Universidad Carlos III de Madrid

Simulation and Experimental Research Activities on Airborne Wind Energy Systems at UC3M

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Introduction

Short Bio

- **2004**, Minor Thesis (B.S. Aerospace Engineering) on a kite flight simulator based on lagrangian formulation (Journal of Aircraft, 2006).
- **2004-2009** PhD on space tethers and nonlinear waves in plasmas
- **2009-2011** Postdoc on laser/plasma interaction (CEA, Paris)
- **2012-2015** Assistant Professor at UPM: tethers + plasmas + AWE systems.
- **2015 – now** Ramón y Cajal Research Fellow at UC3M.
  - *New group in Space Tethers*: one project funded by the Spanish Goverment. Two failed proposals: StG ERC A-ranked but not funded (1.5M€) and coordinator of a FET-OPEN proposal in the reserve list (3M€).
  - *AWE Systems*: 2015-2016 project funded by Fundación BBVA (40k€).
    2016-2018 project funded by Spanish Goverment (44k€).
  - *Plasmas*: electric propulsion (H2020 project MINOTOR)

Introduction

Framework of the visit

- The visit has been funded by the Ministry of Economy of Spain under the project “Simulation and Flight Testing of Power Kites Applied to Wind Energy Generation”. 44k€. 2016-2018.

- The project has three objectives:

  - Develop numerical tools for the simulation of Airborne Wind Energy Systems (AWEs).
  - Give the (very) first steps toward a technology demonstrator -> Flight Testing.
  - Disseminate AWEs in Spain and make networking with consolidated groups.

- Participants: Dr. G. Sánchez-Arriaga (UC3M, PI), Mr. R. Borobia-Moreno (INTA), and Dr. R. Schmehl (TU Delft)

Simulation

2.1 Development of kite simulators

Introduction

- The modellization and dynamic simulation of AWEs are complex tasks because they involve several interlinked bodies, aerodynamic models, optimal control laws determination,….
- The design of AWEs is an iterative process that may involve simulators with different degrees of complexity and accuracy.
- Attention should be paid to the tether because realistic values of the Young's modulus yields to stiff equations.
- There are three approaches
  - Work with the stiff equations (use implicit integrators and solve a heavy problem).
  - Use non-realistic values for the tether stiffness (normally used by lumped-mass-models).
  - Take the infinite stiffness tether limit (bar-models)

2.1 Development of kite simulators

Bar-Based Kite Simulators

- Advantages:
  - The fast longitudinal oscillations of the tethers are eliminated.
  - The resulting set of equations have a good behavior (non stiff).
  - The results are reliable because real tether stiffness is very high.

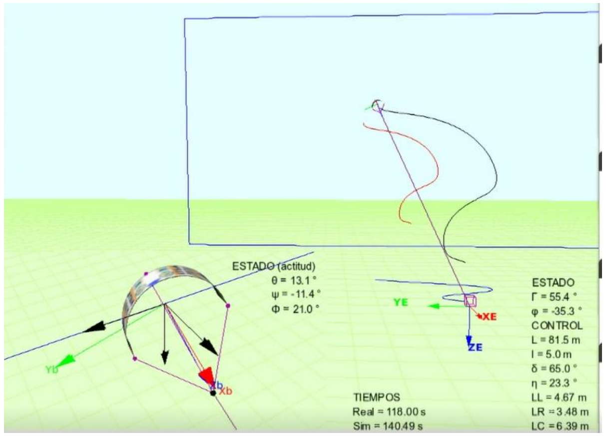
- Disadvantages:
  - The implementation is not straightforward (see below).
  - Rigid kites with more than three tethers are hyperstatics (more unknowns than equations).

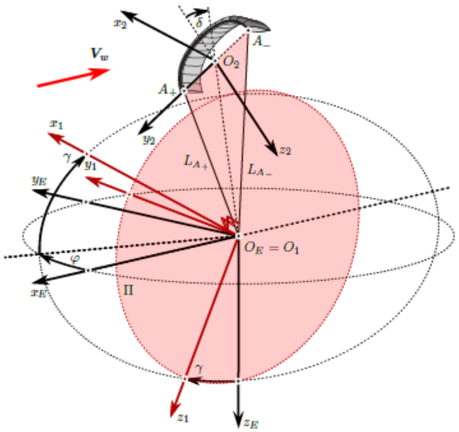
Implementation of Bar-Based Kite Simulator

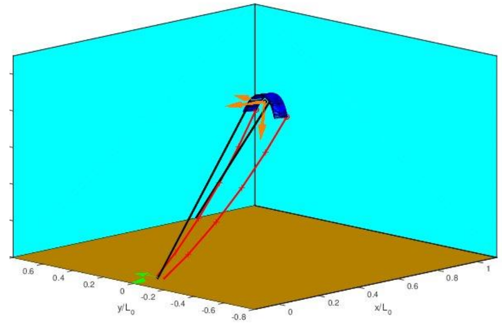
- Classical Mechanics: Newton Law + Constraints
  - Easy implementation but ODEs + Nonlinear Algebraic Equations.
- Analytical Mechanics: Euler-Lagrange or Hamilton Equations
  - Hard implementation but just ODEs.

LAKSA SIMULATION PACKAGE

	KiteFlex	KiteAcrobat	KiteSurf	KiteTrain	KiteElastic
System	Rigid Aircraft 1 flexible tether, bridle, generators	Rigid Aircraft 2 inelastic tethers	Rigid Aircraft 2 rigid + 2 elastic tethers	N Aircraft 2N rigid tethers	Arbitrary number of aircraft and tethers
Language	Matlab,Fortran Paralelizado	Matlab	Matlab	Matlab	Matlab
Application	FlyGen & GroundGen	Traction	UC3M Experimental Setup	FlyGen	Generic Systems

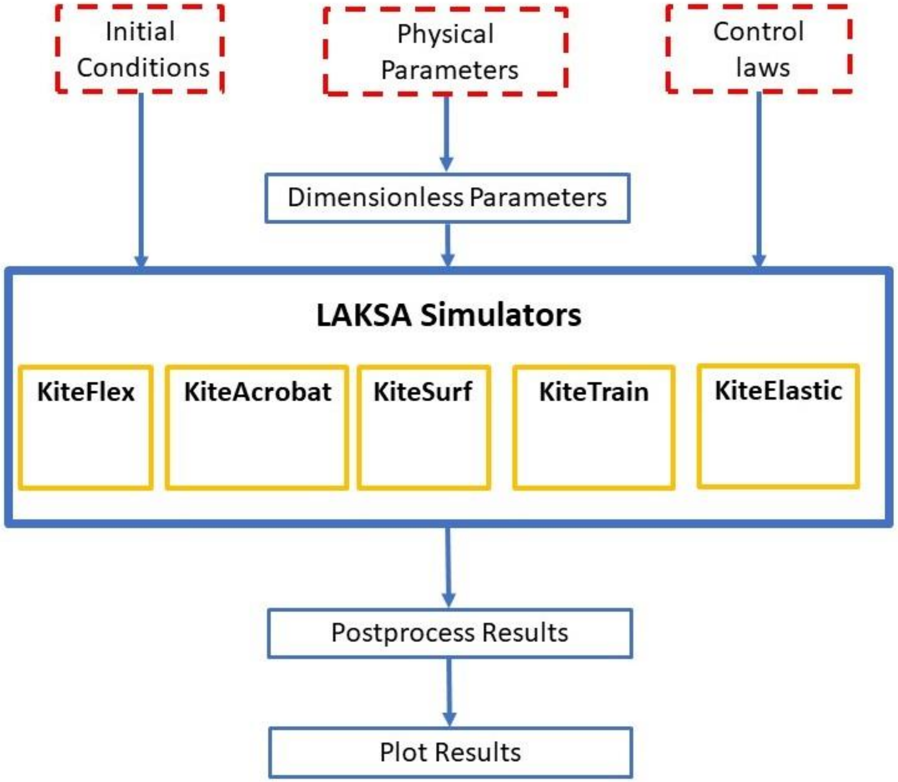






LAKSA is available at https://github.com/apastor3/laksa

LAKSA Architecture



Wish list	LAKSA Solution
Robust	Lagrangian + Minimal coordinate approach (pure system of ODEs)
Non-stiff	Inelastic tethers (fast longitudinal oscillations are removed)
Efficient	The ODEs were found analytically
Reliable	The code passed through several tests

Flight Testing

2.2 Flight Testing

- Short term goals:
  - get real data about the state of the kite and the tethers.
  - get knowledge on experimental activities.
- Medium-term goals:
  - mix real data and simulations to characterize the aerodynamic coefficients of the kite (estimation-before-modeling technique).

2.2 Flight Testing

On-board instruments:

- Inertial navigation unit (GPS, accelerometer, gyroscopes)
- Pitot tube.

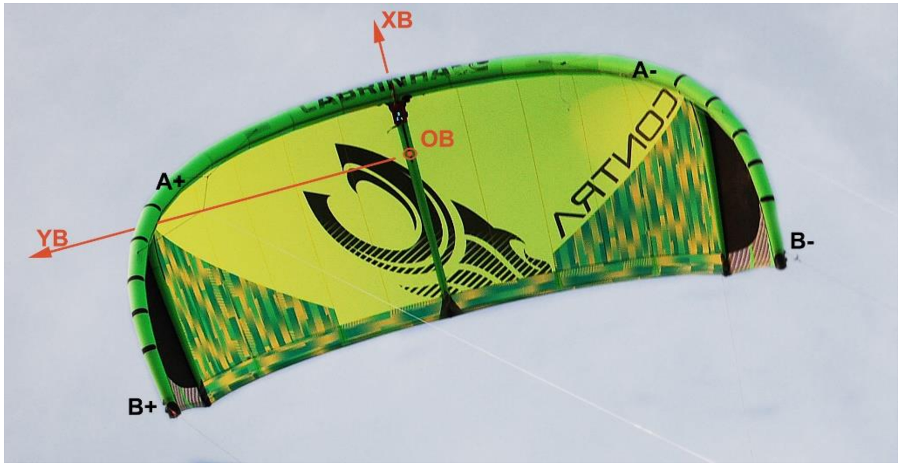
On-ground instruments:

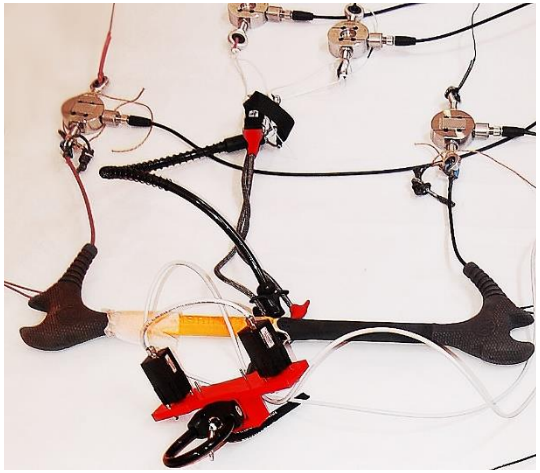
- Load cells
- Position sensors
- Weather station

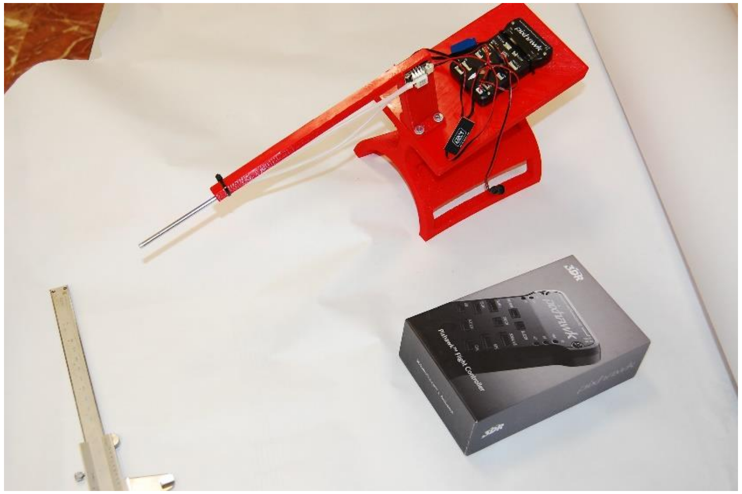
Methodology:

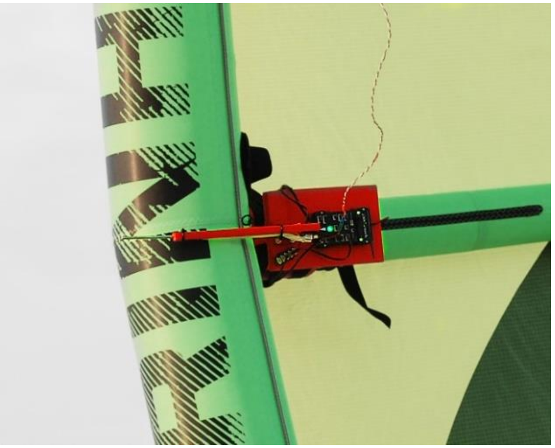
- Iterative process: starting with cheap and low-quality sensors followed by upgrading phases.
- We are now working with the second iteration.

2.2 First iteration

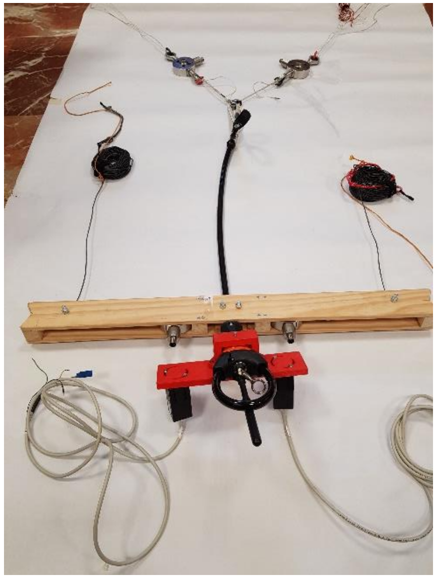




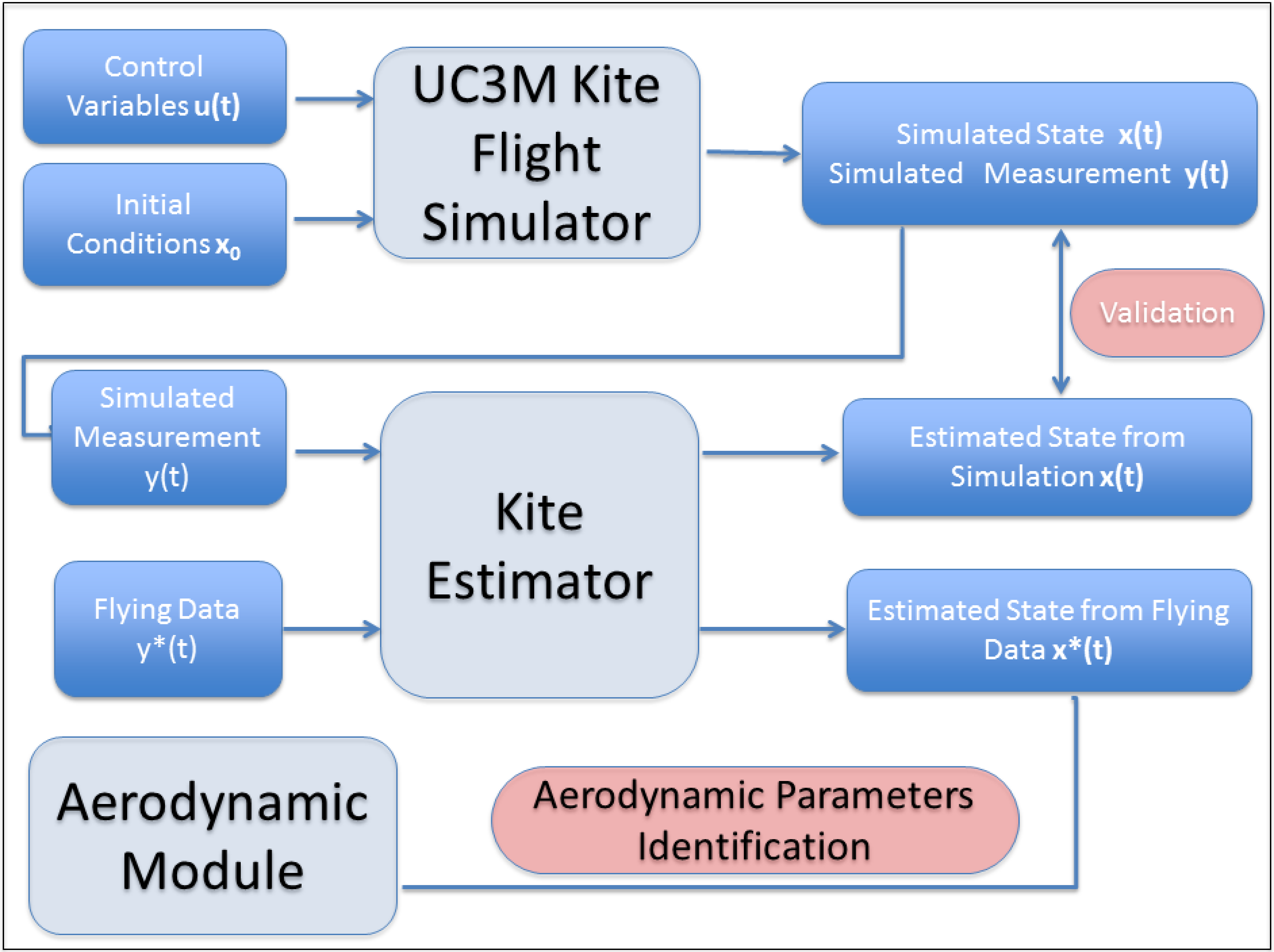




2.2 Second Iteration



2.2 Second Iteration


Control Variables u(t)
Initial Conditions x0
UC3M Kite Flight Simulator
Simulated State x(t)
Simulated Measurement y(t)
Validation
Simulated Measurement y(t)
Kite Estimator
Estimated State from Simulation x(t)
Flying Data y*(t)
Estimated State from Flying Data x*(t)
Aerodynamic Module
Aerodynamic Parameters Identification

Dissemination

2.3 Dissemination and networking

- Spain has started late the research on AWEs.
- Apparently, UC3M is the only active group on AWEs in Spain.
- One of the goals of the project is to disseminate AWEs technologies among both general public, students, and scientific audience.
- Up to now the project has connected UC3M with several institutions (TU Delft, University of Freiburg, INTA, Politecnico of Torino, and Kyushu University).
- The following actions were carried out:
  - Organization of an exposition at Semana de la Ciencia de Madrid 2016 (also in November 2017).
  - 1 ongoing PhD thesis, 2 Master thesis, and 6 B.S thesis.
  - Mr. Hiroki Endo Kyushu Sangyo University visited us in 2017.
  - Dr. Antonello Cherubini visited us in 2017 and delivered a course.

3. Objectives of the visit and work plan at University of Freiburg

- **Objectives of the visit:**
  - Interact with researchers from University of Freiburg, share information, and look for sinergies.
  - Get your first-hand opinion about our simulators.
  - If you wish, share with you our Matlab codes and give support on how to use them.

- **Work Plan is open but there are already some ideas….**
  - Comparison of LAKSA modules with your code (efficiency, computational cost, robustness, ….)
  - Link LAKSA with close-loop controllers and optimal solvers.

Publications on AWE Systems

1. G. Sánchez-Arriaga. Dynamics and control of singled-line kite. The Aeronautical Journal, 2006.
2. L. Salord and G. Sánchez-Arriaga. Flight dynamics and stability of kites in steady and unsteady wind conditions, J. Aircraft 52, 660-666, 2015
3. J. Alonso Pardo and G. Sánchez-Arriaga. A kite model with bridle control for wind power generation, J. Aircraft 52, 3, 917-923, 2015.
4. A. Pastor-Rodríguez, G. Sánchez-Arriaga, M. Sanjurjo-Rivo, Modeling and Stability Analysis of Tethered Kites at High Altitudes, J. of Guidance, Control, and Dynamics, 40, 8, 1892-1901, 2017.
5. G. Sánchez-Arriaga, M. García-Villalba, and R. Schmehl, Modeling and Dynamics of a Two-Line Kite, Applied Mathematical Modelling 47:473–486, 2017.
6. G. Sánchez-Arriaga, A. Pastor-Rodríguez, R. Borobia-Moreno, and R. Schmehl, A constraint-freeflight simulator package for airborne wind energy systems, Journal of Physics Conf. Series, 062018, 2018.
7. R. Borobia-Moreno, G. Sánchez-Arriaga, A. Serino, and R. Schmehl, Flight Path Reconstruction and Flight Test of Four-line Power Kites, Journal of Guidance, Control and Dynamics, 2018.
8. A Lagrangian Flight Simulator for Airborne Wind Energy System, G. Sánchez-Arriaga, A. Pástor-Rodríguez, M. Sanjurjo-Rivo, and R. Schemehl, submited.

* Find these papers in ResearchGate.