MDAO framework approach at ONERA
Focus on ACADIA project

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OpenMDAO european workshop, 12/10/2017

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Outline

- 1. MDAO framework at Onera : why and how ?
  - Multidisciplinary design of aerospace vehicles
  - Early ages : ModelCenter and associated methodological developments
  - Limitations and requirements for a new approach

- 2. OpenMDAO within the ACADIA project
  - Objectives of the internal project
  - Building blocks for a design environment using OpenMDAO
  - Associated methods
  - Demonstration on aerospace use cases

1. MDAO framework at Onera : why and how ?

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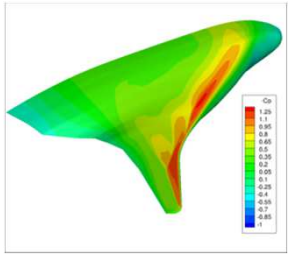
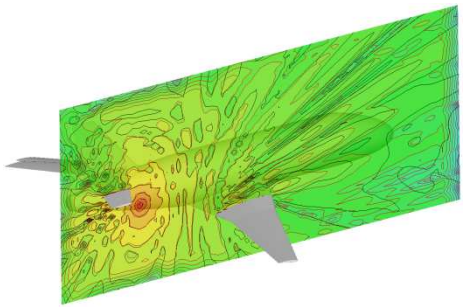
New concepts for aerospace applications

- Several new configurations for aerospace applications under study

Several departments and tools involved

- Multi-disciplinary and multi-fidelity approaches





Performances

Cost

Aerodynamics

Emissions

Structure

Manufacturing

Flight dynamics

Noise

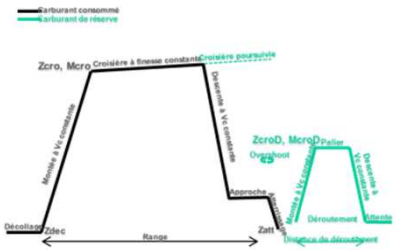
Control laws

Propulsion

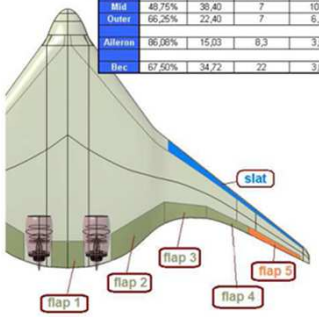
Stealth

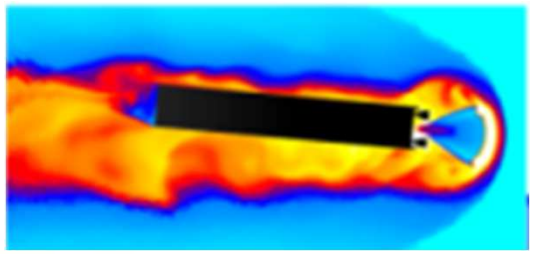
Datalink

Maintenance



Inner 1	3,38%	22,68	2,7	16,32%
Inner 2	29,00%	75,04	8,8	15,54%
Mid	48,75%	38,40	7	10,86%
Outer	66,25%	22,40	7	6,16%
Aileron	86,08%	15,03	8,3	3,54%
Dec	67,50%	34,72	22	3,07%





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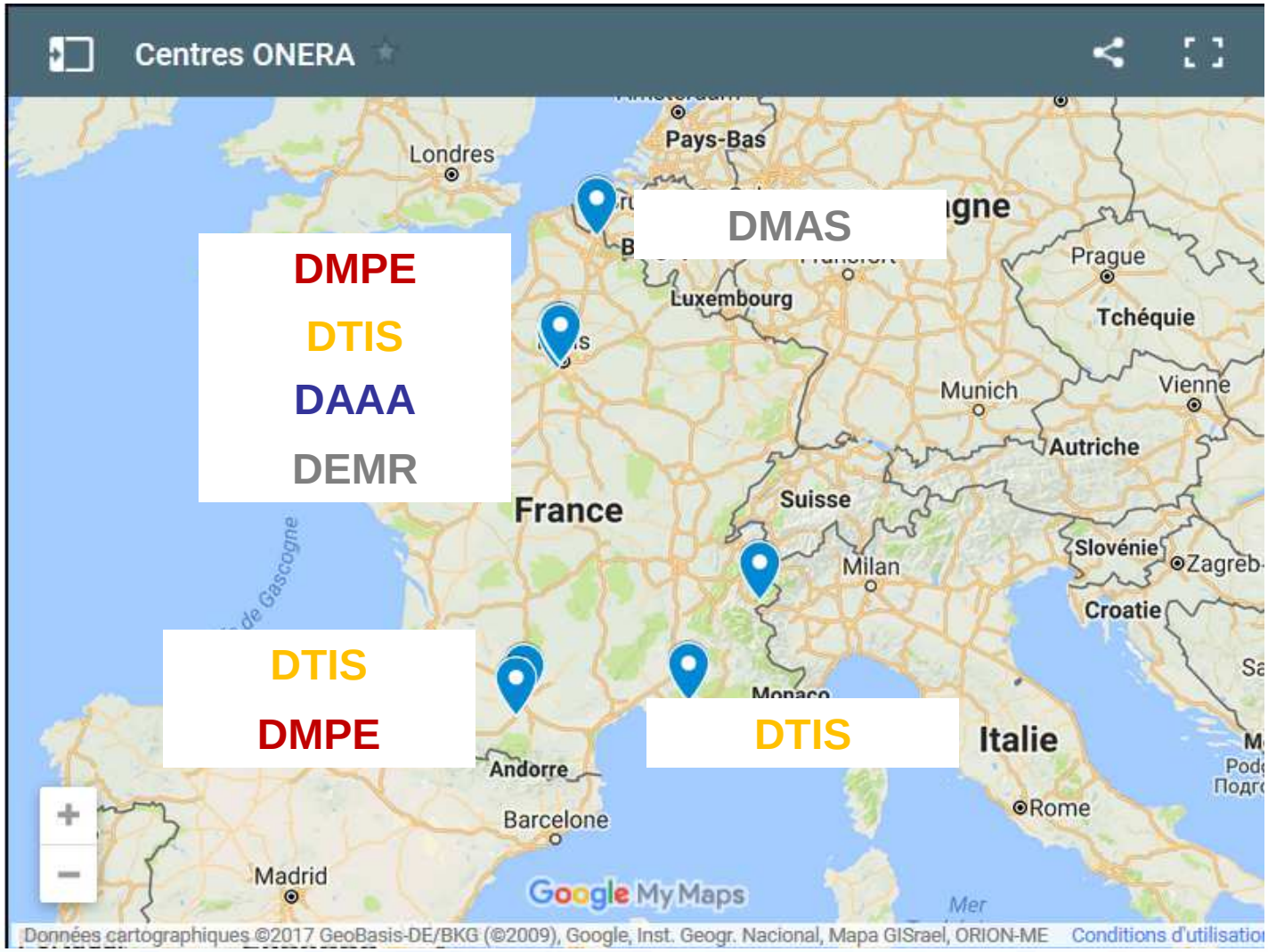
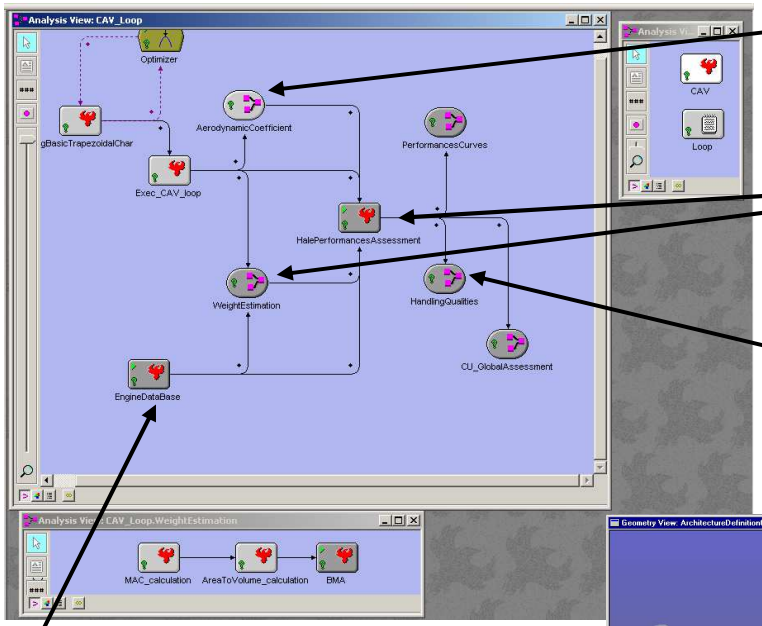
Geographically distributed competences

- Experts and tools from different Onera sites



Early ages : introducing ModelCenter

- At the beginning of 2000, the need for an integration platform of distributed competences is solved by the software ModelCenter (Phoenix Integration)

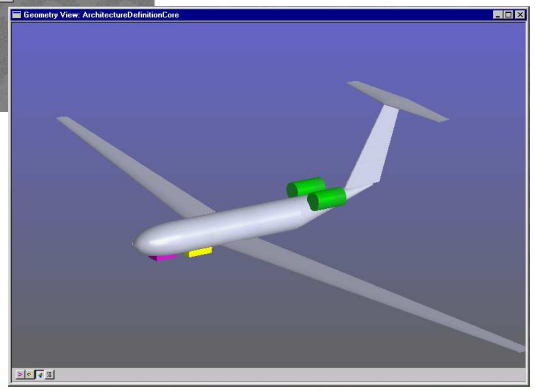


Aerodynamics
(Châtillon)

Missions performance and Weight breakdown
(Salon-De-Provence)

Handling qualities assessment
(Lille)

Engine characteristics & performance
(Fauga-Mauzac)

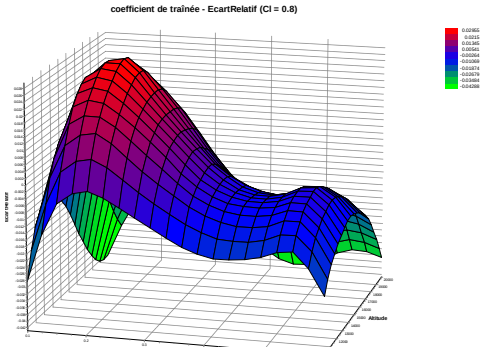


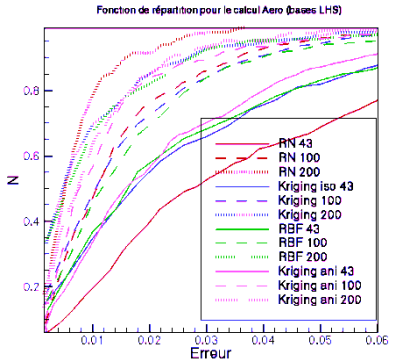
Example of UAV system sizing

- MTOW target
- Payload target (1500 kg)

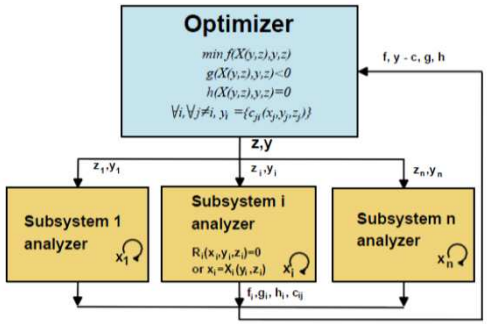
Early ages : first steps in MDO

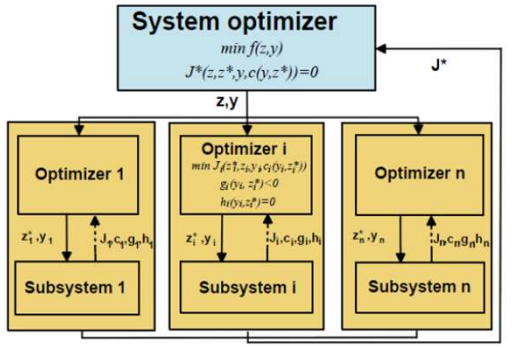
- Apart from process integration, MDO techniques are studied and introduced, using the capabilities of available platforms (ModelCenter, DAKOTA, Matlab/Scilab) -> ***internal project DOOM (2004-2008)***



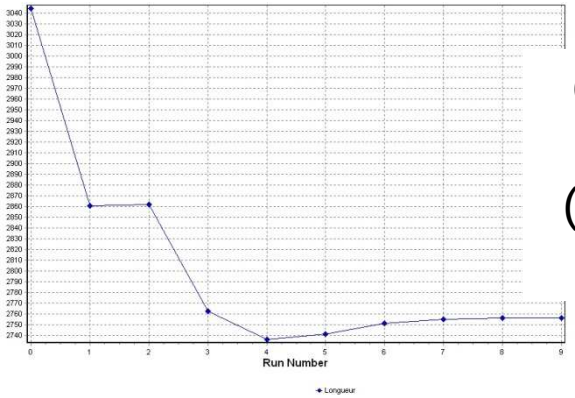


Response surface models : kriging, SVM, RBF, neural networks,…





MDO formulations review and test : monolithic, decoupled, bi-level,…

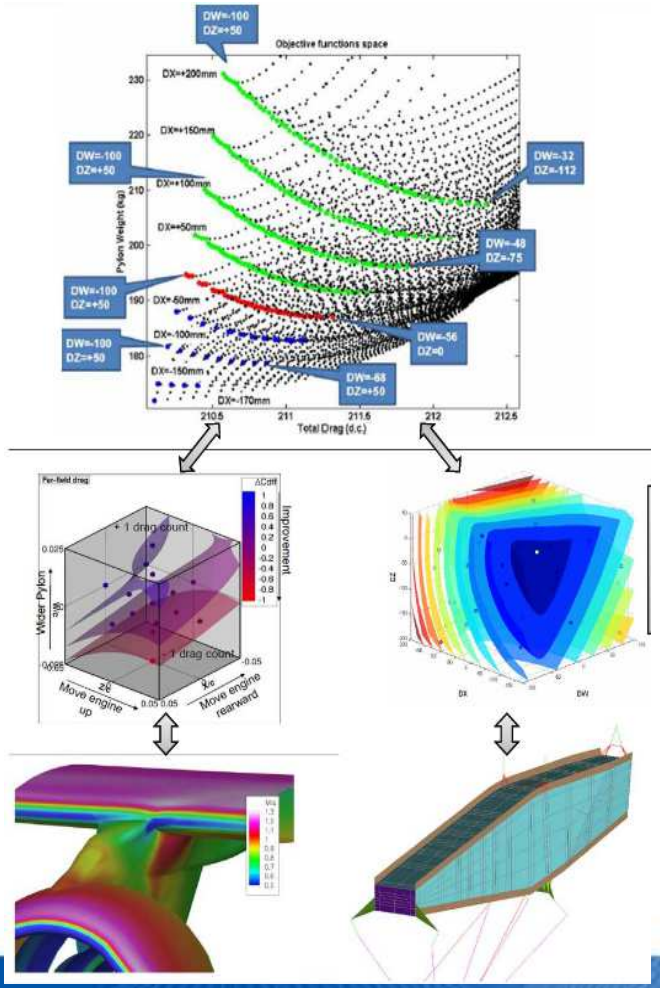


Optimization algorithms : review of methods (gradient, evolutionary,…) and test cases

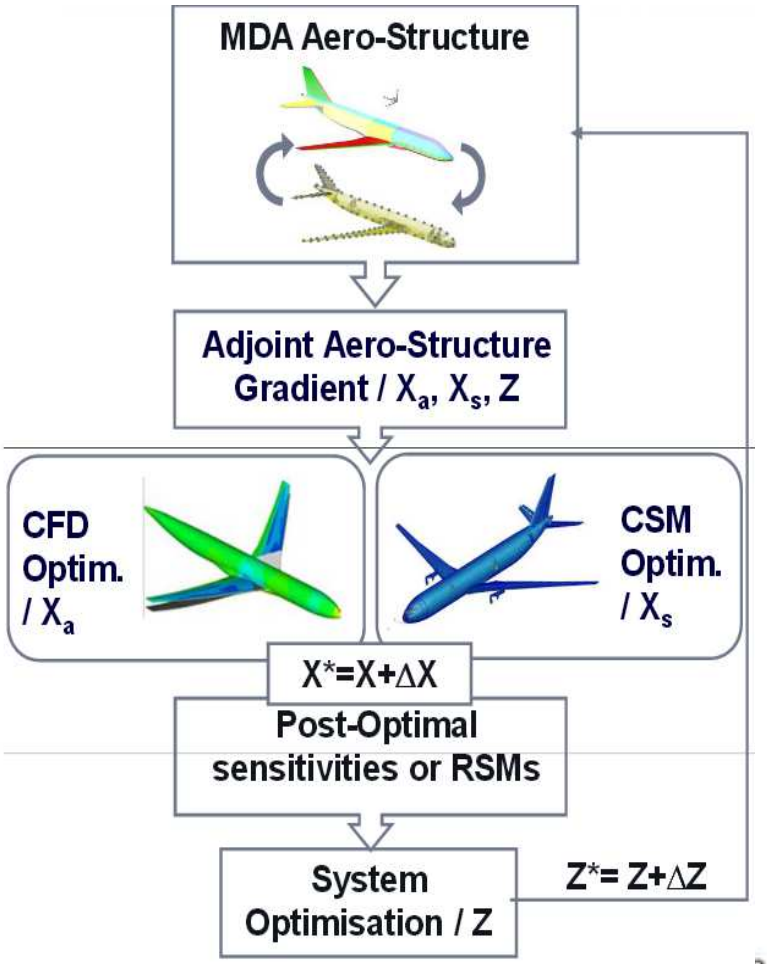
Early ages : first steps in MDO

- Introducing high-fidelity analyses in the design loop

Trade-off through response surface models of optimised disciplines (CRESCENDO)



Fully coupled Hi-Fi MDO wing design using elsA and NASTRAN (ARTEMIS)



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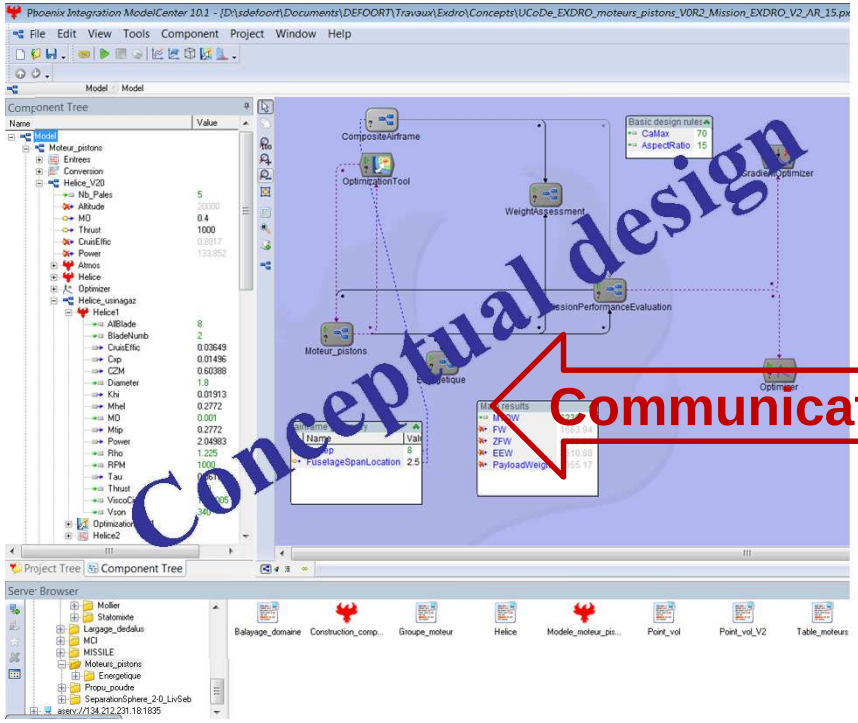
MDAO framework : limitations

- Process integration and toolboxes : 2 extreme practices

Off the shelf commercial software (ModelCenter, ModeFrontier,…)



- **Advantages : plug-and-play, robustness, hotline, various wrappers**
- **Drawbacks : difficult to develop in, cost !!**

Ad-hoc scripting (Matlab, Python, Excel)

```
%-------------------------------------------------------------------------
%
%              Program system_analysis
%
%  This program...
%
%   Author: Jeremy S. Agte      DLR/AE, Göttingen       Fall 2004
%
%  Variables:
%
%-------------------------------------------------------------------------

function[y_input,y_output,G]=system_analysis(x_sh,x_loc,y_input,x_sh_i0,x_loc_i0,y_input_i0,x_loc_,Consts)

%----Execute Gauss Seidel iteration on system to find Y variables----

y_output=[y_input 1];  %-create y_output vector
y_input=y_input+10;  %-ensure iteration begins

for i=1:5000
    if abs(y_input-y_output(1:size(y_input,2))) < ones(1,size(y_input,2))*.000001  %-check tolerance
        break
    end
    y_input=y_output(1:size(y_input,2));  %-update input values

%----Call Subsystem Analysis----(problem dependent)%

    [y1_output,G1] = BB_weight(x_sh,x_loc(:,x_loc_(1).pnt),y_input,Consts);
    [y2_output,G2] = BB_dragpolar(x_sh,x_loc(:,x_loc_(2).pnt),y_input,x_sh_i0,y_input_i0,Consts);
    [y3_output,G3] = BB_power(x_sh,x_loc(:,x_loc_(3).pnt),y_input,x_sh_i0,x_loc_i0,Consts);
    [y4_output] = BB_range(x_sh,y_input);

%----Organize y_output matrix----(problem dependent)%

%-------------L(1)---------We(1)--------Wt(2)--------twst(2)------ESF(2)-------D(3)---------Wf(4)--------
    y_output=[y2_output(1) y3_output(2) y1_output(1) y1_output(3) y3_output(3) y2_output(2) y1_output(2)

%----Combine constraint vectors----%

G=[G1 G2 G3];

end
```

- **Advantages : open, tailored to the needs**
- **Drawbacks : not modular, only mastered by author, coding effort**

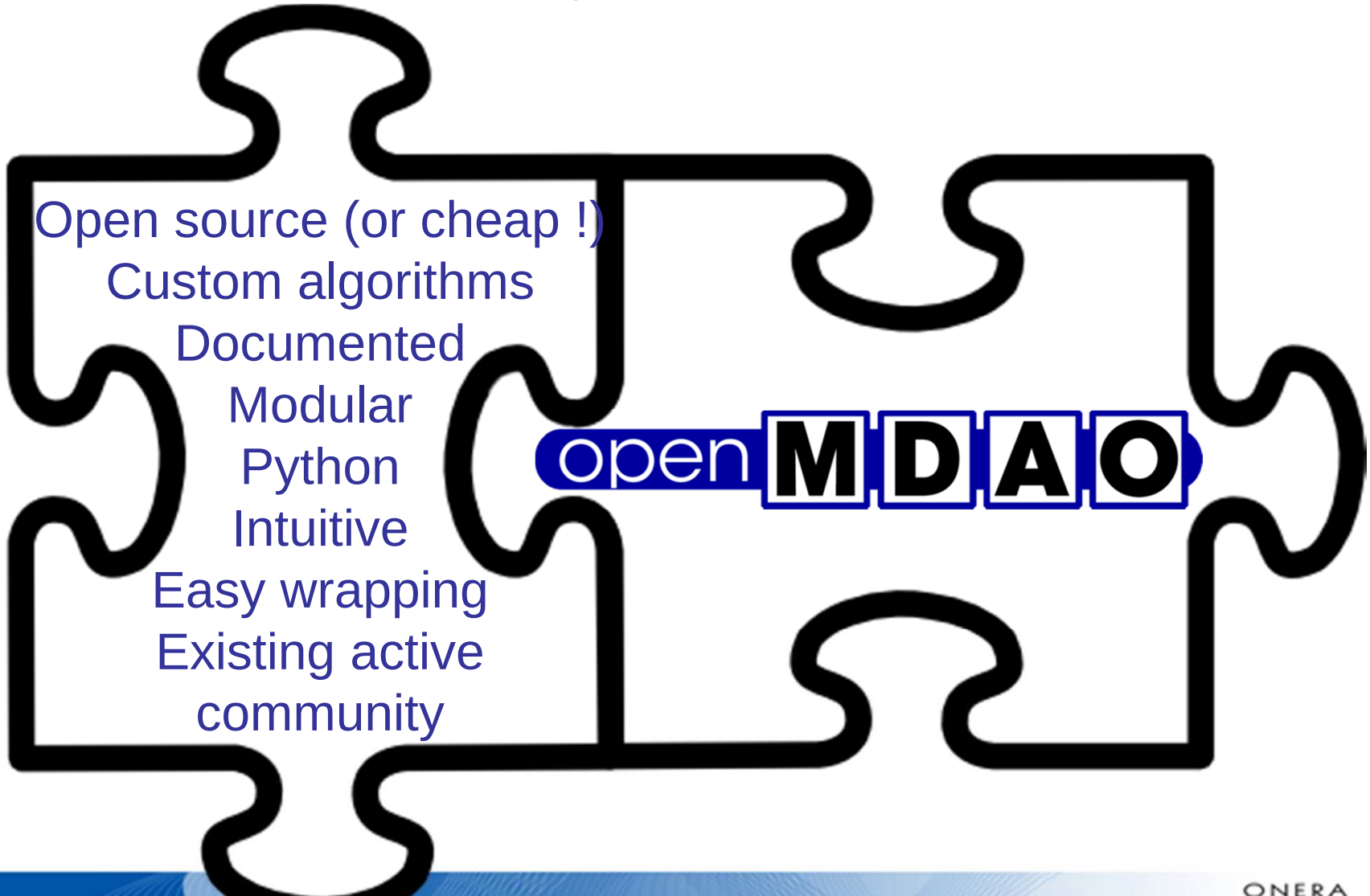
Conceptual design

Communication ?

High-fidelity

MDAO framework : renewed approach

- 2012-2014 : revisit of internal requirements and available solutions



2. OpenMDAO within the ACADIA project

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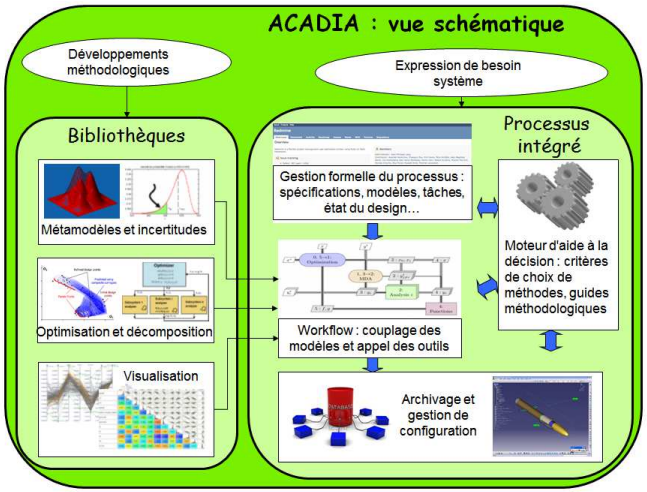
ACADIA in brief

- Stands for « **Design Workshop for Aerospace Innovation** »
- Started in 2014, 4-year project
- **Objective** : define and implement a design environment using advanced methodologies (optimization, RSM, uncertainties, MDO formulations)

- **Contributors :**
  - Structure, Aerodynamics, Control, Energetics, Systems, departments
  - Inheritance from past research at ONERA
  - Mixed capabilities : scientific expertise on design methods, software development, applied engineering

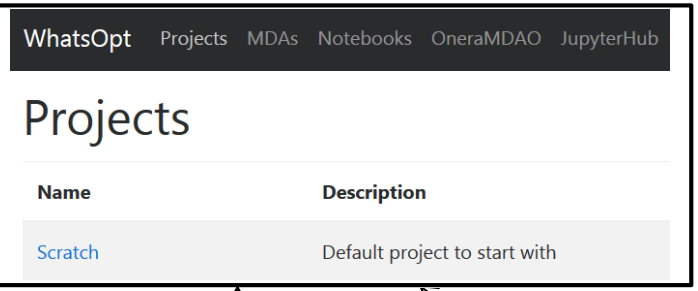
- **Work breakdown structure:**
  - WP1 : design environment
  - WP2 : advanced modelling and optimization techniques
  - WP3 : demonstration



Building blocks for a design environment

WhatsOpt web application presented by R. Lafage on friday

Web Service : requirements, formal definition of process, automatic wrapping, process visualization and execution



Data models : definition and automatic exploitation of a unified representation of the design problem in terms of variables and attributes

```
<aircraft>
    <mission>
    <cabin>
    <geometry>
    <propulsion>
    <aerodynamics>
    <weight>
  <DOC>
</aircraft>
```

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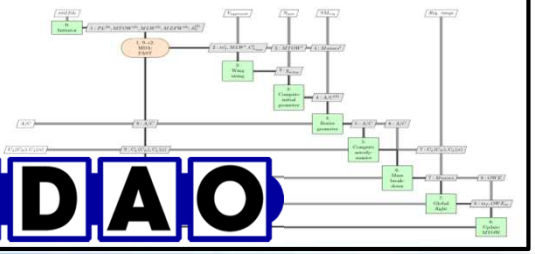
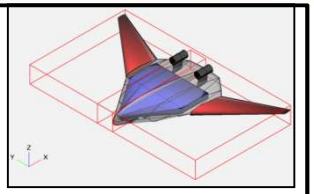
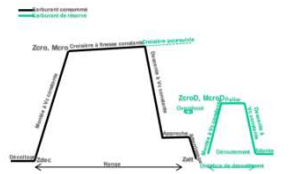
OpenMDAO software: used as integration and optimization framework

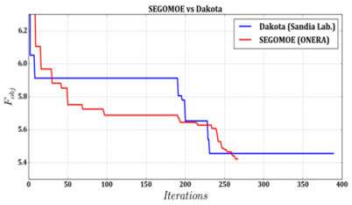


openMDAO





Libraries: disciplinary modules and design algorithms wrapped in OpenMDAO



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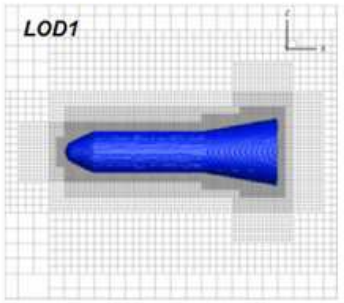
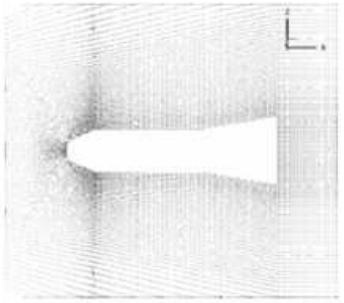
Overview of design methods developed

- Physical and statistical model reduction
  - Immersed Boundary Conditions : quicker aerodynamic evaluation through pre-defined meshing

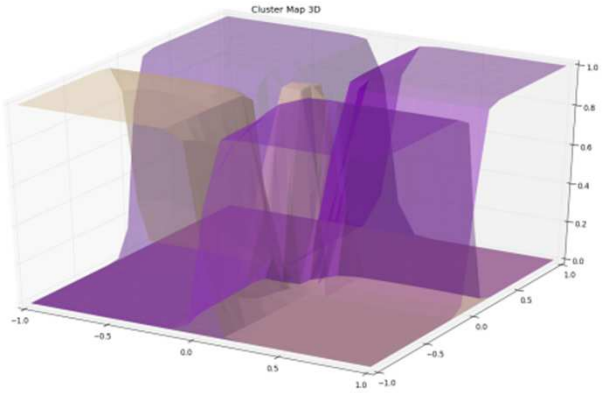


0,73M de cellules – IBC LOD1

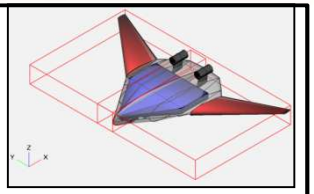


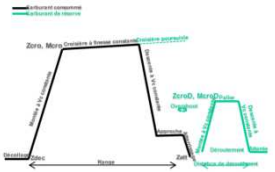
1,00M de cellules – Euler Body Fitted (BF) Grid

  - Mixture of experts (MOE toolbox)



  - Kriging partial least square (KPLS) method for high dimension problems (implemented in the SMT toolbox)





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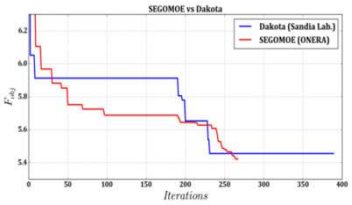
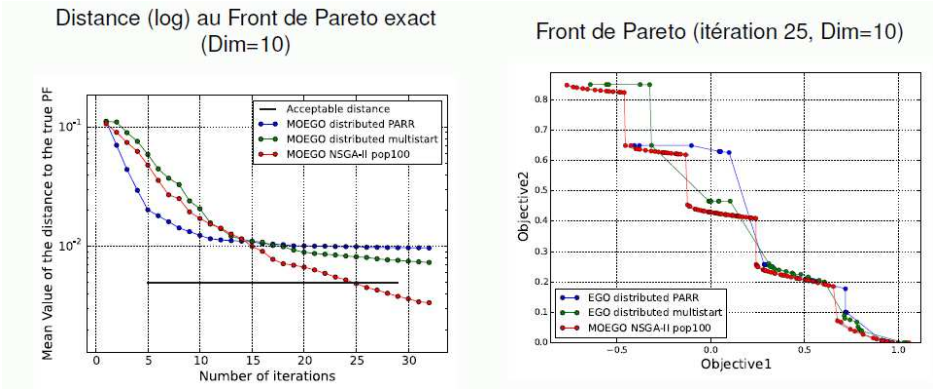
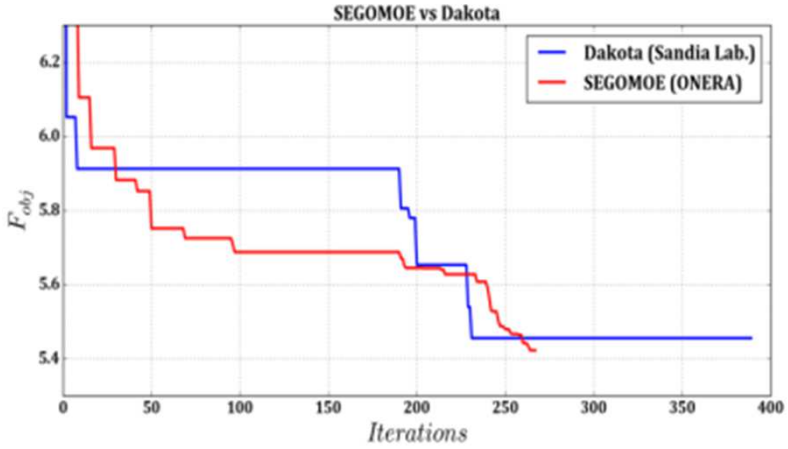


Overview of design methods developed

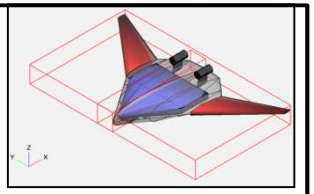
- Optimization
  - Multi-objective optimization under uncertainty (J. Guerra PhD)

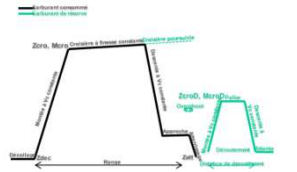


  - Efficient Global Optimization using MOE (SEGOMOE)



Test case performed within the AGILE project





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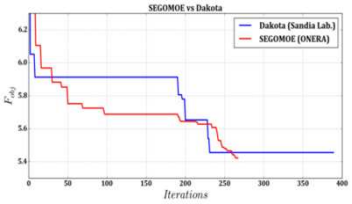
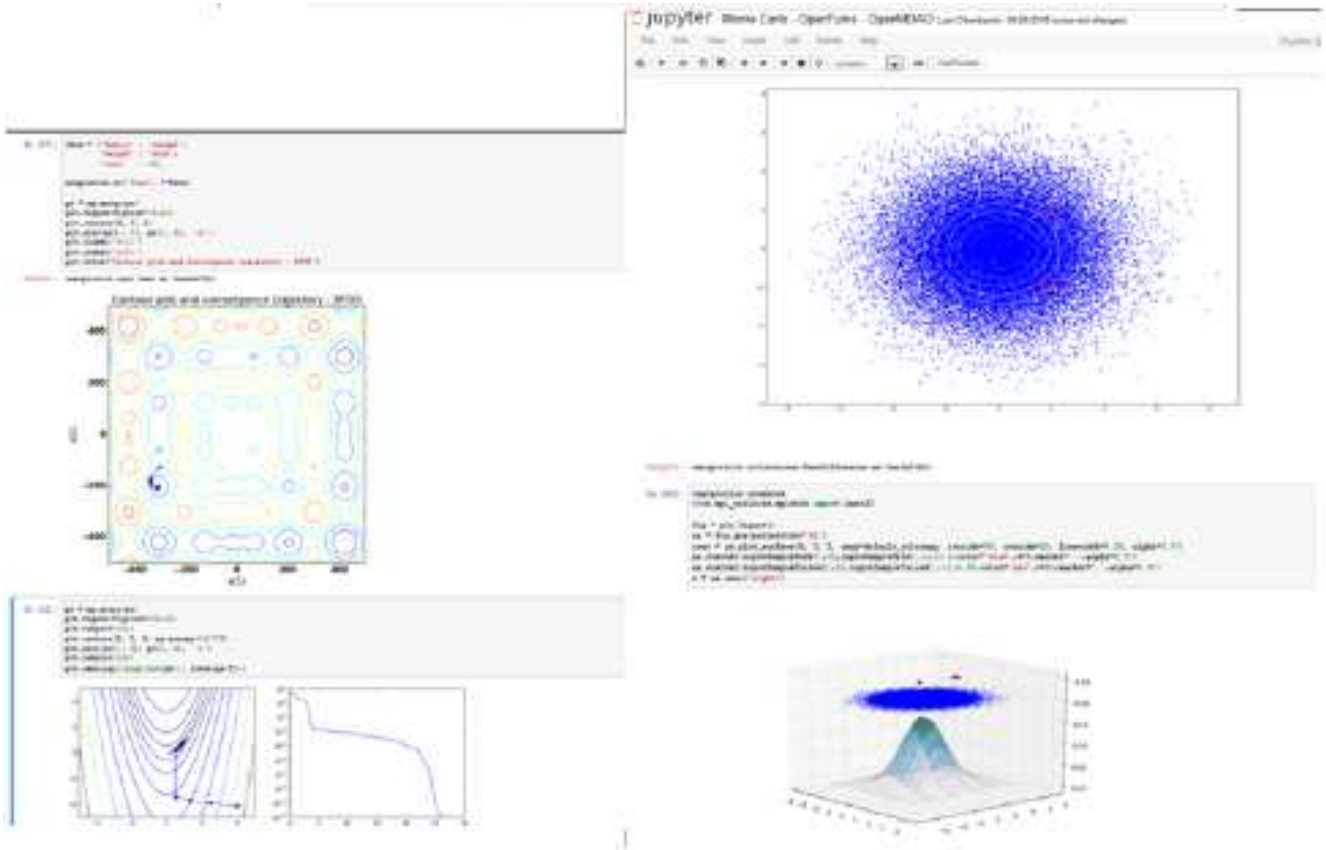
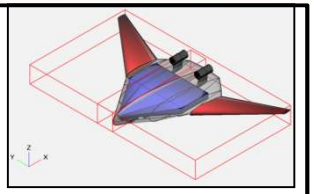
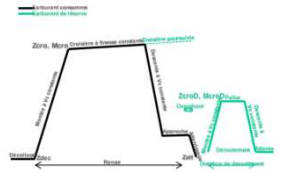


Overview of design methods developed

- Uncertainty management
  - Capitalization of several methods and toolboxes







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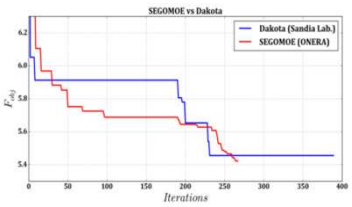
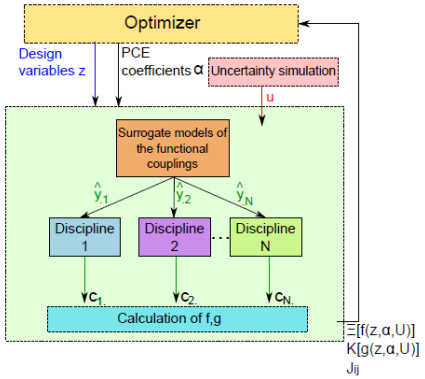
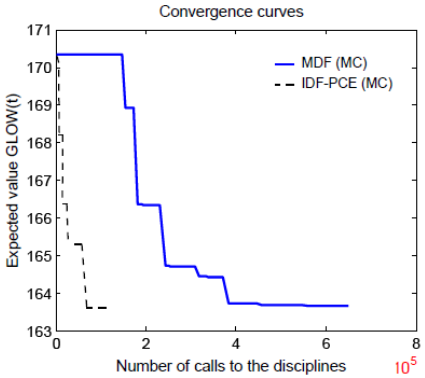


Focus on uncertainties

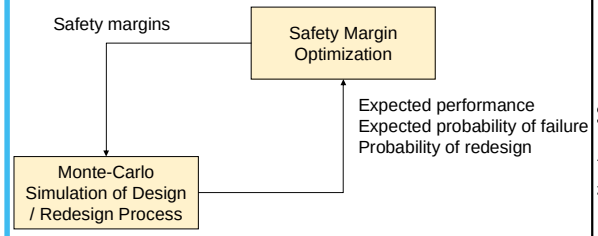
Recent achievements @ ONERA:

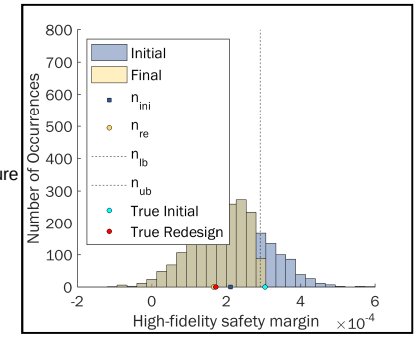
- Decoupled UMDO formulation (PhD L. Brevault - 2015)
- Safety margin optimization under uncertainties (PhD N. Price – 2016)
- MDO with probabilistic surrogates (Post-doc S. Dubreuil – 2017)



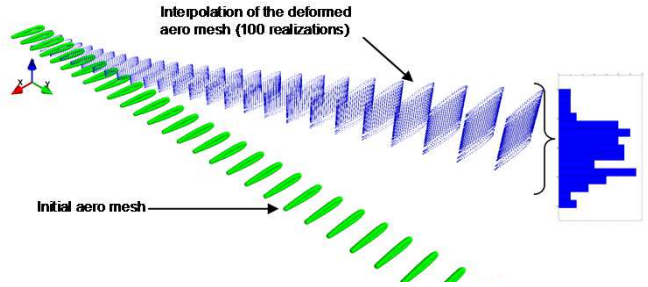


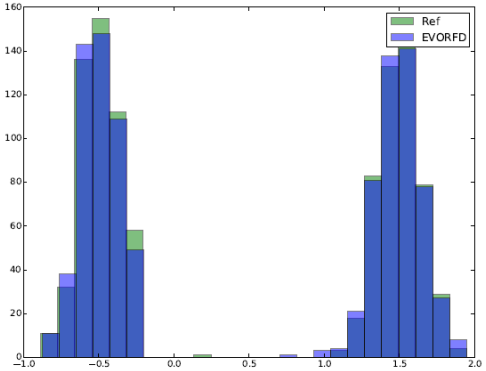
An efficient UMDO formulation for highly coupled problems





A bi-level framework to allocate safety margins under uncertainties



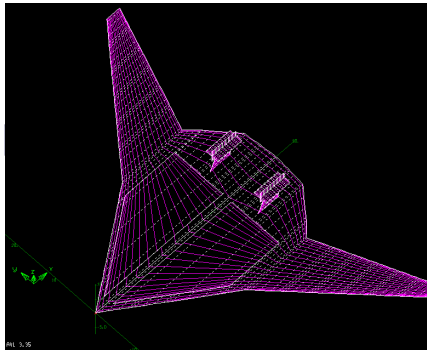


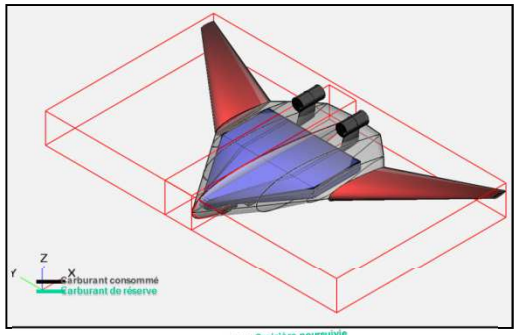
$Z^\star(\xi)$

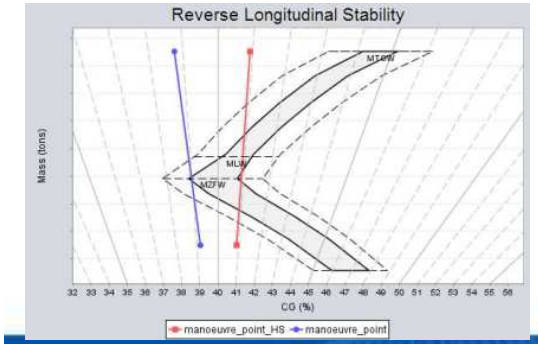
Coupled disciplines approximated by surrogates, propagate uncertainties and estimate minimum location statistics

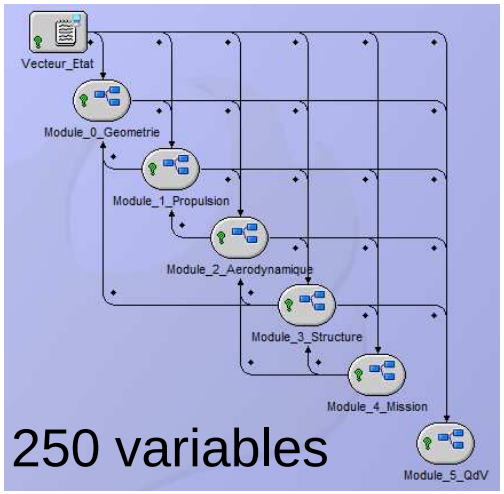
Demonstration case #1 : blended wing body

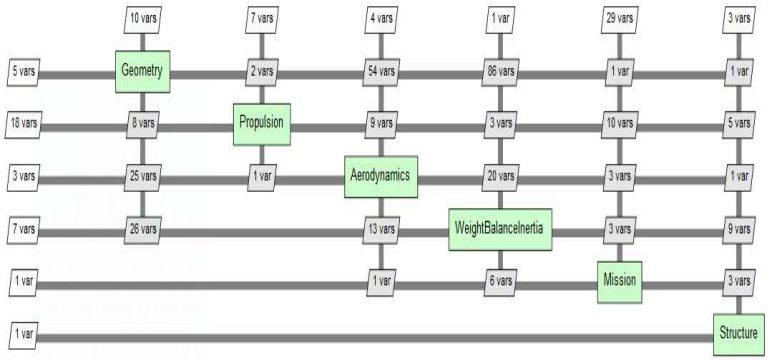
- Internal project CICAV linked to ACADIA
  - Definition of a complete MDA to design a blended wing body
  - Focus on specific disciplines with a higher fidelity
  - Used as a benchmark to transition from ModelCenter to OpenMDAO

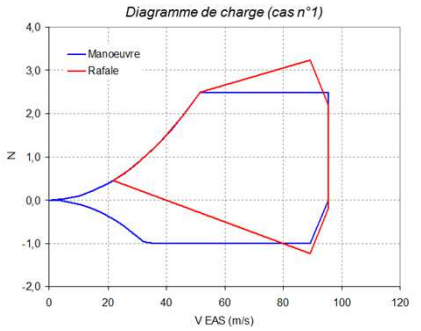


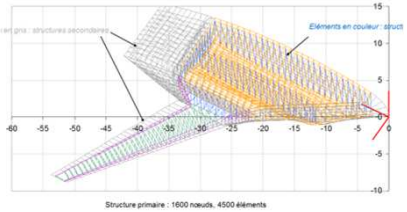












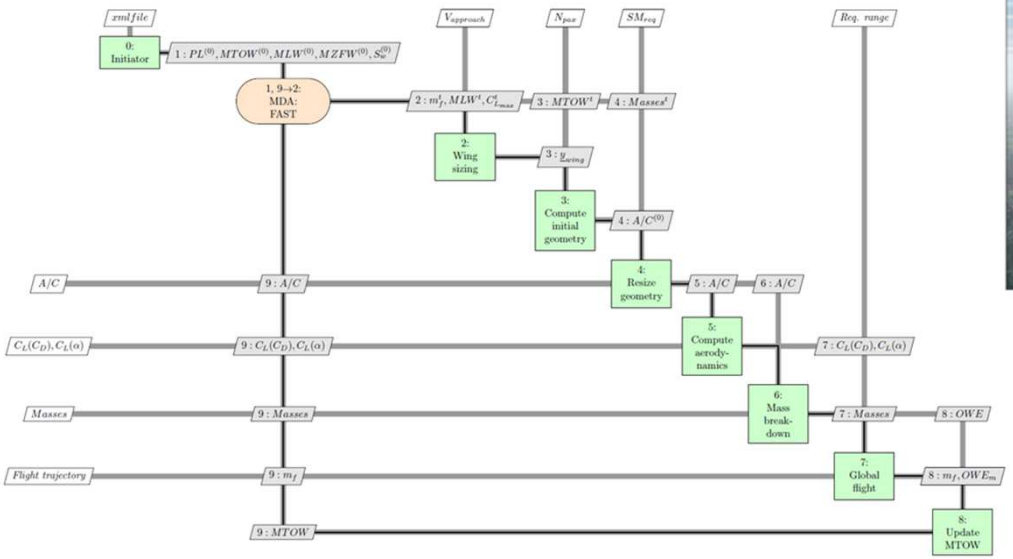
ONERA

Demonstration case #2 : HEP/DEP

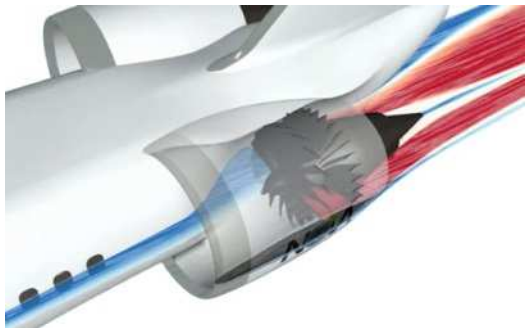
FAST Overall Aircraft Design tool developed in cooperation with ISAE-Supaero

In-house ONERA version incorporating high-fidelity analyses

ONERA MYSTIC



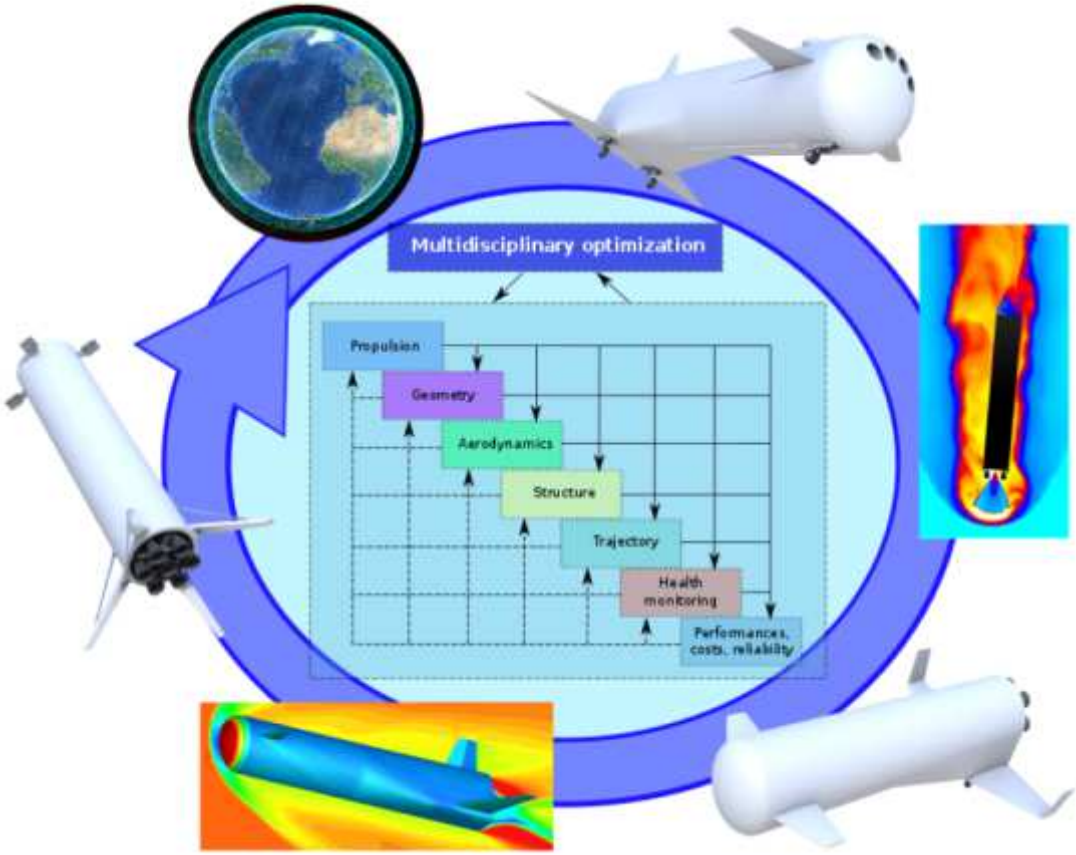
-> currently Python scripting, soon in OpenMDAO 2.0

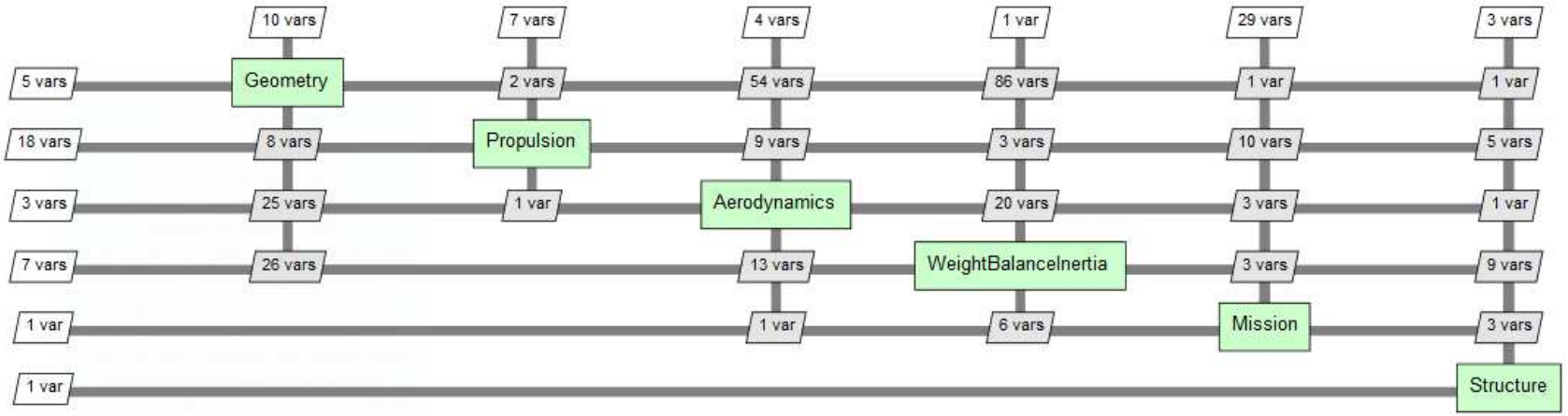


BLI engine integration

Demonstration case #3 : launcher design

Dedicated presentation by L. Brevault this afternoon





Thank you for your attention !