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

Dr. G. Sánchez-Arriaga
Bioengineering and Aerospace Engineering Department
Universidad Carlos III de Madrid

August 2018
Index

1. Introduction
2. Ongoing activities at UC3M.
   2.1 Development of kite simulators.
   2.2 Flight testing and aerodynamic characterization
   2.3 Dissemination and networking
3. Objectives of the visit and work plan at Freiburg.
Introduction

Short Bio


• **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, etc.

• 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**

<table>
<thead>
<tr>
<th>KiteFlex</th>
<th>KiteAcrobat</th>
<th>KiteSurf</th>
<th>KiteTrain</th>
<th>KiteElastic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rigid Aircraft</td>
<td>Rigid Aircraft</td>
<td>Rigid Aircraft</td>
<td>N Aircraft</td>
<td>Arbitrary number</td>
</tr>
<tr>
<td>1 flexible</td>
<td>2 inelastic</td>
<td>2 rigid + 2</td>
<td>2N rigid</td>
<td>of aircraft and</td>
</tr>
<tr>
<td>tether, bridle,</td>
<td>tetherers</td>
<td>elastic tetheres</td>
<td>tethers</td>
<td>tethers</td>
</tr>
<tr>
<td>generators</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Language</strong></td>
<td></td>
<td></td>
<td></td>
<td>Matlab</td>
</tr>
<tr>
<td>Matlab, Fortran</td>
<td>Matlab</td>
<td>Matlab</td>
<td>Matlab</td>
<td>Matlab</td>
</tr>
<tr>
<td>Paralelizado</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FlyGen &amp;</td>
<td>Traction</td>
<td>UC3M Experimental</td>
<td>FlyGen</td>
<td>Generic</td>
</tr>
<tr>
<td>GroundGen</td>
<td></td>
<td>Setup</td>
<td></td>
<td>Systems</td>
</tr>
</tbody>
</table>

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

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

LAKSA Simulators

- KiteFlex
- KiteAcrobat
- KiteSurf
- KiteTrain
- KiteElastic

Initial Conditions → Dimensionless Parameters → LAKSA Simulators → Postprocess Results → Plot Results
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
Dissemination
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).
- 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 synergies.
  • 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.


* Find these papers in ResearchGate.