Autonomous Take Off and Flight of a Tethered Glider for Airborne Wind Energy

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

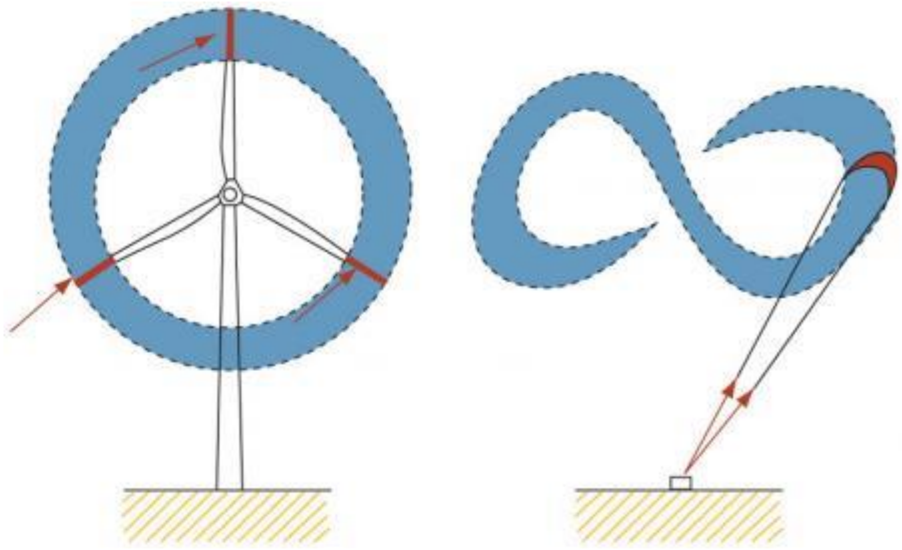
Eric Nguyen Van

ABB

Content

- Introduction, Preliminary Work & Objectives
- Autopilot Design
- Controller Design
- Simulation : Review & Results
- Autonomous Flight Results
- Conclusion and Future Work

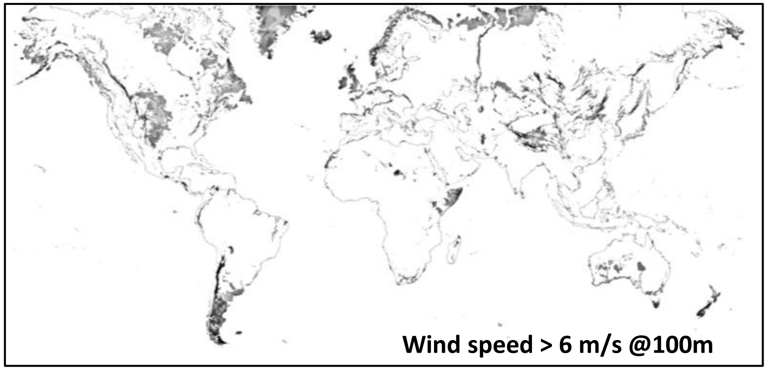
Introduction

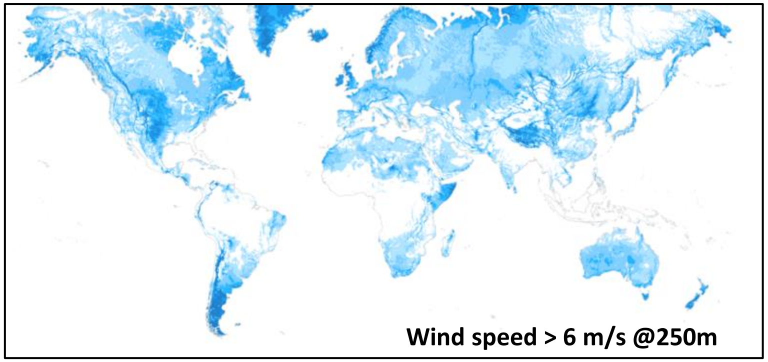


Airborne Wind Energy (AWE) : the concept

Introduction

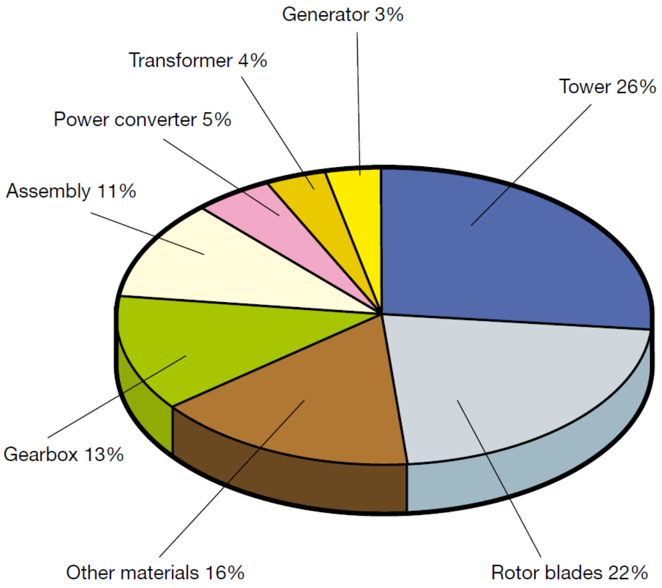
Advantages of AWE





Source Makani Power

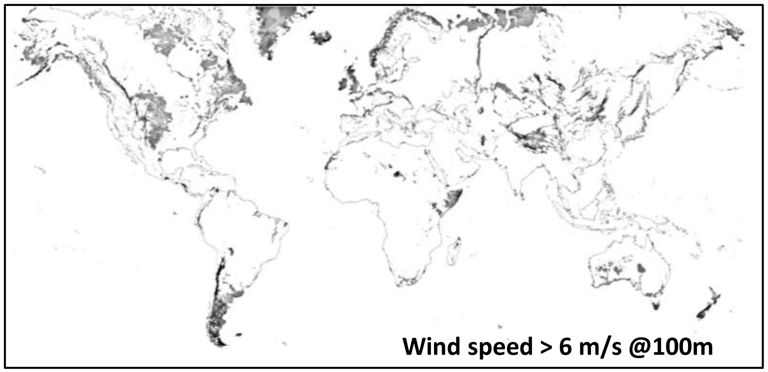
Wind exposition

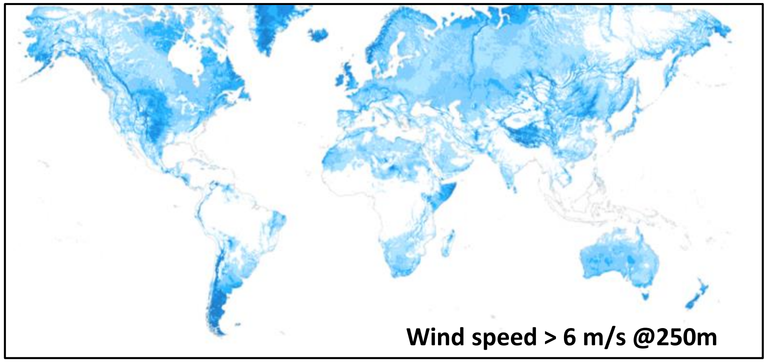


Installation Cost

Introduction

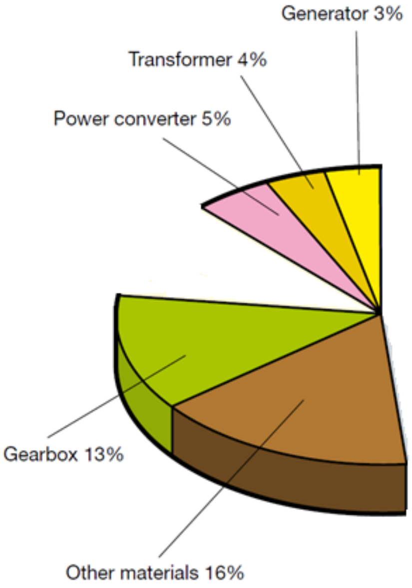
Advantages of AWE





Source Makani Power

Wind exposition



Installation Cost

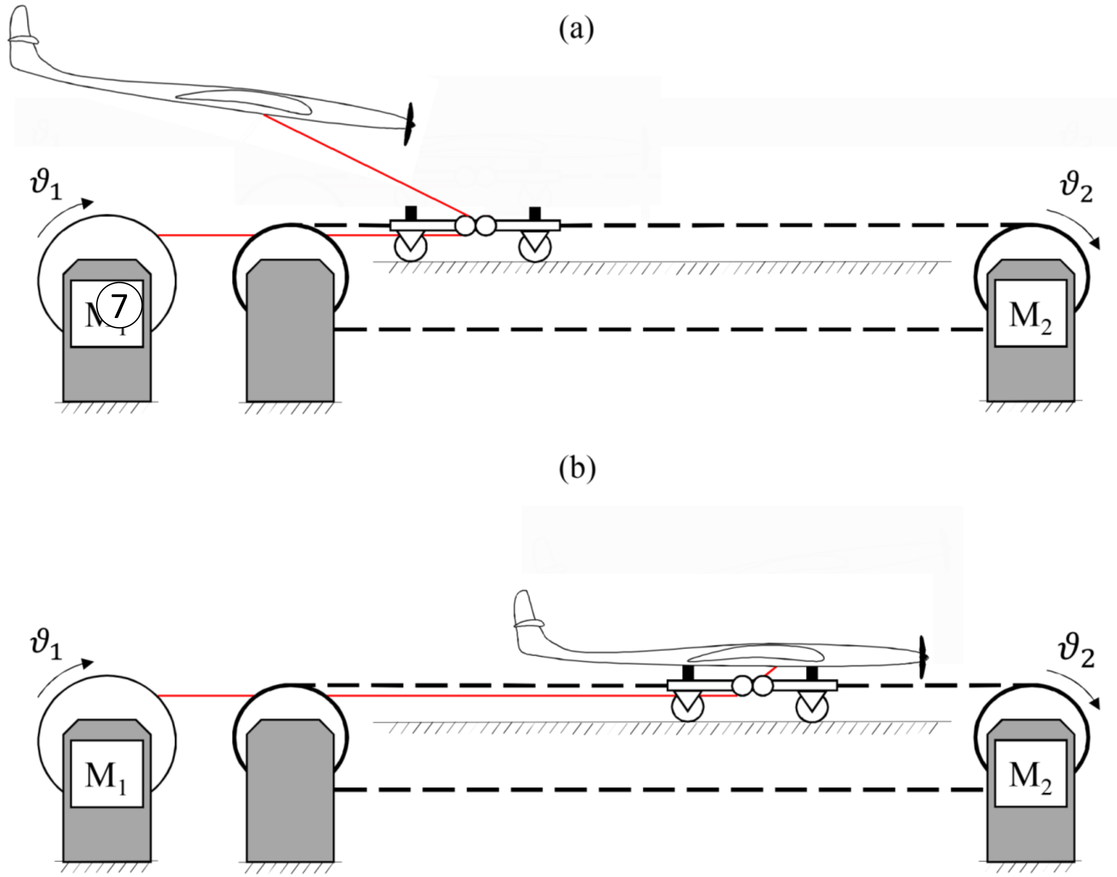
Introduction

Ampyx Power : ground based generation with rigid wing

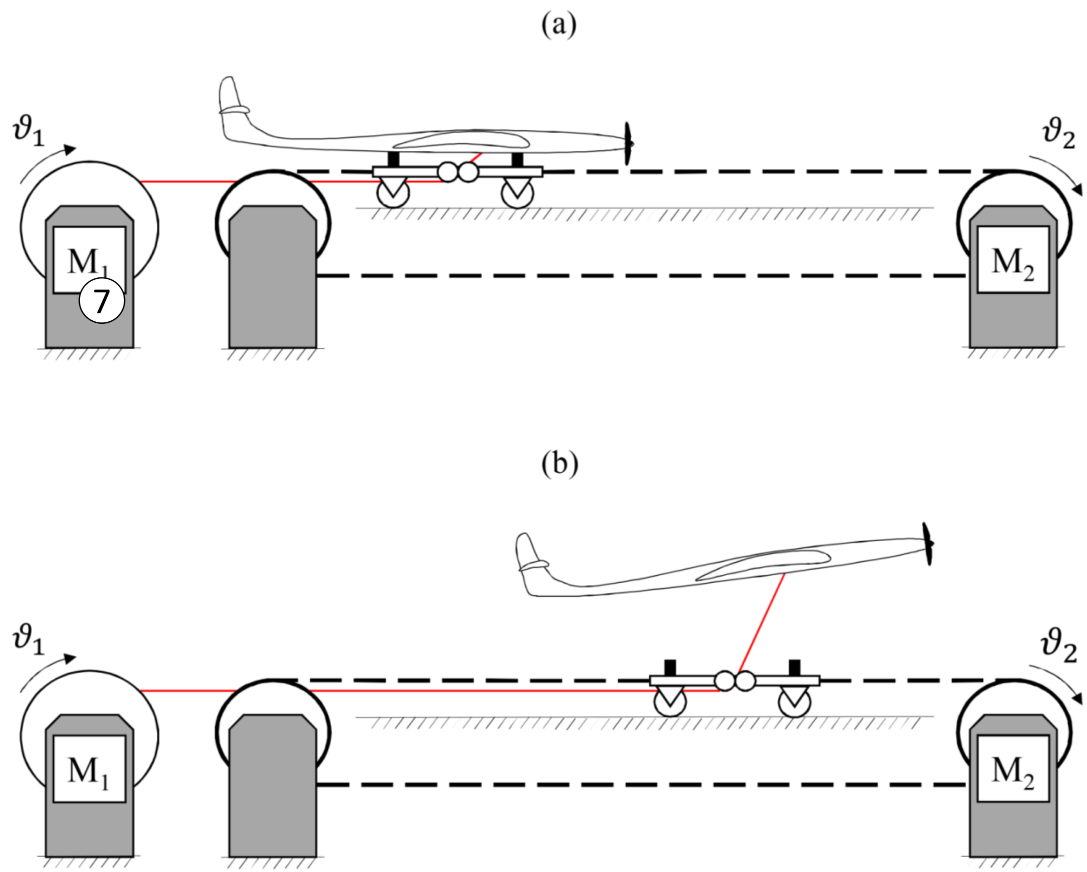
Project at ABB

- Assess the technical and economical feasibility of take off for AWE.
- Build and test a small scale prototype to accomplish take off and landing in a compact area.
- Linear launch and on-board propulsion.

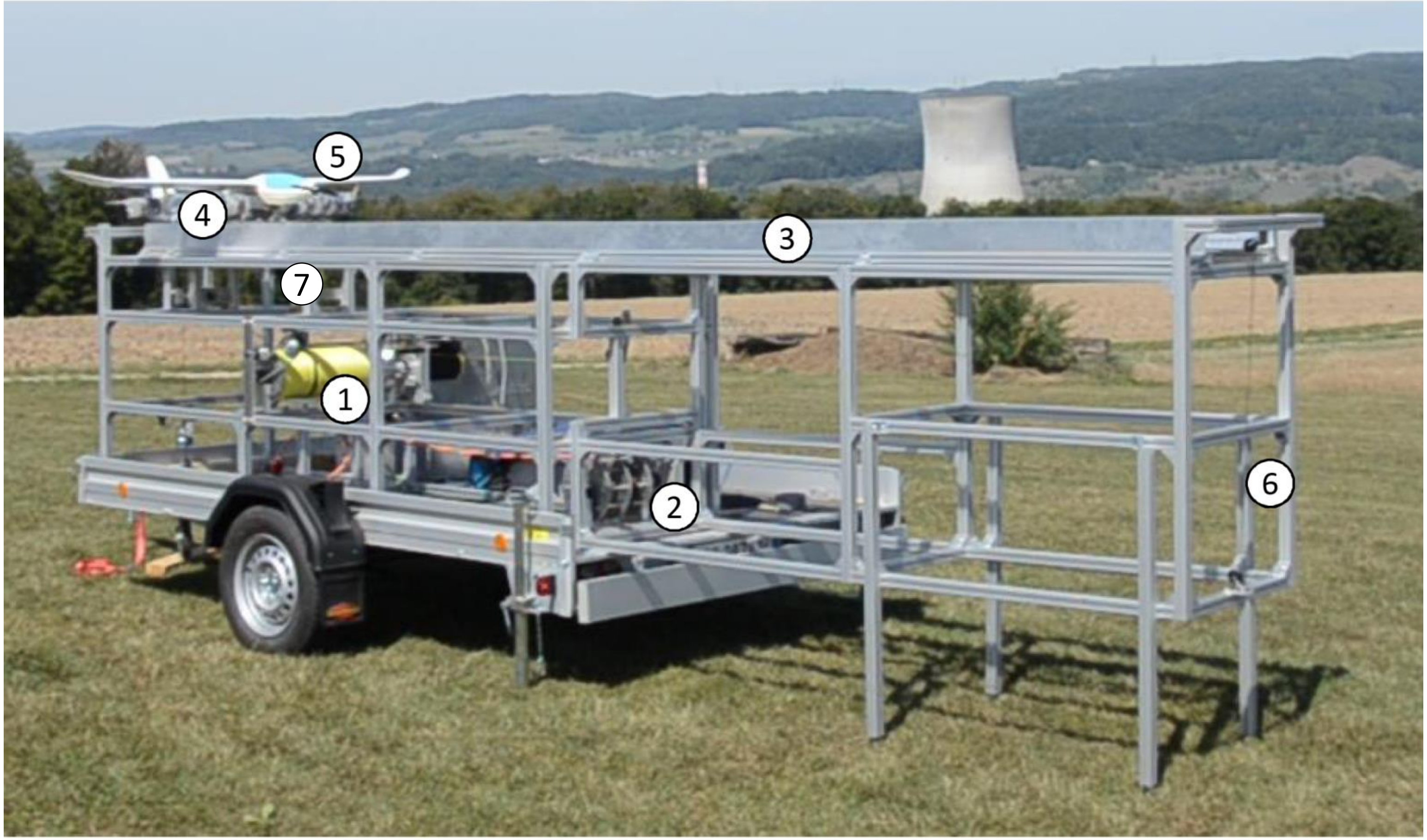
Project at ABB



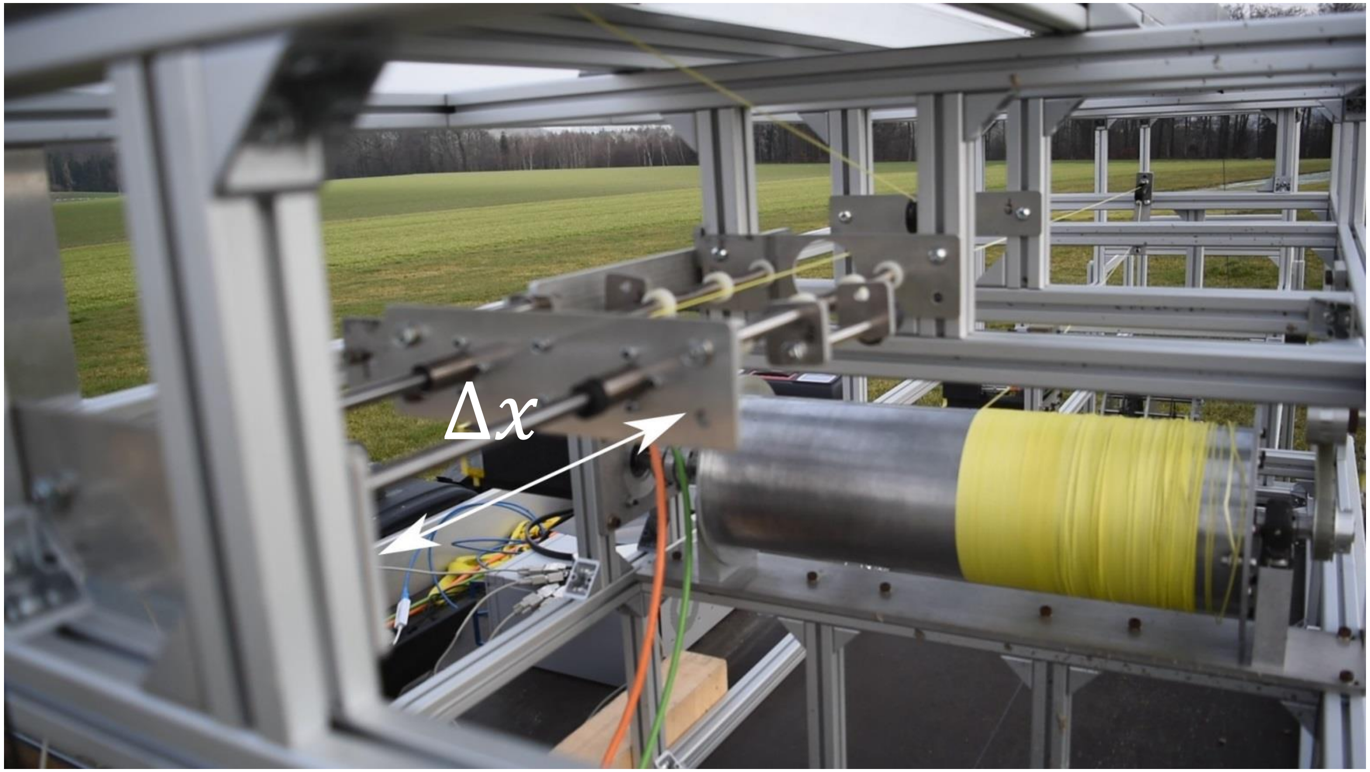
Project at ABB



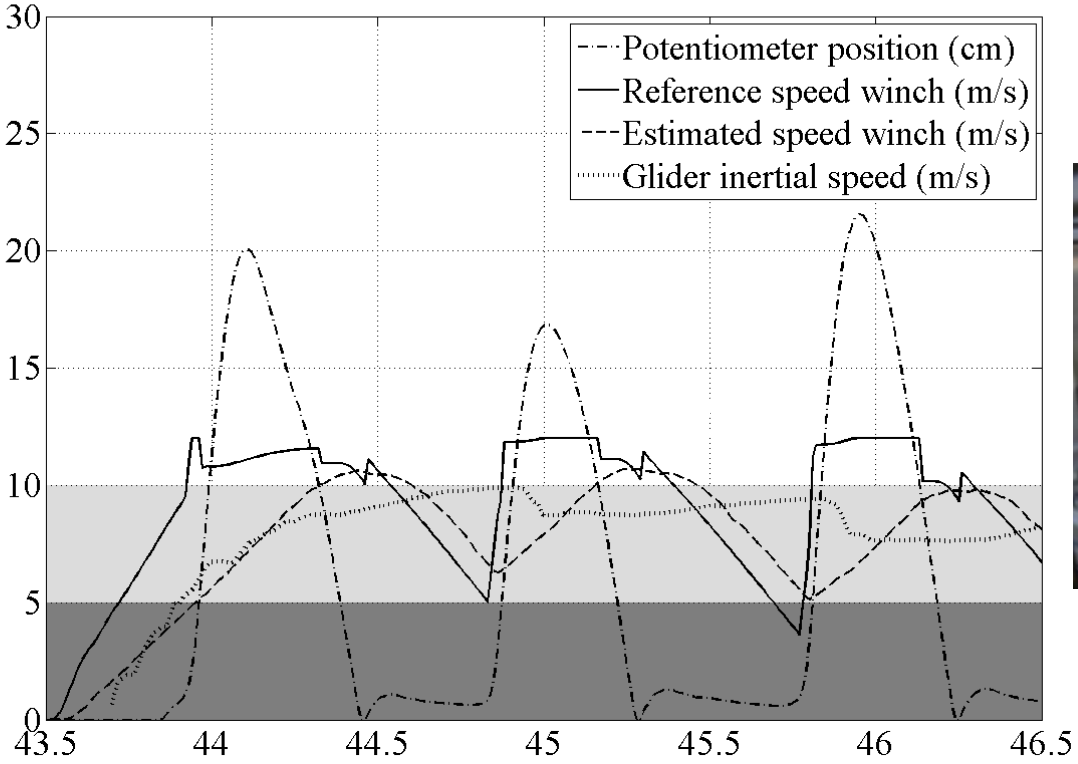
Project at ABB

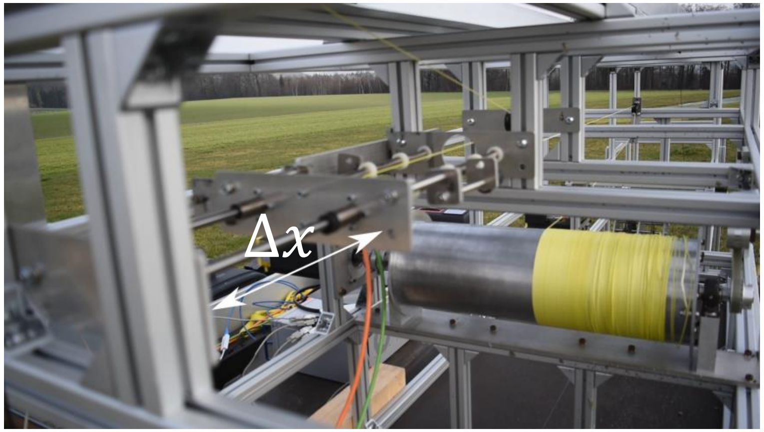


Preliminary Work



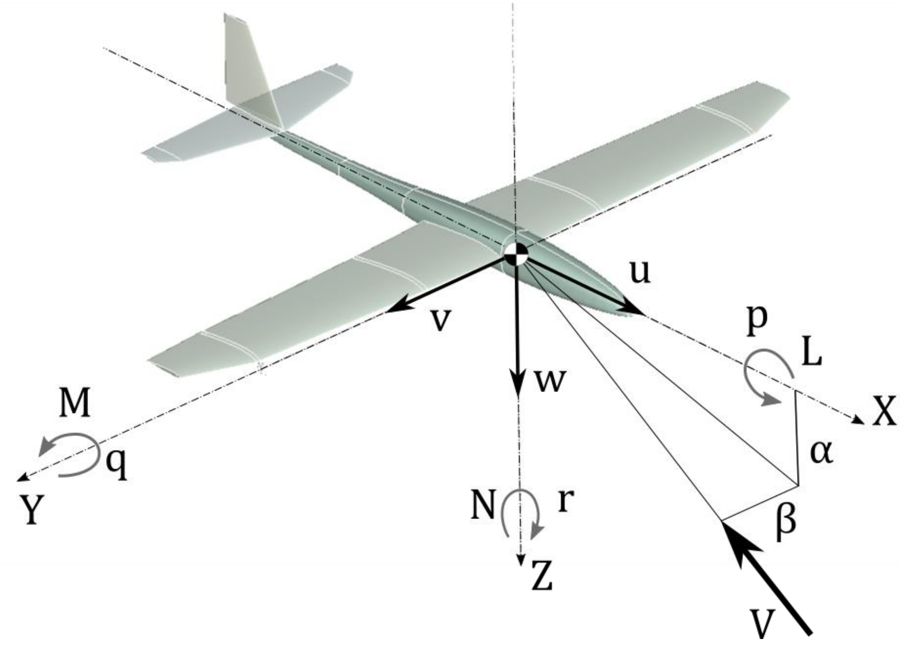
Preliminary Work





Simulation Study

- 6 degrees of freedom aircraft model
- Aerodynamic coefficients obtained by numerical simulation



Simulation Study

- Simulation study

Autonomous take-off and landing of a tethered aircraft:
a simulation study

Eric Nguyen Van, Lorenzo Fagiano and Stephan Schnez*†

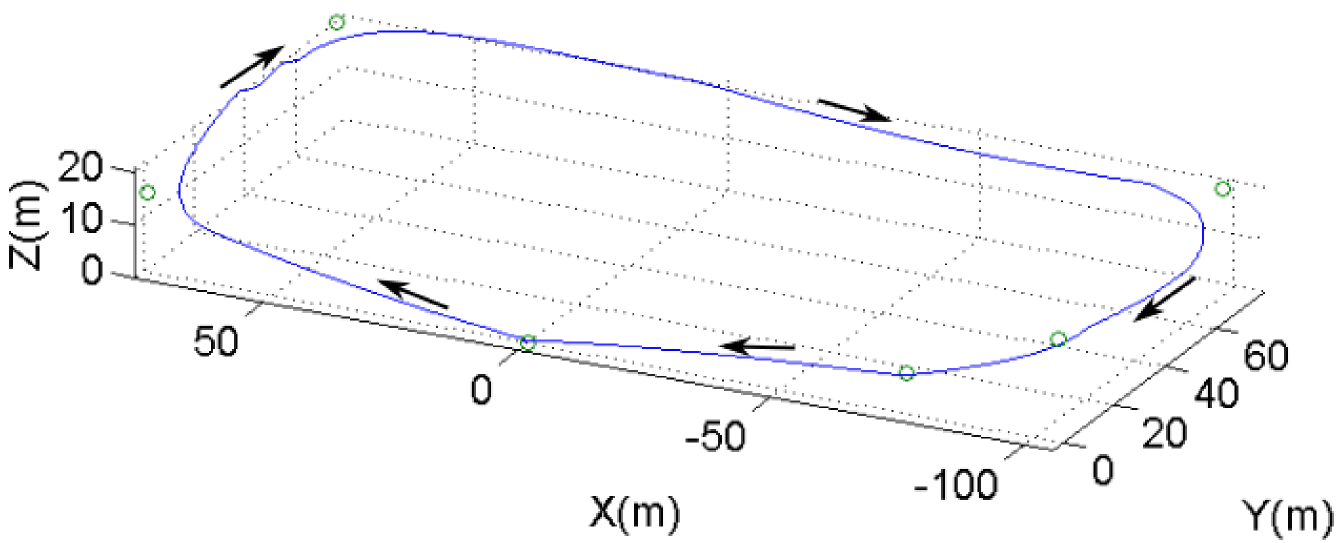
Abstract

The problem of autonomous launch and landing of a tethered rigid aircraft for airborne wind energy generation is addressed. The system operates with ground-based power conversion and pumping cycles, where the tether is repeat-

31, 8]. Small-scale prototypes (10-50 kW of rated power) of the mentioned concepts have been realized and successfully tested to demonstrate their power generation functionalities. Moreover, scientific contributions concerned with technical aspects like aerodynamics [10, 11, 9, 16, 25], controls [24, 12, 6, 14, 21, 17, 22, 34, 13, 35], resource assessment

Simulation Study

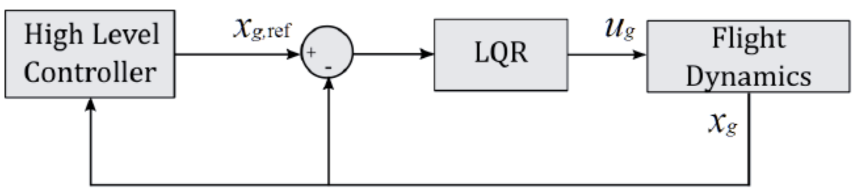
- Simulation study



Simulation Study

- Simulation study

-Linearised model of untethered glider
-Hierarchical controller



-LQR low level controller
-Ground station and glider decoupled

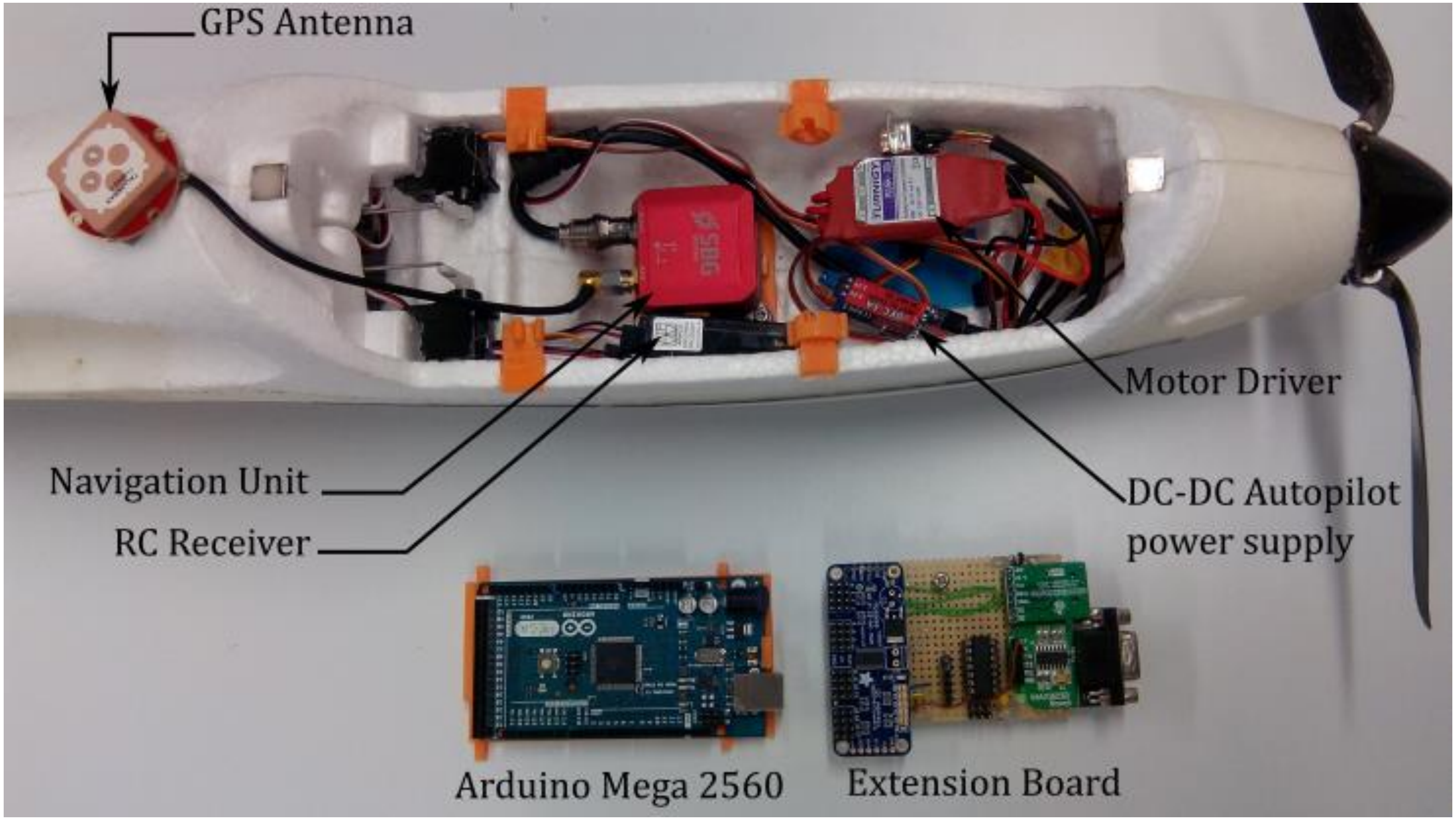
Objectives

- PDM goals
    I. Manual tethered take-off
    II. Automatic flight
    III. Automatic tethered flight
    IV. Automatic tethered take-off and flight

Content

- Introduction, Preliminary Work & Objectives
- **Autopilot Design**
- Controller Design
- Simulation review and results
- Autonomous Flight results
- Conclusion and future work

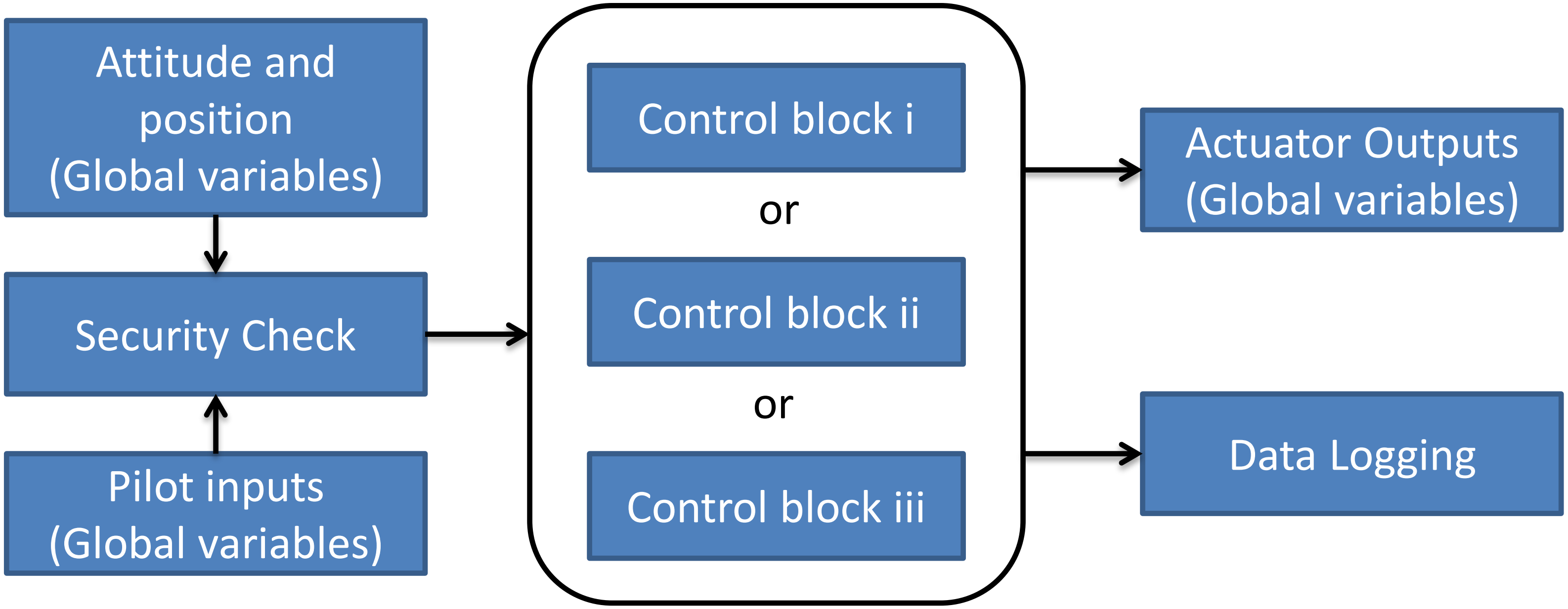
Autopilot



GPS Antenna
Motor Driver
Navigation Unit
RC Receiver
DC-DC Autopilot
power supply
Arduino Mega 2560
Extension Board

Autopilot

Software Architecture

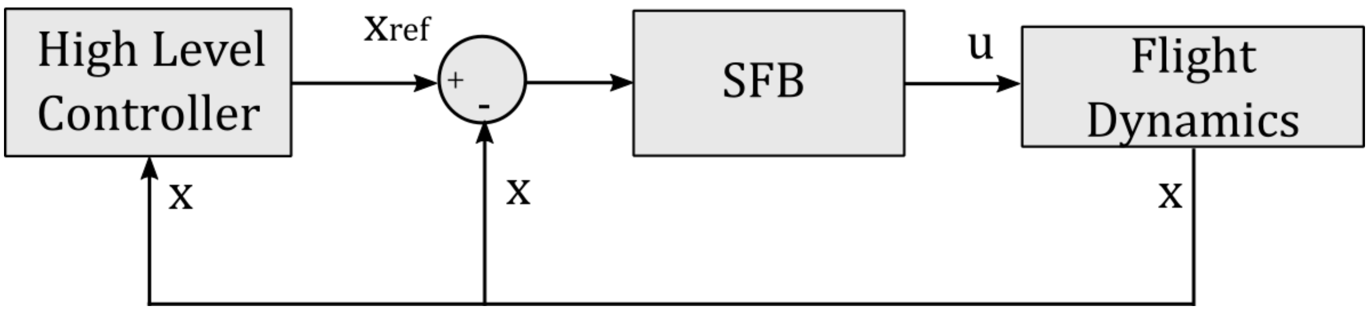


Content

- Introduction, Preliminary Work & Objectives
- Autopilot Design
- **Controller Design**
- Simulation review and results
- Autonomous Flight results
- Conclusion and future work

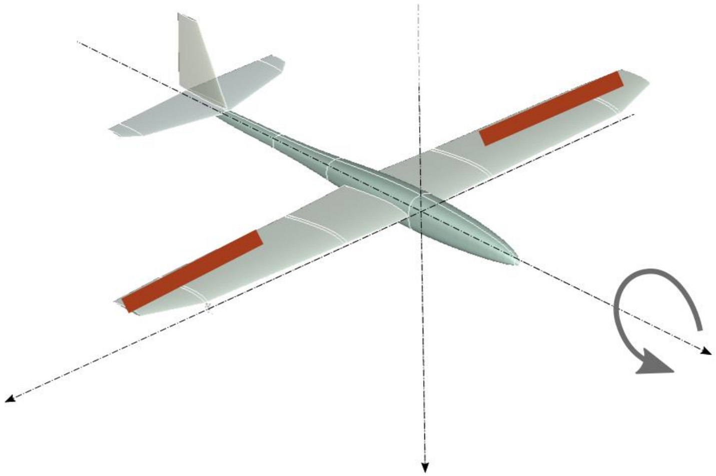
Controller Design

- Controller selected:
  - ‘Decoupled’ State Feedback (SFB)

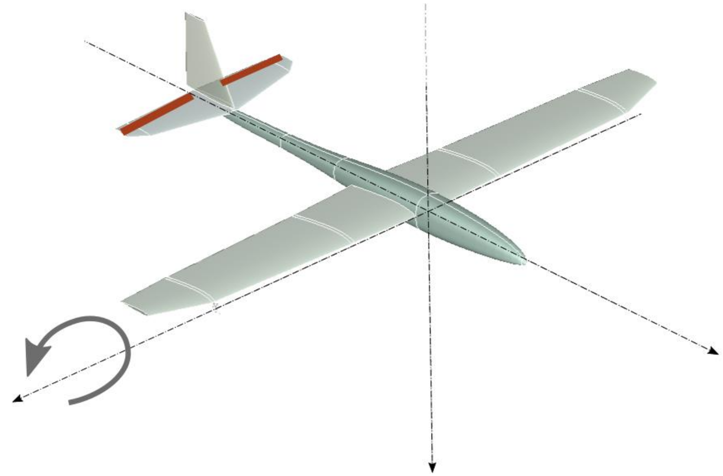


Controller Design

- Control inputs : standard
  - Ailerons -> Roll
  - Elevator -> Pitch



Ailerons -> Roll

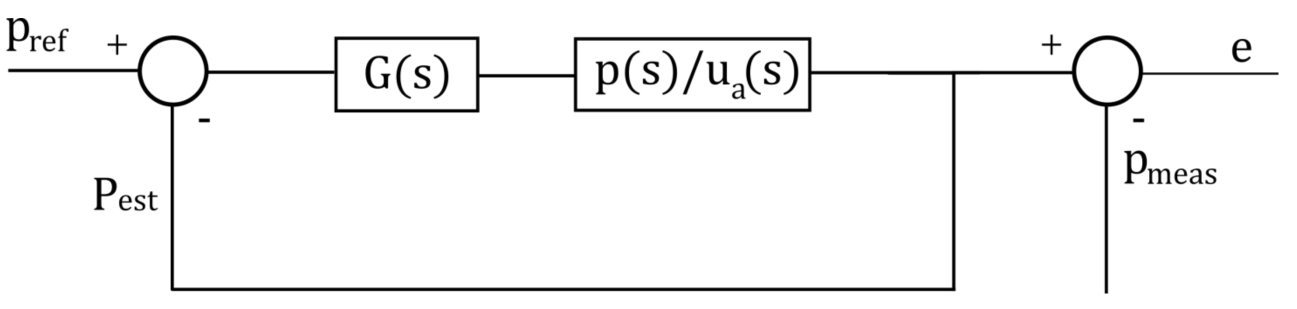


Elevator -> Pitch

Controller Design

- Parameter Identification for first order plant

$$p(s) = \frac{k_p}{\frac{s}{\omega_n} + 1} u_a(\mathrm{s})$$



Controller Design

- Parameter Identification for first order plant

$$p(s) = \frac{k_p}{\frac{s}{\omega_n} + 1} u_a(\mathrm{s})$$

$$\dot{p} = a \cdot p + b \cdot u_a$$

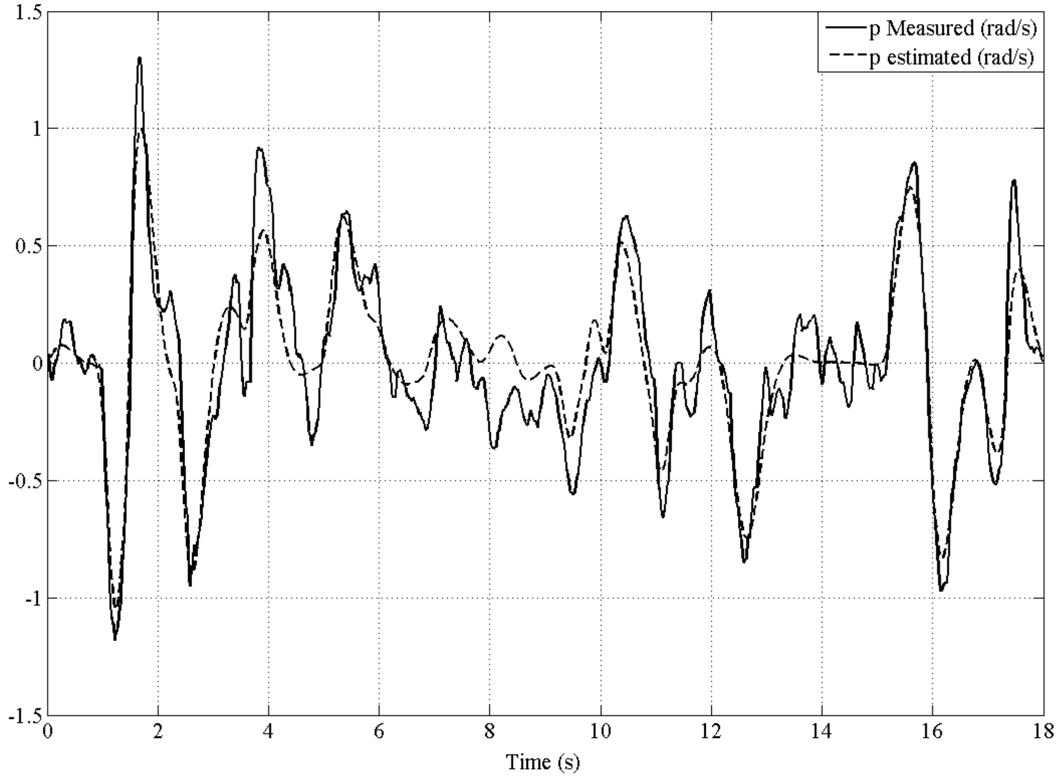
$$\min_{a,b} \| p_{est} - p_{meas} \|$$

$$\dot{p}_{est} = a \cdot p_{est} + b \cdot u_{a,meas}$$

$$p_{est}(0) = p_{meas}(0)$$

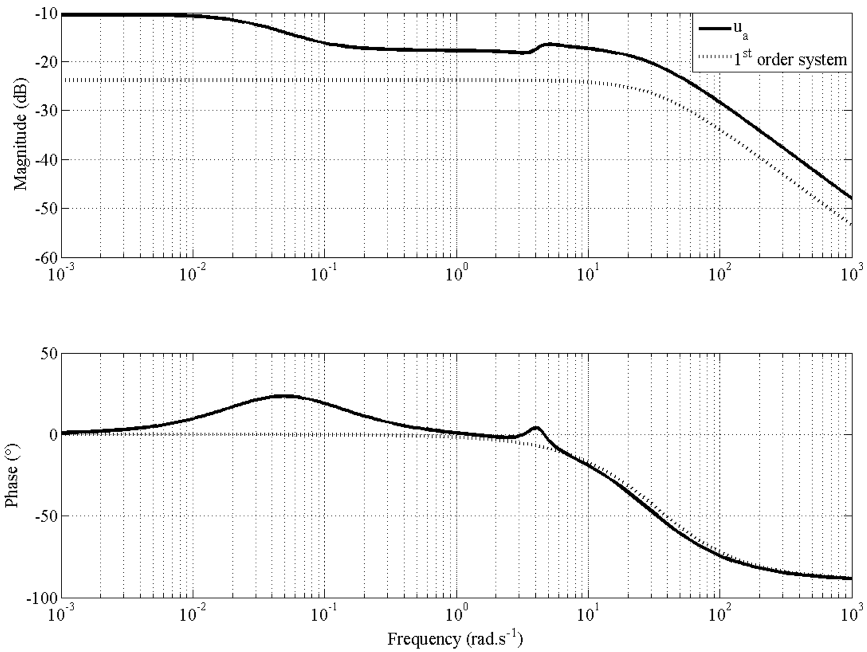
Controller Design

- Parameter Identification for first order plant

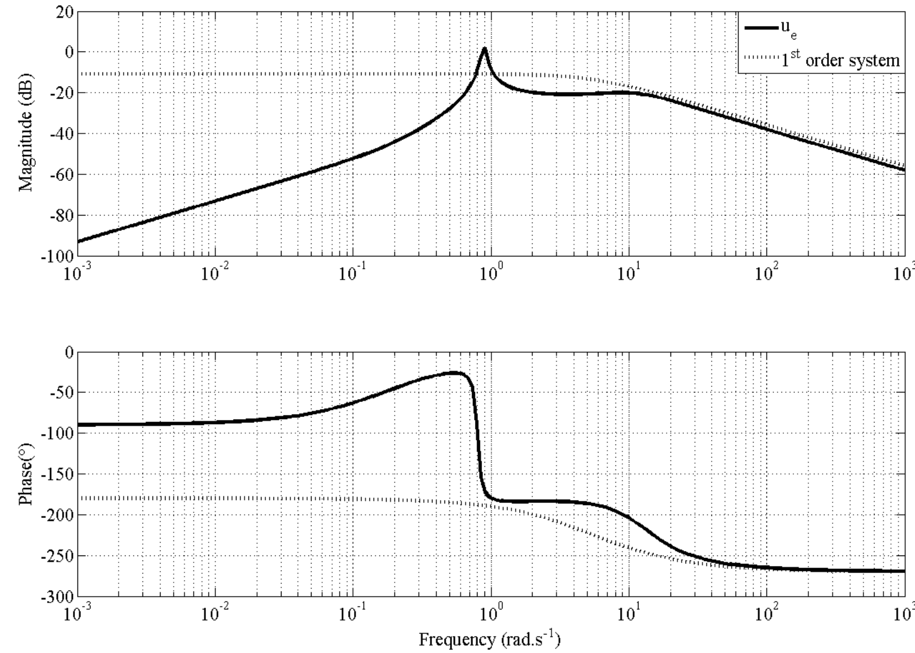


Controller Design

Identified parameters compared with model



Roll rate answer to aileron input



Pitch rate answer to elevator input

Controller Design

- State Feedback

$$\dot{\varphi}(s) = \frac{k}{1 + \frac{s}{\omega_n}} u_a(s)$$

$$\begin{matrix} \dot{\varphi} \\ \ddot{\varphi} \end{matrix} = \begin{bmatrix} 0 & 1 \\ 0 & -\omega_n \end{bmatrix} \begin{pmatrix} \varphi \\ \dot{\varphi} \end{pmatrix} + \begin{bmatrix} 0 \\ k\omega_n \end{bmatrix} u_a$$

Defining, $\vec{e} = \begin{pmatrix} \varphi_{ref} - \varphi \\ \dot{\varphi}_{ref} - \dot{\varphi} \end{pmatrix}$ $\dot{\vec{e}} = \mathbf{A}\vec{e} + \mathbf{B}u_a$

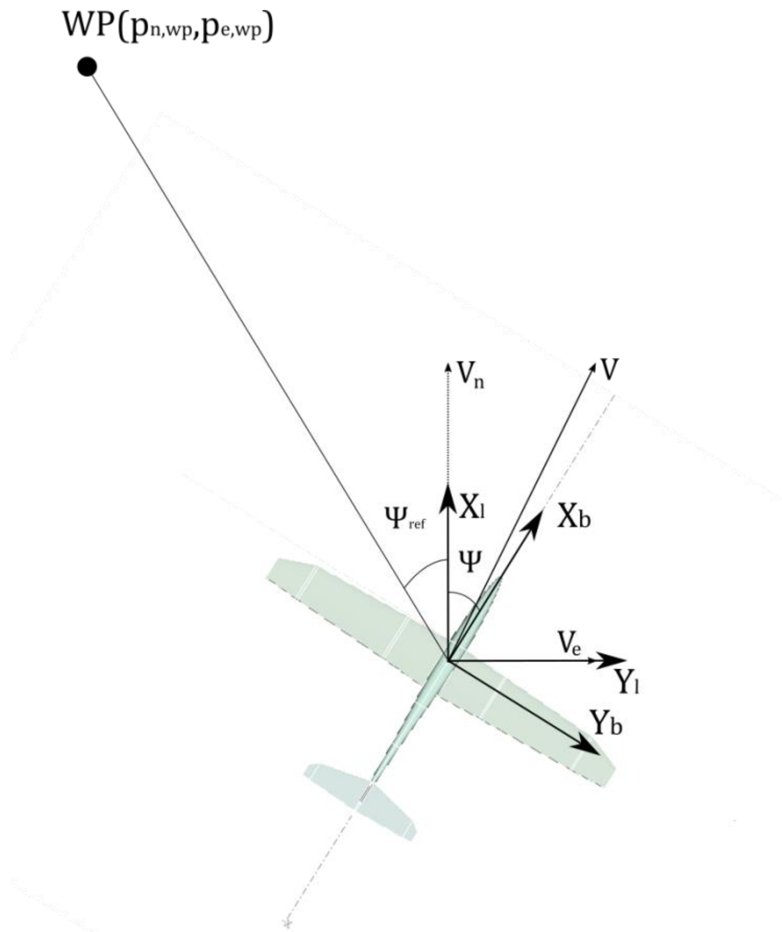
$$u_a = -\mathbf{K}\vec{e}$$

K is deduced with pole placement technique

Controller Design

- High level
  - Heading controller

$$\psi_{ref} = \arctan \frac{p_{e,WP} - p_e}{p_{n,WP} - p_n}$$

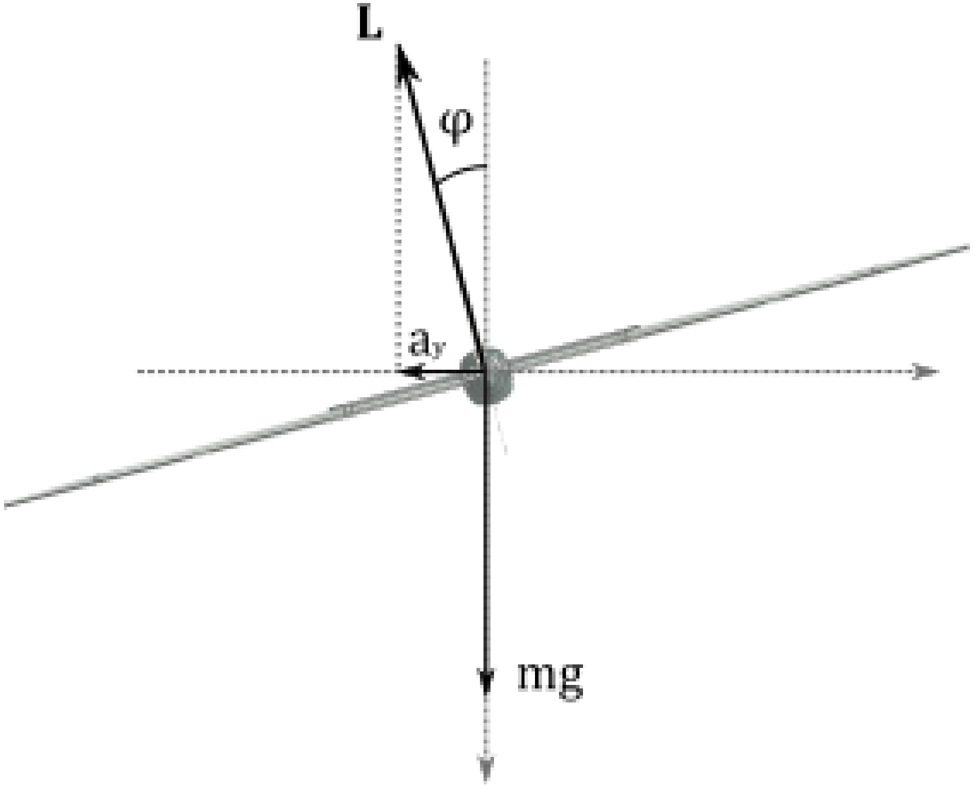


Controller Design

- Steering

$$a_y = k_\psi(\psi_{ref} - \psi)V$$

$$\varphi_{ref} = \arctan\frac{a_y}{g}$$



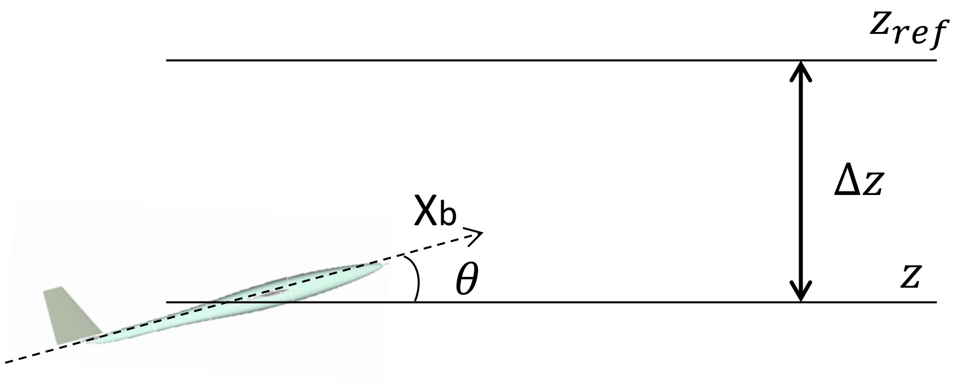
Controller Design

- High level
  - Altitude control, single proportional

$$\Delta z = z_{ref} - z$$

$$\theta_{ref} = k_\theta \Delta z$$

$$k_\theta = \frac{5°}{10(m)}$$



Controller Design

- Airspeed control
  - Proportional controller
  - Adjust the motor rotation speed to track a desired airspeed (measured by pitot probe)

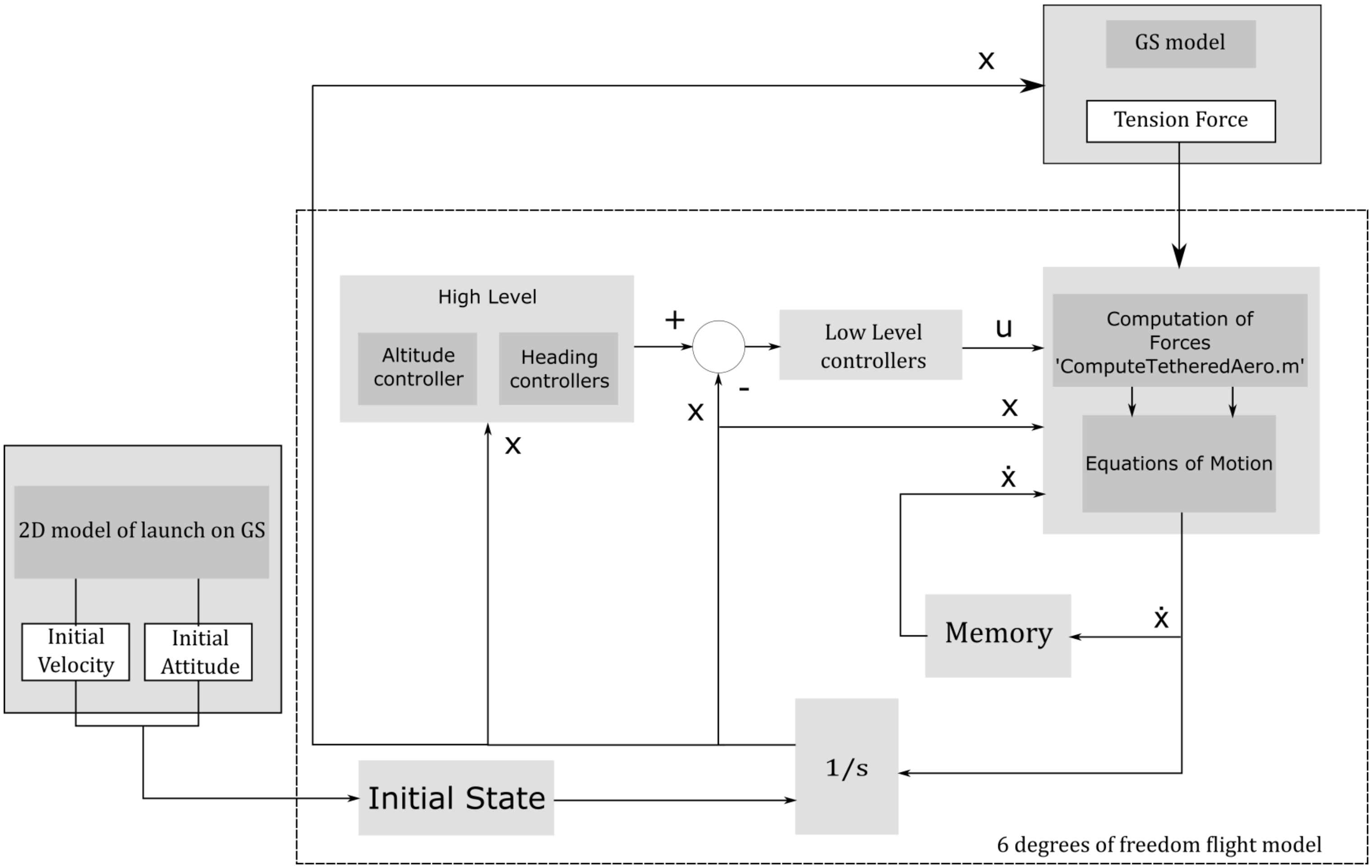
Controller Design

- Take Off procedure
  - Ascent phase : climb in straight line until safety altitude
  - Transition to figure of eight
  - Point targeting switching between two way points to achieve figure of eight.

Content

- Introduction, Preliminary Work & Objectives
- Autopilot Design
- Controller Design
- **Simulation review and results**
- Autonomous Flight results
- Conclusion and future work

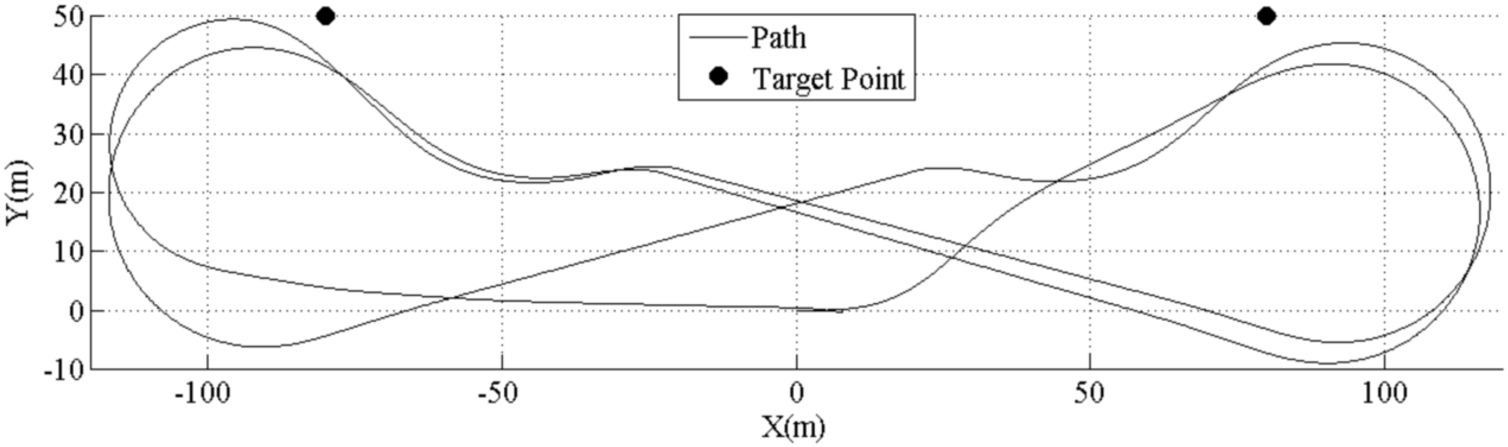
Simulation



GS model
Tension Force
x
High Level
Altitude controller
Heading controllers
+
-
Low Level controllers
u
Computation of Forces 'ComputeTetheredAero.m'
x
x
x
Equations of Motion
ẋ
2D model of launch on GS
Initial Velocity
Initial Attitude
Memory
ẋ
1/s
Initial State
6 degrees of freedom flight model

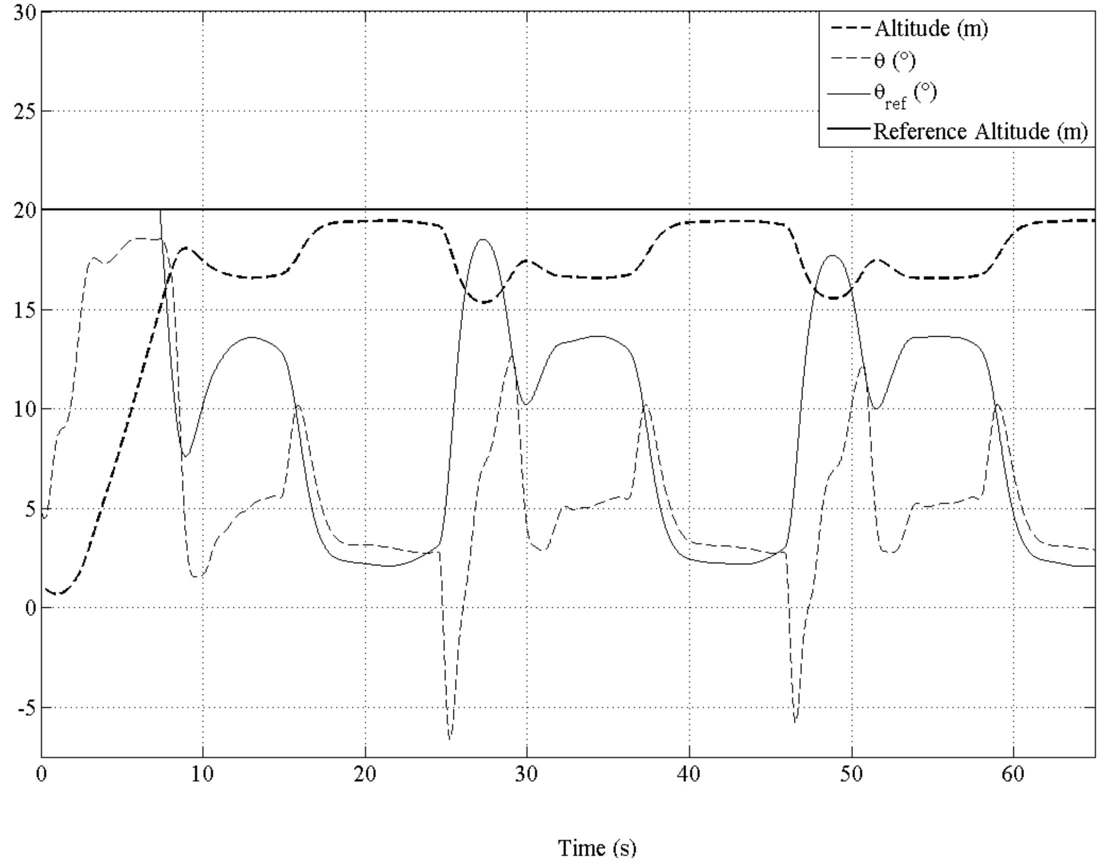
Simulation

Eight trajectory



Simulation

Altitude control



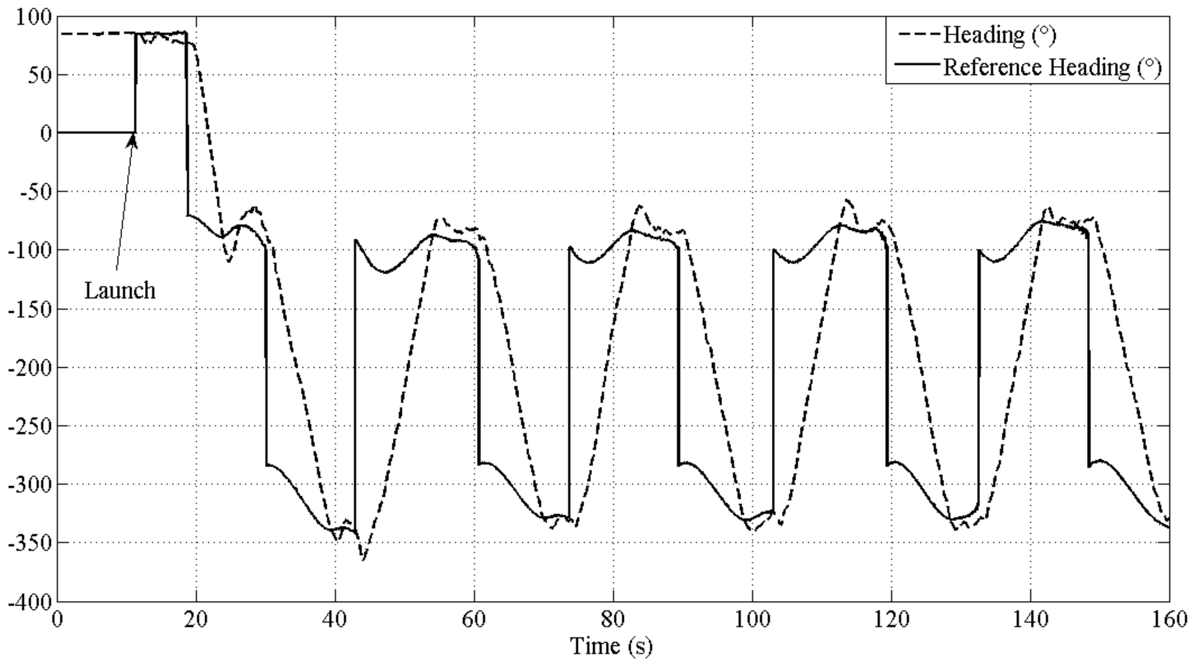
Content

- Introduction, Preliminary Work & Objectives
- Autopilot Designe
- Controller Design
- Simulation review and results
- **Autonomous Flight results**
- Conclusion and future work

Flight Results

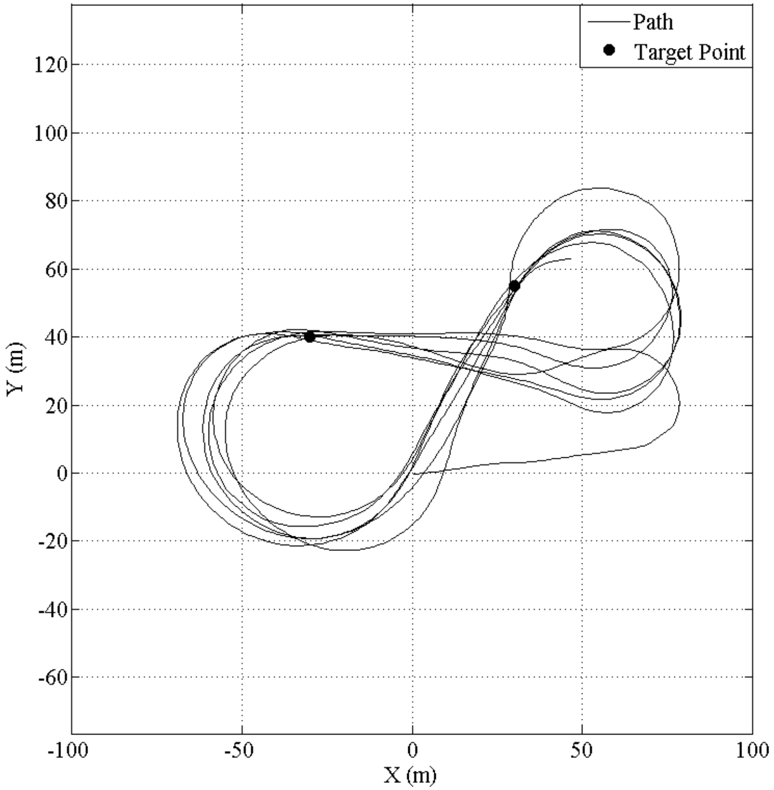
- Autonomous tethered take off and flight.

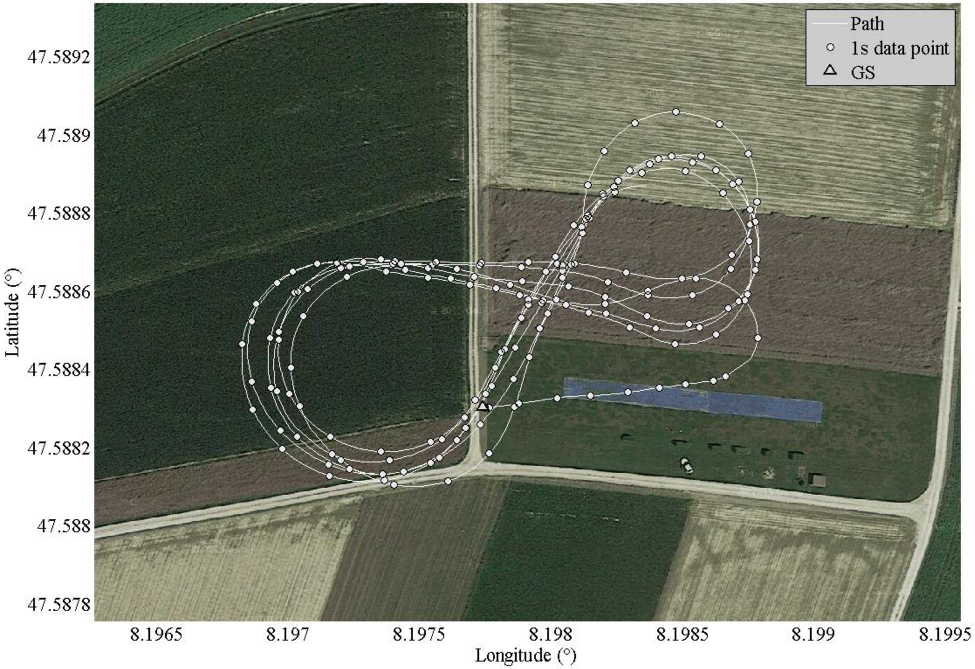
Heading (°)



Flight Results

- Autonomous tethered take off and flight.

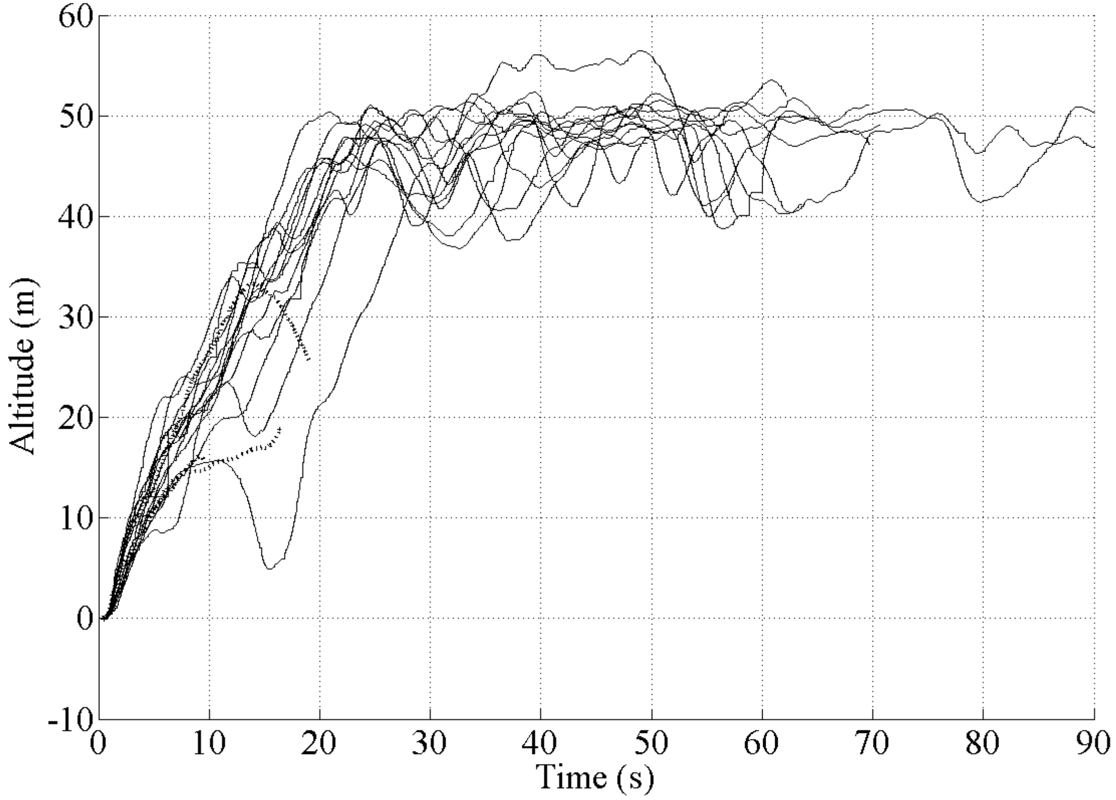




Flight Results

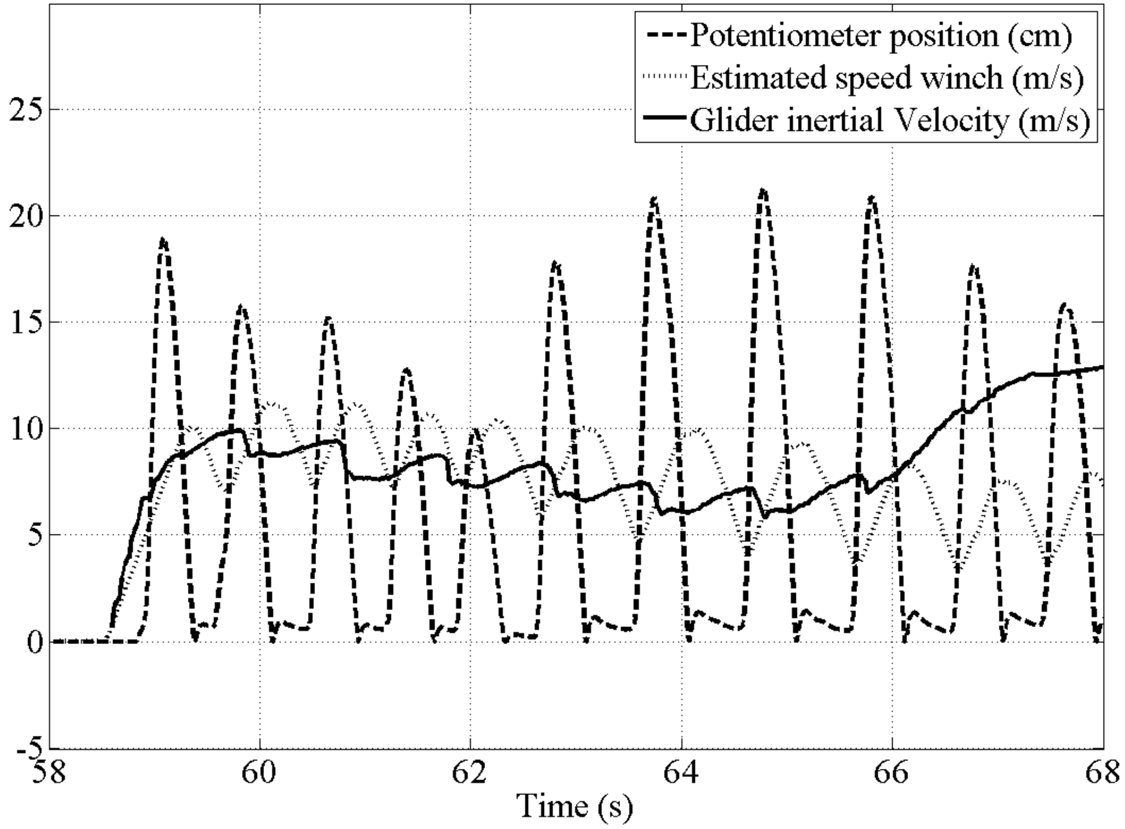
https://www.youtube.com/watch?v=UPiTiHPXciE

Flight Results



Flight Results

Coupled effects with GS



Content

- Introduction, Preliminary Work & Objectives
- Autopilot Design
- Controller Design
- Simulation review and results
- Autonomous Flight results
- **Conclusion and future work**

Conclusion

- PDM goals
  I. Manual tethered take-off ✓

  II. Automatic flight ✓

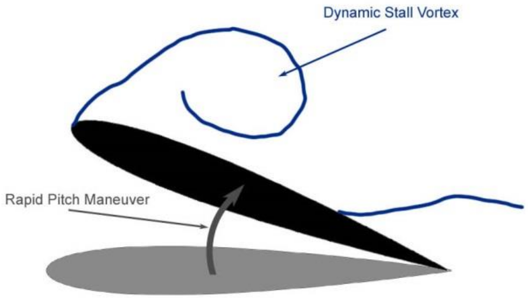
  III. Automatic tethered flight ✓

  IV. Automatic tethered take-off and flight ✓

Future Work

- Landing is missing:
  - Safety, precision, efficiency and compact area
- Topic to study:
  - Short Take Off and Landing (STOL) Aircraft, distributed electric propulsion, dynamic stall.

LEAPTech aircraft source: NASA



Dynamic Stall Vortex

Source : aerospace.illinois.edu

STOL : Pilatus PC6

Souce : pilatus-aircraft

Acknowledgement

ABB Corporate Research:

Dr. Lorenzo Fagiano, Senior Scientist

Dr. Stephan Schnez, Senior Scientist

Felix Rager, Dipl.-Ing. (FH)

EPFL:

Prof. Colin Jones

Prof. Flavio Noca

Autonomous Take Off and Flight of a Tethered Glider for Airborne Wind Energy

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

ABB