Design of autopilots for takeoff and landing of soft kites airborne wind energy systems

Master thesis (6 months internship) followed by a PhD (3 years)

From February 2027

Keywords : Automatic control, Lie Groups, testbench design, microcontroller programming, sensor integration, experimental testing, resource-frugal renewable energy.

Abstract

Airborne wind energy generators are a class of systems producing renewable energy from the wind. However, unlike wind turbines, they also use wind to stay aloft, hence their name [1]. These systems are in the phase of ongoing research and first commercialization [2]. According to a recent white paper for Airborne Wind Europe, flying wind turbines are "a revolutionary solution to access the vast untapped potential of wind resources at heights greater than those accessed by established wind technologies" [3]. Indeed, the absence of a mast makes it easier to capture high altitude winds (300 to 600 m) which are more regular, more powerful and more stable. [4]. Because they **sometimes require up to** 90 **% fewer materials compared to wind turbines**, these systems can be at least 40 % lower in carbon intensity [3]. Considering that i) the European Union has set itself a target of 1000 GW of wind production capacity in 2050 [5] and ii) the intensive use of steel, cement and composite materials increases the carbon footprint of wind turbines and risks slowing down the achievement of these objectives [6], the solution of flying wind turbines seems **essential in the current context of the energy transition**.

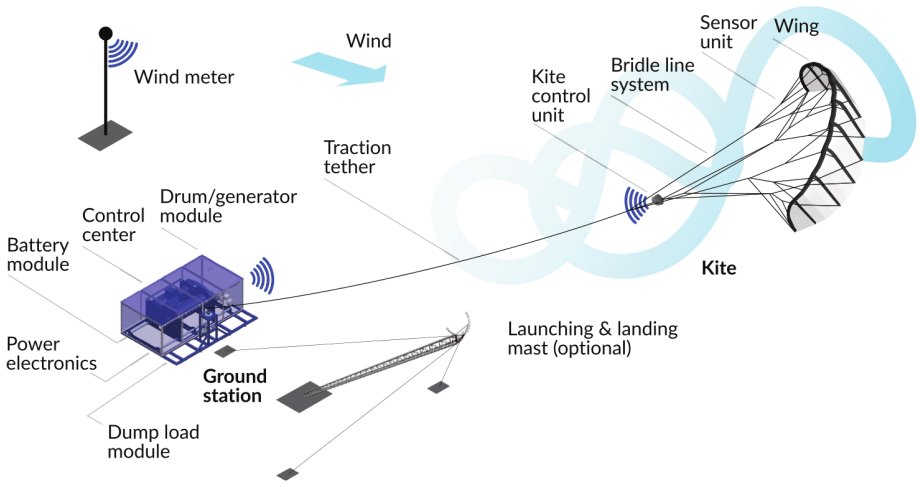

Figure 1: Single-line, ground-generated, flexible sail flying wind turbine system. Image from [7]

The operation of ground generation systems (*ground gen*) is as follows: in a first phase, the sail is pushed by the wind, and follows a figure-of-eight trajectory to maximize its speed, and therefore the force of traction exerted on the cable. By unwinding the cable, the sail drives a generator fixed to the ground, which produces electricity. When the cable is completely unwound, the second phase begins: the kite is controlled so as to exert a minimum

tension and the generator operates as a motor to wind the cable again. The cycle can then start again [1, 8]. For example, Kite Power's "Falcon" system produces 130 kW during the first phase (80% of the time) and consumes 20 kW during the second (20% of the time), i.e. an average production 100 kW [2].

These systems suffer from a **major disadvantage: they are much more difficult to control than classical wind turbines**. Some systems are already in the first commercialization phase, but the installed control laws lack robustness in the face of the great diversity of operating conditions [8]. In particular, there are no existing controls capable of ensuring the autonomous takeoff and landing of soft kites. Therefore, further research is needed.

This internship is part of the Anémodyne project and benefits from the prior work of students, one technician, one engineer, one PhD student and one postdoc. The internship will take place in the spring semester, allowing a teaching from the engineer on the practical side and the postdoc on the theoretical side. It will be followed by a PhD thesis (whose funding is already secured).

The aim of this project is to design control laws for systems evolving on Lie groups (mathematical structures well suited to describe rotations and translations, used in drones and robots), test them in simulations using Julia, and implement them on the testbench for field tests.

At the end of the thesis, we aim to demonstrate the reliability of the autopilot by continuously taking off and landing for 48h (taking shifts with different members of the team for supervision).

By the end of this 3,5 years, the candidate will have acquired high skills in advanced automatic control for unmanned aerial/robotic vehicles as well as hands on experience with testbed implementation, sensor integration and field experiments.

This project offers both the possibility to pursue an academic or industrial carreer.

The missions of the intern and the PhD student include

- Designing a dynamic model of the system
- Comparing this model to existing kite simulators in Julia
- Adapting existing simulators to the anemodyne system
- Running field test to acquire data and validate both a detailed simulator and the kite model
- Designing control laws for a class of systems including the kite's
- Testing controls in simulation
- Programming on Raspberry, arduino, SPIN microcontroller and Pixhawk
- Implementing the controls on the prototype
- Running outdoor test campaings

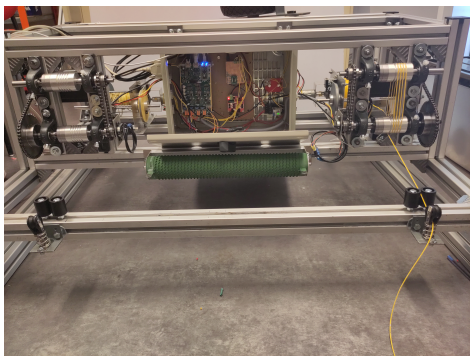

Figure 2: Photography of the ground station.

Profile of the desired candidate

The candidate will have training in advanced Automatic control (state-space, state feedback, nonlinear systems are mandatory) with hands-on experience in mechatronics and microcontroller programming. The candidate will have either a bachelor degree and first year of masters, or other higher qualifications. The candidate will comit to pursue the 6 months internship by a PhD. Applicants having already completed a masters degree can start directly with the PhD.

Practical information

- **Internship & PhD location:** 3 rue Victor Grignard 69100 Villeurbanne
- **Dates:** From february
- **Salary:** [Internship] approx €630 net per month [PhD] €1700 net per month.
- **Benefits:** Participation to international conferences (transport, accomodation and registration), pension and healthcare benefits, 75% of public transport fee covered for, subsidy for univerity canteen, as well as the student status for 3 years, offering a number of advantages in France (cheaper accomodation, free museums, ect.)
- **Employer:** Université Claude Bernard Lyon 1
- **Advisors:** Tanguy Simon (Associate professor, UCBL, Polytech Lyon, LAGEPP), Ulysse Serres (Associate professor, UCBL, LAGEPP), Daniele Astolfi (CNRS Researcher, UCBL, LAGEPP), Ahmad Hably (Professor, UCBL, LAGEPP)

Aplication

Please send an email containing your CV and cover letter to T.Simon : `tanguy.simon@univ-lyon1.fr` (LAGEPP Laboratory)

References

[1] C. Vermillion, M. Cobb, L. Fagiano, R. Leuthold, M. Diehl, R. S. Smith, T. A. Wood, S. Rapp, R. Schmehl, D. Olinger, and M. Demetriou, "Electricity in the air: Insights from two decades of advanced control research and experimental flight testing of airborne wind energy systems," Annual Reviews in Control, vol. 52, pp. 330–357, Jan. 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1367578821000109

[2] "Kitepower - Airborne Wind Energy." [Online]. Available: https://thekitepower.com/

[3] B. Associates, "Getting airborne – the need to realise the benefits of airborne wind energy for net zero," Tech. Rep., Sep. 2022. [Online]. Available: https://airbornewindeurope.org/wp-content/uploads/2023/03/BVGA-Getting-Airborne-White-Paper-220929.pdf

[4] U. Zillmann and P. Bechtle, "Emergence and Economic Dimension of Airborne Wind Energy," in Airborne Wind Energy: Advances in Technology Development and Research, ser. Green Energy and Technology, R. Schmehl, Ed. Singapore: Springer, 2018, pp. 1–25. [Online]. Available: https://doi.org/10.1007/978-981-10-1947-0_1

[5] "Getting fit for 55 and set for 2050, Electrifying Europe with wind energy," ETIP wind, Wind Europe, Tech. Rep., Jun. 2021. [Online]. Available: https://etipwind.eu/publications/getting-fit-for-55/

[6] A. Farina and A. Anctil, "Material consumption and environmental impact of wind turbines in the USA and globally," Resources, Conservation and Recycling, vol. 176, p. 105938, Jan. 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0921344921005474

[7] V. Salma, F. Friedl, and R. Schmehl, "Improving reliability and safety of airborne wind energy systems," Wind Energy, vol. 23, no. 2, pp. 340–356, 2020, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/we.2433. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/we.2433

[8] L. Fagiano, M. Quack, F. Bauer, L. Carnel, and E. Oland, "Autonomous Airborne Wind Energy Systems: Accomplishments and Challenges," Annual Review of Control, Robotics, and Autonomous Systems, vol. 5, no. 1, pp. 603–631, May 2022. [Online]. Available: https://www.annualreviews.org/doi/10.1146/annurev-control-042820-124658

[9] L. Fagiano and T. Marks, "Design of a Small-Scale Prototype for Research in Airborne Wind Energy," IEEE/ASME Transactions on Mechatronics, vol. 20, no. 1, pp. 166–177, Feb. 2015, conference Name: IEEE/ASME Transactions on Mechatronics. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/6822635

[10] L. Fagiano, E. Nguyen-Van, F. Rager, S. Schnez, and C. Ohler, "A Small-Scale Prototype to Study the Takeoff of Tethered Rigid Aircrafts for Airborne Wind Energy," IEEE/ASME Transactions on Mechatronics, vol. 22, no. 4, pp. 1869–1880, Aug. 2017, conference Name: IEEE/ASME Transactions on Mechatronics. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/7912322