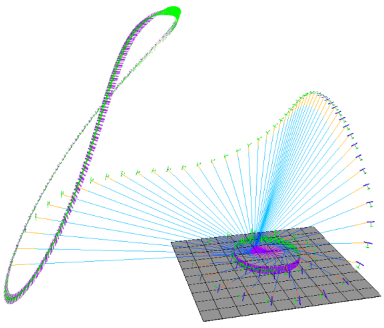
Two PhD Positions in Computational Control and Optimization

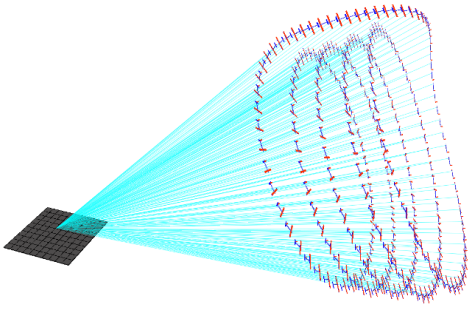
at the University of Freiburg, Germany

These PhD positions are part of the European Training Network "AWESCO - Airborne Wind Energy System Modelling, Control and Optimisation". AWESCO will recruit altogether 14 PhD fellows who are based in different countries but meet regularly during exchange visits, training events, workshops, and summer schools organized by AWESCO. The two PhD positions in Freiburg have a strong methodological focus in the field of computational control and mathematical optimization. They are based in the Systems Control and Optimization Laboratory headed by Prof. Dr. Moritz Diehl. Their aim is the development of advanced optimal control methods and open-source software and their application to industrially relevant optimization and estimation problems. While these methods are generic and applicable in several branches of engineering, they shall be tested and used in close cooperation with the the other AWESCO PhD fellows, in particularly with those who are based in the companies of the AWESCO network - AmpyxPower (Den Haag), Xsens (Enschede), Enerkite (Berlin), SkySails (Hamburg), Makani/Google [x] (Alameda) - during mutual exchange visits of several months duration.

BACKGROUND

Airborne Wind Energy (AWE) is a novel wind energy technology based on flying high-performance wings several hundred meters above the ground in the wind field. These wings are anchored to the ground by a tether, like kites, and perform fast crosswind motions and specially designed cycles to harvest wind energy. AWE taps into the large wind resource in altitudes above 200 meters, and is expected to be able to produce electricity in a larger scale and at a lower price than classical wind turbines. AWE promises to become a major actor in the transition towards a low-carbon economy, and several companies are currently developing prototypes of AWE systems, with a first commercialization target in 2017. While the AWE technology is developing fast, its contribution to our energy system will depend on the solution of several key challenges, some of which require the use of advanced control, estimation and optimization methods. These challenges are, in particular, the automatic control of the system under incomplete knowledge of the varying wind field, as well as model-based system design that includes ways for starting and landing the wings.





The Systems Control and Optimization Laboratory at the University of Freiburg focuses on methods and software for optimal control and estimation, in particular on embedded systems, and its members developed, among other, the open-source tools ACADO, CasADi, and qpOASES. One of its more applied research lines is control and optimization of airborne wind energy systems, a topic on which it is well connected with all major actors in the field, and on which it is supported, besides AWESCO, by the European Research Council (ERC). In order to train its team members and test its methods before their use in industry, it operates a small prototype system consisting of a rotation carousel and RC-planes equipped with advanced sensing and control hardware.

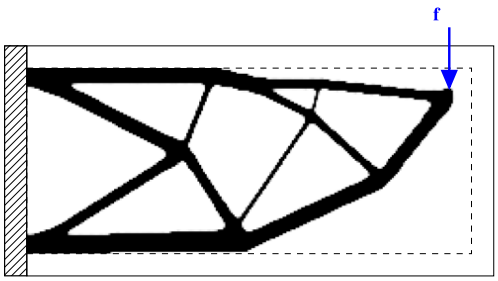
The AWESCO PhD positions will be supervised by world leading experts in mathematical modelling, optimization-based control and estimation, and shall prepare the fellows for a high-level career in advanced control engineering in industry or in academia.

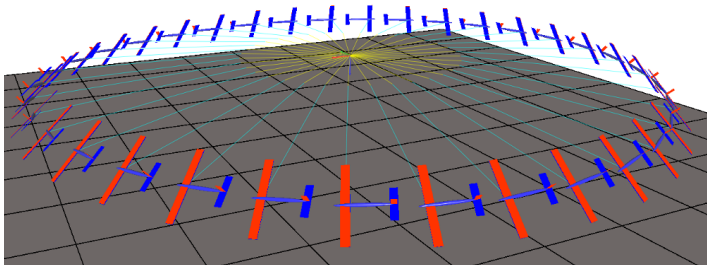
PhD Project 1:

Shape and Topology Optimization for Bridled Rigid Airfoils (Multi-Scenario Design and Trajectory Optimization Methods)

The aim of this PhD position is to develop and use advanced modelling and optimization methods that are able to address challenging design and trajectory optimization problems in aerospace applications, where wings shall be lightweight, have high lift to drag ratios, and good maneuverability and operate in a variety of flight paths. These non-standard multi-physics optimization and optimal control problems combine multiple scenarios in a single problem, and simultaneously optimize fixed design choices (such as constant wing parameters determining the shape and topology) and flexible control strategies (such as variable control trajectories and controller gains). The ultimate dream for airborne wind energy applications would be to formulate and to solve numerically an overall system optimization problem that incorporates all operational points of the system (startup and landing, power cycles at different wind speeds), that ensures that the constraints are respected in all scenarios, and that minimizes a combination of all relevant performance indicators (such as yearly electricity output, aerodynamic and electrical efficiency, mechanical stresses, investment costs, …). In contrast to current industrial practice in simulation-based optimization, the novel optimization methods shall rely exclusively on fast and accurate derivative computations via algorithmic differentiation, and on structure exploiting nonlinear optimization algorithms. Computational efficiency shall be achieved by a smart combination of existing open-source software developed within and outside the Systems Control and Optimization Laboratory (CasADi, IPOPT, numpy/scipy, qpDUNES, ACADO, dynobud, …) and new algorithmic components that might come from the fields of computational fluid dynamics (CFD) and topology optimization, with a focus on the efficient use of parallel computing.

Depending on the interests and qualifications of the selected PhD fellow, the PhD topic can lean more towards algorithm and open-source software development, or more to the formulation and solution of interesting optimization problems. In the first case, the PhD fellow will not put much effort into problem formulations, but only accompany the external users of his/her software in the AWESCO partner groups and learn from their feedback to improve the software. In the second case, the PhD contribution shifts more towards modelling and solution of industrially relevant optimization problems in airborne wind energy. Problems of interest include the design and optimal control of rigid or flexible wing systems (with AmpyxPower, Enerkite, Makani or SkySails), and of novel designs such as dual wing systems. Depending on the interests and qualifications of the candidate, the tools and applications can lean more to flight dynamics, structural mechanics, or computational fluid dynamics (CFD), ideally a combination of these. The tools shall be tested by investigating different possible wing topologies such as different numbers of bridles, extra control surfaces, or asymmetric wing shapes. A two meter wing span prototype might be built and tested using the launch platform at ALU-FR indoors and at Ampyx Power outdoors.





PhD Project 2:

Adaptive and Fault-Tolerant Model Predictive Control and Moving Horizon Estimation

The aim of this PhD project is to develop novel methods for model based predictive control (MPC) that make intensive use of advanced online identification techniques such as moving horizon estimation (MHE) in order to achieve optimal system performance and fault-tolerant control. Main idea is to use adaptive models of parameter changes and error modes and to estimate them together with the system state by advanced MHE formulations. These MHE formulations include nonlinear dynamic models, non-quadratic and sparsity enhancing cost contributions such as L1 norms, and the MPC schemes use non-tracking formulations that are able to optimally exploit parameter changes and compensate possible faults. Motivational use cases in airborne wind energy (AWE) are, first, the identification and partial compensation of actuator or sensor faults (such as a rudder or GPS failure), and second, the active exploitation of spatial variations in the wind field. In this latter use case, one exploits the facts that (a) the tethered wings fly very fast and can thus change their location on the sky in a few seconds, (b) that wind turbulences – gusts - are varying slowly enough in time and space that they can be ”chased” by the wings, and (c) that the wind power increases cubically with the wind speed, making the flight into strong wind regions extremely beneficial for power generation.

Methodological challenges are both on the side of numerical optimal control, where non-standard and non-convex MPC and MHE problems need to be addressed by derivative based embedded optimization methods, as well as on the MHE problem formulation side, where differential equation modelling, flight and wind field dynamics, as well as statistical aspects need to be taken into consideration. The PhD can build on a solid open-source software base (ACADO, qpOASES, qpDUNES, …). Depending on the interests and qualifications of the selected PhD fellow, the PhD topic can lean more towards one or the other side, relying on other team members in Freiburg to complement the work on the numerical side, and external AWESCO colleagues to add input on the modelling side. Aim is to make the developed MPC and MHE methods usable for the control of industrial prototype systems jointly with at least one of the AWESCO companies AmpyxPower, Enerkite, Makani or SkySails, together with the local PhD students, or at the small scale flight carousel in Freiburg.

Timeline and remuneration: Ideal start time for both positions is in spring or summer 2015. The PhD projects last for the duration of three years, and are carried out at the University of Freiburg. The PhD years include one or more longer visits – so called ”secondments” – between one and six months to other groups in the AWESCO network, with some freedom regarding the destinations and durations. The first year is mainly dedicated to studying and getting acquainted with the relevant state of the art in numerical optimal control and modelling as well as the driving application problems, the second year focuses on method development, and the third year on application problems and publications. Funds are reserved for a possible extension into a fourth PhD year at the University of Freiburg. The remuneration is generous and will be in line with the EC rules for Marie Curie grant holders. It consists of a salary augmented by a mobility allowance, resulting in a net monthly salary of about 1900-2300 Euro depending on family status.

SUPERVISORS AND MAIN CONTACTS

Supervising team at the University of Freiburg: Prof. Dr. Moritz Diehl (head of systems control and optimization laboratory), Greg Horn (senior PhD student working on aircraft modelling and optimization software for airborne wind energy), Mario Zanon (senior PhD student working on economic Nonlinear Model Predictive Control formulations), Robin Verscheuren (PhD student focusing on “Code Generation for Embedded Nonlinear Model Predictive Control and Moving Horizon Estimation”).

Main Contacts at the AWESCO Partner Groups which could host secondments: *AmpyxPower:* Soeren Sieberling (head of controls), Gianni Licitra (PhD student); *SkySails:* Dr. Michael Erhard (head of controls); *Makani:* Thomas Van Alsenoy (systems engineer). *Xsens:* Dr. Jeroen Hol (senior research engineer). *Chalmers University:* Dr. Sebastien Gros (professor for control of power systems). *KU Leuven University:* Prof. Johan Meyers (turbulent flow simulation and optimization of large wind parks).

CANDIDATE PROFILES

Ideal candidates have a master degree in one of the following or related fields: control, aerospace or mathematical engineering, numerical mathematics, or computational physics. They should have a good background or interest in mathematical optimization, dynamic system modelling and simulation, and programming (Matlab, C/C++, python, haskell…), as well as a desire to contribute to the development of open-source software and the success of real-world experiments. Proficiency in English is a requirement. The positions adhere to the European policy of balanced ethnicity, age and gender. Both men and women are encouraged to apply.

APPLICATION

To apply, send an email to diehl@imtek.uni-freiburg.de with CC to christine.paasch@imtek.uni-freiburg.de. Subject of your email should be: “AWESCO PhD Application”. Please include:

a) an academic CV and a PDF of your diplomas and transcript of course work and grades
b) statement of research interests and career goals, indicating in which of the AWESCO positions you are interested
c) sample of technical writing, e.g. a paper with you as main author, or your bachelor or master thesis
d) list of at least two references: names, phone numbers, and email addresses
e) some proof of proficiency in English (e.g. language test results from TOEFL, IELTS, CAE, or CPE)

Please send your application a.s.a.p., but latest before March 15, 2015.
(the openings will be closed once suitable candidates have been found)

MARIE CURIE ELIGIBILITY CRITERIA IN SHORT

To be eligible, you need to be an "early stage researcher" i.e. simultaneously fulfill the following criteria at the time of recruitment:

a) Nationality: you may be of any nationality.
b) Mobility: you must not have resided or carried out your main activity (work, studies, etc...) in Germany for more than 12 months in the 3 years immediately prior to your recruitment under the AWESCO project.
c) Qualifications and research experience: you must be in the first 4 years of your research career after the master degree was awarded.

For more information, please visit the following webpages:

http://www.imtek.de/laboratories/systemtheorie

and

http://www.awesco.eu