Cable models for Launching and Landing of the Ampyx Power AWE system

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AWESCO Kick-off Week

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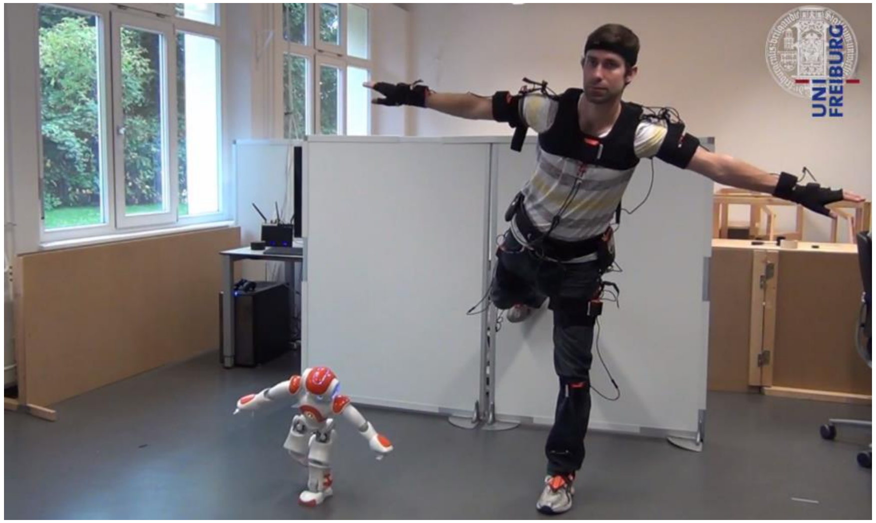
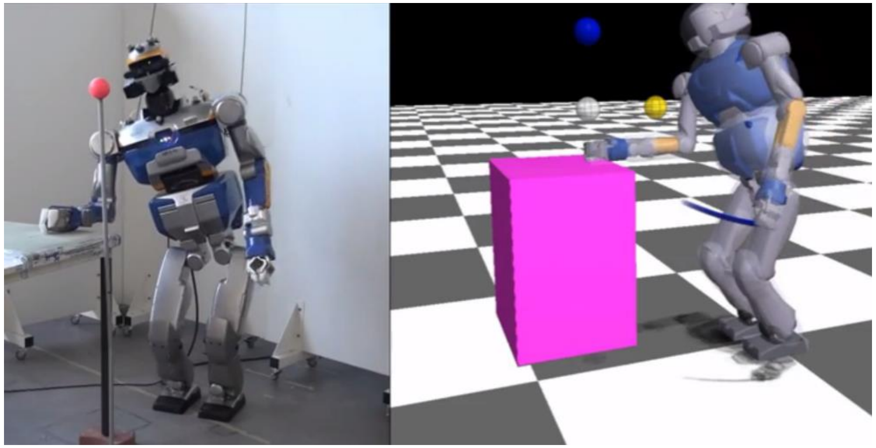
About me

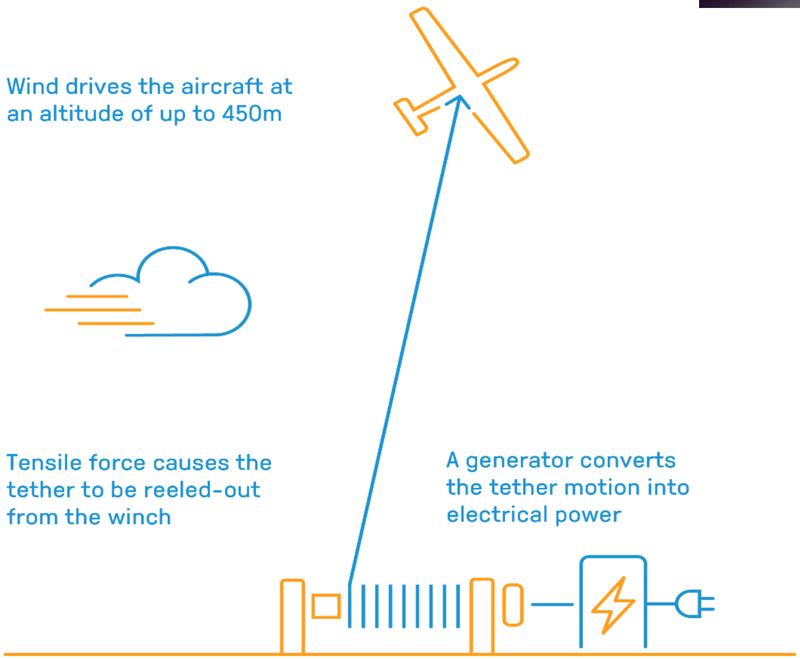
- Master Computer Science at University of Freiburg
- Humanoid Robots Lab Freiburg
  - Motion Capture
  - Robot Kinematics
- LAAS-CNRS Toulouse
  - Robot Dynamics
  - Model Predictive Control
- SYSCOP Freiburg
  - Teaching Assistant
  - Model Predictive Control of Rotational Launch

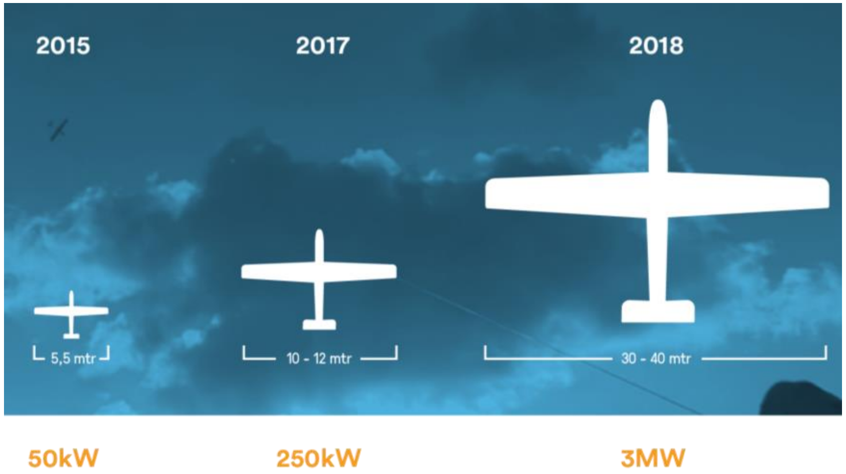




Ampyx Power

- Located in the Hague, the Netherlands
- Founded in 2009
- ~40 employees





Introducing my PHD topic

My PHD topic

Launching and Landing of tethered aircrafts for Airborne Wind Energy

Why investigate L&L

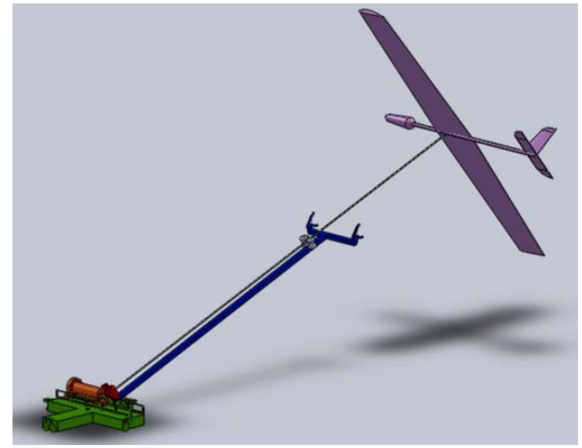
- Mostly unsolved problem
- L&L is critical for AWE systems
  - Strong winds, no wind
  - Maintenance

Main requirements

- Fully autonomous
- Robust
- Small coverage area

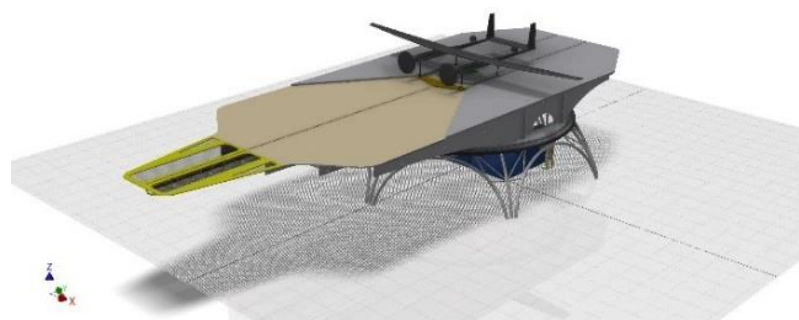
Ampyx L&L history

2010-2016



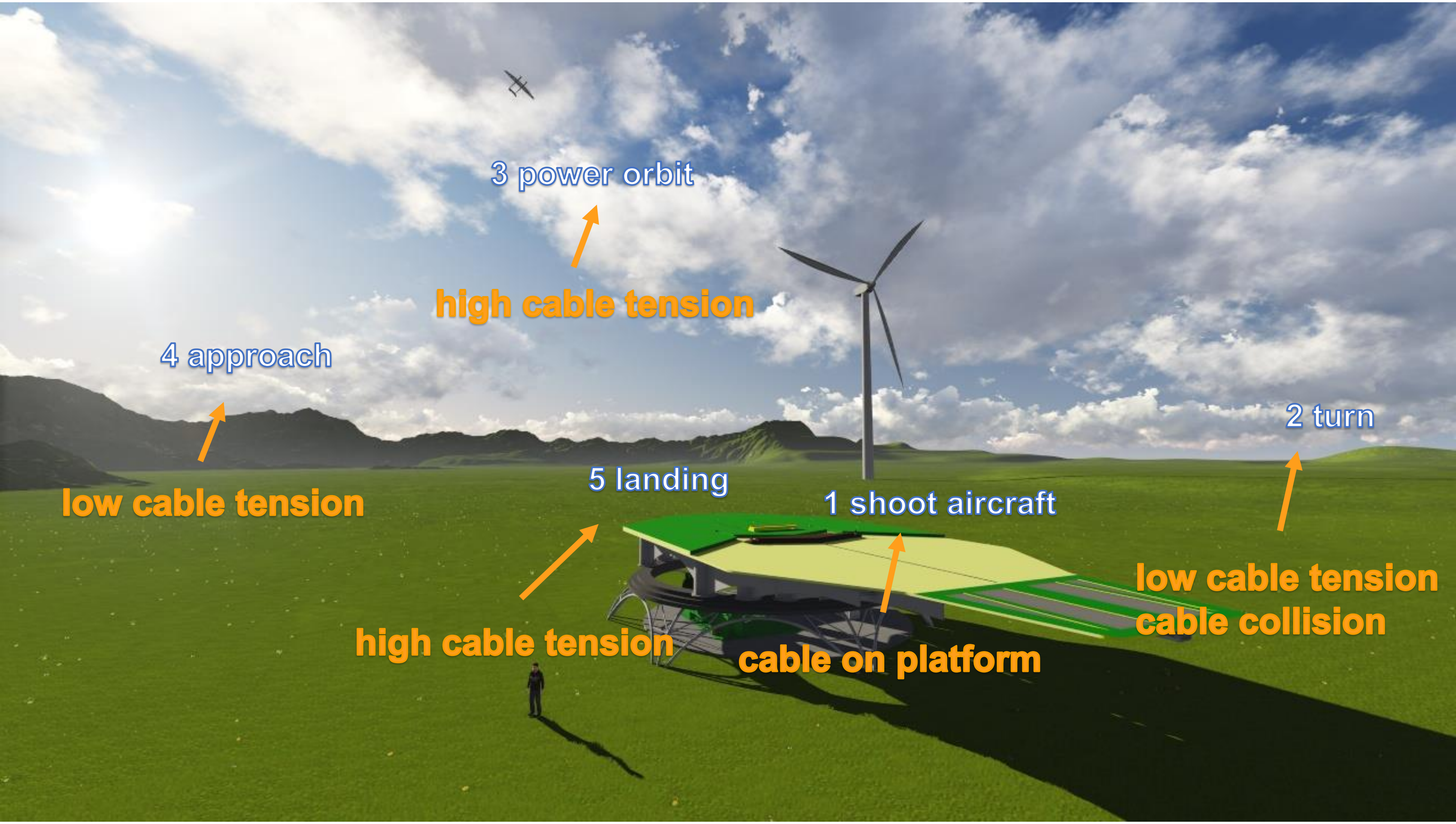
2010

2015



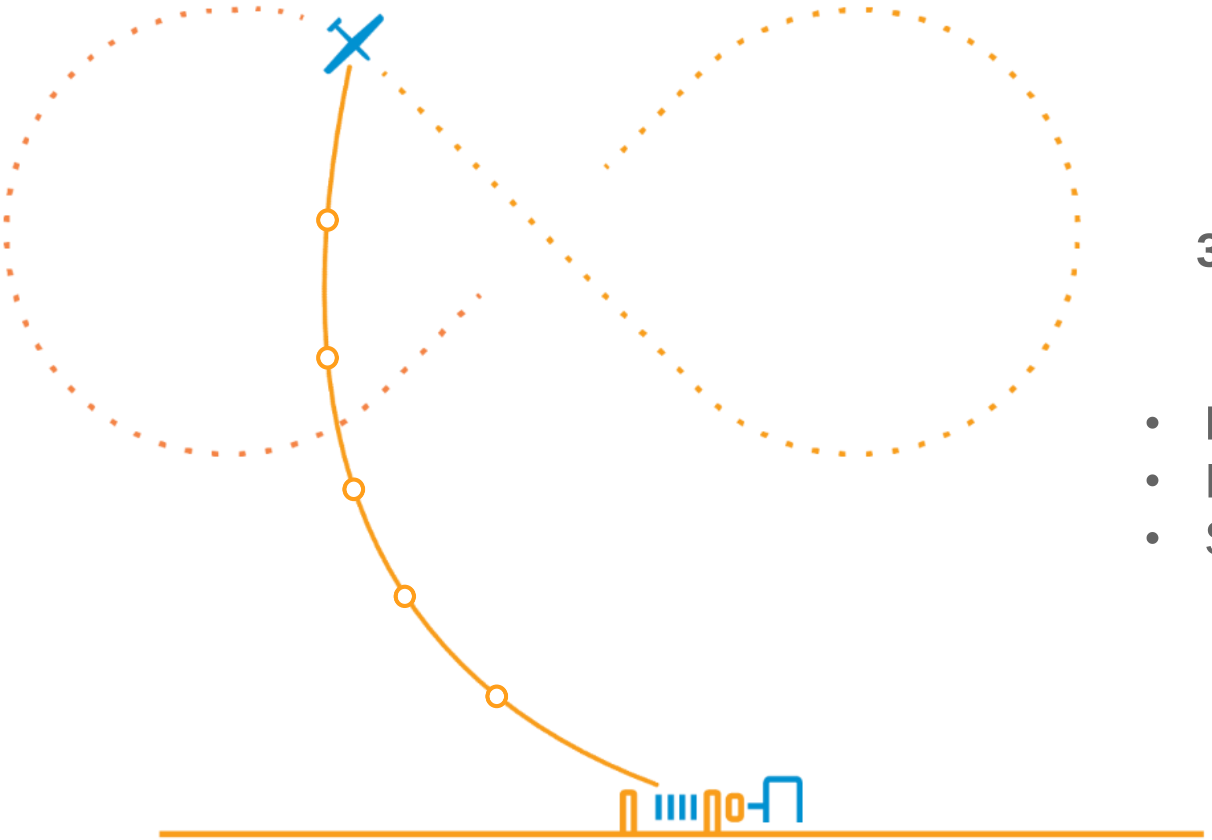
2016

The Ampyx L&L platform



Results on cable modeling

Cable models

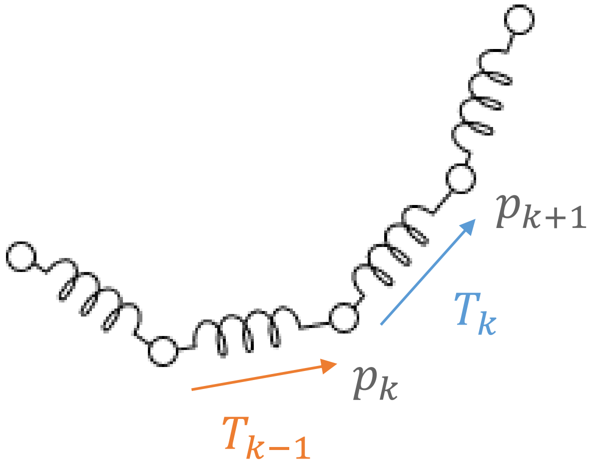


3 implementation of cable models

- Elastic cable ODE model
- Inelastic cable DAE model
- Static cable model

Elastic cable model

- Elements connected by springs
- Model of elasticity
- Simple to implement



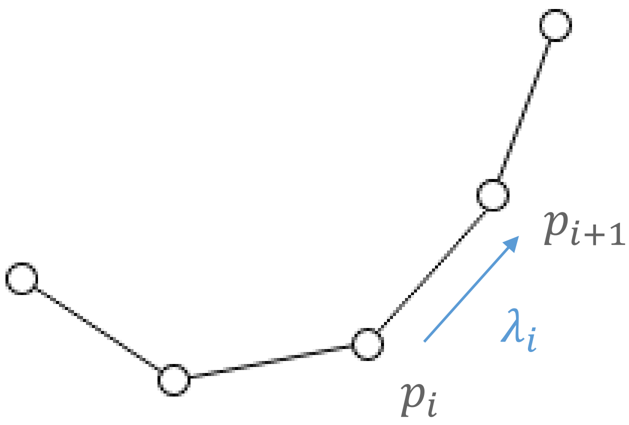
$$F_k = T_k - T_{k-1} - F^G - F_k^D$$

$$T_k = \frac{EA}{l_0}\left(\|p_{k+1} - p_k\| - l_0\right)\frac{p_{k+1} - p_k}{\|p_{k+1} - p_k\|}$$

- Contraction implausible
- Stiff equations

Inelastic cable model

- Inextensible cable
- DAE formulation
- Less stiff equations



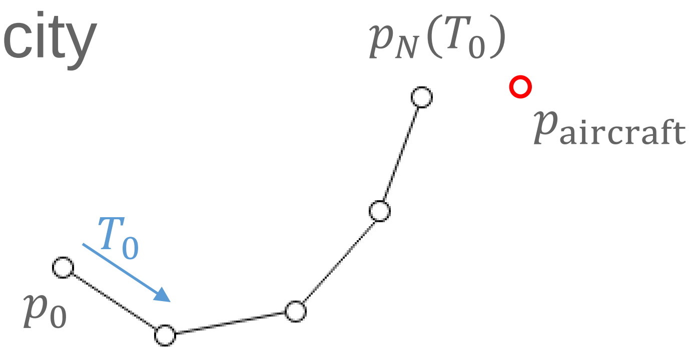
$$c_i = \frac{(v_i - v_{i-1}) \cdot (p_i - p_{i-1})}{\|p_i - p_{i-1}\|} - s_{\text{node}} \quad \text{for } i = 1 \ldots N$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial L}{\partial p_i}\right) - \frac{\partial L}{\partial v_i} - Q_i - \sum_{k=1}^{N} \lambda_k \frac{\partial c_k}{\partial v_i} = 0 \quad \text{for } i = 1 \ldots N$$

- Constraint stabilization
- No model of elasticity

Static cable model

- Solve for cable shape (equilibrium configuration)
- Cable dynamics are neglected
- Accounts for extension due to elasticity



$$\underset{x}{\text{Minimize}} \quad p_N(x) - p_{\text{aircraft}}$$

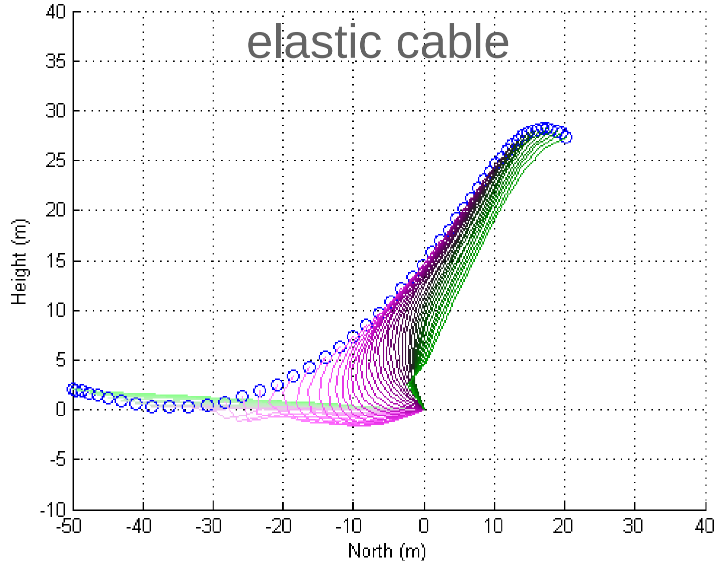
Get $p_N(x)$ by iterative algorithm

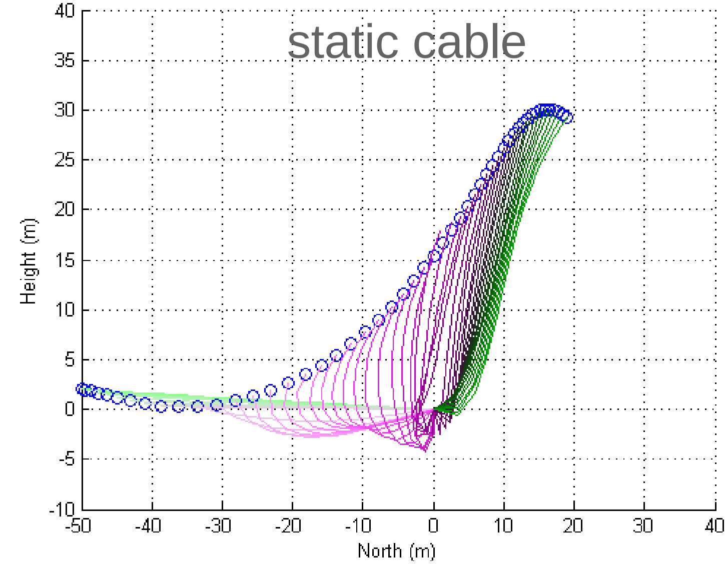
$$p_0 = p_{\text{winch}}, \qquad T_0 = x$$

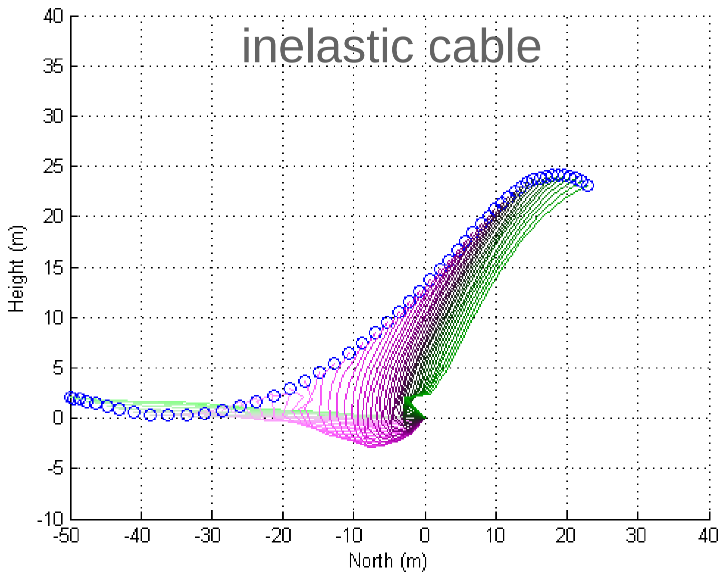
$$p_{k+1} = p_k + \frac{\|T_k\|}{EA}\frac{l_{\text{cable}}}{N}\frac{T_k}{\|T_k\|}$$

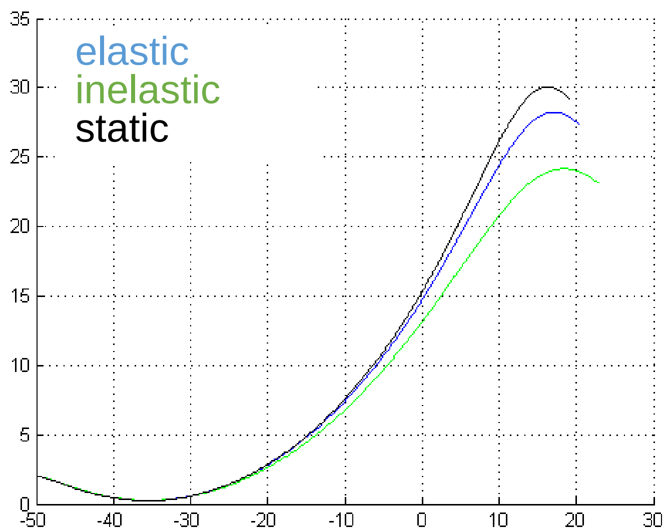
$$T_{k+1} = T_k + m\omega \times (\omega \times p_k) - F^G - F_k^D$$

Launch Simulations









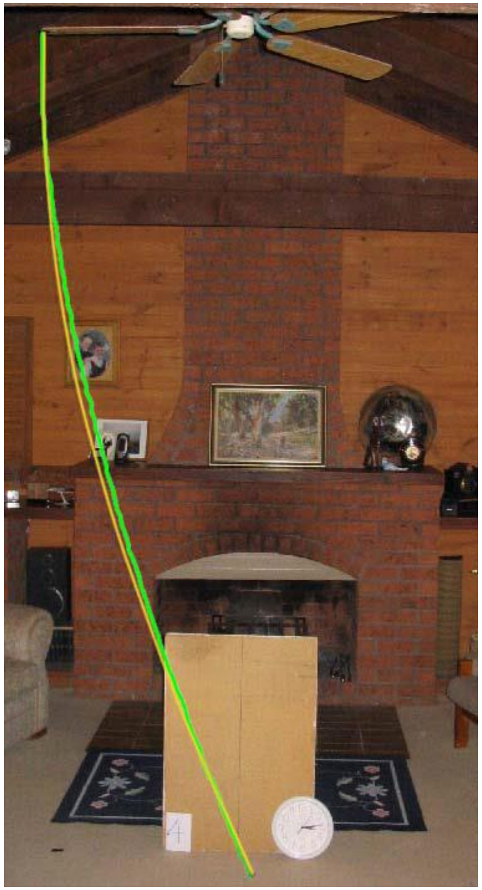
Cable Model Conclusion

- What do the true cable dynamics look like?
- What happens during reeling?

- Perform real experiments
- Derive model from PDE formulation

- Which level of detail do we need to model for trajectory optimization?

- Cables are hard to predict



Courtesy of Paul Williams

My research plan

Research plan

1

Modeling

- Aerodynamics
- Cable dynamics
- Contact dynamics

2

Optimization

- Launch trajectory to power orbit
- Trajectory from power orbit to landing platform

3

Control

- Follow trajectories in a robust way

Software

- Rigid body dynamics and aerodynamics toolbox
- 3D Visualization

- Toolbox for AWE systems optimization with optimal control algorithms

- Model based control toolbox for AWE systems

Secondments

- Interesting for me
  - Sebastien Gros, Chalmers University
  - Colin Jones, EPFL
  - Roy Smith, ETHZ
  - Moritz Diehl, University of Freiburg

- External
  - H.G. Bock or Katja Mombaur, University of Heidelberg
  - Oussama Khatib or Stephen Boyd, Stanford University
  - Emanuel Todorov, University of Washington

Modeling Dynamics of the Ampyx AWE System for Launching and Landing Optimization

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