILITY AND UTILIZATION OF FEG IN THE COUNTRY IRAN + ONE TECHNOLOGICAL APPROACH

A. Hodjat, Sharif University of Technology

Iran, with a large overall amount of high altitude wind energy for at least half of the year is a good candidate for utilizing FEG. For installing the FEGs over Iran, we had to find, places with a safe aerial space which grant us reliable spots. To find these places one has to disregard aerial corridors, and other noted areas from all overhead space of the country in a full 3D map.

Overlap of seasonal data of optimized level and safe area show us the places that are appropriate to fly FEGs over. Next population density (like cities) and land features and high voltage transmission cable route for the desired spots was studied. Then by overlapping these series of data, first we found places over country that are safe and second, found the predicted produced energy during the year according to the skywindpower FEG capacity. This procedure has the potential to be a guideline for any other country.

In addition, a method is studied as a technological approach, combined of two available systems of Skywindpower and Magenn. This method will solve complexity problem of FEG design and is achieved by simpler technology.

TAKE-OFF AND LANDING OF BALANCED KITES

R. Paelinck, *K.U. Leuven*

Using two kites rotating around each other while connected to a Y-shaped tether has a number of advantages over using only a single kite. First, overall drag is reduced significantly because only the end parts of the tethers move fast in crosswind direction.
Second, the configuration counterbalances the centripetal forces that are induced by flying curves. This counterbalancing also acts as a major advantage in the retraction phase of the pumping generation approach, where both kites pull against each other and not in the direction of the main tether.

In order to validate this method, techniques for automatically launching and landing the two-kite system are developed and applied in conceptual ground station designs.
The final small-scale balanced kite ground station, currently in development, will also be capable of launching and landing single kite systems, so control strategies can be verified.

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PERFORMANCE AND STABILITY OF INFLATABLE TUBE KITES

R. van der Vlugt, *Delft University of Technology*

The performance of a kite power system depends for a large part on the performance of the kite. In a pumping system the glide ratio, the maximum allowable wing loading and the ability to power and depower can significantly affect the average input power to the generator.

Development work focused on increasing the maximum load and the depower ability of the Laddermill kite. A major part of the development work was done on the bridle system of the kite. This work showed the importance of a correct and well-balanced bridle. The bridle improvements resulted in a steady increase of depower and maximum load of the kite and increase of the average cycle power of the Laddermill system.

A steady power input to the generator is important to reduce the generator size for a given average power. Test results show that a large part of the power fluctuations are due to the vertical motion of the kite. This indicates the importance of limiting the kite mass.
Results from the kite-specific research will be presented.

Trajectory exploration for tethered planes

M. Zanon, *K.U. Leuven*

Although kite-based wind power generation shows a high potential, there is still a number of issues that must be coped with to ensure a future to this technology.

Planning an optimal operation of the plant and controlling it is one of those issues. One very delicate phase is the starting phase, as wind may be much slower on the ground than in higher altitudes and the plane is more likely to crash as the ground restricts the set of feasible motions: MPC appears as the natural choice for controlling the plant.

In this context the flight simulator is not only a tool to validate plane models; it also gives the possibility to run several virtual experiments, especially for long trajectories for which the optimization problem could be difficult to formulate and solve.

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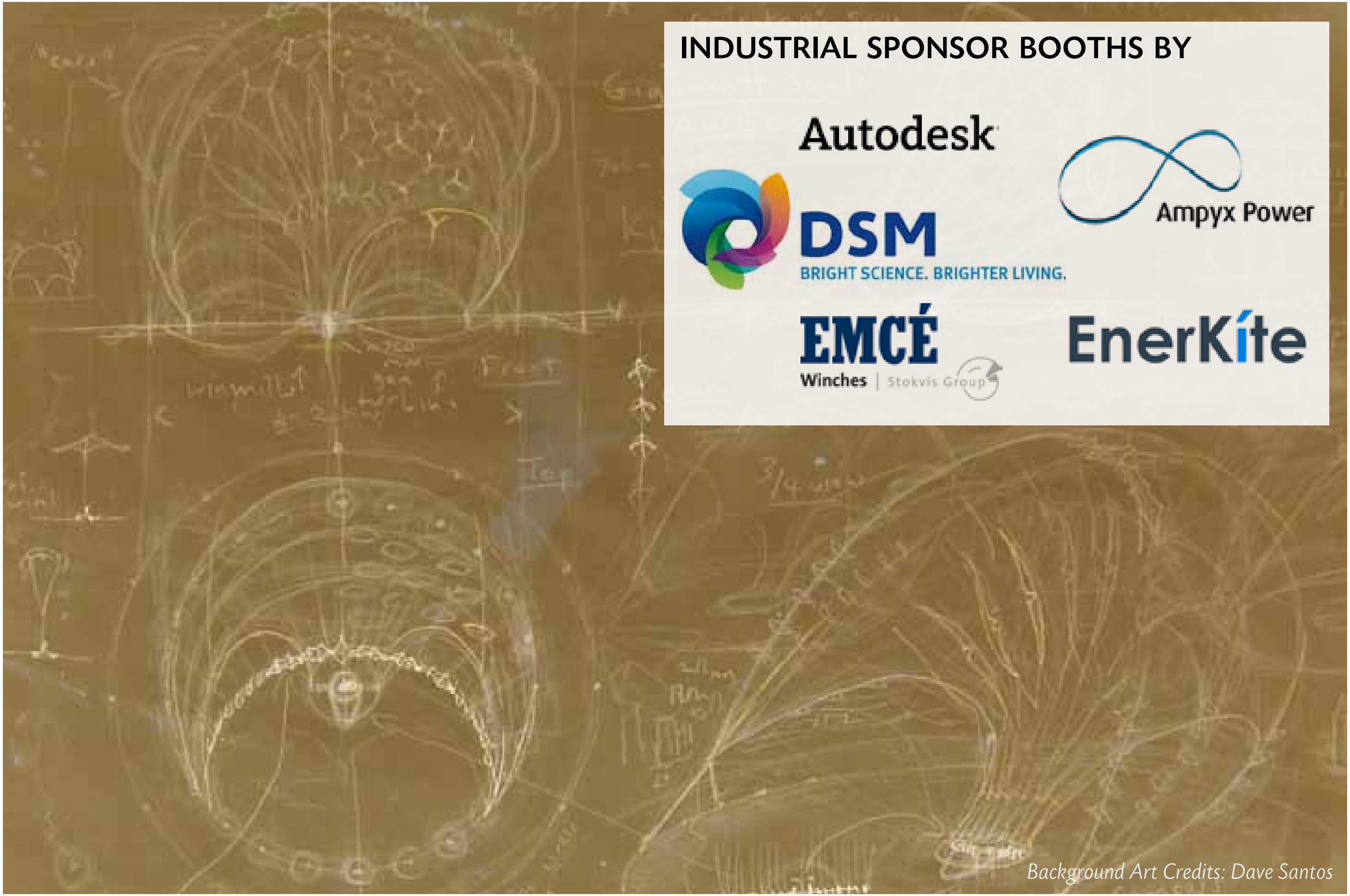

Background Art Credits: Dave Santos

CHRISTIAN EGENHOFER

Christian Egenhofer (DE) is a Senior Fellow at the Centre for European Policy Studies (CEPS), a Brussels-based think tank specialising in EU affairs, where he is head of the Energy, Climate and Environment Programme.

He is also a Senior Research Fellow and Jean-Monnet Lecturer at the Centre for Energy, Petroleum and Mineral Law and Policy at the University of Dundee in Scotland/UK (since 1999). In addition to the University of Dundee, Christian Egenhofer teaches a number of courses on “EU integration” and “energy and climate change” at the College of Europe both in Bruges and Natolin, the Solvay Business School MBA Programme of the Université Libre de Bruxelles and the LUISS University in Rome.

Christian Egenhofer is Director of IMPACT – European Bureau for Consulting and Analysis, a Brussels-based political consultancy.

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EU INNOVATION POLICY

C. Egenhofer, *Centre for European Policy Studies*

Early approaches and policies of 'green growth' in the EU and member states focused on internalisation of external costs and environmental tax reform. These approaches have been developed further over the last two decades, thereby highlighting the potential benefits of sustainability for innovation. Formally, the 'green growth/competitiveness' paradigm has been introduced at EU level as central element of the EU's economic growth strategy in the 2000 Lisbon Economic Reform Agenda. It has also been one of the three justifications of the 2007/08 Climate and Energy Package whereby the EU agreed on targets for greenhouse gas reduction, renewables and energy efficiency. The 'EU 2020 Strategy', the mission statement of the current Barroso II Commission has identified 'sustainable growth' as one its three pillars.

As a result the current innovation policy is being re-formulated. EU R&D support, for long the central plank of EU innovation policy, is being complemented in the form of the Strategic Energy Technology Plan by an additional focus on demonstration and early deployment to overcome barriers of the technology death risk. The presentation will outline EU innovation policy and its different priorities before explaining in more detail the various instruments that the EU applies now or in the future to support immediate deployment of low-carbon technologies.

HIGHWIND : SIMULATION, OPTIMIZATION AND CONTROL

M. Diehl, *K.U. Leuven*

The ERC project "HIGHWIND – Simulation, Optimization and Control of High Altitude Wind Power Generators" at K.U. Leuven runs from 2011-2016. Its aim is to guide the development of the emerging technology from the modeling, optimization, and control side and to do only small scale experiments. Specifically, we develop and use ultra-fast embedded optimization for automatic control and state estimation, and we optimize and test intrinsically stable orbits (attractors) that alleviate the control tasks.

The hardware focus is on rigid wings, pumping power generation, and a novel way for automatic start and landing based on a rotation base, that as a by product allows indoors testing of our embedded control systems. Final aim is the automatic flight and startup of two balanced power planes, and the production of open-source software for the simulation, optimization and control issues of high altitude wind power.
The talk presents joint work with Jan Swevers, Dirk Vandepitte, Boris Houska, Reinhart Paelinck, Milan Vukov, Kurt Geebelen, Joris Gillis, and Mario Zanon.

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POTENTIAL FOR AIRBORNE WIND POWER IN AUSTRALIA – BASELOAD?

Damien Reardon[1], Igor Skryabin[2], Alex Radchik[3]
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This presentation provides an outline of the Australian energy market, a perspective on AWE technology/project developer opportunities, and touches on the significant potential for low emission, hybridized fully dispatchable AWE baseload plant. Using financial mathematics in relation to OTC swaps and exchange traded derivatives, we illustrate patented techniques whereby PPA writers and financial intermediaries can efficiently value such entities.

Australia has some of the most attractive, close-to-load wind resources, and is the highest per capita greenhouse gas emitter in the world. Historically, it has benefitted from very low generation costs thanks to a rich endowment of fossil fuel resources and low population.

These costs are set to spiral, partly as a result of under investment, but predominantly due to escalating fossil fuel prices and carbon price uncertainty. Australia also has a relative abundance of both large and small scale off-grid load situated away from population centers and flight paths, and as such deserves special attention in this phase of AWE development.

HOW HIGH ALTITUDE WIND POWER PLANTS WILL PARTICIPATE AT THE MARKETS FOR EMISSION REDUCTION

G. Lütsch, *NTS Energie- und Transportsysteme GmbH*

With the Kyoto Protocol for the first time in history politicians committed themselves to binding goals regarding the reduction of CO_2.

The protocol installed three instruments:

- Emission trading
- Joint Implementation
- Clean Development Mechanism (CDM)

Besides the "Controlled market" exists a Voluntary Market for Emission Reduction. On both markets emission reduction can be traded.

The current model expired at 2012, after which the CO_2-Emission Rights will be auctioned. Leading experts expect a value between 20 – 80 Euro/t by 2020!
The presentation shows how high altitude wind power plants can participate on the Markets for Emission Reduction.

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THREE YEARS OF WOW SpA.

Carlo Perassi, *WOW SpA.*

As far as we know, WOW SpA was the first worldwide and it's still the only financial holding founded by small investors to support the emerging airborne wind energy industry.

This short presentation is going to take place on the third anniversary of our foundation and it describes how we operate, the kind of projects we are funding and a few predictions about our future, leaving the last part of the talk for questions and answers.

Assystem airborne wind turbine

B. Lau , M. Paerschke, O. Stoller, H. Gründel, *Assystem GmbH*

Assystem, one of the large engineering service companies, introduces here its second generation Airborne Wind Turbine (AWT). While the first one was a lighter-than-air solution, this one will be a hybrid Helium/wing lifted turbine containing 2 counter-rotating rotors. Both onshore and offshore operation is possible.
The rotor characteristics are adapted to the power transmission sky-to-ground. It is designed as a key component of the AWT to reach the Ekman layer.
Power generation is grounded to minimize flight weight, even when using composite materials for most of the flying parts.
Up to now concept studies exists for the relevant features of the AWT. This contains extensive CFD-calculations for various flight conditions to optimize the wing profile of the casing. FEA calculations are carried out to minimize the weight with regards to stress peaks.
Elements for active flight control are integrated to avoid tumbling and to produce lift in times of low wind speed. In addition, two Helium balloons can be unfolding in case of uncontrolled flight conditions.
Plans are to bring to air the new demonstrator until the end of the year. The development is supported by the Assystem Berlin CFD, FEA and CAD competence.

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TOWARD GIGAWATT-SCALE KITE ENERGY

D. Santos, *KiteLab Ilwaco*

Kite stacks, trains & arches are dense-array models for aggregated capacity with enhanced safety & reliability. Testing these methods led KiteLab Group to an Airborne Latticework concept validated in numerous scale-prototype experiments.

Dense-arrays mitigated cubic-mass scaling penalty, boosted stream-tube efficiency & maximized energy extraction by volume, with reduced surface sprawl & integrated control. "Minimal-mass-aloft" by ground-based actuation and avionics favored high-altitude operation, persistence in calm, and inherent stability.
Persistent flight was shown by phased radial tugs or towing. Launching and landing succeeded by self-cascaded sequences. High L/D kiteplanes and turbines resisted mishap flown semi-captive in arrays. Self-oscillating power wingmills on ganglines & halyards "fired" in passive synchrony; a means to drive the largest generators.
Hotswapping, depowering, and "killing" elements was shown. Arrays were assembled mid-air & towed into place.

No critical barrier seems to prevent scale-up of kite energy, even legacy power plants retrofitted as kite hybrids. Aviation regulations offer a basis for large automated operations supervised by a Pilot-In-Control and Visual Observer, rotated in watches. Utility airborne energy in 2025 will involve Super-Density Operations (SDO) in NextGen Airspace.

CORWIN HARDHAM

Corwin Hardham, Ph.D, CEO and CTO of Makani Power is a mechanical engineer with a focus in controls as applied to renewable energy systems. He holds several patents within these areas.

Corwin completed his doctorate at Stanford University developing active hydraulic platforms to improve gravitational-wave detection. His appreciation for design stems from a history of evolving equipment for competition in windsurfing and kiteboarding. Corwin has co-founded several companies, including Squid-labs, Potenco, Wakekite and Makani.

Photo Credits: Makani Power

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Advances in crosswind power generation

C. Hardham, *Makani Power, Inc.*

Recent years have seen significant advances in crosswind power generation. Several teams have demonstrated autonomous flight and power generation. With these accomplishments, the Airborne Wind Turbine is transitioning into the early stages of commercialization. Teams will now focus on scaling up the technology and addressing reliability. Additionally, there are regulatory and market risks that must be addressed with careful analysis ahead of technical demonstrations.

As a global community, the airborne wind energy industry must develop the sophistication and rigor seen in the broader energy industry to develop products that can be deployed at large scale.

EnerKite - wind energy redefined

Alexander Bormann, Christian Gebhard, Bernhard Kämpf, Peter Knauer, Stefan Skutnik,
EnerKite GmbH

Most of today's wind turbines supply their rated output less than a quarter of time. EnerKites will deliver rated power onshore and offshore at least fifty percent of the time.

The presentation will introduce the EnerKite company, its concepts and products towards the next generation of wind power plants. Founded on 20 years of experience and excellence in the field of wind energy, flight mechanics and control as well as kite technology and automation a mobile 30 kW prototype plant is under development. Particular test rigs are developed in order to derive feasible and sustainable solutions.

With one million load cycles and more the lines of YoYo- and ground actuated systems suffer from significant fatigue. The EnerKite rope test rig allows to perform highly dynamic and frequent bending and tension tests. The results are determining the rope, drum and sheave design. By means of windtunnel tests the properties of ropes and air-foils are investigated and optimized.

Using rapid prototyping and newest design methods the EnerKite Experimental Power Plant will be accomplished and operated in the very near future.
This allows to demonstrate and further develop the prototype of the EnerKite Control Unit and the first generation of EnerKites - reinforced and optimized for stronger loads, energy production and automated flights.

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DISCUSSION OF A ROTATING PLATFORM FOR TAKEOFF AND LANDING OF A TETHERED AIRCRAFT

S. Sieberling, R. Ruiterkamp, R. de Bie, E. Bontekoe,
Ampyx Power

Takeoff and landing of a tethered aircraft poses an interesting challenge when requiring fully autonomous operation and turnaround. A solution in the form of a rotating platform is presented. The rotating platform consists of a rotating base and an arm carrying the aircraft at its tip. By spinning up the rotating platform airspeed is induced to the point that the aircraft can provide sufficient lift.

After takeoff the tether is slowly reeled out resulting in a steady circular climb. Landing is performed by reversing this process. The characteristics of using the rotating platform for takeoff and landing are discussed including basic feasibility considerations.

High g-loads and limitations in range (with respect to tether length) turn out to be primarily limiting for smaller scale systems. Small scale flight tests have furthermore indicated that stability of the tethered aircraft is not trivial, especially in outdoor environments. From a simulation and control perspective this reduces the margins for modeling uncertainties, requiring extra attention to modeling of the system.

AIRBORNE WIND ENERGY RESEARCH AT WORCESTER POLYTECHNIC INSTITUTE

D. J. Olinger, I. Hussein, G. Tryggvason,
WPI

The UPWIND Energy Research Group at Worcester Polytechnic Institute (WPI) has been studying airborne wind energy (AWE) systems since 2007. Our work has focused on ground-tethered systems with ground-based power generation. We will summarize our efforts to design, construct, and test a working full-scale AWE demonstrator. In addition, we will review lessons learned, and show how the student work fits into an academic curriculum while preparing students for careers in renewable energy.

Our modeling work, on both rocking-arm and spooling line systems, will be briefly summarized. We introduce a dynamic model for the ground-tethered kite that fully incorporates the kite's pitch, roll, and yaw motions. An adaptive controller that is effective for controlling the kite's motion is developed. We present simulation results that demonstrate adaptive command following, where the kite's pitch and roll angles follow commanded signals and the system is able to generate net power.

This work was supported by the NSF's Energy for Sustainability Program through Grant CBET-0853579.

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STABLE LYING-EIGHT ORBITS FOR KITES

P. Rautakorpi[1], I. Argatov[2], R. Silvennoinen[1],
[1]Tampere University of Technology, [2]Aberystwyth University

A kite simulator to study kite flight when kite is controlled by a given passive periodic control for control angle has been made. It was noticed that simple sine function for control angle with suitable amplitude and period gives a stable orbit for kite and thus infinite flight time with fixed tether length and constant wind. The kite stabilizes itself to a unique lying-eight orbit in the middle of the wind window with completely passive sinusoidal control when initial conditions are not too far outside the stable orbit.

With small tether length change within one orbit it is possible to get many lying-eight orbits with a shape close to each other and generate a significant amount of energy with passive control before the kite gets out of control due to the longer tether.
Thus controls and orbits close to the stable orbits with fixed tether might be useful also for kite wind generators with variable tether length when modified with small corrections.

MODELING AND SIMULATION OF KITE POWER SYSTEMS

R. Schmehl, J. Breukels, J. Schwoll, S. de Groot,
Delft University of Technology

The flexibility of kites and tethers is a challenge for modeling and simulation of kite power systems. Especially for the lightweight membrane structure of an inflatable kite, structural dynamics and exterior aerodynamics are tightly coupled processes which dominate the flight dynamic characteristics and by that also the power generation of the system. For longer tethers, deformation can be substantial, especially in low-load cases, also affecting the achievable power output.

The presentation summarizes various modeling approaches pursued by the Kite Power research group. For flight trajectory optimization and automatic flight control, point mass or rigid body models are typically used for kite and tether. More accurate, but also more expensive, is a multibody system model using several hundred rigid bodies connected by joints to represent the deformable tube structure and a spring damper network to represent the canopy. Also an analysis tool, a Finite Element method, normally applied to airbag deployment simulations, is used to simulate the structural dynamics of kite under load.

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PERFORMANCE FACTORS FOR HIGH-ALTITUDE WIND POWER DEVICES IN PUMPING OPERATION

U. Fechner, *Delft University of Technology*

Until now only few experimental results of kite power systems in pumping operation have been published. Most of the available data pertains to theoretical analyses and simulations. For systematic improvement of the performance of kite power systems a new way to analyse the efficiency will be presented. A number of performance factors were derived that are dependant on different aspects of the kite power system and can be optimized independently. It will be shown how to use these performance factors to analyse the current measurement results of the TU Delft.

It will be explained:

- how to improve average mechanical reel-out power
- how to improve the duty cycle
- how to reduce the electrical reel-in energy
- how to calculate and improve the efficiency of the generator

One goal of the current developments at TU Delft is to increase the average electrical power output to about 16 kW without increasing the physical size of the kite or the winch. To reach this goal, a systematic analysis of the current system and a highly efficient winch are key factors.

CHALLENGES IN GPS RECEIVER DESIGN FOR AIRBORNE WIND TURBINE GUIDANCE

H. Hallam, *Makani Power*

Accurate measurement of position and velocity is important for flight stability, and essential for flight path optimizations that maximize energy production during autonomous crosswind flight.

Differential GPS can provide centimeter-level accuracy, but conventional receivers are hampered by difficulties unique to the airborne wind turbine application.
Strong centripetal acceleration, rapid changes in satellite visibility and electromagnetic interference from on-board electronics all contribute to an unfavorable environment for off-the-shelf GPS receivers.

Makani Power has developed a series of custom GPS receivers that mitigate these problems. We explain how GPS works, the nature of the challenges in this application, and how they can be overcome.

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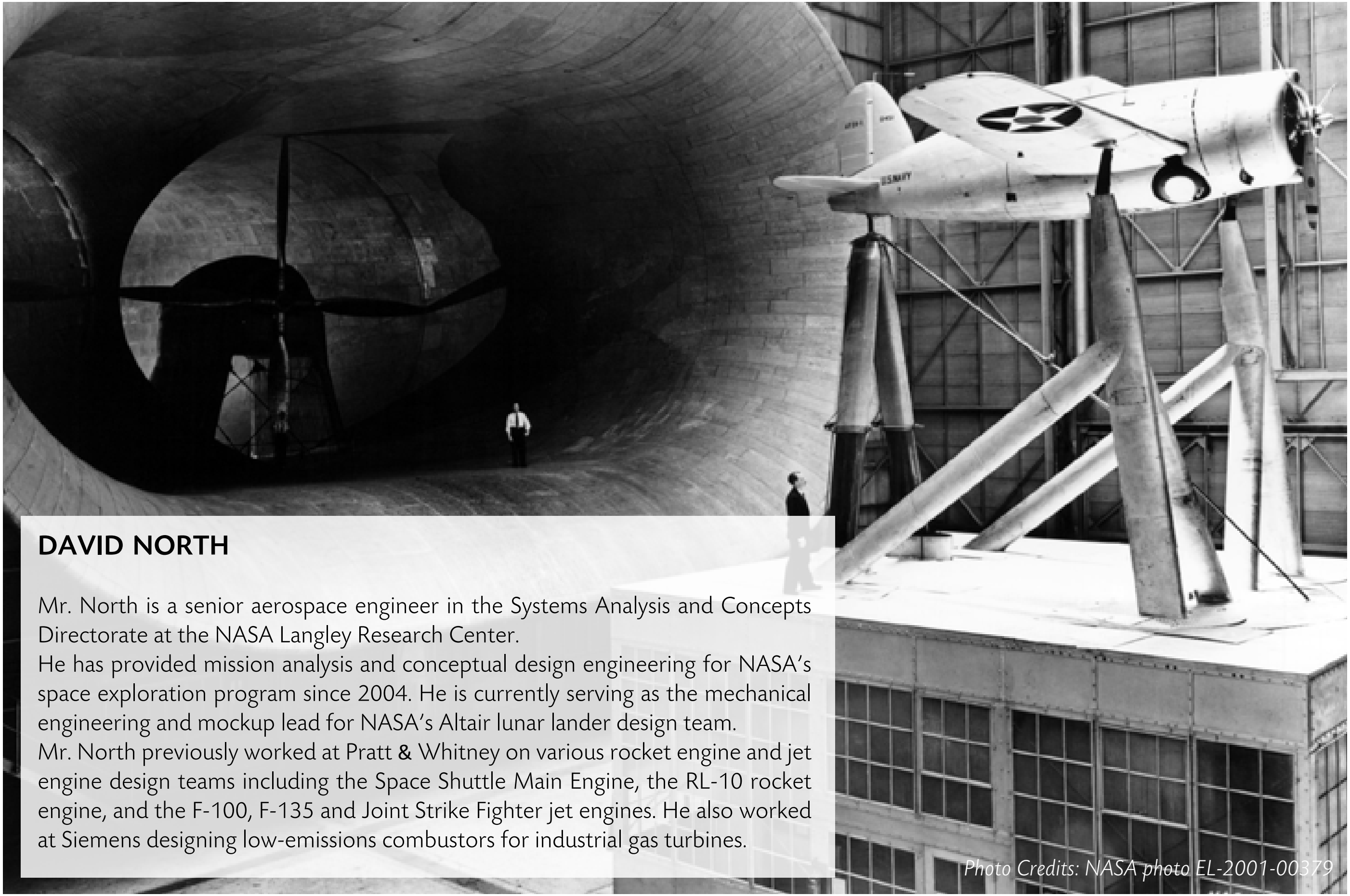

DAVID NORTH

Mr. North is a senior aerospace engineer in the Systems Analysis and Concepts Directorate at the NASA Langley Research Center.

He has provided mission analysis and conceptual design engineering for NASA's space exploration program since 2004. He is currently serving as the mechanical engineering and mockup lead for NASA's Altair lunar lander design team.

Mr. North previously worked at Pratt & Whitney on various rocket engine and jet engine design teams including the Space Shuttle Main Engine, the RL-10 rocket engine, and the F-100, F-135 and Joint Strike Fighter jet engines. He also worked at Siemens designing low-emissions combustors for industrial gas turbines.

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AIRBORNE WIND ENERGY TECHNOLOGY AND REGULATORY GAPS: A NASA PERSPECTIVE

D. North, *NASA Langley Research Center*

NASA has identified key areas of support that are needed to aid in the advancement of this promising technology. These areas include airspace regulation development , system-level and subsystem-level modeling and simulation tools, aerodynamic design and analysis tools tailored for AWE, materials development, autonomous controls technologies, and open prototype testing sites.

Current airspace regulations in both the U.S. and Europe present a challenge going forward for airborne wind energy developers. NASA is working with the Federal Aviation Administration to help them understand the operational requirements of the proposed systems in order to develop new regulations to operate AWE systems in U.S. airspace.

NASA Langley Research Center specializes in both system-level and subsystem-level simulation and testing of aeronautical systems. NASA Langley's potential contribution to the AWE research effort could include work on autonomous control systems, wind tunnel testing, application of inflatable structures to soft kite solutions, tether drag reduction, development of a concept analysis comparative toolkit across the broad design space, aeroacoustic and aeroelastic analysis. Other NASA centers offer additional valuable research capabilities, including the potential of NASA restricted airspace testing centers that could offer third party corroborative experimental evidence and statistical evidence of acceptable airspace safety. Current efforts at NASA are identifying the people, organizations, and tools within the agency to begin collaborative AWE research with private industry and other government agencies.

DYNAMIC ANALYSIS, SIMULATION & DESIGN OF WINCH FOR ENERGY EXTRACTION BY AIRBORNE PARAFOILS

J. Coleman, H. Ahmad, S. Nolan, D. Toal,
University of Limerick

Winch designs for tethered Airborne Wind Energy systems with cyclical power generation phases require detailed analysis to fully investigate and suitably design winching systems within the overall control system.
Efficient and effective control of tether tension must be maintained and distributed between the winch controller and the kite control pod while simultaneously enabling efficient power take off. The airborne system is highly coupled to the dynamics of the ground winch system and as such detailed analysis of the interaction between these systems is required. Dynamic analysis of this nature has been carried out by the authors.

This analysis has led to the development of a winch design which is tailored specifically to the requirements of an AWE system. Through the use of clutching mechanisms the reel out and reel in functions can be mechanically and electrically separated, reversing only the components required to retrieve the tether/airborne system.
This results in a reduced dynamic response time of the machine and enables the possibility of extending the generation phase into recovery phase.

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DEVELOPMENT OF THE SKY WINDPOWER FLYING ELECTRIC GENERATOR

B. Weddendorf, *Velocity Cubed Technologies Inc*

For the past three years, our engineering team has been working to develop and demonstrate a practical Flying Electric Generator for Sky WindPower.

The key feature of the Sky WindPower concept is the use of autogyro rotors. These rotors both provide lift to keep the Flying Electric Generator aloft, and they extract the power of the wind for direct conversion to high voltage electricity. They are also the aerodynamic control surfaces used to stabilize the aircraft in flight.
This makes the Sky WindPower Flying Electric Generator concept uniquely effective at harvesting the energy in the wind.

This presentation will explain our concepts and give a history of our development and testing of the Flying Electric Generator to date.

GEOMETRIC TRAJECTORY TRACKING CONTROL

J. Baayen, *Delft University of Technology*

We present a new, geometric solution to the kite trajectory tracking control problem. Our approach offers three advantages: a stability proof, ease of implementation, and minimal modelling requirements.
The latter is especially important for control of flexible kites, which are hard to model accurately in a point-mass or rigid-body framework.

Kites commonly have a single control input available for steering. In the presentation we show how the differential-geometric notion of turning angle can be used as a one-dimensional representation of the kite trajectory, and how this leads to a single-input single-output tracking problem. In order to facilitate model inversion we linearize the turning angle dynamics in the steering control input and apply energy methods to derive a stabilizing feedback law. We show how the zero-term of the linearization can be measured directly using on-board sensors, and how in this way the control law comes to depend on the control derivatives of the aerodynamic kite model only.

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KATHOLIEKE UNIVERSITEIT LEUVEN

DESIGN OF A WINCH; MODELLING & CONTROL OF THE TETHERED FLIGHT OF A MODEL AIRPLANE

D. Cosaert, K. Elst,
K.U. Leuven

Design of a winch

The plane is attached to a carousel by a tether, providing the possibility for a rotational start. Once in the air our winch controls the tether length. The winch is fast and strong because it has to 'pump' the plane in the air like a kite on the beach. Beside motor mode, generator mode is provided in order to generate power out of the flight pattern.

To estimate this power a cable force sensor is designed to measure the tension in the cable at all times. Beside this, the sensor can also improve the safety by giving a warning when the force becomes too high.

Modelling and Control

Pitch and roll are controlled using a PID-controller which steers the elevator and the ailerons. The parameters used to describe the model in the simulation were first derived from estimations and later from measurements in a wind tunnel.

DETERMINATION OF AIRFOIL SELECTION AND DESIGN PARAMETERS EFFECTS ON THE PERFORMANCE OF VERTICAL AXIS WIND TURBINES

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Integrating wind turbines in urban areas especially over buildings is a new way of producing electricity which is supported in recent years.
The use of vertical axis wind turbines at buildings seems favorable owing to the fact that they do not suffer from frequent wind direction changes, architects like the design and the idea to integrate such design with the building, and they have better response in turbulent wind flow which is common in urban areas.

This paper presents a computational study into the aerodynamics and performance of small scale vertical axis wind turbines and describes the effect of some design parameters including number of blades, airfoil type, turbine solidity and blade pitch angle on the performance of them. To perform the transient simulations, k- turbulence model is chosen and Multiple Reference Frame (MRF) model capability of a commercial CFD solver is used to express the dimensionless form of power output of the wind turbine as a function of the wind freestream velocity and the rotor's rotational speed. The results show that simulated turbines experience a maximum power coefficient of 0.37 in tip speed ratio of about 3.5.

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KATHOLIEKE UNIVERSITEIT LEUVEN

FIRST FEEDBACK CONTROL TESTS FOR FAST FLYING TETHERED AIRPLANES

K. Geebelen, M. Vukov,
K.U. Leuven

In order to be able to perform estimation and control experiments, a test platform suitable for rotation start of two tethered airplanes has been built. This platform allows us to perform experiments both outdoors and indoors, independent of wind and weather conditions. The platform consists of a rotating mechanical structure, the carousel, and one or two airplanes. The control architecture includes a PC based computer and a micro-controller inside the airplane. Orocos Toolchain has been chosen for the underlying control software layer. This toolchain is an architecture-independent component based framework for all aspects of real-time control for mechatronic and airspace systems.

Here we present the first experimental results, in which we performed control of the pitch and roll of the airplane with respect to local acceleration vector. Future research on this test platform includes development of a moving horizon estimator (MHE) for state estimation that fuses multiple sensors such as an inertial measurement unit (IMU), a stereo vision camera system, a GPS etc. Alongside development of a MHE a model predictive controller (MPC) will be developed.

EFFICIENT NUMERICAL METHODS FOR COMPUTATION OF OPEN-LOOP STABLE KITE ORBITS

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Wind power generation using kites has received an increasing attention in the last decade. The main concept of energy generation can be outlined as follows:
kites fly with high speed in crosswind direction and periodically pull their cables to drive a generator on the ground. Solving optimal control problems we are looking for open-loop stable kite orbits, for which the average power at the generator is maximal.

As the motion of kites is affected by wind turbulences, robustness aspects have also to be taken into account. We discuss numerical methods for the computation of periodic and open-loop stable kite orbits as a solution of an optimal control problem taking the above issues into account.

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Effect of design parameters on the flight dynamics of a Kiteplane

E.J. Terink,J. Breukels, R. Schmehl, W.J. Ockels,
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Realizing the potential of the pumping kite power system as a concept for airborne wind energy generation requires a kite that is not only agile and aerodynamically efficient to maximize the power output, but also stable to minimize the control effort. In addition, a low lift mode – in kite terminology called depower – is necessary to implement a swift low power consuming downstroke. A kite that may fulfill these needs is the Kiteplane, an airplane-shaped kite constructed with inflatable beams and canopy surfaces.
This lightweight airframe is connected to the ground station with a single-line tether and supported by lateral bridle lines. The lateral bridle couples the roll and yaw motion as a function of the pitch attitude with respect to the tether.

Simulating the 5-DOF model of the single-line single-kite system reveals that the amount and distribution of lateral aerodynamic surface area is decisive for flight dynamic stability. Furthermore, a power cycle of the geometrically optimized Kiteplane, with elevator and rudder control, yields an average power output of 1 kW/m2 and a capacity factor of 0.6 at a constant wind velocity of 10 m/s.

POSITION AND ORIENTATION DETERMINATION OF A MANEUVERING TARGET BASED ON MOVING HORIZON ESTIMATION

J. Vandersteen, M. Diehl, C. Aerts, J. Swevers,
K.U. Leuven

In order to achieve precise and stable control of a kite, an accurate estimation of the vehicle's orientation and position is required. This estimation is based on onboard angular rate, magnetic field and linear acceleration measurements, GPS information and external cameras. The various sensors, both onboard an external, are subject to measurement noise and bias. Some sensors, e.g. the magnetometer and the cameras, provide only vector observations and the estimation of the vehicle's orientation is further complicated by the nonlinear quaternion kinematics.
This paper presents the moving horizon estimation of the kite states, and shows that this outperforms the extended and unscented Kalman filters, which are the current workhorse filters in the aerospace industry. A moving horizon estimator determines the current state by solving a constrained numerical optimization problem considering a finite sequence of current and past measurement data, an available kinematic model and quaternion constraints. A symplectic integrator is developed to preserve the quaternion norm over the estimation horizon. The various sensors run at different sampling rates. This can be dealt with in a natural way in the moving horizon estimator. The objective function to be minimized is typically a trade-off between minimizing measurement noise and process noise. In order to solve this constrained optimization problem in real-time, an efficient numerical solution method based on the iterative Gauss-Newton scheme has been implemented and specific measures are taken to speed up the calculations such as hot starting from previous solutions and exploiting the sparsity and band structure of matrices to be inverted.

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DO YOU WANT TO INVEST IN FLYING WINDMILLS? CHALLENGES AND PERSPECTIVES OF AIRBORNE WIND ENERGY FINANCING

U. Zillmann, *Daidalos Capital*

Besides many technological and legal issues, securing sufficient financing remains one of the main obstacles for the progress of airborne wind companies. Classic venture capital struggles to provide financing to this new industry.
Too many open questions regarding technical obstacles, legal issues, business plans, market size, timing, profitability, reliability etc. exist to match with the risk profile and the 2 to 5 years investment horizon of venture capital funds.

A broader approach to the financing of airborne wind companies might be a solution to overcome some of these obstacles. A specialized fund for the financing of airborne wind energy with a longer investment horizon could provide both, a vehicle for interested investors willing to help this fascinating new technology as well as a platform to increase the awareness of politics and public for the new technology.
The presentation will discuss how the specialized airborne wind energy fund currently set up by Daidalos Capital could help to overcome the financing difficulties of airborne wind start-ups.

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We express our gratitude to all the companies, institutions and persons taking part in the AWEC2011, Leuven. And for those who submitted presentations for this event, the additional time you have taken to document and share your ideas is highly appreciated. We hope you enjoy the conference and that you establish new contacts as well as continue to expand your network .

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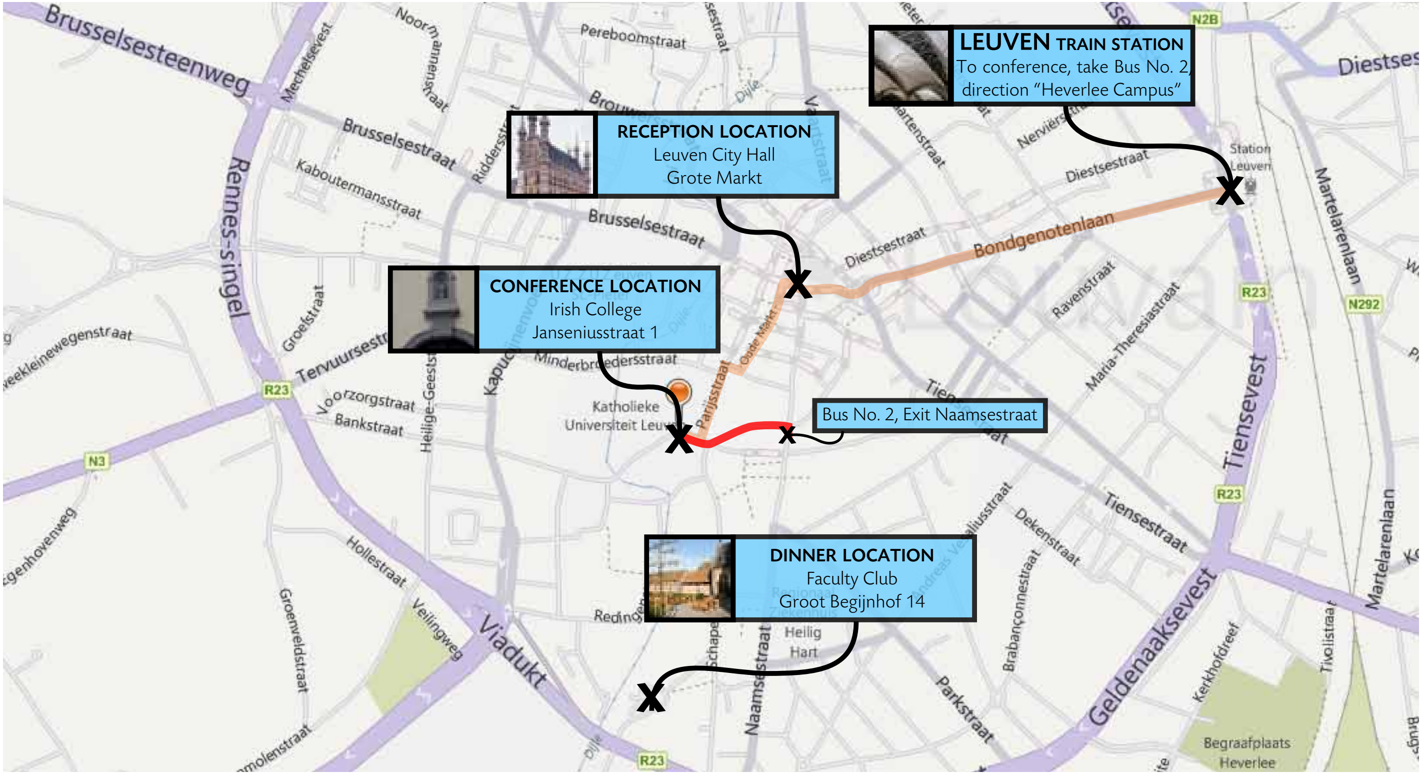

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