SkyScanner

"Deploying fleets of enduring drones to probe atmospheric phenomena"

Project supported by the STAE foundation, 2014 / 2016
(stemmed from the Micro Air Vehicle Research Center)

https://www.laas.fr/projects/skyscanner

(Administrative start on June, 2014 – actual start on Oct. 2014)

Motivations

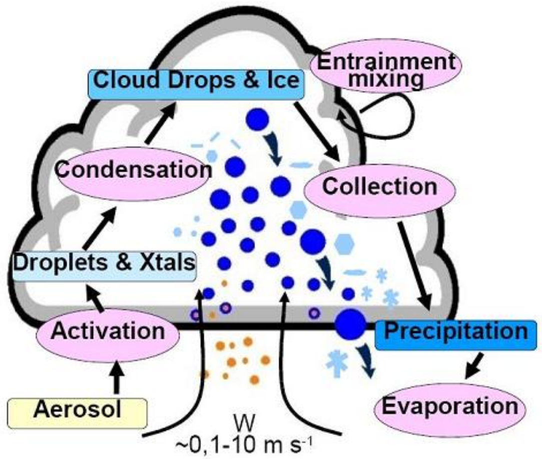
- Follow the evolution of a cumulus cloud to study entrainment and the onset of precipitation

✓ Characterize state of boundary layer below and surrounding a cloud

atmospheric stability
lifting condensation level
cloud updraft

✓ Follow 4D evolution of the cloud

entrainment at edges
inner winds
amount of liquid water
cloud microphysical properties

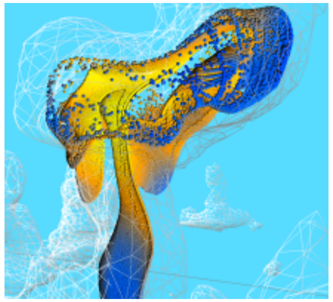


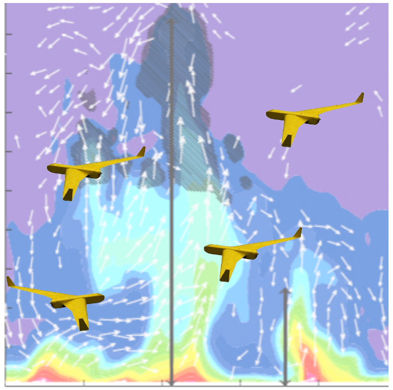
➡ A fleet of enduring drones is required

➡ Researches on the drone conception, the fleet control, and the cloud models

Scope of the project

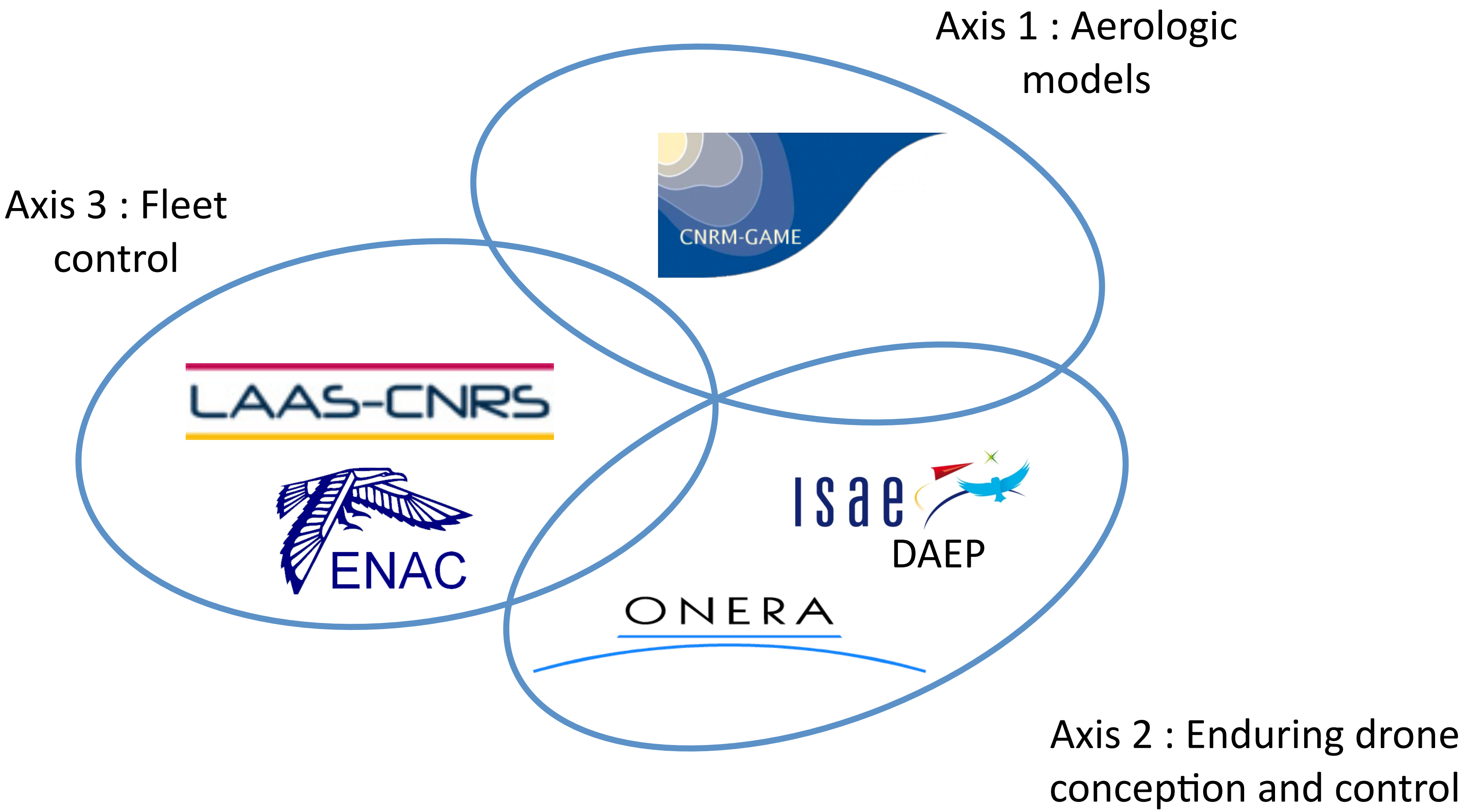
- 3 research axes:
  - Refine aerologic models of clouds
  - Conceive enduring and agile micro-drones
  - Fleet control





Plus: experimental developments and validations

3 research axes / 5 partners



- Funding amounts to five 18 months postDocs / Research Engineers

Partners and people

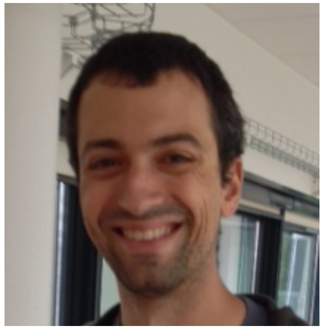
LAAS-CNRS: Simon Lacroix

CNRM-GAME: Greg Roberts, Fred Burnet

ENAC: Gautier Hattenberger, Murat Bronz

ISAE: Emmanuel Bénard

ONERA: Carsten Doll

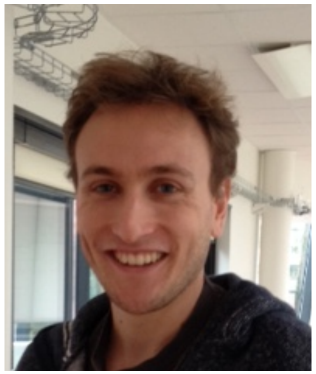

Alessandro Renzaglia


Fayçal Lamraoui


Jean-Philippe Condomines


Elkhedim Bouhoubeiny


X (Sept. 2015)


Christophe Reymann


Jean-François Erdelyi

What are the problems to solve?

Mission: "Deploy a fleet of drones so as to maximize the amount of gathered information on the cloud" (~ adaptive sampling)

- Where to gather information?
- How to represent / maintain the gathered information?
- Which drone(s) allocate to which area?
- How to optimize the trajectories to reach these areas?
- …

Fleet control And cloud modeling

- How to optimize the conception of the drones?
- How to optimize the control of the drones?
- …

Drones conception and control

Outline

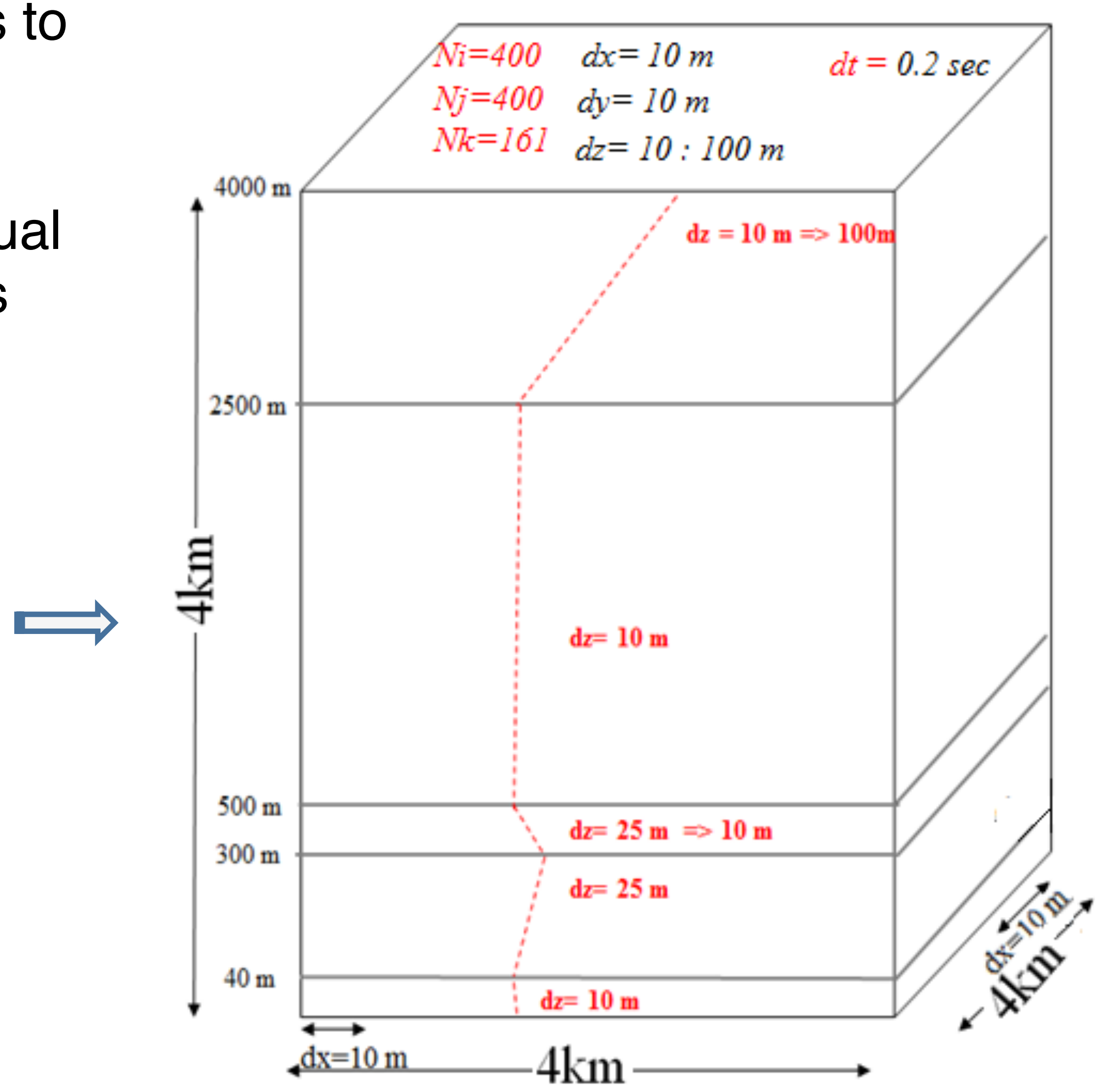
- Aerologic models of clouds
  - Exploit simulations
  - Towards a conceptual model
- Fleet control
  - A hierarchy of models
  - Cloud mapping
  - Cloud exploration
- Enduring and agile micro-drones conception and control
- First experimental developments

Large Eddy simulations (MesoNH)

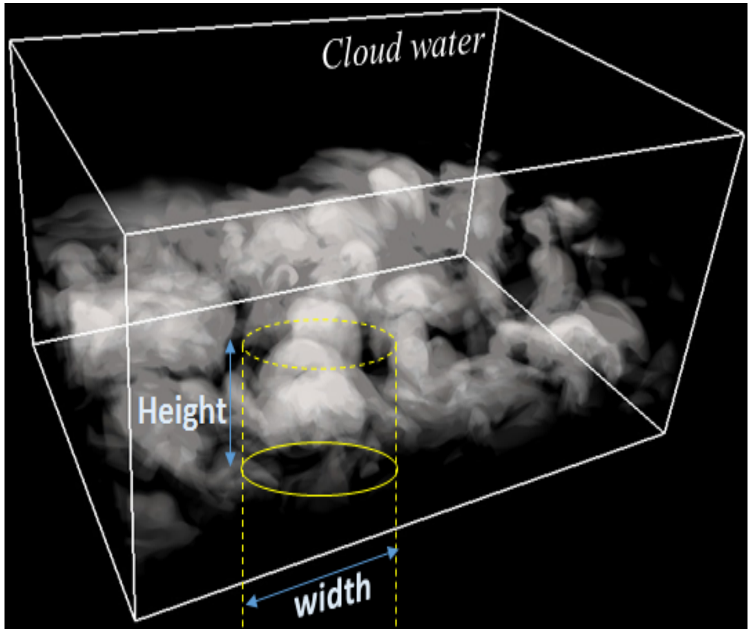
- Two objectives:
  - Provide test cases to the fleet control algorithms
  - Derive a “conceptual model” of cumulus clouds

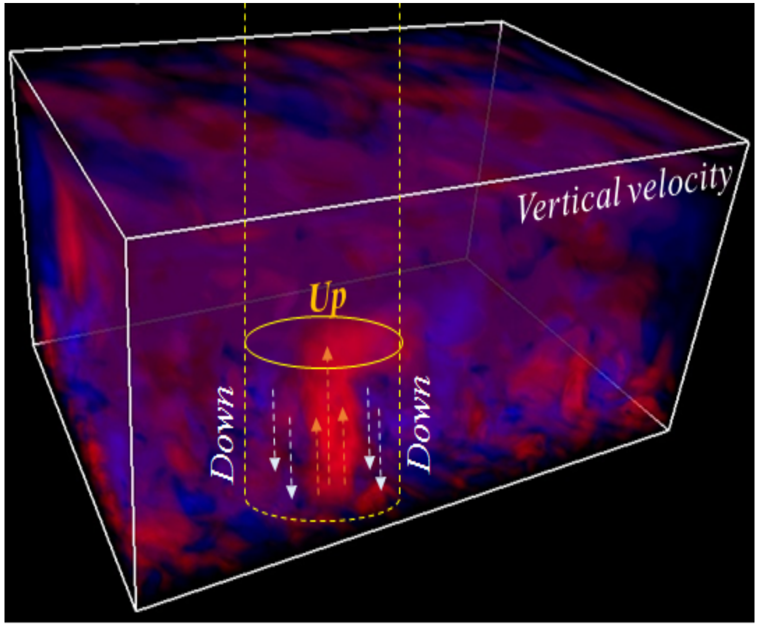
Fields & forcings
(initial data: ARM Field campaign)

Simulation grid



Large Eddy simulations (MesoNH)





Mapped variables: wind, P, T, U, Liquid Water Content

Post-processing (output/second) ⇒ Conceptual Model:

- Cloud geometry vs vertical velocity
- Cloud tracking
- Cumulus microphysics

Outline

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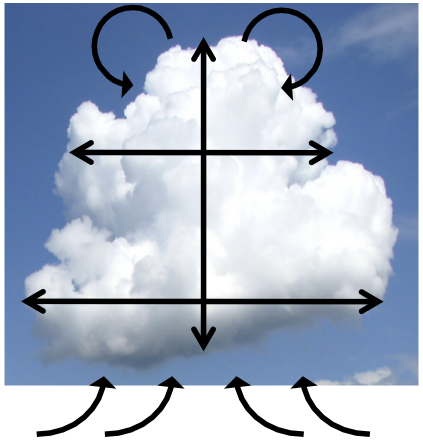
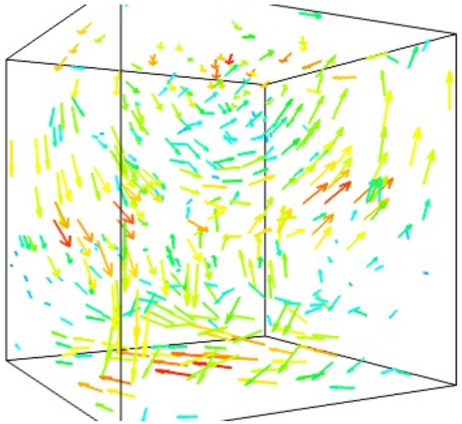
Fleet control: Models

- Models

1. Models of the environment: winds, atmospheric parameters, geometry



“Conceptual” model
(macroscopic, coarse scale)



Dense model
(~ *10m* scale)

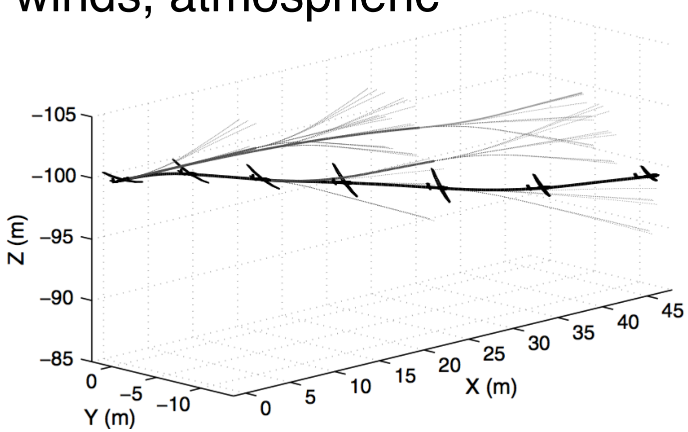
➔ Need to estimate these models (that evolve over time) from data acquired online

Fleet control: Models

- Models

1. Models of the environment: winds, atmospheric parameters, geometry

2. Model of the drones
    - Kinematic constraints



    - Express energy variations
      Kinetic (airspeed)
      Potential
      Stored (battery)

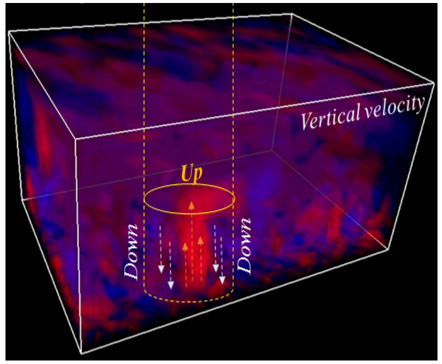
➔ Simulations
- Of the dense cloud models: Meso-NH, JSBSim
- Of the drones : New Paparazzi Simulator
- Finer drone model(s) will be defined and exploited

Fleet control: cloud mapping

- Two challenges:
  - mapping a 4D structure from data perceived over a (small) set of 1D manifolds

From…

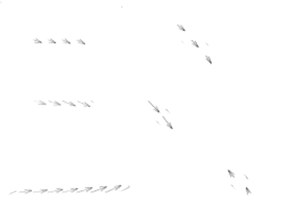
… to:



Fleet control: cloud mapping

- Two challenges:
  - mapping a 4D structure from data perceived over a (small) set of 1D manifolds
  - Update two map structures: coarse global / precise local

From…



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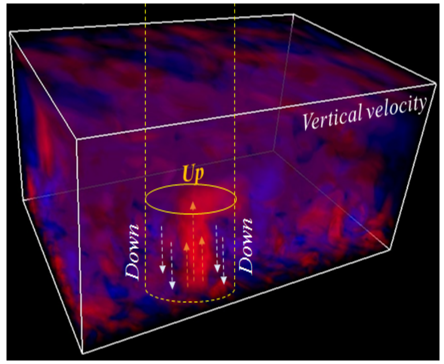
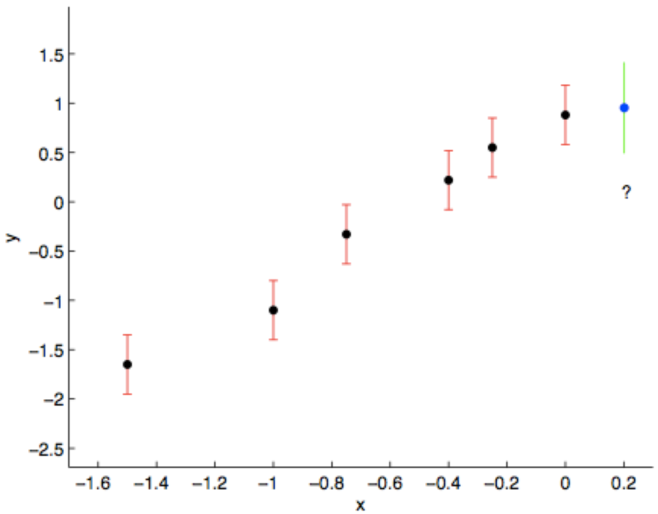


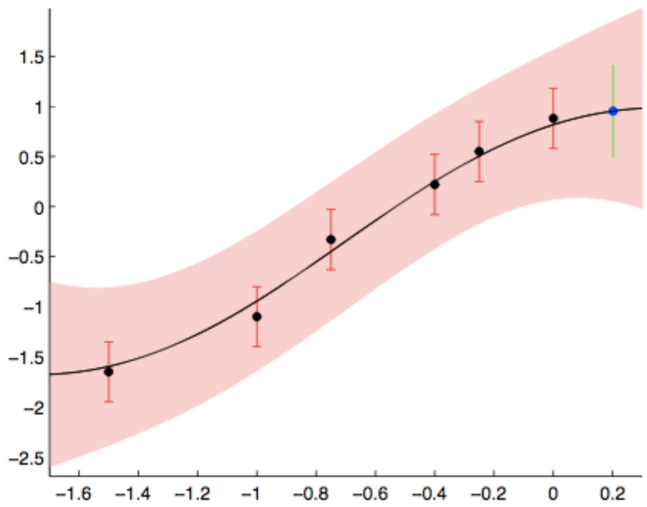
Fleet control: cloud mapping

- Local map: Gaussian Process Regression (*aka* "kriging", originally exploited in geosciences, spatial analysis)

From



to

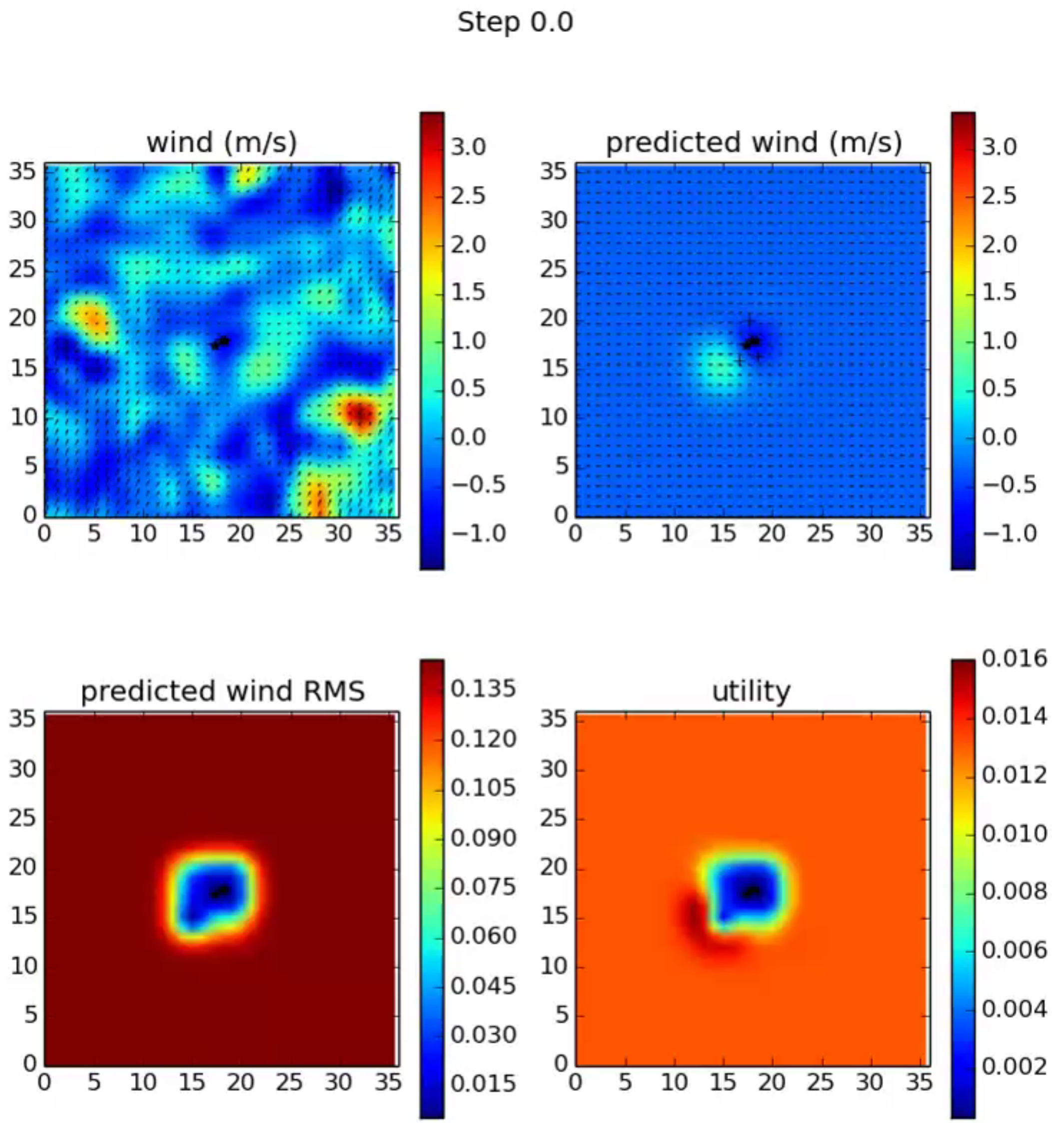


Estimate y^* from any x^* using *only* a kernel function $k(x_1,x_2)$ that encodes the spatial dependence between the data

(still possible to introduce priors on the model – *cf* coarse cloud model)

Fleet control: cloud mapping

- Local map: Gaussian Process Regression
  (*aka* “kriging”, originally exploited in geosciences, spatial analysis)



Fleet control: cloud mapping

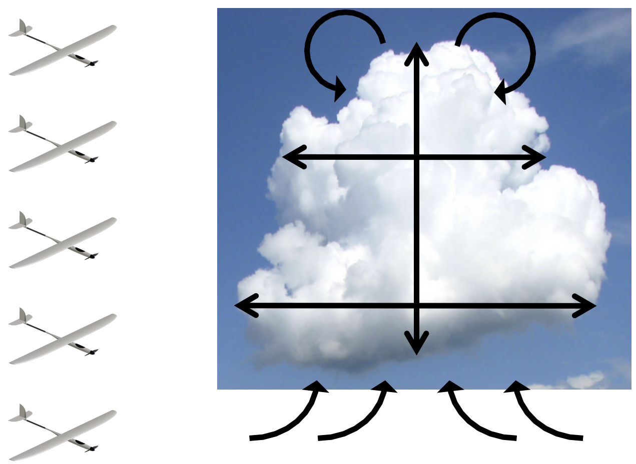
- Numerous open issues:
  - Which kernel(s) exploit
  - Optimize hyper parameters learning (exploit sparsity, develop incremental schemes, …)
  - Inter-parameter correlations
  - Relation with the coarse model
    - GPR initializes the coarse model
    - The coarse model is a prior for the GPR
    - Learn classes of kernels?
  - How to infer the *utility* of perceiving given areas?
  - …

Fleet control: Models and Algorithms

- Models

- Algorithms

1. At a coarse (symbolic level, ΔT ~ 10sec)



➔ Where should what information be gathered?
➔ Who goes where?

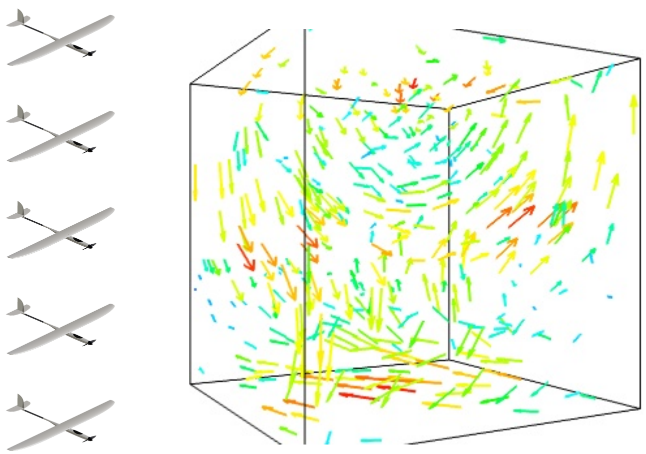
Fleet control: Models and Algorithms

- Models

- Algorithms

1. At a coarse (symbolic level, ΔT ~ 10sec)

2. At a finer level (ΔT ~ 1sec)



➔ Who goes where?

Fleet control: cloud probing

- Two-stages approach

1. At a coarse level:
    - Identification of utility zones / points
    - Allocations of drones to zones (exploit predefined patterns?)

   coarse cloud and drones models — $\Delta T \sim 10$sec

2. For each drone:
    - Plan trajectories with forward simulation
    - Maximise utilities, minimize energy, satisfy time constraints

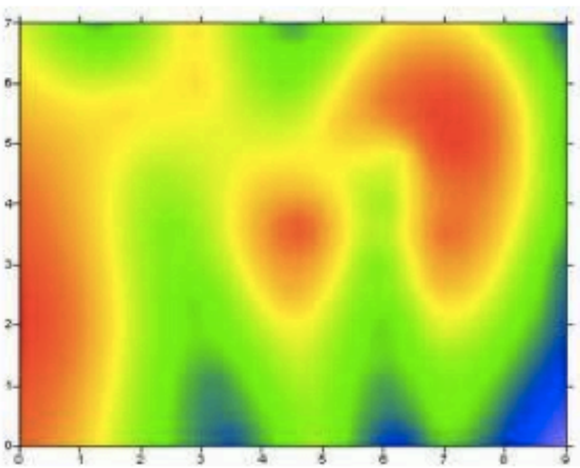
   dense cloud and fine drones models — $\Delta T \sim 1$sec

Fleet control: cloud probing

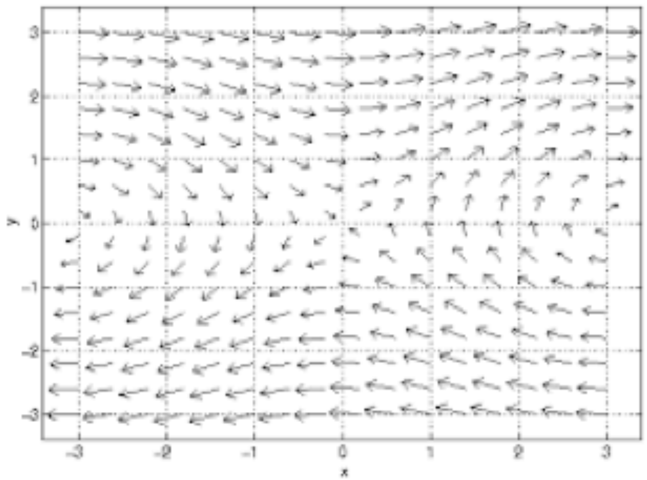
Maximizing collected data taking into account air flows for navigation (energy constraint)

Two different fields as input of our optimization problem:

- Scalar utility field



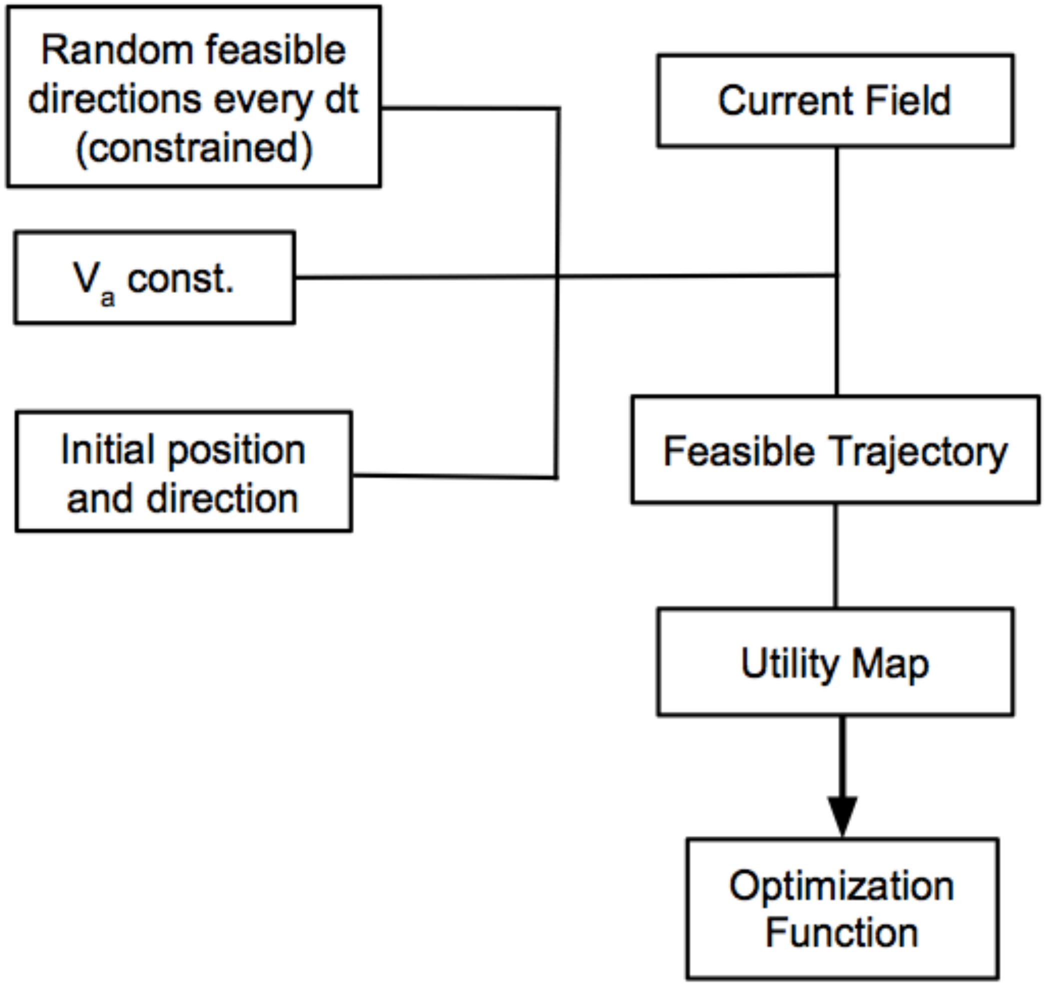
- Currents vector field



- Both fields are: 3-dimensional and time dependent

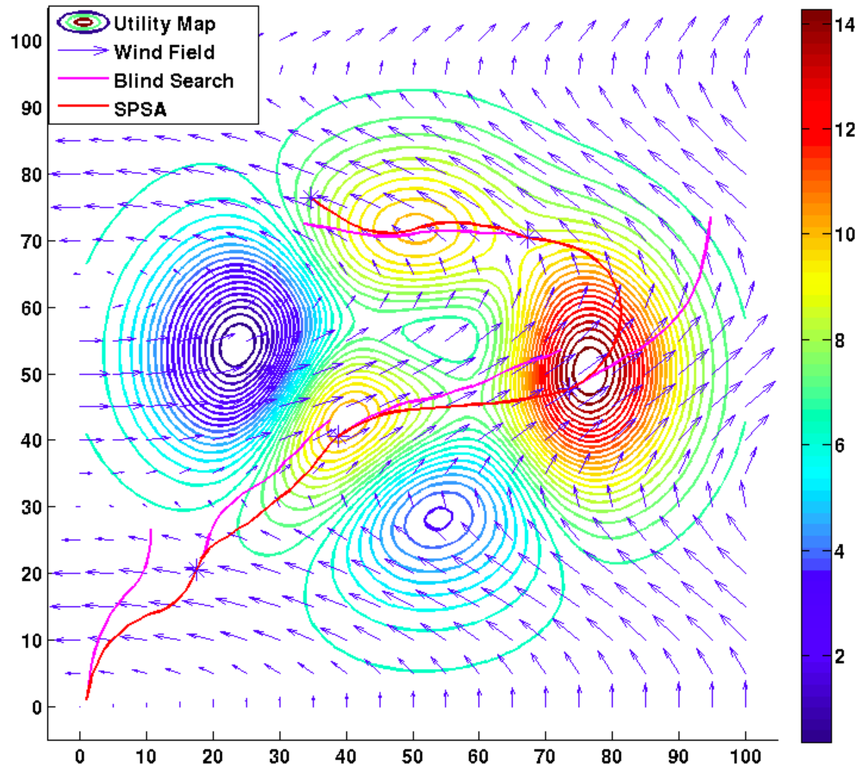
Fleet control: cloud probing

- 2D environments
- Fictitious utility map and currents fields
- Trajectories generation: Random sampling of feasible trajectories for each ΔT time interval
  - Trajectory divided in sub-intervals
  - Sampling in control space

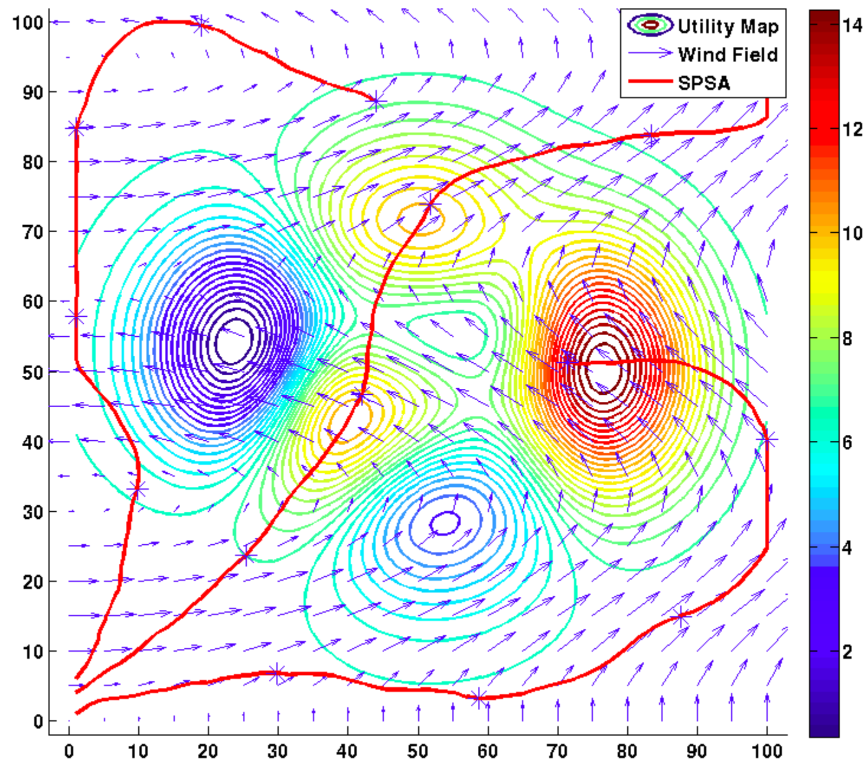


Fleet control: cloud probing

- Preliminary results



One UAV



Three UAVs

Fleet control: Models, Algorithms and Architecture

- Models
- Algorithms
- Architecture
  1. Where are the information processed?
  2. Where are the decisions taken?
  3. Will there be men in the loop?

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Drone conception

Design optimization of enduring mini micro UAV

Objectives

- The main objective is to design a micro UAV for a specific mission profile which mainly consists of flight phases through cumulus clouds
- In parallel, exploiting the atmospheric disturbances such as gusts will be investigated in order to improve autonomous flight

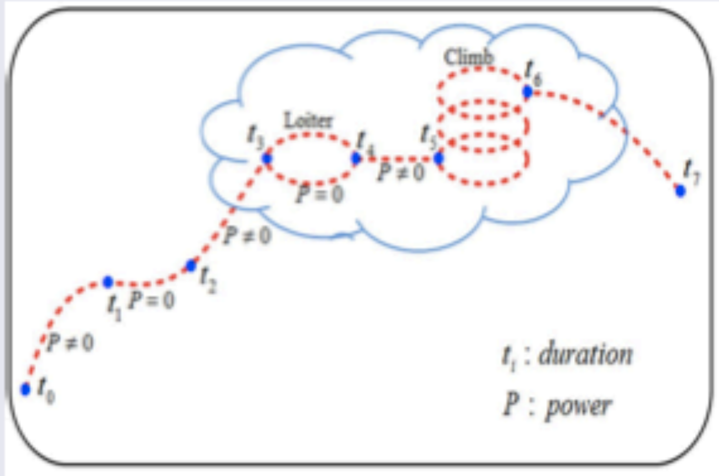
Mission definition

A set of mission profiles are going to be established for the electric powered UAV

There exists several flight phases :

- take-off
- loiter at a constant altitude
- climb to an altitude
- dash

Example of mission profile



Drone conception

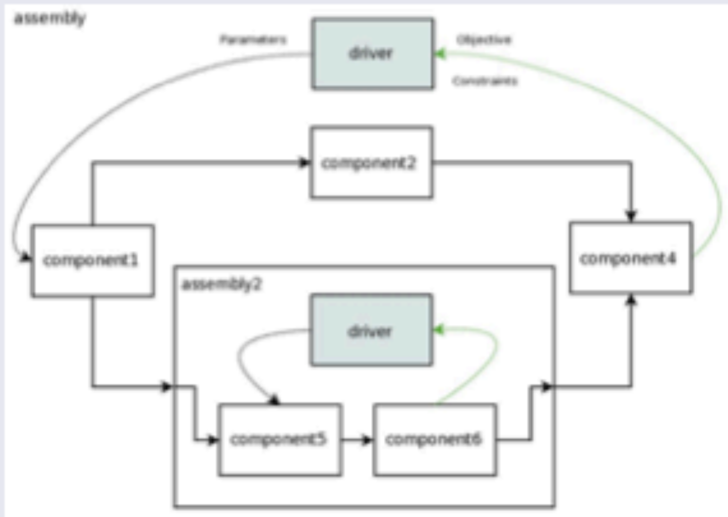
Program selection : OpenMDAO by NASA

OpenMDAO is an open source framework for analyzing and solving MDAO (Multidisciplinary Design Analysis & optimisation)

- Written in Python language
- A problem is represented by a system of objects called components
- Framework that allows for integration of different modules to form a design workflow

Four element concept

- Workflow: ordered combination of components to form a design process
- Components: modules containing analysis tools or simulation models
- Assembly: container for components and manages their data flow
- Driver: analysis algorithm that runs the workflow

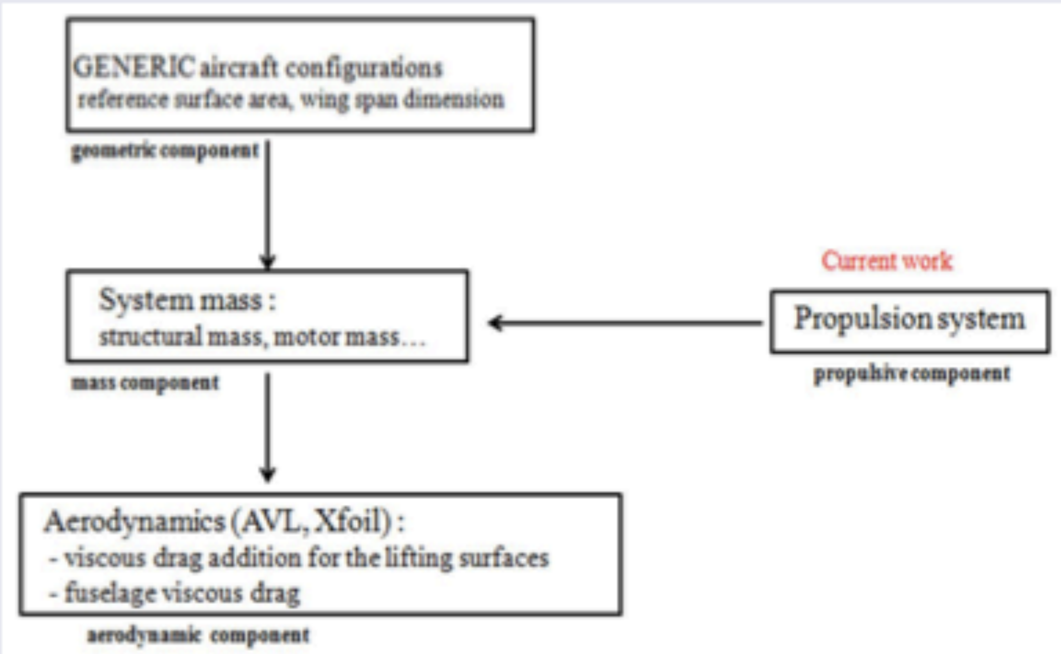


Drone conception

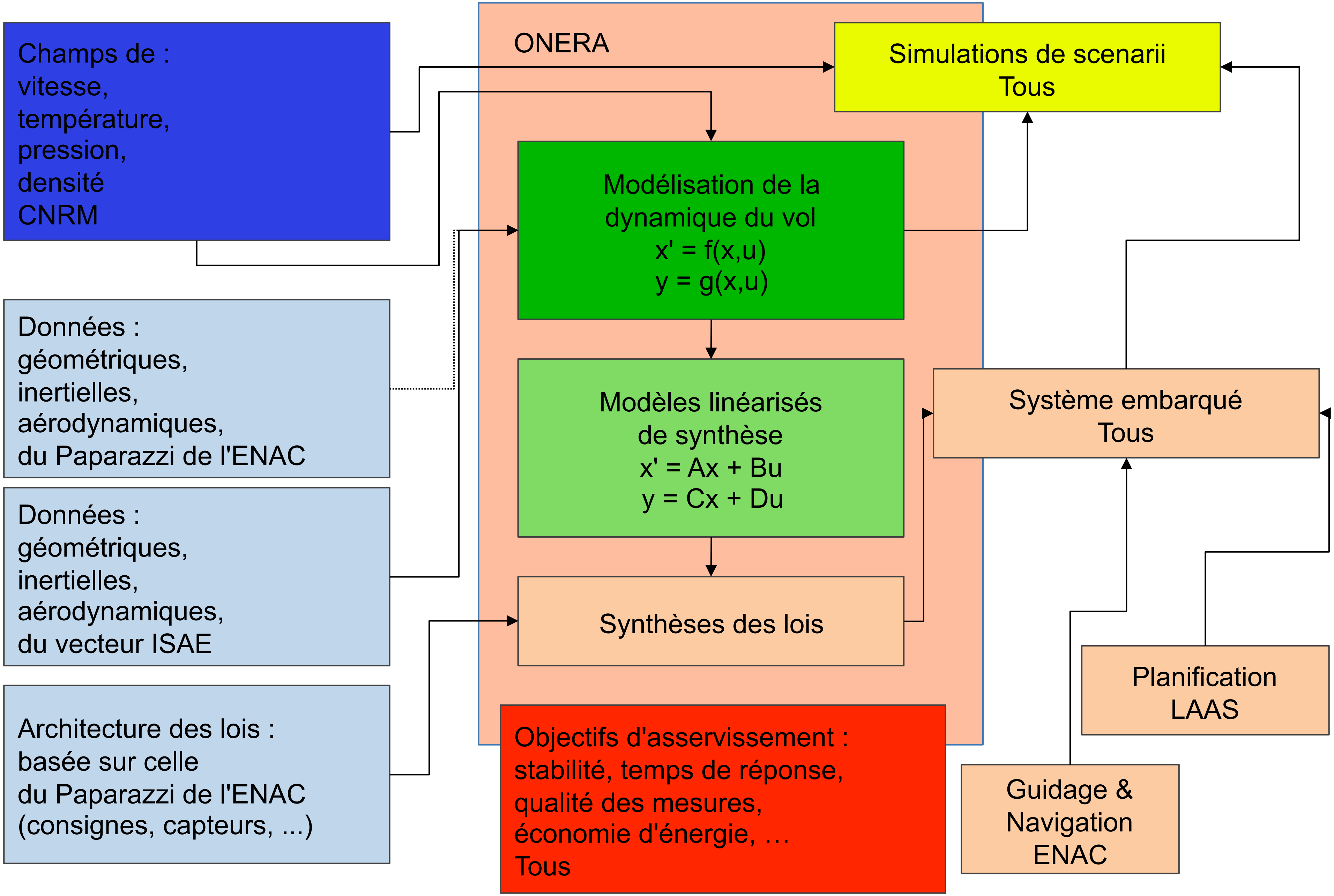
Description of components in the framework

Each component contains :

- A Python module allowing to interface between a program using in the component (ex : AVL, Xfoil) and OpenMDAO
- A inherits class can be written to connect the inputs and outputs of one component to those of other components, allowing data to be passed between them



Drone conception… and control



Drone conception… and control

- Conflicting objectives

	Rejet de perturbation	Profit de perturbation
Qualité de mesure	++	--
Maintien de vitesse	+	-
Maintien d'altitude	+	-
Activité de gouvernes	--	++
Consommation d'énergie	--	++
Exploration verticale fine du nuage	+	-
Exploration verticale rapide du nuage	-	+
Exploration horizontale fine du nuage	+	-
Exploration horizontale rapide du nuage	-	+

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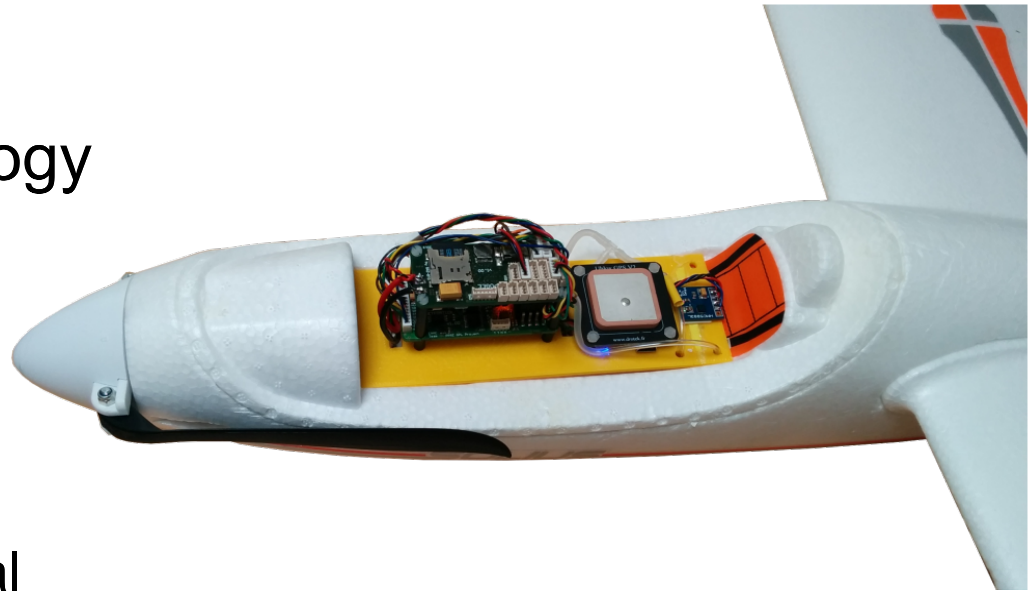
Experimental developments

Main objectives:

- Aircraft modeling methodology
    - Aerodynamic model
    - Propulsion model
    - Aircraft performances (for trajectory planning)
- Wind estimation
    - On-line estimation of the local wind field
- Real flights and experiments
    - Integration of new sensors on a test platform
    - Motor test bench
    - Using the Paparazzi UAV system

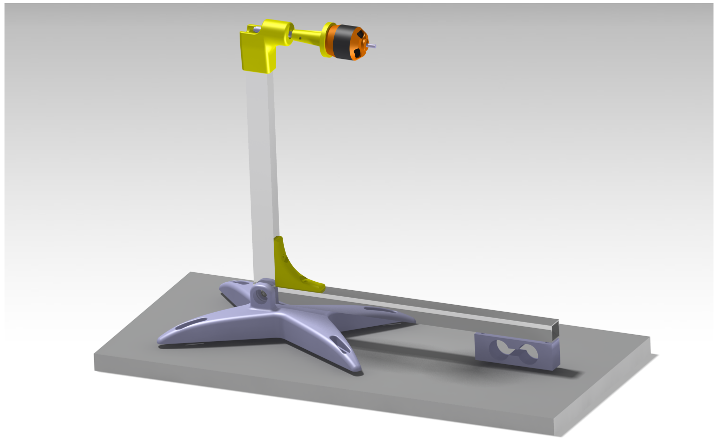


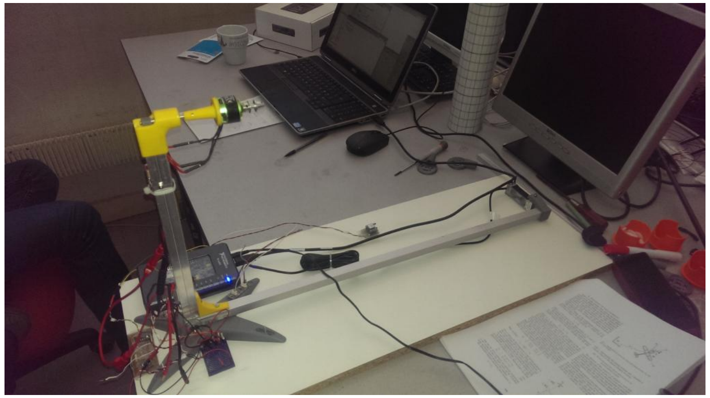
http://paparazziuav.org

Instrumentation

Aircraft integration

- Based on a foam glider (only during the development phase)
- Pitot tube (airspeed norm)
- Angle of attack (airspeed direction) GPS and IMU





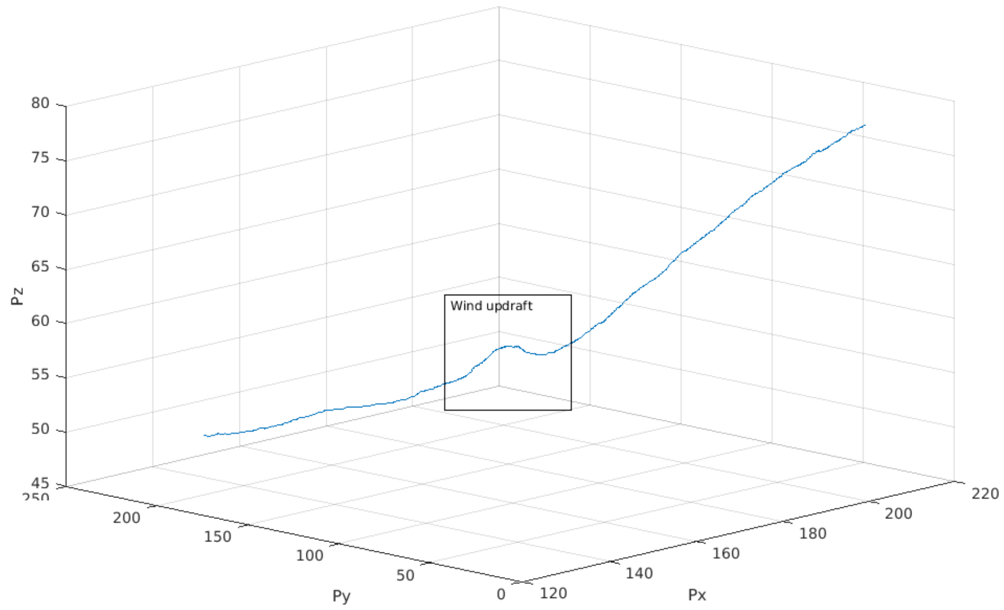
Motor test bench

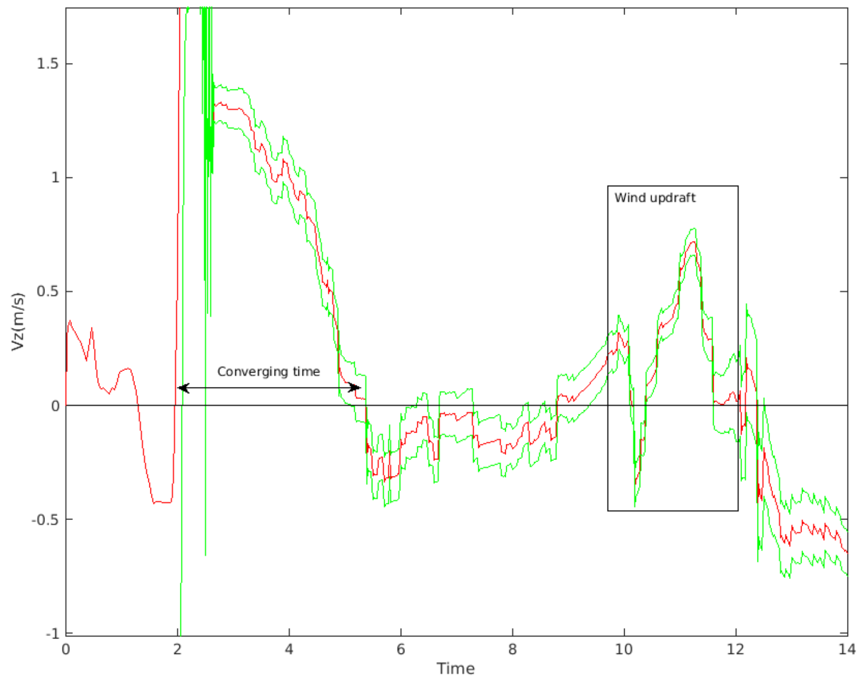
- Build a propulsion model
- Automated measurement procedure

Wind estimation

Estimation of the wind using a non-linear Kalman filter (UKF)

- Inputs : IMU, GPS and airspeed data
- Outputs : 3D wind and/or airspeed vector



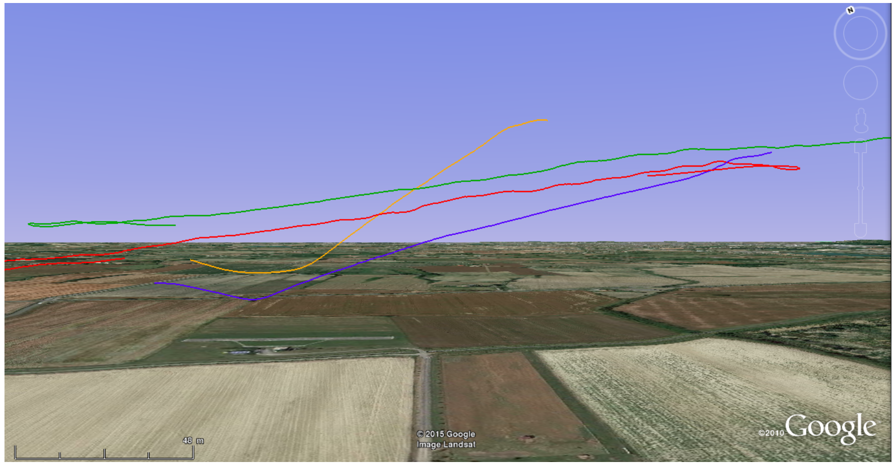


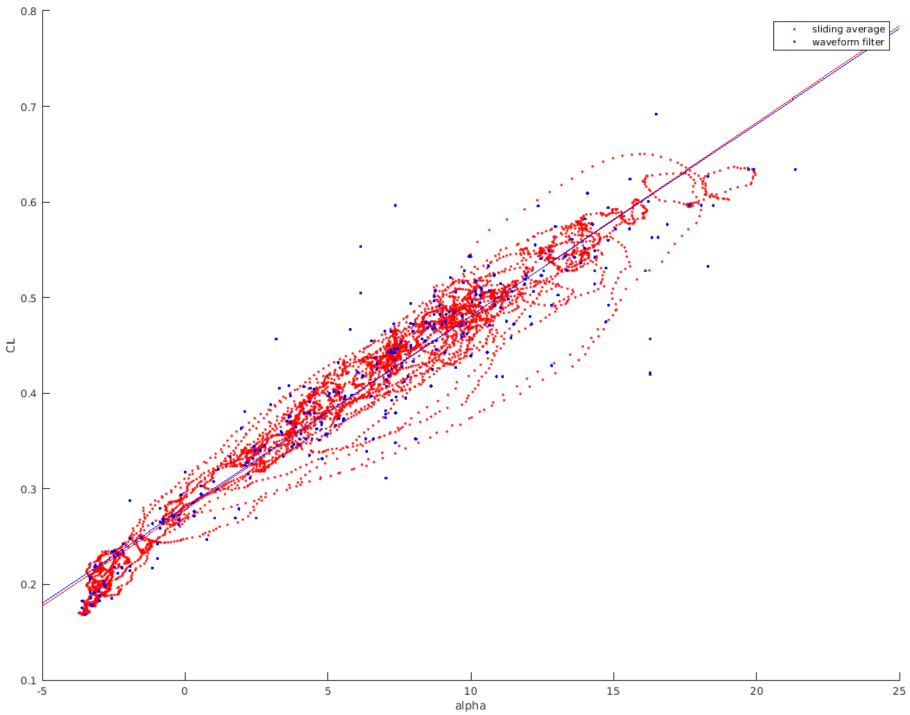
- Detection of a wind updraft during a gliding phase
- Some parameters are only observable while performing imposed maneuvers
- Model will be improved to use the angle of attack sensor or the aerodynamic model as input

Aircraft identification

Aircraft polar estimation

- Gliding flights at different airspeed (angle of attack)
- Automated procedure using the Paparazzi flight plan langage
- Identification methods
  - Polynomial data fitting on simplified model
  - Non-linear least-square optimization : data set is currently too noisy for a good convergence
  - Non-linear Kalman filter (UKF) : under investigation





Aircraft identification

ENAC

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UAV Lab

Summary

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Next May in Toulouse

- Annual conference of the *International Society for Atmospheric Research using Remotely piloted Aircrafts*

www.isarra.org